SERIES NG 1600
PILING AND EMBEDDED RETAINING WALLS

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NG 1601 PILING AND EMBEDDED RETAINING WALLS

NG 1601 General Requirements for Piling and Embedded Retaining Walls

1 (11/03) The Institution of Civil Engineer's Specification (ICE) for Piling and Embedded Retaining Walls 1996 is based on Series 1600.

2 (11/03) Where Series 1600 refers to other Series of the Specification for Highway Works (SHW), the ICE Specification has been modified to include complete descriptions of those requirements.

3 In many cases there will be more than one type of pile or wall that could provide an appropriate solution and the compiler may choose to allow the Contractor to select from a range of possible types. A list of the requirements to be specified is given in NG Sample Appendix 16/1.

4 The following information should be shown on the Drawings (cross-referenced in Appendix 16/1):

- pile layout
- working loads
- location of preliminary piles, identifying separately those to be used as working piles and those not to be used as working piles.

5 (11/03) A comprehensive site investigation carried out in accordance with SD13 (MCHW 5.3.1), SA9 (MCHW 5.3.2) and HD22 (DMRB 4.1.2) is an essential prerequisite to the selection, design and construction of piles and embedded retaining walls. Particular attention should be given to the following aspects, which are particularly relevant to the construction of piles and embedded retaining walls:

- a comprehensive desk study of the site history to assess the risk of obstructions, contamination, quarries, opencast and deep mines, backfilled sites or archaeological finds that could affect the feasibility of pile construction, programme and cost. Suspected obstructions should be identified by probing or preliminary enabling works to confirm their extent
- equilibrium piezometric levels of all possible water tables, including artesian conditions and any seasonal or tidal fluctuations
- permeability of the soils
- presence of coarse, open soils, cavities, natural or artificial, which may cause sudden losses of support fluid in open excavation and require preliminary treatment
- strength and deformation characteristics of soils, particularly weak strata that could cause instability or large deformation
- the presence of boulders or obstructions which may cause difficulties in excavations or driving conditions
- soil and groundwater chemistry which may affect the durability of the piles or wall, the disposal of spoil, and the performance or disposal of support fluid
- the strength and profile of any rock surface beneath the area to be piled or along the wall alignment.

Reports given to the Contractor should be checked to ensure they are relevant to the structure to be built and that the scope of construction works envisaged at the time the site investigation was carried out have not significantly changed. If they have or if the ground investigation reveals additional problems, further investigation should be carried out.

6 Unexpected and emergency situations may arise which, if not dealt with rapidly, could jeopardise the integrity or performance of the completed foundation. It is essential for foundation construction that the various parties accept the possibility that unexpected conditions can occur and that remedial action can be agreed sufficiently quickly for the work to continue without any adverse effects on the completed foundation. For this reason full time supervision is recommended for all piling and embedded retaining walls. Site representatives should be sufficiently familiar with the construction and the design requirements to enable solutions to unexpected or emergency situations to be agreed without unreasonable delay.

7 The tolerances specified are realistic for most sites and ground conditions. However where the ground contains obstructions or for certain ground conditions (eg. pile tip moving from soft to dense layers) tolerances may need to be relaxed. This will necessitate an allowance in the design of pile caps and ground beams to suit the installed pile positions. The Contractor should be informed of the reasons leading to the changed tolerances and the design of the structure to be built on the piles should not be compromised. In some cases the design may require tighter tolerances than those specified in which case the required tolerances should be specified in the relevant Appendix. Plunged stanchions may need to be positioned to structural tolerances which are much tighter than those for piling. If this is the case the tolerances should be specified in the relevant Appendix and the Contractor's method statement should show how the tighter tolerances are to be attained. Casting tolerances of bored piles above cut-off level are specified in Tables 16/3 to 16/5 and in Table 16/7. The Contractor may overpour the piles to whatever level within the tolerance that he wishes but he must ensure that concrete at cut-off level is dense and homogenous.

8 The piling method statement should include sufficient detail to demonstrate that it is compatible with the design assumptions and any site constraints. The following list includes examples of items that may need to be provided:

- Site staff and organisation.
- The experience of the Contractor and his staff with the piling type and the particular ground conditions.
- The details of piling plant should be sufficient to demonstrate its suitability for achieving the required penetration and to work within any noise and vibration limits where these are restricted.
- The sequence of piling which may affect uplift and lateral displacement of driven piles or affect the integrity of nearby cast-in-situ piles.
- Setting out and means of achieving specified tolerances.
- The time period for boring and concreting that may have an influence on the design assumptions for the pile resistance that can be mobilised.
- The length of temporary casing or use of support fluids to maintain adequate support to the ground during construction.
- The method and equipment for cleaning or forming the base of the pile where end bearing is assumed in the design. The design assumptions for end bearing should take into account what can realistically be achieved with the proposed method.
- The methods that will be used to check pile depth, bore stability, base cleanliness and compliance with the specified tolerances.
- The method of placing concrete to ensure it is placed vertically down the bore. Where concrete is placed under water or support fluid the method of placing concrete by tremie should be described.
- (11/03) The frequency and means of testing concrete consistence, strength class and compliance values for grouts.
- The means of placing reinforcement including the lapping of reinforcement cages, the method of maintaining concrete cover and the vertical position of the cage and any additional reinforcement for lifting, handling and placing.
- Details of permanent casings and how they are to be maintained in position during concreting.
- Details of preboring, or other means of aiding pile driveability and measures that will be taken to minimise disturbance of the surrounding ground.
- The level to which concrete will be cast and details of how completed piles are to be protected from subsequent damage.
- Procedures for dealing with emergency situations such as sudden loss of support fluid, obstructions and piles that are out of tolerance.
- Typical record sheets.

9 Consideration will need to be given to the location and condition of adjacent structures and services that are likely to be within the zone of influence of the Works. Certain structures may be particularly susceptible to noise, vibration or ground movement and should be assessed prior to inviting tenders where special measures are likely to be required for protecting these structures. The information on location and condition of these structures together with the restrictions to be imposed and the monitoring requirements should be presented on the Drawings and in Appendix 16/1. The Contractor is required to confirm the information on site and provide proposals in respect of these structures and services.

10 Should an excavation be made alongside completed piles they will be subjected to lateral loading and the design should allow for such conditions where necessary.

NG 1602 Precast Reinforced and Prestressed Concrete Piles and Precast Reinforced Concrete Segmental Piles

1 The following sub-Clauses 2 to 10 apply to precast reinforced and prestressed concrete piles usually supplied for use in a single length without facility for joining lengths together. The remaining sub-Clauses apply to segmental piles.

2 If the manufacture of precast reinforced and prestressed concrete piles differs in any respect from that specified in Appendix 16/2, the Contractor should be asked for complete details of his proposed alternative if these were not submitted at tender stage so that the proposed alternative can be evaluated.

3 (11/03) Cement aggregates and water should comply with Clause 1702, or Clause 1703 where admixtures are used.

4 (11/03) The minimum concrete strength class for precast reinforced piles is C25/30. The minimum cement content and maximum free water/cement ratio for various exposure conditions are given in Table NG 17/1 and British Research Establishment (BRE) Special Digest SD1. Severe exposure conditions are defined in Table 13 of BS 5400: Part 4, as implemented by BD 24 (DMRB 1.3.1), for buried parts of the structure such as piles. This table provides the nominal cover for various strength classes of concrete under particular conditions of exposure. Nominal cover to reinforcement for C25/30 concrete for buried parts of the structure is 45 mm. For hard driving conditions or where reduced nominal cover of 35 mm is required, C32/40 concrete is recommended with a minimum cement content of 400 kg/m³ according to BS 8004 as implemented in BD74 (DMRB 2.1.8). The greater the cover, the greater the tendency for concrete to spall off during hard driving. For prestressed concrete piles the recommended minimum concrete strength class is C32/40 with a minimum cement content of 400 kg/m³. The cement type, minimum cement content and maximum free water cement ratio should be in accordance with Special Digest SD1 to protect buried concrete from acid and sulfate attacks.

5 The designer should state the particular requirements in Appendix 16/2 for the minimum length or set to be obtained. Generally in cohesive soils where piles are designed to carry the load in friction they should be driven to a specified penetration or length. Piles that are predominantly end bearing in cohesionless soils or founded on rock are driven to a set which in some instances is also combined with a minimum length requirement. Guidance on hammer selection is given by Tomlinson (1986). Hammers that are too light or whose delivered energy can deteriorate in energy output can lead to false sets. Effective hammer energy can be measured by dynamic testing. Normally for a well matched hammer and pile system the set will be between 10 and 25 blows for 25 mm penetration. The set for working piles should be established from experience or from a successful preliminary pile test. Set calculations are often not reliable.

6 The length of pile required should be specified by the designer and may be subject to the results of preliminary pile tests. Trial drives are recommended prior to preliminary pile tests or installation of working piles to assess likely variations in driving conditions across the site, to confirm the required sets, and the potential for uplift or lateral displacement of piles driven in groups. The effect of uplift on piles already driven is to reduce their end-bearing capacity and will become a critical factor for the control of piling when this is a main source of capacity, as is often the case for driven piles. Lateral displacement may also cause damage to piles already driven or adjacent structures. Careful trials at the commencement of piling can be used to determine the criteria for pile installation. Sometimes for a preliminary pile test, the test pile is driven first followed by its surrounding anchor piles in an uplift trial. The test pile can then be subjected to a static load test and if successful a new permissable uplift and/or settlement criteria can be set. To minimise uplift and lateral displacement, piles are usually driven in order from the centre of a pile group outwards or away from an adjacent structure. Hammond et al (1980) present data on the uplift of piles due to the driving of adjacent piles for particular pile types and ground conditions. Onerous settlement criteria may not be compatible with the permissable uplift criterion specified in Clauses 1602, 1605 and 1606.

7 Preboring may be used to ease pile driving through dense layers or can be used to reduce lateral movements of the surrounding ground. It may affect the capacity of the pile. Jetting can be used to assist pile driving in certain cohesionless soils but must be used with great care as it may affect the pile capacity and may also wash away soil supporting adjacent structures.

8 The Specification calls for full records to be made for the driving of every pile. Where consistent driving conditions have been established across a site this requirement may be relaxed. As a minimum the Contractor should make a full record for the first pile in each area and for the final 3 m of every pile. In addition full driving records should be made for at least 5% of the piles driven.

9 A feature of driven piles in cohesive deposits is that as the soil is sheared during pile installation, the soil surrounding the pile loses strength. However once the pile has been driven the soil consolidates and 'sets up' around the pile, giving increased capacity. Conversely in fine granular soils (such as silt), dilation of the soil can cause negative pore water pressures (suction), which increase the driving resistance, so giving a false set. Dissipation of the suctions permits the soil to 'relax' so giving a reduced capacity. The timing of dynamic and static pile testing should take this into account.

10 Heavy mechanical breakers to cut down piles should be used with caution as they may induce damage below the point of application. This particularly applies to piles of less than 600 mm diameter.

11 Sub-Clauses 12 and 13 apply to piles made of precast reinforced concrete elements cast at a precasting works away from the site. The elements are joined together as necessary on site during driving, using special proven steel joints, incorporated into the pile elements when cast.

12 (11/03) The guidance in sub-Clauses NG 2 to 10 for precast reinforced and prestressed concrete piles also applies to precast reinforced concrete segmental piles.

13 Joints are generally made of steel and are therefore susceptible to corrosion if exposed to free oxygen and water. Consideration should be given to the location of the joints in completed piles. Generally in relatively low permeability soil beneath the water table there is a low risk of joint corrosion. The risk increases if the joints are located in flowing groundwater conditions in permeable strata at or close to the water table. Special care should be taken if joints or other steel elements are to be located in contaminated soils where anaerobic bacteria can attack the steel. Dock mud is a good example of such a zone. A problem with the final position of a joint can arise when pile driving reaches refusal before the pile is driven to its intended depth.

NG 1603 Bored Cast-in-Place Piles

1 Clause 1603 applies to bored piles in which the pile bore is excavated by rotary and/or percussive means using augers, buckets, grabs or other boring tools to advance where possible a stable open hole. Where the bore is unstable, temporary or permanent casing or support fluids may be used to maintain the stability of the bore during excavation and concreting.

2 (11/03) Cement, aggregates and water should comply with Clause 1702, or Clause 1703 where admixtures are used.

3 (11/03) The minimum concrete strength class for bored cast-in-place piles is C25/30. The minimum cement content and maximum free water/cement ratio for various exposure conditions are given in Table NG 17/1 and British Research Establishment (BRE) Special Digest SD1. Severe exposure conditions are defined in Table 13 of BS 5400: Part 4, as implemented by BD24 (DMRB 1.3.1), for buried parts of the structure such as piles, or moderate in the case of concrete permanently saturated by water with a pH greater than 4.5. This table provides the nominal cover for various grades of concrete under particular conditions of exposure. Nominal cover to reinforcement for strength class C25/30 concrete for buried parts of the structure is 45 mm for severe conditions or 35 mm for moderate conditions. However BS 8004, as implemented in BD74 (DMRB 2.1.8), recommends a minimum additional cover allowance of 40 mm when concrete is cast directly against an excavated soil face. The cement type, minimum cement content and maximum free water cement ratio should be in accordance with Special Digest SD1 to protect buried concrete from acid and sulfate attack.

4 (11/03) BS 8004, as implemented in BD74 (DMRB 2.1.8), limits the concrete stress in the shaft to 25% of the concrete characteristic strength. Where the casing of the pile is continuous and permanent, of adequate thickness and suitable shape, the allowable compressive stress in the shaft may be increased.

5 The length of pile required should be specified by the designer and may be amended following the results of preliminary pile tests. Trial bores may be useful prior to preliminary pile tests or installation of working piles to assess likely variations in soil conditions, bore stability and the permeability of soils to support fluid.

6 The requirement for the diameter of piles not to be less than the specified diameter is monitored by checking for concrete underbreak during concreting. Underbreak over a length of pile may indicate a defect. Apparent underbreak over a cased length of pile with known dimensions is usually caused by the presence of an abnormally high percentage of steel and/or tubing in the pile shaft or an under-reporting of the volume of concrete supplied. Similarly apparent overbreak may be caused by over-reporting the supply of concrete to the pile.

7 (11/03) Typical bored cast-in-place pile diameters are given in Table 15 of BS 8004, as implemented in BD 74 (DMRB 2.1.8). Tripod bored piles generally are of 0.45 m or 0.6 m diameter and up to 25 m long (tripod bored piles longer than 20 m are subject to verticality problems in some ground conditions). Raking tripod piles in particular deviate quickly from their initial alignment and require a larger verticality tolerance. Auger bored piles commonly are bored at diameters ranging from 0.3 m to 2.4 m in 0.15 m increments but piles of much larger diameter (up to 3.6 m) are possible. Larger pile sizes (greater than about 1.5 m) may restrict the choice of Contractors.

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8 (11/03) The Contractor's proposals for concrete cast under support fluid should be checked to ensure that they meet the following:

- aggregates should preferably be naturally rounded well graded gravels and sands when they are readily available in the locality. They must comply with BS EN 12620. The maximum aggregate size should be 20 mm. The sand should conform with 0/4 (CP) or 0/2 (MP) of BS EN 12620. The use of other aggregates may be permitted subject to the suitability of the diameter of the tremie pipe and spacing of reinforcement bars
- a cementitious content of not less than 400 kg/m³ should be maintained. Admixtures are often used to improve the consistence, rate of gain of strength and setting time and these should comply with Series 1700
- the concrete mix should be designed to give high consistence and the specified characteristic strength. The required strength depends on the loading and the requirements of Series 1700 to meet the anticipated exposure conditions. For reinforced concrete cast against soil and below water the minimum grade is C25/30 concrete
- the concrete cover to reinforcement should not be less than the values stated in BS 5400 : Part 4 Table 13, as implemented by BD24 (DMRB 1.3.1). For concrete cast against the ground an additional 40 mm of concrete cover is recommended by BS 8004, as implemented in BD74 (DMRB 2.1.8), and thus the minimum concrete cover to reinforcement is usually 75 mm.

9 Permanent casing may be used:

a) to provide support to zones of the ground surrounding the pile which may become unstable before the pile concrete is set;

b) to provide additional load carrying capacity to the pile in the situation where the concrete plus reinforcement is unable to provide the required load capacity, particularly the capacity to resist lateral loads;

c) as a surface on which slip coat may be spread (see Clause 1607);

d) as a barrier against the ingress of contaminated or aggressive groundwater. Such casing must be in firm contact with the soil surrounding the pile especially at the top and bottom of the section of shaft being cased. This can be done in small diameter shafts by expanding the casing, either by mechanical means or by fluid pressure, although this process is seldom used. In larger shafts the annulus should be filled with a 'thick' cement - bentonite grout;

e) to form piles through water.

Generally, any significant annulus outside the casing should be filled with grout to prevent volume changes in the ground. The casing must be able to withstand the fluid pressure of the grout without buckling.

10 (11/03) The more commonly encountered defects are summarised in CIRIA Report PG2. In particular, the limit on concrete length of free-fall is to avoid the concrete segregating if it hits the reinforcement cage.

11 Where the bases of piles are to be inspected by manned descent, safety must in no way be compromised. Some Contractors have views on manned pile descent which should be sought before such piles are specified. If a large diameter pile in a cohesive material is to derive a significant part of its resistance from its base, the base should be directly inspected as piling equipment smooths soft reworked material to make it appear to a closed circuit television system as if it is intact clay. Only piles in ground which is self-supporting and free from joints and seepages or where the piles are fully cased should be considered for descent. Although BS 8008 permits piles of diameter 750 mm to be descended, in many cases 900 mm piles will be a more practical minimum. The Contractor's method statement for manned descent should be carefully scrutinised to ensure the full requirements of BS 8008 are met.

12 Pressure grouting of the pile base or along a length of the shaft can be carried out in non-cohesive soils to enhance pile performance. The mechanism for pressure grouting of a pile base is discussed by Fleming (1993), who suggests that in addition to giving improved load-settlement characteristics, base grouting can also be used as quality assurance for bases which are required to carry load but cannot be directly inspected. The uplift limits specified for base grouting are typical for most pile types. For very long piles of small diameter, it may not be possible to measure any pile head movement at all. On the other hand, if it is possible to move a very long pile by 2 mm the movement at the pile toe may be considerably greater causing the pile-soil interface strength to fall to a residual value in cohesive soils. In these circumstances the philosophy of base grouting needs careful consideration.

13 It is not possible to rake bored cast-in-place piles if the piles are to be concreted with a tremie pipe.

14 This Clause can apply to mini or micro piles which are small diameter piles used for underpinning existing

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structures, or where working area is restricted, or for locations adjacent to sensitive structures, or where difficult ground conditions exist, such as boulders, fissured rock or man-made obstructions. The piles are usually of 100 to 300 mm diameter and up to 30 m long. Drilling equipment is normally employed and the pile filled with grout, sometimes under pressure to give additional penetration into granular soils. Reinforcement is usually a single bar held centrally in the drillhole by a special spacer.

15 Heavy mechanical breakers to cut down piles should be used with caution as they may induce damage below the point of application. This particularly applies to piles of less than 600 mm diameter.

NG 1604 Bored Piles Constructed Using Continuous Flight Augers and Concrete or Grout Injection Through Hollow Auger Stems

1 Clause 1604 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. The reinforcement is inserted after the pile has been concreted to the surface.

2 (11/03) The guidance in Clause NG 1603, sub-Clauses 2 to 6 and 15 for bored cast-in-place piles also applies to bored piles constructed using continuous flight augers with concrete or grout injection through hollow auger stems.

3 The monitoring requirements for continuous flight auger piles are particularly onerous as these piles are the only pile type where the maintenance of pile bore stability is not observed. Where monitoring of key parameters has not been used, defects have occurred. It is necessary that the Contractor's monitoring system should be automated. In addition it is desirable that the speed of rotation of the auger should be recorded as the number of auger rotations relative to auger penetration is a useful although not essential parameter. Measurement of the speed of auger rotation is not offered by many Contractors. The requirement for regular calibration provides confidence in the complicated automatic monitoring equipment that is often employed.

4 A hard copy of the monitoring output should be available after completion of a pile to provide a common basis for discussion should an incident occur during pile construction. This may allow the Contractor to evaluate rapidly the need for any remedial works before the concrete has set.

5 Typical continuous flight auger piles range in diameter from 0.45 m to 0.9 m in 0.15 m increments and are generally up to 23 m deep below the commencing surface. Longer piles can be constructed by using two lengths of continuous flight auger, but difficulties can arise when splitting the auger (ie. removing the upper length) during concreting when the concrete pressure in the pile bore reduces. This can have an effect on the integrity of the shaft and steps should be taken to ensure the Contractor guards against this.

6 Piles constructed using a continuous flight auger have their reinforcement inserted on completion of concreting. The reinforcement is either pushed or vibrated into the concreted pile shaft. Difficulties may arise inserting heavy or long reinforcement cages or where there has been a delay between concreting and insertion. Particular problems are experienced in very permeable soils where the concrete stiffens more rapidly or where the reinforcement cage has a lot of links or joints which resist its penetration.

7 During boring, when the auger passes from a weak stratum to a strong one, there is a danger that the weak soils will be drawn up the continuous flight by a process known as 'flighting'. This produces local shaft enlargement and possible loss of integrity. Flighting can also occur due to bulking of soils when excavated.

8 Permanent casing is not normally installed in conjunction with this pile type. This means there is no way of reducing friction along a length of pile.

9 With continuous flight auger piles, the soil is not seen until completion of construction. Therefore it is difficult to measure penetration into a particular stratum or to observe whether a feature such as a solution feature has been encountered.

10 The requirement to rebore piles to a safe level below the position of interruption of concrete supply, if the pile cannot be completed in the normal manner, is not practical if the original toe level was dictated by the presence of an impenetrable layer.

NG 1605 Driven Cast-in-Place Piles

1 Clause 1605 applies to piles for which a permanent casing of steel or concrete is driven with an end plate or plug, reinforcement placed within it if required and the casing filled with concrete. It also applies to piles in which a temporary casing is driven with an end plate or plug, reinforcement placed within it and the pile formed in the ground by filling the temporary casing with concrete before and sometimes during its extraction.

2 (11/03) The guidance in Clause NG 1602, sub-Clauses NG 5 to 10 and NG 1603, sub-Clauses

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NG 2 to 5 for bored cast-in-place piles also applies to driven cast-in-place piles.

3 Driven cast-in-place piles can be either top-driven (that is the hammer blows are applied to the pile head) or bottom-driven (where the blows are applied to a plug or steel plate at the base of the casing). Generally Contractors will offer a proprietary system when this pile type is specified. A range of the systems available is summarised in CIRIA Report PG1.

NG 1606 Steel Bearing Piles

1 (11/03) Clause 1606 covers steel bearing piles driven to form part of the Works. Generally, the piles will be hollow tubes, welded sections or H-sections. This section of the specification and notes for guidance does not include steel sheet piling, except insofar as such piles are designed to act as bearing piles supporting vertical loads. Steel sheet piles are covered in Clause 1615.

2 (11/03) Considerable guidance on the specification and installation of steel bearing piles is given in Cornfield (1989) and British Steel (1992). In particular, this publication contains useful advice on design corrosion rates for different situations. However, the corrosion rates in BS 6349 should be designed for.

3 Steel tubes can be driven open (ie. without end plate) or closed (ie. with end plate). If tubes are driven open, then the soil on the inside may ‘plug’, that is the soil inside the tube moves downward with the pile. If the piles are driven closed an end plate is usually welded to the end. Such piles (or piles driven open with partial or total excavation of the soil inside) can be filled with reinforced concrete, in which case it is a driven cast-in-place pile with sacrificial lining or permanent lining. If the tube is driven open and the soil inside is subsequently excavated, considerable care is necessary not to induce inflows of water or soil into the tube.

4 (11/03) The guidance in Clause NG 1602, sub-Clauses NG 5 to 9 for precast reinforced and prestressed concrete piles also applies to steel piles.

5 (11/03) Sub-Clause 1601.31 requires the Contractor to provide details of all preliminary test results at least 5 working days prior to ordering piles for the main work. Varying pile lengths, diameters or thickness of steel after the Contractor has placed his order could be expensive and cause delay. There is a significant risk of having to vary the order where piles are ordered before completion of the preliminary test piles, eg. for rapid programming of the work. For goods materials sampling and testing refer to Clause NG 105.

NG 1607 Reduction of Friction on Piles

1 Where a means of reducing friction on any specified pile is required, one of the following methods can be used:

(a) pre-applied bituminous or other proprietary friction-reducing coating

(b) pre-applied low-friction sleeving

(c) formed-in-place low-friction surround

(d) pre-installed low-friction sleeving

2 Pre-applied coating and sleeving is applicable to driven piles or permanently cased bored piles while the formed-in-place surround and pre-installed sleeving are applicable to driven or bored piles.

3 Most friction-reducing products are proprietary brands and care must be taken to follow the manufacturer’s recommendations. In particular for treatment of driven piles, the pile surface should be clean and dry before application of any coating.

4 The Contractor is required to make available a manufacturer’s specification for any proprietary system used. The use of non-proprietary systems is not recommended as the requirements of a slip layer are both very demanding and partially conflicting, eg. a pre-applied coating is required to remain attached to the pile during driving but is then required to shear during slow soil loading. In particular confirmation that the product used is compatible with the friction reduction assumed in the pile design should be obtained.

5 Any pile tests to prove friction reducing systems should allow for the different rate of load application applied in the test and those that will be applied by the soil to the working piles.

6 Care should be taken when driving piles with pre-applied coating or sleeving though coarse granular soils that the coating or sleeving is not removed.

NG 1608 Non-Destructive Methods for Testing Piles

Integrity testing

1 The purpose of integrity testing is to identify acoustic anomalies in piles that could have a structural significance with regard to the performance and durability of the pile. Integrity tests do not give direct information about the performance of piles under structural loads.

2 The methods available are normally applied to preformed concrete piles made in a single length, and to cast-in-place concrete piles. The constituent materials of the piles should have a large differential modulus of elasticity compared with the ground in which it is embedded to obtain a satisfactory response. 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. Joints in piles, large changes in sections such as underreams and permanent casings are likely to affect the ability to obtain a clear response from the pile toe.

3 Integrity testing is not to be regarded as a replacement for static load testing but as a means of providing supplementary soundness information. Damage to the head of a pile after construction or cracks formed in the pile due to heaving of adjacent clay can often be detected. However the structural significance of this cannot be reasonably assessed without subsequent physical examination of the pile to assess reductions in section, voids or crack widths, their location, orientation and the likely structural effects on the pile.

4 For sonic logging, it is preferable to install four tubes if the pile is of sufficient diameter. This allows the centre of the pile to be integrity checked. On completion of sonic logging it is normal for the tubes to be grouted up with a grout of comparable strength to the concrete in the pile.

5 Preparation of pile heads is required for most types of integrity testing and as several tests can be carried out in a single visit, it is therefore necessary for the Contractor to take account of this in his programme.

6 Further guidance on integrity testing is provided in Appendix F of the ICE Specification for Piling, in Turner (TRL Project Report 113) and in CIRIA guide RP 408.

Dynamic testing

7 The purpose of dynamic pile testing is to determine the response of the pile to dynamic loading and to assess the efficiency of transfer of energy to the pile head from the hammer blow.

8 Dynamic pile testing involves monitoring the response of a pile to a heavy impact applied at the pile head usually from the hammer used to drive the pile. The response is normally measured in terms of force and acceleration or displacement close to the pile head.

9 The results of the test directly obtained refer to the dynamic loading condition. The test is valuable for monitoring hammer efficiency, pile integrity for certain piles and driveability. It should not be considered as a direct substitute for static load testing of piles but can be a useful supplement if correlation between static and dynamic tests is good.

10 Tests are normally carried out on piles that have achieved their final set and the impact provided by the hammer is unlikely to be sufficient to move the pile far enough to mobilise the full pile resistance. Back analysis of dynamic tests to compare with static load tests should therefore be treated with extreme care.

11 If tests are required on restrike some time after installation to assess relaxation or set up effects this should be stated in Appendix 16/8 so that the Contractor can organise his programme accordingly.

12 The results required for typical blows are the output from a simple wave analysis program such as CASE. A more rigorous analysis may be required for selected blows. This will be accomplished using a program such as CAPWAP where the measured results are compared with a theoretical model built up from a knowledge of the soil properties and experience.

13 Further guidance on dynamic pile testing is contained in Appendix E of the ICE Specification for Piling and in Turner (TRL Project Report 113).

NG 1609 Static Load Testing of Piles

1 Clause 1609 deals with the testing of a pile by the controlled application of an axial load. It covers vertical and raking piles tested in compression (ie. subjected to loads or forces in the direction such as would cause the piles to penetrate further into the ground) and vertical or raking piles tested in tension (ie. subjected to forces in a direction such as would cause the piles to be extracted from the ground). Static load testing of piles is the only reliable way to establish a pile's load-settlement behaviour.

2 The purpose of preliminary piles is to validate the pile design and performance criteria and to prove that a Contractor's method of construction can construct viable foundations in particular ground conditions. Where preliminary piles are required they should be constructed sufficiently in advance of the installation of the working piles to allow time for the test, the evaluation of the results and the adoption of modifications if these prove necessary. If it is necessary to specify a precise timing for the construction and testing of preliminary piles this should be included in Appendix 16/9.

3 (11/03) A working pile may be tested at any time during the Contract. Working pile tests are seldom tested to failure. Generally, working piles are tested to verify that the construction methods used have not changed so as to produce piles inferior to the preliminary piles, or to verify that piles which are for some reason suspect have satisfactory load-settlement performance. In some cases such as with driven piles where relaxation or setting up may occur it is necessary to delay the test until about seven days after installation. For all cases it is preferable to test at least one working pile test to be confident that the requirements of the Specification have been met.

4 Where the Contractor has designed the piles and performance criteria are specified, a test is an essential part of the Contract to establish that the piles meet the performance criteria.

5 Preliminary piles should be specified unless the design, factor of safety against failure, construction method and ground conditions are such that the risk of failure of working piles is negligible. Further guidance on static load testing of piles is provided in the ICE Specification for Piling.

6 Guidance on pile load testing procedures is given in CIRIA Report PG7. The methods of loading, ie. under kentledge, against anchor piles or against ground anchors, should be chosen by the Contractor except in some instances for driven piles where the uplift of the test pile during driving of the anchor piles is of interest. Safety of the test arrangement is of paramount importance and the Contractor should give the specified period of notice so that the test assembly can be inspected before the application of any load.

7 The Contractor's method of load application should only impart an axial load into the pile, unless the load is on a laterally loaded pile.

8 The type of test should be stated in Appendix 16/9 as:

- proof load test as sub-Clause 1609.33
- extended proof load test as sub-Clause 1609.34
- constant rate of penetration test as sub-Clause 1609.34
- other systems such as cyclic loading or constant rate of loading test.

Where other systems of test are stated, details should be provided of all the loading stages, measurement requirements and acceptance criteria.

9 The constant rate of penetration test option in sub-Clause 1609.34 is normally used where the ultimate load capacity of a preliminary pile is required, particularly for piles embedded in and bearing on clay soils. It may lead to apparently enhanced capacities by comparison with maintained load tests.

10 Special construction details may be required for preliminary piles in order to provide data that is relevant to working piles where downdrag is expected or which are piles which form part of a deep basement or substructure. Details may include sleeving and instrumentation within the pile. The method of construction should otherwise replicate as closely as possible the methods used to form working piles.

11 It is important that the Design Verification Load is appropriate to the situation of the test and the long-term loads for which the piles are being designed. As an example, if negative skin friction or downdrag is expected on the working piles, twice the expected downdrag force should be added to the Specified Working Load to give the Design Verification Load, once to overcome the positive skin friction over the relevant length and a second to replicate the actual downdrag loading. Where working piles are being installed in advance of an excavation, the Design Verification Load should take account of the support provided by the soil that will be excavated and also by the higher effective stresses giving higher strengths in the soils beneath.

NG 1610 Diaphragm Walls

1 Clause 1610 applies to diaphragm walls in which a trench (the excavation) is formed either by grabs or by reverse circulation cutters. Grabs using either rope operated or hydraulically operated clam shells advance the open excavation by removing material in separate bites while reverse circulation cutters allow almost continuous removal of material within the support fluid returns. Support fluid is used to support the walls of the trench prior to concreting. Each completed element is known as a panel.

2 (11/03) Guide walls are used at the ground surface to ensure positional tolerance, avoid surface erosion and spread temporary loading. Guide walls are essential for maintaining the correct alignment of the wall and to provide a reservoir for the support fluid. The guide wall must be sufficiently robust to support any applied pressures from the ground and forces from the walling equipment. In particular, it should be able to support the surcharge from construction plant, the weight of the reinforcement cage if this is suspended off the guide wall and the reaction force from jacks if these are used to withdraw stop ends. The guide wall should be founded in soils of sufficient strength and stability to minimise the possibility of undercutting beneath the guide wall. The type and design of excavation equipment and the rate of withdrawal from the trench also influence the extent of potential undercutting.

3 The length of panels will depend on the Contractor's equipment, ground conditions, the proximity and loading from adjacent structures and vehicles or plant and permissible movements of the surrounding ground during construction. The stability of the panel relies on pressure from the support fluid within the trench exceeding the active earth pressure and water pressure within the soil arch adjacent to the panel. This surcharge of the ground from foundations and plant may require the hydrostatic pressure of the support fluid to be increased above the level that would otherwise normally be required (Clause 1610, sub-Clause 7) and the panel length restricted to reduce the earth pressure. Lengths of panels will normally vary between about 2 m and 7 m. Longer panels or special T or X shaped panels will normally require more than one tremie pipe to be used to provide an even spread of concrete across the wall section. Loss of support fluid leading to a reduction of fluid head in the excavation can have severe implications for the stability of panels. Careful consideration needs to be given to verticality and positional tolerances, particularly when considering steel design for reinforced T panels.

4 Where vertical loads are to be carried by the wall, the designer should take into account the practical level of cleanliness that can reasonably be achieved with the construction equipment as this could otherwise affect the performance of the wall. The portion of wall above the final formation level is not normally considered as being able to resist vertical loads because of the reduction in horizontal stress and possible tension cracks that can occur in the soil behind the wall as the excavation is carried out. The time taken to construct panels will influence their vertical load capacity. If the panels are required to carry vertical load, the Contractor should be asked to provide the time within which he will have the panel excavated and concreted and this should be checked for compatibility with the design assumptions.

5 (11/03) The Contractor's proposals for concrete cast under support fluid should be checked to ensure that they meet the following:

- Aggregates should preferably be naturally rounded well graded gravels and sands when they are readily available in the locality. They must comply with BS EN 12620. The maximum aggregate size should be 20 mm. The sand should conform with 0/4 (CP or 0/2 (MP) of BS EN 12620. The use of other aggregates may be permitted subject to the suitability of the diameter of the tremie pipe and spacing of reinforcement bars.
- A cementitious content of not less than 400 kg/m³ should be maintained. Admixtures are often used to improve the consistence, rate of gain of strength and setting time and these should comply with Series 1700.
- The concrete mix should be designed to give high consistence and the specified characteristic strength. The required strength depends on the loading and the requirements of Series 1700 to meet the anticipated exposure conditions. For reinforced concrete cast against soil and below water the minimum strength class is C25/30.
- The concrete cover to reinforcement should not be less than the values stated in BS 5400: Part 4 Table 13, as implemented by BD24 (DMRB 1.3.1). For concrete cast against the ground an additional 40 mm of concrete cover is recommended by BS 8004, as implemented in BD74 (DMRB 2.1.8), and thus the minimum concrete cover to reinforcement for diaphragm walls is usually 75 mm.

6 The joints between diaphragm wall panels are not normally watertight, particularly where there is a large difference in piezometric water pressure either side of the wall. Some proprietary joint systems include water bars to improve the degree of watertightness. The achievable degree of watertightness is best judged on the basis of the performance of similar wall systems in similar ground conditions. Where stringent criteria are specified the designer should consider whether additional measures such as grouting of joints or the provision of a facing wall with a drained and ventilated cavity as shown in BS 8102 should be provided to meet the requirements.

7 Preparation of wall surfaces will be required where drainage systems are to be installed and/or finishes applied. Details should generally be shown on the Drawings and cross-referred in the appropriate Appendix.

NG 1611 Hard/Hard Secant Pile Walls

1 Clause 1611 applies to hard/hard secant pile walls which consist of overlapping structural concrete piles constructed by high torque rotary piling equipment. Temporary support of the pile bore is provided by drill casing which generally extends over the full pile length unless continuous flight augers are used. The secant pile wall is constructed in two stages. All piles constructed during Stage 1 are known as primary piles. These are spaced at the specified primary secant pile spacing. All piles constructed during Stage 2 are known as secondary piles. These are positioned between the primary piles and secant (ie. overlap) with the primary piles. Guide walls are usually used at the ground surface to ensure positional tolerance and initial pile bore stability.

2 The programme and sequence of construction of hard/hard secant piles is dependant on the requirement to form interlocking piles in a strictly controlled sequence of primary and secondary piles. The rate of

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gain of strength of primary piles affects the time within which secondary piles can be formed. High torque rotary drilling equipment provides more rapid construction than rigs where the casing is oscillated and this rate of construction needs to be considered by the Contractor in conjunction with the rate of strength gain of primary piles to assess the sequence. Casing oscillators often have more power to cut through concrete.

3 The concrete mix may include admixtures to control the rate of gain of strength particularly in primary piles. Clauses 1702 and 1703 give the permitted cements. Where the Contractor considers that alternative proposals for the concrete mix are required then evidence of trial mixes or previous use should be provided. Where the specified characteristic strength is unlikely to be met at 28 days the Contractor should provide details of the anticipated rate of strength gain and the intervals between testing of concrete cubes and the time (say 56 days) when the specified strength will be met.

4 Particular care is needed with high powered rotary equipment to ensure verticality because of the rapid rate of construction. Oscillators often give better verticality. The Contractor should provide proposals prior to commencing the Works for remedial measures and revisions to the sequence of work in the event that a pile is formed outside the specified verticality tolerance.

5 The setting out and construction of guide walls requires a high degree of accuracy because the cut crescent shape of the inside faces of the secant wall are critical for achieving the correct centre to centre pile spacing and overlap. For a watertight wall, the primary pile spacing will be dictated by the need for pile overlap at the final excavation level; this will depend on the permitted pile position and verticality tolerances and depth of wall.

6 Where applied vertical loads or moments are to be supported by the wall, careful consideration should be given to the differential movement of adjacent piles and the effect on watertightness.

7 Secant pile walls have a greater frequency of joints than a diaphragm wall. Although these are cut concrete joints, in contrast to those of a diaphragm wall formed by a stop end, the watertightness of the secant wall may not necessarily be better than the diaphragm wall. The guidance in NG 1610.6 is also applicable to secant walls.

8 Steel sections are sometimes used in piles instead of reinforcing cages. These should comply with Series 1800. In such cases where the concrete is placed by tremie, two pipes will be required; one on either side of the steel section.

9 Heavy mechanical breakers to cut down piles should be used with caution as they may induce damage below the point of application. This particularly applies to piles of less than 600 mm diameter.

10 (11/03) The guidance in sub-Clause NG 1610.7 also applies to hard/hard secant pile walls.

NG 1612 Hard/Soft Secant Pile Walls

1 (11/03) Clause 1612 applies to hard/soft secant pile walls which consist of overlapping concrete piles constructed by rotary piling equipment. Temporary support of the pile bore may be provided by drill casing which may extend over the full pile length. Alternatively, a continuous flight auger technique may be used for some or all of the piles. The secant pile wall is constructed in two stages. All piles constructed during Stage 1 are known as primary piles. These are spaced at the specified primary secant pile spacing. All piles constructed during Stage 2 are known as secondary piles. The primary piles are formed of a low strength bentonite/cement mix which can be easily cut away by the secondary piles which are formed of reinforced concrete. The secondary piles are positioned between the primary piles and secant (ie. overlap) with the primary piles. Guide walls are usually used at the ground surface to ensure positional tolerance and initial pile bore stability.

2 (11/03) The guidance in Clause NG 1611 sub-Clauses NG 5 to 10 also apply to hard/soft secant pile walls.

3 (11/03) The durability, performance and design life of hard/soft secant pile walls requires particular consideration in relation to the design mix of the soft piles. The soft piles are normally formed with a weak bentonite/cement mix with an undrained shear strength of the order of 0.2 to 0.3 N/mm² (200 to 300 kN/m²) which acts as a void filler. It therefore does not comply with the durability requirements of BS 5400. It is likely that the properties of the bentonite/cement mix will vary more widely than conventional cement-based mixes and allowance for this should be made in the specified requirements for the bentonite/cement mix.

NG 1613 Contiguous Bored Pile Walls

1 Clause 1613 applies to contiguous bored pile walls which consist of bored piles constructed by rotary piling equipment or continuous flight augers. The piles are constructed at centres equal to the pile diameter plus an allowance for temporary casing width and tolerance which can vary between 70 to 150 mm although in soils which are capable of standing vertically a larger spacing may be adopted. Temporary support of the pile bore is provided by casings and if necessary support fluid at lower levels. Guide walls may be used at ground level to ensure positional tolerance.

2 Where stiff clay is to be retained, the designer may consider increasing the pile spacing and provide an in situ reinforced concrete or blockwork facing to be applied during or on completion of excavation. Provision for vertical drains behind the facing between the piles should be considered.

3 Guide walls are recommended where more stringent verticality and positional tolerances equivalent to diaphragm or secant pile walls are required.

4 Contiguous bored piles do not retain water. If the wall is required to retain water then either the space between the piles can be grouted before excavation takes place, or a facing wall added (which may have a drained and ventilated cavity behind, as shown in BS 8102). It should be remembered that grouting between contiguous piles is unlikely to provide as watertight a seal as a secant pile or diaphragm wall.

5 (11/03) The guidance in Clause NG 1611 sub-Clauses NG 9 and 10 also applies to contiguous bored pile walls.

NG 1614 King Post Walls

1 Clause 1614 applies to King Post Walls also known as ‘Berlin Walls’ most often used as temporary upholding works and which may be anchored depending on site conditions. The wall consists of drilling bores of a specified diameter at specified centres, usually between 2.5 m and 4.0 m. Posts, steel beams or pre-cast concrete sections are placed in the bores and their lower section, up to excavation level are concreted into the bore. Temporary casings extending to just above excavation level support the pile bore and the posts until the concrete has set, normally approximately 12 hours. The bore above concrete level is backfilled with spoil or in some cases grout and the temporary casing extracted. During excavation on one side of the wall poling boards or some other form of lagging are placed between the king posts to retain the soil.

2 Where permanent walls are to be constructed in front of a temporary king post wall and the space between is to be filled with compacted material, consideration should be given to the sequence of removal of props or destressing of anchors, the durability of the king post wall materials and the effect of compaction on the permanent wall. The materials forming the king post wall may be removed where practical, provided that the method is such that damage is not caused to the permanent works, adjacent structures, highways and utilities.

3 Relaxation and some ground loss is inevitable in most cases during the excavation and installation of the lagging between the king posts. The wall is permeable and hence groundwater levels behind the wall will be drawn down. These effects can cause damage to structures, highways and utilities if they are near the wall. If damage is likely and unacceptable this form of construction should not be permitted and the diaphragm, secant pile or sheet wall alternatives should be considered.

4 (11/03) The concrete is normally unreinforced. The consistence should be sufficient to allow the concrete to flow around the king post and adequately fill the bore. Where concrete is placed under water or support fluid it should have high consistence. Two tremies may be needed to ensure that concrete flow is uniform either side of the king post.

NG 1615 Steel Sheet Piles

1 Clause 1615 covers interlocking steel sheet pile sections which are generally constructed to resist horizontal soil and water pressures and/or imposed loads. Sheet piles are used in both temporary and permanent situations for cofferdams, retaining walls, bridge abutments and dock and harbour works. They are usually installed by use of impact hammers, vibrators or hydraulic jacking methods. Steel sheet piles have interlocking clutches which are capable of sliding together to form a continuous structural retaining wall. They are produced by hot rolling steel blooms in a rolling mill to form the finished piling sections.

2 Guidance on corrosion and protection of steel piling is given in BS 8002. Further information is given in Cornfield (1989) and can be obtained from the manufacturer.

3 The rolling dimensional tolerance of the sheet piles particularly that of the pile clutch, can be variable from manufacturer to manufacturer. When long sheet piles are to be driven it may become necessary to consider specifying the interaction factor of the clutch in the design in order to reduce the incident of declutching.

4 Sections of ‘Z’ type steel sheet piling (eg. Frodingham) which have their interlocks in the flanges develop the full section modulus of an undivided wall of piling under most conditions. Sections of trough or ‘U’ type steel sheet piling (eg. Larssen) with close-fitting interlocks along the centre line or neutral axis of the sheeting develop the strength of the combined section only when the piling is fully driven into the ground. The shear forces in the interlocks may be considered as resisted by friction due to the pressure at the walings and the restraint exercised by the ground. In certain conditions it is advisable to connect together the inner and outer piles in each pair by welding, pressing or other means, to ensure that the interlock common to the pair can develop the necessary shear resistance. Such conditions arise when:

a) the piling passes through very soft clay or water;

b) the piling is prevented by rock from penetrating to the normal depth of cut-off;

c) the piling is used as a cantilever;

d) the piling is supported by crops or struts but is cantilevered to a substantial distance above the highest waling or below the lowest waling.

If any of these conditions arise and the piles are not connected together into pairs as described, a reduced value of section modulus of the combined section should be used.

5 Sheet pile sections should be selected to ensure that they are capable of withstanding the bending moments and axial loads which will be applied during and after construction and that they are capable of being driven successfully through the soil to the required penetration. Guidance on pile selection is given in BS 8002, Federation of Piling Specialists "Specification for steel sheet piling" or the manufacturer's piling handbook. Jetting can be used to assist pile driving in cohesionless soils but this may affect the performance of the piles under the applied moments and loads. Jetting can also wash away soil supporting surrounding structures.

6 Where noise and vibration are of concern jacking systems are available for installing sheet piles. Some proprietary systems can only be used in ground conditions predominantly comprising stiff clays, other systems can push piles through cohesionless soils as well but may be limited in the penetrations they can achieve.

7 (11/03) For handling purposes, sheet piles of the 'U' type are normally supplied and pitched singly while piles of 'Z' type are normally supplied and pitched in pairs.

NG 1616 Integrity Testing of Wall Elements

1 The purpose of integrity testing is to identify acoustic anomalies in wall elements that could have a structural significance with regard to the performance and durability of the wall element. Integrity tests do not give direct information about the performance of wall elements under structural loads or their watertightness.

2 The sonic logging method is the only meaningful method for concrete wall elements other than contiguous pile walls; results of other techniques will be difficult to interpret and may be misleading. For contiguous pile walls, the techniques given in Clause 1608 can be used and advice in NG 1608 followed.

3 For sonic logging, it is preferable to install four tubes in piles if they are of sufficient diameter. This allows the centre of the pile to be integrity checked. On completion of sonic logging it is normal for the tubes to be grouted up with a grout of comparable strength to the concrete in the pile.

NG 1617 Instrumentation for Piles and Embedded Walls

1 Clause 1617 applies to instrumentation for piles and for embedded walls. The instrumentation can be used for monitoring stresses or displacements in piles either in preliminary load tests or in service and for lateral and vertical loads. The results can be used to derive the load and deflection distribution down the pile or wall.

2 Care should be taken before welding strain gauges to steel to ensure that the type of steel can be welded. Care should also be taken that the welding heat does not cause damage to waterproof seals at either end of the strain gauge.

3 It is very important that one person is responsible for all aspects of instrumentation and has the time to coordinate all the necessary activities. Otherwise, if sufficient care is not taken throughout the installation, reading and interpretation processes, the results can become impossible to interpret.

4 Thought should be given when specifying instrumentation as to how exactly the results will be used. As an example, if inclinometers in a retaining wall are being monitored, it will be necessary to also know the depth and extent of the excavation at each set of readings.

NG 1618 Support Fluid

1 The stability of the pile bore or wall trench during excavation can be maintained using support fluid where the fluid pressure acts against the sides of the excavation to support the surrounding soil and water pressures. In the case of bentonite slurries this action is achieved by the formation of a filter cake in contact with the soil against which the fluid pressure acts. In the case of polymers this action is due to rheological blocking of the fluid in the soil; the penetration distance is small in the case of clayey soils but can be significant in the case of sandy or silty soils. The main factors affecting the stability which can be controlled during the excavation are:

- the level and properties of the supporting fluid
- the size of the panel for diaphragm wall excavations
- the time during which the pile bore or trench is left open relative to the soil and groundwater conditions (loss of shear strength with time)
- the care that is taken not to create suctions with the excavation plant in the support fluid filled excavation.

2 Bentonite is commonly used as a support fluid and in its natural form as sodium montmorillonite exhibits thixotropic properties whereby it forms a gel under quiescent conditions and regains its fluidity under dynamic conditions. Naturally occurring sodium montmorillonite is relatively rare and it is therefore more common to use activated bentonite which is a calcium montmorillonite that has been converted to provide similar thixotropic properties to sodium bentonite. Additives in the form of dispersants and deflocculants are sometimes used to improve the flow characteristics of the fluid, and viscocifiers or flocculating agents are used to improve the gelling or blocking action of the fluid. Further guidance on bentonite and its use and behaviour in the construction of bored piles is described in CIRIA Report PG 3.

3 Support fluids can also be based on other substances such as polymers.

4 Hutchinson et al (1975) report on the various tests available to measure the properties of bentonite and list appropriate tests. These consist principally of the density, plastic viscosity, shear strength, filtration or fluid loss properties, pH and sand content. Knowledge of these properties is relevant to the following requirements of the fluid:

- solid particles are kept in suspension
- the fluid can be easily displaced during concreting
- continuous support of the excavations, for fluids which provide support by rheological blocking.

The concentration of bentonite needed to achieve the above requirements depends on the source of bentonite as described by Hutchinson et al (1975), ranging from 3% for natural sodium montmorillonite to 7% or more for some manufactured bentonites. For activated calcium montmorillonite manufactured in the UK, a concentration of 5% has generally been found to be appropriate.

5 Table NG 16/1 is provided as a guide to the type of test and compliance values that would normally be expected to be provided by the Contractor for activated bentonite manufactured in the UK.

The tests are described in the American Petroleum Institute document “Recommended Practice Standard Procedure for Field Testing Water-based Drilling Fluids” API Recommended Practice 13B-1. Compliance should be checked for the support fluid as supplied to the excavation and prior to concreting because the test requirements of the supporting fluid are different when supporting the excavation compared to the flow conditions needed for effective concreting. Further guidance on these aspects is given in CIRIA Report PG 3 which also identifies the following practical limitations to the construction of excavations under bentonite suspension:

- very permeable strata causing loss of bentonite suspension which prevent the maintenance of the correct suspension level (soil of permeability up to $k = 10^{-3}$ m/sec can be stabilised with bentonite suspensions having concentrations of up to 6% by weight)
- cavities which may lead to sudden or excessive loss of bentonite suspension
- very weak strata, such as some estuarine clays, with cohesion values of less than 10 kN/m². (Very weak strata present a problem with retention of fresh concrete and a casing or liner may be required even if satisfactory conditions during excavation can be obtained)
- water under artesian head.

6 Contamination of the bentonite can be detected by the tests described above and these need to be considered with regard to the effects on construction and performance of the pile or wall. Fine sand in the slurry during excavation may assist the blocking mechanism. However the increase in density and viscosity due to the presence of sand may affect the flow properties and hence the ability of the concrete to displace the fluid during concreting. Also any sediment forming on the base of the excavation may affect the performance of the pile or wall under load if the end bearing component is significant. It is recommended that the sand content should be limited to 2% prior to concreting if working loads are to be partly resisted by end bearing. Contamination with clay, usually in the calcium or aluminium forms of bentonite, can promote ion exchange with the slurry to such an extent that the filter properties are markedly changed. Cement contamination has a similar effect and can be detected by an increase in pH. The shear strength of the slurry is important in keeping small particles in suspension and hence avoid the formation of sediment at the base of the excavation.

7 The replacement of helical reinforcement by hoops or bands of steel spaced well apart is recommended to minimise accumulation of bentonite residue on the intersection of longitudinal and shear reinforcement.

8 The testing of the support fluid should be carried out in a properly equipped site laboratory. Samples of support fluid for testing should be taken from the base of the excavation. Where the test results indicate non-compliance with the stated limits the fluid should be partly or entirely replaced before concreting or further excavation takes place.

9 Current legislation affecting the disposal of support fluid includes the Water Act 1989 and the Environmental Protection Act 1990.

TABLE NG 16/1 - Tests and Compliance values for Support Fluid prepared from Bentonite manufactured in the UK.

Property to be measured	Test method and apparatus	API RP13 Section	Compliance values measured at 20°C	
			As supplied to pile	Sample from pile prior to placing concrete
Density	Mud balance	1	Less than 1.10 g/ml	Less than 1.15 g/ml
Fluid loss (30 minute test)	Low temperature test fluid loss	3	Less than 40 ml	Less than 60 ml
Viscosity	Marsh cone	2	30 to 70 seconds	Less than 90 seconds
Shear strength (10 min. gel strength)	Fann viscometer	2	4 to 40 N/m^2	4 to 40 N/m^2
Sand content	Sand screen set	4	Less than 2%	Less than 2%
pH	Electrical pH meter to BS 3145; range pH 7 to 14	-	9.5 to 10.8	9.5 to 11.7

NG SAMPLE APPENDIX 16/1: GENERAL REQUIREMENTS FOR PILING AND EMBEDDED RETAINING WALLS

[Note to compiler: Include here:]

1 General requirements for piling and embedded retaining walls, cross-referring to Drawings and other Appendices of Series 1600, and including the following as appropriate.

(a) permitted options for piles and embedded retaining walls, and any additional requirements *[1601.23]*

(b) damage criteria for adjacent structures or services *[1601.28]* including conditions, restrictions and monitoring requirements.

2 For Contractor designed structures and elements, requirements to submit design calculations, details of materials to be used and a schedule of dimensions *[1601.24]*.

3 Requirements to supply details of method of piling, the plant and monitoring equipment to be used *[1601.26]*.

4 Requirements to provide copies of piling records *[1601.27]* and records of testing of concrete and steel used in piles *[1601.31]*.

5 Requirements to submit plans for making surveys and monitoring movements or vibration *[1601.28]*.

6 Requirements to submit planned sequence and timing of driving or boring piles or installing wall elements *[1601.29]*.

NG SAMPLE APPENDIX 16/2: PRECAST REINFORCED AND PRESTRESSED CONCRETE PILES AND PRECAST REINFORCED CONCRETE SEGMENTAL PILES

(Note to compiler: Include here:]

1 Requirements for precast concrete piles, including the following as appropriate

(a) specified working loads

(b) (11/03) performance criteria for piles under test as Table NG 16/2 below

(c) type of cement

(d) types and sizes of aggregate

(e) (11/03) strength classes of concrete

(f) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(g) (11/03) method of testing concrete consistence

(h) grades and types of and cover to reinforcement

(i) types of prestressing tendons

(j) grout

(k) marking of piles

(l) penetration or depth or toe level *[1602.29]*

(m) driving resistance or dynamic evaluation or set *[1602.28]*

(n) trial drives

(o) preliminary piles

(p) uplift/lateral displacement trials

(q) pile shoes (where required)

(r) preboring or jetting or other means of easing pile drivability *[1602.33]*

(s) detailed requirements for driving records (including requirements for measurement of temporary compressions and redrives) *[1602.30, 31]*

(t) requirements to submit details of the design, manufacture and tests of the jointing system *[1602.2]*

(u) requirements to submit details to ensure correct cover to and position of reinforcement *[1602.6,7]*

(v) requirements to provide records of construction of piles *[1602.13, 22]* and a certificate of quality *[1602.23]*

(w) requirements to provide information on pile driving equipment *[1602.28]*

(x) requirements to provide details of measures to be adopted to enable piles to comply with Specification where out of tolerance or damaged *[1602.32]*

(11/03) **Table NG 16/2 - Performance Criteria for Piles**

Pile Reference Nos	**Permitted type(s) - Specification Clause No.**	**Specified Working Load (SWL) (kN)**	**Allocated Allowable Pile Capacity (kN)**	**Design Verification Load DVL (kN)**	**Load Factor**	**Permitted Settlement at DVL + 50% SWL (mm)** **Maximum Settlement**	**Minimum Pile Length from cut-off to toe (m)**	**Minimum Diameter or Dimensions of Cross Section (mm)**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Notes

(1) Each and every pile should be allocated a unique reference number or code.

(2) Permitted types of pile are restricted to those specified in the corresponding Clause of the Specification, eg. insertion of "Clause 1603" will restrict permitted type(s) of pile to bored cast in place piles only. Further specification, eg. "underreams not permitted" may be necessary in particular circumstances.

(3) Working Loads specified on drawings should be grouped and each group allocated to one Allowable Pile Capacity, eg. all piles with Specified Working Loads between 858 kN and 930 kN are to be constructed for an Allowable Load of 930 kN. "Grouping" of Working Loads in this way reduces the number of different pile sizes on site and helps eliminate the confusion that can arise when each pile is individually sized.

(4) The Allowable Pile Capacity is the same as or greater than the highest Working Load in each "Group" (see (3) above).

(5) The DVL may be much larger than the Allowable Pile Capacity.

(6) The Load Factor should be specified.

(7) A realistic estimate of the likely lower bound load settlement curve for a pile tested in isolation should be made, and the Permitted Settlement at DVL + 50% SWL taken from that curve. If a stiffer pile than is indicated by the Permitted Settlement is required, then the pile type or dimensions will have to be changed (eg. pile lengthened, larger diameter, or underream added).

(8) (11/03) The stratigraphy of the ground may make it imperative that piles have a minimum length, to ensure penetration into a particular stratum; alternatively, the minimum penetration into a particular stratum can be specified (the column heading will then require to be changed to "Minimum penetration into XYZ").

(9) The minimum pile diameter will normally be determined by the permitted stresses in the pile materials, taking account of axial loads, moments and transverse loads.

NG SAMPLE APPENDIX 16/3: BORED CAST-IN-PLACE PILES

[Note to compiler: Include here:]

1 Requirements for cast-in-place piles, including the following as appropriate

(a) specified working loads

(b) performance criteria for piles under test *[See NG Sample Appendix 16/2]*

(c) types of cement

(d) cement replacement materials

(e) types and sizes of aggregate

(f) (11/03) strength classes of concrete

(g) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(h) (11/03) method of testing concrete consistence

(i) grades and types of and cover to reinforcement

(j) permanent casing *[1603.4]*

(k) support fluid

(l) pile dimensions

(m) pressure grouting *[1603.23]*

(n) preliminary piles

(o) trial bores

2 Requirements for level of support fluid if different from that stated in sub-Clause 1603.5.

3 Requirements for manned inspection of the pile base *[1603.9]*.

4 Requirements to submit details to ensure correct concrete cover to and position of reinforcement *[1603.11]*.

5 Requirements to submit description of equipment, materials and methods to be used for grouting *[1603.24]*.

6 Requirements to provide copies of grouting records *[1603.28]*.

NG SAMPLE APPENDIX 16/4: BORED PILES CONSTRUCTED USING CONTINUOUS FLIGHT AUGERS AND CONCRETE OR GROUT INJECTION THROUGH HOLLOW AUGER STEMS

[Note to compiler: Include here:]

1 Requirements for continuous flight auger piles, including the following as appropriate

- (a) specified working loads
- (b) performance criteria for piles under test *[see NG Sample Appendix 16/2]*
- (c) sampling and testing of pile materials
- (d) types of cement
- (e) cement replacement materials
- (f) concrete or grout admixtures
- (g) types and sizes of aggregate
- (h) (11/03) strength classes of concrete or grout
- (i) (11/03) method of testing concrete or grout consistence *[1604.7]*
- (j) (11/03) designed concrete or grout and maximum free water to cement ratio
- (k) grades and types of and cover to reinforcement
- (l) pile dimensions *[1604.6]*
- (m) trial bores
- (n) preliminary piles

2 Requirements to submit details of supervisors and operators experience *[1604.15]*.

3 Requirements to submit proposals on how to complete a pile in the event of a failure of the rig instrumentation system *[1604.15]*.

NG SAMPLE APPENDIX 16/5: DRIVEN CAST-IN-PLACE PILES

[Note to compiler: Include here:]

1 Requirements for driven cast-in-place piles, including the following as appropriate

- (a) specified working loads
- (b) performance criteria for piles under test *[See NG Sample Appendix 16/2]*
- (c) sampling and testing of pile materials
- (d) type of cement

(e) cement replacement materials

(f) types and sizes of aggregate

(g) (11/03) strength classes of concrete

(h) (11/03) method of testing concrete consistence

(i) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(j) grades and types of and cover to reinforcement

(k) types and quality of permanent casing *[1605.1]*

(l) types and quality of pile shoes

(m) penetration or depth or founding level *[1605.8]*

(n) driving resistance or dynamic evaluation or set *[1605.7, 10]*

(o) trial drives

(p) preliminary piles

(q) uplift/lateral displacement trials

(r) preboring and jetting *[1605.12]*

(s) detailed requirements for driving records (including redrives) *[1602.30]*

2 Requirements to provide information on the driving equipment *[1605.7]*.

3 Requirements to submit details to ensure correct concrete cover to and position of reinforcement *[1605.17]*.

NG SAMPLE APPENDIX 16/6: STEEL BEARING PILES

[Note to compiler: Include here:]

1 Requirements for steel bearing piles, including the following as appropriate

(a) specified working loads

(b) performance criteria for piles under test *[See NG Sample Appendix 16/2]*

(c) grades of steel

(d) sections of proprietary types of pile

(e) thickness of circumferential weld reinforcement

(f) lengths of pile to be supplied and additional lengths *[1606.32]*

(g) types of head and toe preparation

(h) types of pile shoe

(i) surface preparation

(j) types of coating *[1606.18, 27]*, and adhesion checks *[1606.27]*

(k) thickness of primer and coats

(l) welding procedure and tests *[1606.9, 15]*

(m) non-destructive testing of welds *[1606.12]*

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(n) concreting of piles

(o) penetration or depth or founding level

(p) driving resistance or dynamic evaluation or set *[1602.28, 31]*

(q) trial drives

(r) preliminary piles

(s) uplift/lateral displacement trials

(t) preboring and jetting *[1606.36]*

(u) detailed requirements for driving records (including requirements for measurement of temporary compressions and redrives) *[1602.30]*

2 Requirements to submit details of the manufacturing and welding procedures *[1606.10]*.

NG SAMPLE APPENDIX 16/7: REDUCTION OF FRICTION ON PILES

[Note to compiler: Include here:]

1 Particular requirements for reducing friction on piles *[1607.1]* including the following as appropriate

(a) the type and particular description of method to be used

(b) the numbers or other identification of piles to be treated to reduce friction

(c) the length of pile to be treated

(d) preparatory preboring or other work necessary for proper application of the method

(e) depth, diameter and means of ensuring temporary stability of any preboring where required

(f) designated manufacturer’s name and details where a proprietary product is required

(g) testing piles or trial piles to demonstrate the effectiveness of the method.

2 Requirements to submit design of pre-applied low-friction surround/sleeving *[1607.5, 6, 7]*.

3 Requirements for inspection, exposure or extraction of piles *[1607.8]*.

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NG SAMPLE APPENDIX 16/8: NON-DESTRUCTIVE METHODS FOR TESTING PILES

[Note to compiler: Include here:]

Integrity testing of piles

1 Particular requirements for integrity testing *[1608.1]*, including the following, as appropriate

(a) the method of test to be carried out

(b) the number, type and location of piles to be tested

(c) the stages in the programme of works when a phase of integrity testing is to be carried out

(d) the number and location of piles in which ducts are to be placed and number and length of ducts to be provided in each pile for the sonic logging method

(e) preparation of pile head for testing using the vibration method

(f) (11/03) the time after testing at which the test results and findings should be made available, if different from the requirements of sub-Clause 1608.6.

(g) where sonic coring is called for, the depth of pile over which the testing is required, the depth intervals to be not greater than 0.25 m.

(h) the number of days to elapse between pile casting and integrity testing *[1608.2]*.

2 Requirements to submit details of integrity testing firm, etc. *[1608.4]*.

Dynamic testing of piles

3 Particular requirements for dynamic pile-testing *[1608.8]*, including the following, as appropriate

(a) the number, type and location of piles to be tested

(b) the stages in the programme of works when a phase of dynamic testing is to be carried out

(c) the minimum dynamic test load

(d) the time period following installation at which testing is required

(e) measurement of set and temporary compression

(f) details of work to be carried out on a pile head following a test

NG SAMPLE APPENDIX 16/9: STATIC LOAD TESTING OF PILES

[Note to compiler: Include here:]

1 Particular requirements for static load testing of piles *[1609.1]*, including the following as appropriate

(a) type of pile

(b) type of test

(c) loads to be applied and procedure to be adopted in testing preliminary piles *[1609.7 and 34]*

(d) loads to be applied in proof-testing of working piles and particular requirements for procedure *[1609.6 and 33]*

(e) special materials to be used in construction of preliminary test piles where appropriate

(f) special construction detail requirements for test piles

(g) special requirements for pile-testing equipment and arrangement *[1609.21]*

(h) pile installation criteria

(i) time interval between pile installation and testing

(j) removal of Temporary Works

(k) special requirements for the application of a lateral load to a pile detailed in accordance with the expected conditions of loading

(l) details of work to be carried out to the test pile cap or head at the completion of a test.

NG SAMPLE APPENDIX 16/10: DIAPHRAGM WALLS

[Note to compiler: Include here:]

1 Requirements for diaphragm walls, including the following as appropriate

(a) specified working loads

(b) performance criteria for movement under lateral loads

(c) types of cement

(d) cement replacement materials

(e) types and sizes of aggregate

(f) (11/03) strength classes of concrete

(g) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(h) (11/03) method of testing concrete consistence *[1610.11]*

(i) grades, types and bond length of and cover to reinforcement *[1610.9]*

(j) support fluid

(k) panel dimensions (minimum thickness and maximum or minimum panel length) *[1610.5]*

(l) water stop requirements, if any

(m) water retention *[1610.21]*

(n) instrumentation *[1610.22]*

(o) temporary backfill material *[1610.20]*

(p) integrity testing

2 Any restriction on the additional tolerance on panel centre line position given in sub-Clause 1610.15, and the additional overbreak tolerance to be allowed where very soft clay, peat or obstructions are anticipated, *[1610.15]*.

3 Line and level requirements for preparation of wall surfaces *[1610.23]*.

4 Requirements to submit details to ensure correct concrete cover to and position of reinforcement *[1610.9]*.

NG SAMPLE APPENDIX 16/11: HARD/HARD SECANT PILE WALLS

[Note to compiler: Include here:]

1 Requirements for hard/hard secant pile walls, including the following as appropriate

(a) specified working loads (if any)

(b) performance criteria for movement under lateral loads

(c) types of cement

(d) cement replacement materials

(e) types and sizes of aggregate

(f) (11/03) strength classes of concrete

(g) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(h) (11/03) method of testing concrete consistence *[1611.11]*

(i) (11/03) grades and types of and cover to reinforcement, and projecting bond lengths *[1611.3, 1611.9]*

(j) support fluid

(k) pile diameters

(l) pile spacings and overlap at commencing level

(m) water retention *[1611.22]*

(n) instrumentation *[1611.23]*

(o) temporary backfill material *[1611.21]*

(p) integrity testing

2 Requirements, if any, for guide walls *[1611.1]*.

3 Time period between excavation and placing concrete, if different from that specified in sub-Clause 1611.15.

4 Any restriction on the additional tolerance on pile centre line position given in sub-Clause 1611.17, and the additional overbreak tolerance to be allowed where very soft clay, peat or obstructions are anticipated *[1611.17]*.

5 Line and level requirements for preparation of wall surfaces *[1610.23]*.

6 Requirements to submit details to ensure correct concrete cover to and position of reinforcement *[1611.9]*.

NG SAMPLE APPENDIX 16/12: HARD/SOFT SECANT PILE WALLS

[Note to compiler: Include here:]

1 Requirements for hard/soft secant pile walls including the following as appropriate

(a) specified working loads (if any)

(b) performance criteria for movement under lateral loads

(c) types of cement

(d) cement replacement materials

(e) types and sizes of aggregate

(f) (11/03) strength classes of concrete or alternative pile concrete mixes

(g) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(h) (11/03) method of testing concrete consistence *[1612.3, 1611.11]*

(i) grades and types of and cover to reinforcement, and projecting bond lengths *[1611.9]*

(j) support fluid

(k) requirements for self-hardening slurry mix *[1612.3]*

(l) pile diameters

(m) pile spacings and overlap at commencing level

(n) water retention *[1611.22]*

(o) instrumentation *[1611.23]*

(p) temporary backfill material *[1611.21]*

(q) integrity testing

2 Requirements for guide walls *[1612.1]*.

3 (11/03) Time periods between excavation and placing concrete, or self-hardening mix, if different from those specified in sub-Clauses 1611.15 or 1612.11 *[1612.11]*.

4 Any restriction on the additional tolerance on pile centre line position given in sub-Clause 1612.13, and the additional overbreak tolerance to be allowed where very soft clay, peat or obstructions are anticipated *[1612.13]*.

5 Line and level requirements for preparation of wall surfaces *[1610.23]*.

NG SAMPLE APPENDIX 16/13: CONTIGUOUS BORED PILE WALLS

[Note to compiler: Include here:]

1 Requirements for contiguous bored pile walls including the following as appropriate

(a) specified working loads (if any)

(b) performance criteria for movement under lateral loads

(c) types of cement

(d) cement replacement materials

(e) types and sizes of aggregate

(f) (11/03) strength classes of concrete

(g) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(h) (11/03) method of testing concrete consistence *[1611.11]*

(i) grades and types of and cover to reinforcement, and projecting bond lengths *[1611.9]*

(j) support fluids and temporary casings

(k) pile diameters

(l) pile spacing

(m) additional measures for water retention

(n) instrumentation *[1611.23]*

(o) temporary backfill material *[1611.21]*

(p) integrity testing

2 Requirements for guide walls *[1613.1]*.

3 Time period between excavation and placing concrete if different from that specified in sub-Clause 1611.15.

4 Any restriction on the additional tolerance on pile centre line position given in sub-Clause 1613.8, and the additional overbreak tolerance to be allowed where very soft clay, peat or obstructions are anticipated *[1613.8]*.

5 Line and level requirements for preparation of wall surfaces *[1610.23]*.

NG SAMPLE APPENDIX 16/14: KING POST WALLS

[Note to compiler: Include here:]

1 Requirements for king post walls including the following as appropriate

(a) specified working loads (if any)

(b) performance criteria for movement under lateral loads

(c) requirements of king post members

(d) types of cement

(e) cement replacement materials

(f) (11/03) types and sizes of aggregate *[1614.1]*

(g) (11/03) strength classes of concrete

(h) (11/03) method of testing concrete consistence *[1611.11]*

(i) (11/03) designed or prescribed concrete and maximum free water to cement ratio

(j) grades and types of and cover to reinforcement, and projecting bond lengths *[1611.9]*

(k) support fluid

(l) pile diameters

(m) pile spacing

(n) instrumentation *[1614.11]*

(o) temporary backfill material *[1614.10]*

2 Required tolerances *[1614.8]*.

3 Time period between excavation and placing concrete if different from that specified in sub-Clause 1611.15.

NG SAMPLE APPENDIX 16/15: STEEL SHEET PILES

[Note to compiler: Include here:]

1 Requirements for steel sheet piles including the following as appropriate

(a) performance criteria for movement under lateral loads

(b) grades of steel

(c) minimum section modulus, web thickness of sheet pile

(d) surface preparation

(e) types of coating

(f) thickness of primer and coats

(g) types of head and toe preparation

(h) minimum length of sheet pile to be supplied

(i) water retention

(j) restriction on working hours during which driving can take place

(k) types of pile shoe

(l) penetration or depth or founding level *[1615.7]*

(m) driving resistance or dynamic evaluation or set

(n) preboring and jetting or other means of easing pile driveability

(o) detailed requirements for driving records

2 Any requirements for clutch sealant *[1615.5]*.

3 Any requirements for the use of a vibrationless jacking system *[1615.7]*.

NG SAMPLE APPENDIX 16/16: INTEGRITY TESTING OF WALL ELEMENTS

[Note to compiler: Include here:]

1 Requirements for integrity testing including the following as appropriate

(a) the method of test to be carried out

(b) the number and location of wall elements to be tested

(c) the stages in the programme of works when a phase of integrity testing is to be carried out

(d) the number and location of wall elements in which ducts are to be placed and number and length of ducts to be provided in each wall element for the sonic logging method

(e) (11/03) the time after testing at which the test results and findings should be made available, if different from the requirements of sub-Clause 6.

(f) the depth of wall element over which the testing is required, the depth intervals to be not greater than 0.25 m.

(g) the number of days to elapse between wall element casting and integrity testing, *[1616.2]*.

NG SAMPLE APPENDIX 16/17: INSTRUMENTATION FOR PILES AND EMBEDDED WALLS

[Note to compiler: Include here:]

1 (11/03) Requirements for instrumentation of piles or embedded walls *[1617.1, 1617.12]*, including locations where the instrumentation is to be installed, expected load, pressure, displacement or strain range for which results are required, and aims and objectives of the instrumentation.

2 The type of instrumentation required *[1617.2]*.

3 For extensometers, the required movement range *[1617.3]*.

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4 For load cells, whether the load to be measured is compressive or tensile *[1617.5]*.

5 Required times or time intervals for readings *[1617.10]*.

6 Calibration range required *[1617.11]*.

7 Whether the instrumentation monitoring equipment will become the property of the Employer *[1617.15]*, and any particular requirements for monitoring equipment or output required.

8 Whether direct or remote monitoring is required *[1617.15]*.

9 Terminal survey requirements including datum and coordinate grid to be used *[1617.17]*, and frequency of surveying.

10 (11/03) Requirements for the Contractor to submit details of instrumentation Supplier *[1617.2]*.

NG SAMPLE APPENDIX 16/18: SUPPORT FLUID

[Note to compiler: Include here:]

1 (11/03) Requirements for details of support fluid *[1618.1]*, including any minimum material testing requirements or environmental restrictions on use.

2 Requirements for and frequency of testing water not available from a public supply, if required *[1618.3]*.