one-fourth of the total resistance, while it is much less than one- fourth in other cases. The consequence is that surface disturbance must be credited with the contribution of three-fourths or there­abouts of the total resistance, a result which could scarcely have been predicted. Waves are constantly being created as the vessel rolls, and as constantly moving away, and the mechanical work done in this way reacts in a reduction of the amplitude of successive oscillations. Very low waves, so low as to be almost impercept­ible, owing to their great length in proportion to their height, would suffice to account even for this large proportionate effect. For example, Mr Froude estimates that a wave 320 feet long and only 1 1/4 inches in height would fully account for all the work credited to surface disturbance in the fourth case of the preceding table.

“ Another important deduction from the figures in the table is the large proportionate effect of 'keel' resistance as compared with frictional resistance, thus establishing the advantages of deep bilge-keels. Ships of the Royal Navy recently constructed have been furnished with much deeper bilge-keels than were formerly in use, but a limit to the depths that can be fitted is often reached, because of the necessity for compliance with certain con­ditions and extreme dimensions, in order that the vessels may be able to enter existing docks.”

In the Royal Navy advantage has also been taken of the power of loose water within a ship to quell motion. It was first employed in the “ Inflexible ” in a part of the ship lying above the bomb­proof deck, and at the level of the water-line. Its use resulted from a discussion, when the “ Inflexible ” was designed, of the probable effect of water entering this region of the ship through shot holes. The matter has since been thoroughly established by experiment, and affords a new and valuable means of preventing heavy rolling in ships having large initial stability. There is now no hesitation in giving a metacentric height of 6 feet, and obtaining all the security against upsetting which this ensures, because it is felt that the violent rolling formerly inseparable from stiffness can be prevented. The investigation into this matter has been conducted by Mr Philip Watts, Mr R. E. Froude, and Mr W. E. Smith, acting for the Admiralty.

The accompanying memorandum, prepared by the present writer in 1884, gives the general results :—

‘In investigating the phenomena attending the use of water as a means of quelling the motion of ships, Mr Froude has not only taken advantage of the experiments made in the ‘Edinburgh’ by running men across the decks, but he has also studied similar phenomena in a model water-chamber, mounted, rot on a model of a ship, but on a large pendulum weighted to the required ‘period,’ the relative level of the model chamber and the axis of rotation being made to correspond approximately to scale with that in the ship.

"The conclusions, stated in the form of a comparison between the quelling effects of bilge-keels and of moving water, are as follows:— (1) There is a certain depth of water in the chamber which gives the maximum effect ; this is dependent upon the width of the chamber and the period of the ship. (2) With this depth of water the growth of resistance to rolling commences almost at zero of angle, whereas with either a greater or less depth there is practically no resistance at all due to the water up to a certain angle, which angle increases with increase of departure from the proper depth. (3) At larger angles of roll the disadvantage of departure from the proper depth of water is not marked. (4) The resistance of water in a chamber does not increase at all uniformly with increase of angle of roll, but increases rapidly at first and at the larger angles becomes more nearly constant for all angles. (5) The best quantity of water for the original chamber in the ‘Edinburgh’ was 43 tons ; the best for the chamber enlarged by removal of cork walls was 79 tons ; and the best for the chamber extending to the sides of the ship would be 100 tons. The first-named extension improved the resistance at 10° by 21 per cent., and the further extension by another 22 per cent.

“ As compared with bilge-keels the matter is stated as follows while 2 feet addition to the breadth of the bilge-keels adds in round numbers two-thirds to the existing extinguishing power of hull and bilge-keels on the 'Edinburgh' at all angles of rolling, the fully extended water-chamber adds at 3° of roll about six times, and at 5° about three times that power ; at 12° the chamber adds no more than 2 feet of bilge-keel, while at 18° it only adds half as much. It is therefore evident that, while both are valuable, the water-chamber is for most kinds of service much the more valuable of the two.

“ Explaining the cause of the phenomena, Mr Froude says :—

“ ‘The extinguishing or quelling effect of water depends, of course, cæ*teris paribus,* upon the value of the moment represented by the transference of water from side to side, *i.e.,* with a given quantity of water, upon the distance moved by its centre of gravity. This distance increases with increase of angle of roll, and consequently the extinction similarly increases up to a certain point, where we appear to have approximately reached the maximum possible transference of water, and consequently the maximum extinction of which the quantity of water is capable with the dimensions of the chamber. This point occurs generally at a moderate angle, and above

this angle the extinction becomes practically constant. But the extinguish­ing effect of the water of course largely depends also upon the timing of its motion from side to side,—the extinction being greatest when that motion takes place most nearly at the time of extreme angle of ship, *i.e.,* in such a manner ns that the water may be as much as possible running downhill when it is moving across, and as much as possible upon the rising side of the ship when it is stationary. If, on the other hand, the motion of the water across were to take place when the ship is quite upright, the extinction would be *nil.* It is therefore conceivable that for the same total degree of motion or transference of water we may have a very different degree of extinction, according to the timing of that motion. In the motion of the water energy is necessarily wasted, and it is clear that, if we are dealing with a permanent condition of things, *i.e.,* if the ship is being steadily maintained at a constant angle of roll, this waste of energy in each run of water from side to side must be exactly equal to the energy taken out of the ship in each swing by the extinction. The motion of the water may be and generally is of a type very wasteful of energy, the water either rushing across in a mass, and consuming its energy by breaking with great violence against the opposite side, as it does at the larger angles of rolling, or, at more moderate angles, running across in a breaking wave or bore, which consumes its energy as it goes in its own internal resistance ; and under these circumstances the timing of the motion appears invariably to approach pretty nearly to that giving the maximum extinction for the degree of motion. But the motion of the water sometimes takes the form of a mere alternating slope of surface, or tidal swing from side to side, and here there is very little waste of energy, the energy of motion of the flow of water in one direction being converted into potential energy in the shape of rise of water at the side, and then given out again to the water flowing back to the other side, and so on. The waste of energy in this form of motion being almost *nil,* the timing is almost exactly that appropriate to *no* extinction, the water being in the middle of its passage across and the surface being level when the ship is upright.’

“The value of the chamber of course increases as its length in the direction of the keel of the ship increases. The actual size of the chamber we adopted appears to give valuable results, although its extent was necessarily limited.”

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| --- | --- | --- | --- | --- | --- | --- |
| *Tabular Statement of Results of the Above Experiments.* | | | | | | |
|  |  | | Empty | Fully | Empty Chamber. |  |
|  |  | | Chamber. | Two Feet addi­ | Wave |
|  |  | | Existing | Chamber. | tional Width of | Slope. |
|  |  | | Bilge-keels. | Bilge-keel. |  |
|  |  |  | ·5 | ·9 | 3∙8 | ·39 |
|  | Steady rolling in co­ |  | 10 | 3∙8 | 7∙5 | 1∙22 |
|  | periodic waves |  | 15 | 10 ∙5 | ll·l | 2 63 |
|  |  | 20 | 16∙6 | 14·7 | 4∙59 |
|  | Irregular rolling repre­ |  | ·5 | 1∙3 | 4∙1 | ·47 |
|  | sented by angle accu­ |  | 10  15 | 4∙5 | 7∙7 | 1∙32 |
|  | mulated from rest in | | 10∙7 | 11·2 | 2∙67 |
|  | five successive co­periodic waves | | 20 | 16∙6 | 14 8 | 4∙64 |
|  |  | |  |  |  |  |

Iu some lectures recently delivered Mr Smith, assistant con­structor of the navy, illustrated the use of water in quelling motion by models as shown below.

“ The models represented the midship sections of the ‘ Admiral ’ class, and were both of the same weight and size. Each model was mounted on trunuions, marked T, and both oscillated freely on these trunnions in exactly the same time. The models were placed one behind the other, so that the parallelism of the masts was evident to the audience. The model in fig. 7 was provided with a glass tube into which varying quantities of water could be put. An amount of water representing 1/100 of the total weight of the model, f.e., 100 tons in a 10,000-ton ship, was now placed in the tube, the models were started from the same angle as before, and the model with the loose water, instead of keeping up exactly with the other, or rolling more violently, came almost instantaneously to rest.

“ The tube was filled with varying quantities of water, and the effect was always to stop the model much sooner than the model with no weights free to move. The two models were always started from the same angle, so that their relative behaviour could be easily seen. When the tube was quite full there was practically no effect. The two models rolled almost together. The same effect resulted from the motion of a marble representing in weight 100 tons in a ship of 10,000 tons. The same reduction must always occur in a rolling ship if we have a loose weight of any kind whether the