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THE HIGH COURT
COMMERCIAL

2008 4767 P

BETWEEN

JAMES ELLIOTT CONSTRUCTION LIMITED

PLAINTIFF

AND
IRISH ASPHALT LIMITED

DEFENDANT

Judgment of Mr. Justice Charleton delivered the 25th day of May 2011.

1. The plaintiff and the defendant companies have both been involved in construction for generations; as builders and as suppliers to builders respectively. The plaintiff James Elliott Construction Ltd. ("Elliott Construction") has built everything from the simplest of houses to complex specialist projects. The defendant Irish Asphalt Ltd. ("Irish Asphalt") sells quarried materials. This judgment considers whether one of Elliott Construction's buildings was ruined by an abundance of pyrite in underfloor crushed stone infills purchased from Irish Asphalt. It is claimed that this infill, in breach of the contract of sale, expanded and heaved upwards.

2. From 2004 to 2005, James Elliott Construction built the Ballymun Central Youth Facility ("the building"). This is part of the redevelopment of Ballymun town undertaken through Ballymun Regeneration Ltd. ("Ballymun Regeneration"). The building was finished in September 2005. It could have been expected to last for up to 100 years in the form in which it was handed over. Ten years ago, where the building now is, there also was a youth centre. The construction of the new youth centre involved demolishing some of the old one, but retaining a large piece of it. This now forms most of the western area of the building. The construction was then continued over two storeys along a northern and eastern face, and over one storey along the southern face that adjoins the Church of the Holy Spirit. It is a large rectangular structure built around a central courtyard that is open to the sky.

3. Any building may have a suspended floor at ground level or a floating floor. The building has a series of poured concrete floors that rest, or float as the trade says, on the Irish Asphalt infill. Around part of the exterior of the building are pavements that are finished to a high standard. The central courtyard is paved in brick. All of these surfaces rest on the hardcore infill supplied by Irish Asphalt. The hardcore infill specified for this role is called Clause 804. It is normally used for the support of roads because it is hardwearing, of high quality and very durable. Builders use it for floor support, when required to do so by the employer, because of its high levels of stability, toughness and reliability. Clause 804 is crushed rock, in this instance, ranging in size from stones that would fit in the palm of a man's hand (to fit through a 63 mm x 63 mm sieve, though they can exceed that measure in length) to tiny fragments. The building is now, in 2011, a testament to the high standards and social-minded intention of Ballymun Regeneration. Unfortunately, the building previously exhibited serious defects. After practical completion in 2005, cracks began to appear in the ground floor walls. These started out as hairline cracks. Over time more cracks appeared and the condition of the interior walls made the building unusable. Elliott Construction remediated the building in 2009 at a cost of some €1.55 million. Multiples of that sum have been spent on engineering and petrographic investigation and on legal fees. This trial lasted 58 days: 6 days for submissions and the rest for testimony; expert evidence being the vast majority of it. Another case on pyrite heave ran before the Commercial Court for 159 days and then settled. Counsel proofed this case very carefully. They cannot be faulted, but must rather be praised. Calling several experts on the one topic, however, may be an issue that will require the trial judge to be involved in directing appropriate proofs, a step beyond case management, if delay and expense are not to be allowed to potentially defeat the right of access to the court guaranteed in Bunreacht na hÉireann.

4. The cause of this damage is at the centre of the dispute between Elliott Construction and Irish Asphalt. Elliott Construction claims that the bulging and cracking was due to the abundant presence of a mineral called pyrite within the Clause 804 hardcore sold to it by Irish Asphalt. This mineral, it is claimed, reacted with water, producing sulphuric acid and this, in turn, reacted with calcite formations within the crushed stone, causing crystals of gypsum to form, thus opening laminations within the stone, causing fissures, opening existing fissures further and adhering around the stones. This is argued to have caused the floors and brick-paved courtyard to be heaved upwards; making the opening of some doors impossible, buckling and cracking the walls severely and rendering the ground floor of the building effectively useless. Irish Asphalt has claimed that this allegation of pyrite heave is only an unproven theory. It pleads that if it is not established as a probability, the Court should dismiss the action. As a countervailing theory, Irish Asphalt has called evidence to seek to prove that the building was badly designed by Moylan Consulting Engineers ("Moylan"), the contract engineers. In particular, it claims that the Clause 804 infill was used at excessive depth around the foundations, and under the floor slabs of the building and the central courtyard; and that it was not compacted properly, and caused subsidence at different levels. This would give, as regards the cracking of the floors, a similar appearance, Irish Asphalt says, to pyrite heave damage. It is argued that the pattern of floor cracking is not consistent with the plaintiff's case. In addition, the crucial load-bearing foundations, carrying the main supports for the building, were not constructed, it is argued, as was required under the contract between Elliott Construction and Ballymun Regeneration. Irish Asphalt claims that the foundations were not sited at deep level on black boulder clay, but that instead the foundations were placed at an upper level on weaker clay, brown boulder clay and transitional clay, which compromised the load-bearing parts of the building, making it descend into the ground, but leaving the floor slabs behind, giving the appearance of heave and, consequently, causing damage to the walls. As another alternative, Irish Asphalt argues that the building construction was improperly engineered and sank due to weakness at the top level of this black boulder clay. The floors, it says on the foundation subsidence issue, have also descended, but not by as much, perhaps 5 mm or more but making it appear as if there had been heave from under the floor. During the hearing Irish Asphalt initially estimated the rate of descent of the foundation at 20 mm to 25 mm. The bulge factor was thus 15 mm to 20 mm. Later in the course of the hearing, John Campbell, an engineer retained by Irish Asphalt, increased the amount by which the building could have sunk to 43 mm. Insofar as foundations were placed on the brown boulder clay, a settlement could be up to 21 mm. In the transition zone between the black and brown boulder clay, the settlement could be 12 mm. Even if placed firmly in the black boulder clay, a settlement of 10 mm was to be expected. On the case made by Irish Asphalt, the exterior of the building and the load-bearing walls would have been able to take subsidence of that level without showing functional distress. Indeed the highest estimate produced by Irish Asphalt's experts as to the level which the building could sink without such distress exceeded these combined figures. Elliott Construction claims, on the other hand, that the floor slab rose markedly, causing bulging and that the foundations did not sink at all, or sank minimally, being properly sited in black boulder clay. There, subsidence might ordinarily be expected at a level of in or around 2 mm, on the case made by Elliott Construction

5. In short, Irish Asphalt claims that the building was badly constructed both as to the compaction of the infill and the stability of the foundations. It also claims poor engineering and design.

6. On a contract level, Elliott Construction claims to have dealt with Irish Asphalt as a purchaser of its Clause 804 product. It pleads that there is an implied term in the sale of Clause 804 hardcore that it be fit for purpose and of merchantable quality. This assertion as to implied terms is denied and is countered by Irish Asphalt through reference to its terms and conditions. These, it claims, were notified to Elliott Construction and relieve it of liability; save for reimbursing the cost of the material, as the relevant clause specifies.

The relevant part of the alleged contract is quoted at the start of the "chronology" section of this judgment and is later analysed in context. This limitation clause, Elliott Construction argues, was never a term of the contract and, even if it was, is a liability exclusion clause which is unreasonable and thus unenforceable by statute.

Central Factual Issue

7. To understand the phenomenon of pyrite heave one has to appraise the building as to the damage to it and what that shows. The material allegedly responsible must then be dug out and analysed. A search for other possible causes must be part of any analysis in order to ensure a correct analysis. A useful description of the process of pyrite heave was given by the Comité Technique Québécois D'étude Des Problèmes De Gonflement Associés À La Pyrite (CTQ-M200). The basic notions associated with this problem are set out in the following way:-

> "Pyrite (FeS^2) is the main iron sulphide responsible for swelling and is also one of the most abundant minerals on the planet. Pyrite is found in several different types of rock, in fairly low percentages (< 1%).
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> Pyrite exists in different forms, namely massive (chemically stable) and "framboidal" (chemically unstable). The framboidal form is characterized by an agglomeration of very small cubic crystals (not visible to the naked eye) with a very large specific surface. In some conditions, this form of pyrite can oxidize in the presence of water and react with other minerals present in the same rock to form gypsum. Gypsum, when it forms, occupies a much greater volume than pyrite, causing swelling of the granular backfill. The swelling produces cracking and causes concrete floor slabs to heave. In some cases, especially in garages, the foundation walls may also crack and be displaced outwards.
>
> The chemical solutions formed during pyrite oxidation can be absorbed by the concrete, causing the concrete floor slab to sulfatize and heave. The swelling thus has two constituent elements, namely swelling of the aggregate and intrinsic swelling of the concrete slab.
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> This chemical reaction is generally slow, and it takes between 10 and 15 years after the building is constructed before it is visible to the occupants. Slab displacement levels vary, but can be as high as 5 mm per year.
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> The chemical reaction can remain active over long periods (more than 40 years, for example). The speed and extent of the reaction will depend on several factors, including the depth of the backfill, the percentage and type of pyrite present, the water content and porosity of the materials, and so on.
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> Problematic aggregate is generally composed of significant percentages of argillaceous limestone and argillaceous shale. These rocks are composed mainly of clay minerals and carbonates ($CaCO^3$), in varying proportions. They also contain variable percentages of pyrite, but generally not more than 1%.
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> Because these types of rock contain significant percentages of clay minerals, they are more permeable to air and water and less resistant to gypsum crystallization.
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> The percentages of these types of rock in aggregate can vary considerably. For example, materials with very high swelling potential may be mixed with others that have negligible swelling potential, and there are, of course, many intermediate materials between these two extremes. The geographical sectors most affected by swelling are located close to geological formations rich in that particular type of rock, which is mined locally and may be used as granular backfill under concrete floor slabs.
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> Most aggregates used as underfloor backfill contain pyrite and other sulphurs, but a very large percentage of buildings will never exhibit symptoms of pyrite-related problems. This is because pyrite found in hard rock with low clay mineral contents does not oxidize and the materials remain stable".

8. I have used the above only as a description. Certain scientific papers were admitted by both sides into evidence and passages from others were widely debated in testimony. The analysis which follows is, perhaps, overburdened with detail, but so was the trial. In reading this judgment there are four crucial questions which must be borne in mind. These are:

> (1) Did the pyrite under the floors, courtyard and pavement of the building cause heave upwards? This is what the plaintiff contends.
>
> (2) If so, was this alone, or was it very substantially, the cause of the damage to the building? This is what the plaintiff claims to have proven.
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> (3) Did, on the other hand, the floors subside, thus making it appear that they were higher in parts, because the infill around particular areas was improperly compacted? This is a central part of the defence case.
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> (4) Did the foundations and walls of the building sink to an appreciable extent, catching the floor against the walls and partitions, as the defence contends, thus causing cracking in the floors and buckling the plasterboard inside walls at the ground floor level, while leaving no external signs of distress?

9. It is crucial to a finding in favour of the plaintiff that the floors heaved upwards because of pyrite and damaged the building. If it is proven that the floor heaved upwards, then there is no available evidence that this resulted from anything other than pyrite. It is crucial to the establishment in favour of the defence of a potential answer to the condition of the building that the foundations sank. If, in addition, the floor subsided, the defence theory might be partly possible. If the floors subsided on their own, however, without the foundations also going down and ramming the floors against the plasterboard internal walls and internal studded partitions, the damage would look very different. In analysing these questions, as I will shortly elaborate, the plaintiff bears the burden of proof on the first and second questions. In considering those questions, the plaintiff must establish a probability. A state of uncertainty, or the establishment of the plaintiff's case as a possibility at a lesser level to probability, is not enough for the plaintiff to succeed. In analysing the evidence I have constantly in mind, in addition, the two central reasons advanced by the defence as to why heaving of the floor slab is impossible, based on the state of the building. The first is the absence of cracking in the floor slab in the new gym area to the north-west west of the building. The second is a theory that the pattern of cracking in the eastern end of the building establishes the presence of zones of influence consistent with the subsidence of the foundations. Finally, the defence contends that it has shown that minute expert analysis of the stone infill rules out forceful crystal growth.

Expert Evidence

10. The most striking feature of this case was the inability of the experts as to engineering, architecture, geology and petrography on each side to agree on anything of importance to the case. It is not the function of the Court to propound its own scientific theory as to any feature of the evidence. Instead, a decision must be made as to which side of the case, on each particular issue, may be regarded as probable. An expert witness attains a high degree of regard in the judgment of an issue because, by her or his experience and study, adjudication on a subject outside the ordinary experience of a judge may be made. The role of the expert is to elaborate on the principles applicable to an esoteric discipline and to indicate why, as a matter of good sense and as a matter of opinion, a finding of fact ought to be made in one way rather than in the other. In *Davey v. Magistrates of Edinburgh* [1953] S.C. 34 at 40, the Court of Session, through the Lord President, Lord Cooper, made this statement as to the correct approach by a court to the testimony of experts:-

> "Expert witnesses, however skilled or eminent, can give no more than evidence. They cannot usurp the functions of the jury or Judge sitting as a jury, any more than a technical assessor can substitute his advice for the judgment of the Court – *S.S. Bogota v. S.S. Alconda* [1923] S.C. 526. Their duty is to furnish the Judge or jury with the necessary scientific criteria for testing the accuracy of their conclusions, so as to enable the Judge or jury to form their own independent judgment by the application of these criteria to the facts proved in evidence. The scientific opinion evidence, if intelligible, convincing and tested, becomes a factor (and often an important factor) for consideration along with the whole other evidence in the case, but the decision is for the judge or jury."

Normally, no witness is entitled to express an opinion. An expert, however, is and this is on the basis that the expertise of the witness has enhanced his or her testimony to allow for an exception to the ordinary rule. Additionally, experts are often allowed to express even a view on the ultimate issue which is for decision by the court. This could be whether there was a want of care in the construction of a building which has collapsed causing personal injury, or it could be as to whether, as between a choice of phenomena only one of which establishes liability, one is more likely than any other.

11. As this judgment proceeds it will be apparent that the bulk of the evidence was from experts who examined the building or the stone infill and professed to be satisfied that the cause of ruination was for one reason or often for another diametrically opposed cause. In addition to testimony, scientific papers were opened to the Court. At an early stage, I decided that it was unsafe to read any scientific paper without the agreement of the parties that this scientific paper was to be evidence in the case. In addition, to bolster or balance their evidence, or to show that it was based on current scientific orthodoxy, witnesses referred to passages from other scientific papers. Thereby, these became evidence. The function of the court, however, is not to adopt the task of resolving controversy by adding to the canons of science. Rather, a clear choice must be made as between the validity of the testimony on one side or the other and the weight to be attached, as between conflicting opinions, to any which seem to be correct. In *Best v. Wellcome Foundation Ltd.* [1993] 3 I.R. 421 at 462, Finlay C.J. stated:-

> "I am satisfied that it is not possible for either a judge of trial or for an appellate court to take upon itself the role of a determining scientific authority resolving disputes between distinguished scientists in any particular line of technical expertise. The function which a court can and must perform in the trial of a case in order to achieve a just result is to apply common sense and a careful understanding of the logic and likelihood of events to conflicting opinions and conflicting theories concerning a matter of this kind."

12. This has been my approach. Every expert witness has to be evaluated on the basis of sound reasoning. An expert witness is, however, no different to any other witness simply because he or she is entitled to express technical opinions; all of us are subject to human frailty: exaggerated respect based solely on a witness having apparent mastery of arcane knowledge is not an appropriate approach by any court to the assessment of expert testimony. Every judge has to attempt to apply common sense and logic to the views of an expert as well as attempting a shrewd assessment as to reliability. I adopt as useful the statement by Stewart-Smyth L.J. in *Loveday v. Renton* [1989] 1 Med. L.R. 117 as follows:-

> "The mere expression of opinion or belief by a witness, however eminent… does not suffice. The Court has to evaluate on the soundness of his opinion. Most importantly this involves an examination of the reasons given for his opinions and the extent to which they are supported by the evidence. The judge also has to decide what weight to attach to a witnesses' opinion by examining the internal consistency and logic of his evidence; the care with which he has considered the subject and presented his evidence; his precision and accuracy of thought as demonstrated by his answers; how he responds to searching and informed cross-examination and in particular the extent to which a witness faces up to and accepts the logic of a proposition put in cross examination or is prepared to concede points that are seen to be correct; the extent to which a witness has conceived an opinion and is reluctant to re-examine it in the light of later evidence, or demonstrates a flexibility of mind which may involve changing or modifying opinions previously held; whether or not a witness is biased or lacks independence… there is one further aspect of a witness's evidence that is often important; that is his demeanour in the witness box. As in most cases where the court is evaluating expert evidence, I have placed less weight on this factor in reaching my assessment. But is not wholly unimportant; and in particularly in those instances where criticisms have been made of a witness, on the grounds of bias or lack of independence, which in my view are not justified, the witnesses' demeanour has been a factor which I have taken into account".

13. Of these criteria, the most important reasons whereby I have chosen one expert over another have been the manner in which an opinion has been reasoned through and the extent to which opposing views have been genuinely and objectively considered on the basis of their merit. A judge must bear in mind that, notwithstanding that an expert may firmly declare a duty to the court, it is a natural aspect of human nature that even a professional person retained on behalf of a plaintiff or defendant may feel themselves to be part of that side's team. Of particular importance in this case, therefore, has been the extent to which an expert has been able to step back and to consider and to think through an opposing point of view. As with demeanour, this is not readily demonstrated on a transcript of evidence. Rather, to a trial judge, it can be possible to see the degree to which a witness is thinking through the potential for an opposing theory before giving a reasoned answer. Experience in other cases demonstrates that there is a danger that experts may erect a barrier of apparent learning in order to disguise what would be an answer awkward to their side were it to be expressed plainly. Apart from the attractions of logic and reasoning, therefore, assessing an answer based on what is seen and heard in the courtroom remains important.

14. It is on these criteria I reach a conclusion as to which party's expert evidence I prefer. This does not mean necessarily that the rejection of evidence from any particular expert is a challenge to his or her integrity. Rather, I wish to record my gratitude for the clear illumination of, or helpful debate upon, scientific issues by them.

Approach to the Evidence

15. Elliott Construction must prove as a probability that the Clause 804 hardcore sourced from Irish Asphalt is the cause of damage to the building. It must be proved that this material was supplied in breach of contract. There are only two standards of proof in law. One, proof beyond reasonable doubt, is applicable to criminal cases and the other, proof on the balance of probability, is applicable to all other cases. These may be contrasted. Denning J. in *Millar v. Minister of Pensions* [1947] 2 All E.R. 372 described the degree of cogency which the evidence must reach in a criminal case in these terms:-

> "It need not reach certainty, but it must carry a high degree of probability. Proof beyond a reasonable doubt does not mean proof beyond the shadow of a doubt. The law would fail to protect the community if it permitted fanciful possibilities to deflect the course of justice. If the evidence is so strong against a man as to leave only a remote possibility in his favour which can be dismissed with the sentence "of course it is possible but not in least probable", the case is proved beyond reasonable doubt: that nothing short of that will suffice."

16. The burden applicable in a civil case was described by Denning J. in this way:-

> "That degree is well settled. It must carry a reasonable degree of probability, not so high as is required in a criminal case. If the evidence is such that the tribunal can say: "we think it more probable than not", the burden is discharged, but if the probabilities are equal it is not".

17. Similar statements as to the civil standard of proof abound in cases decided in Ireland; for example, see *People (D.P.P.) v. Kiely* (Unreported, Court of Criminal Appeal, 21st March, 2001). The testimony in this case has been replete with expert evidence seeking to establish, or to rebut, any central proposition that would establish causation in favour of Elliott Construction. In countering the proof of pyrite heave, Irish Asphalt has referenced numerous theories as an alternative. These revert, ultimately, to a claim of poor construction of the building: among these are improper compaction of the Clause 804; improper siting, design and construction of the foundations; improperly mixed and hydrated cement; improper loading of the ground floor concrete slab with building-blocks or with the stresses of propping the setting first floor concrete slab. The most important of these will be considered separately. Unless the foundations settled to a substantial degree, however, the appearance of the building, with the floor apparently pushing the walls upwards, cannot be accounted for. Simply because, however, the defendant has engaged with the case through cross-examination and the calling of contradictory testimony does not mean it assumes any burden of proof. On the contrary, it no more assumes a burden of proof by calling evidence and suggesting alternatives as to how the building was ruined than if it had remained completely silent. The weight to be attached to alternative theories might diminish by a defendant being taciturn; and any failure to call evidence on a competing theory suggested to undermine the burden of proof of causation on a plaintiff may ultimately influence how a court would approach the evidence. A failure to call available and relevant evidence on either side may, on a guarded basis, suggest to a court that an adverse inference be drawn. Any defendant, however, is at liberty to challenge the causation of an alleged wrong, whether in contract or in tort, by reference to any alternative, and no burden of proof is thereby assumed. It may be that the multiplicity of potential causes might engender a suspicion of confusion as a tactical approach to the evidence in the mind of the trial judge; but that has not influenced me. A plaintiff must always discharge the burden of proving the wrong asserted against the defendant. The existence of competing defence theories, as against the proposition advanced by the plaintiff, when cast in technical terms, may tempt a trial judge to enter realms of assumed scientific expertise and to lose sight of good reasoning based on established fact. No individual piece of evidence as to, for instance, the chemical reactivity of pyrite crystals or the shape of gypsum crystals or the proper hydration of cement, should be elevated to the status of a determining factor if to do so is to divorce that evidence from the matrix of facts within which it is properly to be seen. Every trial judge is entitled to draw inferences from findings of primary fact. That ability must not be lost sight of, especially where a scientific overlay may seem to fog the issue of causation. Scientific evidence, nonetheless, has informed this case and it is a vital component in the analysis of the issue of proof in order to establish what inferences are appropriate to be drawn from such matters as the condition of the building, the approach to constructing it and the reactivity of the Clause 804 infill under the building and of the alternative source of Clause 804 infill Keegan's quarry which was used when the building was remediated in 2009.

18. Where no cause establishes as a probability that the damage to the building resulted from the Clause 804 hardcore supplied by Irish Asphalt, Elliott Construction, as plaintiff, fails in the burden of proof. As between competing theories, where one may establish probable causation arising from the fault of a defendant, and another theory refutes that, the burden of proof remains at all times on the plaintiff to establish the probability of the theory that establishes liability. In the *Rhesa Shipping S.A. v. Edmunds* [1985] 1 W.L.R. 948 a ship sank far out at sea. The insurance contract which would allow compensation to be recovered by the owners stipulated recovery for losses occurring by reason of the perils of the sea, but not due to simple wear and tear. As between competing theories, it is error by a process of elimination to accept as the probable cause of damage the least likely of a range of possibilities all of which are of themselves unlikely. Two competing theories had been put forward in that case. The peril of the sea to which the vessel had succumbed was claimed to have been a collision with an unknown submarine. As against that possible but infrequently occurring danger, the underwriters posited the collapse of the hull due to wear and tear. The trial judge found for the ship owners applying what Lord Brandon in the House of Lords characterised as the reasoning of Sherlock Holmes: "when you have eliminated the impossible, whatever remains, however improbable, must be truth". As a matter of law, in contrast, the principle of the burden of proof of causation resting on the plaintiff establishes that it is not necessary always to reach a finding of fact and, further, that causation may only be established on the basis of probability, not on the basis of what is unlikely even though it may be the only possible, though improbable, explanation left. Unlike Sherlock Holmes, the requirements of law mean that a judge must say "I do not know" if no cause to the damage is established as a probability. In that case, the vessel had sunk to the deep seabed making examination impossible. In the case at trial, the building is very much present and has been widely photographed, videoed, sampled and explored. The approach of Lord Brandon, overturning the finding for the plaintiff ship owners, at pp. 955 to 956, nonetheless, informs my analysis of the facts of this case:-

> "The first reason is one which I have already sought to emphasise as being of great importance, namely, that the judge is not bound always to make a finding one way or the other with regard to the facts averred by the parties. He has open to him the third alternative of saying that the party on whom the burden of proof lies in relation to any averment made by him has failed to discharge that burden. No judge likes to decide cases on the burden on proof if he can legitimately avoid having to do so. There are cases, however, in which, owing to the unsatisfactory state of the evidence or otherwise, deciding on the burden of proof is the only just course for him to take.
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> The second reason is that the dictum can only apply when all relevant facts are known so that all possible explanations, except a single extremely improbable one, can properly be eliminated. That state of affairs does not exist in the present case: to take but one example, the ship sank in such deep water that a diver's examination of the nature of the aperture, which might well have thrown light on its cause, could not be carried out.
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> The third reason is that the legal concept of proof of a case on a balance of probabilities must be applied with common sense. It requires a judge of first instance, before he finds that a particular event occurred, be satisfied on the evidence

> that it is more likely to have occurred than not. If a judge concludes, on a whole series of cogent grounds, that the occurrence of such an event is extremely improbable, a finding by him that it is nevertheless more likely to have occurred than not, does not accord with common sense. This is especially so when it is open to the judge to say simply that the evidence leaves him in doubt whether the event occurred or not, and that the party on whom the burden of proving that the event occurred lies has therefore failed to discharge such burden."

19. I appreciate there may be cases, such as *Hanrahan v. Merck Sharpe and Dohme (Ireland) Ltd* [1988] I.L.R.M. 629, where it is proper to establish causation by reason of the elimination of other possible causes. Even in that instance, the cause so established must of itself be probable. As between alternative potential tortfeasors an issue may be decided under s. 11(3) of the Civil Liability Act 1961 establishing both as concurrent wrongdoers where it is not certain which of two or more defendants caused the actionable wrong. As between competing theories, however, as to the cause of a wrong, the plaintiff always retains the burden of proving the case that establishes the defendant's liability. In *Quinn (a minor) v. Mid Western Health Board* [2005] 4 I.R. 1 the plaintiff was born with severe handicap in circumstances where the hospital admitted that labour should have been induced at an early gestational age. The cause of the damage, however, was not established as between that fault and the possibility, given the plaintiff's condition, of an early acute episode as the true cause of the harm.

20. At pp. 21 to 22, Kearns J. for the Supreme Court, made the following comment:-

> "Having regard to the complete stand-off between the respective medical experts on both sides of this case, both as to causation and the timing of the plaintiff's injury, I do not believe it was necessary for the trial judge ultimately to decide in favour of one proposition or the other. It was open to him to decide the case by holding, as he did, that the plaintiff had not discharged the burden of proof to establish, on the balance of probabilities, that the plaintiff's injury had occurred in a manner or at a time contended for by the plaintiff's experts. In short, while the obstetric evidence adduced on behalf of the plaintiff provided one credible explanation of events, the radiological evidence adduced on behalf of the defendants provided another, being one based upon scientific and objective criteria, and which the trial judge also found to be credible and which ultimately left him in a position where he was driven to the conclusion that the onus of proof had thus not been discharged.
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> Support for the proposition that the court of trial is not under an obligation in all cases to positively find in favour of one version over another is to be found in *Rhesa Shipping Co. S.A. v. Edmunds* [1985] 1 W.L.R. 948...
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> A trial judge must not, of course, abdicate his duty to endeavour to resolve issues, but even the most conscientious effort may still leave a judge in the position in which O'Sullivan J. found himself at the end of this case. If credible evidence existed which left him in such a quandary he effectively had no option but to decide the case as he did. In my view there was such evidence".

21. In analysing the evidence in this case I am acting on the basis of seeking to establish whether a probability exists for the cause of the ruination of the building itself being pyrite heave. A judge is entitled to put together pieces of evidence, no individual one of which would establish a probability, and to then test if the burden of proof is met by a plaintiff. This approach to reasoning is universal, though often unstated, in civil cases. Each fact used in such analysis must be first established as a probability. Were it otherwise, the burden of proof would not be met since that burden extends not simply to the conclusion based upon the evidence, but to establishing that every piece of evidence is probable before it is capable of being analysed within the context of the question of whether a plaintiff has discharged the burden of proof. Such evidence as is probable should then be considered as to whether, as a body of evidence, a probability is established; in other words that the plaintiff has discharged the appropriate burden of proof. Stated in a criminal context, and according to a much higher standard, the analysis by Robert Lindsey Sands at pg. 177 of his book *Criminal Law and Procedure in the Republic of Ireland* (3rd Ed., London, 1951) is apposite:-

> "The testimony of a witness who actually saw the accused person kill the deceased is direct evidence, but if the deceased had died of poisoning the pecuniary embarrassment of the prisoner, his buying poison and attempting to avoid an inquest and other such facts would be relevant as circumstantial or indirect evidence…
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> Circumstantial evidence is very often the best evidence that the nature of the case permits of. It is evidence of surrounding circumstances which by undersigned coincidence is capable of proving a proposition with the accuracy of mathematics. It is no derogation of evidence to say that it is circumstantial…
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> A jury may convict on purely circumstantial evidence but to do this they must be satisfied not only that the circumstances were consistent with the prisoner having committed the act but also that the facts were such as to be inconsistent with any other rational conclusion than that he was the guilty person…"

22. In this instance, I would not come to a conclusion in favour of the plaintiff based on disparate pieces of circumstantial evidence unless the accumulation of evidence which I accept as probable both establishes the probability that damage to the building was caused by pyrite heave and that no other competing and probable, not merely possible, hypothesis exists to displace it. It follows also, from the cases that I have cited, that where the evidence does not establish a probability in favour of the plaintiff, I am not required to look for a competing or alternative cause in order to hold with the defendant. In this case a number of different categories of evidence, as to monitoring of movement, as to the condition of the building, as to crystal growth and as to swelling tests are each independently, once the foundation subsidence theory is dismissed, enough to establish a probability in favour of the plaintiff.

General Chronology

23. To put the analysis and findings of fact in context, it is necessary to set out a chronology of fundamental events. Some of these are evidenced by correspondence between the parties. Any dispute thereto is noted as this chronology proceeds.

> • **30th January, 2003**: Irish Asphalt writes to Elliott Construction, informing it that it has opened a new quarry at Bay Lane, near Finglas, County Dublin. The quarry is to be opened from 10th February, 2003. It is announced as being available to sell two main products; namely, "3 inch Down" and "Clause 804". Irish Asphalt claim both were being sold subject to conditions, of which condition no. 8 reads:-
>
> "In the event of goods being delivered which are defective, the Company's liability shall be limited to the cost of their replacement. In no circumstances shall the Company be liable for any other loss arising directly or indirectly from the supply of defective materials."

The conditions of sale were absent from the letter originally sent to Irish Asphalt. I will return to this in analysing liability under the contract. It appears that the first delivery from Irish Asphalt to Elliott Construction of Clause 804 occurred on 21st May, 2003. These deliveries were not related to this project.

• **11th February 2003**: Elliott Construction is invited by Ballymun Regeneration to tender to build the Youth Facility building. General specifications of a detailed kind are sent out, together with conditions of contract and a form of tender.

• **17th May 2004**: A final offer to build is made by Elliott Construction to Ballymun Regeneration. This prices the building of the Youth Facility at €2,441,422.00 plus VAT.

• **19th July 2004**: Ballymun Regeneration writes to Elliott Construction declaring that it is its intention to enter into a contract with it for the construction of the building. On the same day a formal contract, entitled '*Agreement and Conditions of Contract for Building Work*', is signed by both parties.

• **16th August 2004**: Elliott Construction begins work on the building. Shortly after, Irish Asphalt begins delivering the rougher 3 inch down stone material for early stages of the construction that are not relevant.

• **27th August 2004**: Irish Asphalt make the first delivery of Clause 804 hardcore to the building site. The delivery docket in respect of each load of Clause 804 for this project ends with the words:-

"This material is sold subject to the terms and conditions available on request. White to accounts - pink to customer - blue to haulier - yellow to file".

Clause 804 hardcore infills excavations at deep levels, supports all of the floors of the building and is the under-surface for the courtyard and relevant external pavements. Some small amounts of hardcore from Roadstone were mixed into hardcore for the courtyard and pavements.

• **3rd November 2004**: Work begins on the digging of the foundations. These are directed by Moylan engineers for Ballymun Regeneration, to consist of 39 individual poured lean mix concrete areas set deep on black boulder clay with 1.5 m² foundation pads on top and with central weight bearing pillars resting thereon to support the first floor in some places. Ground beam foundations throughout the building are also laid to support the main external and internal walls. These are connected to and rest on the foundation pads. Work continues until 13th December, 2004.

• **13th December 2004**: Digging and construction of the last foundation pad at the north-western end of the building where the new gymnasium is situated in the front of the retained piece of the old youth centre.

• **17th December 2004**: The ground floor slabs are poured in concrete to float on the Clause 804 support. These floor slabs are not designed to connect to the walls. Irish Asphalt makes its last delivery of Clause 804 hardcore to Elliott Construction for this job. The total cost, in round terms, for the five deliveries of Clause 804 hardcore is €25,000 plus VAT. About 4 days later, blocks arrive for the external and internal walls and are placed on the drying concrete floor slab. Then the block-work is built up to ground floor level on the ground beam foundations.

• **13th January 2005**: The first floor concrete slabs are poured. This continues in sections until 25th January. This slab is propped with scaffolding on the ground floor slab and then struck from its supports in various zones after twenty-one days, fourteen days and nineteen days. The external block-work is continued up to roof level.

• **11th March 2005**: The external block-work is completed. This is followed by external windows and doors and roof. Then internal fitting commences. The most important aspect of this for the case is that the internal stud walls were dabbed to the block-work and the partition plasterboard attached to metal studding.

• **1st August 2005**: During this month the first snag list is produced. Ballymun Regeneration indicates a long list of snags involving touching up and some, but not excessive, cracking and chipping. Any cracks are hairline. It is not an unusual list at this stage. I do not see this as the start of pyrite heave.

• **2nd September 2005**: Matthew Stephens, the architect for Ballymun Regeneration, certifies that the works are practically complete. Ballymun Regeneration begins to occupy and use the building as a youth facility. The letter from Matthew Stephens reads:- "I hereby certify that within the terms of the contract dated 19th July, 2004, for the works described as 'Ballymun Youth Facility Phase Two, Sillogue Road, Ballymun, Dublin 11, the works were practically completed on the 2nd day of September, 2005. It should be noted that the defects liability period commences on the day after the date of practical completion. The employer then becomes solely responsible for ensuring that the works are adequately insured".

• **10th October 2005**: The second snag list is produced. This shows a number of cracks, six of which are fairly long. The list of snags, however, extends to many other issues. Whereas these cracks have been described as major by Irish Asphalt, they were in fact all either small or hairline cracks. There is no alarm on the part of Elliott Construction at this point. It believes the building is drying out and its view is that the cracking is within expected limits. The snag list is not indicative of anything unusual at this stage. I do not see it as indicative either that pyrite heave has already pushed up the floor slab or of subsidence.

• **28th August 2006**: At a distance of about twenty and a half months from the pouring of the floors, the third snag list is produced. This shows 79 cracks in the ground floor and 40 in the first floor. Those in the first floor are not alarming but are normal shrinkage cracks. The first floor cracks do not, at any stage, need structural work. One quite large crack appears above the ground floor, but this is in a stairwell. It may be reasoned that as the first floor cracks are due to normal reasons some, perhaps half, of the ground floor cracks are unusual. One double door on the ground floor that opens out onto the brick-clad courtyard is jammed at 45 degrees. The courtyard level is lowered at this point by removing the sand under the bricks and laying them fresh. Some of these cracks are a metre long in the ground floor and some of them are only 10 cm long. I find it probable that if there was pyrite heave or sinking walls, the early part of the process had now begun. Elliott Construction is puzzled by the cracks but agrees to proceed to deal with them immediately. Three painters and decorators are employed by Elliott Construction over a period of three days in September to deal with the matter. Even at this point, however, the cracking is not severe. The first floor cracking never becomes severe and this superficial exercise is the effective end of any issue on the upper floors of the building.

• **1st February 2007**: Over the intervening period of five months, cracks in the internal ground floor plasterboard walls and internal stud partition walls of the building keep reappearing. There seems to have been some effort by Elliott Construction to chase the cracks and to repair them as they appeared. For the next period from the snag works in September 2006, over a period of fourteen months, to November 2007, the internal ground floor plaster wall cracks not only reappear but gain in intensity, proliferating throughout the ground floor of the new portion of the building. There are no plaster cracks in the old building and nor is there any structural cracking where the old building wall meets the gym construction on the new foundations at the north-western interface. Cracks may also have appeared in the floor slab but at this stage the building is still being used so the concrete floor slabs are covered. Structural cracking never appears in the walls of the building.

• **20th July 2007**: Irish Asphalt writes to Elliott Construction in these terms:-

"We write to you in light of recent media reports regarding structural problems in certain housing developments associated with the use of stone infill materials allegedly containing excessive levels of pyrites. Pyrite is present in one our quarries, located at Bay lane, County Dublin. The purpose of this letter is to clarify to you that, due to the expansive properties of pyrite under certain conditions, materials containing pyrite should not be used in the following circumstances:

> (i) as under-floor infill in any building, whether residential or otherwise; or
>
> (ii) within 500mm of any concrete or steel structure.

We would point out to you, more generally, that it is the responsibility of the purchaser of materials to ensure that the correct product is chosen to ensure suitability for its intended use. Where a particular use is intended, you should bring this to our attention and provide us with details of the appropriate specification for that intended use. We are more than willing to discuss with you, prior to purchase, your intended us and, in that regard, to evaluate the specification you provide us with in order to advise on the suitability of the product requested.

In addition, where you, as the purchaser, provide us with details of particular specification requirements which you may have, we will test the materials requested for conformity with these particular specifications. We also wish to reiterate that we are committed to providing materials which are fully compliant with any relevant specification(s) assigned to the particular materials supplied, in accordance with our standard terms and conditions of sale.

We trust this clarifies our position and look forward to doing business with you in the future."

• **28th August 2007**: Elliott Construction replies to Irish Asphalt in the following letter that was never responded to:-

"We note the contents of your letter dated 20th July, 2007, and are outraged by same. The duty of care is on you to supply us with material suitable for purpose. It beggars belief that you propose to continue with supplying material contaminated by pyrite. Please inform all concerned in your organisation that you are no longer to supply this or any other defective material to us.

Furthermore, if you have supplied us with material contaminated by Pyrite or anything else, we need a list of the sites supplied and the quantities and dates of delivery. With regard to giving details of where specific loads of stone are to be used and their purpose, we will not be going down that road with you. You only want this to try and pass off poor material and force us into keeping segregated piles of hardcore and managing your problem for you.

Finally, if you have supplied material which is not fit for purpose, there is a question of compensation for ourselves and our clients."

• **17th September 2007**: Patrick Elliott of Elliott Construction meets with Terry Laggan of Irish Asphalt in Brady's Pub in Dublin. Some heat has been generated by cross examintion in relation to the nature of the exchange. An indemnity is sought by Elliott Construction in respect of any defects that might arise due to pyrite in any buildings in which they have used Clause 804 from Irish Asphalt. This is apparently refused by reference to an insurance policy by Irish Asphalt. A view is also expressed, from the point of view of Irish Asphalt, that in a number of projects and buildings around Dublin, builders who have been guilty of bad workmanship are "jumping on a bandwagon" of pyrite heave and claiming compensation unfairly from Irish Asphalt. None of this matters to any ultimate issue as to liability in the case. It is an early summary of the conflicting opinions of the parties. It has not changed.

• **17th October 2007**: The architect for Ballymun Regeneration writes to Elliott Construction to complain about the state of the building. The letter reads:-

"Further to our telephone conversation of today I write to you with reference to the defects to the plasterboard sheeting that was applied to the block work walls on the ground floor of Ballymun Central Youth Facility. A brief summary of events is as follows:

> (1) The original contract documents for the project called for a wet plaster finish to the internal block work of the building. During the course of the contract this was agreed to be amended to the constructed detail of plasterboard on dads with skimmed, painted finish.
>
> (2) The certificate of practical completion is issued. Following this, a number of large cracks occurred in this plasterboard. These cracks were repaired by James Elliott Construction Limited.
>
> (3) In the months subsequent to the repairs being carried out the cracks re-emerged. [Ballymun Regeneration] carried out an inspection of the plasterboard. It was noted that the plasterboard was warping in many areas due to inability of it to expand in any direction. [Ballymun Regeneration] carried out two spot checks of the finished detail behind the skirting boards – in both texts we noted that plasterboard extended right down to concrete slab level and no gaps for potential expansion of the plasterboard was evident.

I have discussed the issue today with Martin Hannay [the site foreman] who has expressed his willingness to carry out his own inspection of the premises…[Ballymun Regeneration] feel it is the only outstanding issue prior to the agreement of the

final account".

• **2nd November 2007**: Ballymun Regeneration write to Elliott Construction in the following terms:-

"Further to the reoccurrence of extensive cracking in the plasterboard lining over recent months, BRL carried out a visual inspection of the building today in conjunction with Moylan Associates (Engineers). The following defects were noted: Extensive cracking, spalling, and bulging in the plasterboard lining at ground floor level in the new building.

Cracking in the ground floor slab where the slab had been left exposed and could be inspected.

Significant cracking and differential movement around the perimeter of the ground floor slab. This was particularly noticeable at external door openings where the ground floor slabs difference of approximately 5 mm were noted along the crack fault line.

The slab appears to have heaved upwards and we believe that there is a very strong probability that the upward heave has been caused by the presence of pyrite in the hardcore fill. Moylans will be reporting back on today's findings early next week. Notwithstanding this, we anticipate that further significant on-site investigation and opening-up work will be required to determine the exact cause of the present failure and to determine the extent of remedial works required. We will be in contact with you to agree arrangements to have this work carried out.

The situation at the YSB raises grave concerns in relation to Sillogue 4 [housing estate]. We have been led to believe that hardcore sourced from the same quarry as the YSB hardcore has been used in Sillogue so that there is a high probability that this material also contains pyrite and that similar structural defects as have appeared in the YSB will manifest themselves in due course in this housing project. Given the potential seriousness of the situation, can you please confirm whether this is, in fact, the case, and if so, what remedial action Elliotts propose to take to address the situation."

• **9th November 2007**: James Elliott of Elliott Construction and his foreman on the job, Martin Hannay, visit the building. They particularly inspect the ruined ground floor area. They are horrified by the level of cracking. With characteristic Dublin humour, one of the people working in the reception area, where there is a gaping crack at head level, asks for a safety helmet. Just under three years have passed since the pouring of the ground floor slabs on to the Clause 804 hardcore infill on 17th December, 2004. The floors in several areas are apparently forced up against the plasterboard of the internal ground floor walls and the room dividing stud partitions are also bulging and cracking

• **1st January 2008**: By this stage Elliott Construction is seeking expert advice as to what has happened to the building. Testing commences on various dates from this period onwards for both sides.

• **13th June 2008**: A plenary summons is issued by the plaintiff against the defendant. The occupiers have left the building, by this stage, for temporary accommodation elsewhere.

• **17th June 2008**: Orpen Franks, solicitors acting on behalf of Elliott Construction, write to Irish Asphalt complaining that the damage to the building is as a result of what they call contaminated hardcore used in the construction and supplied by Irish Asphalt. The plenary summons is enclosed. Irish Asphalt is invited to conduct further testing before remedial works are commenced. Irish Asphalt is warned that Elliott Construction is seeking to recoup the costs of the remedial work.

• **2nd July 2008**: A statement of claim is served.

• **1st September 2008**: Irish Asphalt, during this month, brings interlocutory injunctive proceedings against Elliott Construction to stop remedial work until testing has been completed on its behalf. The result, by settlement of the interlocutory proceedings, is that remedial work is stopped. For a period of a full year, monitoring of the movement within the building is continued.

• **1st May 2009**: A video has been played to the Court that was filmed, on the ground floor during this month at a period immediately prior to the commencement of work on the remediation of the building. This video shows large gaping wall holes, buckling in the walls, substantial open cracks, cracking in the floor slabs, jammed doors and slab and threshold differentials in height. At first floor level there are no such problems. The video can be taken as a correct description of the building prior to remediation. It is not in dispute as to what it shows; the dispute is as to the cause. The video is Appendix II to this judgment.

• **10th May 2009**: Elliott Construction commences remediation to the building. The slab and pavings are removed. During the time that it cannot be occupied, a temporary youth facility is put up. All of the underfloor hardcore is removed from the building. At lower levels, lean mix concrete is poured into some very deep places, followed by hardcore which is compacted, and then radon and insulation and damp-proof barrier. It is followed as in the original construction by wire mesh, and floating concrete floors that rest on the hardcore. Relevant plasterboard walls are repaired and replaced. As with the original construction, the new floors do not rest on the ground beams or foundation pads but float on the Clause 804 hardcore below. The hardcore for the remediation, however, is obtained from Keegan's quarry. It is later used as a control for some tests referred to in this judgment. The foundations are not touched beyond sampling. The first floor does not require remediation. There is some small repair to a stairwell.

• **10th June 2009**: Matthew Stephens, senior architect for Ballymun Regeneration, writes to Elliott Construction giving his understanding of the legal position between them as regards remediation, in the following terms:-

"Further to your telephone query of yesterday, I can confirm to you that no written instruction was written to James Elliott Construction by [Ballymun Regeneration Ltd.] to remove the Lagan hardcore from the BCYF building, but that no written instruction was required to be written under the terms of the contract. A brief synopsis of the contractual situation is as follows:

A Certificate of Practical Completion for the Ballymun Central Youth Facility (Phase 2) was issued by [Ballymun Regeneration Ltd.] to [James Elliott Construction] on September 2nd 2005. Under the terms of the contract (GDLA), the defects liability period commenced on that date and [James Elliott Construction] were liable to rectify any defects arising

in the building within a year of that date. In August 2006, i.e. within the defects liability period [Ballymun Regeneration Ltd.] compiled a list of cracks to the building and issued the list to [James Elliott Construction] requesting they be attended to. In the ensuing months, and following the receipt of expert advice, it emerged that the cracks that were identified during the defects liability period were as a result of heave to the ground floor slab that came about due to excessive levels of framboidal Pyrite in the hardcore laid beneath the ground floor slab of the building. It therefore follows that the responsibility remained with [James Elliott Construction] to carry out whatever measures necessary to rectify the defects and no written instructions from [Ballymun Regeneration Ltd.] was (or is) required."

• **1st November 2009**: During this month, the remediation work finishes. The building is reoccupied by Ballymun Regeneration.

The Ballymun Building Contract

24. The defendant, Irish Asphalt, is not privy to the contract made between the plaintiff, Elliott Construction, and Ballymun Regeneration. Nonetheless, reliance has been placed by the defendant on certain of the conditions within that written contract with a view to arguing a failure to build in accordance with the contract and, consequently, that causation of the wrong should be found in Elliott Construction's breach of contract.

25. The contract documents are multiple and, in some potentially important respects, potentially a source of confusion. The approach by Patrick Elliott, the principal of Elliott Construction, and by his site foreman Martin Hannay has been to view the contract as establishing binding obligations. On issues as to engineering specification they say that Moylan engineers, engaged by Ballymun Regeneration, were followed as to their oral direction and, as regard the detail of features, the architect were followed on the same basis.

26. The contract documentation consists of the civil and engineering specification issued by John Moylan of Moylan, dated December 2002; the general specification of the architect; the form of tender, dated 11th February, 2003; the agreement and conditions of contract for the building work, dated the 19th July, 2004; the bill of quantities sent with the sender documents of 11th February, 2003; the drawings accompanying same; and the modifications to the drawings as issued from time to time. As regards the Clause 804 hardcore fill, the next section of this judgment will deal with that matter in detail.

27. The civil construction engineering specification confirms that the approach of Elliott Construction to the taking of direction from the engineers and architect employed by Ballymun Regeneration was correct. Clause 1.2 provides that no approval by the engineer "shall in any way relieve the contractor of his responsibility for the quality of materials and the standard of workmanship in the finished works and for the strength and durability and appearance of the finished concrete works". This is to be read in conjunction with Clause 1.6 which requires the contractor to submit a programme of works for the approval of the engineer. When that is approved, the engineer is entitled to require the contractor "to carry out any part of the works at any time". In the general specification, it is provided for in Clause 1.4:-

> "Should the contractor find any discrepancies between the various contract documents he shall immediately notify the architect whose decision in writing in respect thereof shall be final."

28. The contract documents number hundreds of pages of closely printed material. The idea of Patrick Elliott, as contracts manager and, more so, of Martin Hannay, as foreman on the job, engaging in a lawyer-like exercise of picking between variants to obligations so as to establish a discrepancy might be relevant to other building contract cases. It is not relevant here. Clause 1.5 of the general specification requires the contractor to make a thorough examination of those documents and drawings and to visit the site. Patrick Elliott and Martin Hannay have emphasised the primacy of the drawings as regards decisions to be made, and the role of Moylan in directing the work on-site. This approach is argued by Irish Asphalt to have been a breach of contract. In particular, it should be remembered that Clause 1.7 of the general specification provides:-

> "The architect has supplied two complete sets of working drawings and two copies of the specification, and will also provide such further explanatory or detailed drawings as he may consider necessary from time to time. The detailed drawings in all cases to be worked to in preference to those of a more general character and figured dimensions are to be followed. Should the contractor consider that extra or additional work should be included in these detailed drawings that may be issued from time to time, he must, within seven days of their receipt by him, represent same to the architect in writing.
>
> The architect will then, if he thinks such representations reasonable, either revise the detail drawings and/or issue an architects instruction. Under no circumstances must the work, as set forth in the specification and shown on the drawings, be varied without the architect's written instructions. The contractor is to accept instructions from the architect only".

29. The reference to detailed drawings in Clause 1.7 and the requirement that these are to be worked to in preference to any of a more general character establishes the primacy of the drawings. This is important as regards the use of any Clause 804 material. When it comes to the contract signed between the parties, the agreement recites:-

> "For the consideration hereinafter mentioned the contractor will upon and subject to the conditions annexed hereto and subject to the said tender and the employer's acceptance thereof dated the 19th day of July 2004 execute and complete the works shown upon the said drawings and/or described in the said specification, bill of quantities and conditions all of which together with this agreement are hereinafter referred to as the contract documents".

30. Clause 2(a) of the conditions provides that the contractor is to carry out the works in accordance with the contract and "with the directions and to the reasonable satisfaction of the architect". The clause goes on to indicate that the architect "may from time to time issue further drawings, details and/or written or oral instructions…" The obligation of the contractor is to "forthwith comply with and duly execute any work comprised in such architect's instructions". This provision emphasises, and again establishes, the primacy of the drawings in the proper approach by a builder to fulfilling the contract obligation. These are documents addressed in standard form, based on long experience as to what is necessary to business people engaged in building. Contract documents are to be construed in accordance with their terms. Those to whom such contract terms are addressed is also of importance. Throughout the course of the case, Patrick Elliott and Martin Hannay emphasised the importance of following the instructions given to them by the engineer and architect on-site. They did not seek, nor were they given, any written notification as to variations. Some directions by way of variation were noted in the site book maintained by Martin Hannay, others were just given on the spot by Moylan or the architect. The ability of the architect, as in Clause 2(a) just quoted, to give instructions orally is potentially contradicted by Clause 8

within the said documents. This provides:-

> "All material and workmanship, unless the architect directs otherwise, shall be of the respective kinds described in the drawings and specification and the contractor shall upon request of the architect furnish him with the vouchers to prove that the materials comply with this requirement. The contractor shall arrange for and/or carry out any test of any materials and/or workmanship which the architect may in writing require".

31. In many instances here, a written note would have helped with a subsequent analysis of what building work by Elliott Construction went either right or wrong. My feeling, however, is that even had instruction notes existed they would have been disputed in this trial. In an ongoing relationship, such as that of employer and employee, outside the specific confines of a lengthy ongoing contract to build, designated by parties described as employer and contractor, the methodology of working can establish the obligations of each side. I am convinced that the contract documents encompass oral directions being given as to the appropriate approach by the architect or, on behalf of the architect, by the engineer on-site. I am convinced by the evidence of Patrick Elliott and Martin Hannay that their approach to this job for Ballymun Regeneration did not differ from their approach to any other job. Further, their wide experience not only of the documents which I have quoted, but of building practices over decades, establishes their correctness in treating the drawings as having primacy over written contract clauses. Because, as was said, and I accept, the drawings show how the building is to be constructed, and in following a chain of command as regards decisions on-site, that established the authority of Moylan as engineers and the architects over them, Elliott Construction acted correctly.

32. The contract terms which I have quoted, and the remainder of the voluminous contract documentation, might be central to a different case involving an alleged breach of contract. I accept that the contract documentation may indicate the obligation of Elliott Construction and that departure from it might, through highlighting a departure from instructions, establish an alternative cause as to why the building was ruined. In this instance, however, it does not do so. If the building was ruined by Elliott Construction due to bad workmanship, then the precise terms of the contract are not required to establish this. Bad craftsmanship can possibly be contracted into, or possibly out of, but it establishes blame only against itself. Fundamental to all of the obligations set out in the various documents is the duty of Elliott Construction to employ proper materials, to work to appropriate standards and to construct for Ballymun Regeneration a youth centre that is fit for purpose, durable, and built according to the highest standards of workmanship and quality. This is what I am required to primarily focus on.

Clause 804

33. Multiple and potentially debatable references abound throughout the contract documents as to the appropriate infill to be used in the construction of the building. Briefly, the excavations required to construct the building involved: firstly, the removal and diversion of existing services or the protection, in the case of the foul sewer pipe which could not be moved, of any municipal facility from damage from the construction; secondly, the excavation and construction of the foundations and their siting on black boulder clay; thirdly, the excavation of the foundation beams for the external wall block-work set between, and connected to and resting on, the pad foundations; fourthly, the appropriate excavation of external footpaths and the internal courtyard; and, fifthly, the excavation to an appropriate depth under the floors at the centre of the buildings. All of these excavations required to be filled with something. On remediation of the building, from 2009 onwards, as I have noted, certain deep sections were filled at that deep level with lean mix concrete on the specific direction of Moylan engineers. On the 2004-2005 construction in question, all the various excavations just detailed were filled with Clause 804 hardcore infill compacted in layers. What is this material?

34. The contract documents make a number of potentially relevant references. The Civil and Structural Engineering Specification provides at clause 1.15:-

> "All materials and equipment shall be of the best of their type and to the satisfaction of the engineer. Materials shall, as far as possible be of Irish manufacture origin, and shall conform to the appropriate Irish standard specification. Where no Irish standard specification exits, materials shall comply with the relevant British standard."

35. Under that document, if an alternative material is to be chosen from that specified, then, under clause 1.17, the contractor must inform the engineer of his choice and requirement can be made that it should be tested before approval. Clause 1.5 of the Demolitions Specifications provides, as regards materials, the following:-

> "The contractor shall supply all materials that may be required for the works. The materials shall be new (unless otherwise specified) and shall be the best procurable of their respective kinds and, so far as it is practicable and so far as this does not add to the cost, shall have been produced in the Republic of Ireland. All goods and materials unless otherwise specified, shall be in accordance with the latest revised British/Irish standards, current at the date of tendering."

Clause 1.12 of the excavation and earthworks specification provides:-

> "Except under a foundations, layers of approved filling material consolidated to the satisfaction of the engineers shall be placed below all ground slabs, on top of which a layer of lean mix shall be placed, all to receive a 1000g Visqueen waterproof membrane placed as shown on the drawings. The fill shall be applied only when the formation level is free of mud and slurry, the formation left shall be exposed for as short a time as possible before removing unsuitable soil and applying the fillings. The formation level shall be lightly rammed and generally levelled before filling commences. Back filling around paths, strip footings and retaining walls shall also be in this approved fill material. Granular rock filling where specified shall comprise either of: gravels, crushed rock or crushed concrete . . ."

36. Specifications are then given for this infill in relation to particles size and percentages passing through sieve sizes while differing as between gravels and crushed rock and concrete. The document goes on to incorporate as part of section L thereof the Dublin Corporation Housing Development Construction Standards and Codes of Practice. This provides that sub-base material "shall comply with clause 804 granular material type B of the specification for road works issued by the Department of the Environment". To add to this cornucopia, the general specification at clause 3.8 declares such matters as that backfill should not be placed against the walls within ten days of completion. It also states:-

> "Backfill shall be in graded fill where the ground floor slabs are floating slabs. The graded gravel to be deposited in horizontal layers not more than 250 mm deep and each layer to be compacted with a vibrating roller, frog hammer or similar to the specified dried density. The filling shall be placed at approximately equal levels on each side of the rising wall in order to minimise differential horizontal pressure on the walls."

37. At clause 3.10 a specification is given for graded gravel filling material. This excludes crushed concrete and crushed gravel. What

is left is crushed stone; hence the order from the Irish Asphalt quarry. This specification requires that it is to be spread in 250 mm layers and to be well-compacted to give a particular dry density. The specification given for the granular filling size is different to that in the Civil and Structural Engineering Specification. Clause 3.11 provides:-

> "Tests shall be carried out when and where the architect considers necessary but in general a dry density test shall be carried to every 600sq.m of compacted material per 250 mm layer and the test repeated until the required degree of compaction is achieved. The utmost care is to be taken to ensure that the require degree of compaction is achieved and the contractors' attention is particularly drawn to the importance of this clause."

38. Added to this, we have the drawings. A copy of the most recent revision of the relevant one, in large scale, was carried about during the job by Martin Hannay as site foreman in his pocket, or kept in the site hut with the site diary, during the works. This says that the internal floors are to consist of "a 150 mm pc concrete slab with 1.42 layer of mesh on dpm insulation and radon barrier to architects detail on 225 mm of well-compacted hardcore clause 804 to D.O.E. specification." This is the most important provision. I agree with the plaintiff's evidence that it overrides the other provisions.

39. When one turns to the Department of Enterprise Specification for Road Works published in 1972, one sees grading. This specifies that the granular material is to be "crushed rock". The grading tables limits differ from the two already referenced. The latest came in May 2004, from the National Roads Authority ("NRA"). This gives a table for granular material type B, under clause 804, which has different sieves to the earlier specification and different percentages of mass, therefore, passing through the relevant sieves. This material is, however, to be "crushed rock" to comply with a relevant specification. That specification states as to sub-clauses 3 and 4 of clause 804:-

> "3. The material shall be laid and compacted at a moisture content within the range of the optimum to 2% below the optimum percentage determined in accordance with the vibrating hammer method test in
>
> IS EN 13286-4 and without drying or segregation.
>
> 4. The material shall be maintained within the moisture content range specified in sub clause - 804-3 whilst awaiting overlaying."

40. Reverting to the chronology, shown above, one simple fact diverts from the interest that may be accorded to a discussion of the appropriate final standards set by the contract. On that issue, it is clear that the contract drawing, as quoted above, sets the relevant standard. I accept the evidence of Martin Hannay that in specifying a depth for Clause 804 infill, that same is a minimum depth. Irish Asphalt held itself out as "supplying Clause 804". This is a known standard within the building industry and one on which Elliott Construction was entitled to rely in ordering, paying for and in accepting deliveries of that product. I accept the evidence of Dr. Michael Maher, engineer, of Golder Associates Canada ("Golder") that material of this description is manufactured to have particular characteristics and that builders purchasing it have an entitlement to rely on that standard. Clause 804 is, in fact, a material superior to what is usually needed for construction infill and underfloor support. It is manufactured and sold on the basis that it is a high quality product. The fundamental requirement for Clause 804 as a construction infill is that it should do the job that it is intended to be used for. This characteristic can be broken down into: firstly, that the material must be inert and not subject to chemical change; secondly, that the material is durable and should not break down due to temperature within the expected limits of the relevant site and moisture within the expected limits of the relevant climate; thirdly, it must be strong enough for its purpose; and, fourthly, when used for roads, the material should not wear, breakdown or polish so that any surface designed to have a particular level of friction becomes polished and slippy.

41. The central issue in the event that pyrite heave is proven by Elliott Construction to have ruined the building is whether the Clause 804 hardcore infill meets the relevant standards or was, instead, supplied in breach of contract. The relevant standard is part of the contract. Inertness, durability and strength are relevant to implied terms as to merchantability and fitness for purpose. These are analysed in a later section of this judgment.

The Chemistry

42. I now wish to give some brief explanation of the chemistry involved in the process whereby the presence of pyrite within a rock infill can cause heave under a floor slab through conversion to gypsum.

43. Pyrite can occur in fine-grained sedimentary rock. Pyrite is a sulphide of iron and is one of the more common of metallic minerals. In clumps, it can be referred to as fools' gold because of its shiny appearance before oxidisation. Pyrite, FeS^2, can oxidise in sedimentary rocks. When well-crystallized in euhedral form it is generally thought to be relatively stable. Pyrite in framboidal masses, however, which has an appearance under a microscope similar to a raspberry, is highly reactive. In this form it can be associated with shale and also with mudstones. Usually in the unstable framboidal form, pyrite oxidises when it comes into contact with oxygen and water. This is the formula: $2FeS^2 + 2H^20 + 70^2 \rightarrow 2FeSO? + 2H^2S0?$. In words, the oxidisation of ferrous sulphide, pyrite, releases ferrous sulphates and sulphuric acid. While in the quarry or the mine, at sometimes great depth, and covered by other layers over millions of years, pyrite, even in framboidal form, will tend to be relatively stable. This is due to the lack of contact in its entombed state with oxygen and water. On being dug out, crushed and exposed to oxidisation, good absorption properties in stone aid the oxidisation of pyrite. This can occur in the mudstones contained in the Clause 804 hardcore from the Irish Asphalt Bay Lane quarry. Because calcite, $CaCO^3$, is usually present in mudstone and shale, and is in fact abundantly present in the Clause 804 relevant to this case, it can react with the sulphuric acid produced by pyrite oxidisation and lead to gypsum forming. On the saturation of the solution, then in the form of different ions in water, gypsum, or calcium sulphate dihydrate, crystallizes from a combination of these ions. The reaction is $H^2S0? + CaCO^3 + H^2O \rightarrow CaSO?.2H^20 + C0^2$. Or, in words, the combination of sulphuric acid with calcite and oxygen and water produces gypsum and carbon dioxide. Oxygen is often naturally dissolved in water; it can also pass readily through water at a sub-capillary level. On crystallizing, the gypsum takes up a larger volume than the initial pyrite and calcite. The water in rock pores and in fissures will carry the ions that can crystallize inside a rock, often in a lesion, opening up a fissure and heaving the rock apart. This crystal form also covers the surfaces of rocks and, on lesions already present within the rocks, naturally and sufficiently present in this Clause 804 infill, heaves the rock apart causing fissures. Covering can also push pieces of rock apart. Existing fissures can also be pushed further apart by gypsum crystal growing forcefully.

44. There has been a great deal of emphasis in this case on lesions and fissures. The coating of small, and to perhaps lesser extent bigger, rock particles can also be a cause of pyrite heave. In this regard, I accept the evidence of, and the expertise of, Jon Hunt of Golder, who gave evidence for the plaintiff Elliott Construction. I take that into account in reaching my final conclusions. While there is no standard formula for the amount of gypsum, calcium sulphate dihydrate, that will cause an infill under a floor to heave, it is apparent from the samples that I have seen, and from the explanations given in court, that its effect can be considerably greater

than its volume. Within a rock, lesions will be opened up and be caused to separate due to gypsum crystallizing. Gypsum does not have to fill the entire surface of the fissure or completely coat a rock particle. As the crystals grow in individual places, they form props that expand the rock leaving the void thereby opened up within the rocks to be filled by readily available air, or perhaps sometimes water. Growth on the surface of small and big particles props open the spaces between stones. An entire compacted infill can be afflicted by this process. The potential problem with the Clause 804 removed from the Bay Lane quarry is, I am satisfied, substantial. The relevant minute images captured by witnesses on each side clearly show multiple framboidal, and very little in the way of euhedral, formation of pyrite. There was very little in the way of a microscopic search for completely oxidized pyrite framboids. A fair estimate of the ratio of framboidal to well-crystallized pyrite is of the order of 70:30. Since compaction of the material for the infill, in my view correctly achieved in this construction, gives a ratio of about 85% to 90% of solids, to 10% or 15% or so of voids, the increase of the rock formation volume due to gypsum growth will cause expansion. It is true that even in well-compacted infill, a void space exists into which crystals can passively grow. It defies good sense, however, to argue that the gypsum crystals will always just grow, or are more likely to grow, into empty space. There is a lot of pyrite present in the Clause 804 infill from the building. The specific gravity of pyrite is 5.0, whereas that of ordinary rock is 2.7. In the Clause 804 supplied by Irish Asphalt from the Bay Lane quarry the percentage of pyrite is 1.5% by volume and 2.7% by weight. The Canadians take, among other factors, 1% by weight content of pyrite as a potential cause for concern in underfloor infill. The nature of the rock and other conditions must be looked at as well, of course. One of the tests conducted by Lloyd Twomey of Ove Arup Ireland ("Arup"), for the plaintiff, was to pour loose infill removed from the building into a receptacle and then to judge the amount of voids present. This yielded void figures between 31% and 37%. This, however, was not compacted. In error, Dr. Alan Peter Boyle, on behalf of the defendant, conducted a thought experiment on the basis of the lower figure. This was incorrect as the loose infill void proportion bears no relation to the compacted infill. He also conducted a thought experiment on the basis that if the solid portion of the underfloor infill was 80%, then the effective amount of pyrite by volume which was reduced from 1.5% to 1.2%. On the basis of 31% void space, an invalid figure in this context, he posited that the solid volume would increase, upon total oxidisation, by 3.15% to around 72%. His view was that most of the pyrite would thus become gypsum in void space. I do not accept the validity of these calculations. I do not accept that gypsum would somehow choose to occupy void space, almost as if by decision, in preference to space where stones are touching, or by nucleation within lesions, or by growing within existing cracks, thus propping open fissures. The process of nucleation of crystal depends upon a supersaturated solution. This can migrate over a number of metres, and will react at a micro level which can completely ignore void space. On analysis of all of the evidence, assisted by the theoretical expertise of all of the scientific experts, I am satisfied that the notion of choice of or predominance of void space for nucleation of gypsum is not scientifically valid. Furthermore, it is contradicted by the facts. Even on correct figures, I do not accept Dr. Boyle's view.

45. On expansion within a confined space, the weakest link will react. In the instance of a building with a floating floor slab, the pyrite to gypsum conversion will expand both sideways, downwards and upwards. Since sideways it would be meeting the resistance of the block walls in the building, and to a lesser extent the foundation beams, and on expanding downwards the solid earth on to which it was compacted, the reaction most probable is to heave the floor slab upwards. This heaving will not occur in uniform fashion but differentially, causing upward movement of the slab and wall bulging and cracking in particular places. As will later be seen, the swelling experiment conducted on behalf of the plaintiff by Dr. Michael Maher of Golder bears out this idea of non-uniform expansion. Where an expanding infill is compacted onto a solid surface, such as a concrete beam, it stands to reason that heave from an ungiving platform will, it stands to reason, affect the process. Where the plasterboard adhering to an external wall overlaps the floor, or where stud partitions are fixed to the ground floor slab, any rise will eventually crack and buckle it. In this instance, the floor slab has not risen in any pattern that I can in any way sensibly construe as relating to the building subsiding. I accept the evidence of Dr. Maher in that regard for its objectivity and conformity with good sense. Here, we are talking about rises in terms of millimetres; perhaps 15 mm to 20 mm or so up to the point where it became clear that the interior of the building was ruined on the ground floor. This finding of ruination became inescapable by late 2007. The slab, however, continued to heave thereafter. This was made clear by the monitors in place over a thirteen month period up to the summer of 2009. I will refer to this in a separate section

46. An explanation of the phenomenon of pyrite heave was provided by *Bérubé et al* [2002] in the following terms:-

> "The formation of iron hydroxides and calcium sulphates leads to a volume increase over 100% with relation to the original materials (calcite, pyrite). Furthermore, these minerals settle into pre-existing fissures within the backfill particles – fissures they tend to open even more. According to some studies, the crystallization of gypsum is sufficient in order to lift a three-meter rock column. A concrete slab of a few decimetres is not enough [resistance]. Luckily, such pressure is usually insufficient in order to lift the foundations supporting a building, which are more charged.
>
> The swelling of concrete slabs on swelling pyritic backfills is usually lower to 1-2 cm per year. They are null to very low during the first years following building construction, even though the reactions occur, but tend to accelerate over time. A delay of roughly 5 to 10 years is not uncommon for heaving to be detected. Afterwards, these phenomena process normally as long as the appropriate conditions remain present, and as long as pyrite is present in the rock (source of sulphur and iron), as well other minerals that are essential to the formation of sulphates (ex.: calcite, etc.)."

47. *Bérubé et al* list the following as the essential conditions:-

> "1. Presence in sufficient quantities of pyrite reactive and accessible to air and moisture.
>
> 2. Presence of moisture and oxygen but non-saturated environment over the groundwater surface also caused phreatic surface.
>
> 3. Presence of calcium carbonates in sufficient quantities (calcite, dolomite etc.), for the formation of gypsum in the rock's voids.
>
> 4. Sufficient backfill thickness, for heaving to be detectable".

48. The authors also mention that a humid and non-saturated environment is required. They point out that under a floor slab such an environment naturally exists. Water penetrates the rock pores and is not fully dried out. Absorbed water allows for oxygen from air, and that already in solution, to cross quickly by diffusion at the site of loaded crystal growth. In Ballymun, there is water table variation and a well heated public building and so moisture in abundance. There is a layer of insulation 60 mm thick between the floor slab and the crushed rock beneath. Insulation helps against heat exchange but it does not stop it totally. The authors believe that the less saturated the environment, the more easily the pH level will drop and pyrite oxidisation will occur. Variation in moisture conditions, which can happen through cycles of drying and wetting, are optimum. They point out that within a heated building the granular infill is relatively hotter and drier at the surface and that a solution rich in the relevant elements issued from pyrite oxidisation tends to migrate towards the top. Swelling by a granular backfill is more likely if the mechanical competence of the rock is low. High levels of calcium carbonates within a rock infill can be indicative of a mineral associated with swelling in these conditions. A

predominance of clay materials can also favour the swelling process. On behalf of the defence, Dr. Boyle produced charts and explanations of the relative interrelationship between pH and oxygen levels. These were of assistance in understanding the entirety of the problem. The nucleation and the growth of crystals takes place, however, not on the basis of a test tube experiment, where the solute is evenly distributed, but on the basis of kinetic forces. It is possible that calcite may neutralise sulphuric acid, but the theoretical basis for discounting a reaction because of the presence of 30% or more calcite is not established. The action of bacteria in this reaction is not completely understood, I was told in evidence. The optimum reaction temperature, according to *Bérubé et al* (2002) is around 32º Celsius. A pH of 3 or 4 seems to be useful to bacteriological action in that regard. A pH of more than 7, where the solute becomes alkaline is inimical, in theory, to the action of relevant bacteria in breaking down the pyrite. Such a pH has been claimed here by the defence, though other figures show a mild acidity just below 7. In the *Bérubé* and Ballivy test experiment for an ideal swelling protocol in 2002 bacteria were introduced. They consider that these are "omnipresent in nature", though they found what was thought to be the right culture by introducing tailings gathered at 20 cm into the soil of a location in Canada. I note now that this introduction seems to have assisted swelling and that in the swelling tests proved in evidence in this case, there was no deliberate introduction of a culture of *thiobacillus ferooxidans* or *thioparus.* I have to face the reality that gypsum has grown in this infill. I consider this in the section of this judgment that relates to monitoring and to the swelling tests conducted on this infill. That does not support Dr. Boyle's hypothesis. Nor was I at all impressed by his strong emphasis on the very insoluble nature of gypsum since the ions that form crystal gypsum do not migrate in that form. What does matter, on the other hand, is that gypsum crystals once formed are very difficult to dissolve. Contact with calcite is essential, on the chemical formula indicated, for the growth of gypsum. Too much calcite, by moving an acid solution towards an alkaline or balanced level, may neutralise what is thought to be the necessary acidic environment. This, again, in theory is very helpful. It is notable, however, that in none of the tests on the infill from under the Ballymun building, was bacteriological activity measured. Nobody looked to see if bacteria of the right kind were present or not in the infill from under the building. I am not content to simply rely, without more, on examples of the percentage of calcite reproduced in a set of scientific papers. This is especially so where many of these, on the basis of the evidence before me, neither state this theory as being essential or even, in some few cases, state a relevant figure. Even where the relevant figure is present, I regard it as merely useful information to add into the analysis of this problem and not definitive to an answer to the issue of whether there was, or was not, pyrite heave.

49. In the case of the building there is a good depth of infill, exceeding 2 m in a relatively few places, but averaging around 0.8 m to 0.9 m; a well heated working environment above the floor slab, which heat will, as a matter of plain sense, migrate down through the floor slab and insulation barrier over time; a water table which is 1.65 m below ground level on average, fluctuating up and down 0.5m, giving a saturation potential of 1.15 m to 2.15 m, together with capillary action; a predominance of mudstones; and a very high level at 1.5% by volume and 2.7% by weight of pyrite in 70% accessible form. There was much emphasis at one point on insulation. If a perfect form of insulation could be found then the heat loss and heat gain problems of buildings would be solved. It has not been found, not even close. On the relevant mechanism, *Bérubé et al* offer, within the context of a conclusion to the first part of their scientific paper, these observations:-

> "The following parameters may simultaneously, and to various degrees, influence the reactivity and swelling rate of a pyritic granular backfill:
>
> • Pyrite abundance and texture (i.e., crystallinity, morphology, grain size and specific surface; ex: framboidal vs. microcrystalline vs. crystalline pyrite).
>
> • Calcium carbonate abundance and distribution (limestone, dolomite).
>
> • Clay material abundance and nature (ex: shale vs. pelite, illite vs. smectite).
>
> • Rock physio-mechanical properties (i.e., porosity, permeability, bedding, fissility, shearing, fissuration, mechanical resistance, etc).
>
> • Backfill grain size (0/20 mm material vs. "clean stone").
>
> • Moisture conditions and variations, and wetting/drying cycles.
>
> • Temperature conditions.
>
> • Backfill thickness.
>
> Thus, a non-clay limestone containing 5% of microcrystalline pyrite might not swell, while a shale containing only 0.1% of framboidal pyrite might swell, due to the presence of more reactive pyrite (i.e., framboidal and easier accessible re: permeability) combined to a smaller resistance capacity to the gypsum crystallization growths (re: mechanical competency).
>
> Moreover some shales were already oxidized during their geological history. Their pyrite was completely transformed into iron oxidise (hematite, etc.). These shales are often, but not always, red or reddish brown and do not constitute a menace when used in a backfill under slabs."

50. It may be commented, in terms of pure chemistry, that the relevant combination in terms of composition of rock and conditions as set out in the *Bérubé et al* paper are present in high degree in the context of the building. This potentially can assist in establishing a probable cause. There are high quantities of small rock particles (less than 20 mm). Drying and wetting cycles are present below the fill and some variation in air moisture levels is to be sensibly expected as well as increases and decreases in expected capillary action. The microclimate is temperate, as opposed to freezing which would slow chemical reactions, and influenced over ordinary working time in upper levels by a well heated building. I accept the evidence of Dr. Maher for the plaintiff in that regard. Sufficient of the rock is, I am satisfied, subject to water permeability and is porous. As will later emerge, in this regard, I accept the evidence of Dr. George Dunlop Matheson and Jon Hunt who gave evidence for the plaintiff. Their view was that the samples from the building which they tested were of sufficient porosity. Some were of low porosity. Here, however, time for reaction was enough. Moreover, while all experts are agreed that the mineralogy of the infill below the building was only 5% shale, all of the lamination counts were far higher than that percentage. Jon Hunt laboriously counted open laminations from the infill at 10%, 14% and 8% over three large samples, making an average of 11%. His analysis was painstaking. Nor am I satisfied that the crushed stone in this infill can be described as very strong. Some substantial portion of it is fissile and with poor mechanical resistance. This was amply demonstrated in court. Clay and calcium structures are abundant. In this *Bérubé et al* paper, which was produced to the Court as evidence, the acidic environment bacteria biological reaction theory is mentioned within an appropriate context and I take that into account. Further research on this issue is needed. The pyrite in the infill from under the building is mostly ripe in form and in situation for oxidisation. It

is not, in my view, sequestered. It is not old and previously oxidised and it is not locked away in predominantly euhedral structures. I will refer to the petrographic evidence which I accept later in this judgment. In that regard, I strongly prefer the plaintiff's expert evidence to that of the defendant.

The Construction

51. Two principal theories were advanced by the defence as to why the building required to be remediated due to ground floor plasterboard wall cracking and bulging and floor cracking. Some subsidiary theories were also advanced and I will deal with any of those that seem to me to be of potential importance in the context of my overall assessment of the evidence. For evidential purposes, the building was divided into 3 zones. Zone 1 is the gym at the north-west and is joined to the old youth centre. It also comprises a bicycle workshop and store over one storey to the south. Zone 2 runs along the north face from the gym to the main entrance. Zone 3 is the entire east of the building.

52. The first theory from the defence was that the foundation pads were not sited, as is specified in the contract, on Dublin black boulder clay. Dublin black boulder clay, by repute and by experience, can accept huge weight. The estimate as to the average loading that the building would place on the ground is of the order of 160 kN per m². The foundations were designed to accept a load of 250 kN per m². In fact few foundations potentially exceed that: the foundation beside trial pit 1 in the middle and to the east of zone 3, and the foundation near the eastern stairwell in zone 2 were of particular importance to the defence analysis. Most support a much lesser bearing. The ground on which the building was constructed consists of a level of topsoil, underneath which brown boulder clay is to be found and, underneath that, black boulder clay. If the foundations were not sited on the black boulder clay, the brown boulder clay would be much less strong. That might safely bear up a lesser building, like a bungalow on strip foundations, but not this one. Had this error occurred it might cause, potentially, the building to subside. Since this issue is particularly important, it is analysed later in this judgment. I turn first to the concrete elements.

53. There was nothing wrong with any of the concrete used in this construction. I am helped by the evidence of Dr. Ian Simms, an expert on concrete who gave evidence on behalf of the defence. As a probability, this concrete is unremarkable. The pattern of the concrete cracking as microscopically examined on small sections being removed from the building is consistent with at least some trauma occurring after hardening. The micro-cracking pattern in the ground beams and pads was indicative of some stress occurring in the building. This could be interpreted as heave or could be interpreted as settlement, according to Dr. Simms. The bearing limits of the concrete in the foundational elements were checked. These are well within the necessary bearing strength.

54. A brief note is now appropriate as to the order in which the building was constructed. In this regard I am satisfied that I can rely on the evidence of Martin Hannay and on the evidence of Patrick Elliott. The first task of Elliott Construction was to survey the site. I am satisfied that Moylan had surveyed the site and that a site report was given to Elliott Construction. There is nothing to suggest that it used this report in any inadequate way or that its approach to the site was flawed. The adequacy of the site survey was criticised by Pearse Sutton of O'Connor Sutton Cronin and by John Campbell of Earth Science Partnership, both defence experts. In my view a competent building team would have built on the information supplied by this survey and, in this instance, did just that satisfactorily. No one has given me an exact sequence in precise terms as to dealing with the old youth centre on the western end of the site. At some stage, part of it was demolished and this may account for the fact that pad foundations at that corner of the construction to the north-west were installed later than the others. One potential cause for concern was the volume of made ground under the building footprint. This describes ground that is not original, but results from the movement of earth by people, usually from other building sites. There was up to 2 m in some places and in others about 0.7 m. This required the siting of the foundations on the black boulder clay, and made it unusually important. Also, the Clause 804 infill had to be properly dealt with as it might rest on made ground.

55. Elliott Construction commenced by a consideration of the contract documents, particularly the drawings, and it also considered the site survey. A great deal of time was spent in locating appropriate services and dealing with them. With gas and electricity, the problem was less severe than with municipal services such as sewage. Gas and electricity tend to be buried at high levels. These were located, dug out and diverted or otherwise appropriately dealt with. The sewage services, which are at a depth placing them within the black boulder clay at more than 2 m below site level, could not easily be diverted. Pearse Sutton for the defence proffered the view that it was negligent not to have entirely moved this sewer. I do not accept this. A concrete detail was placed around the pipes, whereby they were dug out and located, insulated against work damage and then, effectively, bridged to a higher level. At the eastern end of the building this sewage line transects zone 3. In consequence, it was necessary to infill at a very deep level and to compact the Clause 804 hardcore to the appropriate standard. This, I am satisfied, was done properly with the use of 'Wacker' plate. Some of the foundation pads would then be sited in that area and, indeed, one or more rest in part on details of bridging work used to protect the sewage line that traverses this zone going eastwards.

56. At this point in construction, the site would have been excavated below ground level and, although the levels in evidence concerning this were not exact, it was probably about 0.7 m or more below the level of the floors, as they would later be installed. A working platform for the rest of the construction was then installed. This consists of a 120 mm layer of Clause 804 hardcore that was compacted to 100 mm depth. Martin Hannay gave evidence that, at this point, the working platform was established as solid by additionally rolling the entire ground with a JCB tracked vehicle. This weighed just less than 20 tonnes. I am satisfied that, at this level, at least 0.5 m to 0.6 m below the level for the commencement of laying the floors, some degree of stone mechanical damage may possibly have been caused to that lower level of infill due to the great weight of that machine. This, however, was at a very low level, and one that is not relevant to any samples taken here. The stone infill samples taken out for testing in 2009 were removed at a level of 80 mm to 400 mm into the fill. The machine tracked up and down the hardcore so that its tracks consolidated it more than would be required for the support of a floor. The foundations were then dug. I regard the heavy tracking by this machine as inconsistent with any proposition that there was very weak or spongy ground left below the building footprint which could not later support the weight of around 0.8 m to 0.9 m, on average, of hardcore and the approximately 0.2 m floor slab.

57. The building rests on 39 pad foundations. These, in turn, rest on lean mix concrete poured by Elliott Construction, it is claimed, on to the black boulder clay so as to bring it up to a safe level for work on the pad foundations. These support the walls externally and the columns that support the first floor. The pad foundations are linked into and support the ground beams that span between the pad foundations. The walls on the lower level, and the entire construction depend on these. These pad foundations support the ground beams and the walls on the lower level and the first floor level and the roof. Pillars from the pad foundations additionally support the first floor construction. Ultimately, the weight of the entire building is supported by the 39 pad foundations. In reality, possibly some allowance should also be made for the support given by the ground beams. These are not traversing thin air. They rest on brown boulder clay. I have not taken this idea into account, however, because the issue was not analysed in the evidence and I have been given no figures. The pad foundations are, however, crucial. According to the contract these were to be dug to the level of, and sited on, lean mix concrete placed on the black boulder clay. This discovery of the level of the black boulder clay was done by JCB. The excavation started well below floor level at this stage and through the working platform. I was told by Martin Hannay of

Elliott Construction that the digger driver, when scooping out the clay for the foundations, will be aware that a new level has been struck by reason of the reaction of the JCB arm, and the difference in sound between brown boulder clay and black boulder clay. This is a skill and I am satisfied that Martin Hannay has it, and exercised it in his direction of the digging. The evidence also establishes that over a four month period up to the laying of the floors, 21 visits are recorded by Moylan, the contract engineers. This would place them on site some 20% of the time. As regards the pad foundations, however, it is clear from the evidence of Martin Hannay, which I accept, that the Moylan visits coincided, on the basis of caution, with at least the early digging and siting of the lean mix concrete and thus of the pad foundations. These established, in clear terms, both the relevant levels and the appropriate material upon which the foundations were to be placed. I regard it as unlikely that Martin Hannay would not have followed these directions. This applies even were the Moylan engineers not present. It is probable they were present for a substantial percentage of the early digging and laying of the lean mix and of the pad foundations. What is even more acceptable as a probability is that Martin Hannay would, and did, follow their directions.

58. I now want to refer to the levels of hardcore that were installed. In zone 1 these varied from 450 mm to 1370 mm (some of this infill to the north was there over part of the area of the new gym nearest the retained north wall from the prior building); in zone 2 from 300 mm to 1000 mm; and in zone 3 from 560 mm to 2500 mm. The thickness of the floor slab on top of it also varied: from 220 mm to 230 mm in zone 1 at the northern gym area; and 150 mm to 180 mm in zones 2 and 3. Thus, the thickness of the floor slab in zone 1, where there are no cracks, was almost 50% more than in zone 3 which was replete with cracking. It should also be noted that some old foundations were left in place in zone 1. I am satisfied that the deeper levels are, in the main, accounted for by foundation works and service protection works. The contract specifies infill of 250 mm. This, I am satisfied, is a minimum depth in order to establish a firm foundation for the floating floor. This exceeds a 600 mm recommendation by the Building Research Establishment, to which I will be shortly referring, and also exceeds in particular places the Irish Home Bond recommendation of 900 mm. In this regard I accept the evidence of Lloyd Twomey, of Arup, that the general level across the site was of the order of 800 mm to 900 mm. The deeper levels were, as he said, confirming the evidence of Martin Hannay, closer to services and around the foundations. In this regard, Dr. Maher of Golder has said that the normal caution as to excess levels does not apply where an engineer is in charge of the construction. Ian Roberts gave evidence to the same effect. I accept that evidence. What is more important, however, in terms of the analysis of this case, is whether any evidence of distress has manifested in the building due to subsidence in load bearing walls, as opposed to plasterboard wall linings or plasterboard partitions . It has not. I will analyse this issue in full in a later section.

59. From the working platform for the building and courtyard footprint, in most places at least six further levels of hardcore were installed under the building between the external walls. There is no question of these being crushed by the tracked JCB vehicle and thus causing mechanical stone damage. At this stage in the construction that vehicle had to be outside the footprint of the building. Because of its bulk and weight it could not be brought in even by crane. Instead, in areas of depth around the foundations, the 'Wacker' plate was used. In addition, a large mechanical roller was brought in by crane in order to complete the levels to the appropriate height for the floor. These Clause 804 hardcore stones were layered around 120 mm depths and were compacted down to about 100 mm. The minimum depth in any area on the evidence is 300 mm of Clause 804 hardcore. Samples were taken in 2009, as I have said, by the plaintiff at a depth inside the fill of 80 mm to 400 mm. It is very unlikely, for that reason, that the sample being taken ever removed any mechanically distressed material that may have resulted from the tracking of the JCB heavy vehicle. These were the samples tested for this case. The condition of the infill, when later tested on being removed prior to remediation, cannot be accounted for by this cause.

60. I briefly turn now to the issue as to whether the compaction of the Clause 804 infill was taking place on ground that was already distressed. The site diary of Martin Hannay and correspondence in September 2004, and in particular in November 2004, indicates "serious delay" while excavating for drainage due to unstable ground. This correspondence was followed up with a reference to the ground sinking in the area of the gas line. Ground digging stopped in relation to services because of danger and extra trench boxes were ordered because of collapsing ground. These, I am satisfied, however, were isolated problems. In any event, on stripping back the floors and removing the infill for remediation, no distressed ground was observed. Further, on the evidence, no floor subsidence was anywhere indicated by evidence which I accept. These quoted pieces of written evidence might arguably be joined so as to doubt the evidence of Martin Hannay that the quality of the underlying ground was not poor. I accept his evidence that trench boxes are not unusual in such a construction and that pumping and dealing with the ground at deep levels was done properly. Dynamic probe tests were carried out on behalf of both plaintiff and the defendant on the ground. I now wish to mention a selection of the dynamic probe test values which I have heard. In zone 1 under the infill, there are low readings, at 2 and 3, and sometimes lower. The Clause 804 infill was not tested in zone 1. At 2.7 m, 2.8 m and 2.8 m a value of 10 is established at which, and below which when a reading at or above that level is maintained, a probable inference can be made of the presence of black boulder clay. In zone 2 there is penetration into the fill giving values from 8 to 13, 7 to 10, 8 to 20 and 6 and 5. Below that there are low values, some of them coming in at 3, 2 and 1 in the brown boulder clay, or made ground. Black boulder clay is established by reading at 10 at 2.8 m, 2.9 m and 2.8 m. In zone 3 the levels within the fill vary from 7 to 14, 10 to 7, and 7 to 14. The ground underneath is variable and in one case strong. In zone 3, on removal of the infill, the brown boulder clay or made ground is established at values of 2 to 4, 2 to 7, and 2 to 4. The black boulder clay is shown by a reading of 10 at 2.8 m, 2.8 m, 2.8 m and 2.8 m and 2.7 m. As between the evidence for the plaintiff and the evidence for the defendant there are issues as to the torque applied by the defendant. I am satisfied that in the diagram produced to the Court the black and brown interface was either arbitrarily or mistakenly plotted by the defence. Possibly this has something to do with the site survey levels. By this stage, however, that information was less useful. I find it impossible to establish on all of the evidence any real possibility that the black boulder clay suddenly drops from the general value shown above of a mean of 2.8 m to a sudden depth of 3.2 m or greater. Nor I am impressed that an incorrect hammer setting was used initially by Earth Science Partnership in the dynamic probe tests.

61. Those values which I accept as accurate within the infill were more than sufficient as a probability to support a weight of slab which bears down a load of about 10 kN per m². In addition, the weight of infill, and its compaction, means that this varying value (the thickness of the slab is not the same everywhere) is not transmitted down to lower levels. I accept the evidence of Lloyd Twomey of Arup in that regard. On the issue of made ground, it is established that some exists in the area of the building footprint and that the builders had to be careful of it. I am highly suspicious of defence earth values for the dynamic probe of 1, 2 and 3, or even some of 0. I worry seriously about the torque values requiring a subtraction to lead to these values. This, according to the defence, is making out that much of the ground under the building was like peat, or not much better. This proposition does not bear analysis in the context of the use of the heavy JCB to establish a working platform. Nor does it bear up against the evidence which I accept from Martin Hannay that the compaction proceeded in ordered levels. No scenario was put to him of Clause 804 infill sinking into mud, or disappearing. He did not give any such evidence and his entire demeanour was craftsman-like and honest. Any evidence as to delay because of ground problems was concentrated on areas outside the building, apart from one instance pinpointed by him in the vicinity of what is now zone 1, at the north-west. Otherwise, ground problems were outside the footprint of the building. In this, as much else, I am much more satisfied to rely on the evidence of a witness who saw and dealt with this material rather than a conflict of tests between the plaintiff and defendant companies' experts carried out according to competitive and closely argued, but variable, standards. In the event of any conflict, I prefer those carried out on behalf of Arup for Elliott Construction. More

importantly, however, Lloyd Twomey walked on this infill aggregate, when the floor slab was removed, in 2009. He found it very hard. He saw people working on it with pickaxes and shovels in order to get it out. It had a cement-like constituency. It was difficult to remove in order to take samples. It was then entirely taken away. He then walked on the ground, meaning the earth underneath. He described it as brown boulder clay and as springy but not peaty. The defence values are not established so as to counteract this evidence. No controversy can arise as to putting the infill on to brown boulder clay. The infill does not bear up foundation-type weight, and is only designed so as to support the floors which free float on the infill away from any necessity to be born up by the foundations. Such ground was sufficiently strong to bear any weight of infill and the weight of the floor slab.

62. A dynamic probe test was conducted by Arup on the black boulder clay. This involves putting, in essence, a spike in the ground and then dropping a weight on to it while noting the distance of penetration that the spike is able to travel with each blow. Brown boulder clay was estimated by Lloyd Twomey to require six or seven blows per 100 mm at this site. Black boulder clay was 10 blows or more per 100 mm. I am satisfied that the laboratory tests conducted by the defence for the compression of foundation bearing clay material are inherently likely to be less than completely reliable where clay is dug out of the ground. This process removes its inherent strength by applying shearing and shaking forces across it. *Long and Menkiti* (2009) suggest caution with the use of such samples. To carry out these tests, Earth Science Partnership, on behalf of the defence, had to dig up black boulder clay and in essence apply lateral pressure to it within a box and a steel ring and then test the degree to which it was compressed by reference to various weights. By disturbing the clay its strength is undermined. Some of these samples come from window samples. I am less than satisfied by the variable nature of the defence calculations presented. I do not accept that defence evidence. Lloyd Twomey calculated settlement on black boulder clay as being likely to be 1.82 mm. I accept the evidence of Lloyd Twomey that the minimum value described in engineering literature for Dublin black boulder clay is 250 kN per m². It seems fair to describe an average loading value for the building, at most of somewhere around 160 kN per m². At that level, the maximum settlement might at most amount to an insignificant figure of about 2 mm to 4 mm with a pad foundation of 1.5 m² correctly sited. This is far removed from the settlement pleaded by the defence of 25 mm or even 30 mm or 40 mm for the entire building (with the entire floor supposed to be sinking considerably less). John Campbell of Earth Science Partnership, for the defence, suggested, as I earlier mentioned, late in the case that even in black boulder clay the foundations were likely to subside 10 mm. Overall he suggested a subsidence of the building if sited in error on brown boulder clay of 43 mm. This would happen, he said, within two years. I find this timescale to be unsupported. It is similar to the timescale which might be relevant to the wreckage of the building in the chronology. It is not at all convincing. On a correct reading of the strength of the black boulder clay, as explained by Lloyd Twomey, on another of the tests carried out by Earth Science Partnership, the correct bearing capacity is 287 kN per m². This involves cutting the soil, putting it within a ring, and adding weights. This is even more distorting of the true values than in the previous tests. Lloyd Twomey of Arup gave evidence of potential compressibility, giving rise to settlement of between 1.88 mm to 3.8 mm for pads bearing 250 kN per m². I strongly prefer his analysis. The building was not likely to settle to any substantial degree. It is impossible in this case to come to the conclusion that there was any engineering fault in relation to the siting of the building by reference to 39 foundation pads on black boulder clay.

63. When the infill was put in place, it was covered by a layer of sand. The block-work on the ground beams, running between the pad foundations, had already brought the building up to first floor level. A damp proof membrane and radon barrier, insulation and a wire mesh on top was put over the Clause 804 infill and enabled the pouring of the floors. This is indicated in the general chronology. The floors are free of wall constraint in theory; at least that is what the initial plans provided for. The floors on these plans finish 20 mm from the base of the walls. This approach was varied by the agents of the employer who so instructed Elliott Construction as builder. The majority of walls, in accordance with this new approach, were covered by dabs and plasterboard stuck to this, bulging out the wall level 25 mm. Hence, if the floor heaved, or the walls sank on their foundations, the plasterboard would connect and so buckle and crack as a result of a slow-motion collision. This form of damage, as we know, did occur later. The block-work was placed on the new concrete floor in large sections and then moved to different piles and used as and when necessary. There is no evidence which I accept that this caused distress to the floor slabs. In this regard, I think the evidence of Ian Roberts of Arup, who gave evidence for the plaintiff Elliott Construction, is reasonable. I prefer his evidence to the competing defence evidence of Pearse Sutton. There is no evidence that this practice is the cause of any of the distress to the floor slabs that is relevant in the context of the building. The piles of block-work were put in place about four days after the pouring of the slab on 17th December 2004 and remained in place while the block-work was built up from 4th January 2005. Ian Roberts calculated the bearing capacity of the floor on the basis of seven day old concrete. That seven day strength was 18.5 N per mm². At four days the relevant strength would be in or around 8 N per mm², according to Pearse Sutton. Under the relevant recommendations, floors which are laid in concrete should have movement, contraction and expansion lines cut in them in order that such cracks will be absorbed within defined channels. This should be done with twenty four hours. It was done, however, three days after the floors were poured. Martin Hannay indicated that he knew the recommendation put to him but he regarded it as appropriate to leave this floor for the weekend. The competing figures here can be confusing. The explanation carefully arrived at by Ian Roberts of Arup is preferable to the competing evidence of Pearse Sutton. Unfortunately, not all of the relevant figures were not put to Ian Roberts but that is not surprising in the context of the mass of contradictory detail in this trial. Pearse Sutton was of the view that the absence of cracking, which is manifest in zone 1, and throughout half of zone 2, was explicable by the need for less block-work in that area. This was because of the small wall with large windows over most of zone 1. It does not, however, explain a portion of zone 2 which has cracking. Why there should be no cracking in some parts and a lot of cracking as one goes down into the reception area of zone 2, is not easily explained. His view was that inherent small cracks were opened up, which were not visible because they were at a microscopic level, and the weighting of the floor slab by the loads of concrete caused internal damage. The load exerted by such piles of blocks was calculated by Ian Roberts at 2.88 N per mm². It would be in zone 3, according to Pearse Sutton, that most piles of bricks would be needed and that here most damage would have been done. As to why the concrete would be so badly damaged but yet display no evidence of damage on removal of the blocks is difficult to understand. As to the appearance of the cracks, any court would be taking a risk in calculating why zone 2 is so unevenly divided. The thickness of the slab, however, in zone 1 represents a reasonable response to the pyrite heave theory when it is pointed out that there is no cracking in that area. Again, in this area, one is in the realm of opinion and theory. The block laying was done very quickly and the builders were then in position to lay the first floor slab by pouring concrete floor slabs into shuttered sections from 13th January 2005. Photographs have indicated that these concrete floors were scaffolded on to the ground floor slab. Martin Hannay was of the view that these props would not place strain on the ground floor slab. Propping was in place for approximately four weeks. This is not indicated to have caused any damage. By then the concrete, according to Ian Roberts, would have more than exceeded the necessary bearing strength. His view was that this combination of theories, the propping of the scaffolding for the first floor, and the blocks for the ground floor, was improbable. I accept the evidence of Ian Roberts and prefer it to the evidence of Pearse Sutton. There is no evidence of floor cracking at that point. I see no acceptable evidence that some form of latent cracks might have been caused within the structure to emerge later. This is so even though a levelling compound may have disguised some microscopic crack damage. The general chronology indicates the striking of that floor from its shuttering. The block-work was then continued on top of the floor at first floor level, generally, to roof level on the northern, western and eastern sides of the building. On the southern side, beside the church car park the construction is mainly at a one storey level, as I have previously noted. The roof was then put in place. In analysing any theory as to bad construction, it should be borne in mind that fundamental to any issue on behalf of the defence is the theory that the foundations sank. If they did not sink, this does not necessarily mean that the floor slab rose. As to whether it rose or not, requires a separate analysis. A multiplicity of theories as to the appearance of cracking, said to be consistent on the part of the plaintiff with pyrite heave, is not essential to a decision in this matter. As I

indicated towards the start of this judgment, it is around the issues of foundation subsidence and pyrite heave that this decision must turn. The existence or non-existence of bad building practice may assist a finding on one side or the other. Ultimately, they have to be linked in, however, to those two crucial issues. These theories as to patterns of cracking, zones of influence, the appearance of microscopic cracks, the late cutting in of shrinkage channels and the growth of latent cracks might support one side or the other. As properly construed, however, as will emerge in a later section, the evidence does not at all support the foundation subsidence theory on behalf of the defence.

64. Roger Frank Jowett, who testified on behalf of the defence as an expert in building construction, gave evidence of various flaws that arose in construction and design. Central to this was that the building was designed so that the floors could move independently from the frame. His view was that they were bound to move and that therefore a suspended floor slab was appropriate. His view as to how much the building might move was from close enough to 0 mm in some places to 18 mm or 19 mm in other places. These figures were different to some other defence estimates as to the subsidence that I have already quoted. Whereas I do not expect experts to be consistent, it seems preferable to judge each expert on the basis of the inherent consistency of what he/she is saying, or the preferability of any competing evidence, I merely note the divergence. Roger Frank Jowett, stated that movement of this order could do a lot of damage. I am bearing this theory in mind, and his other evidence, in the consideration of this analysis. How such damage might occur by reason of this differential movement was explained by him in this way:-

> "Where I would differ in the design terms I think that having done that, having decided that you needed to take the foundations down deep because you weren't happy with the ground in between, it is a bit barking mad to put the floor slab on to that ground… It doesn't change my view [that there are other examples of similar building in the vicinity where the same slab was used with no problems]. I am very surprised actually that if you have a, I think one of the buildings he referred to was a hospital and one was a multi-story office block, I have never on that type of building seen anybody using that sort of floor slab construction. They are all much more engineered… If you had a 3 mm to 4 mm of settlement and you had a 3 mm to 4 mm of deflection and you had a 1 mm or 2 mm of shrinkage, the answer is you might very well have finished up with this sort of damage. You would certainly have had 3 mm to 4 mm of crack across all of your thresholds and possibly all of your triangles, which would have damaged the floor finishes. So if it was anticipated that there was going to be a vertical differential movement, the building wasn't designed to accommodate that in the floor finish."

65. Most internal walls were lined with plasterboard, skimmed and then plastered. Plasterboard was studded to the old wall of the new gym and then covered by mirrors. In order to make some of the internal divisions, studding was used on to which plasterboard was attached. A serious issue has arisen as to whether this plasterboard was correctly fitted. If it was fitted directly against the ground, then any movement of the floor slab and wall differential settlement through the foundations of the building would result in it cracking and bulging. Indeed, improperly not leaving plasterboard gaps was one of the theories put forward by Ballymun Regeneration in the months immediately prior to the emergence of the pyrite theory. The general chronology refers.

66. There is no internal damage due to subsidence on the first floor of the building internally. There is no damage that is visible, either, in the external or internal bearing walls at either first floor or ground floor level. There are some minor degrees of plaster work damage at the top of one stairwell. There is no damage due to subsidence to the external roof at any level. There are no problems at first floor level internally, either as to the walls or the ceiling. In the internal walls there was severe cracking and buckling of the adhered plasterboard prior to remediation at ground floor level, on the other hand. This makes it likely that there was differential movement only between the walls and the floor internally. This could, of course, be either foundation subsidence or the floors heaving. The floors were not connected to the walls but had the potential to push up against them. This was because of the nature of the plasterboard construction on the inside walls in many places and because of the studded plasterboard partitions. Martin Hannay gave evidence that plasterboard dabbed on to walls, as opposed to fitted to studding, was propped on half inch pieces of plasterboard and aligned and glued, or as is said dabbed, to the walls. This would give room for movement of in or around 10 mm. It was alleged by the defence that this had not been done, contrary to the relevant contract instruction. In relation to metal stud frames for the plasterboards on internal room divisions, I accept that the instructions to Elliott Construction were not to allow for movement on the ground floor, but to make provision for movement in relation to the first floor, because of the roof, Martin Hannay supposed. These instructions were followed. This defence allegation of bad workmanship not leaving room for the plasterboards to move was repudiated by the evidence. During the course of the construction, Martin Hannay took multiple photographs. As a matter of coincidence, the photographs prove a gap in four places in the reception area, where this process of plasterboarding on bearing walls is visible at the relevant time. Another photograph shows the appropriate gap in the gym on the north-west of the building. Roger Jowett, on behalf of the defence, gave evidence that in his opinion the propping in these areas was not removed. One central factor must at all times be borne in mind: I am looking at whether or not the foundations sank. I do not, in any event, find that opinion convincing. It is possible that in places a prop or two was not removed. The slamming up of the floor against the plasterboard either is, or is not, however, the real problem. The answer to this is dependent on whether the floors rose, or the foundations sank and the floors rose differentially.

67. An issue was also raised as to whether the tight fitting of the studded partition walls, fitted to rails at top and bottom, could have caused bulging through the natural movement of a new building. These studded partitions are found in zones 2 and 3 where block-work walls do not establish the division of rooms. These are also found facing the northern internal old-new wall in zone 1. Martin Hannay was following instructions, I am satisfied, by not allowing for movement. A better practice would have been to allow for movement. The defence theory, in this regard, is that by failing to allow room for movement with the deflection of the concrete floor at first floor level that crushing forces on the plasterboard studded to these rail partitions could have caused the bulging that ruined the building at first floor level. On a hypothetical level this is possible. In theory, a comparatively small movement of 7 mm compression over a 2.8 m floor to ceiling of plasterboard can result in an 85 mm bulge. I have taken into account, however, that these plasterboards are fixed. Those in the experiment, to which I have referred, which was reported in the literature to the Court, may not have been held against a rigid studding. In this regard, I am satisfied to rely on the expertise of David Browne of RKD Architects, who gave evidence for the plaintiff. His explanation, in that regard, is preferred by me to the analysis given by Roger Jowett on behalf of the defence. The dead load of the first floor slab would have already been applied by the time these studded partitions were fixed. In reality, I accept that some small degree of accidental give would already have been in place. The live load deflections would have been in the order of less than 4 mm, and not the dead and live load addition of 7 mm or higher contended for by the defence. The deflection which I accept is thus unlikely to cause the level of bulging and cracking seen at first floor level. I take into account that in some areas, to the south of zone 3, block-work walls are overlaying stud partitions on the first floor slab and that a garden with earth might establish a chance of higher deflection. I do not regard this, however, as the cause of any concentration of damage in these areas. I am required to look at the evidence in the context of the entirety of what I accept. It is also significant to a small degree that these studded partitions were not removed, but cut at the base, on remediation of the building. Since that time, the design has not substantially changed. On recent inspection, this live load potential has not, over a year after the remediation has finished and up to the date of the relevant evidence, resulted in any cracking or bulging. I am satisfied to accept the evidence of Martin Hannay that the partition walls and internal facing walls were properly constructed and, as instructed, room for

movement was given or not given only as instructed. I prefer the evidence for the plaintiff of David Browne to any competing evidence.

68. In the context of my overall assessment of the case, while grateful for the analysis which Roger Jowett has brought to bear on the building, I am not at all convinced that his view on these issues can eventually be construed as a reasonable possibility, never mind a probability.

Crack Patterns

69. A potential theory put forward by the defence relates to the failure alleged against Elliott Construction to properly consolidate the hardcore and to use it at depths that were appropriate. Such a practice, had it occurred, would result in a lack of support for the floors due to the hardcore subsiding underneath and could possibly leave some signs similar to that found in the building. Even so, other signs within the building are inexplicable based on this aspect of the defence theory taken on its own. In consequence, I bear in mind as a principal concern the issue as to whether the foundations subsided. I now turn to the pattern of cracking in zone 3, and in part of zone 1 in the bicycle workshop to the south and in the eastern part of zone 2. The defence theory is concentrated on zone 3.

70. The cracking pattern is potentially explicable on two bases contended for by the plaintiff and the defendant. The first, which is the case advanced by Elliott Construction, is that the cracking pattern, particularly in zone 3, where it is most noticeable, shows the floor slab restrained by adherence to the diamond shape cut out around the columns in the middle of the floor where these show no lipping, and restrained around the floor edge, both to some degree, with the highest point in the middle. This highest point would, of course, be caused by heave on the plaintiff's case. These diamond shapes were cut around central columns to allow the shrinkage cuts to be properly put in the floor slabs. Around the floor edges, near walls, the shapes are triangular. In both instances they were shuttered off from the poured concrete of the floating floors resting on the infill but themselves filled with concrete days or weeks later. I remind myself that in zone 3 to the north-east there is a 17 mm lip whereby the floor slab is apparently higher than the triangle around the column. Across the room from that, there is a similar 5 mm lip on a triangle around a supporting column. Slightly to the south there is a 19 mm lip on the triangle around a column. On the one hand, the defence say that this shows that the foundations have sunk, and on the other hand, the plaintiff points to it as clear evidence that the floor slab has heaved upwards. The theory on behalf of Irish Asphalt, testified to in the clearest way by Pearse Sutton, is that the foundations sank and that a zone of influence, as he put it, around the internal columns, particularly in zone 3, would cause cracking in the floor slab as the foundations sank; though there would be some restraint around the edges of the slab as it met the plasterboard, remembering that the floor is not linked to the structural walls, except by this slight over-lipping as previously described, and potentially high points consistent with this pulling down by foundation subsidence which would leave the areas of the floor furthest away from the traction of subsidence at their highest points. Pearse Sutton produced a number of helpful maps superimposing the crack pattern with the data as to level on the floor slab. His definite opinion was that there were zones of influence around places where the foundations sank. The case put forward, it should be remembered, was that micro- cracks would have been earlier caused by overloading due to piles of blocks being put in place four days after the pouring of the concrete and then exacerbated by the propping of the first floor slab on to the ground floor slab. These micro-cracks would not have been noticed, would have been covered by a levelling compound and then would have opened up as the foundations subsided downwards, pulling the floor with it and leaving distinctive cracking pattern to which he testified. During the course of his cross-examination, he was reminded by the Court about the lipping on the diamonds to which I have referred. Matters then continued:-

> "Q. And that is inconsistent of the theory of the zone of influence?
>
> A. No its not. I mean I think if we look at the plan of the cracking and explain the zone of influence its not inconsistent.
>
> Q. And I have to suggest to you that the cracking that is shown there is equally consistent with the slab having risen as it is with the columns, having gone down?
>
> A. No, I disagree completely on this. Because if we have a floor slab that has been lifted and you have a column that runs through that floor slab that has a diamond on it, there is no restraint from that to lift the floor slab up over the diamond and to keep lifting it. The second point is what is causing the cracking that we are seeing in such a pattern that reflects more the pads below the column. There is none. You mentioned previously that the restraint could be provided by the partitions. O.K. if we start of from that point and we're getting uplift and that it is a restraint point, then the cracking should be on the bottom and it should be parallel to the restraint itself. If there is a restraint here and that's uplifting, its going to move like this and I would be expecting that is where the movement is but I'm not seeing that. But the key point here is that the floor slab is not connected to the columns in the middle, there is no – little or no restraint for that to lift completely up and separate from the columns. Yet we're not seeing that.
>
> Q. Yes, but you are seeing that at the triangles?
>
> A. We're seeing movement at the three triangles that I have explained by photograph why there would be that movement.
>
> Q. And you're seeing severe buckling in the partitions in zone 3?
>
> A. We are seeing severe buckling in the partitions in zone 3, particularly around the column at TP 1, trial pit 1.
>
> Q. And that again is consistent with the slab having risen?
>
> A. No, its not. That is – as I explained if you look at the crack pattern and you think about the restraint for that slab to lift they are not consistent at all. There are 90º cracks forming around the area of influence of the pads below which in my opinion can't be explained by uplift.
>
> Q. The zone of influence cracking is not, I mean you have drawn it in such a way that on certain fights, its consistent with that but its not universally consistent?
>
> A. It's not universally, consistent, no. But is very, very close and approximate to that.
>
> Q. Is there any – again, is this your general engineering or do you have any or are there any theoretical bases for showing how slabs will crack in the vicinity of columns?

A. No. What I did was I carried out an exercise of uplift and then downward forces and to see how each of them would behave…

Q. What exercises?

A. The exercise of if it was uplift what would happen. What would happen would be that the floor slab would continually lift and the column and the diamond would stay where it was and you wouldn't experience the cracking around the pad. The pads are not connected to the floor slab in any form or fashion, yet the cracking is reflecting the pads below. There's only one way that can happen and it's not through uplift.

Q. But it depends on your view of what pattern heave of slab takes place, doesn't it?

A. If the crack pattern that we're looking at here had to place given that the slab levels are the lowest at the columns, it would suggest that there is little or no uplift at the columns and that all of the uplift happens around the pad, in a uniform fashion to cause 90º cracks.

Q. Most of the cracks are out in the floor?

A. There out in the floor.

Q. Yes. And that is consistent with the slab having risen at that point?

A. It isn't when you look at all of the crack patterns taken together.

Q. But if you look at them individually they are consistent?

A. If you look at them individually they are not consistent because you have to take the full picture into account."

71. I do not find this defence evidence to be sustainable. No convincing theoretical basis was put forward to support it. No scientific studies were produced to the Court. While the theory is inventive, I do not regard it as anything more than speculation. Another way of looking at the matter would be that there was random heave in consequence of the growth of gypsum and that any such theory as to zones of influence, while helpful to the Court from a debating point of view, is not borne out as a probability. By the pad foundations descending, the already badly compacted Clause 804, as the defence would have me believe, would subside further. This is merely a theory. That theory presents itself to the Court as a mere possibility. In addition, in relation to the cracking pattern in the bicycle workshop, my attention was drawn to manhole covers. The defence view there was that the cracking pattern could be consistent with weakness in the ground and infill due to the prior presence of these manholes, and the works associated therewith. That, again, is a theory. I am not convinced by it. This matter was fully debated with both Dr. Maher and with Ian Roberts, on behalf of the plaintiff. Because the pressure on a floor is from below, as opposed to shrinkage as an internal pressure on drying out of concrete, or pressure due to squeezing or downward forcing, the classic cracks that it is posited on behalf of the plaintiff might occur are star shaped ones on the floor surface as a result of the heaving of the mass. These are said to appear in at least the bicycle workshop and in less clear form elsewhere. I find it difficult to fully accept as probable Dr. Maher's interpretation of the star shape of some cracks. There are not enough of these. It is possible that Ian Roberts may be right that the cracks show no definite star pattern. It is possible that what I have seen in the relevant diagrams, photographs and drawings are merely cracks meeting other cracks. When a crack meets an existing crack, it stops. So, crack patterns are not easily capable of interpretation on the basis of a particular cause. What may be particular can also be random, although the overall appearance may assist any singular interpretation. Of the witnesses who gave evidence on this matter, I am not convinced that any of them on behalf of either the plaintiff or the defendant were doing anything other than trying to be as helpful as they could by intelligently applying a theory to data. I could not base a probability of pyrite heave on the pattern of cracking in the floor slab. That cracking mostly occurred in zone 3, though there are other cracks in parts of zone 2 and no cracks in zone 1. I am not satisfied either that the defence theory has been established as a viable alternative probability. Thus I am not certain enough so as to be able to interpret the crack pattern in a manner which would favour either side as a probability.

72. In addition, it was argued by Mr. Sutton for the defence that the higher points in the gym in zone 1 were over the ground beams left behind on the partial demolition of the old youth centre. I have looked carefully at the mapping of levels in relation to the floor slab in zone 1. I find it very difficult to read anything into those levels, on their own, so as to establish a probability. It should also be remembered that new infill was placed over the ground beams and that in the event of heave the amount of give would in those circumstances be less than if the infill had been placed directly onto soil. In this area, some old infill was left at lower level. I am unable to come to any conclusion as to a pattern there. My only view of all of the evidence is that the lack of cracking in this floor slab of the gym in zone 1 is easily explicable because of its considerably greater depth. Deflection upwards in consequence of heave is easily explained because of greater floor resistance by old ground beams.

73. It should not be forgotten, that at the same time it could be, as was argued by the defence, that the infill was so badly compacted that in subsiding at various points under the floor, particularly demonstrated in zone 3, there was simple floor subsidence that might have led to a pattern similar to the one argued to show floor heave on behalf of the plaintiff. This pattern would involve greater depth of fill in the area of the foundations, thus around the columns and the walls, and therefore a greater likelihood of failure. I therefore turn to that. In doing so, I note that on the one hand the defence are asking me to take into account an over consolidation of the infill, so as to explain the presence of cracking in the stones, on one possible view, while at the same time they are claiming that there is under-consolidation, and therefore subsidence.

Subsidence

74. As I understand it, the Building Research Establishment ("BRE") in Britain, the relevant equivalent of our own Department of Enterprise, produced a digest as to building practices. On the consolidation of hardcore, the BRE says the following:-

"Hardcore may consolidate after building operations are complete if it has been inadequately compacted, if the depth is too great or if materials which can degrade in wet conditions have been used. When consolidation occurs, the ground floor slab loses its support over part or all of its area, gaps appear between the floor and skirting board, the slab can crack and any partitions or features built off it can be disrupted (see figure 2). There had been many cases where this has occurred to some extent. Sites where a considerable depth of hardcore is needed are particularly vulnerable. At one time, the National House Building Council found that settlement of ground floor slabs was the most frequent structural defect in new houses where solid floor construction has been used; they now require that a suspended floor be used for

> the depth of filling material needed is more than 600 mm at any point. Even on sites where the average depth of hardcore over this site is relatively small, difficulties can still be experienced at the edges if deep trenches have been formed to facilitate the construction of the foundations (figure 3)."

There are other indications as to the worth of this warning. In Ireland, in the document produced by Home Bond, giving information to homebuilders called "Right on the Site", a note as to hardcore says: "Do not use hardcore if the depth of fill exceeds 900 mm. A suspended floor construction should be used as it is less liable to failure and is generally is also less expensive"

75. The hardcore used in that instance, however, is specified for homes. The advice is given in order to avoid "sinking floors". The specification in the standard advice for home builders is not Clause 804 for the infill. Instead, a good quality hardcore is recommended. The photographs appended indicate clean crushed well graded stone of about 100 mm² maximum size. This is much bigger than that indicated for this job and is a different material, much more difficult to compact and achieve the necessary ratio of void to solid which a good compacting of Clause 804 hardcore will give.

76. A great deal of cross-examination was conducted on the issue as to whether the compaction was properly done. A 'Wacker' plate had to be used in areas close to foundations, at deep levels, and in areas where the roller could not otherwise be used acceptably. The proof, in relation to this issue comes from Martin Hannay and, on remediation, from Arup. I do not regard the lack of reference in the site diary to compacting as being in any way odd, or indicative of a problem. This is a basic and simple activity on building sites. It cannot be expected that it would be heavily detailed in the diary. Builders are not like lawyers, or even nurses and doctors. When it came to the compaction of the Clause 804 hardcore with the 'Wacker' plate, six passes were used. These six passes had proved to Martin Hannay to be adequate from experience on other jobs. The 'Wacker' plate used was a DPS 1850. There should, in fact, have been more passes to abide by the NRA specification. In this regard, I take into account the evidence of Lloyd Twomey of Arup that the aggregate was tested for compaction and was found to be around 85% to 90% compacted. This would leave 10% to 15% voids. The standard for roads, I am satisfied, is compaction to 95%. The testing here is done in comparison to a control which is prepared under laboratory conditions. There, compaction by reason of lateral and downwards pressure against a surface can be achieved at closer to 100%, or certainly as a standard of maximum compaction. Roads are dynamic and taking huge loads from lorries and juggernauts on a periodic basis. In addition, roads are not well spread as to the loading, as is the slab poured with mesh support over one day at ground floor level in the building. In contrast to a road, in a building, there is no dynamism and unless it is used for a peculiar purpose outside the scope of the use of the building, the variable stress in terms of road usage is largely absent.

77. The differential between the highest and the lowest points of the infill was a surprising 50 mm within any individual room. This did not go in a wave pattern but in a hill and valley formation over some of the aggregate. I take that into account as some small indication in evidence of the kind of differential heave that can be a signal of gypsum formation due to excess of pyrite. I cannot think of any other reasonable explanation. When the roller was used in compaction a minimum of three passes or four passes was regarded as appropriate. The NRA document suggests sixteen passes. This was regarded by Martin Hannay as ridiculous, as eight was supposed to be the appropriate number of passes for consolidation by the much lighter wacker. I agree with Martin Hannay. Backfill, as a matter of good building practice, should not be placed against a wall within ten days of its completion. In this instance, however, in order to bring up the levels from the floors, backfill was placed on each side of the lower block-work and was compacted by rolling or by the wacker plate. Since this was done on each side and to appropriate levels, it operated as a balanced response. There is no evidence of distress to the block-work due to this breach of procedure. There is no evidence, even so, of improper compaction. As to the worst figures presented by the defence for dynamic probe tests on compaction of infill as of 2009, I also bear in mind that nearly five years of heave, and thus de-compaction and an increase potentially in voids, may influence the relevant figures. In this regard, I accept the evidence of Lloyd Twomey for the plaintiff. My analysis suggests that subsidence of the floor because of excess infill or badly compacted infill did not occur. In reality, on removing the slab, subsidence by infill should have been obvious. On stripping back the radon barrier, the infill was there for all to see. At one stage, counsel referred to the diagrams as "rather extreme". While this is a valuable observation, nonetheless, there is an obvious proposition. If the hardcore was improperly consolidated, such that it led to cracking, or the collapse of the slab, some evidence would be available indicating, if not quite a collapse then a dip indicative of infill subsidence at various relevant points. This does not have to be around the edges of the floor, it could be in the middle. There is evidence, certainly, of undulation, and I have already referred to this, but the kind of evidence to be expected of infill subsidence was not proved by the defence and is not available on the plaintiff's evidence.

Foundation Subsidence

78. I now turn to the main defence theory as to the cause of the ruination of the building at ground floor level. The foundation pads, it is alleged, by reason of not being sited on black boulder clay or for other reasons due to poor design by Moylan in putting the foundations on very weak black boulder clay, were caused to subside. I adopt as generally correct by way of description the following general statement by Ian Roberts as to foundation subsidence:-

> "In an ideal world, each footing of a building would be designed to its own particular size to match the loading coming onto it from the structural elements above so that each footing would impart an identical loading onto the bearing stratum below. In reality this does not happen. In order to keep construction simple, footings are constructed to a few discrete sizes depending on the nature of the building and the loading onto the bearing stratum under each footing varies from one footing to the next. The maximum loading onto the bearing stratum would be limited by the designer to the allowable bearing capacity of the bearing stratum that would have been determined from the site investigation. This site investigation would have been carried out before or during the early stages of design. As a result of this design approach, if there is excessive foundation settlement, the significant factor is always "differential settlement" in that the movement varies from footing to footing and does not affect the whole building uniformly. In other works, if there is excessive settlement different footings sink by a different amount from the footings adjacent to it.
>
> This settlement produces bending in the structure spanning from one footing to the next. Since the building materials used in the construction of the Ballymun Youth Centre are brittle in nature it would be expected, if excessive differential settlement were taking place, that there would be signs of distress in the perimeter brickwork and blockwork in the form of cracking of the masonry and to a lesser extent the ground beams, particularly over the foundations. The cracks in masonry panels from differential settlement are typically diagonal in nature rather than being just horizontal or vertical with the cracks stepping from one mortar bed joint to the next via the mortar perp ends or by cracking of the brick or block itself."

79. In analysing the crucial issue of subsidence of the building, it is first necessary to consider any issue as to whether the foundations were improperly sited. Earth Science Partnership, a partnership of technical experts, did certain tests on behalf of the defendant. These were proffered in evidence as showing that the 39 pad foundations were not sited on black boulder clay. At an early stage in the examination of the building they made four boreholes. These were in the central courtyard and outside the building

at north, west and south orientation. This is merely a guide as to where the black boulder clay may be. Had Martin Hannay merely followed the direction of Moylan as set out in the site investigation, he might well have mis-sited the foundations. He did more than that. I find as a fact that the best way of finding the correct level for the foundations in the black boulder clay is to dig and judge, on the basis of experience, as to where it is. If the foundations are sited at a level above that, then they may readily subside. Below the topsoil, brown boulder clay is present. This has a much less strong bearing capacity than the black boulder clay beneath. At the intersection of the black and brown boulder clay, the greater density of the black material can cause water to accumulate above it and thus weaken, for several centimetres above the interface, perhaps 0.3 m, the already weaker nature of the brown boulder clay. It was suggested during the cross-examination of Lloyd Twomey of Arup for the plaintiff that this weakening extends down into the black boulder clay. Giles Sommerwell and John Campbell of Earth Science Partnership, on behalf of the defence, suggested that this was so. They pointed to curves towards weakness at the intersection point, as they interpreted it, in the dynamic probe graphs. I am not satisfied that this is necessarily correct. I am satisfied on the basis of the evidence of Lloyd Twomey of Arup for the plaintiff that there is nothing to suggest that black boulder clay is dangerously weak at the top of the layer where it intersects with brown boulder clay. If this is so, I would like to know how deeply this layer of weakness extends. I do not accept the proposition that where one truly gets to black boulder clay that a danger of subsidence still exists. It is not noted in any of the relevant engineering studies placed before the Court and was not found by Lloyd Twomey to be so in a desk study of buildings designed by Arup within a 750 m radius of the Ballymun building. As regards the depth of the black boulder clay, I note that one borehole drilled by Earth Science Partnership is described in two values by reference to the ordinance data for high tide. These show varying levels of 1 m. In court and during the evidence, this was eventually corrected to a value of 0.5 m. This is not a big help. The black boulder clay does not, as so asserted, drop unexpectedly or rise unexpectedly, over 1 m. Instead, I have paid particular regard to other data which seems to me to, at least, describe a probable trend.

80. In addition to the trial pits dug by Earth Science Partnership, after the slab was removed, and prior to remediation of the building, for testing purposes five holes were dug by hand in the vicinity of the pad foundations. These are called trial pits. These are numbered TP1, 2, 3, 4 and 5. TP1, 2 and 3 are all in zone 3 at the east of the building, as is TP5. TP1 is sited in the vicinity of the municipal sewage pipe. TP4 is in the corridor to the north-east. TP 1 is the object of considerable controversy. Martin Hannay mentioned this in his evidence. He said that he had heard during testing in 2009 that this hole was supposed to have exposed brown boulder clay at the level of the bottom of the lean mix concrete pad under the foundation. He caused a representative from Arup, who was Eoin Wyse, to be present on the 14th August 2009, which is the date on which this first digging was done in the presence of Giles Sommerwell for the defendant. Another engineer, James Lombard, also attended later on 21st August 2009 for another examination. Further digging was done by the plaintiff on this later date. This later digging was to investigate what Martin Hannay had heard by way of rumor which was that TP1 showed improperly sited foundations. He did not hear any such allegation in relation to TP2, TP3, TP4 or TP5. The defendant had claimed, and claimed in evidence, to have excavated TP1 and found the bottom of the pad. Martin Hannay and Eoin Wyse were not convinced, however, on the basis of the earlier excavations which they viewed, that they had reached the base of the pad. James Lombard, a transparently honest and careful witness, made an inspection on the later date down in the excavation. As witnessed by Martin Hannay, an operative excavated down along the line of the lean mix under the pad foundation. They used timber as a measure and also plotted the degree to which the lean mix followed a conical shape at the side. The clay was pried away and exposed a shape that went inwards, but then outwards again, below the level that had already been excavated. The taper inwards was about 150 mm at this point. As it came out again, it had to be excavated between this lean mix, and the next lean mix on which the two pad foundations rested. At 1.6 m below the top of the pad it came in, at around the point of the defendant's excavation, but beneath that it came out again. This lean mix for the pad foundation was resting on lean mix lower down that is probably associated with the municipal sewer pipe. I have already described the detail of this and I regard it as adequate. The clay at the base of the originally improperly excavated pad foundation was dug out when later properly excavated and it was adjudged by James Lombard to be typical of black boulder clay. This time the excavation established an answer to the problem. This lowest level was reached at around 1.85 m below the top of the pad. Digging went down to 2.06 m below the top of the pad. The results of this twice excavated trial hole, properly considered, is that TP1 is the subject of controversy. I resolved that controversy by listening to Mr. Sommerwell, to Mr. Wyse and to Mr. Hannay and to Mr. Lombard as showing that this foundation was properly sited in the black boulder clay.

81. I have also listened carefully to defence evidence and cross-examination and I find that any evidence that foundations at TP1 were not put on black boulder clay to be insufficiently probable. Any doubt on the matter which I had was removed by the evidence of James Lombard. The expertise of James Lombard makes the evidence on behalf of the plaintiff certain. I prefer his evidence to that of any other witness. He is an obviously honest and reliable person.

82. I now wish to refer to the evidence concerning the other trial pits. Two sets of inconsistent diagrams were produced. I do not regard this as being helpful as a contribution from the engineers acting on behalf of the defence. In court, Giles Sommerwell gave a final view in relation to the siting of TP2 as being "hit and miss". In the second sets of diagrams, this was presented as if there was a problem. It was presumed on behalf of the defence that this foundation ended well before the black boulder clay. This was done, however, on a basis that is unexplained. When I turn to the original diagram in relation to TP2, the foundation is shown as resting on a level which is described as "very stiff, dark grey to black, blue, slightly sandy, gravelly, silt clay with some rounded to sub-rounded and angular cobbles". The notes of Giles Sommerwell were presented as better. I do not know why I should accept that TP3 was stopped at a level above the black boulder clay, and above the base of the foundation, because of ingress of water. I would find it difficult to establish any probability that there was anything wrong with this foundation on the basis of any evidence produced in court. There is no such proof. TP4 was originally placed by the defence investigations within the black boulder clay. The initial diagram in relation to this shows the matter clearly. Again, the foundation is shown as penetrating within what is described as "grey, black, Dublin boulder clay". The relevant note again reads, on the original diagram "very stiff, dark grey to black, blue, slightly sandy, gravelly, silt clay with some rounded to sub-rounded and angular cobbles". TP5 was on the basis of the original diagram also situated well within the black boulder clay. The evidence of Giles Sommerwell, in the end, was on the basis of satisfaction in that particular regard. All of the parties having been initially led to believe that there was a problem with TP1 and the evidence having concentrated on whether it was correct or incorrect, and having been led to believe that TP3 was not conclusive because of water infiltration, the evidence developed. It is not satisfactory for any judge to attempt to adjudicate on the matter on the basis that what I have quoted from the original diagrams is some kind of a word-processing error. Whereas it seemed to me that Giles Sommerwell was doing his best, his evidence falls to be considered against that background. In the result his evidence is not convincing.

83. An attack has also been made by Pearse Sutton, for the defence, on the lean mix under the pad foundations on the basis of inwards slope from top to bottom, or on the basis that they have a semi-conical shape, to put the matter another way. In my view this likely conical shape of the lean mix pad foundations does not matter. Using a digger, this is the normal shape that is achieved. I accept the expertise of Lloyd Twomey for the plaintiff in that regard. It has not been established in evidence that the lean mix areas resting on the black boulder clay are anything other than covering at least a toe area of 1.5 m^2. I might also comment that in so far as I can rely at all, a matter on which I have serious doubt, on the dynamic probe tests done on behalf of the defence, that these variously show a value of 10 being reached, but followed by 10 or more, showing in my view the black boulder clay, over levels that vary in depth up to 0.3 m. This is less then the eventual variation claimed by the defence on the basis of the four trial holes of 0.5 m.

It establishes to my mind that careful excavation and experience are of much greater importance than disputing testing protocols. Everything about the evidence of Martin Hannay suggested to me that care had been taken. I reject the defence contentions. I am satisfied that these five foundations at TP1, 2, 3, 4 and 5 were sited on poured lean mix concrete directly on black boulder clay. It is possible that there is a genuine conflict of evidence as regards the digging around the foundations at TP1 conducted by Earth Science Partnership and Arup, because of the proximity thereto of the sewage pipe and the concrete detail necessary to cover that. I believe that Giles Sommerwell for the defence was disadvantaged by circumstances. His hand test in the trial pits is not the best measure of accuracy. I also find the run of the case peculiar. All the way through, up to the late calling of defence witnesses, counsel on both sides and the Court were under the impression that only TP1 was causing controversy, while TP3 was uncertain because of water. This changed to a contention that TP2, TP4 and possibly TP5 were problematic with only TP4 probably sited in the black boulder clay. Counsel were then furnished with a second set of diagrams. This is not their responsibility: counsel act on instructions, I believe what was described in the original defence diagrams, which I have already quoted, to be more reliable. I note that Lloyd Twomey in this re-examination preferred to rely on the trial pits than the dynamic probe or other tests. One wonders why? I am expected now to accept, notwithstanding what I have quoted, that the clay found under the relevant foundations, in the trial pits, should merely be described as "stiff" as opposed to "very stiff". Somewhere within Earth Science Partnership some errors are being made. I am not prepared to resolve these against the plaintiff. On considering all of the evidence, I believe that the balance of the evidence comes out clearly in favour of the plaintiff. The foundations rest on black boulder clay.

84. In addition, I was referred in passing to foundation cores that were done at various points throughout the building by Arup. These involved drilling directly through the foundations from ground level and down to the lowest point. By measuring the depth of penetration below ground level and before the foundation ceased, in other words before concrete ran out and became clay of whatever type, an inference can be drawn as to the probability as to whether the foundations are at the correct level and rest on black boulder clay. Since I am satisfied that the four boreholes opened by Earth Science Partnership and the probes show a relatively plain area of black boulder clay at around 2.6 m to 2.8 m below ground level, the results of these foundation cores might assist. I take into account the possibility of a variation in level in the black boulder clay of around perhaps 0.3 m as potentially established in the evidence. The first core in the foundations, in the area of the gym at the north-west, allegedly showed a penetration of the foundations to 2.98 m; the second in the area of the bicycle workshop to the south of the construction was written up to show foundation penetrating to 2.98 m; the third, in zone 2, supposedly shows a penetration to 3.14 m; and the fourth, in zone 3, where the kitchen now is, was written up to show a penetration to 3.28 m below ground level. This evidence was attacked as being hearsay. That objection is correct. The testing people were not called. That being so I can take no account of it. That, however, makes no difference to the result. I have scanned the original defence of diagrams on the trial pits and put them as an appendix to this judgment. They are Appendix I. The video of the state of the building is Appendix II.

85. I see no basis for any evidence suggesting that the black boulder clay dipped over a substantial portion of this site substantially below a level of 2.8 m.

86. The digging out of the pad foundations could not establish a completely square or rectangular shape. Instead, as with any digging by a bucket JCB, the levels tapered outwards from the deepest level to the level of the working platform. A non-toothed bucket was substituted at this point to scrape away loose earth and to establish a flat base. On behalf of the defence, Pearse Sutton claimed that it was "unbelievable to adjudge when black boulder clay had been reached by using a mechanically digger." I am satisfied that an experienced workman can tell the difference between black boulder clay and brown boulder clay. Martin Hannay is such. Firstly, black boulder clay can be seen, albeit that one might be looking down a hole in excess of 2.0 m or 2.5 m. It was strongly argued that this was an incorrect procedure. In particular, Pearse Sutton argued that it was likely to undermine the foundations. In *Wall and Farrell* (1997), the following occurs which is argued to be important to the defence:-

> "A common problem that is apparent to anyone who regularly inspects foundation trenches is that of maintaining the bottom of the trench clean and firm. Very often the excavated material is piled up beside the excavation if the trenches are close together and this loose material keeps falling back in. If the sides are loose also there may be no option but to timber the sides. This will be required for safety anyhow with depths of 1.2m and over. A deep untimbered trench requires the sides to be sloped well back and to the costs of the extra excavation over a timbered trench must be added the extra cost of replacing and consolidating the backfill.
>
> A related problem is the omission of final excavation. The excavator bucket leaves the bottom of the trench very uneven with high points and pockets. In addition the teeth of the bucket tend to rip up the surface leaving it loose. It is essential to finish off the last 75 mm or so by hand. The author remembers visiting a site where the first foundations of a large contract were to be pored. Truck loads of concrete were waiting impatiently while the excavator was finishing it's [sic] work with no time for any manual cleaning of the bottom of the trenches. There had been a full scale site inspection that morning by the architect, consulting engineer, agent and resident engineer who had decided that an extra 300 mm should be removed, and then gone off to lunch. The order for the concrete had not been cancelled".

87. In any adjudication of this issue consideration must not only be given to what is possible, but also as to what has happened. Therefore, the issue as to whether there has been a substantial subsidence in the foundation becomes more important. The Court also has regard to the opinion expressed by Martin Hannay as to the adequacy of this procedure and the great experience that he brings to bear on the issue. As to the ordinary approach over many buildings the opinion of Ian Roberts of Arup is important. I accept the evidence of Ian Roberts that the procedure adopted was adequate. On to the black boulder clay, in respect of each of these 39 foundation sites, lean mix concrete was poured. This is a form of concrete with less cement and more aggregate. Essentially, as I have said, this was to bring the working level up to an acceptable depth for constructing the foundations. There was some rush in relation to those on the north-western area of the site. There is no acceptable evidence, however, that this caused any problem whatever with the construction. Within a matter of days, or in the case of the north-western foundation pads hours, a different form of concrete was poured to establish the shuttered, and therefore, regular pad foundations with steel structures enabling these to link in to supporting columns and to the ground beams that would be stretched between them at the periphery to support external walls, including external walls around the central courtyard. The relevant excavations around the foundations were then filled with Clause 804 hardcore. This was compacted. The ground beams linking between the pad foundations were then dug. These were poured with appropriate concrete, staked with steel in a skilful manner and then shuttered off so that proper beams of stress bearing concrete at an appropriate level could be poured. When these were deshuttered, the block-work was built up. Again, the depth levels are not completely certain but it appears that the block-work on each side had Clause 804 compacted against it in layers so as to bring the levels up to the appropriate depth and height for laying the floor. I am satisfied that foundation construction was correct.

88. Were all, or some, of the foundations of the attached new building to have been sited improperly above the black boulder clay, or otherwise badly engineered or made, then some settlement might reasonably be expected. There are, I remind myself, 39 pad foundations in the building. Any one or more of them might be sited improperly. It is of the level of improbability that all 39 were sited improperly. It is also highly improbable that a substantial number sank without causing visible distress to the external walls. As against

that possibility, the pride in workmanship and the clear answers given by Martin Hannay in evidence indicate, in terms of his demeanour, both truthfulness and a determination to carry out the instructions of the engineers on-site. The evidence of Dr. Maher for the plaintiff was that if the condition of the building was to be explained by settlement, then this settlement would be differential; in other words that one foundation pad would settle at a different rate to the others. That is correct. There is no evidence whatsoever that this happened. There was no case material produced before the Court which would suggest any other experience on an international basis of such settlement without distress within a building of this size and shape. Textbooks were referred to but experts on each side had differing views. Among the most serious problems, therefore, with the foundation settlement theory has been the lack of any evidence which shows differential settlement.

89. If the defence case is correct, there would probably need to be relatively consistent or improbably harmonious subsidence over the northern, western, eastern and southern sides of the building at levels between 20 mm and 25 mm. During the course of the case, as I earlier noted, the possible levels of subsidence were revised so that I could now consider levels of subsidence above that and, indeed, on the evidence of John Campbell of Earth Science Partnership, for the defence, levels which might reach 43 mm. This latter figure, however, should not be used to disparage the defence theory. The higher figure would only be reached in the event that the foundations were sited in the brown boulder clay. At times, it has just been difficult to follow the nature of the argument by the defence experts. If, however, one looks at the figure on the basis that the danger zone, of especially waterlogged brown boulder clay, was mistaken for black boulder clay and that black boulder clay can result in subsidence, then 22 mm might be the correct figure. John Campbell's values were of up to 21 mm in brown boulder clay, together with 12 mm in the danger zone. In competent black boulder clay the settlement would be 10 mm. This adds up to 43 mm. His view was that there could be up to 30 mm of settlement. His view also was that the black boulder clay was not competent once it was reached but constituted part of a special zone of danger. His view of this zone of danger seemed to me to differ from that of other defence witnesses since the theory, as I followed it, would indicate that this zone of danger might be more competent than competent brown boulder clay, as opposed to less competent. This is mystifying. The defence have also identified two parts of the building as being the point at which the deepest subsidence occurred. These are in the vicinity of TP1 at the eastern part at the middle of zone 3, and the foundation at a stairwell, close to the reception area in zone 2. Apart from the theory of relatively consistent subsidence, Pearse Sutton, for the defence, has pointed out that the building has some jointing along its length which it allows for a degree of differential movement. This might mean, on the defence theory, that the least subsidence occurred in zone 1, which all the defence witnesses agree, with the deepest subsidence probably at or near the two points which I have mentioned. This, on the defence theory, is supposed to have occurred so gradually that it is not expressed in structural wall damage. This defence theory is not borne out by the evidence; nor is it likely. In addition to foundation subsidence, the floors, due to the subsidence, and due to poor compaction, are alleged to have settled as well, or perhaps to have been dragged down, but only of the order of some 5 mm. I have dealt with that. In the result, the relevant sections of the building are supposed to have gone down by 20 mm to 25 mm or 30 mm or more and the floor by only 5 mm. This leaves, the defence argue, the result that the floor appears to be bulging upwards, cracking the walls and driving the plasterboard outwards.

90. A theory was also put forward that one of the pad foundations was overloaded at a calculation in excess of 350 kN per m². This pad foundation, curiously, is in the vicinity of TP1 and the sewage pipe beneath. The load on it is eccentric. This establishes the possibility that a loading at this point would cause the foundation to turn, and thus to subside considerably. In looking at this potential theory I note that there are four pad foundations along the east of the building at the wall, three further proximate ones to the north, three columns supporting the first floor in the centre, and three pad foundations supporting the construction close to the courtyard. Fundamentally, I ask myself where is the evidence of subsidence. If there was subsidence of 20 mm to 30 mm would it become manifest in the external appearance of the building? Pearse Sutton, on behalf of the defence, suggested subsidence in some areas, particularly zone 2 north wall, of perhaps 25 mm. Would this be consistent with the way the building now presents? Ian Roberts for the plaintiff did a calculation in relation to the bearing on the foundation at TP1. Accepting an eccentric bearing of 350 kN per m², it should also be remembered that the lean mix under the foundation should be bigger, that it is placed in resistant ground and that therefore it is held on each side by the ground. The weight of the lean mix with the pad foundation resting on top of it, Ian Roberts claimed, reorients the foundation because of the side restraining effect of the ground. This ground could be brown boulder clay, but it could be perhaps slightly weaker, or even weaker made ground, and the weight and dimension of the lean mix. The expansion joints in the building would disguise this, the defence theory propounds. A manhole construction is situated near this foundation pad. It is probable that this dates back to the 1960s. The ground here could be weaker. Pearse Sutton regarded this as probable. This could reduce the resistance factor. Ian Roberts has made a calculation that reduces the bearing on this pad below 250 kN per m². I have listened carefully to his evidence and I accept his view on this pad foundation. I also accept his calculation. Pearse Sutton emphasised that the correct standard in relation to the bearing capacity of foundations was to engineer them to the safest levels for the worst possible circumstances. It therefore has also to be borne in mind that the engineering of the building must be done on the basis of safe levels. In any such case, however, it is very unlikely that the Court would be entitled to act on the basis of calculations in the absence of evidence. It strikes me as being very unlikely that evidence of subsidence would be hidden so that the walls as structural elements of the building would not crack or manifest distress externally but that subsidence would appear in an otherwise invisible descent of many of the pad foundations and, with them, the walls being crushed into the floor slab, thus causing buckling of the plasterboard adhering to them, and the plasterboard partitions attached as a matter of cosmetics to the internal walls. I cannot accept that this happened. There are two reasons for this. The first is the absence of any practical manifestation in the structural walls of the building. The second, which I will deal with in another section, is the relationship between the old and the new parts of the building. This, to my mind, is also inconsistent with the defence theory.

91. Ian Roberts and Dr. Maher for the plaintiff were of the view that if settlement had occurred in the building, exterior cracking to the brick-cladding should be visible. Here a difficulty arises. In order for there to be a lack of distress, it seems to me to be sensible that the settlement should have occurred as between the 39 pad foundations in the building at a variable or improbably gradated or at a near even overall equal level. There may be some possible room for differential. As between the pad foundations, the ground beams stretch at a distance, measured to the centre point, between 2.2 m and 8.7 m. The longer distance gives rise to a greater tolerance of subsidence for structural elements depending on the foundations. In one of the textbooks, Tomlinson, *Foundation Design and Construction* (London, 2008), higher levels than 500 are recommended as a dividing factor. Dividing 500, as a notional basic calculation figure into the distances the ground beams span between the pad foundations, 8,700 mm and 2,200 mm, gives potential tolerances of 17.4 mm to 4.4 mm. Other potential figures were put in cross-examination on behalf of the defence. As the evidence moved into the defence case, the possible measures of subsidence increased from 20 mm to 25 mm up to 25 mm to 32 mm and possibly beyond. No figures of these dimensions were put to the engineers giving evidence on behalf of the plaintiff. The view put forward by Pearse Sutton for the defence was that at a point adjacent to the lift shaft in zone 2, at the north wall, and at TP1, the greatest subsidence occurred. This was of the order of 25 mm or more. It is to be appreciated that there are 39 pad foundations and that for this subsidence to occur, without leaving marks on the building, some form of gradation is necessary. According to Pearse Sutton, the least subsidence occurred in zone 1 in the gym. Then, subsidence rapidly increased from an estimated level there of 5 mm to 25 mm over a span that is less than half of the length of the north face of the building. That level of subsidence would lessen but then increase to another point of deeper subsidence at TP1. Therefore, gravity would tend to pull an object in zone 1 northwards, where the foundations have supposedly sunk at the northern end, on the defence theory, those at the south being essentially tied

into the old foundations. Gravity would tend to pull an object in zone 2 towards the reception and lift shaft area. Gravity would tend to pull any object in zone 3 at the north or south towards the middle and east in the direction of TP1. It should be remembered that while some of these ground beams are long, many of them are short. I carefully looked at the relevant diagrams in order to ascertain whether any such pattern was reasonably possible.

92. Calculations done by Pearse Sutton on the basis of further passages in Tomlinson suggested that potential settlement tolerances of 45 mm and even 60 mm would be possible as between spans across the building without distress being caused to the external walls on which the foundations were situated. It must be remembered that the depth of one brick is 65 mm and that the exterior of the building is generally brick-clad. This tends to put these large figures into prospective. As to why, furthermore, these settlements would occur in a gradated or stepwise fashion and would extend if not close to uniformly, then certainly in a harmonious pattern, leaving no external trace over the vast majority of the pad foundations is not explained. As to why, as well, if the two points of deepest subsidence were correctly identified, these would not move on their own, causing obvious differential settlement as to the next nearest foundation pads was not satisfactorily explained either. In addition to that, a search would have to be made for a reason why any other of 39 new pad foundations would subside. In analysing the evidence as I heard it, I was constantly asking myself as to what basis there might be in fact to support a theory whereby pad foundations that were not overloaded, in accordance with the calculations available on the evidence, but temporarily accepting as a possibility the two potential places that I have identified, would sink. Pearse Sutton's view, in addition, was that under normal circumstances some 10 mm of settlement over the first number of years of life of the building might naturally be expected, even in competent black boulder clay, and that this, of itself, would not cause visible external distress. John Campbell, for the defence, produced a similar figure. That level of settlement as suggested, however, would be additional to the unprofessional levels of settlement caused by the improper siting of the pad foundations and the overloading of some of them due to miscalculation.

93. Even were I to accept these defence views and calculations, or even were there to be evidence to potentially validate this as a possibility, it would be unreasonable not to look for actual evidence. Dr. Maher's view for the plaintiff was that the further the ground beams were apart the more that could be tolerated in terms of differential settlement, and that the closer they were together the less they could tolerate. This makes good sense. I believe that the views that he expressed carefully took into account any countervailing case put to him. I note as well that Lloyd Twomey, on behalf of the plaintiff, regarded this hypothesis as being required to be borne out in physical evidence before he could accept it. I note the passages in the textbook as put on behalf of the defence to these witnesses and the other passages later expounded in direct testimony by defence experts. I believe, however, that a practical approach to what has happened is more likely to yield a true result. Fundamentally, what I come up against is the absence of physical signs. In the course of his evidence, Dr. Maher said the following:-

> "I find it hard to accept [that there could be differential settlement of this building of up to 17.4 mm without any cracks appearing on the exterior brick work] but it's a structural issue. I would find it hard to accept that if you had a differential settlement between two pad footings, set 8m apart of as much of 17 mm that you wouldn't see any damage in a brick wall that's resting on that and that is supported on that at each end. I would find that hard to accept… and I would not accept, if you were telling me that these pad footings have settled by relative to each other of 17 mm order I would not accept that. And I would not accept that you could get that in that building and not see any damage in the exterior of the building. I do not – and you know maybe the structural engineers have to deal with that but I would be very, very surprised if it can be proven that that building could settle by that amount and you would see no damage on the outside".

94. This viewpoint is correct and it accords with ordinary reason. I accept the evidence of Lloyd Twomey of Arup and Dr. Maher of Golder for the plaintiff in preference to any opposing testimony on this issue.

95. Ian Roberts, of Arup, was of the view that he could not conceive of adjacent foundation pads sinking differentially 17.4 mm and not manifesting in structural signs. I bear in mind as well a possible theory of gentle subsidence over a wide area and gradated steps to accommodate the continuing external integrity of the building without stark differences between individual foundation pads. The figures presented by Tomlinson indicate how much deflection could occur without cracking the superstructure of a building. The length of the beam is important here. On any analysis, the tolerance of settlement as between 4.4 mm and 17.4 mm is less than the level of settlement needed to be established for the defence theory. I take these figures as these were the ones proposed by defence experts and so put to Dr. Maher by the defence in cross-examination. Clearly, if these are not tolerable without distress becoming visible in the walls any larger figures are not. Any such possibility might exist had there been near uniform settlement. Of course, an argument can be made that as regards the distance between the largest beams, there had been 17.4 mm of settlement differential as between the pad foundations and as regards the shortest, some 4.4 mm of settlement. In addition it could be argued that any differential settlement was evened out as between those tolerances over the building. This is at the level of high improbability. The location of these foundations and the type of ground they rest on, however, has also to be taken into account.

96. Dublin black boulder clay is well studied and appears in engineering literature. In the vicinity of the building, the famous towers of Ballymun were erected in the 1960s. Records indicate that these were sited on black boulder clay. Still standing at the time of my site inspection in November 2010, the Count Joseph Plunkett Tower, named after one of the signatories to the 1916 proclamation, across the road shows no sign of distress. The reason for the removal of the famous Ballymun towers was planning and not poor foundations. I draw no inference from this because it could be that the foundations of this other building are engineered differently so as to spread the load more equitably over a wider area of foundations even though it is ten storeys or more high. More recent studies indicate the possibility of lenses appearing in black boulder clay, whereby areas of weakness may suddenly appear. Variability is also a possibility. These studies can be debated. Engineering is, however, a practical business and I am looking here for practical evidence upon which to base a conclusion that is likely, as opposed to speculative.

97. An issue has arisen as to whether siting the 39 pad foundations on black boulder clay could, in itself, give rise to subsidence. In Tomlinson, qualitative descriptions are given together with the co-efficient of volume compressibility. This is called the Mv. At values below 0.05, are listed heavily over consolidated boulder clays and stiff weathered rock. At values below 0.05 and 0.10, of low compressibility, are listed boulder clays and very stiff blue clay such as London clay. I now reproduce the table as it provides valuable common sense guidance and a reasonable approach based on debate among the experts in this case to the issues:-

Table 2.11 Compressibility of various types of clays

Type	Qualitative Description	Coefficient of volume compressibility m_V (m^2/MN)

Heavily overconsolidated boulder clays (e.g. many Scottish boulder clays) and stiff weathered rocks (e.g. weathered siltstone), hard London Clay, Gault Clay, and Oxford Clay (at depth)	Very low compressibility	Below 0.05
Boulder clays (e.g Teeside, Cheshire) and very stiff 'blue' London Clay, Oxford Clay, Keuper Marl.	Low compressibility	0.05 – 0.10
Upper 'blue' London Clay, weathered 'brown' London Clay, fluvio-glacial clays, Lake clays, weathered Oxford Clay, weathered Boulder Clay, weathered Keuper Marl, normally consolidated clays (at depth)	Medium compressibility	0.10 – 0.30
Normally consolidated alluvial clays (e.g. estuarine clays of Thames, Firth of Forth, Bristol Channel, Shatt-al-Arab, Niger Delta, Chicago Clay) Norwegian 'Quick' Clay	High compressibility	0.30 – 1.50
Very organic alluvial clays and peats	Very high compressibility	Above 1.50

98. I feel that I do not need to go into issues as to medium compressibility or high compressibility or very high compressibility, such as peat or alluvial clays, because what is in issue here is black boulder clay which fits within the range of low compressibility to very low compressibility. That is why any reasonable engineer would choose it as the area within the ground to site foundations of this kind. The defence experts have also claimed that on removing samples from the trial pits they have found that the black boulder clay operates at significantly less compressibility and less sheer strength than the text would indicate. The removal of samples from the ground necessarily causes disturbance. I am not prepared to rely on the defence figures in this regard. I have already expressed my reasons. Instead, I strongly prefer the analysis conducted by Lloyd Twomey. It must be remembered that there was a very wide range of results, as well, in relation to the use of dynamic probes. Depending upon whether *Butcher*, *Tonks* or *White* were used in the calculations relevant to bearing strength for a building foundation, a resultant difference of factors of up to a multiple of five could be sourced.

99. As a useful observation, I note the opinion on black boulder clay given by *Wall and Farrell* (1990) as follows:-

> "Foundations in the brown boulder clay have generally being designed for toe pressures 100 to 200 KN/m². In some places the brown boulder clay is as dense as the black in which case higher pressures may be appropriate. Allowable bearing pressures on the black boulder clay have varied from 250 KN/m² to 500 KN/m². Generally no allowance has been made for differences in the size of footings. Sometimes lower pressures than those indicated by laboratory tests are used because of any assumed possibility of the clay being softened during construction by water in the trenches or because of the presence of lenses of gravel. There has been no recorded case of structural distress to buildings founded on black boulder clay with these bearing pressures. Indeed a Victorian mill building has been found recently to have internal columns four storeys high founded on 600 square stone bases with a calculated bearing pressure well over 1,000 KN/m²."

100. A number of other theories were posited to explain some of the damage within the building. Firstly, it was put that this was a complicated building. On behalf of the plaintiff, David Browne did not agree with this theory. He described the building plan as simple, as a conventional construction with no significant cantilevers anywhere in the building. He might have, at the link between the old and the new parts of the building, used different joints. His view, however, was that the existing joints had performed well. In the small wall and large window area of the building, it was posited that there could have been rotation to explain the lift internally of the windowsill due to the weight of the windows combined with high wind pressure. The view of David Browne was that if this was so, there should be signs of distress in the supporting block-work. That view presented as sensible. There was no evidence of this kind of damage. It is also possible, the defence contended, that wet block-work was put into the building. Ireland is a very wet place with average rainfall having notoriously increased from an average of about 30 days to an average of about 50 days over the three summer months in recent years, though with very welcome exceptions. It is undesirable that block-work should be left out in the open. This commonly happens in Ireland. The estimate by David Browne as to the possibility of shrinkage over the combined block-work at first floor level was of the order of 1 mm. None of these theories stack up as being anything beyond the merest possibility. I do not accept them.

Old and New

101. Another problem with the defence foundation settlement theory is the notion of the old building that is incorporated in the new construction similarly settling, though *in situ* for twenty years, or failing to exhibit distress because of differential settlement between old and new at the north-western corner wall, now internal to the new gym where the old joins the new, at ground floor level or above at roof level. At this point where the old building is joined to the new building at the north-western section, there is no evidence of cracking in the walls or distress indicative of settlement at differential levels as between the old and the new sections. All the experts as to settlement commented that settlement tends to occur in the early life of any building. Since the old section existed for two decades before the construction of the new, it must be regarded as well settled and since, if the theory put forward by the defence is correct, much of the new building settled due to improper construction or design or siting of the foundations, a differential settlement as between the old and the new sections of the building might be expected. One possible theory was that the old building settled down further. One might ask whether the old building settled down at the same rate as other parts of the new construction, or if it remained in the same place? The defence theory was that this area of intersection between old and new, the gym at the north of zone 1, settled much less than the other areas, which I have mentioned in zone 2 and zone 3. This is just too convenient.

102. There are some peculiar features to the attached new building gym in zone 1. There is less Clause 804 infill under the floor slab than in zone 3 and a thicker floor. There are old ground beams from the section of the old building that was removed for the new

construction left as part of the infill. The old wall of what is now the dance studio was studded before the plasterboard was attached to the northern side. There were mirrors attached to that wall. There is a mastic joint between the old construction and the new. In addition, an abbey slot could allow some vertical movement, though I accept its primary purpose is to restrain the brick. At the western end going into the dance studio in the old building from the gym, there is a slight lip where the new floor meets the old one. It rises at one point to 7 mm. The new floor is that slight amount higher. It is argued that if the floor indeed rose that the same phenomenon should be seen at the door over more towards the east. It is not. That doorway is even. Here, I am satisfied on the evidence of Eoin Wyse for the plaintiff, rebar linking old to new slab restrains the floor. Acting on the fundamental theory that heave will occur at the point of least resistance, this peculiarity is ironed out. I have also considered the triangles from which the pillars supporting the first floor proceed in the gym. These columns, inside these triangles, are linked in by steel to the old building. I note the triangle differential levels there at the west doorway of 18 mm, 13 mm and 0.4 mm. I note the levels as of the centre at 6 mm, 4 mm and 0.5 mm. The one at the east has not moved. The lowest levels point north. The same phenomenon on the east equally is probably to be explained as to rebar. I have carefully analysed what Roger Jowett, for the defence, said in this regard about the lip on the western doorway being in place during construction, after apparently a screed had already being put over a 20 mm lip. This is not at all probable. A similar view was expressed by Pearse Sutton for the defence as part of a well-argued presentation as to what had gone on inside the building. I take the same view as to that evidence. In zone 1, in addition, the floor cracking is least, but this is explicable by reason of the depth of the slab. There is also some level of restraint. One has to take into account, as well, the possibility that one of the old foundation ground beams below the floor slab acted as a fulcrum, causing the argued for movement downwards of the foundations at the north-western wall to counterlever the entire of the slab upwards. This was described by Ian Roberts for the plaintiff as unlikely. I accept his analysis on this point. The fulcrum theory was regarded by Pearse Sutton as an over-simplification. His view was that the four pad foundations to the north of zone 1 had sunk by about 5 mm. This added a moment in through the somewhat thicker concrete slab which impacted to the south, where the slab is adjacent to the old building. This moment might cause the slab to move upwards at its southern end. In looking at that view, however, it is difficult to explain the figures for lipping in the three triangles around the three pad foundations with pillars at the southern side. On a theoretical basis this view deserved closer analysis.

103. Where the three foundation pads with pillars occur on the southern side of the gym alongside the old structural wall, these tied into the existing foundations. Over on the eastern side, there is in addition an existing foundation over which the ground beam runs, and it is tied in, providing additional support. At that eastern doorway, rebar links the old with the new. Ground beams run north to south between the external pillars and pad foundations and the internal ones. Underneath these there is an old foundation running east to west. The two northernmost pad foundations are unaffected but, according to Pearse Sutton, carry a lesser load, in any event. No support on the basis of measured floor levels is to be derived for this theory, in my view. Instead, an argument is put forward by the defence that because the highest level of the slab, when measured prior to remediation, occurred at points that were close to or were over the older foundations, that this disproved the issue of pyrite heave. At those points, however, there was a Clause 804 infill, as there is elsewhere, the difference being that here it is compacted on to the concrete beam structure, as opposed to the more forgiving earth. It is also hard to know how, even taking into account the influence of the old foundations, the pad foundations at the north only subsided 5 mm, according to the defence theory. This, it should be remembered, is not an observation measured by the defence but is an analysis based upon prediction. One wonders what happened to the up to 10 mm subsidence even in "competent black boulder clay"? The crucial issue of the absence of damage to the internal wall that marks out the old building from the new was explained by the defence on the basis that the slab to the northern end could have sunk of an order of 5 mm, cantilevering the slab on the southern end, facing the old wall, and under the plasterboard on that wall, upwards. Depending on the position of the fulcrum, and the possible means of analysis in this context, as well as the moment issue, a range of figures could present. As to whether the slab would be strong enough to behave in that way does not appear to have been noticed by the defence when they say that fundamental to their theory that the building is inconsistent with pyrite heave, is the absence of any cracking in the floor slab. Perhaps the slab would be strong enough, in that regard, because it is much thicker. If so, it might rise as a unit due to pyrite heave, but that is not likely to be uniform. Slabs can also deflect. I do not believe that it counter-levered. The precise measurements were also referred to. One cannot expect uniform floor level readings in a building that has been subjected to pyrite heave. Variations can also be accounted for on the basis of the appearance of the foundations underneath and the strength of rebar linking old to new. Such evidence as is presented by the defence cannot account for a foundation drop of 20 mm to 25 mm or 32 mm. The defence theory is that the foundation drop here was only 5 mm. That is difficult to reconcile even on a theoretical basis. If a major foundation drop did not occur here, but occurred at other points in the building, differential settlement and the expected results of that ought to be seen along the northern face of the building. That is not present. If the foundation drop did not occur here, but at other points in the building, differential settlement and the expected results of that predictably ought to be seen.

104. In this area of the gym in zone 1 where it joins the old building, apart from the lipping that I have described, there are two other telling features. The first is the openings in the plasterboard for the wall electrical sockets, which were screwed into steel fittings attached to the old wall at the south. These are about 25 mm higher on the northern wall than are the steel fixings screwed into the original wall behind it. Does this indicate upward slab movement that pushed up the plasterboard on studding fixed to the floor slab? Pearse Sutton, John Campbell and Roger Jowett, on behalf of the defence, gave evidence that if this was so damage ought to be seen to the plasterboard of a particular kind, involving shearing of the screws at the site of the electrical sockets. The screws, in other words, ought to damage the plasterboard by being forced upwards into it. The view presented by the defence was that it was probable that the plastering contractor, or whoever had cut the holes on the basis of an indication by a wire merely protruding through, would not have measured 450 mm correctly off the floor, but approached the job badly. Roger Jowett also gave evidence that a kind of back plate could have been fixed into the metal electrical socket fitting on the solid wall behind the plasterboard. This was demonstrated in court. It is highly ingenious. An exhibit, in that regard, has been kept by Mr David McLoughlin registrar. This ignores, however, that professional Irish builders will be highly unlikely to engage in Mecano-like activities in the course of their work. It is not at all probable that experienced workmen would go around fiddling with back plates and nuts and screws and drilling extra holes into a metal back plate, while fixing it in place to cover up bad construction in the first place. Nor is it likely that experienced workmen would not be able to measure a fixed distance off a floor. Roger Jowett's analysis has helped. It renders the movement of the floor upwards much more probable. I also heard evidence from the electrician who removed these electrical plug sockets. It expressly contradicted the defence theory. I accept that evidence. I did not need that evidence, however, the theory being at the level of the highest improbability. I have taken into account as well the siting of other electrical sockets. Evidence from this area indicates as a probability that the floor slab did move upwards.

105. Another issue which emerged was the fixing of the studding on to which the new plasterboard is attached on the old northern wall where it meets the new gym. This involves a hole being drilled in the old wall and a flexible metal attachment that looks in photographs to come out about 20 mm, for the purposes of attaching the studding. If the workers were doing their job correctly, these metal attachments would come out of the wall horizontally and then be screwed in to the long metal studs which are attached to the plasterboard. Photographs taken on the examination of the building indicate that these metal attachments are not horizontal. Instead they bend upwards from the wall to the studding at a severe angle. This is just too much of a coincidence. I find for the plaintiff on this issue also.

106. One of the fundamentals of the opinion that the building had suffered from pyrite heave proffered by Dr. Maher on behalf of Elliott Construction was the relation between the old and the new portions of the building as it now exists. Dr. Maher was of the view that if the foundations of the new building had settled that there would be cracks on the outside, as evidence of distress to the supporting wall to which they are tied, and that the new internal wall of the old building, which was retained, where it is linked to the new building would show distress. This was because the differential subsidence of the new foundations, had it occurred, would have caused cracking in that old wall. When a building is built, a level of subsidence can be expected, as I have said. Thus, if the heave appearance in the floors was due to the subsidence of the foundation in the new buildings, definite levels of distress should be found in the link between the old and the new and particularly when the buildings interfaced by the use of the new northern wall on the western face to which the new portions of the building were linked. This distress is absent. Nor is there any distress in the roof. There is no distress in the brick work to the external part of the building at any place.

107. When the new portion of the building was being linked at the north-west corner on to the old, the foundation pads were laid first, the ground beams were linked into them, and then these were, in turn, linked into the old building. The absence of damage at this point is central to the undermining of the defence case of foundation subsidence. Real differential settlement as between the foundations and exterior structure of the building and the floors which were free floating on the infill might possibly have caused the buckling of the plasterboard on the walls. This issue of the old and new building link is one of the principal issues that stand between the defence theory and the plaintiff's case of pyrite heave. The defence case made for lack of distress at the link between the old building and the newly constructed building was skilfully put to Dr. Maher and answered in the following passage:-

> "Q. … I just want to explain to you… what our experts will be saying has happened here in relation to this partition and the electric socket [that ended up higher on the plasterboard than its fitting on the old wall behind] what our case in relation to this is as follows:- what we say is that the new building… is tied into the old building. The new building is settling because it is tied in by rebar into the old building. This is bringing about an effect where there is no movement in the old building but in fact the tilt is operating on the floor slab so in effect it is causing the floor slabs to crack. And the reason it is doing that is, as the ground beams settle and tilt, the infill on top of it also settles and tilts. And because there isn't a great amount of infill over it, the floor slab above it is also tilting and that this is actually, as this slab settles down…exercising an upward tilt on the slab. It's a very small movement…of an order of magnitude of about 5 mm. And its happening because there are significant amounts of ground beams in that part of the building and that this tilt is in fact bringing about a pressure on the partition to raise it upwards and therefore you see the partition going upwards just above the electrical socket?
>
> A. I find that an extremely complicated explanation to explain the absence of differential cracking between the new building and the old building in fact it doesn't explain that. Because I presume what you're saying, you are suggesting that the outside of the gym [the north-western portion of the new building linked into the old building] is settling, so the foundations on the outside of the gym are settling and in some way they are causing the floor to tilt or rotate. Why would the top of the building not becoming away from the old building?
>
> Q. Because it is tied in with rebar?
>
> A. That the top of the building I don't think could be tied in with rebar. You know, I could see the foundations or ground beams but I can't see the top of the building. The building tilts.
>
> Q. My instructions are that the roof is tying it in at the top?
>
> A. Yes, but that would have been some distress there. If you have a building – its not have very wide building, so any differential movement on the outside of that building would definitely cause distress in the top upper part of the building and it would tear away from the existing building. It couldn't just – every thing stays intact. If you are talking about this outside the building settling, where is that distress going to show up? It has to show up in the top part of the building.
>
> Q. No, because the level of settlement and the level of movement is of a relatively small order of magnitude in this part of the building, its only about 5 mm?
>
> A. Its only about 5 mm but yet that is causing the upward pushing of the …
>
> Q. Yes. As the foundations for the new building settle, that is bringing about – the fill above its settles?
>
> A. Yes.
>
> Q. The slab is resting on that fill and therefore it is bringing about a rotation or a tilting of the floor slab and that it raises it up slightly and then actually raises up the partition also?
>
> A. So has this tilting then been detected in the survey that was done on the slab before it was removed?"

108. My view on this matter is that I have heard nothing which undermines what Dr. Maher has said. The new building did not go downwards, rotating the floor and thus tilting at the point where, to the south, it joins the old building. No such effect is demonstrated.

109. In considering the issue as to foundation settlement I have looked carefully at the evidence of Roger Jowett and Pearse Sutton in the helpful way they explained their theories as to what might have happened to zones 1, 2 and 3. As to zone 1 and the dwarf wall and large windows, issues of the weight of the window and wind pressure do not establish themselves as probable. In addition, however, I take into account that when Martin Hannay removed the skirting board, the cracking of the displaced wall in zone 1, into which fingers could be fitted, subsided twenty minutes later. This indicates to me an upward pressure that was removed. Of course, it could be a pressure by reason of foundation settlement but I have scoured the testimony to find any evidence that I could possibly accept, on a reasonable basis, for this theory. Again, this evidence, in the context of the entire state of the building and my findings of fact in that regard, shades into more than an improbability. Roger Jowett's theory for the defence as to the triangles in zone 1 not being cleaned out was new at the late stage of the case in which it first made an appearance. That is not important because it was unconvincing in itself. In addition, Pearse Sutton for the defence explained that under some of the triangles in zone 3, the insulation was absent and the radon barrier was draped over the columns. This, he believed, could add to the subsidence of the triangles themselves, especially because the pillars at the centre of zone 3 did not show a differential as to the diamonds around them. The same issue, he believed, might explain the eastern-most triangles in zone 1, and the centre triangle. This issue involves a gap being present in the concrete and it sliding away from the main floor slab, to which it must at least have been likely adhered, and going

downwards into that gap under its own weight. There is no evidence to support this elegant theory. Any theory as to block shrinkage, as explained for the defence by Roger Jowett and by Dr. Simms, gives rise to minimal movements. In order to be able to explain the condition of the building with, as Roger Jowett believed, a lesser level of the foundations subsidence than in the high figures postulated in some other of the defence evidence, I was in effect urged by the evidence to put a large number of small movements together with a view to explaining the condition of the building in a manner consistent with there being no heave. I would also have to be able to explain the condition of the gym at the north-western corner. I have received great assistance from these experts for the defence. By deconstructing the individual portions of the building and in enabling me to look at detail, the case made by Dr. Maher for the plaintiff has been strengthened.

110. I therefore conclude that the foundations and supporting walls of the building did not sink beyond a normal and very small measure. I now turn to the upward movement alleged in the floor slab. Here I am analysing whether, if it happened, it was caused by pyrite heave.

Sulphur

111. Tests were carried out under the supervision of Dr. Maher by Golder for the plaintiff in order to determine the total sulphur content in substantial samples of infill taken from the building. This can be measured in acid soluble sulphur and water soluble sulphur. In one of the few measures of agreement between the parties, pyrite has been established, as I have earlier stated, at 1.5% by volume and 2.7% by weight in the Clause 804 as it was put under the building. All but two of the building infill samples tested in 2009 had a total sulphur level equal to or greater than 1%. Dr. Maher presented a view that the pyrite levels in the infill which gave rise to many thousands of floor heave problems in Québec in Canada were in the range of 0.8% to 1% pyrite. The pyrite levels removed from Ballymun were generally of the order of twice and sometimes three times these values. Pyrite in mudstone, however, may not react as easily as in Québec shale. There was some Roadstone infill in small quantities in some places like the courtyard. These are not at a level so as to make no difference to my analysis as to probability. High levels of water soluble sulphate were detected in the Bay Lane Clause 804 infill from under the building. Sulphur and sulphate concentration determined in laboratory tests of infill from the building showed substantial levels of pyrite, some of which were 2%. The footpath infills ranged between 0.6% and 2.3%. In contrast, pyrite levels from the new infill obtained for the remediation of the building from Keegan's quarry was of the order of much less than 1%. The original infill under the old building that was preserved, the dance studio, was of a similar very low order. These levels are negligible. High sulphur levels can lead to cracking and disintegration in concrete when sulphate ions penetrate the material. I will return to this.

112. An issue has arisen as to whether the relevant Irish standard does or does not require that Clause 804 hardcore infill has a sulphur content of less than 1%. On one side of this issue, Dr. Maher of Golder and Lloyd Twomey of Arup have given evidence for the plaintiff that their interpretation of the standard is in favour of the maximum 1% sulphur content standard. For the defence, Dr. Ian Simms and others have interpreted the standard as declaring that there is no requirement for sulphur at less than 1% in Clause 804 infill. I have listened to those views. They have helped in exposing a difficult problem of construction. What now follows is my interpretation; it is not the acceptance of any construction offered by a witness.

113. I.S. EN 13242: 2002 establishes the Irish standard on aggregates for unbound and hydraulically bound material for use in civil engineering work and road constructions. This is the European standard adopted in Ireland by use of a cover sheet. The foreword stated that appropriate existing practice is compared to the new requirements in the standard "mostly in tabular form" and goes on to indicate that "the user can select the relevant categories dependant on the end-use requirement of the aggregates". Under the heading of chemical requirements, at Clause 6.1.1, the following appears:-

> "The necessity for testing and declaring all properties in this clause shall be limited according to the particular application or end use or origin of the aggregate. When required, the tests specified in clause 6 shall be carried out to determine the appropriate chemical properties…
>
> NOTE 2 When a property is not required, a "No requirement" category can be used.
>
> NOTE 3 Guidance on selection of appropriate categories for specific applications can be found in national provisions in the place of use of the aggregate".

114. Under the heading of "Total sulphur" it is stated:-

> "When required, the total sulphur content of the aggregate, determined in accordance with EN 1744-1: 1988, clause 11, shall be declared in accordance with the relevant category specified in Table 13".

115. That table indicates that there are three categories of requirement for total sulphur content: more than 1%, less than 1%, and no requirement. A note is attached indicating that special precautions are necessary for pyrrhotite, which is different to pyrite, and even more highly reactive. Under Annex ZA it is declared that compliance with the relevant clauses "confers a presumption of fitness of the aggregates… for the intended uses indicated herein" within the standard. Clause 7 deals with durability requirements. This states:-

> "The necessity for testing and declaring all properties in this clause shall be limited according to the particular application or end use or origin of the aggregate. When required, the test specified in clause 7 shall be carried out to determine appropriate durability properties…
>
> NOTE 2 When a property is not required, a "No requirement" category can be used.
>
> NOTE 3 Guidance on selection of appropriate categories for specific applications can be found in national provisions in the place of use of the aggregate".

116. An issue has arisen between the parties as to the national provision in Ireland. Is it the Department of Enterprise Specification for Road Works (1978), the NRA Specification for Road Works, Road Pavements - Unbound Materials (March 2000), the NRA Notes for Guidance on the Specification for Road Works, Road Pavements – Unbound Materials (March 2000), as the defendant argues on the one hand, or is it as the plaintiff contends, S.R. 21:2004 from the National Standards Authority? I regard it as being the latter. This document is entitled "Guidance On The Use Of I.S. EN 13242:2002 – Aggregates For Unbound And Hydraulically Bound Materials For Use In Civil Engineering Work And Road Construction". It is published by the National Standards Authority of Ireland as ICS 91.100.30. The relevant end-users are specified according to schedules. The document is a "guidance" document. It is also issued by the same body as promulgated I.S. EN 13242:2002. Furthermore, I note that arguments on the non-applicability of the standard based on its revision were furthered by reference to a similar document ICS 91.100.30 promulgated in 2007 by the same body: S.R.

21:2004+A1:2007.

117. My view is that the end-use requirements of the aggregate can be chosen by virtue of S.R. 21:2004 which I consider constitutes the relevant guidance. By choosing material referable to one of the annexes thereto, this is expressed as a choice of end-use by reference to category. It is argued, however, that this standard is not binding in law. I do not agree. Even were S.R. 21:2004 not legally binding of itself, it becomes legally binding by virtue of a course of dealings between the parties whereby Clause 804 is offered and is chosen with respect to the appropriate use of the aggregate. Thus by an employer specifying Clause 804 infill to a builder, the contract is to use the material as it is understood within the construction industry. To act otherwise would be to move outside a well described category. That point is strengthened where a quarry holds itself out as supplying Clause 804 infill according to that description. The guidance note on S.R. 21:2004 indicates in the foreword:-

> "I.S. EN 13242 does not supersede any Irish Standard but it does specify requirements that differ from those currently in use in specifications.
>
> This Standard Recommendation (S.R. 21:2004) is one of series published by the NSAI to provide National Guidance on the use of I.S. EN 13242:2002 and the other aggregate standards. Where appropriate existing practice is compared to the new requirements, mostly in tabular form, the user can select the relevant categories dependent on the end-use requirement of these aggregates.
>
> The Standard Recommendation has been prepared by the Road Standards Committee of the NSAI.
>
> This document is published to provide guidance only and does not purport to include all the necessary provisions of a contract. Users are responsible for the correct application. This Standard Recommendation is not to be regarded as an Irish Standard."

118. The introduction indicates that the Standard Recommendation merely provides advice because I.S. EN 13242: 2002 specifies requirements that differ in some cases from the requirement contained in a specification for roadworks by the NRA As the note in the document specifies:-

> "It is important to highlight that I.S. EN 13242:2002 is not solely dedicated to the specifications of road construction, however, the majority of usage will be within this general area."

Material chosen by reference to specification for roadworks, however, as the note indicates, is not solely used for road construction. Clause 804 is widely used for road construction but it is also used as a stable infill on which to float floors within buildings. The document continues:-

> "I.S. EN13242: 2002 specifies a range of categories for properties to enable users to select appropriate limiting values for the wide range of aggregates used in unbound and hydraulically bound materials produced in Europe. In most instances, provision is also made for producers to identify a "declared value" for properties when the value is outside indicated categories.
>
> This guidance recommends limiting values for aggregate properties within the ranges permitted in I.S. EN 13242:2002. Where possible, these recommended values are equivalent to those specified in the NRA Specification for Road Works.
>
> Specifers will need to define I.S. EN 13242:2002 categories for properties that are relevant to the particular end-use of an aggregate. Some example specifications listing recommended I.S. EN 13242:2002 aggregate categories for particular properties for aggregates with different end-uses are provided in Annexes A, B, C, D and E."

119. Clause 3.1 illuminates the wording by declaring that clauses 5, 6 and 7 of the Standard Recommendation begin with a general sub-clause which draws attention to the necessity to specify only those properties relevant to the particular aggregate and end-use of the aggregate. Where this is the case, the wording "when required" is used. The document continues by making reference to tables of specified requirements that allow the user to choose the appropriate category for each property. The category designation is intended to be self-explanatory and related to the specified limiting value. This makes it clear that a reference to a particular category within the annex is an indication of end-use. Clause 3.4 refers to 'Chemical requirements'. Within the context of total sulphur, it is explained that Clause 6.3 of the Standard Recommendation "limits the total sulphur content to 1% by mass for aggregates other than blast-furnace slag". It continues:-

> "For current Irish aggregate sources where the measured value of total sulfur content during initial testing is 0.1% by mass or less, it should be unnecessary to undertake further testing. In this case the total sulfur content can be assumed to conform to the 1% limit unless there is a significant change in the quarry deposit."

120. It would therefore be necessary to determine what use is to be made of the categories of annex in respect of which the material is being ordered. It must be remembered that this Clause 804 NRA specification allows this as a choice of appropriate material. Clause 4 deals with the provision of the Construction Products Directive: Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products, OJ L 40 11.2.99. It states that conformity to those identified requirements confer the prescription of fitness "of the aggregate and filler aggregate for the intended uses indicated in the scope of I.S. EN 13242:2002".

121. Turning to the annexes, it be hard to regard Annex A as useful. This is a specification in respect of pipe bedding and other activity which is not relevant here. Apart from just looking at description, it is also appropriate to have regard to the individual wording of each annex. This can help illuminate potential use. I will look at these tests in detail in another section. I note, for now, the reference to fragmentation in accordance with the Los Angeles abrasion test has 50% disintegration. I will look at these tests in detail shortly. For the moment it suffices to note that this would be very unsatisfactory under buildings and under any public road. Turning to Annex B, I note the reference to the Los Angeles abrasion test at 50% tends also to rule that out also. Turning to Annex C, which is an example specification "for fill material", there is no particular application there unless the user, or purchaser, which would be Elliott Construction in this case, specifies what it is for. If Annex C is applicable then there is no requirement that sulphur content be less than 1%. Turning to the properties of the infill, I note that it is very undesirable for building construction. I accept Dr. Maher's evidence for the plaintiff in that regard. It is consistent with poor grade materials such as three inch down stone which does not have the specific grading limit or the tests applicable to Clause 804 under the NRA specification. In relation to fragmentation of the rock, Annex C sets out Los Angeles abrasion results between 40%, 50%, 60% and no requirement. This would mean that up to 60% of the sample degrades under that test or that there is no requirement. This is very undesirable in terms of infill or road material.

In fact, at no requirement it is close to useless. The maximum applicable under the NRA standard for Clause 804 from May 2004 is 30%. Turning to Annex D, I note that the grading shapes, fines content and fines quality is chosen in accordance with the requirements of the end-use as specified in the NRA specification for roadworks. Once Clause 804 is ordered then the relevant grading and particle size distribution is also chosen. That is what was ordered here as a matter of contract. A later analysis of such evidence as I accept from Patrick Elliott refers. In addition to that, Annex D refers to an "example specification for unbound sub-bases for road pavements." This is indicative of the Clause 804 infill specified on the contract drawing previously quoted. It is high quality material used under roads. This material was specified under the contract by the engineers for the building as being suitable for floor support infill. Furthermore, under Annex D, the resistance to fragmentation is to be 30% in accordance with the Los Angeles abrasion test. This is the Clause 804 standard. A magnesium sulphate soundness value is given as 25. This is the correct soundness value as specified for Clause 804 infill by the NRA in May 2004. The surface specification is irrelevant. The total sulphate is specified as being less than 1% by mass. That is the standard applicable. In relation to Annex E, for cement-bound materials, which is not relevant, but which is again a high standard, similar magnesium sulphate values are given together with a worse fragmentation value and a similar grading.

122. This Clause 804 was not to be used for cement making. Instead, the aggregate infill was to be used in supporting floating floors in accordance with the same standard of material as would be required for Clause 804 in a roadway. Elliott Construction, for this job, ordered two different grades of material from Irish Asphalt. Three inch down material was ordered, which is a crude material used for a site platform outside the building footprint, and Clause 804, which is of a particular quality. I am convinced, therefore, that Annex D is appropriate. Later in this judgment, within the context of the implied term as to merchantable quality, I consider the applicable contract. To supply material at anything greater than a 1% sulphur value is a breach of contract. This is applicable in this instance as a matter between the parties. In taking account of later modifications to the standard, these it seems to me, provide clarification to what has been difficult to work out as a matter of fact from the documents to which I have referred, and which has been the subject of conflicting evidence from experts. In that later standard a guidance note is introduced which gives a new requirement specifically for granular fills. Parties would then be choosing Annex E, which is an example specification for cement bound materials. This did not exist in a separate category before. Its introduction, however, has not changed the applicable standard. More especially, it has not changed the nature of the contract made between these parties. I will return to this.

123. A question has been raised as to whether an unbearable and therefore unlikely burden has been placed upon quarries by the 1% total sulphur standard. It is reasonable, in this context, for a quarry to test what it is proposing to sell to multiple users. In this regard, I accept the evidence of Lloyd Twomey. A test for sulphate would indicate whether there is a problem potentially. A test by x-ray will confirm whether this is in the form of pyrite. A petrographic slice will enable pyrite to be seen for definite and determine whether it is in framboidal or euhedral form. In extreme cases, a scanning electron microscope might be used. This checking is not unreasonable at all given the potential of the infill to wreck roads and buildings if it swells. It is far from unreasonable in the context even alone of this case. It is reasonable in the context of a quarry selling Clause 804 crushed stone. I prefer the case of the plaintiff.

124. This has two consequences. Firstly there is a breach of contract. Secondly, by reason of the nature of the material it may constitute a risk to the concrete used in the ground beams and in the pad foundations. I now turn to that.

Risk to Concrete

125. This Clause 804 infill material contains more than the 1% limit for sulphur content. In fact, the tested infill from the building shows a level of at least 1.41% on average for total sulphur. In this regard I accept the evidence for the plaintiff of Lloyd Twomey of Arup. Ballymun Regeneration, the public body which commissioned the building, is argued to be entitled to a measure of reasonable security as to the structural elements. Simply because the pattern, as Dr. Simms put it for the defence, of sulphate content at various points from the surface inwards is consistent with a pattern common to concrete that is exposed to wetting and drying, does not entitle the Court to ignore this issue. The reality of the elevated total sulphur level remains a serious problem. Dr. Simms examined samples of concrete from the buildings. His view was that there was, as of 2009, no evidence of sulphate attack. There was no risk, he said, to the floor slab. This was because the floor slab was removed from the infill by a polystyrene layer and by the radon and installation barrier. I agree. The buried concrete was the focus of his evidence. He found the view of Dr. Maher on sulphate attack to be unconvincing he said:-

> "Because sulphate is relatively soluble, concrete contains sulphate of course, as I think I said before lunch when concrete gets wet and then dries again, some of the sulphate moves towards the drying surface. So you tend to get, not inevitably, but sometimes you tend to get the effect of the sulphates building up at the surfaces. In this case the difference was just a few percentage points. It wasn't enough to suggest to me that there is a massive invasion of sulphates".

The following questions and answers then occurred:-

> "Q. The total sulphur is 1.41%... Dr. Maher's view was that, look, if this was private householder and you had these high levels of sulphur, because of the risk of sulphate attack he wouldn't be saying to them, dig the whole thing out. What he would be saying is, watch it over a period of time and let's see where we are at. On the other hand, in relation to a public building, which this is, which is supposed to last 50 or a 100 years, or in the case of this one [the Four Courts] it has lasted 210 or 211 years so far, he would be saying you have to get it out. Do you have a view on that?
>
> A. My view is, if I am investigating an existing structure as opposed to investigating the risks to a planned structure, I would want to know what are the risks and if I find there is risk of sulphate attack, I would want to know, you know five years had gone by, there must be evidence of the start of sulphate attack. So, I would then look at concrete samples to see if there was any evidence of sulphate attack. In this case, I have seen none. There is not any microscopic evidence of the initiation of sulphate attack.
>
> Q. So you wouldn't dig it out?
>
> A. I couldn't see the justification of doing so on that basis, no.
>
> Q. What about the … 1.41% [sulphur value]?
>
> A. That's the total sulphur value… Well, it doesn't follow that all the sulphur is going to become more sulphate. If you are planning in advance, if you are saying I have a green field site and I want to build something new and I don't want any risk of sulphate attack, then the approach of S.D. 1 is to say, well let's take the worst possible case, let's take the total sulphur value and let's assume its all going to become sulphate and we'll plan on that basis. But I suggest that's not a

sensible way of approaching an existing building, because otherwise you would be taking some very dire decisions, I think."

126. What Dr. Simms was saying was that he saw no evidence of sulphate attack coming. His feeling was that the concrete was similar to concrete he had seen many times in wet ground. I found Dr. Simms evidence to be honest, expert, and helpful. It is not, however, the only potential answer to the issue of total sulphur. This youth centre building is not a temporary structure. Clearly, a building which has a long life may be repaired many times. As regards its fundamental structural elements such as its foundations and floor, these can be expected to have a reasonable life. In the context of a public building it would not be unreasonable to suggest that the building should last over a period of 50 years and up to 100 years, and perhaps more, as to its structural elements. Given the total sulphur level, would the building as constructed have had that reasonable level of durability? During the course of the case, reference was made to a patent idea called "Project Grout". It was alleged that Pearse Sutton, the defence engineering expert, was involved in this. I accept that there is no evidence that he has made a patent application but, as he said, this matter was thought through by him and a number of colleagues. The idea is to develop a grout that would act like water at a capillary level and invade and smother a potententially expansive infill. Chemical reactions would then stop. Whereas nobody told me that this would be a solution to potential sulphate attack, and it seems to have been thought of as a solution in relation to potential heave, I would see it as logical that by neutralising infill in this way that it would also have an effect on sulphate attack on concrete.

127. The approach of Dr. Simms is helpful. In terms of taking a drastic step simply because of elevated sulphur levels of spending over a €1m on remediating the building, I would regard that in any ordinary situation as an improbable step. Of itself, I cannot see it would justify the removal of the infill. There was little attention focussed on alternatives to removal. The case made by the plaintiff, concisely put, is that if infill in significant quantities is used against concrete, whether foundations or blocks, then elevated sulphur levels run the risk of sulphate attack against the substructure of the building. I am not satisfied that if the building was not remediated that the level of sulphate attack to be expected over the life of the building constitutes an unreasonable risk for any public body to take. Dr. Maher's evidence on the matter was impressively self-questioning. In every respect, I found this approach of his to be reassuring. A useful section was as follows:-

> "I mean obviously at design stage you want to avoid creating problems that would lead to deterioration of a building. At the same point, if you have an existing building and you find the situation has already arisen, surely you would have to be concerned about that and determined to do something about it, whatever that might be. Maybe you would just say, well I am prepared to live with it and hope it doesn't' happen, I don't know. You know, but I think its the same principle involved, that you should not put high sulphate material adjacent to concrete… if [Ballymun Regeneration] purchases a building or wants a building, they are expected to build in accordance with acceptable standards. So, therefore, if they determine or it subsequently determined, it doesn't meet standards and it doesn't meet standards because of the future risk of sulphate attack and sulphate damage below the ground that you won't see until it becomes a structural issue, why would they be willing to accept that. So I think they would say, well, I bought a properly functioning building, I want to use it for 50 to 100 years, if there is sulphate there that could lead to damage to that concrete, that's not what I purchased, so therefore replace. Now, if [Ballymun Regeneration] is told well, you have got high elevated sulphate levels under your building it going to cost you 1.5M to fix it, do you want to fix it. And then you might look for mitigation measures such as well, mainly we monitor it every few years and take some samples and see if it is developing. But it's not a situation that … as an engineer if I was asked to say will you write a letter to satisfy [Ballymun Regeneration] that there will be no problems with respect to future sulphate attack on this building, I would have say very definitely not, I would not write that letter, because you are flaunting all the guidelines that are out there and so you are accepting a situation that no one would willingly create. That is why we test these materials beforehand, because you don't want to create a problem. If you have already got… sulphate on site just because its a natural occurrence on the site and you don't want to move your building, then you would design different features into the building to prevent the sulphate damage which is you can use concrete that doesn't react to sulphate damage. But its more expensive … I think you would be justified in replacing the infill but you may not have to replace it all, maybe I should clarify that, because really you might only have to replace the area that was against the concrete, you know, the typical guideline is 500 mm from concrete. So whether practically you could do that and not totally take out the floors [is] debatable. You might be able to, for example, you know, dig a trench around the entire and put in a coating on the concrete to protect it. But, you know, it may end up just as expensive as taking it out… I agree there is no sulphate attack [as yet]. But again it only been… five years. Sulphate attack is usually a longer term process and it is usually more of the order of ten years. You know, I don't know how frequently the problem is occurring in Ireland but it is a real problem in all kinds of places and its a very costly fix to fix sulphate damage."

128. The chemical tests which are relevant to an analysis of this infill are referable to sulphur. There is nothing in the evidence to suggest that the sulphur in this infill from the building is derived from anything other than pyrite. It could be derived from barite, from impure forms of calcite, from pure sulphur or from organic material. There is nothing to show, however, any such substantial admixture beyond pyrite. The Golder results for total sulphur ranged between 0.59% and 2.1%; averaging 1.54%; the Arup results average 1.41%. Both exceeded the 1% limit. Dr. Simms figures are between 1.33% and 2.09% for total sulphur on various tested samples. Sulphate is a reference to sulphur compounded with oxygen, as opposed to sulphide, which does not have oxygen in its compound. It is important to test for sulphate in order to determine whether or not the estimate given by Dr. Maher, that up to 30% of the pyrite in this sample had oxidised, is, or is not, correct. The analysis conducted by Dr. Simms, on behalf of the defence, shows an estimate of 35% to 50% of pyrite oxidised. This contrasts markedly with the petrographic analysis conducted on behalf of the defence by Professor Kokelaar and Dr. Boyle. Taking a reasonable view of this evidence, and of the petrographic evidence which is analysed later, at the moment I tend on balance towards the view that a large proportion of the total sulphur has become, and will become in future, a sulphate. I think, nonetheless, that as a matter of probability the approach by a reasonable building owner would be to monitor this situation. I appreciate, in that context, that a reasonable building owner would be worried about the disintegration of concrete under the foundations. This has not happened yet and there is no sufficient sign of it happening. Possibly some measures that are less drastic than removing the floor slab and then removing the infill might be found; here I am thinking about such solutions as project grout or oxygen deprivation or water flooding. These would be thought through by a reasonable building owner as to cost and as to the prospect of success and as to any possible side effects. I would find it improbable, however, as a sole basis for deciding this case that Ballymun Regeneration could reasonably ask for the entire infill to be removed on the sole basis without more of the sulphur content of the under floor infill near the concrete foundation elements.

Sulphur and Sulphate

129. Because of mention at trial, I now need to look at some of the bulk chemistry tests. In this regard, gypsum is an oxidised form of sulphur. Whereas other possibilities occur, there is again no tenable evidence to suggest any source of sulphate other than gypsum. I do not accept that Arup in using an up-to-date transport research laboratory method of testing, as opposed to the British testing protocol set out in BS EN 1744 – 1:1998, was in error. What is important is what the results show me as to the amount of pyrite that

has oxidised.

130. Water soluble sulphate will tend to show a lesser value than acid soluble sulphate in a test to determine the probabilities as to what proportion of the total sulphur has oxidised. There is nothing to suggest to me that the oxidised sulphur in this infill is some other compound than gypsum, which is present in a sufficiently high proportion to make a difference to the test. Gypsum is low water soluble. Acid dissolves more gypsum than water. Even in the water soluble sulphate test, some degree of HCl acid is added to the solution, at least in Canada, one or two drops per litre, in order to speed the process of solution. As of 2004 to 2005, on supposedly removing material only from the quarry, the Bay Lane quarry results showed sulphate at levels of 0.01% per litre. Dr. Maher's test results on the Clause 804 infill from the building were high. The Arup results were at 0.38%. Dr. Simms presented results for the defence for water soluble sulphate, at between 0.319% and 0.341% and 0.341%. The NRA specification provides that materials placed within 500 mm of cement bound materials, such as concrete, should not have a water soluble sulphate that exceeds 0.2% of sulphate per litre. As already commented, given the dynamic of chemical change within this infill, whereby pyrite becomes gypsum, in other words sulphur to sulphate, no one can say after the material has been in the ground for up to five years that the test results obtained in 2005 on leaving the quarry are not correct. Because the infill is not chemically stable, sulphate results can change. In terms of the bulk chemistry, however, the acid soluble sulphate as tested at the end of 2009 shows, on Dr. Maher's results, a low of 0.37% and a high of 2.7%. The results for Arup were 1.41%. The reason that this is important is that when all the total sulphur that potentially could oxidise in gypsum is calculated, and then the acid soluble sulphate is taken away, which is a fair value for what has already oxidised, the calculation then leaves a proportion of material that if all were to oxidise could possibly oxidise. In expressing the maximum result that could possibly oxidise, taking away the figure that has already oxidised, a figure is left which is expressed as a percentage. This simple chemistry yields, on these figures, a result of around 30%. The total potential sulphate, as presented by Dr. Simms for the defence, shows values between 6.27% and 3.99%. His total gypsum potential is measured at between 4.52% and 3.17%. His current equivalent pyrite is measured, as of 2009, at between 2.54% and 1.35%. This last factor is taken from sandy, or fine, fractions. I think it is reasonable to conclude as a probability that pyrite has been oxidising quicker in smaller samples of stone. There is a dispute as to the total potential gypsum, as between a figure of 7% to 11%, as presented by Dr. Maher, and he prefers a value of around 10%, and the defence value as presented by Dr. Simms which shows a maximum of 4.52%. Clearly, the oxidisation of pyrite has been proceeding relatively rapidly, given the results in relation to fines. Even if that were not so, I would find it improbable to suppose that the quarry material, on removal in 2004, contained very high sulphate levels. The tests by the quarry contradict this figure. I think a reasonable figure at 6% to 7% is probable in relation to potential gypsum, given that 70% of is in framboidal form. Dr. Boyle, on behalf of the defence, was even more sceptical as to the amount of oxidised pyrite. He said that he did not see 30% oxidised pyrite and was of the view that the pyrite might never oxidise. His analysis was 15% based upon the petrographic study of 18 thin sections, 6 on fines and 12 on larger rocks. His true opinion was that in fact around 5% of the pyrite had oxidised. He also offered a view that a colleague had indicated to him that only 1% had oxidised. He did not see any voids where pyrite was before. It is hard to see that he was specifically looking for those. Professor Peter Kokelaar for the defence was possibly more real in his approach but declined to express figures for oxidised pyrite. Both also criticised the bulk chemistry tests in relation to sulphate. His view was that the vast majority of the pyrite had not oxidised. The relationship between bulk chemistry tests and petrographic analysis has probably not yet been properly studied. This evidence was useful on a theoretical level. The practical approach by Dr. Maher and by Lloyd Twomey is preferable on the entirety of the evidence.

131. The bulk chemistry tests indicate another factor in favour of pyrite heave, as opposed to any other explanation. The relevant bulk chemistry results can all be used to establish a probability. There is also a more basic test.

132. A Canadian standard from Quebec, CTQ-M200 as previously referenced, has been used in relation to some of the tests for comparison purposes. One per cent pyrite, in that regard, gives medium to high swelling potential as measured by the official body in Quebec. The sample from the building, as has been indicated, is far higher. In addition, the porous nature of the rock, the presence of calcite, a reasonable temperature within the building, which is bound to influence the infill beneath though slowed by the insulation, and the availability of hydration and oxygen do not rule out swelling or lessen the implication of that value. I take into account, in this regard, the nature of the rock and the high level of calcite. This does not disturb my conclusions. If anything, the probability is that it is higher in the circumstances encountered in this infill.

133. Two serious issues arose in cross-examination as to the appropriateness of the testing done by Arup in order to reach a conclusion that the infill in the building had a high swelling potential. These related to the proper interpretation of the results, firstly, and, secondly, the appropriateness of using the Canadian standard. It is obvious that the plaintiff's experts used it responsibly as to its indications. I regard the Canadian document, although promulgated in respect of Quebec only, as providing reasonable guidance against a background of wide experience. There is no case tenable on the evidence of Lloyd Twomey for the plaintiff engaging in selective analysis for the purpose of producing a result that shows the material to have a high swelling index. In the Canadian document, at para. 2.5, the following warning is given:-

> "Care is needed when interpreting the values at obtained and the analysis must exercise prudence in this respect. The following table indicates, for information purposes only, the general correlation between the pyrite equivalent percentage and the chemical swelling potential. The potential values show and offer information purposes only and several other elements, petrographic facies, [petrographic swelling potential indicator], sulphate, crystalline, structure, percentage of play minerals etc, must also be considered when drawing conclusions".

134. I accept the answer which follows from Lloyd Twomey as indicative that this warning was taken into account:-

> "... my entire report with the serious of checks and balances. We start by doing aggregate testing to determine the physical susceptibility of this material to aggregate heave. So the magnesium sulphate soundness test shows it is poorly resistant to a crystal swelling within its material. The [Los Angelos] abrasion test shows low durability. The flakiness index test shows it flaky material. In addition we then undertook the chemical analysis to come up with the swelling potential, and the swelling potential is, could it swell. Don't forget, the aggregate tests looked at the water absorption, so could water and air get at this pyrite? Yes it could. And has it? Well yes, it has, because we have fairly elevated or very elevated levels of acid soluble sulphate which have been attributed by our side, certainly, to being gypsum. So this reaction is going on. We then, following the chemical tests, and following the aggregate tests, did [x-ray diffusion] tests to try and determine do we have clay minerals? Do you have pyrite? Do we have gypsum and what is the make-up of the rock. We found we do have clay minerals. We found we do have pyrite, we do have gypsum. We then did petrographic tests to see where this gypsum might be, what form is the pyrite present in, is it in framboidal form or is it in a euhedral form. We then followed that up with [scanning electron microscope analysis] to look at it in even more detail. So everything I have done has been a serious of checks and balances."

135. I do not accept the challenge to the evidence for the plaintiff on the bulk chemistry analysis.

136. I also find it appropriate to use the Canadian standard for the bulk chemical tests. The method of calculating pyrite was correctly applied by Arup in relation to the relevant calculation. I accept the following evidence from Lloyd Twomey:-

> "The method of calculating the equivalent pyrite is to take 1.87 times the total sulphur – 0.34 times the percentage [of] SO?. We did that. We calculated the SO? in a different manner, in a more robust manner we believe... so we have undertaken what we felt was the most appropriate method of accurately assessing what these values are and we have applied that to a simple calculation, which is a stoichiometric chemical equation that is not reliant on the method of testing, that is not reliant on the type of rock, it is a chemical equation that is put in mathematical form. We have applied that and we have found the equivalent pyrite value, even using a more conservative sulphate breakdown method, has given high level of pyrite which are well in access of the medium to high swelling potential of 1%."

137. Some reality is needed in the assessment of these figures and in the approach to these calculations. Firstly, the original level of pyrite has been correctly calculated, and is agreed, as being well in excess of the Canadian standard of medium to high swelling potential of 1% by weight as regards the original rock. Secondly, in terms of calculating the amount of pyrite that has already oxidised, and thus in this instance has probably become gypsum, I have checked the figures in the witness statements submitted on behalf of the plaintiff and in the transcript and these vary between 20% and 32%. The maximum figure presented on behalf of the defence by Dr. Simms is 50%, with the lowest value of 35%. I have considered the views of Dr. Boyle and Professor Kokelaar and on the overall state of the evidence I feel that petrographic analysis should be approached with caution. It is, of its nature, not a bulk test. It involves a selection of samples and judgment on those samples. The absence of completely oxidised pyrite framboids, as Professor Kokelaar said, is hard to judge. In terms of analysis with a view to establishing whether or not a probability has been reached on behalf of the plaintiff, the acid soluble sulphate test is of some assistance. What matters more is the swelling potential of this rock and whether it can be reasonably calculated that there has been substantial change from sulphide compounds to sulphate over five years. That has been established. Conversion to gypsum results in a larger volume then the weight figure would imply. This is because of the propping quality of crystals. I note also that in evidence, Dr. Simms, in referring to the testing by RSK Group Plc, on behalf of the defendant, stated:-

> "If the properties that we found for the material from under the floor [in the Ballymun Building] after five years, were the same as the properties we found for a freshly processed material then we probably would not recommend the use of that material [as an aggregate under a building or under roads]."

138. In another part of this judgment I consider the possibility as to whether the material has changed beyond the oxidisation of pyrite. A high sulphate level after five years of exposure to oxygen and water does not of necessity imply similar results for material freshly removed from a quarry. The high total sulphur level, however, will remain the same. This figure reflects the relevant element. What can happen to that element depends upon the conditions.

Material Analysis

139. I now consider the physical tests on this stone. The chemistry testing results tend to show that there may have been a significant chemical change within the material. That is likely to be the growth of gypsum. However, from the point of view of any ultimate finding of fact in this case, I discount this entirely. I need hard evidence to establish a probability. A breach of contract is established by reference to a failure to comply with S.R. 21:2004. Actual evidence of swelling is also needed. This can be established from the monitoring of the building for movement, which is dealt with in a later section of this judgment, or from inferences that are to be drawn from the state of the building, which I have already set out in terms of findings of fact, or from swelling tests on the infill, which I shall shortly turn to, or from minute analysis of crystal growth within the infill, an issue that I shall deal with after considering the relevant physical requirements in contract for this infill and what the tests on the infill removed from the Ballymun building show.

140. As to the physical properties of the rock, I accept the evidence of Jon Hunt for the plaintiff that 11% of open laminations were counted over thousands of pieces of rock by him in the samples looked at on behalf of Elliott Construction. His evidence in relation to laminations is important. Whereas there is a difference in the interpretation of what a lamination is and whether, in particular, this rock would split across a lamination, indicating strength, the analysis by Jon Hunt is acceptable to me in terms of probability. Following on a painstaking scrutiny of samples from under the building, he gave the following evidence for the plaintiff:-

> "I suppose I found out that the majority of the samples were elongated platy and consisting, comprising of calcareous mudstone… I was dividing up between limestone and calcareous mudstone and then counting the laminations in these then. So the second part of it would be to count how many had laminations and how many didn't and the next part would be to take the ones with laminations and see how many of these, how many laminations were in each of them. The next part after that would be to take those laminations and see how many were open versus how many were closed… Sometimes you can see either a fracture or else you can see a tiny change in grain size or colour… I would count [partings as laminations]… for the purposes of this exercise I would count them the same. Because it's a distinct boundary between one piece of a particle and another… In all of them the medium fraction [of the stone seems to have more particles] and it seems to have a higher mass of laminations then the courser ones… We could show that across all fractions that we examined there were laminations across all fractions. It wasn't just confined to one size fraction or another. Secondly, we were able to establish that most, the majority of the samples had laminations, the majority of the particles showed laminations and a percentage of these had open laminations and so above that, 11% of the total mass of each of sample had particles with open laminations and from these we could say that from our experience of opening these particles they do contain gypsum and therefore then that gypsum is growing in these particles and going on to produce active swelling… 89%... still have a potential to open along these laminations… I think you know it's very difficult to identify pores [in the rock]. It's certainly not, certainly there are pores but as I said, its very, very difficult, because of the fine grain nature, it's very difficult to tell where the grain boundaries are in a lot of minerals."

141. Professor Peter Kokelaar for the defence did not agree with this analysis. He looked at the material in the quarry in 2009. 95% of it he regarded as calcareous mudstone. A rock was porous, he indicated, if there are holes within the rock which are interconnected, and if they are connected to the surface then the rock is permeable. He described this material as mainly being impermeable; though if it were damaged, by blasting and crushing and compaction, the sequestered nature of what was inside it would be diminished to a degree. His view was that as the sedimentary layers in the stone from the quarry in 2009 tend to break across the lamination that this showed that the laminations did not constitute planes of weakness. He described this as a rock which was not dominated by micas or clay minerals. He asserted that platy flakes were absent in terms of alignment and therefore did not provide a plane of weakness. His view on the infill from under the building was similar to that removed from the quarry in 2009 as to strength and porosity. Shale, which was 5% of this rock, was confined to separate sedimentary layers. He agreed with Jon Hunt that perhaps 10% of the rock had gypseferous partings on removal from the building. He whacked the larger pieces with a geological hammer. Since he accepted that 5% of the rock might be shale, and possibly less, it is telling in terms of probabilities that at least 10%, nonetheless,

had gypseferous partings after five years in the ground. 77% of the material was not capable of being subject to that test because it was too small to be hit with a geological hammer. Of the top 23% in size, tested because they were big enough to apply a hammer to, 16% split and of these 10% were gypseferous. It is an obvious inference, therefore, that more than the shale at 5% has an issue. The painstaking nature of the analysis conducted by Jon Hunt is preferable. I also accept his views as to porosity which were expressed in response to a question as to whether pyrite would be sequestered, or locked away, in this rock:-

> "I don't think it can be considered as locked away, because of all these clay minerals here. It allows water in, we have established that the water absorption through the physical testing is allowing the water in. I think the water, you can't say, that it's locked away completely, just because it's not on a boundary or a lamination… Usually if you want to find something that is impermeable you will see crystals, or grains that interlock very well and had very low porosity and here we can see that it's obviously not that. There is areas here of clay minerals that can be used as pathways, these grains aren't interlocking very, very well… It's these particles that are [holding it together] these grains they are bound together because they have been put under, in order to create that rock, to make it a rock, you have had to put it under pressure and temperature in order to seal it in, essentially bake it. If you put a cake into the oven you can pour it around but once it's been baked even though you have no pressure or anything you can now cut the cake… It's bound together, the grain boundaries are stuck together and the clay here is also, it's stuck together. Not by super glue obviously, but by nature in itself in that you have crushed it down and squashed it.

142. In making this choice I also have regard to the water absorption test results, to which I shall shortly refer, and to the sensible test conducted by Dr. George Dunlop Matheson with a view to determining porosity.

143. The mineral composition of rock as removed in sampling by the defendant from the quarry in 2009 and the infill as tested on being removed from the building in Ballymun tends to show similar characteristics. This is argued to be indicative of the 2004 infill in Ballymun being the same as what could be delivered from the quarry in 2009 and therefore what was delivered by the quarry in 2004. I do not accept that. Mineral composition tells one what is within the rock as regards minerals. I am satisfied that mineral composition does not tell one much about the strength and durability of the rock. It is how these components interact within a particular stone that determine engineering quality. The rock under the building from 2004 to 2009 consisted of 80% to 85% calcareous mudstone: quartz and feldspar, which are hard, at 50%; calcite dolomite at 30%; and illite and chlorite at 18.8%. The rock was 10% to 15% limestone: quartz and feldspar at 30%; calcite at 69%; and traces of illite. Finally, the rock was about 5% shale: quartz at 63%; calcite at 7% and illite and chlorite at 29.3%. The porous nature of this mudstone matters as does the sufficient calcite levels at over 30%. Telling me the mineral composition of the rock may help in some circumstance but it does not indicate how an infill performs. These figures therefore do not assist me one way or the other. I accept the evidence of Dr. Matheson for the plaintiff that it can be very misleading just to base an assessment of a rock on mineralogy analysis. When asked a question on how he could assess the behaviour of a rock for engineering purposes, the following exchange took place:-

> "A. If you in fact had a number of the minerals we say is present and you had individual groups of them and you ground them all down to whatever size you want and you mix them all together so that you have got that composition that we have and you tried to look at the engineering properties of that, for instance, it wouldn't be a rock. It would just be a pile of small fragments. There would be no texture between them, there would no cohesion, it would a soil, it would not be a rock. It would neither be durable, it would not have engineering properties.
>
> Q. I presume you can tell some things from the mineral composition. Like if you have a rock and it says diamond, you know that its hard?
>
> A. You know from analogy, that's were a diamond normally comes from… but I would suggest you need other things, like experience of that particular rock type or similar rock types or even a visual examination of that rock, either in a quarry or in your hand before you can tell its engineering properties.
>
> Q. Can you tell something from having it in your hand?
>
> A. Yes, definitely. You can tell what the minerals usually are in it. You can tell the fabric of it, whether in fact it's bedded or banded. You can tell the texture between the individual crystals. You can look to see if it's strong, to see if it has been indurated, which is buried. You can see whether it is metamorphic. You can see the features and textures which make up the engineering properties. You can see them, you can't necessarily quantify them.
>
> Q. If you tap with a hammer, can that tell you something?
>
> A. Yes, that is an additional one. If in fact you tap it or hit it with a hammer you might find nothing happens, that means it is strong to very strong. If you in fact hit it with a hammer and it breaks up, you know it is weak. If you take your fingernail and you open it up, that means it's very weak. If in fact you take a knife and scratch it, you normally know there are weak minerals in there.
>
> Q. And if you put a drop of water on it and see whether it absorbs or not you are looking at permeability and porosity?
>
> A. It is an indication of it. It's not an absolute test for it. It is an indication.
>
> Q. So these are just, if you like, the mining engineer's ready reckoner?
>
> A. Yes, in fact, every engineering geologist's ready reckoner. I would suggest that it is the most important piece of the lot, rather than the testing".

144. It is difficult to be satisfied that the material taken by way of a borehole directly from the Bay Lane quarry in 2009 represents the material delivered to the Ballymun building site from the quarry in 2004. Professor Kokelaar, for the defence, indicated that a borehole was dug in 2009 down to a depth of 61 metres. Since the strata dip away from the 15 m face that was left five years later, he felt that by going down 61 m a good representation of similar material was available. He said that he would be fairly confident that what he intercepted in the borehole would be representative of what would have been quarried 10, 20 or 30m away in 2004. It seems to me that Professor Kokelaar was doing his best in that regard. On an analysis of the entirety of the evidence, however, I cannot accept that material extracted in 2009 from the Bay Lane quarry is probably the same as, or even close to, the material that was delivered to the Ballymun building in 2004.

145. In this context, as well, I have considered the evidence of Sean Cassidy, the technical manager of Irish Asphalt, and John

Johnson, the safety, health and environmental monitor with the Lagan Group. Sean Cassidy indicated that he did not personally do the routine tests in 2004 on the stone which he described. He felt that if an issue was discovered with the tests that he would be told. John Johnson indicated that he collected material in the quarry at Bay Lane on two occasions in 2004 and that on other occasions it was other people who collected it and delivered it to him. He had no idea why the Los Angeles abrasion test results as between the building infill and the quarry results would increase but felt that this could be because the material was, as he thought, immersed in water under the building. He claimed not to be surprised by the 2009 building test results. This was despite the fact that he asserted that he did 10% fines tests, Los Angeles abrasion tests, magnesium sulphate soundness tests and water absorption, but not a water liquid limits, tests on the material through 2004. He also believed that the material passed the general plasticity test. If it had not, he said, he would have proceeded to do the plastic limits test. He felt the tests were more than enough and that the samples were taken directly from the quarry. In the light of all the evidence in the case, I am not convinced by this evidence.

146. The strength of rock depends not just on its mineral content but also depends on the texture between those minerals and on the fabric of the rock. It is therefore different to look at a rock from a geology viewpoint and from an engineering-property viewpoint. What is relevant in this case is the strength and durability of the rock. The relevant physical tests are therefore turned to. I regard it as appropriate to look at this matter in the round. It is wrong to take individual tests in isolation and to claim that there is a potential for this Clause 804 infill to heave, or to decide that it has heaved. Every test that is accepted as probable provides a partial answer. It is the accumulation of these answers that may turn the individual results into a robust finding of probability, or undermines, the crucial issue of pyrite heave due to gypsum formation.

147. Extremely varied results were obtained as between tests carried out variously on extraction in 2003, 2004 and 2005 on crushed rock taken from the Bay Lane quarry and tested on behalf of Irish Asphalt and test results obtained by Golder in Canada and Arup in Ireland on the Ballymun infill removed in 2009. The strongest case put for the defence by Irish Asphalt for the differential between the two sets of test was that made by Professor Kokelaar. He said:-

> "Well, I offer this as a hypothesis and it's really just as a potential explanation. Clearly the difference between the aggregate when it's in quarry and when it's recovered from the sub-floor is that when you recover it from the sub-floor it does have this encrusting material, it's cemented quite firmly to the surface and indeed the aggregate actually has to be pickaxed up, so it does actually have porous material cemented to the surface, and there are plenty of SEM images that show the encrusting material. What happens in the aggregate when the acid is released is that some of the calcite dissolves, it releases sound or quartz and feldspar, that's probably a lot of the grey loose material that's dirty, it's liberated from the surfaces of the material. And where the carbonate and to some extent gypsum re-precipitates, it cements these c-rusts that we image. Now the material has also got fractures in it, and if you then submit the materials to the magnesium sulphate test, which I understand is fairly aggressive, magnesium sulphate will get into those porous encrusting coatings and it will blow those off or destroy those coatings, and so the net effect is that you will a grain size reduction because basically if you put a fragment into the test that had a crust on it, it comes out of the test with several cycles of magnesium sulphate expansion and you get degraded material with a different granulometry, because the crust has broken off and there has been a grain size reduction. I think to some extent that crusting material and also the fractures is an explanation for the water absorption because that crust which becomes part of the outer coating of the thing is relatively absorbent. Now, I can quantative the extent of that and I wouldn't pretend to, but it's a potential explanation for the physical difference, that is that recovered aggregate will have cemented material that is porous and some of the damage has probably been accomplished in the compaction, so fractures and the porous crust will affect both water absorption and magnesium sulphate testing."

148. I am grateful to Professor Kokelaar for the brilliant intellectual analysis he has brought to this case. On the entire of the evidence, however, I cannot see that rock is likely to change in nature so fundamentally as the differential between the test results from 2004, the apparently routine quarry tests, to 2009, the tests on the infill from under the building, suggest, simply because it has been consolidated and left under a floor slab for five years. Rather, I am satisfied, on the basis of the evidence of Dr. Maher, for the plaintiff, that the difference in these tests cannot be accounted for in consequence of the treatment of the Clause 804 infill at the time of construction or its presence under the building for a period of nearly five years prior to being removed and tested. The test results from 2003 and 2004 are not consistent with the material seen and tested by Golder and Arup. If the material was of good quality it would not change. Whereas crushing causing more fines might apply at a level in excess of about 500 mm or more below the upper surface of the compacted aggregate in the building, there is no acceptable evidence to suggest that it probably could occur above that. Samples were taken, as I have said, at depths into the infill from 80 mm to 400 mm. This possible crushing at a depth of 500 mm and more into the infill arises because of the rolling of the material to create a working platform by a tracked vehicle. Blasting and crushing an extraction may cause sheer stresses to the entirety of the rock. I am taking that into account. I have already noted that I am struck by the reiteration by the defence of references to compaction, in relation to the condition of the material, and the inconsistency of that case with the infill subsidence theory. In addition, it is correct that this material was blasted and then crushed in a stone crusher as part of the quarrying process. That quarrying process, according to the defence case, was on a very strong rock, save for the 5% shale. I note, as well, that Gareth Llwyd Jones a petrographic expert for the plaintiff, noted the number of cracks in this material on his first report. At that stage, he knew nothing about the case being made as to the possibility of pyrite heave. Nor is it probable that there has been a transfer of clay material into the infill under the building by the water table. That transfer might possibly take place in the presence of rushing water. The evidence established that boulder clay is very impermeable. After all, this is the reason why above the layer of black boulder clay, the brown boulder clay was presented by some witnesses as being weaker than normal. I appreciate that John Campbell for the defence had a different view. It also strikes me as being improbable that with the rise and fall in the water table large quantities of mud particles could be taken up and deposited thus changing the nature of the material. The water table does not come up to the tested levels in any event. Whereas capillary action might be responsible for some dissolved minerals, or just possibly tiny mineral fragments, saturation of the sample in mud from below the level of the infill does not make sense. Contamination by clay could not have come about by natural methods. At a very low level, which I am satisfied is well below 500 mm of infill, it is theoretically possible that in some areas there was contamination by collapsing trenches, or construction work. Any competent testing of this material would, however, have indicated that. It has not shown up on any testing. This cannot account for the variability in the results that follow.

150. This Court is not acting as a tribunal. It does not always have to say what the probable cause of something is. The issue is whether the plaintiff has proved its case. There are many possibilities as to why the physical test results differ significantly from what was obtained on allegedly random testing of samples by the quarry in 2003 to 2005 and the test results on the material dug out from the building in Ballymun in 2009. The most likely explanation may be that the nature of the material changes as the rock face changes. Two million tonnes of rock have been removed from the quarry during the relevant period of 2004 to 2009. Since rock faces can change from metre to metre, in some instances, there can be considerable difference between what was delivered in 2004 and that which may be available in 2009 from what is the same quarry but a different rock face. Although the mineral composition of the rock might be similar, that does not determine how an aggregate performs in engineering terms. This is to be established by relevant tests. I can see no basis in relation to the relevant tests which follow as to how the material may have changed. In that regard I

note the concession by Lloyd Twomey and Dr. Maher for the plaintiff on the acid soluble sulphate issue. There was no such concession in relation to the tests which follow, apart from those which are irrelevant in terms of swelling potential. The rock has changed because of gypsum formation. No other change is probable.

151. I now turn to the physical tests. There are two issues here. The first is whether the material had the potential to heave. The second is whether there was a deviation from the Clause 804 standard which overtly determined the contractual relationship between the parties. I leave any issue as to terms implied by law to a later section of this judgment. On these two issues, I regard the tests which follow as providing a probable guide to the nature of the material delivered. The tests done under Dr. Maher and under Lloyd Twomey for the plaintiff were in relation to the nature of the aggregate, in order to understand how it would perform in practice. I regard the testing as giving me reliable information on the infill. These tests help establish whether it might be likely to respond to pyrite heave or not.

152. It seems to me that the amount of fines within the material, while a breach of Clause 804, is not a material breach of the standard. I therefore do not take that into account. As to the 10% fines tests, this has been replaced from earlier standards by the Los Angeles abrasion test. An equivalent of 10% fines standard is presented in S.R. 21:2004, which applies to civil engineering works. What matters in a physical sense is that there was a high level of fines in this material. The increased surface area allows for the potential of relatively swifter reaction. This, however, is not important to any contractual issues based upon the Clause 804 standard. That standard did not require a plasticity test but, as of May 2004, it specified a liquid limit test.

153. Of the 53 samples from the building only 35, according to Arup, were non-plastic. This means that there are plastic fines in the rock. This indicates an inherent characteristic of the rock infill that is important. Plasticity means that the rock can be made to adhere into a ball, about a fist size, as I understand it, with the addition of water and that can be rolled out then into a sausage shape. The tests are related. The point of thinness where the sausage cracks gives the plastic to non-plastic rating.

154. The flakiness index test was stated by Dr. Maher not to be relevant in establishing susceptibility to heave. The moisture density relation test is one to be carried out by the user. In fact, it was not done by Elliott Construction prior to putting in the infill. Instead, the matter was approached on the basis of craftsmanship. There is nothing whatever in the evidence to suggest, however, that this either establishes a cause for heave or a further reason why, on considering the entirety of the evidence, any case might be made out as to infill subsidence. There is nothing which establishes a probability in the case that sodden, or over-moist, fill was put in below the floor level of the building such as to later cause subsidence. Water absorption, on the other hand, is a relevant test to the heave issue. Water retained in the rock is obviously important. I must first of all make a comment on my approach.

155. With the multiplicity of tests that are possible and that are specified in standards, I feel that I should specify what I regard as potentially important to an analysis of pyrite heave. Firstly, is there pyrite within the material? In this instance of the Ballymun building there is a lot and I have already given figures. Secondly, is the pyrite framboidal or euhedral or is it locked in oxidised rings in which there are no cracks? In this instance it is predominantly framboidal and that which is oxidised, from almost five years in the ground under the building, show cracks. Euhedral forms of pyrite can oxidise too, though theory posits more slowly. Thirdly, is the available pyrite in abundance so that pyrite heave would be rendered likely? The figures have already been given and this constitutes an alarming proportion, exceeding the relevant Canadian standards. Fourthly, is the rock a large surface area or is it a small surface area? It stands to reason that the more surface area that is available in the rock, the more areas there are where water and dissolved oxygen and air can penetrate. If one takes a cube of rock at 1 m^3, six surfaces of 1m area are available. This means that a 1 m^3 rock has 6 m^2 of surface. If this is cut in half, two further square metres are available. This rock contains portions from 63 mm^2 and below size to tiny fines. It follows that there is a very large surface area indeed available for reaction. This opens up the area where the rock has exposed pyrite and opens up the possibility of water and oxygen entry into places where pyrite would, prior to mining and crushing, and in the consequent increase of surface area, be locked away. Fifthly, is the rock permeable? This is rock which contains many open fissures, I have already indicated the figure of 11%. In addition, however, it is obvious from infill samples produced in court, and my assessment of the expert evidence is that it contains multiple laminations. Air and water can penetrate this rock. Sixthly is the rock porous? If it is, then water, including water with dissolved oxygen, can get into the rock and can stay and move within the rock. This can also bring the relevant minerals, as previously analysed, into fissures in order to nucleate the crystal growth process from a solution. All indications are that much of the rock has a sufficient porosity. Most of the samples tested by Dr. Matheson were marked by him as involving slow water absorption. But there was absorption. Seventhly, are relevant minerals available for the reaction of converting pyrite into gypsum? These minerals are present in abundant quantities and are accessible. Eighthly, is the rock so strong that crystal formation will not disturb its intact nature? Ninthly, are the calcite minerals available sufficiently in the rock? Tenthly, is there any set of factors, or any countervailing factor, to stop heave occurring? Lastly, is it likely, therefore, that chemical reactions will take place so that pyrite can be converted and gypsum can grow thus causing heave through opening laminations by propping, by opening existing fissures further, by increasing the amounts of void, and through propping between pieces of rock or fines? I now turn to what are the more relevant physical and minute tests.

156. Having stated my approach as a matter of sense derived from the theoretical basis helpfully put before the Court by the experts, particularly Professor Sevastopoulo, Professor Kokelaar and Dr. Matheson, I also set out the relevant results. As regards what is relevant to the four tests which are next referred to, three figures are given at least. The figures on behalf of Irish Asphalt were figures derived from tests done on the rock as sampled at the Bay Lane quarry between 2003 and 2005. The figures in relation to Golder resulted from tests done for the plaintiff in Canada on infill material removed from the Ballymun building. Figures from Arup for the plaintiff came from the same source. Finally, on these four tests, it emerged eventually that the defendant had done its own tests on the material removed from under the building and these can be referred to as well.

157. The Los Angeles abrasion test involves taking particles between sieve size 10 mm and 14 mm. These are supposed to be in a dry state for the purposes of the test. No one is suggesting that the material removed from the building was sodden and there is no evidence but that the test was carried out properly for the plaintiff. The infill is put into a cylinder with steel ball bearings and rotated 500 times. What is then measured is how much of the test material remains at the 10 mm to 14 mm size. The NRA Clause 804 specification of May 2004 says that there should be no degradation beyond 30%. The test results from the quarry in 2003 to 2005 indicate results between 20% and 30%. All therefore passed. Golder carried out no such tests. The Earth Science Partnership tests on behalf of the defence, on the infill removed from the building, came out at 41%. The Arup result is 34%. This is a fail indicating that the material is not Clause 804. There are other test results, which in combination establish a serious situation.

158. In the magnesium sulphate soundness test the sample is again sieved to 10 mm and 14 mm particles. A solution of magnesium sulphate is added and then what happens with the growth of crystals is measured. This mimics to a degree the effect of degradation by reason of water ice. Within a road situation, in inclement weather in the winter, ice is formed within cracks in roadways, and under roadways. It is therefore important that the surface, and undersurface, of a road, the latter being relevant here, should not degrade by virtue of ice forming within laminations and opening the material. The NRA Clause 804 specification from May 2004 indicates a toleration of unsound material at a maximum of 25%. This would be the amount of material subject to breakdown in this context. The

test results from the quarry between 2003 and 2005 indicate results of degradation of between 3% and 9%. This is extremely good. The range obtained from Golder on the building infill was between 38% and 67%. The average was 54%. The defence result in 2009 on the infill removed from the building was 52.5%. The Arup result was between 46% and 76%, with an average of 61%. These results are very poor. While this test was not devised for pyrite heave, it stands to reason that it is of some importance. If the growth of crystals should cause a large degradation, then gypsum crystals forming within the material will cause both degradation and heave. In addition, they may heave between tightly compacted particles. This test measures chemical weathering and the material indeed failed very badly.

159. The liquid limits test is on fines only. It is at the other end of the plastic limit test. This measures at what point the very small particles of rock flow as a liquid. The material has water added to it and is penetrated with a cone of a particular weight and with particular dimensions. Golder used only one cone. This was an old fashioned form of the test and provides me only with some information. Arup used the correct method by reference to penetration by four cones. Between 2003 and 2005 the results obtained at the quarry at Bay Lane indicated acceptable results. Under Clause 804 this test is specified to be determined in accordance with a cone pentameter method as in BS 1377. The standard is to be not greater than 20 as the relevant factor on the graph. The quarry historical results were coming in between 18 and 21. Golder results on the Ballymun infill varied between 30 and 37, coming out at an average of 34. Arup results came in between 23 and 41, depending on the sample, and averaged out at 30.7. The defence 2009 results on the infill removed from the building averaged at 29. Lloyd Twomey on behalf of the plaintiff, in dealing with this, stated that the only thing which he deduced from both the liquid limits and the plasticity tests are that they indicated that you could have some plastic fines. I am not using these results in isolation. I am looking at them as a combination of factors. The law on proof by probability through circumstantial evidence requires me to so approach it. I note that the local clay displays elevated results for liquid limit from 40 to 49. On clay, this is what is to be expected. There is no standard on boulder clay. You do not use boulder clay as underfloor infill in modern times. I do not accept that boulder clay could have resulted by migration in contamination of the relevant samples, particularly at the level at which they were taken, the care taken in the building process and the relevant height of the water table. The Ballymun infill fails this standard.

160. I turn next to the water absorption test. Table 8/2 of the NRA specification of May 2004 indicates a requirement for aggregates used in unbound mixtures for subbase and roadbase of less than 2%. The difference between the tests done by the quarry on a sample and those done on the material removed from the building by the plaintiff is that one was tested on particles from 5 mm to 40 mm, whereas the standards say 3 mm to 31 mm. I do not regard this as significant in likely difference for this test. I am still provided with information, though the surface area is greater. I take that into account in relation to probabilities. The quarry results between 2000 and 2005 indicate results that are well within the 2% water absorption limit. They vary between 0.5% and 1.1%. In contrast the average from Golder was 3.1%, with variables of between 2.6% and 3.9%. The results from Arup had variables between 2% and 4.6%, averaging at 2.95%. I do not regard it as significant that a pycnometer was used in relation to the quarry tests and that a gas jar method was used in relation to the Golder and Arup results. A complaint is made that a wrong standard was used by Arup. They used BS 812-2 from 1995. There is a slight difference to the European standard in EN 1907 6200 from 2000. I repeat, what I need here is information. The gas jar method is a good method. There are some affinities in this test, it is true, with the magnesium sulphate test. The defence tests in 2009 on the infill removed from the building averaged at 2.55%. Taking into account that there may be more surface area on the tests done on behalf of the plaintiff, this is still a clear fail. I accept the evidence of Lloyd Twomey that the nature of the rock would not change due to absorption over time by reason of immersion. The water table figures, again, are relevant in that regard and I take them into account. The infill in Ballymun was not immersed in water but there was plenty of air and plenty of moisture nearby, potentially plenty of capillary action, and plenty of moisture within the air.

161. Thus on the water absorption test, the liquid limits test, the magnesium sulphate soundness test and the Los Angeles abrasion test, the material removed from the building in Ballymun clearly fails the Clause 804 standard. This establishes a breach of contract.

162. It was put that the opinions given by Dr. Maher of Golder and Lloyd Twomey of Arup for the plaintiff were biased against the defendant. By way of example, I quote the written opinion by Lloyd Twomey:-

> "The overwhelming majority of the material tested for this report is [on aggregate from Bay Lane quarry removed from the building]. All of the Bay Lane aggregate tested fails at least two of the Clause 804 requirements, while of the remaining tests, between 47 and 97% of the Bay Lane sample tested failed the requirements for Clause 804 material. These tests, which indicate the overall quality of the aggregate in terms of grading, clay content, plasticity, strength, a resistance to wear, ability to absorb water and ability to resist chemical weathering, show that the material may be classified as a poor quality aggregate. In summary:
>
> • 97% of Bay Lane aggregate tested is outside the Clause 804 grading curve typically at the 'fines' end indicating an excess of fines.
>
> • 100% of Bay Lane aggregate tested is in excess of the specified liquid limit of 21 ranging up to 41%, and in some cases having a plastic limit measured up to 28% (Clause 804 should be non-plastic). This suggests that the fines present are behaving in plastic manner and suggests that the source material is of poor quality, such as a mud stone. A material with excessive plastic clay materials will have low strength, will be sensitive to moisture and will reduce the cohesion and shear strength of the aggregate.
>
> • 87% of the Bay Lane aggregate tested had LA abrasion test values in excess of the specified limit of 30. This suggests that the material is weak, has low abrasion resistance and is more prone to degradation, relative to Clause 804 aggregate.
>
> • 100% of the Bay Lane samples has 10% fines value below the SR21 equivalent requirement of 130 kN with the maximum value achieved of 65kN. This suggests that the material is weak and is prone to physical breakdown, in comparison to the Clause 804 aggregate.
>
> • 47% of the Bay Lane aggregate tested for flakiness index, had values in excess of the specified limit of 35. This suggests that the aggregate has a platy habit (i.e. flat and thin). Indicative of a laminated or closely bedded source material. Flaky aggregate physically has lower strength than blocky aggregate and typically does not compact into as dense a matrix as blocky aggregate will.
>
> • 100% of the Bay Lane aggregate tested for magnesium sulphate soundness test has values in excess of the specified limit of 25%, with the maximum value measured of 76%. This test simulates the ability of an aggregate to resist weathering. This test is also related to the water absorption test, where an aggregate with high water absorption value tends to have a low soundness.

• 93% of the Bay Lane aggregate tested for water absorption had valued in excess of the specified value of 2% indicating that air and moisture can penetrate into the aggregate. Strong aggregate tends to have low water absorption values below 1%.

While the above tests are relevant to the performance of the material as an aggregate, they are also relevant to the ability of the material to weather and to resist expansive forces. The material is shown to allow moisture and air to penetrate into the body of the aggregate. This means that moisture can attack any minerals contained within the aggregate, such as pyrite and cause it to break down.

The material is shown to be flaky, indicative of a laminated/closely bedded fine-grained structure within aggregate. This means that the aggregate is likely to have anisotropic strength and potential weaker those within the fragments.

The material is shown to have poor strength and durability, which means that one expansive forces begin to exert on the material and once weathering begins, the material is more likely to break down.

The material is shown to have a low soundness and resistance to weathering processes, which means it is susceptible to breaking down and is unlikely to be able to resist expansive forces.

All the above indicates that the material supplied to the Ballymun Youth Centre from Bay Lane quarry was of poor quality, could not be classified as Clause 804 is susceptible to break down by pyrite oxidation and is unlikely to be unable to resist expansive forces within the aggregate".

163. The explanation of the test results indicate some further explanation and some variability, on cross-examination, between that which was expressed and that which has just been set out. Dr. Maher is in the same position. Any such variability is not indicative of deceit: it is indicative of debate. I am satisfied that both Dr. Maher and Lloyd Twomey are highly reliable as witnesses; I listened to one for seven days and the other for six and they always gave the impression of answering reasonably and with real thought as to the nature of the opposing issue. By reason of the failure of the tests indicated, the view of the Court is that the material is of poor quality, is not inert and does not conform to Clause 804 standards as the contract between the parties specifies.

164. Many test results were challenged by an allegation of deviation from a standardised procedure. It was argued, in addition, that no standard testing protocols were available in respect of stone infill that had been dug out from under a building after several years supporting a floor slab. The precise methodology of the test can vary. What is important to the Court is the nature of the information it provides. Using a different test to that specified in the standard may, in some instances, indicate that a fail is a breach of contract. Using the correct test is a more direct methodology. I appreciate that the Clause 804 tests are applicable to stone tested directly from a quarry as in 2004. Tests on underfloor infill that has gone wrong are not given by an Irish or European standard. What, however, a reasonable person wants to know in a case like this is what has gone wrong. What the tests do is to provide a route towards a reasoned analysis. What is important to the Court is that information is supplied that can lead to a conclusion based on probability.

165. The foregoing analysis on tests of water absorption, Los Angeles abrasion, liquid limits and magnesium sulphate soundness renders the plaintiff's case of pyrite heave more likely. It supports the physical findings in relation to the building that pyrite heave took place. Therefore, the finding that the foundations are stable, together with the analysis of what the tests on the infill under the building demonstrate and the state of the building itself, establishes a probability of pyrite heave. There are also other indications as to the cause of the building and I proceed to consider these separately.

Swell Tests

166. Three sets of swelling tests were conducted in an effort to address the pyrite heave issue. One of these sets of tests was conducted for the defence in Canada on material removed freshly from the Bay Lane quarry in 2009. So, it was not on the Ballymun infill at all. This test was devised and supervised by Professor Gérard Ballivey on behalf of Irish Asphalt. Professor Ballivey did not give evidence. I have taken into account such answers as were given by witnesses when Professor Ballivey's report was put to them. Questions put by counsel, however, are never evidence. Two other sets of tests were done on the Clause 804 infill that had been in the Ballymun building since 2004 and which was removed in 2009. When the sets of test results are compared, as between those two sets from the Ballymun infill, and the one set of tests on the freshly quarried material in 2009, an inference may be drawn that those conducted by Professor Ballivey indicate a different rock face with a different swelling potential. However, I discount any such inference and look at the results from the swelling tests that I accept and analyse what those results mean. I simply note the differential in the results from these tests on the infill from the building on Clause 804 infill from the Ballymun.

167. Since there was a slightly different methodology in each of these three sets of tests, a brief outline is appropriate. The purpose of all of the tests was to determine whether the three sets of samples of crushed stone, given ample access to water and air, would show any swelling or upwards movement. The Ballivey 2009 test involved a steel cylinder with a depth of fill to 116 mm across a diameter of 100 mm. No appreciable movement, experts accepted, was detected on this 2009 freshly quarried stone. The Golder test, devised by Dr. Michael Maher for the plaintiff, involved a set of concrete cylinders with a 300 mm depth of Ballymun infill, over a number of varying sizes of Ballymun samples, with a 500 mm diameter. The Arup test, conducted under the supervision of Lloyd Twomey for the plaintiff, involved a 600 mm depth of Ballymun infill in a series of 900 mm diameter concrete cylinders. In the Golder and Arup tests there were several samples, including fines isolated from larger sizes, and portions from various sections of the building. In scientific tests a control is important: clause 804 infill from Keegan's quarry, used on remediating the building in 2009, was used as the control in the Arup and Golder tests. This never appreciably moved. Furthermore, it is important that this was treated as to hydration in the same way as in the Golder and Arup tests, as were the samples of infill removed from the building. The Ballivey test involved placing the cylinder of freshly quarried and crushed infill in a tray of water, so that hydration was constantly available, though not over the entirety of the depth. Were any of these samples immersed in water, then it may be confidently expected that no reactions would take place. The super-saturation of ions could not reasonably be expected in those circumstances. The Arup test placed the samples from the building constantly in a 150 mm tray of water. The Golder tests involved providing hydration at the base of the sample, allowing it to penetrate under the bottom of the ring and through holes drilled in that concrete cylinder. This water was removed every two weeks and air was allowed, in consequence, to penetrate in its stead for a similar period. This process was repeated over a period of seven months. In each of the samples, for the three sets of tests, Ballivey, Arup and Golder, compaction was attempted. It is fair to regard this as being a reasonable level of compaction, thought it is impossible to say whether it exactly matches that of the infill within the building. No test is perfect. The Golder and Arup tests on the infill from the building were a reasonable effort, which provide probable results. I regard each of the tests as providing some useful information. I do not regard the Ballivey test, in so far as it was accepted in evidence, as undermining the case of the plaintiff. The plaintiff's witnesses accepted the stated results, for what they were worth. It was conducted on different rock material taken at a time when some 2 million tonnes of

rock extraction separated the Ballymun infill from the Bay Lane 2009 material that Professor Ballivey tested in Canada.

168. As regards temperature, the Ballivey samples seem to have been kept at a moderate room temperature. The Golder test was subject to a variation in ordinary room temperature; generally from 16º up to 25º Celsius. The samples in their concrete cylinders were kept in a tiny room in Naas that varied according to the use of the building. On one holiday period, when people left and so switched off the heat, the temperature dropped to a chilly 8º Celsius. The Arup test was maintained at 35º Celsius. Naturally, a higher temperature tends to speed up reaction. There are so many potential variables, however, that relate to compaction, deliberately introducing bacteria, temperature, hydration and the particle size of the material that caution needs to be exercised.

169. The Golder test was begun on 8th August 2009 and continued over the seven month period to 2nd March 2010. The Ballivey test on freshly quarried stone from 2009 was over several weeks, a much shorter period than seven months; in any event it showed no swell. The Arup test began in September 2009 and continued up to early 2011. One has to bear in mind that on commencing the swell test in respect of the Ballymun material, the Golder and Arup tests, as opposed to the fresh 2009 material in the Ballivey test, the infill had been subjected to at least the potential for swelling over the five year period mentioned up to the commencement of the tests. This is significant in terms of any adjudication as to whether swelling had taken place, or whether there was more reactivity for further swell. I bear in mind the cross-examination of Dr. Maher and Lloyd Twomey on these issues. I bear in mind, as well, the average depth of fill at somewhere around 0.8 mm to 0.9 mm over the entire depth of the site in its three zones. In that regard, the average depth of fill is not likely to be reproduced in every place. It varies from place to place, as the figures already indicated in this judgment note, and of its nature, compaction is likely to be slightly different from place to place. In some places the depth of infill is less than the average and in others it is more. I bear in mind, as well, that with samples that are finer, the surface area allows any natural permeability and porosity of the rock greater access to the pyrite. The continuance of the gypsum growth reaction that is the engine of swelling is thus likely to be initiated earlier, although it may exhaust itself somewhat sooner. I am also of the view that none of these laboratory tests can give an exact figure of swell, given the five years gap that the infill spent under the building, or was otherwise exposed. This is significant because the material, if it oxidised and expanded due to gypsum growth, did so over that period of time. As to the precise point at which pyrite heave is at its strongest, there was no exact evidence available. I have been assisted by the evidence of Dr. Ian Simms, the defence concrete expert and geologist, on this issue. There is no standard swelling chart. On buildings in Canada, pyrite heave can manifest at the two year mark, but more typically at the five to ten year mark or even as late as 30 or 40 years. Pyrite heave can also begin within two years. One case mentioned by Professor Kokelaar, which is that referenced in *Hoover and Lehmann*, (2009) illustrates this. There, a building was in place for several years in circumstances which caused the support to be saturated with water. Naturally, this militates against super-saturation of ions, even at a micro-location level. When an addition was put to that building, the nature of the construction lowered the water level and, as Professor Kokelaar indicated, his enquiries into the case had indicated that swelling began within two years:-

> "Now what happened at this stage was that this rock was exposed, it expanded…it's quite a well known phenomenon that when you relieve the overburden there is an elastic release of stress which leaves the fracturing. What happened was this system was actually flooded with water. When they dug this outcrop to become the foundations of part of a hospital building, this area was flooded. It had to be pumped at the time of building, a membrane was put on top, a concrete slab was put on top of it, and it remained flooded and in that condition for 14 years without doing anything, except, I would suggest, probably growing idiomorphic gypsum in fractures that were already open. What then happened, after 14 years of nothing, which would say is analogous to the Ballymun situation, they then dug another foundation nearby at a slightly lower level and that actually caused the water table to drop by four feet and then all of a sudden this system up here, which had been flooded, became dried, at least partially dried. And then, within two years, there was heave. And so basically the damage followed a long period of flooding and it was only when there was drying that the heave actually onset."

What matters as well in a test of material removed from under a building is whether the material is likely to continue to heave. This helps as an indication, together with the physical condition of the building, and the nature of the infill, in deciding if an infill was responsible for damage. I accept the plaintiff's case in this regard. Swelling activity within the tested material may also justify its removal. Finally, a positive swell test may show that the material is not chemically inert. This may have a bearing as to whether it is of merchantable quality, whether it is fit for purpose, whether a breach of contract has taken place and how a finding of fact is to be made on the swelling issue.

170. The Arup data showed some level of swell. In each instance it was appropriate to discount the initial swell in relation to the hydration effect. The Arup tests used bulk samples of Keegan infill, as removed from a stockpile on site, as a control. Two samples of infill, originally from the Bay Lane quarry, were used on the experiment. These were taken from zone 3 of the building. These were processed into one sample. One of these was passed through a 10 mm sieve. The sample was thus divided as between fines and stones above 10 mm. The replacement fill showed an equivalent pyrite of 0.04%; this is the fill quarried from Keegan's quarry and used on remediation of the building in 2009. The sample from under the building that was greater than 10 mm showed an equivalent pyrite value of 2.1%. The fines showed an equivalent pyrite value of 1.9%. Each of the samples was compacted in 200 mm thick layers, using a vibrating hammer inside the concrete pre-cast ring. Pressure and temperature changes were monitored inside the central layer of the fill for each of the three cylinders applicable in this series of tests. Water level at the bottom was constant throughout. The concrete rings, both in the Arup and the Golder tests, acted as a confining layer on the horizontal plain, while a steel plate at the top took the place of the floor slab. The Keegan infill, used on remediating the building, did not move to any real extent. The Arup results showed very little swelling on the sample of fines. This was in the order of between 0.18 mm and 0.3 mm over a fifty-two week period. On the slightly larger material, the level of swell was of the order of 0.36 mm to 0.66 mm. I accept, however, the opinion of Lloyd Twomey for the plaintiff that this shows that the material from under the building moved. His view was that this experiment was not a quantitative test because the material had already been dug up and subjected to hydration and oxidisation, potentially, for about five years. The trend results in the tests on the two relevant samples are not static; both show a definite upward trend, moving month by month. Notwithstanding potential oxidisation over that period of exposure, since having been removed from the quarry five years previously, the material continues to expand. It stands to reason that fines may already have reacted because of a bigger surface area. More massive rock will delay.

171. In the Golder test, as between the fine material, which swelled rapidly early on, and the coarser material, which took time to begin heaving, the surface access theory is borne out. Concrete pipes, similar to that in the Arup test, were used for the Golder experiment. There were, in effect, six components to the test. All of the tested infill material was removed from zone 3. This was divided into four sub-samples: an all-in sample, which was as received; a fine fraction which passed through the 5 mm sieve; a course fraction retained after sieving out the 5 mm material; a duplicate sample of all-in; a sample removed from stockpiles at Keegan's quarry; and a test cylinder that was set up and left empty to see if there was an appreciable effect in that regard. Four test results are important: the Keegan's infill; the fine sample; the greater than 5 mm sample and the all in sample that was monitored. The following table represents the chemical tests results on these samples:-

Sample No.	Material Type	Total sulphur (%)	Sulphur present as Sulphate (%SO_4)	Equivalent Pyrite Present (%)	Orig'nl % of Pyrite Present
BY-B	Keegan's Clause 804 (Medium Grained Limestone	0.03	0.03	0.04	0.06
BY-D	Calcareous Mudstone/Siltstone 5mm Minus	1.6	2.2	1.62	2.99
BY-E	Calcareous Mudstone/Siltstone 5mm and greater	1.5	0.90	2.24	2.81
BY-F	Calcareous Mudstone/Siltstone 'all in'	1.3	0.84	1.91	2.43

172. The compaction was done with a 'Wacker' plate and gages were attached. A steel roof represented the slab. In summary, Keegan's infill swelled by 0.02 mm. This is utterly insignificant. It is, however, a good control because it was treated in the same way as the other samples. The two all-in Bay Lane samples from the building swelled, over a period of 33 weeks by 0.68 mm and 0.63 mm over a depth of 300 mm. The coarse material swelled by O.57 mm. The fine material swelled by 0.36 mm. Over the period the early swelling in the fine material was overtaken by the all-in material. The coarse material lagged behind. The following is a diagrammatic representation of the relevant results:-

(see 'average movement in all cells.gif' graphic below)

173. The top of the capping plates showed non-uniform swelling; there was variation in heave as measured by the three dial gages. The rate of heave is continuous and relentless. At one point in the cross-examination of Dr. Maher, it was put that Professor Ballivey would give an opinion to the effect that one could not translate a 300 mm depth of fill into a 900 mm figure by multiplying this by three. This evidence was not given. Dr. Maher did not accept this proposition. To me, it does not make sense. I accept the following evidence from Dr. Maher:-

> "The depth of fill [in our test] was 300 mm… so much less than *in situ*. I suppose the average… at the site was 900. I think we heard it may have gone up to over [2000 mm] in places but I think the typical might have been around 900 mm. … so this is quite a bit less. The trend [in the tests]… seems to get a little bit steeper after a certain number, after say twenty-four weeks, this looks like a slightly steeper rate. I think what I was most surprised about was the uniformity of the heave and that did surprise me a bit because I think before I did this I was under the impression that we might have got it more in step form and that we might have seen a period of time when it would build up and then you would see the release and you would see sort of stepwise… there was no real constraint on the plate [on top to which the gages were attached]… when we measure the movement at the top of the plate it ends up the very uniform growth rate. If we look at the other all-in sample, … as I mentioned there was a difference in bulk density between the two samples and I would have expected just natural variation that wouldn't identically match. But the order of magnitude [of this second sample] is very similar. … and we look at the comparison with the other two samples which were just you know a screen sample. Firstly we would look at the 5 mm minus so this was the fine component. The interesting thing on this one is that for the first twenty-four weeks it was the fastest moving one, so the rate was slightly higher than the all-in up until about week twenty-four or twenty-five. And this is again as we would expect. Because we said the finer portion is more, has pyrite that is more accessible to oxidisation and therefore we would expect that to have a faster rate and kick in earlier on and to proceed faster. But then it seemed as if week 24 the rate decreased and it slowed down a little bit and maybe it [was] sort of running out of steam at this stage, but nevertheless at the end of seven months we are still not too far off the amount we got from the all-in, we are still at .5 or … about .57 or so of a millimetre after seven months. Then we look at the course fractions [samples] and this was the slow starter and basically had expanded at a much slower rate but again has been very steady, so it ended up around .36 mm or so after seven months. So to me this makes perfect sense, this is logical. If we look at the amount we got… we were typically getting 0.2 mm per week… it was very clear… we got a millimetre in material that was 300 mm thick [per year] so if you pro-rate that, that would give you for 900 mm [depth of average fill under the building] would give you equivalent of about 3 mm per year and by experience and understanding and view of the levels of heave that you will get in a typical building would be of the order of 3 to 6 mm per year and I believe that is consistent with what has been detected at Ballymun after four or five years, we are getting about 15 mm or so. So again that's the order of magnitude and I think that is what we have detected here… We used a concrete pipe with a rigid base, we put the material in, we put a plate on top. The only human intervention once we set the test up was putting water in every two weeks and taking it out. So we did not apply any pressure, any stress. It was sitting there… in the lab without anyone interfering with it… to me it proves very clearly that the swelling is on-going and is still occurring at a significant rate. I mean this rate would definitely cause to continue structural damage in a building at the order of 1 mm a year in 300 mm thick fill is significant. I can't directly relate the amount that we measured to what would happen *in situ* because of the different conditions, different levels of compaction, different temperatures, different environments… but I would hope that it would give an order of magnitude and I think that's what it has. We shouldn't expect pyrite heave to producing 20 mm in a year. The order of magnitude is 4-3, 4, 5, that's the order of magnitude for what occurs. Four or 5 mm is not a big amount and most buildings could tolerate that, it's the fact that it is continual year after year. Unlike, I might add, unlike settlement due to foundation settlement which decreases over time, there is no indication that pyrite heave does not decrease over time until you would be very late in the process and certainly the experience in Quebec was that after forty years it was still heaving. So I have no basis to say that that rate won't continue and I believe it will continue over tens of years".

174. The evidence has indicated to me that this material is not only capable of movement, but has probably significantly moved under the building. This factor should therefore be added as a factor in considering the probability of pyrite heave within the building as opposed to the defence theory of foundation subsidence catching the overhanging plasterboard of the internal walls and plasterboard partitions coupled with a degree of floor subsidence. I also note that there was no deliberate introduction of the correct form of bacteria. My prior reference to the universal presence of bacteria derived from *Bérubé et al* (2002) indicates their approach to deliberate introduction of particular micro organisms as helpful to swelling.

175. The Golder and Arup swell tests have been attacked by the defence experts as showing nothing of importance to the resolution of the issue as to whether the building infill under the floors swelled. This attack was, to take some of the apparently more substantial points on the basis, firstly, that a concrete ring should not have been used. According to Dr. Ian Simms, concrete itself would show some movement. While this is correct, no reasonable figures have been produced which would give me an indication as to how the potential expansion and contraction of concrete would somehow squeeze up the infill in these tests without also showing some downward movement on relaxation. I note as well the evidence of a crack in one of the concrete cylinders which Dr. Maher ascribed to expansion. This is probably correct. The helpful figures given by Dr. Simms in relation to concrete blocks perhaps offered the potential for further analysis. This was not likely to have had an effect here. Pearse Sutton, a defence engineering expert, also attacked the test on a second basis which was that the swell demonstrated by the tests was minimal. He also said the dial gauges should not be drilled into un-reinforced concrete rings, because it could crack them. I see no evidence of this. Cracks were everywhere on the defence case: except in the zone 1 gym. The control is important as an answer to this point as well. Pearse Sutton felt that the expansion of wet and dry concrete, wetting and drying cycles and temperature rises could distort the test. In reality the control disposes of this point. He also mentioned, thirdly, that the steel components could rust, and that by rusting expansion could be caused in itself. There is no evidence of rust. I do not accept as probable that criticism, or any other criticism, made by the defence experts. I do not believe, in addition, that the very minimal figures presented as to movement in concrete due to saturation and then drying out, as adjudged against the walls of a building, could be an explanation for what the Arup and Golder tests indicate as a strong probability. I am not prepared to accept any criticism, fourthly, on the basis of the Golder test using cycles of hydration. This is sensible, potentially mirroring the effect of the rise and fall of the water table. What could be said is that these matters could be studied further by the academic community.

I regard the Golder and the Arup tests as providing a reasonable and reliable result. Over time the swelling test by these firms may be reported in some scientific journal and eventually experts may agree a protocol. Any court of trial, meanwhile, is required to look for information that fits the probability standard; and these tests meet that standard.

176. I regard Dr. Maher as a careful witness who took into account every criticism of his evidence before answering in a reasoned manner. It is correct that the movements in the swell test are small. One is dealing, however, under the building with a greater depth of infill, with different conditions of compaction and hydration and with a much longer time period. One is also dealing with the unknown quantity, as Dr. Simms helpfully expressed it, which is the issue of our inability to know how various kinds of stones subject to pyrite heave might behave over long periods of time. As I have mentioned, there is no standard chart in a textbook on pyrite heave in that respect. What matters is that there is movement on the Arup test and that a reasonable opinion has been based on the Golder test. I therefore do not regard this test as unproven. I do not regard this test as lacking scientific validity. Rather, it is a rational attempt to gather data on material which, certainly as regards the fines, may have reached beyond the point of greatest accumulation of swell after five years in the underfloor environment of the building. I therefore accept as a probability for the plaintiff the evidence in relation to the swell test as testified to by Lloyd Twomey and Dr. Maher. The swell test results establish the probability of pyrite heave as the cause of the ruination of the Ballymun building, coupled with the finding that the foundations are stable.

Minute Scrutiny

177. Any piece of the stone infill from under the Ballymun building can be examined in a number of ways. It can be taken up in the hand, scraped and tapped. It can be looked at with a hand lens. It can be looked at under a microscope and bombarded by electrons and analysed by electron microscopy. Ordinary binocular microscope examination is usually done for the purposes of scrutiny by a petrography specialist. There is a general form of preparation for this analysis. A thin section of 30 microns, involving two cuts, is made and then the surface to be examined is polished. This sawing and then grinding is done with water. Since gypsum is soluble in water, and since gypsum crystals do not score highly in terms of hardness, there is an appreciable danger that this form of preparation will remove what in this instance has been primarily sought; gypsum crystals forcefully opening up fissures within rock. There was a marked disagreement between the experts on the petrographic analysis of the samples taken from the Ballymun building. The views presented on behalf of the plaintiff by Dr. George Dunlop Matheson, Gareth Llywd Jones and Jon Hunt were markedly disagreed with by Professor John Ballivey, Professor George Sevastopoulo and Dr. Alan Boyle for the defence. These disagreements were not simply on the basis of what such analysis revealed. Major theoretical differences emerged between both sides. Some of the rock samples were also analysed by scanning electron microscope ("SEM"). This provided magnification up to 8,000 times. The disagreements between the experts then further magnified, rather than diminished; the latter being the, perhaps naïve, expectation of the Court since greater clarity might thereby be predicted. On microscopic examination, X-ray diffraction ("XRD") was used to show the quantity of minerals by proportion. This is not necessarily accurate. Minerals need to be predicted as only percentages of what is sought will be expressed. In addition, relevant figures can have error predictions. For instance, the amount of gypsum shown by this method was reduced by reason of potentially false readings. A number of the thin sections were examined by SEM. These required samples to be coated with carbon or gold to make them conductive. There was no suggestion that this coating process reduced the presence of gypsum. For SEM the samples were subjected to an electron beam that scans the surface area. In addition, the back scattered energy can be used to determine the elemental composition of a small area on which the electron beam is focussed. This is different to the mineral composition, but it can supply some pertinent information.

178. Different methods of preparation were also used. The defence experts tended to prise open a section. This produced a planar aspect which was looked across at an oblique angle rather than down on. They claimed that the three dimensional image thus produced was better than simply sawing across a vein, or breaking across a vein in the case of several of Dr. Matheson's examples. The defence experts claimed that this methodology showed clearly that no forceful growth had taken place within the samples from the Ballymun building. That view, together with the non-cracking of the floor slab in the gym area of zone 1 and the interpretation of the crack pattern in zone 3, constituted defence bulwarks against the plaintiff's case of pyrite heave. The plaintiff's experts disagreed that no forceful crystallisation had been demonstrated. Their generally cross-section views, the plaintiff's experts claimed, showed what was important in terms of indicating crystal growth. Gareth Jones, however, for his fifth report used a special form of preparation. In so far as preparation is relevant to any conclusion I must reach, I will note that in the appropriate place.

179. Two matters should be remembered in this analysis. Firstly, the defence experts definitely claimed that there was no evidence of forceful growth in any of the samples analysed. They disputed the evidence proffered on behalf of the plaintiff. Fundamentally, the defence case was that forceful growth did not in fact happen in the infill taken from under the Ballymun building. In addition, the defence argued that there was no acceptable evidence of forceful growth produced by the plaintiff. Consequently, the focus of this section of the evidence tends to be by way of analysis and dispute concerning the samples produced by the plaintiff's experts. That would be the emphasis of what follows. It was also the focus of most of the testimony.

180. I regard it as appropriate, in addition to a consideration as to whether forceful growth of gypsum causing heave within the infill actually took place, to look at the potential of this stone for forceful heave. The former helps in the analysis of the latter. There, the evidence concentrated on the report by Dr. Matheson in relation to swelling potential.

181. I next need to refer to some terminology. An axial crystal is not present in any relevant way in this case. Fortunately any dispute on this crystal does not call to be resolved. I take this dispute into account, although it does not directly impact on this case. An antitaxial crystal grows from the vein wall. These are typically crystals of minerals that are not found in the host rock. Antitaxial crystals, growing within a rock, and being found in a fissure, are generally thought to be able to open up the fissure. The orientation of these crystals is supposed by scientific orthodoxy to be required to be 90º or close to that across the horizontal plane of a vein. While that principal is generally agreed on each side, whether such forceful growth has or has not occurred is a matter that experts can endlessly debate while looking at precisely the same sample. Syntaxial crystals grow into open space and form on each side of an already open rock vein. These can exhibit a mirrored battlement structure at the centre of the formation. This kind of formation is not present in any of the samples analysed as I adjudge the probabilities. Thus, in circumstances, where the defence experts have claimed that there has been syntaxial crystal growth, I disagree. An ataxial crystal is characterised by growth from the centre of the vein within a rock. These are typically crystals of minerals found in the host rock. Fibrous crystals, which is another potentially relevant category, are absent in this sample, although there was one mention. I discount these as being relevant, as I adjudge the probabilities.

182. I want to give some indication as to my approach. This, again, is practical though I record that I derive great assistance from the expert evidence on each side. As with the swell test, it can help to have a control. In the analysis report prepared by Dr. Matheson, concerning swelling potential, the Keegan Clause 804 infill, used on the remediation of the building, was selected for comparison. This seems to be more like a limestone material than a mudstone material. It is claimed that it is therefore irrelevant. I do not agree. It is useful to compare the results on this control material in analysing the Clause 804 infill removed from the building. For a reaction to take place which can be properly classified as a pyrite heave, the correct approach would seem to me to be similar to the correct approach for a basic analysis of what is in the rock. There has to be pyrite. It will react more quickly if it is framboidal rather than euhedral. There has to be calcite. An abundance of clay minerals can assist hydration of the reaction. Porosity in the rock is essential to retaining water, and is necessary in assisting penetration and migration. On these issues I have already indicated that my view of the evidence coincides with the testimony given for the plaintiff by Jon Hunt. In this regard, it should be noted that the relevant solutions can migrate over metres. Where gypsum infills, or partly infills, a rock vein, this may assist a case of pyrite heave. It is not at all necessarily determinative. The close examination of the crystals provides further possible information on the nature of the gypsum crystals present and their function within the rock.

183. Professor Kokelaar and Dr. Boyle, on behalf of the defence, produced six criteria all of which they claimed have to be met before it could be valid to infer forceful growth within this Clause 804 material. Very few of these criteria are agreed by the plaintiff's experts. Firstly, Professor Kokelaar states that the crystal has to be in contact with the rock on both sides of the fissure that is purported to have been forced open. He says that conceivably, however, a crystal may become detached from one wall and remain as an isolated pillar if the fracture was widened by other crystals. This principle is agreed. However, when it comes to an examination of the samples, and the Court has seen all of the samples by way of large scale projection, it has to be borne in mind that one is looking at tiny areas in high magnification. I take into account that some crystals, which were once in contact with either the top or the bottom of a fissure, may have been disturbed. Secondly, Professor Kokelaar stated that crystal ends which are anhedral, or pitted, as opposed to being idiomorphic, or well formed, are indicative of the crystal having grown into space, in other words apart from rock contact. Dr. Matheson disagrees. Because material can come through the pore of the rock into the growing crystal, he considers that crystal which has caused forceful growth does not necessarily need to be deformed. It can, Dr. Matheson claims, be indented in forceful growth but he states that it must also be remembered that a crystal will correct to follow its molecular shape, provided supersaturated solute is available. Jon Hunt said that this second proposition of Professor Kokelaar does not need to be correct if a crystal is heaving against a flat surface. My view of the evidence is that while Professor Kokelaar may generally be correct, incidences of correction and of flat heaving against flat can also occur. Thirdly, Professor Kokelaar posited that crystals have to be shown as not only spanning the fracture but to be a single crystal and continuous. Dr. Matheson disagrees, as does Gareth Jones. There could be one crystal, or two, or more on their analysis. The defence case mentions that a median line, present as in the classic analysis by Taber (1916), is not necessarily evidence of forceful growth and further can be mistaken for a bridge of rock towards the centre of non-forceful growth. The plaintiff's experts claim that a median line is a classic feature of forceful crystal growth, with smaller crystals towards the centre and larger and longer ones at the vein edge. In general, the defence experts consider that for forceful growth what is called a median line may be merely rock dust incorporated during the growth of single crystals, wall-to-wall, within a fissure. My view on the evidence is that while a median line is not essential, as described by the plaintiff's experts, it can be a feature of forceful crystal growth and can therefore point in that direction. I am also of the view that a single crystal spanning the fissure is not the only kind of crystal formation that can cause a forcing apart of rock. Fourthly, Professor Kokelaar argues that crystals close to parallel sided, in columnar or fibrous shape, are needed because growth is by addition from the substrate of rock and growth competition is severely limited. This causes a major issue with Dr. Matheson. He feels that forceful growth can occur through crystals growing parallel to the walls but in contact with the walls. I agree with Dr. Matheson. Fifthly, Professor Kokelaar argues that crystals in a cluster, in which crystals are parallel to each other as opposed to perpendicular, cannot be forceful. Dr. Matheson thinks that crystals oriented in a parallel fashion can prise apart a fracture. I agree with Dr. Matheson. Sixthly, Professor Kokelaar claims that in order to forcefully heave apart a vein, the crystals have to grow close to perpendicular to the fracture walls. He illustrated this by a calcite vein with thousands of tightly packed perpendicular crystals opening the wall. Dr. Matheson is of the view that it is not necessary to have lots of parallel crystals side by side: where there is a cluster, then the crystals can be roughly perpendicular. I agree with Dr. Matheson. Lastly, an issue arose in relation to the saturation of the solution and the level that is needed for an addition to the crystal which is touching both sides of the rock to continue to grow and so to heave it apart.

184. I think it is important to record at this point that Dr. Matheson made no attempt, although he was accused of this, to mislead the Court. Dr. Matheson did not misstate any analysis based upon scientific papers and did not set out to make the Court believe that any of his evidence had a foundation in published science where it did not. His evidence was reliable on the first occasion and when he was recalled. Because of an accusation of the kind which I have mentioned, he was recalled. The nature of the evidence which he gave on the second occasion, while it clarified what he said on the first occasion, did not show any indication to the Court that he was anything other than a careful, conscientious, practical and highly experienced witness. His view that there was a potential answer to the question of the mechanism of the occurrence of forceful crystal growth in this kind of stone by reference to anisotropic pressure values and supersaturated solute coming through rock pores, which at the sub-capillary level where molecular attraction at an electro-static level causes a liquid not to behave in a non-liquid form, is, in terms of the hypotheses presented to the Court, the one which seems on the evidence to be most likely to provide an answer. That view of the theory is not at all, however, an essential component of the analysis which follows. In addition to these disputes among the experts on each side, for the defence Dr. Boyle also posited strongly that sunflower shaped groups of crystals, or double sunflower crystals, could never forcefully heave. His cross-examination on this issue convinces me that he is incorrect. Dr. Matheson was of the view that sunflower shaped groups of crystals could be responsible for forceful heave, where crystals within such structures are in contact with both sides of a fissure. I agree with Dr. Matheson.

185. I want initially to refer to Dr. Matheson's first report. This concerned swelling potential. The basic notions of this were taken

from CTQ M200. Much criticism was advanced in relation to that choice. In particular, it is claimed that he should have taken into account pH. An analysis in relation to bacteria could, on the same basis, also be argued to be relevant. My view, on all of the evidence, is that the criteria which he took were reasonable and likely to lead to accurate predictions on the basis of what is probable. This was especially so, in the context of the micro-photography of the polished thin section which he appended. My view is that everything said by Dr. Matheson was amply justified by the physical sample images which were displayed on a projector to the Court. My view, as well, as regards his second report on SEM images is that there is no basis upon which I can exclude samples from zone 1. There was nothing to suggest that these were different to the other samples, whereby I could make a decision that they constituted, instead of material that originally came in 2004 from the Bay Lane quarry, material which was left behind 20 years earlier from the infill over that later demolished part of the youth centre. This decision is based on the samples as they are analysed. I think the same as regards any possible Roadstone material. It is not probable that there are any such samples mistakenly analysed here. My view, as well, is that pieces which are longer than 63 mm could get through the sieve and are admissible in evidence.

186. The choice made by Dr. Matheson in relation to swelling potential in the infill samples of rock involved looking at whether or not there was pyrite, pyrite framboids, calcite, porosity, and clay in the form of kalonite and illite. The eventual rating of potential for swelling was classified between low, medium, high and very high. This choice was not arrived at, I am confident after hearing Dr. Matheson, except in the context not only of these relevant criteria, but also upon a minute examination of the relevant samples. This was a very careful process conducted by Dr. Matheson. He also commented on the fabric of the rock, the apparent porosity of the rock, the strength of the rock, its reaction to HCl, in addition to making several other detailed comments which were concise and to the point.

187. Turning to these, sample 0742 is classified as having a potential for swelling at very high to high. Dr. Matheson felt there was an infill of gypsum from wall-to-wall in the vein but that was a view he could not state categorically. If this was gypsum, then there could have been forceful growth. In the result, however, he left the position as being equivocal between forceful or passive growth. These particular petrographic slides would not show that, he said. Sample 0757 was classified as having a very high potential for swelling. While there was no infill, the gypsum could have been lost in preparation. There was thus no evidence of forceful growth. Sample 0762 was classified as having a very high potential for swelling. The pyrite was sequestered in the rock and appeared to be fresh. Sample O842 showed possible gypsum. The swelling potential was classified as being very high. Sample O827 could not be unequivocally stated to have gypsum within a vein. Dr. Matheson felt that the fractures were not en echelon. This kind of fracture in a rock is a step like set of fractures and it classically is posited as an indication of mechanical damage. As a principle this was not disputed between the plaintiff's and the defendant's experts. As to whether a fracture was truly en echelon or just random cracks on the bedding planes or not properly interpreted as such was heavily disputed. The defence experts saw a lot of en echelon fractured rock. They could not say it was evidence of forceful growth. The potential for swelling was very high. Sample 0830 showed some empty fractures. There was also pyrite deterioration. The swelling potential was very high. He commented that it looked as if there was major alteration and loss of material as regards the pyrite. In relation to none of these samples, beyond swelling potential, could Dr. Matheson say there was evidence for forceful growth. Sample O833 involved a vein where Dr. Matheson could not be categorical in his opinion, but thought there was gypsum. The potential for swelling was very high. Sample 0844 was rejected as not coming from the Bay Lane quarry. A sample from Keegan's quarry, used to remediate the building in 2009, was tested. This was shown as having a low swelling potential. It contrasts markedly with the other samples. Sample 1295 involved an analysis of fines. Potential for swelling was adjudged to be very high. The strength was weak and there was fast water absorption. Sample 1296 was a larger sample. The swelling potential was very high. Gypsum crystals and crystal aggregates were found. Dr. Matheson commented that he had a big problem keeping gypsum in the rock because of washing. His experience was that in the context of the usual forms of preparation with water gypsum was lost. These samples generally showed slow water absorption.

188. I then come to the second report. Here there was a lot of defence criticism of the breaking across technique of preparation, but I regard this as misplaced. Whereas Dr. Matheson's work was previously designed to evaluate the potential for swelling in rock, this report looked at the size and form of any pyrite and searched the form of the gypsum in order to seek to establish links between the formation of any crystals and swelling. I regard the report as comprehensive and careful. Three of the analyses came from the same piece of rock. In this regard, we are looking at cross-sections. The sets of images from the one rock were images 4, 5, 6; images 7, 8, 9; and images 10, 11, 12. On 4, 5, 6, Professor Kokelaar, for the defence, was of the view that the gypsum shown did not meet the six criteria; that what was shown was more like a broken sunflower; that the growth was not antitaxial wall-to-wall growth of crystals. He did see not a crystal extending from wall-to-wall; instead this was passive syntaxial growth. It could be a sunflower. If it was, he said, only the centre was shown. He felt it was inescapable that this was not forceful growth because the crystals were growing from the middle towards the edges. On 7, 8, 9, Professor Kokelaar said that there was a median line with broken crystals. He suspected a sunflower. He thought the terminations were euhedral. He felt that the force of the crystals could not be through going but that what was being shown was a badly damaged sunflower cluster. The earlier set of images was shown as misleadingly close to the wall but he did not see it touching. On these three sets of images, Dr. Boyle said as regards 4, 5, 6 that he was looking at a broken cross-section through a double-sided rosette or sunflower. He would judge the crystal terminations to be idiomorphic. He felt that he would have needed to see a planar view of the crystals. On images 7, 8, 9, Dr. Boyle was of the view that he would need to see the side and the bottom in order to form a view. He said there was a hint of a gap. He saw idiomorphic terminations. He would also need to see the top. Again, he said it was a double-sided sunflower. On images 10, 11, 12, Dr. Boyle saw an apparent median line. He suspected that it was a double-sided sunflower. He said this was because of what he had seen on his own samples, on the defence side, on the basis of three dimensional and of planar view. He would say that it was not forceful growth. If there were two or more crystals he would not think that it was forceful growth.

189. Dr. Matheson's view on images 4, 5, 6 was that evidence was shown of forceful growth. He thought that the fractures in the rock were not caused by excavation. He felt that there was no evidence of well formed crystal termination. On images 7, 8, 9, there was nothing to suggest to Dr. Matheson that the growth of gypsum was not forceful. There was sharp contact. His view was that this constituted forceful growth. He also noted broken crystals of a kind which can occur when a rock is forced apart. On images 10, 11, 12, he noted material lost from the host rock. He said this was an example of crystal heave. Having viewed the images, and having heard the explanations from the experts on both sides, I am satisfied that Dr. Matheson is correct.

190. Images 15, 16, 17, Dr. Matheson indicated were not evidence of forceful growth. Instead, he said that the growth of gypsum was opportunistic and not forceful. Images 23, 24, 25, were described by Dr. Boyle in the context of en echelon fractures. He said that these crystals were petals on a double-sided sunflower. He did not see this crystal as pushing. He noted a single crystal on top. He claims the notion of a median line as small crystals and then bigger crystals outside as being what he called nonsense. He felt that the crystals somehow amalgamated. I find his explanation to lack any sense.

191. On these images, Dr. Matheson disagreed that en echelon fracture patterns were shown. He pointed to the median line of gypsum. He said the sample was evidence of forceful growth. I agree with Dr. Matheson.

192. Images 27, 28, 29 were described by Dr. Boyle as a sunflower. The images are what Dr. Boyle would expect while looking at

above in respect of the other images as seen from the side. In any event, he dismissed it because of idiomorphic shapes. Dr. Matheson was of the view that a rosette could cause forceful growth. The basis on which it would heave would be the same as for any crystal. Nonetheless, Dr. Matheson's view was equivocal in relation to these images.

193. Images 35, 37 and 38 involved the outside of a piece of rock. Dr. Boyle agreed that they showed crystals growing on the outside. He did not see this growth as being antitaxial. He did not see this as being rock to rock contact but just a growth in some muddy accretion on the surface. Dr. Matheson's view on images 35, 37, 38, was that they showed crystals growing on a stone fragment after he had tried to wash them off. He said that it showed that wall-to-wall contact between fragments which can also cause forceful growth. In this instance, however, he could not be unequivocal in terms of his response.

194. Finally, images 41, 42, and 43 were produced by Dr. Matheson. He saw them as showing porous rock and gypsum growing around the pore channels. He did not produce it, however, as evidence of forceful growth. It was interesting, even still, in terms of his exposition of the dynamic of forceful crystal heave.

195. Given the balanced and measured nature of the evidence given by Dr. Matheson, and his clear intent to analyse opposing points of view, the Court relies on his opinions as noted.

196. In addition to Dr. Matheson's opinion, I have also the benefit of Jon Hunt's view of a particular sample. He accepted, in cross-examination, that he could not unequivocally say that crystal growth had been forceful. In that regard, I would note his approach as being careful and conscientious. I have relied on various sections of his expert view on the wider issue in relation to the nature of this rock.

197. In addition to those reports, I also have the benefit of five reports from Gareth Llwyd Jones. The first three of these reports is on samples of the most component rock in the Ballymun building infill. Of the seven samples, I have taken into consideration five different pieces. These are made the subject of the first, second and third reports. By the time of the third report, four samples were being looked at intensively. For the fourth and fifth reports, three new samples were taken. These became four cuts that were subjected in the fifth report to closer analysis, including SEM scanning in the case of two. I regard Gareth Jones as an honest, careful and diligent witness. His practical approach highly impressed me as being both objective and professional.

198. Gareth Jones' second report was not taken into consideration. His first report, in its conclusions by way of comparison to his fifth report, was made the subject of an admirably challenging cross-examination. It was his view, on his first report, that the five samples did not, on their own, provide evidence of forceful heave. At this stage however, he was not looking for gypsum heave. His usual analysis practice in looking at rock samples, however, was to note features out of the ordinary. He knew nothing of the background of the case at trial as of that point. It was only when he was asked to look for gypsum, as regards the second, third, fourth and fifth reports, that this became an issue for him. It is of significance, however, and as I have earlier noted, that a caveat was put in his first report: "[t]hese muddy limestones also display fine cracks in the aggregate sub-parallel to the edges as seen under the microscope." By his fifth report, on the three new stones brought to him by Eoin Wyse, he had come to the conclusion that fractures which he thought could initially be explained on the basis of mechanical forces were now caused by gypsum heave. He said that he was initially impressed by the number of cracks. He told the court that while his first report was not capable of being presented as evidence of forceful growth, that it was a hint of what was to come. He had thought, at that stage, that the cracks were empty. Then he learnt that there was an alleged problem with the site and that therefore the cracks had to be looked at as to what they indicated. His third report was not therefore on new material. It used thin sections which were, at that stage, prepared in a standard way. Samples 1, 2, 3 and 4 were used because there were no cracks in sample 5. In his first report, no gypsum was observed in the cracks but calcite was observed. On one hand-specimen he thought he could see gypsum. This, of itself, was not presented as evidence of forceful growth. On two other samples there was gypsum on the weathered surface, not in the cracks, but this was not presented by him as evidence of forceful growth. There were said by the defence to be a number of en echelon crack patterns in the samples. In an overall sense, however, he interpreted this as being randomly caused within the rock as opposed to by mechanical pressures. His view was forcefully challenged by Professor Sevastopoulo for the defence. He said that a random occurrence of en echelon fractures was of very high improbability. Gareth Jones, on the other hand, saw no reason why gypsum could not cause cracking in places that come out in a step-like formation, either up or down. The bedding pattern, he said in that regard, was not sufficiently taken into account by the defence witnesses. I agree with his opinion. In one crack, Gareth Jones found gypsum that completely infilled part of the crack. Apart from that, the cracks were empty. Again, the preparation of these samples for his early reports needs to be borne in mind. The most he could say was that this fourth sample was some evidence, contributory evidence, but not evidence on its own, of forceful growth. He could not rule out forceful growth on the basis of this third report because gypsum had been identified. Therefore, his view was that it would be unfair to say that there was no evidence of forceful growth. That evidence, however, is not unequivocal. Therefore no evidence was possible from either the first or third reports which was indicative directly of forceful growth.

199. By the time of the fourth and especially the fifth reports, his view strengthened to the point where he expressed an opinion that there was evidence of forceful growth. On this issue, the following exchange took place:-

> "Q. If I could ask you… what I want to put to you in relation to all of this, Mr. Jones, is that when one goes through your five reports, one sees a fairly dramatic development in your thinking in relation to this matter, would that be fair?
>
> A. That's a reasonable comment.
>
> Q. I want to suggest to you that in fact the conclusions that you have come to in your fifth report seem almost to come out of nowhere?
>
> A. Well, I see them as a natural progression in the development of what we were doing…
>
> Q. What was the cause of the natural progression as you perceive it in reports 3, 4 and 5 as you would identify it?
>
> A. Well, I think you can see that what was happening was that we were seeing different aspects, and because of what we were seeing we went on to do further work. So that the first one [the third report] looked at the cracks, saw that they had been probably filled, there were still residual gypsum in the cracks, they were probably gypsum veins. In the fourth report, we actually tried to see if we could see gypsum in the aggregate pieces, which we did. And so when it was decided that we were not looking at complete data, we needed to look at how the preserved samples and we took the measures which I described yesterday to produce quality thin sections. That about far more details need to be seen and to be reported on."

200. I accept this evidence from Gareth Jones. The view expressed in the fourth report was stood over in evidence by Gareth Jones in the following way. He said it was not impossible that mechanical damage could have caused a fracture in the first sample examined. Crystals, however, have grown into that space. His view was that the crystals he saw could cause forceful growth. His view was similar to Dr. Matheson in not limiting forceful growth by gypsum crystals to perpendicular antitaxial crystal formations alone. He said that the mechanism of contact of the crystal with the wall rock, the solute passing through the wall rock, and the contact with the crystal depositing more crystal could work against parallel formations. In the second sample, he found there was a median line in the gypsum vein. By reason of later information he was satisfied to so identify the crystal. His view was that his second sample brought the analysis a good way further down the road of providing evidence of forceful crystal growth. The third sample identified an empty crack. On higher magnification there was some mineral infill present which he could not say was gypsum. Therefore this third sample was not put forward by him as evidence of forceful growth. His view was that passive growth could turn into forceful growth by reason of the same mechanism at point of contact between the crystal and the rock wall. He would look for a median line, columnar crystals growing sub-parallel and terminations against the wall rock.

201. Gareth Jones markedly refined his preparation method for his fifth report. Sawing through of the samples was done without water and the grinding of the surface that was to be examined was prepared with very little water, while the sample itself was cut at 40 microns thick as opposed to the usual 30 microns. I regard this method as establishing a much better probability of good and reliable results than any other method, including oil lubricated sawing. I reject the criticism made by the defence of this method of preparation.

202. The purpose of this preparation for the fifth report was to preserve as much as possible of whatever was in the vein. Blue dye was also put on after the first cut. How that appears, in terms of its shade, on binocular microscopic examination can, I am satisfied, indicate the situation to an experienced petrographer and enable a judgment as to whether a crystal completely fills, or once completely filled, to the top and bottom of the vein. It was suggested to Gareth Jones, that he had misinterpreted what he saw. The defence witnesses further said he had mistaken crystals further back for those nearer to the lens. I regard it as absurd that a practical man like Gareth Jones, who has made his living from rock analysis over 30 years, would confuse an oblique view of a sample so as to put crystals against a rock face where there are none. I do not believe, in addition, that the storage of the samples over a number of months in the site hut in a black plastic bag so changed the nature of the samples as to make this analysis unreliable. It must be remembered, when discussing images that were seen in court, that they are only images. Gareth Jones saw much more when he was conducting the actual examinations with a microscope. These he described both professionally and honestly.

203. I turn then to the four relevant cuttings. Professor Sevastopoulo commented that on sample 0830 there was growth from the walls which was syntaxial, and therefore could not be forceful. On being asked, he said it could be a double-sided sunflower. Dr. Boyle discounted this image as being indicative of classic en echelon damage which gypsum had passively filled. Dr. Boyle thought that the crack pattern was consistent with external damage; that the crystals were growing at the wrong angle; and that there had been a misinterpretation because of the thickness of the sample. The relevant SEM image of this, he thought, was a double-sided sunflower. Gareth Jones' view in relation to sample 0830, which also contained SEM images, was that the cracks were caused by gypsum. He said that instead of concentrating on a particular fraction of an image one had to look at the bigger picture. He said the crystal growth was active because of a view across the entire rock where many of the veins have what he described as a "classic condition". He said that these veins were evidence of forceful growth. All were caused by gypsum. The SEM image showed unequivocal evidence of forceful growth. There was a median line and the crystal met forceful growth indications, as he saw them. He felt the SEM image was complementary. I agree with the analysis of Gareth Jones.

204. Moving to images 0762, Dr. Boyle commented that these were a sunflower structure. He felt there could be a mistake looking at crystals below. That mistake could arise from looking at cross-polarised light, it would be like looking at "four stained glass windows", he said. He said he thought there were gaps in places and that any view expressed by Gareth Jones was on the basis of a mistake in seeing crystals below. He disagreed that this could be a classic example. The crystals would have to be 90º, or close to that, and not leaning over. On these images, which did not include SEM, Gareth Jones saw wall material in the middle, with bladed crystals on higher power magnification. He thought that these indications were conclusive: a median line, bladed crystals, contact with both sides and a good length of crystal. He examined this carefully on his X200 Zeis binocular microscope. I agree with the analysis of Gareth Jones.

205. One of the impressive aspects of the evidence of Gareth Jones is that he felt himself entitled to make concessions, where they were due. Images associated with 0745 were described by him as not being evidence of forceful growth but as beginning to get there.

206. The images associated with sample 0850, were described by Dr. Boyle as passive filling of mineral growth from the wall into space. He saw en echelon fractures. These were systematic. He would find it very surprising if gypsum could do that. On the SEM image he found what he thought was a double-sided sunflower. This was a space filling sunflower with euhedral terminations. These were elongated and parallel. As in other instances, which he spoke of, in many of these images, crystal growth was described as stopping just short of the rock face.

207. The images associated with sample 0850 were described by Gareth Jones in the context of a crack which he could see as being empty at the edge, which was slightly conical in shape, occurring as it extended into the stone. Because of the overall picture, he made a reasonable assumption that it was once gypsum filled. He saw this as evidence of forceful growth. The SEM images showed many touches between the crystal and the fissure. While the greater magnification tended to reduce the clarity of the overall picture, he could also see a median line. I agree with the analysis of Gareth Jones.

208. Apart from this evidence I have taken into account the evidence from defence witnesses whereby samples were analysed and commented on in their own right. In particular the removal of the top from the sample was supposed to be better in terms of finding evidence of potential forceful growth. I do not agree that that was necessarily so. I think that sunflowers were too often seen. I derive great benefit, notwithstanding that, from the evidence of Professor Sevastopoulo. He analysed A19, A20, A21, A22 and A23. On A19 he felt the crack was there first. He felt the cracks were en echelon. On A20 he saw a nice euhedral gypsum crystal growing into open space which could not be heave. On A21 he felt that a sample might have come from boulder clay and made ground. That sample was, in any event, en echelon and very likely not to be random cracking. There were some small amounts of gypsum in cracks. Some were fine grain. Some large euhedral crystals were found which could not be involved in heave. In A22 he found a median zone of spalled wall rock. This could be consistent with forceful crystallisation but he felt that it could not be proved. He saw other explanations, especially in the light of listening patiently to a great deal of evidence. In A23 he found an odd piece of limestone with a well-developed coating. It may not have come, he thought, from the Bay Lane quarry. He saw no unequivocal evidence of forceful crystallisation. He felt SEM images were vastly to be preferred because one could get three dimensions. Professor Kokelaar also commented on images. His evidence was to the effect that they were not forceful; that he saw idiomorphic terminations on many of them; that he saw sunflowers where the core was not higher; that wall-to-wall contact could be wrongly inferred; that he found images that were not touching both walls; and that any gypsum was following the fracture. In others he found syntaxial growth away

from the core. He saw dissolution and he saw gypsum growing on micro-calcite. On this, my view is that gypsum growing on micro calcite can involve an existing fraction that has been forced open further. I am grateful for his brilliant illumination and that of Professor Sevastopoulo which has helped the process of reaching a decision. In addition, the wide-ranging musings of Dr. Boyle are taken into account and were of assistance.

209. On my analysis, the probabilities in this case come out firmly in favour of the case made by the plaintiff. On its own, the evidence of forceful crystals growth in the context of the stable foundations of the building establishes a probability in favour of the plaintiff.

A Proposal

210. It is likely only a judge, in listening over several weeks to the evidence as to minute analysis which has been presented by both sides, would be fully aware of the expert contradictions in this case. Petrographic samples were shown and a debate ensued as to whether crystals had originally been attached to the top part of a rock that had been fragmented for the purposes of taking these images, or the bottom. A debate was also possible as to whether this process of fragmentation resulted in displacement. As to whether the top or the bottom of any such gypsum crystal identified actually touched a surface, argument ensued. As to whether the rock showed en echelon type of fracturing, or the opening up of laminations along bedding planes, extensive contradictory testimony ensued. When a sample was scanned with an electron microscope, magnifying the image by up to 8,000 times, similar arguments were amplified. These concerned, among other issues, whether or not the crystals identified as gypsum showed or did not show a median line. It was also possible to dispute whether or not a median line was or was not indicative of forceful crystallisation. This was despite the appearance of such in one of the earliest and best studies of forceful crystal growth; that of Taber (1916). It is possible, as Professor Kokelaar suggested on behalf of the defence, that Taber was dealing with very old formations where gypsum had grown in existing cracks. This is not, however, probable. Experts also disagreed over whether a median line was merely incorporating rock dust or a shard of displaced stone, and therefore mistakenly interpreted as a median line, or whether a median line could ever consist of very small central crystals when forceful growth was occurring. As to whether, on a cross-section, the top and bottom of a crystal touched the rock surface, shadows were brought into play, as was the possibility that an experienced practical petrographer, such as Mr. Jones, might be seeing the crystals behind, on an oblique view, and therefore forming an incorrect opinion. The shapes of the crystals were subject to what seemed like endless debate. Perfect examples of calcite crystals, not gypsum crystals, were shown by Professor Kokelaar as the form in which this gypsum should appear in the event that crystal heave was to be demonstrated as possible.

211. In one of the most startling examples of the potential for contradiction as between experts, four images were produced in the report of Dr. Boyle. These were published examples of forceful heave by gypsum. In the first of these, *Penner et al* (1972), Dr. Boyle would not have regarded the sample shown as evidence of forceful growth. In the second, an image from *Grattan-Bellew and Eden* (1975), some parts of the forest of crystals in the image were noted to be at a less than 90º angle. This was explained on the basis that some crystals could have been removed, or displaced, on the fracture being opened. The theory of the defence experts required near universal perpendicular orientation. In the third example published as evidence of forceful growth, *Wilson* (1987), Dr. Boyle indicated that the rock fractures that apparently resulted from crystal heave looked to be en echelon. This is a stark contradiction of the publication. En echelon fractures, as I have said, are supposed to inconsistent with forceful growth. Dr. Boyle's view of this image was that he would say that this would "be not proven". A final photograph of gypsum fibres bridging lens shaped fractures, reproduced in *Hawkins* (1997), was described by Dr. Boyle as a poor image. Professor Kokelaar had quite similar views and expressed scepticism as to the forceful nature of crystals shown in a paper by *Hoover and Lehmann* (2009). These authors, I was required to be convinced, were not crystal experts, and they published under a different speciality it is true, and had picked the wrong images even though an entire hospital had been emptied through the gypsum crystal heave they were purporting to report on. It was very extraordinary, in the context of the evidence, that Dr. Boyle had given a large amount of evidence as to the appearance of double-sided sunflowers. These appeared all over the place. A random question by the Court to Professor Sevastopoulo indicated that double-sided sunflowers were unknown to crystal science prior to the commencement of this case. On asking Professor Kokelaar about this, he posited that these were the only possible interpretation of several images. Up to this revelation, the Court had been left under the impression that double-sided sunflowers were being pursued as some form of scientific orthodoxy. While this was clearly not deliberate, it was not at all helpful either.

212. Then we move into the contradictions as regards crystal shapes. I do not intend to repeat these at length. However, I have had contradictory evidence as to whether one massive crystal, or set of parallel and perpendicular crystals, so described, from top to bottom of a fissure is necessary for crystal heave; whether two or more crystals growing from a median line can be indicative of forceful growth; whether a number of parallel crystals can forcefully heave; whether sunflower arrangements apparently seen on moving the roof of a fissure, or on side as opposed to planar view, can be consistent with heave, or even adopt that shape while partially growing in a forceful manner; whether a 90º angle in a single crystal top to bottom of a fracture is necessary for forceful crystallisation, or something very close to it; whether euhedral terminations completely rule out forceful growth, or whether flat against flat is possible, or whether a crystal will assume its molecular shape as it grows, or can become euhedral after removal from under the floor due to what was argued on one side to be the ready presence of the moisture and oxygen in a black bin liner; whether secondary calcite renders forceful crystal growth on top of this to be impossible; and, finally, in terms of what seems to be apparently important in this analysis, whether en echelon fracturing is to be interpreted as impossible in the context of crystal heave.

213. Even more significant has been the issue of preparation. Here too, there is no standard form of approach. Some of the samples were washed first, this was Dr. Matheson's approach. He used a pliers on several of his samples to prepare views of cross-sections. I do not regard this as inappropriate, as the defence experts have opined, and nor do I consider that it will result in a loss of rigour. The search, after all, for the perfect heaving gypsum crystal continues, notwithstanding the fact that, according to Professor Kokelaar, these samples from the Ballymun building are the most studied in the history of science. When Mr. Jones decided to prepare a thin section by sawing at 40 microns, instead of 30 microns, he was accused by defence witnesses of putting himself in a situation where he could confuse a wider breadth of crystals as being connected when they were not, thus leading to a false judgment. This was notwithstanding his years of experience as a practical petrographer. Whereas Mr. Jones and Mr. Hunt used water to lubricate their sawing and grinding activities, on thin sections, Dr. Boyle used oil. The relationship between the viscosity of the oil and the security of the quite soft gypsum crystals could also be debated. In this instance, it was only touched upon. The fact that the diamonds in the saw and the grinder used could be bigger than the crystals that are being sought to be exposed could also be debated. My view was that by far the most satisfactory results were obtained in the careful preparation used by Mr. Jones for his final report. Dr. Matheson's samples were also satisfactory. By taking the lid off fractures, as was done for many of the defence samples, my sense of the evidence leads me to believe that the results were potentially less satisfactory. I believe that dry sawing, grinding using minimal water, the application of appropriate fixative blue colour, and a wider depth of sample at 40 microns as opposed to 30 microns gave more satisfactory results. Perhaps the key to these satisfactory results was the polishing of the sample with minimal water. This form of preparation, in my view, should be adopted as a standard. A debate might also ensue as to whether confined stone distorted by crystal growth might show en echelon fractures; these indicate mechanical damage but, one wonders,

what is going on when stones are swelling against each other with little room to move? I take speculation as to any potential answer into account in the analysis that I have given as to facts.

214. The contradictions proffered in terms of opinion on the swelling tests could also be explored. In summary, the use of a concrete tube was deprecated by the defence and chosen by the plaintiff's side. Their swell expert, Professor Ballivey never gave evidence however. I see no reason why a concrete tube cannot succeed or why a steel box would be better. The availability of constant hydration, or the removal of hydration from the bottom of a sample and its replacement, over fortnightly cycles, was also disputed by the defence experts. It is possible that a swelling test could be conducted with hydration present all the time. This would only be valid, however, were the hydration to be present at the base of the sample to allow for air moisture and for capillary action; the phenomenon which I regard as a probability was present under the floor slab in the Ballymun building. To do otherwise would be an immersion experiment and that for ordinary reasons of sense would be senseless. It would show no pertinent results. To grout the fissures with capillary-action liquid would also probably lessen or even remove the problem. Immersion, if extended over the entire sample, would stop crystal growth by reducing the saturation level of the water by ions. That much, at least, is obvious.

215. One thing emerges as being crystal clear to me. This entire area of forceful growth with gypsum has not been sufficiently studied. I am grateful to the expert witnesses who did their best to apply a theory to a problem which has insufficient laboratory data. It would be possible for a university to adopt something similar to the Maher swell test over a period of three years or more. The infill should be well-compacted. Perhaps absence and presence of relevant bacteria and the percentage of calcite present and pH levels could be noted. Movement should be monitored. A number of samples should be examined in various sizes over a large number of tests. Before this is done, a representative sample should be subjected to a petrographic analysis to determine the form of the bedding planes, and the form of any cracks *in situ*. The relationship of pyrite and gypsum, if present, should be noted. Then at an interval of one year, two years and three years the material should be taken out and subjected to the Jones method of preparation and analysed as to the form and shape of the crystals, where heave has been proved, in order to give definitive guidance. I regard it as probable, having heard many days of theory, that inconvenient facts to the defence theories in this case would be shown which would require a re-evaluation. I also regard it as probable that Dr. Matheson's exposition for the defence of the mechanism behind forceful crystal growth in confined fissures in porous rock would be found to be at least worthy of further analysis. I come to this conclusion having been aided as to the theoretical basis for forceful crystallisation by the brilliant expositions of Professor Kokelaar and Professor Ballivey and the wide knowledge of Dr. Boyle. On the basis which I have explained earlier in the judgment, however, I strongly prefer the evidence for the plaintiff of Dr. Matheson, Jon Hunt and Gareth Jones. I now move on to an entirely separate area of the case whereby forceful heave was sought to be proven by monitoring movement within the building over several months.

Monitoring Movement

216. A large number of monitoring points were established on the building with a view to assessing movement: a couple on the walls externally; several on the floors, with a few of these on the floor of the old building; on the thresholds linked to the ground beam and foundations below; and one between the floor slab and the threshold. Readings on the internal wall, which is buckled, were also taken initially, as I understand it, but these were not likely to be helpful. I propose to refer to some of these. These monitors were not measuring instruments that were in place for the entire period of monitoring; the exception being the floor to threshold instruments. Instead, they consisted of marked points in the floor and on the wall. They were measured periodically with a stave. This was to tell if the floor was moving upwards or whether the walls of thresholds, resting on the foundations, were moving downwards. If the walls or thresholds were moving downwards, it would assist the foundation settlement theory. It must be borne in mind, however, that some small levels of foundation settlement are to be expected in a fairly new building. If the floor was moving upwards it would assist in proving the pyrite heave theory. I can think of no alternative possible explanation on the evidence in this case. Nor could Professor Kokelaar indicate any other possible mechanism apart from pyrite converting to gypsum that could have caused heave in the floor slabs. These marked points were levelled against three independent levelling datum points external to the building. One was on a piece of granite rock outside the building, one was on a footpath near the Church of the Holy Spirit and one was on Count Joseph Plunkett Tower. The latter monitor was in place for the last six months of monitoring. The datum level is usually single. In a normal situation, as I understand it, from the evidence of Ian Roberts, one can achieve accuracy in relation to any of its individual reading of about 0.8 mm. Some monitoring professionals will claim a higher level of accuracy. Here, however, Coastway Ltd., which did the monitoring on behalf of Moylan, and then on behalf of Arup and O'Connor Sutton Cronin, indicated that there might be a margin of error of plus or minus 2 mm. This would mean that the very lowest point might be 2 mm higher, while the highest point could be 2 mm lower and vice versa. This, if I accepted it, would make the margin of error one of 4 mm instead of 1.6 mm. On one floor threshold to slab, a monitor was put in place permanently, as opposed to being measured theoretically with a level by a human technician on outside datum points, which is what happened with the others. However, this fixed monitor only shows relative movement; it cannot indicate if the foundation has moved down or the floor slab has moved up. The relevant monitoring points, levelled against the outside datum points, unless otherwise indicated, were measured over just short of one year. These show movement against the external datum points up and down. An opinion has been expressed by Roger Frank Jowett, an expert in building construction who gave evidence on behalf of the defence, that the monitors were not in place for sufficient time. I find this most improbable. On 30th July 2008, defence engineering experts O'Connor Sutton Cronin asked for existing monitoring to be continued on the basis that, as they put it, "the extent of monitoring and the duration should be such as to cover a period of five to six months sufficient to allow comprehensive results to be recorded for two seasonal changes". Pearse Sutton regarded a year of monitoring as being sufficient to give reasonable results. Nevertheless, he regarded these results as being capable of a very high margin of error, as being inconsistent with some other internal data in the results, and capable of being in error because, for instance, of the expansion of the piece of granite which was one of the external measuring points, or the rise and fall of Count Joseph Plunkett Tower, another and obviously steady monitoring point. This is not at all probable.

217. Thomas Nesbitt, a senior land surveyor with Land Surveys who gave evidence for the plaintiff was of the view that the measure of error contended for by the defence of plus or minus 2 mm on every reading, high or low, was far too high. He was careful to say that he did not regard it as being in any way misleading, much less deliberately misleading, but instead he called it "an over exaggeration". He thought it was a doubling of the relevant tolerance and that 0.5 mm to 1 mm, the ordinary measure, was more reasonable. He is an experienced man. His evidence was measured and he thought carefully about every answer. Mark Hudson, an experienced surveyor and a director of Coastway Ltd., gave evidence for the defence that instrumental imperfections, observer inability to make perfect observations, and climatic conditions involving wind, rain and temperature, coupled with the lack of perfection in computing meant that all the results should be subject to the plus or minus 2 mm variation. It is to be noted that in July 2008, his company gave an estimate in writing as to the expected variability. I quote:-

> "The expected accuracy used [in] this method and equipment would be of the order of 0.7 mm/km. Environmental factors such as weather and the large number of setups to complete the survey will play a part in the accuracy. The net results of these factors would mean that in reality the accuracy should be of the order of 0.5 mm – 1.00 mm for this job."

218. The British Research Establishment Digest from 1993 suggested a variability of plus or minus 0.5 mm. This was put to the

witness. He did not agree with it, notwithstanding an improvement in equipment over the intervening eighteen years. When making his final report, Mr. Hudson indicated in writing, and I quote:-

> "An accuracy analysis has been undertaken on each set of weekly monitoring levelling runs. The combined multiple level loop accuracy analysis indicates the mean closing error, combined with instrument error and error due to precision. The accuracy analysis combined over the 26 week monitoring period was plus/minus 1.0 mm. (Refer to the accuracy analysis of the monitoring points in Appendix E). A decrease in accuracy can be attributed to a multitude of factors as discussed in s.4.2, including operator errors, weather, temperature and environmental factors. This decrease in accuracy is estimated to be plus/minus 1.0 mm. Combined survey accuracy is therefore calculated to be plus/minus 2.0 mm".

219. Listening to Mr. Hudson, I was struck by his fastidiousness. He made several references to the wind conditions and to the sheer number of set-ups within the levelling loops. On one or more of the loops he mentioned that he had 14 set-ups and that each could have an error of up to 0.2 mm. While they might be expected to cancel each other out, the probability of them all being in the same direction and amounting to an error of 2.8 mm is extraordinarily slight. He stated that every time you use your staff you can have error and that every time you use your instrument you can have error. I was struck as well by the fact that an estimate four months into the assignment, as of July 2008, being the plus or minus 0.5 mm to 1 mm variability, was unlikely to be wrong. My assessment is that Mr. Hudson's evidence was over-careful. In contrast, the evidence of Thomas Nesbitt gave due weight to factors of variability while coming up with a sensible level of plus or minus 1 mm. I am also influenced by the view of Ian Roberts for the plaintiff. He regarded it as reasonable to take the variability level at plus or minus 1 mm. It is appropriate, from the point of view of a reasoned analysis, however, to look at the results on the worst case scenario before returning to the tolerance of plus or minus 1 mm, which I regard as having being firmly established on the evidence as probable. I do this as the monitoring results can be enough when coupled with evidence that the foundations did not subside as contended for by the defence, to establish a probability in favour of the plaintiff.

220. At this point, some raw data is presented which might reasonably be regarded, in any ordinary case that is sensibly judged, as highly influential. The first set of data is in respect of recorded movements on the external floor, internal slab, the existing slab in the old dance studio in the old building, the external walls, the threshold, the old wall in the gym and at sills, ceilings and doors. The last are not really important as they are on the damaged internal first floor plasterboard lining of the structural walls. The relevant data which follows indicates readings up and down of 1 mm or more, up and down of 2 mm and more, and up and down of 4 mm and more. Thus, the smaller figures are subsets of the larger. Here is the full table for the 58 weeks, which includes for the last six months the third outside benchmark on the very stable Count Joseph Plunkett Tower. The figures for the monitoring period of 58 weeks from 5th March 2008 to 14th April 2009 are set out in tabular form:-

	UP 1mm+	DOWN 1mm+	UP 2mm+	DOWN 2mm+	UP 4mm+	DOWN 4mm+
MONITORING POINTS 103	57	3	33	0	13	0
EXTERNAL FLOOR 7	5	0	5	0	4	0
INTERNAL SLAB 58	47	1	24	0	9	0
EXISTING SLAB 2	0	0	0	0	0	0
WALL 19	2	2	2	0	0	0
THRESHOLD 5	0	0	0	0	0	0
EXISTING WALL 2	0	0	0	0	0	0
CILL 4	0	0	0	0	0	0
CEILING 2	2	0	1	0	0	0
DOOR 2	1	0	1	0	0	0
MISSING 2						
%	55.3	2.9	32.0	0	12.6	0

221. When defence engineering experts O'Connor Sutton Cronin took over the monitoring from October 2008, the period of 58 weeks in the previous chart is the larger set of this period of 27 weeks. This time the external floor, the internal slab, the existing slab in the old building in the dance studio, the external walls, the thresholds and the existing wall points in the dance studio in the old building were monitored. With the inclusion of the Count Joseph Plunkett Tower, Mr. Hudson agreed that the accuracy of the results should be better and thus the variability decreased, though he did not say by how much beyond his very large variability figures. These are the figures presented, on the same basis of sets and subsets, for the monitoring period of 27 weeks from 6th October 2008 to 14th April 2009:-

	UP 1mm+	DOWN 1mm+	UP 2mm+	DOWN 2mm+	UP 3mm+	DOWN 3mm+
MONITORING POINTS 88	26	4	13	0	5	0
EXTERNAL FLOOR 5	0	0	0	0	0	0
INTERNAL SLAB 49	26	0	13	0	5	0
EXISTING SLAB 0	0	0	0	0	0	0
WALL 26	0	4	0	0	0	0
THRESHOLD 6	0	0	0	0	0	0
EXISTING WALL 2	0	0	0	0	0	0

222. What also might be important also to any reasonable analysis of probability was lipping between foundational elements and floor slab, the latter being higher. There was the 3 mm to 7 mm lip at the western threshold, old to new, of the gym in zone 1; the 18 mm, 13 mm and 0.7 mm readings at the points in the western triangle showing lipping in the dance studio; the 6 mm, 0.5 mm and 4 mm lipping in the next eastern triangle; the lack of movement in the next triangle eastwards and the lack of movement in the next doorway eastwards. The least movement, as I have said previously, in terms of triangle lipping was to the north in that gym area of zone 1. In zone 2 the doorway out to the corridor showed a 7 mm to 12 mm lip between threshold and slab. There was a 16 mm lip, as between floor and threshold in the doorway out to the courtyard in the middle of zone 3. There was a 0 mm lip from the boat store out into the courtyard as between slab and threshold. There was an 11 mm to 16 mm lip between the youth workroom slab and threshold. There was a 15 mm lip between floor slab and threshold in the bicycle workshop. It should be noted that there is a 17 mm lip, the floor being higher in each case I remind myself, in the triangle at the north-east of zone 3; there is a 5 mm lip opposite it, and in the triangle to the south, there is a similar 19 mm lip. On their own, all of these monitor results would convince any reasonable person that the walls, dependant on the foundations, were relatively stable, but might have moved very little. The raw data indicates even more powerfully that, over this period of a year, the floor slab was continuing to heave upwards to an appreciable degree. I take into account inconsistencies and potential for error, in the manner I have indicated. It is highly probable that over this period the floor slab rose cumulatively to what had occurred before. This evidence is clear and convincing. I accept it.

223. The conclusion of Ian Roberts, who is not a statistician, on reading these monitor results was that the walls probably dropped by a very small amount of 2.5 mm over the period of March 2008 to April 2009 and that the slab rose by 4.5 mm. These are overall and roughly averaged figures without any tolerance for error. A tolerance for error should be built in. Given the plus or minus 2 mm margin of error, the walls may not have moved at all, and the slab may merely have risen by 0.5 mm. Taking the plus or minus 1 mm margin of error, a general estimate of wall descent would be 0.5 mm coupled with a 3.5 mm of floor slab ascent. In areas near columns, for reasons previously explained, a lesser movement may be explained by restraint. In middle points in the floor away from columns there should be less restraint. There can be other factors at work as well. In looking at threshold monitors, I take into account the possibility of a deflection in the ground beam, though I am convinced that this is not going to be as large a deflection as if the ground beam was spanning thin air. It rests on something, be it brown boulder clay or made ground. There must be some level of support. I have no reason, in any event, to believe that any such deflection would be as high as was claimed by the defence over two years after construction. I turn instead to specific data.

224. Monitors 13 and 14 were placed to the south of zone 2 on an adjacent threshold and floor slab. A reading as of March 2009 looks like an error was made in taking the level of the slab and to the lesser extent the threshold. This reading, however, does not assist in a material way with any resolution of the issues. The threshold is barely moving. Its movement is well within the higher tolerance, if it moved at all. The slab, from highest to lowest points measured a movement of about 8 mm. Adding 2 mm to the lowest point, and subtracting 2 mm from the highest, gives a definite movement of 4 mm. Using plus or minus 1 mm, the slab has risen 6 mm. Monitor 16 and 17 measured zone 3 internal slab and threshold. The threshold barely moved, and is within the 2 mm tolerance. The slab, from lowest to highest point, moved over 9 mm upwards. Again, taking the highest possible variations, this shows a move upwards in excess of 5 mm in the slab. Using plus or minus 1 mm, the slab has risen 7 mm. Monitors 28 and 29 were placed on the threshold and on the floor slab in the bicycle workshop to the south. A claimed slight rise in the slab and slight fall in the threshold is within the higher measure of tolerance. At monitors 40 and 41, in zone 3 to the south, the threshold remains within the higher measure of tolerance and the floor rises. The slab movement from lowest to highest point can be measured to 5 mm. Perhaps it is somewhat less. This gives a definite change, subtracting the larger tolerance, of 1 mm rise in the slab, but perhaps it is not definite. Using plus or minus 1 mm, the slab has clearly risen. Pearse Sutton does not regard this data as being significant. As an engineer he would not pay heed to it, he said, or reach a probable conclusion on the basis of it. He also pointed out some inconsistent results. I am more than puzzled by this opinion but I have taken this testimony into account. It does not change the obvious and inescapable conclusion.

225. Two points in the courtyard were monitored. I return to the fact that some Roadstone material was admixed with the Clause 804 from the Bay Lane quarry. There is nothing to suggest this Roadstone material was highly reactive to pyrite heave, or was indeed reactive at all. No such evidence was presented in the case. One has to be careful, nonetheless, in construing this evidence. The rise, in an area which was exposed to wind and rain, but for most of the year would probably have lower temperature than the inside of the building, showed over 9 mm rise. The higher measure of tolerance would indicate a 5 mm bulging of the courtyard over the year. The plus or minus 1 mm rise would show a rise of 7 mm. An almost precisely similar result was obtained in relation to monitor 7. I do not believe the wall monitors outside it, 32 and 33 show a useful result. Monitor 4, on an external wall is flat and shows no movement. Monitor 6 on the external wall of the courtyard shows a fall of 1 mm over a year. This, again, is not useful given either the 1 mm or the 2 mm measure of tolerance. Monitors 42 and 69 in zone 3, in the youth work room, are linked. These show a rise that over a shorter period, if they are taken separately, could be argued is no result that is of relevance. If taken together there is a small rise. Monitor 77 in the new gym in zone 1 shows a slight upward trend. Slab monitor at 79 and wall monitor at 78 apparently show a small fall. With differential heave, what is going up in one place may be restrained in another or not subject to the same upwards pressure in another. This, I also note, is within the larger level of tolerance. I accept the evidence of Ian Roberts for the plaintiff that the normal order of movement in a building that is a few years old could be of the order to 1 mm to 3 mm settlement. There are seasonal changes up and down with moisture but these are very small. I note, as well, the evidence of Pearse Sutton and John Campbell for the defence that one might expect a 10 mm normal subsidence in the building over a period of its first years, even in black boulder clay. This is too much. I prefer the evidence of Ian Roberts. Using the lower level of tolerance in all these instances does not disturb the clear result and in the vast bulk of cases enhances it.

226. In addition, three particular examples were pointed out of areas where monitors were placed very closely together and where there were inconsistent readings. Pearse Sutton put particular emphasis on these. These three areas were referable to the bicycle workshop threshold to the courtyard in zone 1; a point near the courtyard wall in the vicinity of the public entrance in zone 3; and in the same general area, but on the other wall nearest the road. Some of these inconsistencies may be explained by reference to the cement trapped around a column, or by restraint, or partly by the measure of tolerance. This evidence does not disprove the slab rise. Gypsum heave is not uniform. The response of a floor slab under the internal heave need not be consistent. If, on the defence case, ground beams can deflect, then so can slabs and what it pitched up in one place can be under a seesaw type of motion in another. What this argument, in any event, does not do is undermine the general and marked trend of the slab. This is shown in various places to be upwards. The walls and thresholds, the foundation linked elements, on the other hand, are within the level of movement that might be expected applying either measure of tolerance as appropriate. In particular I have looked at these results by applying the lower measure of tolerance.

227. I have looked through the results from all of the monitors. I have paid particular regard to those which continue for the full period of the year. I have discounted those which show no appreciable movement. When a tendency is looked for, however, there is no doubt in my mind that a probability is established of a clear rise in the floor slab. If this were looked at in the other direction, and the relevant monitors were showing the floor slab going downwards, and the thresholds descending by even more, or even any subsidence at all, even discounting possible extreme and reasonable measures of tolerance, as I have done here, the defence theory of the foundation subsidence would be supported. On the monitoring evidence presented, that defence theory is not supported.

Instead, the case of pyrite heave is clearly proven.

228. This conclusion is obviously strengthened by the exercise of reducing the level of tolerance from plus or minus 2 mm to plus or minus 1 mm. This is appropriate. In addition to this raw data, the Court was presented with the evidence of two distinguished statisticians. Dr. Gabrielle Kelly brilliantly illuminated the statistical theory when applied to a range of data such as I have mentioned. She felt that Dr. Cathal Walsh, who gave evidence on behalf of the plaintiff, had misstated and misapplied the relevant theory. I have carefully considered the evidence for the defence of Dr. Kelly and for the plaintiff of Dr. Walsh. I do not regard their evidence as necessary to the resolution of this issue. I listened to it with great care, however. In the event that it were necessary for me to make a choice, then it seems to me that having regard to what I have learnt from the brilliant exposition of Dr. Kelly, that Dr. Walsh's opinion on the trend lines and his methodology would be maintained.

229. In her evidence, Dr. Kelly criticised the making of a joint probability statement. This was because independent probabilities cannot be computed unless they are independent. The sets of deviations from the line, the residuals, she said, showed a similar pattern in most cases if two monitoring stations were taken. The consequence of that might be that if one had a sequence of measurement errors, she argued, that somehow led to a slope going up, the pattern would be repeated in many other monitoring stations because they all followed similar patterns in terms of measurement errors. This would result in the same slope going up too many times when a graph was plotted. Even though, she said, forty-four slopes were positive, it was possible that only two of them could be regarded as positive because they were independent. She therefore thought that the least squares method of analysis was unsuitable. Looking at the difference between the first and last measurement for the different monitoring stations of the wall, she could see an increase when the initial measurement was low and a decrease when the initial measurement was high. This meant, she argued, that if the measurement started a little low then it was going back to an average. She helpfully compared this on a common sense basis to taking blood pressure. Dr. Kelly also looked at the floor separately and concluded that there was a relationship between the first value and the difference that was observed.

230. Dr. Cathal Walsh computed a regression line using a piece of statistical software called "R". This gave the best fit using the least squares regression. He said that whenever one fits models in order to determine a true underlying process, there are a number of assumptions that underpin the fit. One of these is that the scatter about the line is within a particular statistical distribution. His approach was to carry out a visual examination of the distribution of residuals. These are the differences between the points and trend line. He rejected the proposition that the normal probability distribution did not apply if one looked across these points; Dr. Kelly having applied a different diagnostic test to Dr. Walsh. He examined any correlation between the residuals by returning to his original analysis and looking at the diagnostics. On a visual examination some large residuals were identified. His view was, however, that nothing in that would concern him in terms of the assumptions that underpinned the analysis. He said:-

> "Residuals are actually just differences between the locations and the trend lines. And some of these were particular large. In fact we see an instance of it here in this case, the third last data point is quite far away from the trend line, perhaps bigger than one would anticipate given the rest of the residuals. The other thing one does is checks to see what influence each of the points has on the fit of the regression line and if one particular point has a much greater influence on the fit than the others, then one might be concerned that it prejudices the fit and gives incorrect results. Now, measures that I looked at, diagnostic measures, suggested that that wasn't the case, that these points weren't unduly influencing the fit. Dr. Kelly points out that nonetheless the distribution doesn't conform with that which one requires for the assumptions to hold. In order to then investigate this further, I looked across at all of the locations and identified residuals that were large, this is what one might call outliers in the data, so there are differences between the trend line and the actual observed value that were particularly large. Now these can arise for a number of reasons but one might imagine if there was change of staff doing the measurement or if there was particularly inclement weather or some such then these may arrive. In order to determine whether or not they impacted on my analysis I removed these times at which the large residuals were observed, entirely, from the data and refitted the trend lines. It turned out that there were four time points for each of the sets of data that were removed and the impact of removing these is given in the second schedule of my report. So I have said if we remove these points, refit the lines, does it change my conclusions and the answer is no it doesn't. I then re-ran the diagnostic tests that Dr. Kelly had carried out and they passed."

231. I find this statement by Dr. Walsh to be convincing. I feel obliged to record, nonetheless, that the debate between him and Dr. Kelly has greatly illuminated the correct approach to statistical analysis.

232. It is clear to me that a probability is established that the floor moved upwards significantly during the time of monitoring, that the foundations moved hardly at all and that the plaintiff's case is thereby borne out. The same result is obtained using a common sense approach to the data as by using a statistical analysis.

Use of Clause 804 in Implied Terms

233. It has been argued on behalf of Irish Asphalt that the Irish legislation as to sale of goods should not be applied to this contract. In addition, it is argued for the defence that were that legislation to be applied, then it must be construed in such a way that the European standards applicable to Clause 804 are the only ones which would apply. Relying on *Nathan v. Bailey Gibson Ltd.*[1998] 2 I.R. 162, it is urged that European law takes precedence over national law and that in the case of any conflict European law must prevail. Pursuant to European Parliament and Council Directive 98/34/E.C. of 22 June, 1998 laying down a procedure for the provision of information in the field of technical standards and regulations and of rules on Information Society Services, O.J. L204/37, 21.7.1998, it is argued that the technical specification set out in the relevant standards must take precedence over national legislation, or that national legislation must be construed in accordance with such standards. Article 1, as amended by European Parliament and Council Directive 98/48/E.C., defines a technical specification as:-

> "a specification contained in a document which lays down the characteristics required of a product such as levels of quality, performance, safety or dimensions, including the requirements applicable to the product as regards the name under which the product is sold, terminology, symbols, testing and test methods, packaging, marking or labelling and conformity assessment procedures."

234. Pursuant to Article 7, as amended, member states have particular obligations which are set out as follows:-

> "Member States shall take all appropriate measures to ensure that, during the preparation of a European standard referred to in the first indent of Article 6(3) or after its approval, their standardisation bodies do not take any action which could prejudice the harmonisation intended and, in particular, that they do not publish in the field in question a new or revised national standard which is not completely in line with an existing European standard."

235. It is urged that European standards are, in consequence, binding on all members and must be literally transposed as national standards. This allows a product, it is urged, to freely circulate within the European Union. It is to be noticed that there may be a prohibition on the marketing of goods which are liable to endanger the safety of persons, animals or property, but that, it logically flows from this argument, is the only qualification open to member states. The standards are therefore urged to be of quasi–legislative effect.

236. Firstly, I do not accept that the material supplied to Elliott Construction by Irish Asphalt meets the relevant standard. That analysis does not need to be repeated. Secondly, while it is true that goods conforming to a standard should circulate freely within the European Union, national consumer legislation is not thereby abrogated. Implications as to a fetter on the free movement of goods might arise where national consumer legislation is shown to have the effect of inhibiting movement between member states. Further, the relevant legislation, were that to be the case, and here it is not proven, is designed to protect the safety of people, animals and property. It would therefore come within a lawful exception as set out in the European directive. In this litigation, it must be remembered, a building and its ruination is in issue. It is therefore lawful under the relevant directive. Even were that not so, there is no mandate whereby this Court could overturn national consumer legislation or construe it in a way which castrates its effect. To do so would, in itself, be contrary to European Law.

237. No rule of statutory interpretation entitles a judge to turn national legislation into something it is not just because the State has an obligation under European law that is not fulfilled. The European Court in *Marleasing S.A. v. La Comercial Internacional de Alimentacion S.A. (C-106/89)* [1990] E.C.R. 4135, required that courts of member states construe legislation in accordance with their E.U. obligations. The European Court made it clear in *Bernhard Pfeiffer & Ors. v. Deutsches Rotes Kreuz (C-397/01 to C-403/01)* [2004] E.C.R. I-8835 that this interpretation, however, cannot be so extreme as to do violence to the national legislation, turning it into something that it is not; or, as the Court of Justice says, *contra legem*. Finally, I do not accept that a standard is a law and is to be given effect to as if it were a European regulation or directive.

238. I turn therefore to the legislation which protects the purchasers of products and provides implied terms.

239. Section 10 of the Sale of Goods and Supply of Services Act 1980 amends the original sections of the Sale of Goods Act 1893 so that the applicable law as to an implied condition as to merchantability and fitness of goods for purpose is now set out as follows:-

> 14(1) Subject to the provisions of this Act and of any statute in that behalf, there is no implied condition or warranty as to the quality or fitness for any particular purpose of goods supplied under a contract of sale.
>
> (2) Where the seller sells goods in the course of a business there is an implied condition that the goods supplied under the contract are of merchantable quality, except that there is no such condition—
>
> (a) as regards defects specifically drawn to the buyer's attention before the contract is made, or
>
> (b) if the buyer examines the goods before the contract is made, as regards defects which that examination ought to have revealed.
>
> (3) Goods are of merchantable quality if they are as fit for the purpose or purposes for which goods of that kind are commonly bought and as durable as it is reasonable to expect having regard to any description applied to them, the price (if relevant) and all the other relevant circumstances, and any reference in this Act to unmerchantable goods shall be construed accordingly.
>
> (4) Where the seller sells goods in the course of a business and the buyer, expressly or by implication, makes known to the seller any particular purpose for which the goods are being bought, there is an implied condition that the goods supplied under the contract are reasonably fit for that purpose, whether or not that is a purpose for which such goods are commonly supplied, except where the circumstances show that the buyer does not rely, or that it is unreasonable for him to rely, on the seller's skill or judgement.
>
> (5) An implied condition or warranty as to quality or fitness for a particular purpose may be annexed to a contract of sale by usage.
>
> (6) The foregoing provisions of this section apply to a sale by a person who in the course of a business is acting as agent for another as they apply to a sale by a principal in the course of a business, except where that other is not selling in the course of a business and either the buyer knows that fact or reasonable steps are taken to bring it to the notice of the buyer before the contract is made.

240. The first issue is whether the goods were of merchantable quality. This Clause 804 hardcore infill was not as fit for the purpose for which it was bought as might reasonably be expected by a builder purchasing it. It was not as durable as it was reasonable for the purchaser to expect having regard to its description as suitable for under roadway fill. It could not have been expected by the purchaser that, contrary to the relevant experience of builders, this Clause 804 infill would expand and ruin the building into which it was put. The evidence of Dr. Maher referred to earlier as to durability, inertness and strength thus applies. I accept that evidence in full in this context.

241. I regard it as central to the contracts between Elliott Construction and Irish Asphalt, that the material to be supplied carried the characteristics of Clause 804 hardcore infill as had been established through use by numerous builders over the years since 1972. It would be completely contrary to the purpose for which that material was required for it to swell up when used as infill under buildings and ruin floors and buckle walls. The nature of this type of hardcore is as described in the Building Research Establishment Digest, in the following way:-

> "The principal uses of hardcore are as make-up material to provide a level base on which to base a ground floor slab, to raise levels, and to provide a dry, firm base on which work can proceed or to carry construction traffic.

A variety of materials have been used satisfactorily but difficulties can occur and there are a number of factors that need to be taken into account in the selection of materials for use as hardcore. Ideally, they should be granular and drain and consolidate readily; they should be chemically inert and not affected by water. However, few of the materials available at reasonable costs satisfy these requirements completely. The main hazards to be avoided are chemical attack by hardcore materials on concrete and brickwork, mortar, settlement due to poor compaction and swelling or consolidation due to changes in moisture content or chemical instability."

242. It is argued that this Clause 804 infill was capable of a number of uses; consequently if one of the purposes for which this kind of material is commonly bought can be proved to be suitable, then, it is asserted, the goods remain of merchantable quality. In *Aswan Engineering Co. v. Lupdine Ltd.* [1987] 1 All E.R. 135, the Court of Appeal in England upheld such an argument. In that case the plaintiffs bought pails of waterproofing varnish from the defendant. These were exported to Kuwait where they were left on a quayside in the full glare of the sun which raised the temperature of the plastic containers to around 70º Celsius. Curiously, the Court of Appeal incorporated the former statutory law on this subject notwithstanding that the Sale of Goods Act 1979 had amended the Sale of Goods Act 1893, which was common to Britain and Ireland as of the date it had been passed. In effect, and with great respect, it seems to me that the Court of Appeal applied the law as of 1978. The implications of this older and now reformed legislation can be seen from the case of *Christopher Hill Ltd. v. Ashington Piggeries* [1972] 1 A.C. 441. There, the House of Lords, applying the Act of 1893, held that contaminated animal meal, which would have done no harm of any appreciable kind to pigs or poultry, but which killed large quantities of mink, remained merchantable because the former survived heartily while the latter died in droves. This was one of a number of purposes, was the reasoning, for which the meal could be bought. It should be remembered that the previous s. 14(2) of the Sale of Goods Act 1893 provided for the implication of a term as to merchantability in a contract of sale in this way:-

> "Where goods are bought by description from a seller who deals in goods of that description (whether he be the manufacturer or not), there is an implied condition that the goods shall be of merchantable quality; provided that if the buyer has examined the goods, there shall be no implied condition as regards defects which such examination ought to have revealed."

243. The Sale of Goods and Supply of Services Act 1980 completely recast the circumstances of liability as between the purchaser of goods and services and the seller. The prior law is not relevant save insofar as sections of the previous legislation were maintained or incorporated intact and where the statutory context within which such provisions are to be interpreted has not changed in any relevant way. In terms of the recasting of any statutory model by extensive amendment this would be a rare result. I note that some four months after *Aswan Engineering in Rogers v. Parish Ltd*. [1987] Q.B. 933, the Court of Appeal was not inclined to accept an argument that a Range Rover motor car which got its purchaser, as is said, from A to B, but with accompanying extraordinary noises and a rapid decline in its cosmetic appearance was not to be regarded as merchantable. By implication, the Court of Appeal dismissed an argument that a car was of merchantable quality if one of its purposes was fulfilled, which was simply because it conveyed passengers reasonably well. Another purpose of a motor car, the Court held, was to be a source of pride to its owner who could not reasonably be expected to put up with weird engine noises and an off-putting exterior. Central to the decision was the re-casting of the 1893 legislation by the Sale of Goods Act 1979. At pp. 942 to 943, Mustill L.J. stated:-

> "In the course of argument before us our attention was drawn to various expressions of opinion in cases decided before the enactment of the [Supply of Goods (Implied Terms) Act 1973]… as to the precise significance of the term "merchantable quality". In my judgment this is not a practice to be encouraged. The Act of 1973 was an amending Act and it cannot be assumed that the new definition was included simply because the draftsman saw a convenient opportunity to reproduce in more felicitous and economical terms the gist of the speeches and judgments previously delivered. The language of section 14(6) is clear and free from technicality, and it should be sufficient in the great majority of cases to enable the fact-finding judge to arrive at a decision without exploring the intricacies of the prior law. In my judgment the present is not one of those exceptional cases where it may be necessary to have recourse to the former decisions in order to give a full meaning to the words of the subsection".

244. In the later Australian case of *Cavalier Marketing (Australia) Pty. Ltd. v. Rasell* [1990] 96 A.L.R. 375, the Supreme Court of Queensland held that it was not sufficient for goods to meet the merchantability standard merely because they were suitable for one of the purposes for which such goods are commonly bought. In that instance a carpet was in question. The judgment in *Rogers v. Parish Ltd*. was followed. Simply because a carpet was fit for the purpose of covering a floor but was ugly because of reverse piling, did not make it merchantable. A carpet is bought for aesthetic reasons as well as for reasons of warmth and comfort. At pp 400 to 401 of his judgment, Cooper J. sensibly stated:-

> "The definition of merchantable quality requires a determination of two matters. The first matter for determination is the identification of the "purpose or purposes for which goods of that kind are commonly bought". The second matter for determination is whether the goods are as fit for the purpose or purposes, so identified, as is reasonable to expect, having regard to the listed criteria. This is an objective test. Goods may have more than one normal purpose e.g. a utility motor vehicle has two obvious purposes, namely, to act as a means of transport to convey the driver from A to B and also to act as a means of transport to convey the cargo from A to B. Some consumers may acquire a utility solely as a means of personal transport; others may acquire for both purposes. In my view, as a matter of construction and as a matter of legislative intent, the section requires that all normal purposes for which goods are commonly bought should be brought into consideration. Fitness is to be tested against each of these purposes and none are to be excluded. The position is otherwise if the terms of the contract of supply between the direct supplier to the consumer (including any description applied to the goods by that supplier) or, alternatively, any description applied by the corporation (i.e. manufacturer/importer/ distributor) to the goods, requires that a particular normal purpose be excluded. Such a construction is reasonable in both the interests of the consumer and the corporation. First, it addresses the reasonable expectations of the consumer at the time of acquisition of goods that they will be fit for all there normal purposes, subject to the terms of the contract of supply to which the consumer has agreed. Secondly, it addresses the reasonably expectations of the corporation as to the purpose or purposes to which the goods will be put. Thus, the corporation may by the description, if any, it attaches to the goods, the price it receives and any other relevant circumstances, place goods in circulation in such a manner that the corporation made delineate the relevant purpose or purposes itself. Alternatively, it may provide information as to purpose with the goods which information is sufficient to enable a consumer to make an informed choice. If the consumer has information as to the purpose or purposes, contemplated by the corporation as being those for which the goods are fit, any expectation on the part of the consumer as to another, although normal, purpose would be unreasonably"

245. In this instance, the Clause 804 infill was neither chemically inert, nor durable, nor sufficiently strong. The lack of merchantability thereby disclosed is not displaced as an implied condition by any argument that it would be suitable for being put under an external tarmacadamed car park where, it might be argued, though I am certainly not deciding this, the heave of 25 mm or 30 mm or 35 mm over a few years variably over the surface tarmacadam laid above it might not make much difference.

246. Having decided that the goods are not of merchantable quality, I turn next to the argument made on behalf of Elliott Construction that the Clause 804 supplied to it by Irish Asphalt was not reasonably fit for the purpose of being put under floating floor slabs in a high-specification engineered building. The issue which arises here under s. 14(4) of the Act of 1980 is whether the purchaser, Elliott Construction, made known to the seller, Irish Asphalt, any particular purpose for which the goods were being

bought. As previously held, the goods were not of merchantable quality. As to whether there was an express or implied transfer of information as to particular purpose, the most important evidence was that given by Patrick Elliott. He accepted that he did not supply any copies of the much debated and very lengthy Ballymun Regeneration contract to Irish Asphalt. The following questions and answers were then exchanged:-

> "Q. Did you ever ask anybody from Irish Asphalt to come and look at the site in Ballymun?
>
> A. They visited the site regularly with their deliveries.
>
> Q. These were the people who drove the trucks?
>
> A. They were employees. But they knew the nature of the job they were supplying to… the job was called the Ballymun Central Youth Facility, it was hardly a motorway.
>
> Q. Did you ever tell anybody in Irish Asphalt that you were going to use the 804 to backfill the up to 2,590 mm?
>
> A. Specifically no, we didn't.
>
> Q. Or that you were going to use it for under the building?
>
> A. It would be implied, why else would [we] have been buying the Clause 804 hardcore of[f] them, it's a structural infill material…
>
> Q. Do I take it from that…, that you wouldn't have mentioned to [Mr. Lagan of Irish Asphalt] any of the projects that you were involved in?
>
> A. No. Of course because we had to discuss the projects…because a factor of price is how far did the trucks have to drive to get to the project…so, the project had to be discussed.
>
> Q. But can I take it from that, that in fact all you would have told… Irish Asphalt… [was] that you were building a youth centre in Ballymun… and where it was located, that beyond that, that no further details were given in relation to the project?
>
> A. No, because other things would be of a lot of interest to [Irish Asphalt] was the volume of material required for the project… obviously the bigger the project the more interested they were in it. So, the projects would always come up, they would say how much material is in it, what type of material do you want, you know, is it Clause 804, is it three inch down, what do you want us to supply? So the type of project would always come up in conversation…
>
> Q. Our evidence will be that we did not know what you were using the product for and that you simply ordered the product and we supplied it to you, and in so far as you ordered it to be delivered at Ballymun, we delivered it to Ballymun. Do you accept that?
>
> A. No, I don't. I believe Lagan's did know what they were supplying, the types of projects they were supplying it for. There was a long relationship between the two companies. They knew we were a general building contractor and not engaged in civil engineering and road building works and works of that nature. They knew we were primarily into, you know, building factories and buildings like the youth centre and such around Dublin. In actual fact, many of – I won't say how many but they supplied a number of projects which were within a mile of [the] quarry.
>
> Q. Yes. Well, our evidence will be that of course we knew that it was delivered to Ballymun and we knew what you were building there in general terms but that we were not told, nor was it ever made clear to us, nor was there ever any negotiation on the issue about the purpose for which you are using the 804 or the 3 inch down or the 6 inch down that you were ordering from us. Do you accept that?
>
> A. No, I don't accept it. And I would point to the letter your own clients wrote in, I think it was July 2007, where they chose to inform us at that point in time that there were constraints on the suitability of the material. They never informed us of any issue prior to that. I believe they knew the type of projects they were supplying. I believe they knew, they must have known that we weren't buying – we weren't – pardon me for …, we were not buying this stuff for the good of our health, we were buying it to use in buildings that we built.
>
> Q. Yes. But our evidence will be that you never told anybody in the defendant's company whether it was to be used for underfloor fill or for roads or for general fill or for any particular purpose and that the purpose of the intended use of each of the products you ordered was never mentioned by anybody in your company to anybody in the defendant's company?
>
> A. No, I won't accept that, that even if were, I'm sure the site foremen if they were boarding floors or whatever they would be telling Lagan's, right, we're getting ready, we're going to do this floor in two weeks, we would need X amount of material and they would be gearing up to get the material in on time… Personally I never rang Terry [Lagan of Irish Asphalt] and said I'm doing a floor next week, I need this, no I didn't.
>
> Q. And you never indicated to – I must put it to you that you never in fact sought to ask for the defendant's advice in relation to how you would use the material which you ordered from the defendant from the Ballymun Facility?
>
> A. No, because when you order Clause 804 you order material to a particular standard that is accepted across the industry".

247. I accept the answers given by Patrick Elliott, notwithstanding the skill shown in cross-examination on these points. The evidential absence of Terry Lagan as a witness is also noted, though this does not influence my decision. Patrick Elliott struck me as being an honest person. I also accept that it was not reasonable for Elliott Construction, as the purchaser of material, to carry out a suite of tests on the material, costing somewhere in the region of €4,000, on a lorry load of hardcore costing somewhere in the region of €190. That remains the case even though in this case some €25,000 worth of Clause 804 material was bought. The material was not merchantable. It was not fit for purpose. In addition, I hold that it did not meet the Clause 804 standard. The standard for Clause 804 also determined what was being offered and what was being accepted. The material analysis and bulk chemistry results are laid

down with a view to establishing the material as being stable, durable and strong enough for purpose. These tests may, under the relevant standard, establish a presumption for suitability. Even were they fulfilled, which they were not, this Clause 804 infill is manifestly not of merchantable quality and it is also unfit for purpose. Such material is not inert if it changes in volume and shape and randomly causes heave contrary to the purpose for which it was so obviously used in relation to this building project. Even if any such concept as inertness were not applicable, and in my view it clearly is, relevant analysis indicates that the Clause 804 stone infill did not comply with the Clause 804 standard for infill.

Notice

248. An issue arises on the evidence as to whether the terms and conditions of sale, including a clause limiting liability to the cost of the original Clause 804 infill, were notified by Irish Asphalt to Elliott Construction. It is as well to repeat the condition contended for as limiting liability, which was previously quoted in the general chronology. Condition no. 8 reads:-

> "In the event of goods being delivered which are defective, the Company's liability shall be limited to the cost of their replacement. In no circumstances shall the Company be liable for any other loss arising directly or indirectly from the supply of defective materials."

249. In addition, Elliott Construction received a number of delivery dockets for this building job, and other jobs, which end with the words:-

> "This material is sold subject to the terms and conditions available on request. White to accounts - pink to customer - blue to haulier - yellow to file".

250. As a matter of law the party seeking to rely on an exclusion clause has the burden of proof that it was incorporated into the contract. Ample case law has been cited by counsel and I appreciate that assistance. Much of this case law is contradictory, though counsel opened a relevant selection of cases, and an overall restatement is outside the scope of this judgment. I have also been aided by the treatment of this topic in McDermott, *Contract Law*, (Dublin, 2001) at chapter 8.

251. By far the best way of incorporating a condition into a contract is by means of a written document that is signed by the party against whom the clause will operate. Another effective way is by a webpage check whereby one can only move on to purchase a product on acknowledging electronically that one accepts the terms and conditions of sale. Neither happened here. Much of the case law is confined to its own facts. There is very little in terms of amplification of the fundamental principle that a party seeking to rely on an exclusion or limitation clause must give the party to be bound reasonable notice of that clause. The transport cases seem to establish that purchasing a ticket which contains conditions means that you can be bound by the conditions whether you have read them or not; that possibly you are not bound if you do not know that the ticket contained any such conditions; that if you know there is writing on a ticket and believe that it sets out conditions, you are bound whether you read them or not; and that even if you did not believe that the writing on the ticket contained conditions, you will nonetheless be bound if reasonable notice was given. Examples of these disparate outcomes are found in the case law. In *Richardson, Spence & Company v. Rowntree* [1894] A.C. 217 the passenger was handed a folded ticket. On opening it writing emerged which, had it been read, limited liability for any loss on the journey. As the plaintiff did not know that the writing contained conditions and as it was held that the transport company had not done that which would have been reasonably sufficient to give the plaintiff notice of these conditions, an award, unlimited by the relevant condition, was upheld on appeal. Many of the cases as to notice remain peculiar to their own facts. At a remove from a view that the trial judge may have taken to the merits of the case, it is easy to dispute the legal reasoning involved. It can be the case that a notification that a contract has issued, in accordance with the radio jingle we listen to in Ireland almost every day we turn on a radio, "subject to terms and conditions" allows for an argument to be made that some onerous clause was to be incorporated. The success of such a plea, however, must depend on the circumstances. An exclusion clause printed in a faraway place in respect of a severe limitation on contractual liability for entry into a premises will not be sufficient: *Thornton v. Shoe Lane Parking Ltd*. [1971] 2 Q.B. 163. Neither will a notice of exclusion or limitation be sufficient after a contract to hire a hotel room has been concluded: *Olley v. Marlborough Court Ltd*. [1949] 1 K.B. 532. On the other hand, in *Shea v. Great Southern Railways Co*. [1944] 1 Ir. Jur. Rep. 26, a receipt indicating that a bicycle was carried on public transport at the owner's risk and that the ticket was issued "subject to the company's rules and regulations" was held to have excluded liability for a destroyed bicycle even though the master copy of the terms and conditions was covered up by the opening of the door of the omnibus. In that case the essence of limitation was recorded on the receipt. A minute reference on a train ticket to terms and conditions, which required a special enquiry as to the master copy, was not enough in *Shearan v. Great Southern and Western Railway Co.* (1898) 12 I.L.T.R. 108 to establish inclusion as the defendants had failed to do what was reasonable in drawing the attention of the plaintiff to the limitation of liability. Sometimes the approach of the courts seems to depend on the onerousness of the clause in question. In *Thornton v. Shoe Lane Parking*, Lord Denning M.R. referred (at 170) to clauses which are "so wide and so destructive of rights that the court should not hold any man bound by it unless it is drawn to his attention in the most explicit way". Rhetorically, he referred to some clauses as requiring "to be printed in red ink with a red hand pointing to it – or something equally startling". This dictum based on the reasonableness of notice of an apparently unattractive exclusion clause has been developed by some later decisions so that unusually onerous clauses are required, as Dillon L.J. noted in *Interfoto Library v. Stiletto Ltd*. [1989] Q.B. 433 at 438 to 439, to be "fairly brought to the attention of the other party". This suggests an analysis of the quality of the clause as opposed to the quality of the notice whereby any clause in issue was incorporated into a contract. In *A.E.G. (U.K.) Ltd. v. Logic Resources Ltd.* [1996] C.L.C 265, Hobhouse L.J. suggested that this tendency of assessing incorporation by reference to the onerous nature of a clause should not be allowed to continue. The law of notice as to a term should be the same test of reasonable steps being taken to bring the condition in question to the attention of the other party to the contract and that should, he thought, be uninfluenced by considerations of fairness. By analysing the nature of the clause, the courts were in danger of trespassing on the realm of the legislature; such a task, he considered, was not for individual decisions in contract cases but was a matter for unfair contract terms legislation. Even he, however, regarded the unusual nature of a clause as being significant as to whether any contended for notice was reasonable or not. This seems to me to be correct; but that is as far as I would take the tendency. In *Carroll v. An Post National Lottery Company* [1996] 1 I.R. 433 at 461 to 462, Costello P. adopted the approach of reasoning through the incorporation of a condition based on principles of fairness as well as the traditional issue of reasonable notice:-

> "When it is generally known that tickets and other documents which contain conditions are not read by those to whom they are given then there is an implied understanding that there is no condition included in them which is unreasonable to the knowledge of the party tendering them… The party receiving a document which forms part of a contract between him and the party tendering it may know that it contains conditions which he does not take the trouble to read. But if the condition relied on by the party tendering the document is particularly onerous or unusual that party must show that is has been fairly and reasonably brought to the other party's attention. If he cannot do so, then he cannot rely on it."

252. While I am not prepared to disagree with this decision, I will apply here a test as to reasonable notice. I approach the matter in

that tradition-bound way because contracts are based upon what people agree. Any absence in agreement is not to be supplied by litigation and a court is not entitled to alter the plain wording of an agreement, save as required by statute or, in the rare circumstances where that might be possible, by necessary implication. Each party to a contract, moreover, is to be judged as if that party is acting out of rational motives and expects the other side to act reasonably both in the performance of obligations and in the incorporation and construction of terms. People will not easily agree to what is unfair but even less readily will unreasonable actions be expected in consequence of an agreement concluded by reasonable people. I would therefor analyse this case on the basis of the traditional test as to whether Irish Asphalt took reasonable steps to bring what is clearly an onerous limitation clause to the attention of Elliott Construction. Here, unlike in many of the cases, we are not dealing with an individual. Both plaintiff and defendant are corporations. This is of a degree of importance. It is reasonable, in the context of contract law, to have regard to the fact that a decision that a limitation clause should be incorporated into a contract would be made at senior management level within a company that might later seek to rely upon it. It would also be reasonable to expect that such a corporation would notify any other corporation that it seeks to be bound by that limitation clause at the same level. Even if that were not so, ordinary sense would suggest that the rule in contract law whereby reasonable notice should be given of an exclusion clause requires that the concept of reasonableness should incorporate at least a potential analysis as to whether the corporation which is expected to be bound by the clause would be notified in a reasonable way. In terms of ordinary sense as to the workings of corporate structures, this requires notification at a level within the corporation which might reasonably be expected to be effective in terms of bringing the clause to the attention of the appropriate decision making level within that corporation. It is thus of significance that a choice was made by Irish Asphalt to notify the terms and conditions by way of a marketing letter that was addressed to Elliott Construction at high level where these kinds of decisions might reasonably be expected to be made after appropriate analysis as to the risks and consequences of entering into such a contract with such a limitation clause. The relevant correspondence is set out below.

253. Some of the delivery dockets were signed by Martin Hannay. He is a responsible person within the company. That responsibility is limited, however. He is an on site foreman. His view on the delivery dockets was that any reference to conditions dealt with such things as price. In any event, he did not give too much thought to the laconic statement about terms and conditions being available on request that was printed on the delivery dockets. That was in accord with his practical responsibilities in supervising day-to-day building work.

254. To resolve the issue of notice I first need to refer to four letters. The first two of these are, to my mind, the most important. On 29th January 2003, a template letter was drawn up within Irish Asphalt. This announces the opening of a new quarry at Bay Lane and the products which it will sell. There is no indication on the front of the letter of any terms and conditions. The letter was designed, however, to be used on standard notepaper belonging to Irish Asphalt which had terms and conditions printed on the back. That, however, is manifestly not the only notepaper used by Irish Asphalt. On 30th January 2003, that template letter was sent, by way of a mail merge to many customers, and addressed to "Tom Dolphin" of Elliott Construction. The general chronology refers. This letter was discovered by the defendant as if the terms and conditions were printed on the back. This was formally sworn to in an affidavit by Irish Asphalt as being a copy in that form. It is not. The original letter was discovered by Elliott Construction. I have seen the letter. It does not have the terms and conditions on the back. The back is blank. Every year there was supposed to be a price increase letter. The relevant one here would be the letter of 27th January 2004. Through this letter, Irish Asphalt announced to its customers that prices had increased. Again, it was said to have been the practice in Irish Asphalt to send out these letters with terms and conditions printed on the back. Ciara Cassidy gave evidence on behalf of Irish Asphalt that it was standard practice in the office, of which she was head of finance and the company secretary, to have terms and conditions on the back of all credit notes, annual price increases and quotations. This price increase letter was one which Patrick Elliott had no recollection of receiving. I accept his evidence. There is no reliable evidence that he received it. I am asked to rely on systems as supplying probable evidence of notice. The systems of the defendant are short of reliable, particularly in terms of proof that the correct note paper with the terms and conditions printed on the back were always, or even routinely, used for important communications as to any new offer of product or any price alteration. Lastly, there is a price quotation letter of 31st May 2003. This letter would have been sent by fax and so it is unlikely that the operative, if the terms and conditions were on the back of that particular document, turned it over and resent the back of the letter with the fax. The terms and conditions relevant to this case were drawn up in 2003 and changed in 2007. Of these documents the most fundamental are the template letter of 29th January 2003 and, most importantly, the promotional letter to Mr. Dolphin of 30th January 2003 which is based on it. Were it not for the fact that Elliott Construction kept a copy of this letter, I would have been under the impression that by reason of the system supposedly in place the terms and conditions had been notified as at the time when Irish Asphalt began to deal with Elliott Construction. As regards the price increase letter and the price quotation letter I am urged to rely on the supposed system. I accept that Patrick Elliott is an honest witness. The apparent challenge to his evidence, in contrast, by way of office systems does not establish a probability to counter his evidence. The systems are established by the evidence, instead, as random. It is clear that they were not systematically followed. There are three credit notes from Irish Asphalt with the terms and conditions printed on the back. Claiming back credit for relatively small errors is not a reasonable context within which the party in error as to price charging is to announce a limitation clause for all future contracts. Such discourse is unlikely to be noticed. It does not concern the formation of a contract but the true performance of an existing obligation by reference only to price and perhaps, on occasion, to quantity. It takes place within the routine context of accounts. The three credit notes are urged by the defence to provide evidence of a system of dealing between the parties that would establish the terms and conditions as part of the relevant contract. Two of these credit notes were signed on receipt within Elliott Construction by a girl called Emma McDermott. I accept Patrick Elliott's evidence that she was a junior accounts clerk. That is not an appropriate level for such notice. These three credit notes with the terms and conditions on the back would have been dealt with by Emma McDermott or by Maeve O'Reilly. The relevant part of the cross-examination of Patrick Elliott reads as follows:-

> "Q. I want to put to you the three credit notes with the terms and conditions on the back?
>
> A. O.K.
>
> Q. Because what we see, Mr. Elliott, is that in fact if we look at the first one, 1A, stapled to that credit note, which is credit note 949, which is January 2004, you see a James Elliott document in blue; do you see that?
>
> A. I do.
>
> Q. It says "passed by M.O.R.". That's Maeve O'Reilly, isn't that right?
>
> A. Yes.
>
> Q. So clearly Maeve O'Reilly authorised this credit note; isn't that correct?
>
> A. I'm not going to dispute that with you… If her initials are on it, I accept it.

Q. If we go to tab 9 of the booklet which are the documents we've retained in relation to this and if you go to the third page, 15th January 2004, a letter from your company to Irish Asphalt, requesting the credit note and it's written by Maeve O'Reilly in accounts, do you see that?

A. Yes, I don't dispute that.

Q. So Maeve O'Reilly is also clearly involved in the credit note process?

A. Patricia [Maxwell, the main person working in the Accounts Department] probably asked her to write this letter.

Q. Well, the point is…

A. I don't know who – I assume Patricia would have asked her to write this letter, perhaps Maeve [O'Reilly] on a given day wrote this, worked out what the credit note was based on a batch of documents and sent the letter off, told Patricia what she was doing and sent the letter off, I don't know.

Q. The next two credit notes are the ones that are initialled by Emma McDermott, but in fact if you look at tab 4 of your booklet… and look at the second credit note which is credit note 903… you see that's also approved by M.O.R., that is Maeve O'Reilly; isn't it?

A. Well, I would say all that demonstrates is that Maeve [O'Reilly] was doing the same type of work as Emma [McDermott].

Q. That is precisely the point, isn't, Mr. Elliott, that it's not just Emma McDermott who was involved in this, it's also Maeve O'Reilly?

A. You see, I think you're trying to make the leap that Maeve O'Reilly is somehow an integral manager in the company and that is something I simply don't agree it and its not the case and has never been the case. And I think it demonstrates that then nature of the work that Maeve was doing was, I don't mean to, how can I put this, but the work was not demanding work.

Q. Can I ask you, how did you find out that these initials were those of Emma McDermott?

A. I asked my sister because Maeve's husband, I mentioned her husband had a stroke, he passed [away] last Saturday, so my sister Hazel found this information out.

255. I accept Patrick Elliott's answers as the truth in this regard. In addition, I note that in the course of the case a box of correspondence and business documents was handed over by Elliott Construction to Irish Asphalt. Of all the varied correspondence in this box, only three credit notes contain the terms and conditions on the back. There are three further credit notes among these documents which are on original Irish Asphalt notepaper which have no terms and conditions on the back. In addition to that, there are two others with no terms and conditions on the back and here the Irish Asphalt notepaper is photocopied and not professionally printed. At the relevant time, it is probable that Irish Asphalt was a very busy company, as I hope it continues to be. It seems to me to be probable that the wrong notepaper was used on multiple occasions. It seems also probable that the systems avowed to were very unreliable. Further, the photocopying of notepaper is far more likely to have occurred in the Irish Asphalt offices because of a temporary shortage rather than in Elliott Construction's offices.

256. Notification of an exclusion clause, for it to be operative, must be actual or must involve the party seeking to rely on it taking reasonable steps to incorporate that clause into the contract through notice. I stated above that the template letter of 29th January 2003 and the letter that was supposed to incorporate the terms and conditions on the back of such a template letter sent on 30th January 2003 were the most important documents. This is because there are two parties to this matter. Looked at from the point of view of Elliott Construction, it, as a purchaser, is entitled to believe that any purchase it makes of building materials is subject only to any ordinary terms and conditions that might be established in such a transaction. Even were terms as to merchantability and fitness for purpose under the Sale of Goods and Supply of the Services Act 1980 implied by law, such conditions might be incorporated into many ordinary contracts of sale. Otherwise, why does a purchaser bother to enter into the transaction whereby the purchaser becomes the owner of goods? For construction materials it would be unreasonable to expect a builder to ever contemplate that his liability to hand over to the employer a habitable and sound building would be undermined by reference to a condition in a contract which gave no recourse in the event that the materials which he purchased to build the building ruined the building. Building materials are purchased by builders on the basis that they are reasonably sound and reasonably durable. The higher the quality of the product that is chosen the more that expectation is enforced. There was some attempt during the course of this hearing to suggest that Elliott Construction was either wrong, or was not legally obliged, to readily agree with Ballymun Regeneration to remediate this ruined building. The argument was not advanced as the hearing progressed. In choosing to deal with Irish Asphalt, Elliott Construction was entitled to rely on the high standing of that company based on the reliability of its products. While this assumption turns out to have been false it was, nonetheless, unquestionably reasonable. If Elliott Construction put ruinous materials into a building it can expect to have the employer complain, at least. I am not deciding here any issue of liability between Elliott Construction and Ballymun Regeneration as it was not before me.

257. Looking at this contract of sale from the point of view of Irish Asphalt, it was entitled, should it have so chosen, to seek to limit its liability by reference to an exclusion clause. As a matter of law, incorporation of the exclusion clause in the contract requires it to take reasonable steps to that end. It is obvious what it thought such reasonable steps were. Firstly, it drew up a one page template letter. Instead of being a one page letter, this could have been a two page letter with all of the terms and conditions as part of the text. After all, the terms and conditions are not voluminous and would fit readily on a page. Its expectation was that each template letter would be placed on standard notepaper which had the terms and conditions clearly printed on the back. Anyone who was proposing to buy from the new Bay Lane quarry, therefore, would have known, from the very start, that if the material that he/she purchased was not of good quality, and would ruin any building into which it was put, that his/her recourse would be limited to the purchase price of the material. This, for the reasons stated, is a highly onerous clause and one which would otherwise not be expected. It would leave the builder to lose his reputation and possibly his profit, and more, should the material turn out not only to be of bad quality but also to be actively dangerous to the contemplated construction project. Therefore, it was entirely reasonable for Irish Asphalt to set out its terms and conditions from the very start. This it failed to do; though that is probably what it would have done had office systems been reliable. It also felt that it was worthwhile to remind customers, on every price increase, that liability was so severely limited. There is no evidence in this case that such notice was ever given to Elliott Construction. Then it has delivery dockets with every delivery it makes. These merely recite that the delivery is made subject to terms and conditions. The

delivery docket is generated as evidence of delivery. What term or condition did Irish Asphalt regard as important in the context of such delivery? It was certainly not the limitation clause. As regards the person to whom such a notification of an onerous limitation clause should be made before any contract was entered into, it is clear again that Irish Asphalt, by choosing the purchasing manager of Elliott Construction, Tom Dolphin, or indeed by writing to any appropriate executive in that firm, felt that notification of this exclusion clause should be made at the top level. This is reasonable because notification is then reliable; the people who would make any relevant decision within the company are to be told. They can then make the crucial decision to buy what may be unreliable or even destructive building materials without recourse. This may be argued that it should be regarded as reasonable notice. Because of an error in notepaper, this reasonable step in notification was not taken by Irish Asphalt. I do not regard isolated instances where terms and conditions appear in the context of Elliott Construction seeking to be reimbursed for overcharging through an accounts system that no one would reasonably expect would involve people at the level of Tom Dolphin, or any decision making level as to the formation of important contracts, to be reasonable notice.

Fair and Reasonable

258. Were I to be wrong in relation to the issue of the proper incorporation of the limitation clause into the contract, I propose briefly to consider whether condition no. 8 is enforceable as a matter of law.

259. Section 22 of the Sales of Goods and Supply of Services Act 1980, amends the original Sales of Goods Act 1893 so that, as to the exclusion of implied terms and conditions, it now reads as follows:-

> "55(1) Subject to the subsequent provisions of this section, where any right, duty or liability would arise under a contract of sale of goods by implication of law, it may be negatived or varied by express agreement, or by the course of dealing between the parties, or by usage if the usage is such as to bind both parties to the contract.
>
> (2) An express condition or warranty does not negative a condition or warranty implied by this Act unless inconsistent therewith.
>
> (3) In the case of a contract of sale of goods, any term of that or any other contract exempting from all or any of the provisions of section 12 of this Act shall be void.
>
> (4) In the case of a contract of sale of goods, any term of that or any other contract exempting from all or any of the provisions of section 13, 14 or 15 of this Act shall be void where the buyer deals as consumer and shall, in any other case, not be enforceable unless it is shown that it is fair and reasonable.
>
> (5) Subsection (4) shall not prevent the court from holding, in accordance with any rule of law, that a term which purports to exclude or restrict any of the provisions of section 13, 14 or 15 of this Act is not a term of the contract.
>
> (6) Any reference in this section to a term exempting from all or any of the provisions of any section of this Act is a reference to a term which purports to exclude or restrict, or has the effect of excluding or restricting, the operation of all or any of the provisions of that section, or the exercise of a right conferred by any provision of that section, or any liability of the seller for breach of a condition or warranty implied by any provision of that section.
>
> (7) Any reference in this section to a term of a contract includes a reference to a term which although not contained in a contract is incorporated in the contract by another term of the contract.
>
> (8) This section is subject to section 61 (6) of this Act."

260. The schedule to the Act of 1980 provides for the criteria in relation to which the incorporation of a limitation or exclusion clause in a contract for the sale of goods may be adjudged to be fair and reasonable, and is as follows:-

> 1. "In determining for the purposes of section 13, 31, 40 or 46 of this Act or section 55 of the Act of 1893 (inserted by section 22 of this Act) if a term is fair and reasonable the test is that it shall be a fair and reasonable one to be included having regard to the circumstances which were, or ought reasonably to have been, known to or in contemplation of the parties when the contract was made.
>
> 2. Regard is to be had in particular to any of the following which appear to be relevant:
>
> (a) The strength of the bargaining positions of the parties relative to each other, taking into account (among other things) alternative means by which the customer's requirements could have been met;
>
> (b) whether the customer received an inducement to agree to the term, or in accepting it had an opportunity of entering into a similar contract with other persons, but without having to accept a similar term;
>
> (c) whether the customer knew or ought reasonably to have known of the existence and extent of the term (having regard, among other things, to any custom of the trade and any previous course of dealing between the parties);
>
> (d) where the term excludes or restricts any relevant liability if some condition is not complied with, whether it was reasonable at the time of the contract to expect that compliance with that condition would be practicable;
>
> (e) whether any goods involved were manufactured, processed or adapted to the special order of the customer.
>
> In this Schedule—
>
> "*contract*" includes "*agreement*",
>
> "*term*" includes "*agreement*" and "*provision*"."

261. The onus of proving that the limitation clause was fair and reasonable rests with Irish Asphalt, as it is the party seeking to rely on it. For the reasons already given it is clear that this contract term is not a fair and reasonable one, having regard to the circumstances, which were, or ought reasonably to have been, known to or in the contemplation of the parties when the contract was made. In particular, as I have previously held, it would be unreasonable for the purchaser to start testing quarried stone which

was sold pursuant to a specification as being Clause 804 infill. Any testing requirement would reasonably, in that regard, fall on the quarry. They are supplying a product to multiple customers. The circumstances that ought reasonably to have been known to the parties would have included the discovery by the quarry of the almost 3% by weight level of pyrite within the stone. This could have been discovered by petrographic analysis or by bulk chemical testing. Irish Asphalt, as the quarry, could have been expected to sell and indeed did sell millions of tonnes of this material. As against that, the bargaining power of a purchaser, including his/her ability to carry out a minute analysis of the stone, is vastly different. On purchasing the material advertised, even in the letter regarding the opening of the Bay Lane quarry, as being Clause 804 hardcore infill, any reasonable builder would have regarded it as meeting with the specification set out in clause 804 of the Department of Enterprise Specification for Road Works (1972) as brought up to date from time to time. At a more basic level, any builder would have expected that it would fulfil the purpose of holding up a floor slab and, even more so, that it would not expand and ruin a carefully constructed building. In terms of the difference in bargaining powers and knowledge between the parties, the party to the contract of sale which is producing the material in volume clearly has the greater responsibility to enquire. Whereas it could be said that there were other means by which Elliott Construction could have chosen another source of Clause 804, there was nothing to suggest to Elliott Construction that any stone infill described in that way would, as between one quarry and another, be in any way different. Any of the tests that might be contemplated within the terms of the contract between Ballymun Regeneration and Elliott Construction would have been unlikely to uncover a suspicion that a high level of pyrite was present. Elliott Construction, as a customer, did not receive an inducement to agree to this term. It did not know of it. In terms of para. 2(c) of the schedule to the Act, I am satisfied that Elliott Construction, as customer, neither knew nor ought reasonably to have known, of the existence and onerous extent of the term. There is nothing in terms of the custom of the trade of building which would have alerted it, on the evidence that I have received, to such a term. My prior analysis as to reasonable notice is referable here as well. In terms of para. 2(d) of the schedule, compliance with the condition must fairly be regarded as utterly impractical. If the stone infill were to swell and ruin a building, the builder would become the party against which liability for defects would be sought to be primarily enforced. An argument could be made, on the other hand, that the quarry would be a party against which no one could have recourse. I have not analysed such potential liability in negligence as it is not part of the case but I regard this potential scenario as neither fair nor reasonable.

262. An argument was advanced late in the case for the plaintiff that the relevant exclusion clause entitles the builder to recover, as condition no. 8 says, "the cost of replacement" of the material. This contended for construction of the contract clause, it is argued on behalf of Elliott Construction, contemplates that the infill should be dug out and replaced by proper infill. That is an absurd construction of the contract and one which I am not prepared to entertain. It was probably to avoid judges distorting contracts in favour of what appeared fair on the merits of individual exclusion and limitation clauses that regulation of clauses and the introduction of statutory implied terms was introduced by legislation. In this context, were I to accept the inclusion and the fairness and reasonableness of the relevant clause, which I do not, the cost of replacing the materials would have been contemplated by both parties to limit liability to €25,000, being the amount for which the hardcore infill was bought. The wording under consideration could not involve the cost of digging it out of a completed building and then making the building, as might be said in other instances not involving pyrite, as good as new.

Conclusions

263. There is no doubt that the Ballymun building constructed in 2004 to 2005 was ruined by 2007 to 2008 and had to be remediated in 2009. Having contracted to build a youth centre that was reasonably fit for purpose, I hold that Elliott Construction acted reasonably in agreeing to fully remediate the building. As to the cause of the damage which made this undertaking necessary, there are two main possibilities. These are that the floor heaved upwards, cranking the floor slab into the plasterboard lining the walls and the plasterboard partitions between rooms; or that the building sank to the same result. As between these two possibilities it has been proven as a probability that the damage to the building came about as a result of the floors heaving upwards. This was the sole cause of the damage to the building.

264. If the foundations had been shown to have sunk, then the Court would have dismissed the plaintiff's case. It has not been established that the foundations sank. Some very small degree of movement in the foundations is probable. My conclusion is that it was no more than would be normal for a building of this kind over a ten year period. While an estimate in that regard is very difficult, my view is that over the five relevant years, the foundations subsided less than 5 mm. The foundations were properly sited on black boulder clay and were and are stable. As regards defence theories concerning additional and destructive movement within the building by reason of the deflection of the first floor slab, expansion and contraction of block-work and other factors, these, to my mind, are utterly minimal and are not in any event an explanation for the cause of damage to the building.

265. A substantial part of the defendant's case was an attempt to establish that crystal heave was impossible. This has not been proven. Had the defendant shown this as a probability, I would have been obliged to consider the dismissal of the plaintiff's case. On the contrary, acting on the evidence of Dr. Matheson, Mr. Jones and Mr. Hunt, I regard crystal heave as having being proved as integral to the infill supplied by Irish Asphalt to Elliott Construction. Quantifying the degree of heave by reference to petrography and SEM samples is impossible. What is probable is that it happened in sufficiently substantial measure to ruin the building. Had crystal heave been shown by the plaintiff not to be impossible, but not to have been proven, then it would have been possible nonetheless to hold for the plaintiff by reference, at least, to the monitoring results coupled with the absence of any other cause for the floors to have heaved upwards during the period scrutinised. On its own, however, sufficient evidence has demonstrated crystal heave to be a probability.

266. Independently, the Golder swell test evidence is accepted. This evidence, on its own, taken within a proper context of the reports of Dr. Maher and Lloyd Twomey, establishes a probability that the floor slab heaved. The Arup test, while providing lower levels of movement, substantially backs that up.

In the context of a public building which is expected to last at least 50, and more likely 100, years, it is not yet reasonable to remove the infill supplied by Irish Asphalt solely because of the high sulphur content of the infill. That only establishes a possible danger into the future. Removing the infill because of actual heave is, on the other hand, entirely reasonable.

267. The monitoring tests carried out on the building over a one year period established that the foundational elements, on which the external walls rest, have hardly moved downwards at all. In contrast it is impossible for any judge to ignore the fact that the floor has been shown by careful monitoring over a period of a year, and a six month period within that year, to have moved upwards. In the event, which I doubt, that a statistical analysis overlay is required in that regard, I strongly prefer the evidence for the plaintiff. Given the absence of any other cause, apart from pyrite heave, which could result in the floors moving upwards, the monitoring results are, coupled with this evidence, enough to prove the plaintiff's case.

268. Any one of the following pieces of evidences would have entitled the plaintiff to succeed: the monitoring results showing the floor slab rising while the foundations remain essentially static; the crystal heave evidence; the swelling tests; the state of the

building showing heave coupled with failure of the infill material on crucial tests; or the chemical test results on the infill coupled with the necessity to remove it because of danger to concrete elements. Because of the state of the evidence, I have no option but to find in favour of the plaintiff on four of these five elements. Had there been only one finding for the plaintiff, I would still be obliged to find in favour of the plaintiff because a probability is thereby established. I have analysed the evidence separately in each of those blocs in order to come to that conclusion. I have based no conclusion, on this separate re-analysis of the evidence, on the bulk chemistry tests. I therefore hold for the plaintiff on the basis that the foundations are sufficient and stable coupled with the nature of the material under the floors; coupled with the monitoring results; coupled with the swell tests; coupled with the crystal heave evidence. Each of these is separate. Cumulatively, I also hold for the plaintiff in respect of any combination of these findings coupled with the foundation stability finding.

269. The material supplied by Irish Asphalt to Elliott Construction was not of merchantable quality. Therefore, there was a breach of contract. In addition, the implied condition as to fitness for purpose was an obligation by Irish Asphalt to Elliott Construction under the contract. The material was not fit for purpose. The exclusion clause was not incorporated into the contract by the defendant as against this plaintiff. Even had it been, in the context of the case, it would be neither fair nor reasonable to enforce it.

Result

270. In the result there will be damages for the plaintiff. The quantum of damages has not been analysed in this judgment because that issue was not put in evidence beyond the figure casually mentioned at the start of this judgment. I am conscious of possible delay and of the obligations of the Commercial Court towards the parties to litigation before it. If necessary, I will commence a hearing on that issue in the first week of the new term. In the meanwhile, the parties may discuss for a short time the amount of judgment that I will enter on behalf of the plaintiff.