4 DEEP FOUNDATIONS

4.1 PRECAST REINFORCED AND PRESTRESSED CONCRETE PILES

4.1.1 General

1 The provisions of this Part apply to end-bearing piles, friction piles, tension piles and transversely loaded piles installed by driving, by jacking, and by screwing or boring with or without grouting.

2 The purpose of QCS is to provide as a general technical guide for acceptable construction work practices in the State of Qatar, considering this; any addition for technology, material, specification, standard that are not mentioned in this section or their modification, shall be subject to approval as stated in the introduction of QCS (00-02)

4.1.2 Limit States Considerations

1 The following limit states shall be considered and an appropriate list shall be compiled:

(a) Loss of overall stability;
(b) bearing resistance failure of the pile foundation;
(c) Uplift or insufficient tensile resistance of the pile foundation;
(d) Failure in the ground due to transverse loading of the pile foundation;
(e) Structural failure of the pile in compression, tension, bending, buckling or shear;
(f) combined failure in the ground and in the pile foundation;
(g) combined failure in the ground and in the structure;
(h) Excessive settlement;
(i) Excessive heave;
(j) Excessive lateral movement;
(k) Unacceptable vibrations.

4.1.3 Precast Reinforced and Prestressed Concrete Piles

1 Scope

(a) This Part applies to precast concrete driven piles usually supplied for use in a single length without facility for joining lengths together.

(b) Related Sections and Parts are as follows:

2 References

The following Standards are referred to in this Part:

ASTM D1143/D1143M Standard Test Methods for Deep Foundation Elements Under Static Axial Compressive Load

ASTM D3689/D3689M Standard Test Methods for Deep Foundation Elements Under Static Axial Tensile Load

ASTM D3966/D3966M Standard Test Methods for Deep Foundation Elements Under Static Lateral Load

ASTM D4428/D4428M Standard Test Methods for Crosshole Seismic Testing

ASTM D5882.....Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations

ASTM D6167.....Standard Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper

ASTM D6760.....Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing

BS 2789, ...Specification for spheroidal graphite or nodular graphite cast iron

.....EN 1563; Founding. Spheroidal graphite cast irons

BS 3100, ...Specification for steel castings for general engineering purposes

.....EN 10293; Steel castings. Steel castings for general engineering uses

BS 5573, ...Code of practice for safety precautions in the construction of large diameter boreholes for piling and other purposes

BS 5930 .....Code of practice for ground investigations

BS 7613, ...Specification for hot rolled quenched and tempered weldable structural steel plates

.....EN 10025-6; Hot rolled products of structural steels - Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition

BS 8110, ...Structural use of concrete.

EN 1992 .....Eurocode 2: Design of concrete structures

3 Submittals

(a) The Contractor shall order the piles to suit the construction programme and seek the Engineer's approval before placing the order. When preliminary piles are specified, the approval of the piles for the main work will not necessarily be given until the results of the driving and loading tests on preliminary piles have been received and evaluated.

4 Quality Assurance

(a) After a pile has been cast, the date of casting, reference number, length and, where appropriate, the prestressing force shall be clearly inscribed on the top surface of the pile and also clearly and indelibly marked on the head of the pile. Lifting positions shall be marked at the proper locations on each pile.

5 Tolerances in Pile Dimensions

(a) The cross-sectional dimensions of the pile shall be not less than those specified and shall not exceed them by more than 6 mm. Each face of a pile shall not deviate by more than 6 mm from any straight line 3 m long joining two points on that face, nor shall the centre of area of the pile at any cross section along its length deviate by more than 1/500 of the pile length from a line joining the centres of area at the ends of the pile. Where a pile is less than 3 m long, the permitted deviation from straightness shall be reduced below 6 mm on a *pro rata* basis in accordance with actual length.

6 Handling, Transportation and Storage of Piles

(a) The method and sequence of lifting, handling, and storage of piles transporting and storing piles shall be such as to avoid shock loading and to ensure that the piles are not damaged. Only the designated lifting and support points shall be used. During transport and storage, piles shall be appropriately supported under the marked lifting points or fully supported along their length.

(b) All piles within a stack shall be in groups of the same length. Packing of uniform thickness shall be provided between piles at the lifting points.

(c) Concrete shall at no time be subjected to loading, including its own weight, which will induce a compressive stress in it exceeding 0.33 of its strength at the time of loading or of the specified strength, whichever is the lesser. For this purpose the assessment of the strength of the concrete and of the stresses produced by the loads shall be subject to the agreement of the Engineer.

(d) Pile may be rejected when the width of any transverse crack exceeds 0.3 mm. The measurement shall be made with the pile in its working attitude.

4.1.4 Materials and components

1 Fabricated Steel Components

(a) In the manufacture of precast concrete piles, fabricated steel components shall comply with BS 7613 grades 43A or 50B, cast steel components with BS 3100 grade A, and ductile iron components with BS 2789.

2 Pile Toes

(a) Pile toes shall be constructed so as to ensure that damage is not caused to the pile during installation. Where positional fixity is required on an inclined rock surface or in other circumstances, an approved shoe may be required.

3 Pile Head Reinforcement

(a) The head of each pile shall be so reinforced or banded as to prevent bursting of the pile under driving conditions.

4 Main Reinforcement

(a) The main longitudinal reinforcing bars in piles not exceeding 12 m in length shall be in one continuous length unless otherwise specified. In piles more than 12 m long, lap splicing will be permitted in main longitudinal bars at 12 m nominal intervals, with no more than 25 % of the bars lapped at one location, and laps staggered by a minimum of 1.2 m. Laps in reinforcement shall be such that the full strength of the bar is effective across the joint.

(b) Lap or splice joints shall be provided with sufficient link bars to resist eccentric forces.

(c) Sufficient reinforcement shall be provided for lifting and handling purposes.

5 Concrete

(a) Unless otherwise agreed by the Engineer, concrete shall be compacted with the assistance of vibrators. Internal vibrators shall be capable of producing not less than 150 Hz and external vibrators not less than 50 Hz. Internal vibrators shall operate not closer than 75 mm to shuttering.

(b) Vibrators shall be operated in such a manner that neither segregation of the concrete mix constituents nor displacement of reinforcement occurs.

(c) Immediately after compaction, concrete shall he adequately protected from the harmful effects of the weather, including wind, rain, rapid temperature changes and frost. It shall be protected from drying out by an approved method of curing.

(d) Piles shall not be removed from formwork until a sufficient pile concrete strength has been achieved to allow the pile to be handled without damage.

(e) The period of curing at an ambient temperature of 10 °C shall not be less than that shown in Table 4.1. If the temperature is greater or less than 10 °C, the periods given shall be adjusted accordingly and shall be approved.

(f) When steam or accelerated curing is used the curing procedure shall be approved. Four hours must elapse from the completion of placing concrete before the temperature is raised. The rise in temperature within any period of 30 min shall not exceed 10 °C and the maximum temperature attained shall not exceed 70 °C. The rate of subsequent cooling shall not exceed the rate of heating.

Table 4.1
Period of Curing at 10 °C

Type of cement	Wet curing time after completion of placing concrete, d
Ordinary Portland	4
Sulphate-resisting Portland	4
Portland blast-furnace	4
Super-sulphated	4
Rapid-hardening Portland	3

6 Formwork

(a) shaped point or shoe, then the end of the pile shall be symmetrical about the longitudinal axis of the pile. Holes for handling or pitching, where provided in the pile, shall be lined with steel tubes; alternatively, approved inserts may be cast in.

(b) Formwork shall be robust, clean and so constructed as to prevent loss of grout or aggregate from the wet concrete and ensure the production of uniform pile sections, free from defects. The piles are to be removed from the formwork carefully so as to prevent damage.

4.1.5 Prestressing

1 General

(a) Tensioning shall be carried out only when the Engineer is present, unless otherwise approved. In cases where piles are manufactured off site, the Contractor shall ensure that the Engineer is given adequate notice and every facility for inspecting the manufacturing process.

(b) Prestressing operations shall be carried out only under the direction of an experienced and competent supervisor. All personnel operating the stressing equipment shall have been trained in its use.

(c) The calculated extensions and total forces, including allowance for losses, shall be agreed with the Engineer before stressing is commenced.

(d) Stressing of tendons and transfer of prestress shall be carried out at a gradual and steady rate. The force in the tendons shall be obtained from readings on a recently calibrated load cell or pressure gauge incorporated in the equipment. The extension of the tendons under the agreed total forces shall be within 5 % of the agreed calculated extension.

2 Concrete Strength

(a) The Contractor shall cast sufficient cubes, cured in the same manner as the piles, to be able to demonstrate by testing two cubes at a time, with approved intervals between pairs of cubes, that the specified transfer strength of the concrete has been reached.

(b) Unless otherwise permitted, concrete shall not be stressed until two test cubes attain the specified transfer strength.

3 Post-Tensioned Piles

(a) Ducts and vents in post-tensioned piles shall be grouted after the transfer of prestress.

4 Grouting Procedure

(a) Grout shall be mixed for a minimum of 2 min and until a uniform consistency is obtained.

(b) Ducts shall not be grouted when the air temperature in the shade is lower than 3 °C.

(c) Before grouting is started all ducts shall be thoroughly cleaned by means of compressed air.

(d) Grout shall be injected near the lowest point in the duct in one continuous operation and allowed to flow from the outlet until the consistency is equivalent to that of the grout being injected.

(e) Vents in ducts shall be provided in accordance with Clause 8.9.2 of BS 8110.

5 Grout

(a) Unless otherwise directed or agreed by the Engineer

(i) the grout shall consist only of ordinary Portland cement, water and approved admixtures; admixtures containing chlorides or nitrates shall not be used

(ii) the grout shall have a water/cement ratio as low as possible consistent with the necessary workability, and the water/cement ratio shall not exceed 0.45 unless an approved mix containing an expanding agent is used

(iii) the grout shall not be subject to bleeding in excess of 2 % after 3 h, or in excess of 4% maximum, when measured at 18 °C in a covered glass cylinder approximately 100 mm in diameter with a height of grout of approximately 100 mm, and the water shall be reabsorbed after 24 h.

6 Records

(a) The Contractor shall keep detailed records of times of tensioning, measured extensions, pressure gauge readings or load cell readings and the amount of pull-in at each anchorage. Copies of these records shall be supplied to the Engineer within such reasonable time from completion of each tensioning operation as may be required, and in any case not later than noon on the following working day.

(b) The Contractor shall keep records of grouting, including the date, the proportions of the grout and any admixtures used, the pressure, details of interruption and topping up required. Copies of these records shall be supplied to the Engineer within such reasonable time after completion of each grouting operation as may be required, and in any case not later than noon on the following working day.

4.1.6 Driving Piles

1 Strength of Piles

(a) Piles shall not be driven until the concrete has achieved the specified strength.

2 Leaders and Trestles

(a) At all stages during driving and until incorporation into the substructure, the pile shall be adequately supported and restrained by means of leaders, trestles, temporary supports or other guide arrangements to maintain position and alignment and to prevent buckling. These arrangements shall be such that damage to the pile does not occur.

3 Performance of Driving Equipment

(a) The Contractor shall satisfy the Engineer regarding the suitability, efficiency and energy of the driving equipment. Where designated, dynamic evaluation and analysis shall be provided.

(b) Where a drop hammer is used, the mass of the hammer shall be at least half that of the pile unless otherwise approved by the Engineer. For other types of hammer the energy delivered to the pile per blow shall be at least equivalent to that of a drop hammer of the stated mass. Drop hammers shall not be used from floating craft in such a manner as to cause instability of the craft or damage to the pile.

4 Length of Piles

(a) The length of pile to be driven in any location shall be approved prior to the commencement of driving.

5 Driving Procedure and Redrive Checks

(a) The driving of each pile shall be continuous until the specified depth or resistance (set), or both, has been reached. In the event of unavoidable interruption to driving, the pile will be accepted provided it can subsequently be driven to the specified depth or resistance (set), or both, without damage. A follower shall not be used unless approved, in which case the Engineer will require the set where applicable to be revised in order to take into account reduction in the effectiveness of the hammer blow.

(b) The Contractor shall inform the Engineer without delay if an unexpected change in driving characteristics is noted. A detailed record of the driving resistance over the full length of the nearest available pile shall be taken if required.

(c) At the start of the work in a new area or section, a detailed driving record shall be made over the full length of the first pile and during the last 3 m of subsequent piles until consistency of behaviour is established. Where required, detailed driving records shall also be made for 5 % of the piles driven, the locations of such piles being specified by the Engineer.

(d) The Contractor shall give adequate notice and provide all necessary facilities to enable the Engineer to check driving resistance. A set or resistance measurement shall be taken only in the presence of the Engineer unless otherwise approved.

(e) Redrive checks, if required, shall be carried out to an approved procedure.

6 Final Set

(a) When driving to a set criterion, the final set of each pile shall be recorded either as the penetration in millimetres per 10 blows or as the number of blows required to produce a penetration of 25 mm.

(b) When a final set is being measured, the following requirements shall be met:

(i) The exposed part of the pile shall be in good condition without damage or distortion.

(ii) The helmet, dolly and any packing shall be in sound condition.

(iii) The hammer blow shall be in line with the pile axis and the impact surfaces shall be flat and at right angles to the pile and hammer axis, and the head of the pile protected against damage from hammer impact.

(iv) The hammer shall be in good condition, delivering adequate energy per blow, and operating correctly.

(v) The temporary compression of the pile shall be recorded, if required.

7 Preboring

(a) If preboring is specified, the diameter and depth of prebore shall be as designated.

8 Jetting

(a) Jetting shall be carried out only when the Contractor's detailed proposals have been approved.

4.1.7 Risen Piles

(a) Piles shall be driven in an approved sequence to minimise the detrimental effects of heave and lateral displacement of the ground.

(b) When required, levels and measurements shall be taken to determine the movement of the ground or of any pile resulting from the driving process.

(c) When a pile has risen as a result of adjacent piles being driven, the Engineer may call for redriving or other testing to demonstrate that the performance of the pile is unimpaired. If required, the Contractor shall make proposals for correcting detrimentally affected piles and for avoidance or control of heave effects in subsequent work.

4.1.8 Repair and lengthening of piles

1 Repair of Damaged Pile Heads

(a) If it is necessary to repair the head of a pile during driving, the Contractor shall carry out such repair in an approved way which allows the pile-driving to be completed without further damage. If the driving of a pile has been accepted but sound concrete of the pile is below the required cut-off level, the pile shall be made good to the cut-off level, using an approved method so that it will safely withstand the imposed design load.

2 Lengthening of Reinforced and Prestressed Concrete Piles

(a) Any provision for lengthening piles incorporated at the time of manufacture shall be as designed or approved.

(b) If no provision for lengthening piles was incorporated at the time of manufacture, any method for lengthening shall be such that splices are capable of safely resisting the stresses during driving and under service load and shall be subject to approval.

3 Driving Repaired or Lengthened Piles

(a) Repaired or lengthened piles shall not be driven until the added concrete has reached the specified strength of the concrete of the pile.

4.1.9 Cutting off pile heads

1 Unless otherwise directed by the Engineer, when the driving of a pile has been approved the concrete of the head of the pile shall be cut off to the designated level. The length of splice reinforcing bars projecting above this level shall be as designated.

2 Care shall be taken to avoid shattering or otherwise damaging the rest of the pile. Any cracked or defective concrete shall be cut away and the pile repaired in an approved manner to provide a full and sound section at the cut-off level.

4.2 PRECAST REINFORCED CONCRETE SEGMENTAL PILES

4.2.1 Scope

1 This Part applies to piles made of elements cast at a precasting works away from the site, where work cannot normally be closely supervised by the Engineer. The elements are joined together as necessary on site during driving using special proven steel joints incorporated into the pile elements when cast.

2 Related Sections and Parts are as follows:

This Section
Part 1,..... General Requirements for Piling Works
Part 2,..... Concrete Works for Piling
Section 5, ... Concrete.

4.2.2 References

1 The following Standards are referred to in this Part:

API 5L,.....Interpretation of non-destructive testing, (American Petroleum Institute, “API 5L Specification for Line Pipe”)

BS 4, ...Structural steel sections

.....EN 10025; Hot rolled products of structural steels

.....EN 10056; Structural steel equal and unequal leg angles

.....EN 10365; Hot rolled steel channels, I and H sections. Dimensions and masses

BS 5135, ...Specification for arc welding of carbon and carbon manganese steels

.....EN 1011-1; Welding. Recommendations for welding of metallic materials - General guidance for arc welding

.....EN 1011-2; Welding. Recommendations for welding of metallic materials - Arc welding of ferritic steels

BS 6265, ...Specification for resistance seam welding of uncoated and coated low carbon steel

.....ISO 16433; Resistance welding. Procedure for seam welding of uncoated and coated low carbon steels

BS 2789, ...Specification for spheroidal graphite or nodular graphite cast iron

.....EN 1563; Founding. Spheroidal graphite cast irons

BS 3100, ...Specification for steel castings for general engineering purposes

.....EN 10293; Steel castings. Steel castings for general engineering uses

BS 7613, ...Specification for hot rolled quenched and tempered weldable structural steel plates

.....EN 10025-6; Hot rolled products of structural steels - Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition

BS 8110, ...Structural use of concrete.

.....EN 1992; Eurocode 2: Design of concrete structures

EN 1997 .....Eurocode 7: Geotechnical design,

EN1997-1 .....Eurocode 7: Geotechnical design - Part 1: General rules, (Section 7 Pile foundations)

4.2.3 Submittals

1 The Contractor shall order the piles to suit the construction programme and seek the Engineer's approval before placing the order. When preliminary piles are specified the approval for the piles for the main work will not necessarily be given until the results of the driving and tests on preliminary piles have been received and evaluated.

4.2.4 Quality Assurance

1 A certificate of quality from the pile manufacturer shall be provided to the Engineer when required stating that the designated requirements have been fulfilled during manufacture.

2 Each pile element shall be marked in such a manner that it can be identified with the records of manufacture, which shall state the date of casting, the cement type, concrete grade, element length and any other relevant data. On delivery, the pile elements shall be accompanied by records of manufacture.

4.2.5 Tolerances in Pile Dimensions

1 The cross-sectional dimensions of the pile shall be not less than those designated.

2 The head of a pile element or the end of the pile upon which the hammer acts shall be square to the pile axis within a tolerance of 1 in 50.

3 Each pile joint shall be square to the axis of the pile within a tolerance of 1 in 150. The centroid of the pile joint shall lie within 5 mm of the true axis of the pile element.

4 Each face of a pile element shall not deviate by more than 6 mm from any straight line 3 m long joining two points on that face, nor shall the centre of area of the pile at any cross-section along its length deviate by more than 1/500 of the pile length from a line joining the centres of area at the ends of the element. Where a pile element is less than 3 m long the permitted deviation from straightness shall be reduced below 6 mm on a *pro rata* basis in accordance with actual length.

4.2.6 Handling, Transportation, Storage and Acceptance of Piles

1 The method and sequence of lifting, handling, transporting and storing piles shall be such as to avoid shock loading and to ensure that the piles are not damaged. Only designed lifting and support points shall be used. During transport and storage, piles shall be appropriately supported under the marked lifting points or fully supported along their length.

2 All pile elements within a stack shall be in groups of the same length. Packing of uniform thickness shall be provided between piles at the lifting points.

3 Concrete shall at no time be subjected to loading, including its own weight, which will induce a compressive stress in it exceeding 0.33 of its strength at the time of loading or of the specified strength, whichever is the less. For this purpose the assessment of the strength of the concrete and of the stresses produced by the loads shall be subject to the approval of the Engineer.

4 A pile element shall be rejected when the width of any transverse crack exceeds 0.3 mm. The measurement shall be made with the pile in its working attitude.

4.2.7 Materials and components

1 Fabricated Steel Components

(a) In the manufacture of jointed precast concrete segmental piles, fabricated steel components shall comply with BS 7613 grades 43A or 50A, cast steel components with BS 3100 grade A, and ductile iron components with BS 2789.

2 Pile Splices

(a) The splice joints shall be close-fitting face to face and the locking method shall be such as to hold the faces in intimate contact. The design and manufacture of the splicing system shall be approved by the Engineer prior to the commencement of the Contract.

(b) A spliced pile shall be capable of withstanding the same driving stresses or service axial loads, moments and shear stresses as a single unspliced pile of the same cross-sectional dimensions and materials.

(c) The welding of a joint to main reinforcement in lieu of a lapped connection with projecting bars affixed to the joint will not be permitted.

3 Pile Toes

(a) Pile toes shall be constructed so as to ensure that damage is not caused to the pile during installation. Where fixity is required or socketing into rock, or in other circumstances, an approved shoe may be required.

4 Pile Head Reinforcement

(a) Where the pile head is not furnished with a joint, it shall be so reinforced or banded as to prevent bursting of the pile under driving conditions.

5 Main Reinforcement

(a) The main longitudinal reinforcing bars shall be in one continuous length. Splicing of bars will not be permitted except at element ends.

(b) Concrete cover to steel reinforcement shall be in accordance with the requirements of BS 8110.

(c) In very aggressive ground or exposure conditions, cover greater than 25 mm may be required, but alternative protection methods may be approved.

6 Formwork

(a) If a pile is constructed with a shaped point or shoe, then the end of the pile shall be symmetrical about the longitudinal axis of the pile.

(b) Holes for handling or pitching, where provided in the pile, shall be lined with steel tubes; alternatively, approved inserts may be cast in.

(c) Formwork shall be robust, clean and so constructed as to prevent loss of grout or aggregate from the wet concrete and ensure the production of uniform pile sections. The piles are to be removed from the formwork carefully so as to prevent damage.

4.2.8 Driving piles

1 Strength of Piles

(a) Piles shall not be driven until the concrete has achieved the specified characteristic strength.

2 Leaders and Trestles

(a) At all stages during driving and until incorporation into the substructure, the pile shall be adequately supported and restrained by means of leaders, trestles, temporary supports or other guide arrangements to maintain position and alignment and to prevent buckling. These arrangements shall be such that damage to the pile does not occur.

3 Performance of Driving Equipment

(a) The Contractor shall satisfy the Engineer regarding the suitability, efficiency and energy of the driving equipment. Where required in the particular specification, dynamic evaluation and analysis shall be provided.

(b) Where a drop hammer is used, the mass of the hammer shall be at least half that of the pile at the moment of driving unless otherwise approved by the Engineer. For other types of hammer, the energy delivered to the pile per blow shall be at least equivalent to that of a drop hammer of the stated mass. Drop hammers shall not be used from floating craft in such a manner as to cause instability of the craft or damage to the pile.

4 Length of Piles

(a) The length of pile supplied to be driven in any location and any additional lengths to be added during driving shall he approved prior to the commencement of pile-driving. During the execution of the Works, any changes to the supplied lengths shall be approved.

5 Driving Procedure and Redrive Checks

(a) Except when making field splices, the driving of each pile shall he continuous until the specified depth or resistance (set), or both, has been reached. In the event of unavoidable interruption to driving, the pile will be accepted provided it can subsequently be driven to the specified depth or resistance (set), or both, without damage. A follower shall only be used when approved, in which case the Engineer will require the set where applicable to be revised in order to take into account reduction in the effectiveness of the hammer blow.

(b) The Contractor shall inform the Engineer without delay if an unexpected change in driving characteristics is noted. A detailed record of the driving resistance over the full length of the nearest available pile shall be taken if required.

(c) At the start of the work in a new area or section a detailed driving record shall be made over the full length of the first pile and during the last 3 m of subsequent piles until consistency of behaviour is established. Where required, detailed driving records shall also be made for 5 % of the piles driven, the positions of such piles being specified by the Engineer.

(d) The Contractor shall give adequate notice and provide all necessary facilities to enable the Engineer to check driving resistance. A set or resistance measurement shall be taken only in the presence of the Engineer unless otherwise approved.

(e) Redrive checks, if required, shall be carried out to an approved procedure.

6 Final Set

(a) When driving to a set criterion, the final set of each pile shall be recorded either as the penetration in millimetres per ten blows or as the number of blows required to produce a penetration of 25 mm.

(b) When a final set is being measured, the following requirements shall be met:

(i) The exposed part of the pile shall be in good condition, without damage or distortion.

(ii) The helmet, dolly and any packing shall be in sound condition.

(iii) The hammer blow shall be in line with the pile axis and the impact surfaces shall be flat and at right angles to the pile and hammer axis.

(iv) The hammer shall be in good condition, delivering adequate energy per blow, and operating correctly.

(v) The temporary compression of the pile shall be recorded if required.

7 Preboring

(a) If preboring is specified, the diameter and depth of prebore shall be as designated.

8 Jetting

(a) Jetting shall be carried out only when the Contractor's detailed proposals have been approved.

4.2.9 Risen Piles

(a) Piles shall be driven in an approved sequence to minimise the detrimental effects of heave and lateral displacement of the ground.

(b) When required, levels and measurements shall be taken to determine the movement of the ground or of any pile resulting from the driving process.

(c) When a pile has risen as a result of adjacent piles being driven, the Engineer may call for redriving or other testing to demonstrate that the performance of the pile is unimpaired. If required, the Contractor shall make proposals for correcting piles detrimentally affected and for avoidance or control of heave effects in subsequent work.

4.2.10 Repair and lengthening of piles

1 Repair of Damaged Pile Heads

(a) If it is necessary to repair the head of a pile during driving, the Contractor shall carry out such repair in an approved way which allows the driving of the pile to be completed without further damage. If the driving of a pile has been accepted but sound concrete of the pile is below the required cut-off level, the pile shall be made good to the cut-off level, using an approved method so that it will safely withstand the imposed design load.

2 Lengthening of Piles

(a) Where piles are required to be driven to depths exceeding those expected, leaving insufficient projection for bonding into the following works, the piles shall be extended or replaced as required by the Engineer using approved materials and methods.

4.2.11 Cutting off pile heads

1 Unless otherwise specified, when the driving of a pile has been approved the concrete of the head of the pile shall be cut off to the designated level. The length of splice reinforcing bars projecting above this level shall be as designated.

2 Care shall be taken to avoid shattering or otherwise damaging the rest of the pile. Any cracked or defective concrete shall be cut away and the pile repaired in an approved manner to provide a full and sound section at the cut-off level.

4.3 BORED CAST IN PLACE PILES

4.3.1 Scope

1 This Part applies to bored piles in which the pile bore is excavated by rotary or percussive means, or both, using short augers, buckets, grabs or other boring tools to advance the open bore. Where the open bore is unstable, temporary or permanent casing or bentonite suspension may be used to support the wall of the bore prior to concreting.

2 Related Sections and Parts are as follows:

This Section
Part 1,..... General Requirements for Piling Works
Part 2,..... Concrete Works for Piling

Section 3, Ground Investigation
Section 5, Concrete

4.3.2 References

1 The following codes of practice are referred to in this Part:

BS 5573, ...Code of practice for safety precautions in the construction of large diameter boreholes for piling and other purposes

BS 5930 .....Code of practice for ground investigations

4.3.3 Quality Assurance

1 Inspection

(a) Each pile bore which does not contain standing water or drilling fluid shall be inspected directly or indirectly prior to concrete being placed in it. This inspection shall be carried out from the ground surface in the case of piles of less than 750 mm diameter. Torches or other approved means of lighting, measuring tapes, and a means of measuring verticality shall be provided. For piles of 750 mm diameter or larger, equipment shall be provided, by the Contractor to enable his representatives and the Engineer to descend into the bore for the purpose of inspection. Any method of descent and the equipment used shall comply with the requirements of BS 5573.

2 Cleanliness of pile bases

(a) On completion of boring and where inspection of a dry pile bore indicates the necessity, loose, disturbed or softened soil shall be removed from the bore. Where pile bores contain water or drilling fluid, a cleaning process shall be employed before concrete is placed. Large debris and accumulated sediment shall be removed using appropriate approved methods, which shall be designed to clean while at the same time minimising ground disturbance below the pile bases. Water or drilling fluid shall be maintained at such levels throughout and following the cleaning operation that stability of the bore is preserved.

3 Samples and Testing

(a) If required in the Contract, soil, rock or groundwater samples shall be taken or soil tests carried out in-situ while the pile is being bored. The samples shall be taken to an approved laboratory for testing as specified.

(b) The taking of samples and all subsequent handling, transporting and testing shall be carried out in accordance with Section 3, Ground Investigation.

4.3.4 Materials

1 Permanent Casings

(a) Permanent casings shall be as specified.

2 Drilling Fluid Supply

(a) A certificate shall be obtained by the Contractor from the manufacturer of the bentonite powder showing the properties of each consignment delivered to the Site. This certificate shall be made available to the Engineer on request. The properties to be given by the manufacturer are the apparent viscosity range (in Pascal seconds) and the gel strength range (in Pascal) for solids in water.

3 Drilling Fluid Mixing

(a) Bentonite shall be mixed thoroughly with clean fresh water to make a suspension which will maintain the stability of the pile bore for the period necessary to place concrete and complete construction. The temperature of the water used in mixing the bentonite suspension, and of the suspension when supplied to the borehole, shall be not lower than 5 °C.

(b) Where saline or chemically contaminated groundwater occurs, special precautions shall be taken to modify the bentonite suspension or prehydrate the bentonite in fresh water so as to render it suitable in all respects for the construction of piles.

4 Drilling Fluid Tests

(a) The frequency of testing drilling fluid and the method and procedure of sampling shall be proposed by the Contractor for approval prior to the commencement of the work. The frequency may subsequently be varied as required, depending on the consistency of the results obtained, subject to approval.

(b) Control tests shall be carried out on the bentonite suspension, using suitable apparatus. The density of freshly mixed bentonite suspension shall be measured daily as a check on the quality of the suspension being formed. The measuring device shall be calibrated to read to within 0.005 g/ml. Tests to determine density, viscosity, shear strength and pH value shall be applied to bentonite supplied to the pile bore. For average soil conditions the results shall generally be within the ranges in Table 4.2.

Table 4.2.
Tests on Bentonite

Property to be measured	Range of results at 20 °C	Test method
Density	Less than 1.10 g/ml	Mud density balance
Viscosity	30 - 90 s or less than 0.020 Pa • s	Marsh cone method Fann viscometer*
Shear strength (10 minute gel strength)	1.4-10 Pa Or 4-40 Pa	Shear meter Fann viscometer
pH	9.5 - 12	pH indicator paper strips or electrical pH meter

* Where the Fann viscometer is specified, the fluid sample should be screened by a number 52 sieve (300 μm) prior to testing.

(c) The tests shall be carried out until a consistent working pattern has been established account being taken of the mixing process, any blending of freshly mixed bentonite suspension and previously used bentonite suspension, and any process which may be used to remove impurities from previously used bentonite suspension. When the results show consistent behaviour, the tests for shear strength and pH value may be discontinued, and tests to determine density and viscosity shall be carried out as agreed with the Engineer. In the event of a change in the established working pattern, tests for shear strength and pH value shall be reintroduced for a period if required.

4.3.5 Boring

1 Boring Near Recently Cast Piles

(a) Piles shall not be bored so close to other recently completed piles as to damage them.

2 Temporary Casings

(a) Temporary casing of approved quality or an approved alternative method shall be used to maintain the stability of a pile bore which might otherwise collapse.

(b) Temporary casings shall be free from significant distortion. They shall be of uniform cross-section throughout each continuous length. During concreting they shall be free from internal projections and encrusted concrete which might adversely affect the proper formation of piles.

(c) The use of a vibrator to insert and withdraw temporary casing may be permitted by the Engineer subject to compliance with Noise and Disturbance and Damage to Adjacent Structures of this section and to the method not causing disturbance of the ground which would adversely affect the construction or the capacity of piles.

(d) Where piles are bored under water or bentonite suspension in an unlined state, the insertion of a full-length loosely fitting casing to the bottom of the bore prior to placing concrete will not be permitted.

(e) Where permanent casing is specified to ensure the integrity of a pile, the Contractor shall submit for approval his proposals regarding the method of installation.

3 Stability of Pile

(a) Where boring takes place through unstable water-bearing strata, the process of excavation and the depth of temporary casing employed shall be such that soil from outside the area of the pile is not drawn into the pile section and cavities are not created outside the temporary casing as it is advanced.

(b) Where the use of drilling fluid is specified or approved for maintaining the stability of a bore, an adequate temporary casing shall be used in conjunction with the method so as to ensure stability of the strata near ground level until concrete has been placed. During construction the level of drilling fluid in the pile excavation shall be maintained within the cased or stable bore so that it is not less than 1.0 m above the level of external standing groundwater at all times.

(c) In the event of a rapid loss of drilling fluid from a pile excavation, the bore shall be backfilled without delay and the instructions of the Engineer shall be obtained before boring at that location is resumed.

4 Spillage and Disposal of Drilling Fluid

(a) All reasonable steps shall be taken to prevent the spillage of bentonite suspension on the Site in areas outside the immediate vicinity of boring. Discarded bentonite shall be removed from the Site without undue delay. Any disposal of bentonite shall comply with the regulations of the local controlling authority.

5 Pumping from Pile Bores

(a) Pumping from pile bores shall not be permitted unless the bore has been sealed against further water entry by casing or unless the soil is stable and will allow pumping to take place without ground disturbance below or around the pile.

6 Continuity of Construction

(a) For a pile constructed in a stable cohesive soil without the use of temporary casing or other form of support, the pile shall be bored and the concrete shall be placed without such delay as would lead to significant impairment of the soil strength.

7 Enlarged Pile Bases

(a) A mechanically formed enlarged base shall be no smaller than the dimensions specified and shall be concentric with the pile shaft to within a tolerance of 10 % of the shaft diameter. The sloping surface of the frustum forming the enlargement shall make an angle to the axis of the pile of not more than 35 °.

4.3.6 Extraction of casing

1 Workability of Concrete

(a) Temporary casings shall be extracted while the concrete within them remains sufficiently workable to ensure that the concrete is not lifted. During extraction the motion of the casing shall be maintained in an axial direction relative to the pile.

2 Concrete Level

(a) When the casing is being extracted, a sufficient quantity of concrete shall be maintained within it to ensure that pressure from external water, drilling fluid or soil is exceeded and that the pile is neither reduced in section nor contaminated.

(b) The concrete level within a temporary casing shall be topped up where necessary during the course of casing extraction in such a way that the base of the casing is always below the concrete surface until the casting of the pile has been completed.

(c) Adequate precautions shall be taken in all cases where excess heads of water or drilling fluid could occur as the casing is withdrawn because of the displacement of water or fluid by the concrete as it flows into its final position against the walls of the pile bore. Where two or more discontinuous lengths of casing (double casing) are used in the construction the proposed method of working shall be approved.

3 Pile Head Casting Level Tolerances

(a) For piles cast in dry bores using temporary casing and without the use of a permanent lining, pile heads shall be cast to a level above the specified cut-off so that, after trimming, a sound concrete connection with the pile can be made. The casting level shall be within the tolerance above the cut-off level shown in Table 4.3, but shall not be above the original ground level. No pile shall be cast with its head below standing water level unless approved measures are taken to prevent inflow of water causing segregation of the concrete as temporary casing is extracted, and, where approved by the Engineer, the groundwater level for each pile shall be treated as the cut-off level for the purpose of calculating tolerance.

(b) For piles cast in dry bores within permanent lining tubes or permanent casings, or where their cut-off levels are in stable ground below the base of any casing used, pile heads shall be cast to a level above the specified cut-off so that, after trimming, a sound concrete connection with the pile can be made. The casting level shall be within the tolerance above the cut-off level shown in Table 4.4, but shall not be above the original ground level.

(c) For piles cast under water or drilling fluid, the pile heads shall be cast to a level above the specified cut-off so that, after trimming to remove all debris and contaminated concrete, a sound concrete connection with the pile can be made. The casting level shall be within the tolerance above the cut-off level shown in Table 4.4, but shall not be above the commencing surface level. Cut-off levels may be specified below the standing groundwater level, and where this condition applies the borehole fluid level shall not be reduced below the standing groundwater level until the concrete has set.

(d) Where the cut-off level of piles lies at depths greater than 10 m below the original ground level, then the tolerances given in Tables 4.3, 4.4 and 4.5 will be varied after discussion with the Contractor and before the commencement of the piling to take account of the special conditions which apply.

Table 4.3
Casting Tolerance above Cut-off Level for Piles Cast In Dry Bores Using Temporary Casing and Without the Use of a Permanent Lining

Cut-off distance below commencing surface, *H*, m	Casting tolerance above cut-off level, m
0.15-10.00	0.3 + *H*/12 + *C*/8 where *C* = length of temporary casing below the commencing surface*

* If *H* is greater than *C*, then this tolerance is no longer applicable and the tolerances in Table 4.4 will apply.

Table 4.4
Casting Tolerance above Cut-off Level for Piles Cast in Dry Bores within Permanent Lining Tubes or Permanent Casings, or Where Their Cut-Off Levels is in Stable Ground below the Base of Any Casing Used

Cut-off distance below commencing surface, *H*, m	Casting tolerance above cut-off level, m
0.15-10.00	0.3 + *H*/10

Table 4.5
Casting Tolerance above Cut-off Level for Piles Cast Under Water or Drilling Fluid**

Cut-off distance below commencing surface, *H*, m	Casting tolerance above cut-off level, m
0.15-10.00	1.0 + *H* /12 + *C*/8 where *C* = length of temporary casing below the commencing surface

** In cases where a pile is cast so that the cut-off is within a permanent lining tube, the appropriate tolerance is given by deletion of the casing term *C*/8 in the table.

4 Water levels

(a) During extraction of temporary casings, where circumstances are such that newly placed unset concrete is brought into contact with external groundwater, precautions shall be taken to ensure that the internal concrete pressure at all levels within the pile exceeds the external groundwater pressure.

5 Temporary backfilling above pile casting level

(a) After each pile has been cast, any empty bore remaining shall be protected and shall be carefully backfilled as soon as possible with approved materials.

6 Disposal of excavated material

(a) Disposal of excavated material shall be carried out by the Contractor as necessary to facilitate the Works and to the satisfaction of the Engineer.

7 Cutting off pile heads

(a) When cutting off and trimming piles to the specified cut-off level, the Contractor shall take care to avoid shattering or otherwise damaging the rest of the pile. Any cracked or defective concrete shall be cut away and the pile repaired in an approved manner to provide a full and sound section at the cut-off level

4.4 BORED PILES CONSTRUCTED USING CONTINUOUS FLIGHT AUGERS AND CONCRETE OR GROUT INJECTION TROUGH HOLLOW AUGER STEMS

4.4.1 Scope

1 This Part applies to bored piles which employ a continuous flight auger for both advancing the bore and maintaining its stability. The spoil-laden auger is not removed from the ground until concrete or grout is pumped into the pile bore from the base of the hollow-stemmed auger to replace the excavated soil.

2 Related Sections and Parts are as follows:

This Section
Part 1,..... General Requirements for Piling Works
Part 2,..... Concrete Works for Piling

Section 3, Ground Investigation.
Section 5, Concrete

4.4.2 Materials

1 Concrete Mix Design and Workability

(a) Where not otherwise stated in this Part, the concrete shall comply with Section 5. The design and workability of concrete to be used in the formation of a pile shall produce a mix which is suitable for pumping. It shall have a minimum slump of 150 mm unless otherwise approved and a minimum cement content of 340 kg/m^3. The mix shall be designed so that segregation does not occur during the placing process, and bleeding of the mix shall be minimised.

2 Grout Mix Design and Workability

(a) Mix design of grout shall be subject to approval. Cement, water and aggregates for grout shall be according to Section 5. Course aggregate to be used shall be of 6 mm nominal size and shall be rounded and evenly graded.

(b) The workability of grout mixes, where used, shall be measured by a suitable and approved means. The procedure for monitoring the suitability of grout throughout the Works shall be stated in writing to the Engineer before beginning of the Works and shall be subject to approval.

(c) Additives to the grout shall require prior approval of the Engineer.

3 Reinforcement

(a) All reinforcement shall be placed with the minimum delay after the completion of the concreting or grouting operation. It shall be designed and fabricated in cages to permit it to be placed in the correct position and to the depth specified through the concrete or grout of the pile. Suitable approved spacers shall be provided to maintain the specified concrete or grout cover to steel.

(b) The transverse reinforcement of any reinforcing cage shall be approved and may consist of either spirals, hoops or links.

(c) Longitudinal main steel reinforcement shall be continuous over the specified length. Where splices are necessary, the number of laps shall be kept to a minimum and bars shall be welded or joined together in an approved manner.

(d) Reinforcement shall be supported and centred so that it will provide the required projection above the cut-off level, and the proper concrete cover.

4.4.3 Boring

1 General

(a) During uncased boring with continuous flight auger, the feed forward and speed (revolutions per minute) are to be adjusted according to the soil conditions in a way that the excavation of soil will be limited to a quantity that the lateral support of the uncased borehole wall will be ensured.

2 Boring Near Recently Cast Piles

(a) Piles shall not be bored so close to other piles which have recently been cast as to damage them.

3 Removal of Augers from the Ground

(a) Augers shall not be extracted from the ground during the boring or construction of a pile in such a way that an open unsupported bore or inflow of water into the pile section would result. While withdrawing the continuous flight auger, the auger shall be rotated in the same direction as during drilling into the soil or shall be withdrawn without rotation.

4 Depth of Piles

(a) Any failure of a pile to reach the designated depth shall be reported to the Engineer without delay and a full statement of the reasons given.

5 Suitability of Boring Equipment

(a) The piles shall be bored using approved and suitable equipment capable of penetrating the ground without drawing surrounding soils laterally into the pile bore.

4.4.4 Placing of concrete or grout

1 Equipment for Supply of Concrete or Grout to Piles

(a) Grout or concrete shall be supplied to the pile through suitable tubing and the hollow auger stem. All pipe fitments and connections shall be so constructed that grout does not leak during the injection process.

2 Commencement of Concrete or Grout Supply to Each Pile

(a) The base of the auger stem shall be fitted with a suitable means of sealing it against ingress of water and soil until concrete or grout placing begins.

(b) At the beginning of concrete or grout placement this sealing device shall be removed by the application of concrete or grout pressure. Care shall be taken to ensure that the auger is lifted only sufficiently to initiate the flow of concrete or grout, and that water inflow and soil movement at the base of the auger are minimised. The technique and equipment used to initiate and maintain the concrete or grout flow shall be such that a pile of the full specified cross-section is obtained from the maximum depth of boring to the final pile cut-off level.

3 Rate of Supply of Concrete or Grout

(a) The concrete or grout shall be supplied to the pile at a sufficient rate during auger withdrawal to ensure that a continuous monolithic shaft of the full specified cross-section is formed, free from debris or any segregated concrete or grout.

(b) The rate of withdrawal of the auger, the injection pressures and the rate of supply of concrete or grout shall be measured and recorded throughout the phase of auger withdrawal for each pile.

(c) The Contractor shall submit proposals for his method of monitoring construction for approval before beginning the Works.

4 Completion of Piles

(a) If the concrete or grout placing in any pile cannot be completed in the normal manner, then the pile shall be rebored before concrete has hardened and shall be completely replaced.

5 Casting Level of Pile Head

(a) Concrete or grout shall be cast to the original ground level in all cases, and the reinforcing cage set, as appropriate.

4.4.5 Cutting off pile heads

1 When cutting off and trimming piles to the specified cut-off level, the Contractor shall take care to avoid shattering or otherwise damaging the rest of the pile. Any laitance, or contaminated, cracked or defective concrete shall be cut away and the pile repaired in an approved manner to provide a full and sound section up to the cut-off level.

4.5 DRIVEN CAST IN PLACES PILES

4.5.1 Scope

1 This Part applies to piles for which a permanent casing of steel or concrete is driven, reinforcement placed within it if required, and the casing filled with concrete. It also applies to piles in which a temporary casing is driven, reinforcement placed within it and the pile formed in the ground by filling the temporary casing with concrete before and during its extraction.

2 Related Sections and Parts are as follows:

This Section
Part 1,..... General Requirements for Piling Works
Part 2,..... Concrete Works for Piling

Section 5, Concrete
Section 3, Ground Investigation.

4.5.2 Submittals

1 Where the Contractor wishes to form a pile with an enlarged base, details of the proposed method of forming the base and the materials to be used shall be submitted at the time of tendering.

4.5.3 Quality Assurance

1 Before placing concrete in a pile casing, the Contractor shall check in an approved manner that the casing is undamaged, and free from water or other foreign matter. In the event of water or foreign matter having entered the pile casing, either the casing shall be withdrawn, repaired if necessary and re-driven, or other action shall be taken as may be approved to continue the construction of the pile.

4.5.4 Materials

1 Permanent Casings

(a) Permanent casings shall be as specified. Where a permanent casing is to be made from a series of short sections it shall be designed and placed so as to produce a continuous water-free shaft. The dimensions and quality of the casing shall be adequate to withstand the stresses caused by handling and driving without damage or distortion.

2 Temporary Casings

(a) Temporary casings shall be free from significant distortion. They shall be of uniform external cross-section throughout each continuous length. During concreting they shall be free from internal projections and encrusted concrete which might prevent the proper formation of piles.

3 Pile Shoes

(a) Pile shoes shall be manufactured from durable material capable of withstanding the stresses caused by driving without damage, and shall be designed to give a watertight joint during construction.

4 Reinforcement

(a) This type of pile shall normally be reinforced over its full length unless permanently cased. The use of shorter reinforcement in piles which are not permanently cased shall be subject to the approval of the Engineer.

(b) The number of splices in longitudinal steel bars shall be kept to a minimum. The full strength of each bar shall be effective across each splice, which shall be made so that there is no detrimental displacement of the reinforcement during the construction of the pile.

4.5.5 Driving piles

1 Piling Near Recently Cast Piles

(a) Casings shall not be driven or piles formed so close to other piles which have recently been cast as to damage them.

2 Performance of Driving Equipment

(a) The Contractor shall satisfy the Engineer regarding the suitability, efficiency and energy of the driving equipment

(b) Drop hammers shall not be used from floating craft in such a manner as to cause instability of the craft.

3 Length of Piles

(a) The length of pile to be driven in any location shall be approved.

4 Driving Procedure

(a) Each pile casing shall be driven continuously until the specified or approved depth or resistance (set), or both, has been reached. In the event of unavoidable interruption to driving, the pile will be accepted provided on resumption the casing can be driven to the specified depth or resistance (set), or both, without damage.

(b) The Contractor shall inform the Engineer without delay if an unexpected change in driving characteristics is encountered. A detailed record of the driving resistance over the full length of the nearest available subsequent pile shall be taken if required.

(c) At the start of the work in a new area or section a detailed driving record shall be made over the full length of the first pile to be installed and over the last 3 m of the driving of subsequent piles until consistency of behaviour is established. Where required, detailed driving records shall also be made for 5 % of the piles driven, the positions of such piles being specified by the Engineer.

(d) The Contractor shall give adequate notice and provide all facilities to enable the Engineer to check driving resistance. A set shall be taken only in the presence of the Engineer unless otherwise approved.

5 Final Set

(a) Where piles are driven to a set, the final set of each pile, pile shell or casing shall be recorded either as the penetration in millimetres per ten blows or as the number of blows required to produce a penetration of 25 mm.

(b) When a final set is being measured, the following requirements shall be met:

(i) The exposed part of the pile casing shall be in good condition, without damage or distortion.

(ii) The dolly, helmet and packing, if any, shall be in sound condition.

(iii) The hammer blow shall be in line with the pile axis and the impact surfaces shall be flat and at right angles to the pile and hammer axis.

(iv) The hammer shall be in good condition, delivering adequate energy per blow, and operating correctly.

(v) Temporary compression of the pile casing shall be recorded if required.

6 Preboring

(a) If preboring is specified the pile casing shall be pitched after preboring to the designated depth and diameter.

7 Jetting

(a) Jetting shall be carried out only when the Contractor's detailed proposals have been approved by the Engineer

8 Internal Drop Hammer

(a) Where a casing for a pile without an enlarged base is to be driven by an internal drop hammer, a plug consisting of concrete grade 20 with a water/cement ratio not exceeding 0.25 shall be placed in the pile. This plug shall have a compacted height of not less than 2.5 times the diameter of the pile. Fresh concrete shall be added to ensure that this height of driving plug is maintained in the casing throughout the period of driving, and in any event a plug of fresh concrete shall be added after 1.5 h of normal driving or after 45 min of hard driving, or, should the driving of a pile be interrupted for 30 min or longer, fresh concrete shall be added prior to driving being resumed.

4.5.6 Risen Piles

1 Piles shall be driven in an approved sequence to minimise any detrimental effects of heave and lateral displacement of the ground.

2 When required, levels and measurements shall be taken to determine the movement of the ground or any pile resulting from the driving process.

3 When a pile has risen with detrimental effects as a result of adjacent piles being driven the Contractor shall, if required, submit to the Engineer his proposals for correcting or compensating for this and for avoidance or control of heave effects in subsequent work.

4.5.7 Extraction of casing

1 Workability of Concrete

(a) Temporary casings shall be extracted while the concrete within them remains sufficiently workable to ensure that the concrete is not lifted.

2 Concrete Level

(a) When the casing is being extracted, a sufficient quantity of concrete shall be maintained within it to ensure that pressure from external water or soil is exceeded and that the pile is neither reduced in section nor contaminated.

(b) Concrete shall be topped up as necessary while the casing is extracted until the required head of concrete to complete the pile in a sound and proper manner has been provided. No concrete is to be placed once the bottom of the casing has been lifted above the top of the concrete.

3 Vibrating Extractors

(a) The use of vibrating casing extractors will be permitted subject to Part 1 (Noise and Disturbance) and (Damage to Adjacent Structures).

4 Concrete Casting Tolerances

(a) For piles constructed without the use of a rigid permanent lining, pile concrete shall be cast to the original ground level.

(b) Where piles are constructed inside rigid permanent lining tubes or permanent casings, pile heads shall be cast to a level above the specified cut-off so that, after trimming, a sound concrete connection with the pile can be made. In this case, the tolerance of casting above the cut-off level shall be determined according to Table 4.6.

Table 4.6
Casting Tolerance above Cut-off Level for Piles Constructed Inside Rigid Permanent Lining Tubes or Permanent Casings

Cut-off distance below original ground, *H,* (m)	Casting tolerance above cut-off level (m)
0.15 to any depth	**2.2** + *H*/10

5 Repair of damaged pile heads and making-up of piles to the correct level

(a) When repairing or extending the head of a pile, the head shall be cut off square in sound concrete, and all loose particles shall be removed by wire brushing, followed by washing with water.

(b) If the driving of a pile has been accepted but sound concrete of the pile is below the cut-off level, the pile shall be made good to the cut-off level with concrete of a grade not inferior to that of the concrete of the pile.

6 Lengthening of cast-in- place piles after driving

(a) When it is required to extend a cast-in-place driven pile above ground, the materials to be used and procedures to be adopted shall be subject to the approval of the Engineer.

7 Lengthening of permanent pile casings during construction

(a) The lengthening of permanent steel pile casings by adding an additional length of the same steel casing during construction shall be carried out in accordance with the relevant clauses of this Section or by other approved methods. The use of casing extension materials and methods other than those specified shall be subject to approval.

8 Temporary backfilling above pile casting level

(a) After each pile has been cast, any hole remaining shall be protected and shall be carefully backfilled as soon as possible with approved materials.

9 Cutting off pile heads

(a) When cutting off and trimming piles to the specified cut-off level, the Contractor shall take care to avoid shattering or otherwise damaging the rest of the pile. Any cracked or defective concrete shall be cut away and the pile repaired in an approved manner to provide a full and sound section to the cut-off level.

4.6 STEEL PILES

4.6.1 Scope

1 This Part applies to driven steel piles designed to act as bearing piles.

2 Related Sections and Parts are as follows:

This Section
Part 1,..... General Requirements for Piling Works
Part 2,..... Concrete Works for Piling

Section 3, Ground Investigation.
Section 5, Concrete

4.6.2 References

1 The following standards and other documents are referred to in this Part:

API 5L,.....Interpretation of non-destructive testing, (American Petroleum Institute, “API 5L Specification for Line Pipe”)

BS 4, ...Structural steel sections

.....EN 10025; Hot rolled products of structural steels

.....EN 10056; Structural steel equal and unequal leg angles

.....EN 10365; Hot rolled steel channels, I and H sections. Dimensions and masses

BS 3100, ...Specification for steel castings for general engineering purposes

.....EN 10293; Steel castings. Steel castings for general engineering uses

BS 5135, ...Specification for arc welding of carbon and carbon manganese steels

.....EN 1011-1; Welding. Recommendations for welding of metallic materials - General guidance for arc welding

.....EN 1011-2; Welding. Recommendations for welding of metallic materials - Arc welding of ferritic steels

BS 6265, ...Specification for resistance seam welding of uncoated and coated low carbon steel

.....ISO 16433; Resistance welding. Procedure for seam welding of uncoated and coated low carbon steels

BS 7613, ...Specification for hot rolled quenched and tempered weldable structural steel plates

.....EN 10025-6; Hot rolled products of structural steels - Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition

4.6.3 Submittals

1 Where coatings are specified, the Contractor shall submit for approval full details of the coating procedure and surface preparation according to relevant British or Swedish Standards.

4.6.4 Quality Assurance

1 The Contractor shall provide the Engineer with Works test certificates, analyses, and mill sheets, together with a tube manufacturer's certificate showing details of the pile number, cast number of the steel and a record of all tests and inspections carried out. The Engineer has the right to inspect any stage of the manufacturing processes and shall be given adequate notice by the Contractor of such processes and production tests, provided that, once he has been notified, any delay in his attendance does not cause delay to, or disrupt, the manufacturing process. The Contractor shall provide the Engineer with samples for independent testing when requested.

2 The Contractor shall submit for approval full details of the welding procedures and electrodes, with drawings and schedules as may be necessary. Tests shall be undertaken as may be required by the relevant British Standard or as may be required by the Engineer. Only welders who are qualified in the approved welding procedure in accordance with the tests laid down in the relevant British Standard, or who have a proven record over the previous six months, or who have attained a similar standard, shall be employed on the Works. Proof of welders' proficiency shall be made available to the Engineer on request.

4.6.5 Delivery, Storage and Handling

1 The Contractor shall

(a) Order the piles to suit the construction programme.

(b) Obtain the Engineer's approval before placing the order.

2 When preliminary piles are specified, the approval for the piles for the main work will not necessarily be given until the results of the driving and tests on preliminary piles have been received and evaluated.

3 Each pile shall be clearly numbered and its length shown near the pile head using white paint. In addition, before being driven, each pile shall be graduated at appropriate intervals along its length and at intervals of 250 mm along the top 3 m.

4 All piles within a stack shall be in groups of the same length and on approved supports. All operations such as handling, transporting and storing of piles shall be carried out in a manner such that damage to piles and their coatings is minimised.

4.6.6 Materials

1 Pile Shoes

(a) Cast steel shoes shall be of steel to BS 3100, grade Al. Flat plate and welded fabricated steel shoes shall be grade 43A or 50A, conforming to BS 7613 and related standards.

2 Strengthening of Piles

(a) The strengthening to the toe of a pile in lieu of a shoe or the strengthening of the head of a pile shall be made using material of the same grade as the pile unless otherwise approved.

3 Manufacturing Tolerance

(a) All piles shall be of the type and cross-sectional dimensions specified. For standard rolled sections the dimensional tolerances and weight shall comply with the relevant standard. The tolerance on length shall be -0 and +75 mm unless otherwise specified. For proprietary sections the dimensional tolerances shall comply with the manufacturer's standards. The rolling or manufacturing tolerances for proprietary sections shall be such that the actual weight of section does not differ from the theoretical weight by more than +4 % or -2½ % unless otherwise agreed. The rolling or manufacturing tolerances for steel tubular piles shall be such that the actual weight of section does not differ from the theoretical weight by more than ±5 %.

4 Straightness of Piles

(a) For standard rolled sections the deviation from straightness shall be within the compliance provisions of BS 4, Part 1. When two or more rolled lengths are joined by butt-jointing, the deviation from straightness shall not exceed 1/600 of the overall length of the pile.

(b) For proprietary sections made up from rolled sections, and for tubular piles, the deviation from straightness on any longitudinal face shall not exceed 1/600 of the length of the pile nor 5 mm in any 3 m length.

5 Fabrication of Piles

(a) For tubular piles where the load will be carried by the wall of the pile, and if the pile will be subject to loads that induce reversal of stress during or after construction, the external diameter at any section as measured by using a steel tape on the circumference shall not differ from the theoretical diameter by more than ±1.

(b) The ends of all tubular piles as manufactured shall be within a tolerance on ovality of ±1 % as measured by a ring gauge for a distance of 100 mm at each end of the pile length.

(c) The root edges or root faces of lengths of piles that are to be shop butt-welded shall not differ by more than 25 % of the thickness of pile walls not exceeding 12 mm thick or by more than 3 mm for piles where the wall is thicker than 12 mm. When piles of unequal wall thickness are to be butt-welded, the thickness of the thinner material shall be the criterion.

6 Matching of Pile Lengths

(a) Longitudinal seam welds and spiral seam welds of two lengths of tubular piles being joined shall, whenever possible, be evenly staggered at the butt. However, if in order to obtain a satisfactory match of the ends of piles or to meet specified straightness, the seams cannot be staggered evenly, then they shall be staggered by at least 100 mm.

7 Welding

(a) Welding of H-piles and piles that will be subjected to stress reversal, during or after construction, shall be in accordance with BS 5135.

(b) For a tubular pile where the load will be compressive and non-reversible and will be carried by the wall of the pile or by composite action with a concrete core, the welding shall be to BS 5135 or BS 6265.

8 Coating Piles for Protection against Corrosion

(a) Where coatings are specified they shall be provided in accordance with the Particular Specification. In general, coatings will not be called for where piles are fully in contact with undisturbed natural soils or below the standing water table. Cathodic protection may be called for when there is a possibility of stray electrical current from the supported structure flowing to earth through the piles.

4.6.7 Acceptance Standards For Welds

1 Acceptance Standards for Shop Welds

(a) Longitudinal or spiral welds made in the manufacture of tubular piles are subject to the acceptance standard for interpretation of non-destructive testing specified in latest edition of API 5L. The maximum projecting height of weld reinforcement shall not exceed 3 mm for wall thicknesses not exceeding 13 mm and 5 mm for wall thicknesses greater than 13 mm.

(b) Longitudinal welds joining the constituent parts of the box or proprietary section shall be in accordance with the manufacturer's specification.

(c) The maximum projecting height of weld reinforcement for circumferential welds in tubular piles shall be the same as specified above for longitudinal welds in tubular piles.

2 Acceptance Standards for Site Butt Welds

(a) Welds shall comply with the requirements of the *Weld Quality Acceptance Standards for Site Butt Welds in Steel Bearing Piles* published by British Steel Corporation, General Steels Group.

4.6.8 Acceptability and inspection of coatings

1 The finished coating shall be generally of smooth and uniform texture and free from sharp protuberances or pin holes. Excessive sags, dimpling or curtaining will not be acceptable.

2 Any coat damaged by subsequent processes, or which has deteriorated to an extent such that proper adhesion of the coating is in doubt, shall be removed and the surface shall be cleaned to the original standard and recoated with the specified number and thicknesses of coats.

3 The completed coating shall be checked for thickness by an approved magnetic thickness gauge. Areas where the thickness is less than that specified shall receive approved additional coating.

4 Average measured thickness should be equal to or greater than the specified thickness and no single reading should be less than 85 % of the specified thickness. The completed coating shall also be checked for adhesion by the cross-hatching method with lines spaced at ten times the thickness of the coating. Adhesion tests should not be carried out prior to seven days after coating.

5 The tests shall be made on 10 % of the piles. Areas where the adhesion is not approved shall be sand blasted and recoated. The coating shall be approved before pitching and driving of the piles.

4.6.9 Driving of piles

1 Leaders and Trestles

(a) At all stages during driving and until incorporation in the superstructure, the free length of the pile shall be adequately supported and restrained by means of leaders, trestles, temporary supports or other guide arrangements to maintain position and alignment and to prevent buckling. In marine works, lengths which remain unsupported after driving shall be adequately restrained until incorporated into the permanent Works. These constraint arrangements shall be such that damage to piles and their coatings is minimised.

2 Performance of Driving Equipment

(a) The Contractor shall satisfy the Engineer regarding the suitability, efficiency and energy of the driving equipment. Where required in the Contract, dynamic evaluation and analysis shall be provided.

(b) Where a drop hammer is used, the mass of the hammer shall be at least half that of the pile unless otherwise approved by the Engineer. For other types of hammer the energy delivered to the pile per blow shall be at least equivalent to that of a drop hammer of the stated mass. Drop hammers shall not be used from floating craft in such a manner as to cause instability of the craft.

3 Length of Piles

(a) The length of pile to be driven and any additional lengths of pile to be added during driving shall be approved by the Engineer.

4 Driving Procedure and Redrive Checks

(a) The driving of each pile shall be continuous until the specified depth or resistance (set), or both, has been reached. In the event of unavoidable interruption to driving, the pile will be accepted provided it can be driven to the specified depth or resistance (set), or both, without damage.

(b) A follower shall not be used unless approved, in which case the Engineer will require the set where applicable to be revised in order to take into account reduction in the effectiveness of the hammer blow.

(c) The Contractor shall inform the Engineer as soon as an unexpected change in driving characteristics is noted. A detailed record of the driving resistance over the full length of the nearest subsequent pile shall be taken, if required by the Engineer.

(d) At the start of the work in a new area or section a detailed record shall be made over the full driving length of the first pile, and during the last 3 m of the driving of subsequent piles, to establish the driving behaviour. Where required, detailed driving records shall also be made for 5 % of the piles driven, the locations of such piles being specified by the Engineer.

(e) The Contractor shall give adequate notice and provide all necessary facilities to enable the Engineer to check driving resistance. A set or resistance measurement shall be taken only in the presence of the Engineer unless otherwise approved.

(f) Redrive checks, if required, shall be carried out in accordance with an approved procedure.

5 Final Set or Resistance

(a) When driving to a set criterion, the final set of each pile shall be recorded either as the penetration in millimetres per ten blows or as the number of blows required to produce a penetration of 25 mm.

(b) When a final set or resistance is being measured, the following requirements shall be met:

(i) The exposed part of the pile shall be in good condition, without damage or distortion.

(ii) The dolly and packing, if any, shall be in sound condition.

(iii) The hammer blow shall be in line with the pile axis and the impact surfaces shall be flat and at right angles to the pile and hammer axis.

(iv) The hammer shall be in good condition, delivering adequate energy per blow and operating correctly.

(v) The temporary compression of the pile shall be recorded, if required by the Engineer.

6 Preboring

(a) If preboring is specified the pile shall be pitched after preboring to the designated depth and diameter.

7 Jetting

(a) Jetting shall be carried out only when the Contractor's detailed proposals have been approved.

4.6.10 Risen Piles

1 Piles shall be driven in an approved sequence to minimise any detrimental effects of heave and lateral displacement of the ground.

2 When required by the Engineer, levels and measurements shall be taken to determine the movement of the ground or any pile resulting from the driving of adjacent piles.

3 When a pile has risen as a result of adjacent piles being driven, the Engineer may call for redriving or other testing to demonstrate that the performance of the pile under load is unimpaired. If required, the Contractor shall make proposals for correcting detrimentally affected piles and for avoidance or control of heave in subsequent work.

4.6.11 Preparation of pile heads

1 If a steel superstructure is to be welded to piles, the pile cut-off shall be square and to within 5 mm of the elevations shown on the Drawings. If pile heads are to be encased in concrete they shall be cut to that same tolerance and protective coatings shall be removed from the surfaces of the pile heads down to a level 100 mm above the soffit of the concrete.

4.7 MICROPILES (TO BE ADDED LATER)

4.8 REDUCTION OF FRICTION ON PILES

4.8.1 Scope

1 This Part includes preapplied bituminous or other proprietary friction-reducing coating, pre-applied low-friction sleeving, formed-in-place low-friction surround, and preinstalled low-friction sleeving.

2 Related Parts are as follows:

This Section
Part 1,..... General Requirements for Piling Works
Part 2,..... Concrete Works for Piling
Section 3, Ground Investigation.

4.8.2 Submittals

1 Where the particular method of reducing friction is not specified, the Contractor shall submit full details of the method which he proposes.

4.8.3 Friction Reducing Methods

1 General

(a) Where a means of reducing friction on any specified length of pile is required by the Contract, the Contractor shall provide a suitable interface between pile and soil by one of the following, or other approved, methods

(i) Preapplied bituminous or other proprietary friction-reducing coating.

(ii) Preapplied low-friction sleeving.

(iii) Formed-in-place low-friction surrounds.

(iv) Preinstalled low-friction sleeving.

2 Preapplied Bituminous or other Friction-Reducing Coating Materials

(a) Where a proprietary product is specified, the process of cleaning pile surfaces, and the conditions and methods of application shall conform to the manufacturer's current instructions. All materials shall conform to the manufacturer's specification, which shall be given to the Engineer before any coating is applied.

(b) Where a friction-reducing material has been applied to a preformed pile prior to installation, it shall be protected from damage during handling and transportation. In the event of inadvertent damage to the coating, it shall be repaired on site, prior to the pile being driven, to the same specification as the original coating. Where bituminous materials are involved, precautions shall be taken as necessary in hot weather to prevent excessive flow or displacement of the coating. The coated piles shall be adequately protected against direct sunlight and, if stacked, they shall be separated to prevent their coatings sticking together.

(c) In the case of applied coatings, the piles shall not be driven when the air temperature is such that the coating will crack, flake or otherwise be damaged prior to entry into the ground. Where bituminous materials are involved, driving shall be carried out while the temperature is at or above 5 °C unless otherwise approved or called for in the manufacturer's instructions.

3 Preapplied Low-Friction Sleeving

(a) Piles may be driven with a preapplied low-friction sleeving subject to the approval of the detailed design and method by the Engineer.

4 Formed-In-Place Low-Friction Surround

(a) Where a hole is bored in the ground and filled with low-friction material through which a pile is subsequently driven or placed, the method and the properties of the low-friction material both above and below standing groundwater level, together with the dimensions of the prebored hole in relation to the pile, shall be approved by the Engineer.

5 Preinstalled Low-Friction Sleeving

(a) Where a system is employed involving placing a low-friction sleeve in the ground prior to pile installation, the detailed materials and method of installation of the sleeving shall be approved by the Engineer.

4.8.4 Inspection

1 The Engineer may call for piles to be partially exposed or extracted at the commencement of a contract in order to demonstrate that the method of installation does not impair the effectiveness of the system in the circumstances of use on the particular site. Where damage is found to have occurred, or is likely to occur in the opinion of the Engineer, additional measures or variation of the method may be called for. At the discretion of the Engineer, further inspections shall be carried out to ascertain the effectiveness of the additional measures.

4.8.5 Driving resistance

1 Allowance shall be made in driving piles to a required resistance or set for any differences between the short-term driving resistance and the long-term static resistance of the coating or surrounding low-friction material which is in use.

4.9 PILE LOAD TESTING

4.9.1 Static Load Testing of Piles

1 Scope

(a) This Part deals with the testing of a pile by the controlled application of an axial load. It covers vertical and raking piles tested in compression (i.e. subjected to loads or forces in a direction such as would cause the piles to penetrate further into the ground) and vertical or raking piles tested in tension (i.e., subjected to forces in a direction such as would cause the piles to be extracted from the ground).

2 References

The following standard is referred to in this Part:

BS 1881, ...Methods of testing concrete.

3 Submittals

(a) When required, the design and full details of the proposed load application system shall be submitted to the Engineer prior to the commencement of testing. The load application system shall be satisfactory for the required test.

4 Definitions

(a) Allowable pile capacity: a load which is not less than the specified working load and which takes into account the pile's ultimate bearing capacity, the materials from which the pile is made, the required factor of safety, settlement, pile spacing, downdrag, the overall bearing capacity of the ground beneath the piles and any other relevant factors. The allowable pile capacity indicates the ability of a pile to meet the specified loading requirements.

(b) Compression pile: a pile which is designed to resist compressive (downward) axial load.

(c) Constant rate of penetration (CRP) test: a test in which the pile is made to penetrate the soil at a constant controlled speed, while the loads applied at the top of the pile in order to maintain the constant rate of penetration are continuously measured. The purpose of the test is to derive the ultimate bearing capacity of a pile and not its load settlement characteristics.

(d) Constant rate of uplift (CRU) test: the same in principle as the CRP test, but the pile is subject to tension rather than compression. The purpose of the test is to determine the 'pull-out' capacity of a pile.

(e) Design verification load (DVL): a test load, in lieu of a specified working load, applied to a single pile at the time of testing to determine that site conditions conform to design assumptions. This load will be peculiar to each preliminary (test) pile and should equal the maximum specified working load for a pile of the same dimensions and material, plus allowances for soil-induced forces and any other particular conditions of the test.

(f) Kentledge: ballast used in a loading test.

(g) Maintained load test: a loading test in which each increment of load is held constant either for a defined period of time or until the rate of settlement falls to a specified value.

(h) Preliminary pile: a test pile installed before the commencement of the main piling works or a specific part of the Works for the purpose of establishing the suitability of the chosen type of pile and for confirming its design, dimensions and bearing capacity.

(i) Proof load: a load applied to a selected working pile to confirm that it is suitable for the load at the settlement specified. A proof load should not normally exceed the design verification load plus 50 % of the specified working load.

(j) Raking pile: a batter pile, installed at an inclination to the vertical.

(k) Reaction system: the arrangement of kentledge, piles, anchors or rafts that provides a resistance against which the pile is tested.

(l) Specified working load (SWL): the designated load on the head of a pile.

(m) Tension pile: a pile which is designed to resist a tensile (upward) axial force.

(n) Test pile: any pile, preliminary or part of the works, to which a test is applied.

(o) Ultimate bearing capacity: the load at which the resistance of the soil becomes fully mobilised through friction, end bearing or a combination thereof.

(p) Working pile: one of the piles forming the foundation of a structure.

5 Construction of a preliminary pile to be tested

(a) Notice of Construction

(i) The Contractor shall give the Engineer at least 48 hours' notice of the commencement of construction of any preliminary pile which is to be test-loaded.

(b) Method of Construction

(i) Each preliminary test pile shall be constructed in a manner similar to that to be used for the construction of the working piles, and by the use of similar equipment and materials. Any variation will be permitted only with prior approval.

(c) Boring or Driving Record

(i) For each preliminary pile to be tested, a detailed record of the conditions experienced during boring and of the progress during driving, shall be made and submitted to the Engineer daily, not later than noon on the next working day. Where the Engineer requires soil samples to be taken or in-situ tests to be made, the Contractor shall include that in the daily report, as well as the test results.

(d) Concrete Test Cubes

(i) In the case of concrete piles, four test cubes shall be made from the concrete used in the manufacturer of each preliminary test pile and from each 50 m^3 of the concrete used in the manufacture of working piles. If a concrete pile is extended or capped for the purpose of testing, an additional four cubes shall be made from the corresponding batch of concrete. The cubes shall be made and tested in accordance with BS 1881.

(ii) The pile test shall not be started until the strength of the cubes taken from the pile exceeds twice the average direct stress in any pile section under the maximum required test load, and the strength of the cubes taken from the cap exceeds twice the average stress at any point in the cap under the same load. Variation of procedure will be permitted only if approved by the Engineer.

(e) Preparation of a Working Pile to be Tested

(i) If a test is required on a working pile the Contractor shall cut off or otherwise prepare the pile for testing as required by the Engineer.

(f) Cut-off Level

(i) The cut-off level for a preliminary test pile shall be approved by the Engineer.

(g) In addition to all the other requirements stated under this section of the QCS, all Preliminary test piles can be instrumented in accordance with the following as applicable:

(i) ASTM D1143/D1143M – 07 (2013) – sub-Clause 7.4.4

(ii) ASTM D3689/D3689M – 07 (2013) – sub-Clause 7.4.4

(iii) ASTM D3966/D3966M – 07 (2013) – sub-Clause 7.8

6 Supervision

(a) The setting-up of pile testing equipment shall be carried out under competent supervision and the equipment shall be checked to ensure that the set-up is satisfactory before the commencement of load application.

(b) All tests shall be carried out only under the direction of an experienced and competent supervisor experienced with the test equipment and test procedure. All personnel operating the test equipment shall have been trained in its use.

7 Safety precautions

(a) General

(i) Design, erection and dismantling of the pile test reaction system and the application of load shall be carried out according to the requirements of the various applicable statutory regulations concerned with lifting and handling heavy equipment and shall safeguard operators and others who may from time to time be in the vicinity of a test from all avoidable hazards.

(b) Kentledge

(i) Where kentledge is used, the Contractor shall construct the foundations for the kentledge and any cribwork, beams or other supporting structure in such a manner that there will not be differential settlement, bending or deflexion of an amount that constitutes a hazard to safety or impairs the efficiency of the operation. The kentledge shall be adequately bonded, tied or otherwise held together to prevent it becoming unstable because of deflexion of the supports or for any other reason.

(ii) When kentledge constitutes the principal component of a reaction system, its weight for each test shall be at least 25% greater than the maximum test load for that test. The weight may be determined by scale or the density and volume of the constituent materials. In adding kentledge, care shall be taken to properly position the centre of gravity of the stack.

(c) Tension Piles, Reaction Piles and Ground Anchorages

(i) Where tension piles, reaction piles or ground anchorages constitute the principal components of a reaction system, they shall be so designed that they will resist the forces applied to them safely and without excessive deformation which could cause a safety hazard during the work. Such piles (which, unless approved, will not be working piles) or anchorages shall be driven in the specified locations, and all bars, tendons or links shall be aligned to provide a stable reaction in the direction required. Any welding employed to extend or to fix anchorages to a reaction frame shall be carried out so that the full strength of the system is adequate and unimpaired.

(d) Testing Equipment

(i) In all cases the Contractor shall ensure that when the hydraulic jack and load-measuring device are mounted on the pile head the whole system will be stable up to the maximum load to be applied.

(ii) If in the course of carrying out a test any unforeseen occurrence should take place, further loading shall not be applied until a proper engineering assessment of the condition has been made and steps have been taken to rectify any fault. Reading of gauges should, however, be continued where possible and if it is safe to do so.

(iii) Where an inadequacy in any part of the system might constitute a hazard, means shall be provided to enable the test to he controlled from a position remote from of the kentledge stack or test frame.

(iv) The hydraulic jack, pump, hoses, pipes, couplings and other apparatus to be operated under hydraulic pressure shall be capable of withstanding a pressure of 1.5 times the maximum pressure used in the test without leaking. The maximum test load expressed as a reading on the gauge in use shall be displayed and all operators shall be made aware of this limit.

(e) Pile Head for Compression Test

(i) For a pile that is tested in compression, the pile head or cap shall be formed to give a plane surface which is normal to the axis of the pile, sufficiently large to accommodate the loading and settlement measuring equipment and adequately reinforced or protected to prevent damage from the concentrated load applied by the loading equipment.

(ii) Any test pile cap shall be concentric with the test pile; the joint between the cap and the pile shall have a strength equivalent to that of the pile.

(iii) Sufficient clear space shall be made under any part of the cap projecting beyond the section of the pile so that, at the maximum expected settlement, load is not transmitted to the ground by the cap.

(f) Pile Connection for Tension Test

(i) For a pile that is tested in tension, means shall be provided for transmitting the test load axially without inducing moment in the pile. The connection between the pile and the loading equipment shall be constructed in such a manner as to provide strength equal to 1.5 times the maximum load which is to be applied to the pile during the test.

8 Reaction systems

(a) Compression Tests

(i) The reaction for compression tests shall be provided by kentledge, tension piles or specially constructed anchorages. Kentledge shall not be used for tests on raking piles except where the test set-up has been specifically designed to conform to Item 7(g). and has been approved by the Engineer.

(ii) Where kentledge is to be used, it shall be supported on cribwork and positioned so that the centre of gravity of the load is as close as possible to the axis of the pile. The bearing pressure under supporting cribs shall be such as to ensure stability of the kentledge stack.

(b) Tension Tests

(i) The reaction for tension tests shall be provided by compression piles, rafts or grillages constructed on the ground. In all cases the resultant force of the reaction system shall be coaxial with the test pile.

(ii) Where inclined piles or reactions are proposed, full details shall be submitted for approval prior to the commencement of testing.

(c) Working Piles

(i) Working piles shall not be used as reaction piles without approval from the Engineer.

(ii) Where working piles are used as reaction piles their movement shall be measured and recorded to with an accuracy of 0.5 mm, and recorded.

(d) Spacing

(i) Where kentledge is used for loading vertical piles in compression, the distance from the edge of the test pile to the nearest part of the crib supporting the kentledge stack in contact with the ground shall be not less than 1.3 m.

(ii) The centre-to-centre spacing of vertical reaction piles from a test pile shall conform to Paragraph 1 above, but shall be not less than three times the diameter of the test pile or the reaction piles or 2 m, whichever is the greatest, except in the case of piles of 300 mm diameter (or equivalent) or less, where the distance may be reduced to 1.5 m. Where a pile to be tested has an enlarged pile cap, the same criterion shall apply with regard to the pile shaft, with the additional requirement that no surface of a reaction pile shall be closer to the pile cap of the test pile than one half of the pile cap plan dimension.

(iii) Where ground anchorages are used to provide a test reaction for loading in compression, no section of fixed anchor length transferring load to the ground shall be closer to the test pile than three times the diameter of the test pile. Where the pile to be tested has an enlarged pile cap, the same criterion shall apply with regard to the pile shaft, with the additional requirement that no section of the fixed anchor transferring load to the ground shall be closer to the pile cap than a distance equal to one half the pile cap plan dimension.

(e) Adequate Reaction

(i) The reaction frame support system shall be adequate to transmit the maximum test load in a safe manner without excessive movement or influence on the test pile. Calculations shall be provided to the Engineer when required to justify the design of the reaction system.

(f) Care of Piles

(i) The method employed in the installation of the reaction system shall be such as to prevent damage to any test pile or working pile.

9 Equipment for applying load

(a) The equipment used for applying load shall consist of a hydraulic ram or jack. The jack shall be arranged in conjunction with the reaction system to deliver an axial load to the test pile. Proposals to use more than one ram or jack will be subject to approval by the Engineer of the detailed arrangement. The complete system shall be capable of safely transferring the maximum load required for the test. The length of stroke of a ram shall be sufficient to account for deflexion of the reaction system under load plus a deflection of the pile head by up to 15 % of the pile shaft diameter unless otherwise specified or agreed prior to commencement of test loading.

10 Measurement of load

(a) A load measuring device shall be used and in addition a calibrated pressure gauge included in the hydraulic system. Readings of both the load measuring device and the pressure gauge shall be recorded. In interpreting the test data the values given by the load measuring device shall normally be used; the pressure gauge readings are required as a check for gross error.

(b) The load measuring device may consist of a load measuring column, pressure cell or other appropriate system. A spherical seating of appropriate size shall he used to avoid eccentric loading. Care shall be taken to avoid any risk of buckling of the load application and measuring system. Load measuring and application devices shall be short in axial length in order to secure stability. The Contractor shall ensure that axial loading is maintained.

(c) The load measuring device shall be calibrated before and after each series of tests, whenever adjustments are made to the device or at intervals appropriate to the type of equipment. The pressure gauge and hydraulic jack shall be calibrated together. Certificates of calibration shall be supplied to the Engineer.

11 Control of loading

(a) The loading equipment shall enable the load to be increased or decreased smoothly or to be held constant at any required value.

12 Measuring pile head movement

(a) Maintained Load Test

(i) In a maintained load test, movement of the pile head shall he measured by one of the methods in Items 11 (d), (e), (f), (g) in the case of vertical piles, or by one of the methods in 11 (d), (f), (g) in the case of the raking piles, as required.

(b) CRP and CRU Tests

(i) In a CRP or a CRU test, the method in Item 11 (d) shall be used. Check-levelling of the reference frame or the pile head shall not be required. The dial gauge shall be graduated in divisions of 0.02 mm or less.

(c) Reference Beams and Dial Gauges

(i) An independent reference beam or beams shall be set up to enable measurement of the movement of the pile to be made to the required accuracy. The supports for a beam shall be founded in such a manner and at such a distance from the test pile and reaction system that movements of the ground do not cause movement of the reference beam or beams which will affect the accuracy of the test. The supports of the beam or beams shall be at least three test pile diameters or 2 m from the centre of the test pile, whichever distance is the greater.

(ii) Check observations of any movements of the reference beam or beams shall be made and a check shall be made of the movement of the pile head relative to a remote reference datum at suitable intervals during the progress of the test.

(iii) The measurement of pile movement shall be made by four dial gauges rigidly mounted on the reference beam or beams, bearing on prepared flat surfaces fixed to the pile cap or head and normal to the pile axis. Alternatively, the gauges may be fixed to the pile and bear on prepared surfaces on the reference beam or beams. The dial gauges shall be placed equidistant from the pile axis and from each other. The dial gauges shall enable readings to be made to an accuracy of at least 0.1 mm and have a stem travel of at least 25 mm. Machined spacer blocks may be used to extend the range of reading. Equivalent electrical displacement-measuring devices may be substituted.

(d) Optical Levelling Method

(i) An optical levelling method by reference to a remote datum may be used.

(ii) Where a level and staff are used, the level and scale of the staff shall be chosen to enable readings to be made to within an accuracy of 0.5 mm. A scale attached to the pile or pile cap may be used instead of a levelling staff. At least two reliable independent datum points shall be established. Each datum point shall be so situated as to permit a single setting-up position of the level for all readings.

(iii) No datum point shall be located where it can be affected by the test loading or other operations on the Site.

(e) Reference Wires and Scales

(i) Two parallel reference wires, one on either side of the pile, shall be held under constant tension at right angles to the test pile axis between supports formed as in the method in Item 11 (d). The wires shall be positioned against scales fixed to the test pile head in an axial direction and the movements of the scales relative to the wires shall be determined.

(ii) Check observations of any movements of the supports of the wires shall be made and a check shall be made on the movement of the pile head at approved time intervals. Readings shall be taken to within an accuracy of 0.5 mm.

(f) Other Methods

(i) The Contractor may submit for approval any other method of measuring the movement of the test pile head.

13 Protection of testing equipment

(a) Protection from Weather

(i) Throughout the test period all equipment for measuring load and movement shall be protected from exposure to adverse effect of weather.

(b) Prevention of Disturbance

(i) Construction activity and persons who are not involved in the testing process shall be kept at a sufficient distance from the test to avoid disturbance to the measuring apparatus. Full records shall be kept of any intermittent unavoidable activity that might affect the test set-up.

14 Notice of test

(i) The Contractor shall give the Engineer at least 24 hours' notice of the commencement of the test. No load shall be applied to the test pile before the commencement of the specified test procedure.

15 Test procedure

(a) Proof Load Test Procedure (working compression piles)

(i) The maximum load which shall be applied in a proof test shall normally be the sum of the design verification load (DVL) plus 50 % of the specified working load (SWL). The loading and unloading shall be carried out in stages as shown in Table 4.7. Any particular requirements given in the particular contract documentation shall be complied with.

(ii) Following each application of an increment of load, the load shall be maintained at the specified value for not less than the period shown in Table 4.7 and until the rate of settlement is less than 0.25 mm/h and decreasing. The rate of settlement shall be calculated from the slope of the line obtained by plotting values of settlement versus time and drawing a smooth curve through the points.

(iii) Each decrement of unloading shall proceed after the expiry of the period shown in Table 4.7.

(iv) For any period when the load is constant, time and settlement shall be recorded immediately on reaching the load, at not more than 5 min intervals up to 15 min; at approximately 15 min intervals up to 1 h; at 30 min intervals between 1 h and 4 h; and 1 h intervals between 4 h and 12 h after the application of the increment of load.

(v) Where the methods of measuring pile head movement given in Item 11 is used, the periods of time for which loads must be held constant to achieve the specified rates of settlement shall be extended as necessary to take into account the lower levels of accuracy available from these methods and to allow correct assessment of the settlement rate.

Table 4.7

Load *	Minimum time of holding load	
25% DVL	1 h	
50% DVL	1 h	
75% DVL	1 h	
100% DVL	1 h	
75% DVL	10 min	
50% DVL	10 min	
25% DVL	10 min	
0	1 h	
100% DVL	6 h	
100% DVL + 25% SWL	1 h	
100% DVL + 50% SWL	6 h	
100% DVL + 25% SWL	10 min	
100% DVL	10 min	
75% DVL	10 min	
50% DVL	10 min	
25% DVL	10 min	
0	1 h	
100% DVL	6 h	
100% DVL + 50% SWL	6 h	
100% DVL + 75% SWL	1 h	
100% DVL + 100% SWL	6 h	
100% DVL + 75% SWL	10 min	Applicable
100% DVL + 50% SW	10 min	to tests on
100% DVL + 25% SW	10 min	Preliminary
100% DVL	10 min	Pile only
75% DVL	10 min	
50% DVL	10 min	
25% DVL	10 min	
0	1 h	

* SWL denotes specified working load; DVL denotes design verification load.

(b) Test Procedure for Preliminary Compression Piles

(i) The procedure to be adopted for carrying out load tests on preliminary compression piles shall be either the extended proof load test procedure or the constant rate of penetration testing procedure given below. A normal proof load test will constitute the first stage of such a test unless otherwise specified.

(ii) Extended proof load test procedure. Where test pile is to be loaded up to the sum of design verification load (DVL) plus 100 % of the specified working load, the loading procedure may be carried out as a continuation of the proof load testing procedure given in Item 14 (a).

(iii) Following the completion of the proof load test, the load shall be restored in two stages (DVL, DVL +50 % SWL), and shall subsequently be increased by stages of 25 % of the specified working load. Following each application of an increment of load, the load shall be maintained at the specified value for the period shown in Table 4.7 and until the rate of settlement is decreasing and is less than 0.25 mm/h.

(iv) Where verification of required minimum factor of safety is called for or the pile is to be tested to failure, the loading procedure shall be continued after reaching DVL +100 % SWL stage by increasing the load in increments of 25 % of the specified working load or other specified amount until the maximum specified load of the test is reached. Following each application of increment of load, the load shall be maintained at the specified value for not less than 1 h and until the rate of settlement is decreasing and is less than 0.25 mm/h, or other approved rate appropriate to the stage of loading and its proximity to a failure condition. Permissible settlement at the load corresponding to the required minimum factor of safety called for in the design will not normally be specified.

(v) The rate of settlement shall be calculated from the slope of the line obtained by plotting values of settlement versus time and drawing a smooth curve through the points. Reduction of load at the end of the test shall be gradual as required by Item 14 (a).and the final rebound of the pile head shall be recorded.

(vi) Constant rate of penetration (CRP) testing procedure. Where it is required to determine the ultimate load of a preliminary compression pile, and particularly where piles are largely embedded in and bearing on clay soils, the CRP testing procedure will normally be specified.

(vii) The rate of movement of the pile head shall be maintained constant in so far as is practicable and shall be approximately 0.01 mm/s.

(viii) Readings of loads, penetration and time shall be made simultaneously at regular intervals; the interval chosen shall be such that a curve of load versus penetration can be plotted without ambiguity.

(ix) Loading shall be continued until one of the following results is obtained

The maximum required test load.

A constant or reducing load has been recorded for an interval of penetration of 10 mm.

A total movement of the pile base equal to 10 % of the base diameter, or any other greater value of movement specified, has been reached.

(x) The load shall then be reduced in five approximately equal stages to zero load, penetration and load being recorded at each stage.

(c) Testing of Piles Designed to Carry Load in Tension

(i) The testing of piles designed to carry load in tension shall follow the same procedure as specified in 4.9.1

(ii) In testing by the constant rate of uplift method, overall movements of the pile head will normally be less than those expected in a constant rate of penetration test. The rate of movement of the pile head shall be maintained at approximately 0.005 mm/s in so far as is practicable.

16 Completion of a test

(a) Removal of Test Equipment

(i) On completion of a test and subject to the approval of the Engineer, all measuring equipment and load application devices shall be dismantled and checked. All other test equipment, including kentledge, beams and supporting structures shall be removed from the test pile location. Measuring and other demountable equipment shall be stored in a safe manner so that it is available for further tests, or removed from the Site as approved by the Engineer.

(ii) Temporary tension piles and ground anchorages shall be cut off below ground level, and off-cut materials removed from the Site. The ground shall be restored to the original contours.

(b) Preliminary Test Pile Cap

(i) Unless otherwise specified, the head of each preliminary test pile shall be cut off below ground level, off-cut material shall be removed from the Site and the ground restored to the original contours.

(c) Proof Test Pile Cap

(i) On completion of a test on a proof pile, the test pile cap shall be prepared as specified and left in a state ready for incorporation into the Permanent Works. Any resulting off-cut materials shall be removed from the Site.

4.9.2 Presentation of results

1 Results to be submitted

(a) During the progress of a test, all records taken shall be available for inspection by the Engineer.

(b) Results shall be submitted as

(i) Preliminary report of the test results to the Engineer, unless otherwise directed, within 24 hours of the completion of the test, which shall show.

1. For a test by maintained load: for each stage of loading, the period for which the load was held, the load and the maximum pile movement at the end of the stage.
2. For a CRP or CRU test: the maximum load reached and a graph of load against penetration or load against uplift.

(ii) The final report of recorded data as prescribed in Item 15 (b).within ten days of the completion of the test.

2 Schedule of Recorded Data

(a) The Contractor shall provide information about the test pile in accordance with the following schedule where applicable.

(i) General.

1. site location contract identification
2. proposed structure
3. main contractor
4. piling contractor
5. engineer client/employer
6. date and time of test

(ii) Pile details.

1. all types of pile
2. identification (number and location)
3. specified working load (SWL)
4. design verification load (DVL)
5. original ground level at pile location
6. head level at which test load was applied
7. type of pile
8. vertical or raking, compression or tension

9. shape and size of cross-section of pile, and position of any change in cross-section
10. shoe or base details
11. head details
12. length in ground
13. tip Elevation
14. dimensions of any permanent casing
15. concrete piles
    - concrete mix/grade
    - aggregate type and source
    - cement type and cement replacement and type where used
    - admixtures
    - slump
    - cube test results for pile and cap
    - date of casting of precast pile
    - reinforcement
16. steel piles
    - steel quality
    - coating
    - filling or core materials type and quality, if applicable

(iii) Installation details.

1. all piles
    - dates and times of boring, driving and concreting of test pile
    - difficulties and delays encountered
    - date and time of casting concrete pile cap
2. bored piles
    - type of equipment used and method of boring
    - temporary casing - diameter, type and length
    - full log of pile borehole
    - method of placing concrete
    - Volume of concrete placed
    - driven preformed and driven cast-in-place piles
    - Method of support of hammer and pile driven length of pile or temporary casing at final set
    - Hammer type, and size or weight
    - Dolly and packing, type and condition
    - Driving log (depth, hammer drop, blows per 250 mm, interruptions or breaks in driving)
    - Final set in number of blows to produce penetration of 25 mm
    - Redrive check, time interval and set in number of blows to produce penetration of 25 mm or other agreed amount at final set and at redrive set, for a drop hammer or for a single acting hammer the length of the drop or stroke, for a diesel hammer the length of the

stroke and the blows per minute, for a double acting hammer the operating pressure and the number of blows per minute

condition of pile head or temporary casing after driving

use of a follower

use of preboring

use of jetting

lengthening

method of placing concrete

(iv) Test procedure.

1. mass of kentledge
2. tension pile, ground anchorage or compression pile details
3. plan of test arrangement showing position and distances of kentledge supports, rafts, tension or compression piles or ground anchorages, and supports to pile movement reference system
4. jack capacity
5. method of load measurement
6. method(s) of penetration or uplift measurement

(v) Test results.

1. in tabular form
2. in graphical form: load plotted against pile head movement
3. ambient temperature records during test.

4.9.3 Low strain Integrity test

1 This test shall be carried out in accordance with ASTM D5882 in a frequency as mentioned in Section 2

4.9.4 Grosshole Sonic Logging Test

1 This test shall be carried out in accordance with ASTM D4428, D6760 in a frequency as mentioned in Section 2

4.9.5 Calliper Logging Test

1 This test shall be carried out in accordance with ASTM D6167 in a frequency as mentioned in Section 2

4.9.6 Axial Tensile Load Test

1 This test shall be carried out in accordance with ASTM D3689/D3689M in a frequency as mentioned in Section 2

4.9.7 Lateral Load Test

1 This test shall be carried out in accordance with ASTM D3966/D3966M in a frequency as mentioned in Section 2

4.9.8 Alternative Methods for Testing Piles

1 Scope

(a) This Part outlines the alternative methods for testing piles. A significant advance in identifying the existence of defects in construction of piles has been the development and adoption of modern integrity testing systems which may be employed to check the quality of construction when required by the Engineer. In addition to the above, instrumented methods for the measurement of pile displacement can be used as follows:

(i) All preliminary test piles (compression, tension, and lateral loading)
(ii) One type of each working pile per project site [type being defined as either a change in geometry (diameter, length, shape) or function (compression, tension, lateral loading)
(iii) The installed instruments within the working piles shall be kept operational and the data collected post project completion and delivered to the concern Authorities, the Owner and the Engineer regularly for specific period as required by the Engineer.
(iv) The strain gauges shall be installed and compliant to the following standards:
1. ASTM D1143/D1143M – 07 (2013) – sub-Clause 7.4.4
2. ASTM D3689/D3689M – 07 (2013) – sub-Clause 7.4.4
3. ASTM D3966/D3966M – 07 (2013) – sub-Clause 7.8

(b) Dynamic pile-testing is normally used to evaluate the pile capacity, soil resistance distribution, and immediate settlement characteristics, hammer transfer energy (efficiency), and pile stresses during driving. The results obtained relate directly to dynamic loading conditions.

(c) Related Sections and Parts are as follows:

This Section

Section 2

2 Quality Assurance

(a) The testing shall be carried out by an approved firm.

(b) The interpretation of tests shall be carried out by persons competent in the test procedure, and the full test results and findings shall normally be given to the Engineer within 10 d of the completion of each phase of testing. Full details of the ground conditions, pile dimensions and construction method shall be made available to the specialist firm when required in order to facilitate interpretation of the tests.

3 Integrity-testing of piles

(a) General

(i) Integrity-testing of piles is designed to give information about the physical dimensions, continuity and consistency of materials used in piles, and not to give direct information about the performance of piles under the conditions of loading. The methods available are normally applied to preformed concrete piles made in a single length, to steel piles and to cast-in-place concrete piles.

(ii) This type of testing will not be regarded as a replacement for static load testing, but as a source of supplementary information.

(iii) There is normally a limit to the length: diameter ratio of pile which can be successfully and fully investigated in this way, depending on the ground conditions.

(iv) In the event that any anomaly is found in the results of such testing, the Engineer may call for further testing to be carried out in order to investigate the cause, nature and extent of the anomaly and whether the pile is satisfactory for its intended use.

(b) Method of Testing

(i) Where integrity-testing is called for but the method is not specified, the method to be adopted shall be approved by the Engineer and shall be one of the following

1. The sonic method.

The vibration method.

The sonic logging method.

(ii) Other methods may be adopted subject to the approval of the Engineer and subject to satisfactory evidence of performance.

(c) Age of Piles at Time of Testing

(i) In the case of cast-in-place concrete piles, integrity tests shall not be carried out until 7 d or more have elapsed after pile-casting, unless otherwise approved by the Engineer.

(d) Preparation of Pile Heads

(i) Where the method of testing requires the positioning of sensing equipment on the pile head, the head shall be clean, free from water, laitance and loose concrete and readily accessible for the purpose of testing.

4 Dynamic pile-testing

(a) General

(i) Dynamic pile-testing involves monitoring the response of a pile to a heavy impact applied at the pile head. The impact is often provided by the pile-driving hammer and response is normally measured in terms of force and acceleration or displacement close to the pile head.

(ii) The results directly obtained refer to dynamic loading conditions. Interpretation in terms of static loading requires soil- and pile-dependent adjustments, and corroboration from experience may be required to correlate dynamic testing with normal static load tests as specified in clause 4.9.1 of this Section.

(iii) Details of the equipment to be used and of the method of analysis of test results shall be provided to the Engineer before the commencement of testing.

(b) Measuring Instruments

(i) All instruments affixed to the pile for the purpose of measuring stress and movement, and all equipment for receiving and processing data shall be suitable for the purpose. The equipment required to be attached to the pile shall be appropriately positioned and fixed to the approval of the Engineer.

(c) Hammer

(i) The hammer and all other equipment used shall be capable of delivering an impact force sufficient to mobilise the equivalent specified test load without damaging the pile.

(d) Preparation of the Pile Head

(i) The preparation of the pile head for the application of the dynamic test load shall involve, where appropriate, trimming the head, cleaning and building up the pile using materials which will at the time of testing safely withstand the impact stresses. The impact surface shall be flat and normal to the axis of the pile.

(e) Time of Testing

(i) Dynamic load tests shall be carried out at appropriate and approved times after pile installation. The time between the completion of installation and testing for a preformed pile shall normally be more than 12 h, and in the case of a cast-in-place concrete piles shall be after the concrete has reached 75 % of its specified 28 day strength so that the pile is not damaged under the impact stresses.

(f) Set Measurements

(i) Where required and appropriate, the permanent penetration per blow and temporary compression of the pile and soil system shall be measured independently of the instruments being used to record the dynamic test data.

(g) Results

(i) Initial the results shall be provided to the Engineer within 24 hours of the completion of a test. These shall include

1. The maximum force applied to the pile head.

The maximum pile head velocity.

The maximum energy imparted to the pile.

(ii) Normally within 10 d of the completion of testing final report shall be given to the Engineer which includes:

1. Date of pile installation.

Date of test.

Pile identification number and location.

Length of pile below ground surface.

Total pile length, including projection above commencing surface at time of test.

Length of pile from instrumentation position to tip.

Hammer type, drop and other relevant details.

Blow selected for analysis.

Test load achieved (i.e. total mobilised deduced static load).

Pile head movement at equivalent design verification load.

Pile head movement at equivalent design verification load plus 50 % of specified working load.

Pile head movement at maximum applied test load.

Permanent residual movement of pile head after each blow.

Temporary compression.

4.10 DESIGN METHODS AND DESIGN CONSIDERATIONS

4.10.1 Design method

1 The design shall be based on one of the following approaches:

(a) The results of static load tests, which have been demonstrated, by means of calculations or otherwise, to be consistent with other relevant experience;

(b) Empirical or analytical calculation methods whose validity has been demonstrated by static load tests in comparable situations;

(c) The results of dynamic load tests whose validity has been demonstrated by static load tests in comparable situations;

(d) The observed performance of a comparable piles foundation, provided that this approach is supported by the results of site investigation and ground testing.

2 Design values for parameters used in the calculations should be in general accordance with design parameters from geotechnical investigations report, but the results of load tests may also be taken into account in selecting parameter values.

3 Static load tests may be carried out on trial piles, installed for test purposes only, before the design is finalized, or on working piles, which form part of the foundation.

4.10.2 Verification of Resistance for Structural and Ground Limit States in Persistent and Transient Situations

1 When considering a limit state of rupture or excessive deformation of a structural element or section of the ground (Structural and Geotechnical), it shall be verified in accordance with (Eurocode1997-1) or equivalent.

4.10.3 Design Considerations

1 The behavior of individual piles and pile groups and the stiffness and strength of the structure connecting the piles shall be considered.

2 In selecting calculation methods and parameter values and in using load test results, the duration and variation in time of the loading shall be considered.

3 Planned future placement or removal of overburden or potential changes in the ground-water regime shall be considered, both in calculations and in the interpretation of load test results.

4 The choice of type of pile, including the quality of the pile material and the method of installation, shall take into account:

(a) the ground and ground-water conditions on the site, including the presence or possibility of obstructions in the ground;

(b) the stresses generated in the pile during installation;

(c) the possibility of preserving and checking the integrity of the pile being installed;

(d) the effect of the method and sequence of pile installation on piles, which have already been installed and on adjacent structures or services;

(e) the tolerances within, which the pile can be installed reliably;

(f) the deleterious effects of chemicals in the ground;

(g) the possibility of connecting different ground-water regimes;

(h) the handling and transportation of piles;

(i) the effects of pile construction on neighboring buildings.

5 In considering the aspects listed above, the following items should receive attention:

(a) the spacing of the piles in pile groups;

(b) displacement or vibration of adjacent structures due to pile installation;

(c) the type of hammer or vibrator used;

(d) the dynamic stresses in the pile during driving;

(e) for those types of bored pile where a fluid is used inside the borehole, the need to keep the pressure of the fluid at a level to ensure that the borehole will not collapse and that hydraulic failure of the base will not occur;

(f) cleaning of the base and sometimes the shaft of the borehole, especially under bentonite, to remove remolded materials;

(g) local instability of a shaft during concreting, which may cause a soil inclusion within the pile;

(h) ingress of soil or water into the section of a cast-in-situ pile and possible disturbance of wet concrete by the flow of water through it;

(i) the effect of unsaturated sand layers around a pile extracting water from the concrete;

(j) the retarding influence of chemicals in the soil;

(k) soil compaction due to the driving of displacement piles;

(l) soil disturbance due to the boring of a pile shaft.

4.11 AXIALLY LOADED PILES

4.11.1 Limit state design

1 The design shall demonstrate that exceeding the following limit states is sufficiently improbable:

(a) ultimate limit states of compressive or tensile resistance failure of a single pile;

(b) ultimate limit states of compressive or tensile resistance failure of the pile foundation as a whole;

(c) ultimate limit states of collapse or severe damage to a supported structure caused by excessive displacement or differential displacements of the pile foundation;

(d) serviceability limit states in the supported structure caused by displacement of the piles.

2 Normally the design should consider the margin of safety with respect to compressive or tensile resistance failure, which is the state in which the pile foundation displaces significantly downwards or upwards with negligible increase or decrease of resistance.

3 For piles in compression it is often difficult to define an ultimate limit state from a load settlement plot showing a continuous curvature. In these cases, settlement of the pile top equal to 10% of the pile base diameter should be adopted as the "failure" criterion.

4 For piles that undergo significant settlements, ultimate limit states may occur in supported structures before the resistance of the piles is fully mobilized. In these cases a cautious estimate of the possible range of the settlements shall be adopted in design.

4.11.2 Compressive Ground Resistance

1 To demonstrate that the pile foundation will support the design load with adequate safety against compressive failure, the following inequality shall be satisfied for all ultimate limit state load cases and load combinations:

$$F_C \leq R_C$$

Where

F_C: design axial compression load on a pile or a group of piles

R_C: design value

2 In principle Fc should include the weight of the pile itself and Rc should include the overburden pressure of the soil at the foundation base. However these two items may be disregarded if they cancel approximately. They need not cancel if:

(a) downdrag is significant;

(b) the soil is very light,

(c) the pile extends above the surface of the ground.

3 For piles in groups, two failure mechanisms shall be taken into account:

(a) compressive resistance failure of the piles individually;

(b) compressive resistance failure of the piles and the soil contained between them acting as a block.

NOTE: The design resistance shall be taken as the lower value caused by these two mechanisms.

4 The compressive resistance of the pile group acting as a block may be calculated by treating the block as a single pile of large diameter.

5 The stiffness and strength of the structure connecting the piles in the group shall be considered when deriving the design resistance of the foundation.

6 If the piles support a stiff structure, advantage may be taken of the ability of the structure to redistribute load between the piles. A limit state will occur only if a significant number of piles fail together; therefore a failure mode involving only one pile need not be considered.

7 If the piles support a flexible structure, it should be assumed that the compressive resistance of the weakest pile governs the occurrence of a limit state.

8 Special attention should be given to possible failure of edge piles caused by inclined or eccentric loads from the supported structure.

9 If the layer in which the piles bear overlies a layer of weak soil, the effect of the weak layer on the compressive resistance of the foundation shall be considered.

10 The strength of a zone of ground above and below the pile base shall be taken into account when calculating the pile base resistance.

NOTE: This zone may extend several diameters above and below the pile base. Any weak ground in this zone has a relatively large influence on the base resistance.

11 Punching failure should be considered if weak ground is present at a depth of less than 4 times the base diameter below the base of the pile.

12 Where the pile base diameter exceeds the shaft diameter, the possible adverse effect shall be considered.

13 For open-ended driven tube or box-section piles with openings of more than 500 mm in any direction, and without special devices inside the pile to induce plugging, the base resistance should be limited to the smaller of:

(a) the shearing resistance between the soil plug and the inside face of the pile;

(b) the base resistance derived using the cross-sectional area of the base.

4.11.3 Ultimate compressive resistance from static load tests

1 The manner in which load tests are carried out shall be in accordance with 4.11.2 and shall be specified in the Geotechnical Design Report.

2 Trial piles to be tested in advance shall be installed in the same manner as the piles that will form the foundation and shall be founded in the same stratum.

3 If the diameter of the trial pile differs from that of the working piles, the possible difference in performance of piles of different diameters should be considered in assessing the compressive resistance to be adopted.

4 In the case of a very large diameter pile, it is often impractical to carry out a load test on a full size trial pile. Load tests on smaller diameter trial piles may be considered provided that:

(a) the ratio of the trial pile diameter/working pile diameter is not less than 0,5;

(b) the smaller diameter trial pile is fabricated and installed in the same way as the piles used for the foundation;

(c) the trial pile is instrumented in such a manner that the base and shaft resistance can be derived separately from the measurements.

NOTE: This approach should be used with caution for open-ended driven piles because of the influence of the diameter on the mobilisation of the compressive resistance of a soil plug in the pile.

5 In the case of a pile foundation subjected to downdrag, the pile resistance at failure, or at a displacement that equals the criterion for the verification of the ultimate limit state determined from the load test results, shall be corrected. The correction shall be achieved by subtracting the measured, or the most unfavorable, positive shaft resistance in the compressible stratum and in the strata above, where negative skin friction develops, from the loads measured at the pile head.

6 During the load test of a pile subject to downdrag, positive shaft friction will develop along the total length of the pile. The maximum test load applied to the working pile should be in excess of the sum of the design external load plus twice the downdrag force.

7 When deriving the ultimate characteristic compressive resistance from values measured in one or several pile load tests, an allowance shall be made for the variability of the ground and the variability of the effect of pile installation.

8 The systematic and random components of the variations in the ground shall be recognized in the interpretation of pile load tests.

9 The records of the installation of the test pile(s) shall be checked and any deviation from the normal execution conditions shall be accounted for.

10 The characteristic compressive resistance of the ground may be derived from the characteristic values of the base resistance and of the shaft resistance in accordance with Eurocode1997-1.

4.11.4 Ultimate compressive resistance from ground test results

1 Methods for assessing the compressive resistance of a pile foundation from ground test results shall have been established from pile load tests and from comparable experience.

2 A model factor may be introduced as described as following to ensure that the predicted compressive resistance is sufficiently safe :

(a) the range of uncertainty in the results of the method of analysis;

(b) any systematic errors known to be associated with the method of analysis

3 In assessing the validity of a model based on ground test results, the following items should be considered:

(a) soil type, including grading, mineralogy, angularity, density, pre-consolidation, compressibility and permeability;

(b) method of installation of the pile, including method of boring or driving;

(c) length, diameter, material and shape of the shaft and of the base of the pile (e.g. enlarged base);

(d) method of ground testing.

4.11.5 Ultimate compressive resistance from dynamic impact tests

1 Where a dynamic impact (hammer blow) pile test [measurement of strain and acceleration versus time during the impact event is used to assess the resistance of individual compression piles, the validity of the result shall have been demonstrated by previous evidence of acceptable performance in static load tests on the same pile type of similar length and cross-section and in similar ground conditions.

2 When using a dynamic impact load test, the driving resistance of the pile should be measured directly on the site in question.

NOTE A load test of this type can also include a process of signal matching to measured stress wave figures. Signal matching enables an approximate evaluation of shaft and base resistance of the pile as well as a simulation of its load-settlement behaviour.

3 The impact energy shall be high enough to allow for an appropriate interpretation of the pile capacity at a correspondingly high enough strain level.

4 The design value of the compressive resistance of the pile could be calculated and verified according to Eurocode1997-1.

4.11.6 Ultimate compressive resistance by applying pile driving formulae

1 Pile driving formulae shall only be used if the stratification of the ground has been determined.

2 If pile driving formulae are used to assess the ultimate compressive resistance of individual piles in a foundation, the validity of the formulae shall have been demonstrated by previous experimental evidence of acceptable performance in static load tests on the same type of pile, of similar length and cross-section, and in similar ground conditions.

3 For end-bearing piles driven into non-cohesive soil, the design value of the compressive resistance shall be assessed by the same procedure as in 4.11.5.

4 When a pile driving formula is applied to verify the compression resistance of a pile, the pile driving test should have been carried out on at least 5 piles distributed at sufficient spacing in the piling area in order to check a suitable blow count for the final series of blows.

5 The penetration of the pile point for the final series of blows should be recorded for each pile.

4.11.7 Ultimate compressive resistance from wave equation analysis

1 Wave equation analysis shall only be used where stratification of the ground has been determined by borings and field tests.

2 Where wave equation analysis is used to assess the resistance of individual compression piles, the validity of the analysis shall have been demonstrated by previous evidence of acceptable performance in static load tests on the same pile type, of similar length and cross- section, and in similar ground conditions.

3 The design value of the compressive resistance derived from the results of wave equation analysis of a number of representative piles, shall be assessed by the same procedure as in 4.11.3.

NOTE Wave equation analysis is based on a mathematical model of soil, pile and driving equipment without stress wave measurements on site. The method is usually applied to study hammer performance, dynamic soil parameters and stresses in the pile during driving. It is also, on the basis of the models, possible to determine the required driving resistance (blow count) that is usually related to the expected compressive resistance of the pile.

4.11.8 Ground tensile resistance

1 The design of piles in tension shall be consistent with the design rules given in 4.11.2, where applicable. Design rules that are specific for foundations involving piles in tension are presented below.

2 To verify that the foundation will support the design load with adequate safety against a failure in tension, the following inequality shall be satisfied for all ultimate limit state load cases and load combinations in accordance with Eurocode1997-1.

3 For isolated tensile piles or a group of tensile piles, the failure mechanism may be governed by the pull-out resistance of a cone of ground, especially for piles with an enlarged base or rock socket.

4 When considering the uplift of the block of ground containing the piles the shear resistance along the sides of the block may be added to the resisting forces.

5 Normally the block effect will govern the design tensile resistance if the distance between the piles is equal to or less than the square root of the product of the pile diameter and the pile penetration into the main resisting stratum.

6 The group effect, which may reduce the effective vertical stresses in the soil and hence the shaft resistances of individual piles in the group, shall be considered when assessing the tensile resistance of a group of piles.

7 The severe adverse effect of cyclic loading and reversals of load on the tensile resistance shall be considered.

8 Comparable experience based on pile load tests should be applied to appraise this effect.

4.11.9 Ultimate tensile resistance from pile load tests

1 Pile load tests to determine the ultimate tensile resistance of an isolated pile shall be carried out in accordance with 4.9.1 and with regard to 4.11.3.

2 The design tensile resistance could be calculated and verified according to Eurocode1997-1.

4.11.10 Ultimate tensile resistance from ground test results

1 Methods for assessing the tensile resistance of a pile foundation from ground test results shall have been established from pile load tests and from comparable experience.

2 A model factor may be introduced as following to ensure that the predicted tensile resistance is sufficiently safe.

(a) the range of uncertainty in the results of the method of analysis;

(b) any systematic errors known to be associated with the method of analysis

3 The design value of tensile resistance of a pile could be calculated and verified according to Eurocode1997-1.

4.11.11 Vertical displacements of pile foundations

1 Vertical displacements under serviceability limit state conditions shall be assessed and checked.

2 When calculating the vertical displacements of a pile foundation, the uncertainties involved in the calculation model and in determining the relevant ground properties should be taken into account. Hence it should not be overlooked that in most cases calculations will provide only an approximate estimate of the displacements of the pile foundation.

NOTE For piles bearing in medium-to-dense soils and for tension piles, the safety requirements for the ultimate limit state design are normally sufficient to prevent a serviceability limit state in the supported structure.

4.11.12 Pile foundations in compression

1 The occurrence of a serviceability limit state in the supported structure due to pile settlements shall be checked, taking into account downdrag, where probable.

NOTE When the pile toe is placed in a medium-dense or firm layer overlying rock or very hard soil, the partial safety factors for ultimate limit state conditions are normally sufficient to satisfy serviceability limit state conditions.

2 Assessment of settlements shall include both the settlement of individual piles and the settlement due to group action.

3 The settlement analysis should include an estimate of the differential settlements that may occur.

4 When no load test results are available for an analysis of the interaction of the piled foundation with the superstructure, the load-settlement performance of individual piles should be assessed on empirically established safe assumptions.

4.11.13 Pile foundations in tension

1 The assessment of upward displacements shall be done and Particular attention should be paid to the elongation of the pile material.

2 When very severe criteria are set for the serviceability limit state, a separate check of the upward displacements shall be carried out.

4.12 TRANSVERSELY LOADED PILES

4.12.1 Design method

1 The design of piles subjected to transverse loading shall be consistent with the design rules given in 4.10, where applicable. Design rules specifically for foundations involving piles subjected to transverse loading are presented below.

2 To demonstrate that a pile will support the design transverse load with adequate safety against failure, the following inequality shall be satisfied for all ultimate limit state load cases and load combinations:

$$Ftr \leq Rtr$$

Where;

Ftr: design value of the transverse load on a pile or a pile foundation
Rtr : design resistance of transversally loaded pile

3 One of the following failure mechanisms should be considered:

(a) for short piles, rotation or translation as a rigid body;

(b) for long slender piles, bending failure of the pile, accompanied by local yielding and displacement of the soil near the top of the pile.

4 The group effect shall be considered when assessing the resistance of transversely loaded piles.

5 It should be considered that a transverse load applied to a group of piles may result in a combination of compression, tension and transverse forces in the individual piles.

4.12.2 Transverse load resistance from pile load tests

1 Transverse pile load tests shall be carried out in accordance with 4.9.6.

2 Contrary to the load test procedure described in 4.9 tests on transversely loaded piles need not normally be continued to a state of failure. The magnitude and line of action of the test load should simulate the design loading of the pile.

3 An allowance shall be made for the variability of the ground, particularly over the top few meters of the pile, when choosing the number of piles for testing and when deriving the design transverse resistance from load test results.

4 Records of the installation of the test pile(s) should be checked, and any deviation from the normal construction conditions should be accounted for in the interpretation of the pile load test results. For pile groups, the effects of interaction and head fixity should be accounted for when deriving the transverse resistance from the results of load tests on individual test piles.

4.12.3 Transverse load resistance from ground test results and pile strength parameters

1 The transverse resistance of a pile or pile group shall be calculated using a compatible set of structural effects of actions, ground reactions and displacements.

2 The analysis of a transversely loaded pile shall include the possibility of structural failure of the pile in the ground.

3 The calculation of the transverse resistance of a long slender pile may be carried out using the theory of a beam loaded at the top and supported by a deformable medium characterized by a horizontal modulus of subgrade reaction.

4 The degree of freedom of rotation of the piles at the connection with the structure shall be taken into account when assessing the foundation's transverse resistance.

4.12.4 Transverse displacement

1 The assessment of the transverse displacement of a pile foundation shall take into account:

(a) the stiffness of the ground and its variation with strain level;
(b) the flexural stiffness of the individual piles;
(c) the moment fixity of the piles at the connection with the structure;
(d) the group effect;
(e) the effect of load reversals or of cyclic loading

2 A general analysis of the displacement of a pile foundation should be based on expected degrees of kinematic freedom of movement.

END OF PART