STRUCTURAL CONCRETE

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NG 1701 Concrete - General

Specification of Concrete

1 In the Specification the concept of concrete as a single material has been adopted. It is therefore the responsibility of the designer to specify in Appendix 17/1 the type of concrete required to ensure both the strength and the durability of the finished structure. By the definitions given in Clause 1702 limitations on the constituent materials are already established.

Designed Concrete

2 Note that I.S. EN 206-1 and the Irish National Annex to I.S. EN 206-1 cover prescribed and standardized prescribed concretes. Guidance on the specification of designed concrete is given in 6.2 of I.S. EN 206-1. The Contractor should be responsible for selecting the constituent material proportions in accordance with Clause 1705 to achieve the required strength and consistence, but the designer is responsible for specifying the minimum cement content, maximum water/cement ratio, the Exposure Class, and other properties required to ensure durability in accordance with Clauses 1703 and 1704.

Designed Concrete	Specification sub-Clause
Compressive strength class of concrete	1704.1
Minimum cement content	1704.2
Required type and class of cement	1702.1
Maximum water/cement ratio	1704.2

In appropriate circumstances any of the information listed in Appendix 17/1 may be included, but great care should be taken to ensure the requirements specified do not conflict with each other.

Requirements for Fresh Concrete

3 Unless specified otherwise the requirements for the concrete in the fresh or plastic state, particularly its consistence, should be selected by the Contractor/Producer who should inform the designer of the requirements. The designer should add this requirement to the Specification.

It may be necessary when working in cold or hot weather to control the temperature of fresh concrete (see sub-Clause 1710.6 or 1710.7).

Where the minimum dimension of concrete to be placed at a single time is greater than 600mm and especially where the cement content is likely to be 400 kg/m^3 or more, measures to reduce the adverse affects of temperature, such as the selection of aggregates with low coefficients of thermal expansion or of a cement type with a slower release of heat of hydration, should be considered. In exceptional cases other measures to reduce the temperature or to remove evolved heat may be necessary.

NG 1702 Concrete – Constituent Materials

Cement

1 In addition to the cements listed, CEMI cement conforming to I.S. EN 197-1 with a mass fraction of 66% to 80% of combination of ggbs conforming to IS EN 15167-1, or CEMIII/B cement may be used for special applications such as sulphate resistance of buried concrete, but it should not be used in the surfaces of exposed concrete where there is a risk of surface scaling under conditions of freezing and thawing.

The use of blended cements containing pulverized-fuel ash or ground granulated blastfurnace slag may increase concrete durability and resistance to both chloride ingress and sulphate attack. However, care should be taken due to possible delayed strength development and particular attention should be paid to curing in accordance with sub-Clause 1710.5.

Cements containing other pozzolanic materials such as silica fume and metakaolin are excluded from the Specification for the present time until more widespread experience is gained of their use to confer long term durability to structures exposed in aggressive environments.

Aggregates

2 (i) General. In general the aggregates specified in sub-Clause 1702.2 of the Specification should be used. In exceptional circumstances and for particular special applications the designer may specify the use of aggregates other than those specified in sub-Clause 1702.2, including types of gradings not covered by the appropriate Irish Standards, provided that there are satisfactory data on the properties of concrete made with them. Recycled concrete aggregate (RCA) and recycled aggregate (RC) are excluded from the Specification for the present time until ongoing research is completed to establish the long term durability to structures exposed in aggressive environments, especially chloride-bearing environments.

When high strength concrete is required, the source as well as the type of aggregate may need careful selection based on the results of initial testing.

Where it is known that the property of any aggregate is likely to have an unusual effect on the strength, density, shrinkage, moisture movement, thermal properties, creep, modulus of elasticity or durability of concrete made with it, the designer should take account of these factors in the design and workmanship requirements.

The ten per cent fines test for resistance of coarse aggregate to fragmentation has been replaced by the Los Angeles test given in I.S. EN 1097-2 but there is no direct correlation between the test methods. The Los Angeles coefficient is declared in accordance with the relevant category specified in Table 12 of I.S. EN 12620. The Los Angeles coefficient category should be the category specified in the project specification or, where a category has not been specified, it should meet the requirements of LA_{40}. However, this limitation may exclude perfectly usable materials and aggregates with LA coefficient values above 40 may also perform satisfactorily in normal concrete but it is recommended that their strength performance be established in concrete trials before use. A note stating this is included in the Specification (see sub-Clause 1702.2).

Aggregates having a high drying shrinkage, such as some dolerites and whinstones, and gravels containing these rocks produce concrete having a higher drying shrinkage than that normally expected. This can result in deterioration of exposed concrete unless special measures are taken. For further information refer to BRE Digest 357.

When air cooled blastfurnace aggregate conforming to I.S. EN 12620 is used, sampling and testing should be carried out at sufficiently frequent intervals to conform the bulk density.

Despite initial compliance with the minimum density, substantial variation above this minimum can change the characteristics of the concrete mix if the weights of the aggregates are kept constant. If such variations occur, the mix should be adjusted to allow for them. Further advice on this subject can be obtained form the UK Building Research Establishment.

(ii) Maximum aggregate size. The preferred maximum aggregate sizes of an aggregate are 40mm and 20mm, but if a smaller size is necessary it should be 10mm.

Admixtures and Pigments

3 (i) General. Admixtures should be specified by type and effect.

Many admixtures are highly active chemicals and may impart undesirable as well as desirable properties to the hardened concrete; their suitability should generally be verified by initial testing. The initial testing should contain cement of the same make and type and from the same source as that intended to be used for the permanent Works. If two or more admixtures are thought to be required in any one mix, the manufacturer of each should be consulted. The trials should confirm that the admixture is compatible with all the other constituents of the concrete and show whether it accelerates or retards the setting time and results in any loss of consistence.

Only in exceptional circumstances, for example in hot weather, should retarders be used in structural concrete. Consideration may be given to their use in grouts for prestressing tendons, especially in hot weather (see NG 1711.1).

(ii) When a concrete of Class 32/40 or lower is subject to freezing when wet and/or subject to the effects of salt used for de-icing, it should contain entrained air.

The carbon contained in pulverized-fuel ash and certain pigments can substantially reduce the effectiveness of some air-entraining agents. This does not usually create a problem but care may have to be taken when using these materials. In some cases it may be necessary to increase appreciably the amount of admixture used. The amount of air entrained in a designed concrete can also be affected by many other factors, among which are:

(i) Type and amount of admixture used.

(ii) Consistency of the concrete.

(iii) Concrete proportions.

(iv) Type and grading of the aggregate.

(v) The length of time for which the concrete is mixed.

(vi) Temperature. In the range of 10°C to 30°C an increase of 10°C can reduce the amount of entrained air by about 25%.

(vii) The cement type, source, fineness and cement content of the concrete.

NG 1703 Concrete – Exposure Classes

1 Environmental and ground conditions are classified as exposure classes in Tables 1 and 2 of I.S. EN 206-1. Table 1 gives a non-exhaustive list of examples applicable in Ireland. All relevant exposure classes pertaining to the structure or structural element should be identified. There can be specific structures or elements where the exposure does not readily fit the descriptions given in the exposure classes. In such situations, designers should use design judgement for that application. Since the final concrete requirements are dependent on the exposure classes, Appendix 17/1 makes allowance for the relevant exposure classes to be listed.

NG1704 Concrete – General Requirements

General Considerations

1 The minimum requirements for the strength and durability of the concrete in the hardened state should be decided by the designer from consideration of EN 1992-1 and the guidance in NG 1704.2 but if in addition a special property or a particular surface finish is required, these minimum requirements may have to be considerably exceeded.

The strength class of concrete required depend partly on the particular use and the characteristic strength needed to provide the structure with adequate ultimate strength and partly on the exposure conditions and the cover provided to any reinforcement or tendons (see EN 1992-1 and the Irish National Annex).

Compressive Strength Class of Concrete

2 Compressive strength is specified according to I.S. EN 206-1 by a dual classification comprising the characteristic strength of 150mm diameter by 300mm length cylinders followed by the characteristic strength of 150mm cubes, e.g. C20/25. Table NA. 1 of the Irish National Annex to I.S. EN 206-1 gives recommended strength classes to be used in specifications in Ireland. Note that this Table contains some extra classes compared with Table 7 of I.S. EN 206-1.

Intended Working Life

3 Table NA. 5 of the Irish National Annex to I.S. EN 206-1 gives recommended limiting values for composition and properties of concrete for an intended working life of at least 50 years. Road bridge and other structures are normally designed for a working life of 120 years, which might require more onerous requirements than those given in Table NA. 5. However, it is preferred to provide increased concrete cover instead of increasing concrete quality in order to achieve increases in working life. In some situations it might be appropriate to achieve increased intended working life by reducing contact between chloride and the concrete or the use of stainless steel reinforcement – examples of this approach are the provision of bridge deck waterproofing and surfacing on decks, and the provision of stainless steel reinforcement in parapet edge beams.

Road bridges and other structures designed in accordance with IS EN 1992-1 for a service life of 100 years, which corresponds to an "intended working life of at least 100 years" in I.S. EN 206-1, may be deemed to satisfy the requirements to design for 120 years.

Cover to Reinforcement

4 The concept of Structural Class in IS EN 1992-1-1 (and / or the appropriate Irish National Annex) allows for the designer to determine the minimum cover (c_{min}) based on exposure class, service life, strength class, member geometry and quality control. The nominal cover is generally given by the sum of $c_{min} + \Delta c_{dev}$ where Δc_{dev} (the allowance for deviation) should be taken as 15mm (or such other value as may be given by the appropriate National Annex). In some applications such as precast concrete and thin concrete sections where the design is sensitive to cover variation, the design issues and practical fixing considerations may dictate that the allowance for cover deviation (or tolerance) should be reduced to 5mm. However, the default value of 15mm should be used unless there is clear evidence that a lower value is appropriate. The nominal cover, including the allowance for cover deviation (fixing tolerance) should be clearly stated on the drawings.

Selection of Limiting Values for Concrete Composition and Properties

5 Having identified the limiting values for concrete composition and properties relevant to all identified exposure classes pertaining to the particular structure element, these values should be compared and the most onerous values selected and specified. Values selected should be the highest strength class, the lowest maximum w/c ratio, the highest minimum cement/combination content and cement/combination types that are suitable for all the identified exposure classes.

Minimum Cement Content and Maximum Water/Cement Ratio

6 The designer should state in Appendix 17/1 the minimum cement content required for each concrete. One of the main characteristics influencing the durability of any concrete is its ability to absorb water. With strong dense aggregates, a suitably low absorption is achieved by having a sufficiently low water/cement ratio, by ensuring sufficient hydration of the cement through proper curing methods, and by ensuring maximum compaction of the concrete. Therefore for given aggregates the cement content should be sufficient to provide adequate consistence with a low water/cement ratio so that the concrete can be fully compacted with the means available.

Water reducing admixtures conforming to I.S EN 934-2 can be beneficial in reducing the free water/cement ratio.

Table NA. 5 of the Irish National Annex to I.S. EN 206-1 applies to concrete made with cements described in sub-Clause 1702.1. The cement content may need to be greater than the minimum values given in Table NA. 5 when trial mixes (see NG 1705.2) indicate that this is necessary for:

(i) the consistent production of a concrete with a maximum free water/cement ratio not greater than that given for a particular condition; and

(ii) the conditions of pacing and compaction.

Maximum Cement Content

7 Cement contents in excess of 550 kg/m^3 should not be used unless special consideration has been given in design of the increased creep, risk of cracking due to drying shrinkage in thin sections, and higher thermal stresses in thicker sections. For higher strength classes of lightweight aggregate concrete, cement contents in excess of 550 kg/m^3 may be used provided that the concrete produced is suitable in all respects.

Maximum Chloride Content

8 The maximum chloride content of concrete is specified by means of a chloride class. Relevant classes are given in Table 17/1.

Maximum Sulfate Content

9 Sulfates are present in most cements and in some aggregates; excessive amounts can cause expansion and disruption in the concrete. However, as no tests exist to determine mobile sulphate content, it is usual to measure the acid soluble sulphate content of cements and aggregates. The relationship between such measurements and the mobile sulfate content of the hardened concrete is variable and therefore no universal sulphate limit can sensibly be applied to concrete.

Control of Alkali-Silica Reaction

10 (i) It is generally accepted that alkali-silica reaction can only occur if reactive minerals are present, the alkali level of the concrete is above a certain level and a sufficient supply of water is available. For concrete road bridges and other structures it must be assumed that sufficient water will be available so that aggregate types and alkali levels must be controlled. Most cases of alkali-silica reaction appear to be associated with the use of high alkali cements.

(ii) Requirements to minimise the occurrence of alkali-silica reaction are part of the general requirements of Clause 1704. These are based on the guidance given in IEI/ICS Report 'Alkali-Silica Reaction: General Recommendations and Guidance in the Specification of Buildings and Engineering Works; 2002'.

(iii) Extremely reactive aggregates, comprising those aggregates containing detectable quantities of opal, glass and calcined flint, should not be used alone or in combination with other aggregates.

Buried Concrete Exposed to Sulfates

11 (i) Recommended limiting values for compositions and properties of concrete are given in Table NA. 5 of the Irish National Annex to I.S. EN 206-1, which include concrete exposed to aggressive chemical environments (including buried concrete exposed to sulfates). The recommendations in Table NA. 5 are only valid for the limiting values for exposure classes for chemical attack from natural soil and ground water given in Table 2 of I.S. EN 206-1. It is considered that in most cases, in Ireland, of buried concrete exposed to chemical attack (including sulfates) from natural ground and ground water, that the exposure class designation as given by Table 1 of I.S. EN 206-1 (i.e. XA1 or XA2 or XA3) is appropriate and that the recommendations of Table NA. 5 are valid. However, in cases where the assumptions stated in Table 1 of I.S. EN 206-1 for chemical attack are suspected of not being valid then a special study may be needed to establish the relevant exposure conditions where the following conditions apply either singly or collectively;

(a) limits outside of Table 2 of I.S. EN 206-1;

(b) other aggressive chemicals are present;

(c) the ground or water is polluted chemically;

(d) there is high water velocity in combination with the chemicals in Table 2 of I.S. EN 206-1.

In practice, where the assumptions of Table 1 of I.S. EN 206-1 for chemical attack are not satisfied, then the designer may specify one or more of the following additional protective measures:

(a) enhanced concrete quality;

(b) controlled permeability formwork;

(c) provision of surface protection;

(d) provision of a sacrificial layer;

(e) address drainage of site.

Recommendations on the protection of buried concrete exposed to sulfates can be found in Building Research Establishment Special Digest SD1 'Concrete in Aggressive Ground' (published in four parts by BRE), which covers a wider range of environmental actions than I.S. EN 206-1 and includes mobile ground water, acids and brown field sites. BRE Special Digest SD1 uses the concept of 'structural performance level'; foundations and other buried structural elements of road bridges and other structures should be classed as high performance level.

Where buried concrete is exposed to sulfates on the earth face and to de-icing salts on the exposed face then the use of CEMI SR cement (i.e. SRPC to BS 4027) might not be appropriate where the exposure class is both XA3 and XD3 or XD4 in accordance with Table 1 of I.S. EN 206-1. In such circumstances the designer should consider specifying CEMI cement in combination with a Type II addition, as follows:

(a) CEMI cement conforming to I.S. EN 197-1 with a mass fraction of 21% to 35% of combination of pfa conforming to IS EN 450-1 (CII B-V) but provided that the pfa content is a mass fraction of not less than 25% of cement or combination;

(b) CEMI cement conforming to I.S. EN 197-1 with a mass fraction of 36% to 55% of combinations of pfa conforming to IS EN 450-1 (CIVB-V) but provided that pfa contents is a mass fraction of not more than 40% of cement or combination;

(c) CEMI cement conforming to I.S. EN 197-1 with a mass fraction of 36% to 65% of combination of ggbs conforming to IS EN 15167-1 (CIIIA);

(d) CEMI cement conforming to I.S. EN 197-1 with a mass fraction of 66% to 80% of combination of ggbs conforming to IS EN 15167-1 (CIIB + SR).

Where a CEMI cement in combination with a Type II addition is specified by the designer in order to provide concrete with sulphate resisting properties then this should be clearly stated in Appendix 17/1.

Design of Concrete for Piles

(ii) Design of concrete for piles will need careful consideration if ground assessment indicates highly aggressive ground or water, particularly so if required for high performance structures in which the piles are required to resist tension forces or horizontal loads which create bending moments. In adverse situations the design of the piles must be carefully appraised, and additional precautionary measures such as the use of Range C aggregate concrete (refer to BRE SD1) or sleeving considered.

In general, precast and in-situ concrete piles through natural undisturbed unweathered sulphide/sulfate-bearing ground appear to carry little risk or deterioration by sulfate attack. An exception may be cases where the unweathered ground has seepage paths through discontinuities or more preamble zones and there is a flow of groundwater through these which has a high concentration of sulfate derived from a source such as deposits of gypsum.

In the case of concrete piles in contact with well-weathered sulfate-bearing clay (such clay is generally free from sulfides such as pyrite), the outer surface should be regarded as at some risk of sulfate attack particularly if ground conditions are wet. Such attack could potentially reduce the skin friction component of pile load-bearing capacity. The concrete design should be based on the results of a thorough ground appraisal that determines sulfate concentrations at appropriate close vertical intervals (say 1 metre apart).

In-situ concrete piles through 'made' ground may be especially vulnerable to sulfate attack. Waste materials from mining and industry are often rich in sulfides and sulfates. Also, made ground composed of formerly unweathered pyrite-rich clay may potentially have high sulfate contents due to oxidation and bacterial processes. Thorough ground appraisal is needed prior to concrete design. Appropriate procedures are given in BRE Special Digest SD1 (Part 1). Effects on inadequately specified concrete piles could include significant reduction in pile section and corrosion of reinforcement, as well as loss of skin friction.

Drainage Considerations

(iii) Sulfate and/or acid bearing groundwater should be intercepted, if possible, before coming into contact with buried concrete, and backfill must be adequately drained. Structure-specific and carrier drains in proximity to the structure or building foundations should be designed to ensure that they have sufficient capacity and that they can be maintained. Detailing of the design of drainage and its construction should be undertaken with care to avoid accidental discharge of contaminated water into backfill to structures, or on to buried concrete surfaces.

Specifically designed groundwater drainage is the preferred additional protective measure where a hydrostatic head of groundwater greater than five times the concrete section thickness is present.

Sulfates Resulting from Sulfides in the Ground

(iv) The risk of deterioration due to sulfate attack, including the thaumasite form of sulfate attack (TSA), is worse where clays or other sulphide bearing materials have been excavated, reworked and replaced adjacent to buried concrete. The rapid oxidation of sulfides, particularly pyrites, in disturbed ground, results in enhanced levels of sulfates in the soil and groundwater.

Careful consideration must be given to the choice of materials surrounding buried concrete. They must be assessed in relation to the presence and sources of sulfates, the prevailing groundwater conditions, the provision and location of drainage, the proposed usage of the structure, and coatings and other protective measures to be used. Though there may be benefits in considering the use of non-sulphate/sulphide bearing backfills in proximity to structures, designers would need to assess the potential for sulfate migration from remote sources through the backfill.

Large excavations to deep foundations create sumps around buried concrete. If they are unavoidable then account should be taken of the more aggressive groundwater conditions and steps taken to provide adequate drainage to the backfilled excavation and to prevent groundwater entering from the surrounding area. On no account should such excavations be refilled with clays containing high concentrations of sulfates and sulfides.

Irrespective of the type of backfill, designers should try to ensure that groundwater is intercepted by drains or other means to prevent groundwater reaching buried concrete.

Surface Protection

(v) At present there is little information available on the protection afforded by commercially available coatings and tanking against sulfate attack. Traditional methods of using bitumen emulsion based coatings have not been fully effective in all the cases of TSA investigated so far. However, such coatings, properly applied, appear to offer some measure of additional protection, and are an acceptable additional protective measure.

The main requirements of coatings and tanking are listed below:

- provide an impermeable barrier;
- be resistant to sulfates and other deleterious chemicals;
- have a neutral effect on the concrete substrate;
- be resistant to envisaged mechanical damage;
- be easy to apply correctly;
- have long term durability;
- be cost effective.

Such coatings and tanking must be applied in accordance with the manufacturer's instructions, and the workmanship must be of a high standard to maintain their integrity.

As an alternative to commercial coatings and tanking, there appears to be some merit in considering the use of additional 'sacrificial' concrete in buried construction. This could be achieved by providing an additional sacrificial thickness of cover concrete integral with a parent concrete or by constructing a separate layer of concrete made from range C aggregates.

A sacrificial concrete layer is one of the additional protective measures given in BRE SD1. The quality of such a layer should be at least equal to that of the inner concrete. Although service data are scarce, BRE Special Digest SD1 (Part 2, Section 5.6) suggests an additional sacrificial layer of 50mm thickness. The design of the concrete element would need to be reappraised to reflect the additional concrete.

Where TSA is considered possible, the need to exercise good control over the maintenance of the design cover in reinforced concrete construction is emphasised to minimise the risk of, and delay the onset of, reinforcement corrosion.

NG 1705 Concrete – Requirements for Designed Concrete

Conformity Criteria

1 Conformity criteria for compressive strength are given in 8.2.1.3 of I.S. EN 206-1.

Suitability of Proposed Constituent Material Proportions

2 Initial tests should establish a concrete that satisfies all specified requirements for fresh and hardened concrete. Where the specifier or producer can demonstrate an adequate design, based on data from previous tests or long-term experience, this may be considered as an alternative to initial tests. Details of initial testing are given in Annex A of I.S. EN 206-1.

1706 Concrete – Production

General

1 In a significant change from previous Irish practice, I.S EN 206-1 contains detailed provisions for production control. It requires the concrete producer to have a documented production control system and it sets out a list of general requirements, followed by procedures that amplify some aspects of these general requirements. These procedures are allowed to be varied to take account of:

- the kind and size of the production;
- the works;
- the particular equipment being used;
- procedures and rules in use at the place of production;
- the use of the concrete.

What is not specifically stated, but is understood, is that any alternative procedure should achieve effective control of that aspect of production and be documented.

Every reasonable opportunity and facility should be taken to inspect the materials and the manufacture of concrete and to take any samples or to make any tests. All such inspection, sampling and testing should be carried out with the minimum of interference with the process of manufacture and delivery.

Consistence at Delivery

2 Additional Water. In general water or admixtures should not be added to delivered concrete and is forbidden by I.S. EN 206-1. The addition if extra water to a designed concrete will not only increase the slump, but will also increase the shrinkage potential and permeability of the hardened concrete. The extra water will also reduce the final compressive strength of the concrete and its durability.

NOTE: If more water or admixtures are added to the concrete in a truck mixer on site than is permitted by the specification, the concrete batch or load should be recorded as "non-conforming" on the delivery ticket. The party who authorized this addition is responsible for the consequences and this party should be recorded on the delivery ticket. "Non-conforming" concrete should not be included in the Permanent Works.

NG 1707 Concrete – Conformity and Identity Testing

Conformity

1 In a further significant change from previous Irish practice, I.S. EN 206-1 requires the concrete producer to determine conformity. This is logical as only the producer has sufficient data to be able to declare statistical conformity with the specification. Where the producer detects non-conformity that was not obvious at the time of delivery, this non-conformity has to be declared to the relevant specifiers and users. Some independent re-assurance that this has been done as required is one of the strongest reasons why concrete should be subject to product certification, and reference should be made to the product certification scheme for ready mixed concrete, see NG Sample Appendix 1/25: Product Certification Schemes. The conformity test results and associated analysis should be provided by the concrete producer at least every 3 months.

Non-conformity

2 The action to be taken in respect of the concrete that is represented by the test results that fail to meet the requirements of I.S. EN 206-1 may range from qualified acceptance in less severe cases to rejection and removal in the most severe cases. In determining the action to be taken, due regard should be given to the technical consequences of the kind and degree of non-compliance, and to the economic consequences of alternative remedial measures either to replace the substandard concrete or to ensure the integrity of any structure in which the concrete has been placed.

In estimating the concrete quality and in determining the action to be taken when the tests indicate non-compliance, the following should be established wherever possible:

(a) the validity of the test results, and confirmation that specimen sampling and testing have been carried out in accordance with the appropriate parts of I.S. EN 12350 and I.S. EN 12390;

(b) the constituent materials proportions actually used in the concrete under investigation;

(c) the actual section of the structure represented by the test cubes;

(d) the possible influence of any reduction in concrete quality on the strength and durability of this section of the structure.

Additional tests may be carried out on the hardened concrete in the structure to confirm its integrity or otherwise. These may include non-destructive testing methods or the taking of cored samples (see NG 1727) for laboratory examination and testing.

Identity Testing

3 (i) The specifier or user of the concrete has the right to check the concrete supplied to them. This does not form part of conformity testing, but the producer may opt to use such data in the assessment of conformity. Such testing is called “identity testing”, not “acceptance testing” although in reality its purpose is to decide if a particular batch or batches are acceptable to the specifier or user.

(ii) Identity testing identifies with a high level of probability whether a particular batch or batches come from a conforming population. I.S. EN 206-1, Annex B provides rules for the assessment of strength for one or more batches of concrete.

(iii) The Irish National Annex to I.S. EN 206-1 gives identity test criteria for slump and air content of single batches of concrete. These are the same as the conformity criteria for single batches of concrete. Such testing will determine if the particular batch is accepted or rejected.

(iv) The specifier is responsible for organising any identity testing, see Appendices 1/5 and 1/6.

Identity Testing Rates

4 The need for identity testing and the rate of testing should be matched to the use of the concrete. Low strength class concrete usage and concrete used in less critical structural elements usually will not require identity testing to be undertaken, unless there is a specific cause for doubt over quality. High strength class concrete and concrete used in structurally critical elements will usually always require identity testing, to confirm that the supplied concrete conforms to the required characteristics of the specified concrete.

5 Where identity testing for compressive strength is required, it should be described in Appendix 17/4, and be in accordance with the requirements given in Annex B of I.S. EN 206-1.

6 Where identity testing for slump and air content is required on individual batches of concrete, it should be described in Appendix 17/4, and it should be in accordance with the requirements given in the Irish National Annex to I.S. EN 206-1.

7 Where identity testing is not restricted to cases of doubt or random spot checks, the type to be carried out, the volume of concrete should be described in Appendix 17/4.

8 Typical rates of sampling for identity testing are given in Table NG 17/1 below, but not less than one sample should be taken on each day for each concrete class used.

9 Higher rates of sampling and testing may be required at the start of work or if the level of quality is in doubt; conversely, rates may be reduced when high quality has been established.

TABLE NG 17/1: Typical Rates of Sampling and Testing

Use of concrete	Sample from one batch selected randomly to represent an average volume of not more than the lesser of (assumes batches of 6m^3)
Prestressed concrete	12m^3 or 2 batches
Reinforced concrete	From 24m^{3}or 4 batches to 96m^3 or 16 batches depending on application
Mass concrete	May not be required

10 For special reinforced concrete such as end blocks, half-joints or other highly stressed areas the rates of sampling for prestressed concrete may be considered more appropriate.

Air Content of Fresh Concrete

11 It should be noted that the method of measuring air content described in I.S. EN 12350-7 is not applicable to concrete made with lightweight aggregate.

Additional Tests on Concrete for Special Purposes

12 Additional cubes may be required for various purposes. These should be made and tested in accordance with I.S. EN 12390, but the methods of sampling and the conditions under which the cubes are stored should be varied according to the purpose for which they are required. For determining the cube strength of prestrssed concrete before transfer or of concrete in a member before striking formwork or removing cold weather protection, sampling should preferably be at the point of placing, and the cubes should be stored as far as possible under the same conditions as the concrete in the members. The extra cubes should be identified at the time of making and should not be used for the normal conformity or identity testing procedures.

NG 1708 Concrete – Surface Finish

General

1 The type of surface finish required depends on the nature of the member, its final position in the structure, and whether or not it is to receive an applied finish. The appropriate finish, which may vary from face to face, should be carefully chosen and clearly specified.

Wherever possible, samples of surfaces of adequate size (preferably incorporating a horizontal and vertical joint and reinforcement representative of heavily congested zones of reinforcement) should be agreed before work commences. All the factors affecting the quality of the surface finish from formwork should be carefully studied. For detailed descriptions of these factors and their interrelationship, attention is directed to the pamphlet 'Appearance Matters 3 The Control of Blemishes in Concrete', Cement and Concrete Association.

Texture, colour and durability are affected by curing (see NG 1710.5). Where appearance is important, curing methods and conditions including the time of removal of formwork require careful consideration. Components that are intended to have the same surface finish should receive the same treatment.

Control of Colour

2 Where uniformity of colour is important, all materials should be obtained from single consistent sources. In formwork the replacement of individual plywood sheets or sections of timber in large panels should be avoided.

Colour can be affected by curing.

Release Agents

3 Release agents for formwork should be carefully chosen for the particular conditions they are required to fulfil. Where the surface is to receive an applied finish, or it is to be impregnated, care should be taken to ensure the compatibility of the release agent with the subsequent treatment process, for example no deleterious residue should be left.

Surface Finishes for Concrete

4 (i) The class of finish should be shown on the drawings. Class F1 finish should be specified for unexposed formed surfaces and Class F2 finish normally for exposed surfaces. F3 finish is very costly and should only be used for small areas. F4 is appropriate where large areas are required to have a first-class appearance. Although metal parts should never be permanently embedded within the cover depth from the surface of the concrete, internal ties can be used in ways which will not detract from the appearance. For instance, if made coincident with certain types of surface features (e.g. vertical grooves formed to break up large areas or features which create shadow effects) the holes are practically indiscernible and an economical design of formwork ensues. The designer is urged to be flexible in his requirements for surface features bearing such facts in mind. For Class F3 and F4 finishes, it is recommended that trial panels should be made. Class F5 finish is primarily intended for precast pretensioned beams. The position of the exposed surfaces in the finished structure should be taken into account in determining the extent of making good. In cases where beams are of the same design it is possible, within practical limits, to minimise the extent of making good by selecting beams with the best surface finish for positions of maximum exposure.

(ii) Class U2 finish should normally be specified for exposed concrete; Class U3 being reserved for positions where the surface is required to be especially smooth for function or aesthetic reasons; Class U4 finish is to be used for bridge decks that are to receive waterproofing systems; Class U5 finish is reserved for footbridge surfaces that are to receive either separate or combined systems, or coatings of waterproofing and surfacing materials. The method adopted for finishing a surface which is to receive deck waterproofing should be such that a layer of laitance is not left on the surface nor the course aggregated exposed.

(iii) Other classes of finish should be fully specified and scheduled in Appendix 17/3 and should, if possible, be related to samples that are readily available for comparison. Included under this heading is any finish that requires the coarse aggregate to be permanently exposed, the use of special forms or linings, the use of a different concrete mix near the surface, grinding brush-hammering or other treatment.

Protection

5 High quality surface finishes are susceptible to subsequent damage, and special protection may have to be provided in vulnerable areas.

This is particularly relevant for precast elements (especially facing elements for reinforced walls) where careful consideration needs to be given to the handling and storage of these to prevent marking of the surface by timber supports, plastic spacers etc.

NG 1709 Concrete – Protection Systems

General

1 Impregnation is carried out by spraying concrete surfaces with a hydrophobising material that penetrates the concrete and reacts with the silicates and moisture present. This produces a water repellant but vapour permeable layer that inhibits the ingress of water and/or chloride and sulfate ions. Effectiveness of this layer is determined by the quality of the hydrophobisation and the strength and permanence of the bond between the silane molecule and the concrete substrate. The depth of penetration will vary depending on concrete quality and moisture content. Impregnation is known to be effective for at least 15 years provided it has been applied correctly. Longer service lives are anticipated. However, it is considered advisable until further experience is gained to assume that reapplication will be necessary after about 20 years.

2 Because of the wide variety of structural types and span arrangements, etc. all parts of a structure are not equally at risk from attack. Generally the risk depends upon the degree of exposure to water and salts which in turn will depend on the geometry, design and location of individual members. It is highly desirable to treat all exposed reinforced and prestressed concrete surfaces subjected to spray and/or possible leakage from deck joints. The following is intended as a guide when completing Appendix 17/2:

(i) piers, columns, crossheads and abutments subjected to spray;

(ii) piers, columns, crossheads and abutments with a deck joint above but with no provision for positive drainage. The tops of these members should also be treated where possible;

(iii) bearing shelves, ballast walls and deck ends with a deck joint above, where possible;

(iv) structures in marine environments and columns and soffits over brackish water. A marine environment is usually experienced within 1 km of the coast or tidal waters unless there are special local conditions.

(v) where possible, concrete parapets and parapet plinths (all inclinations) and those areas not protected with deck waterproofing;

(vi) deck beams and soffits;

(vii) wing walls within 8 metres of the edge of the carriageway;

(viii) retaining walls within 8 metres of the edge of the carriageway;

(ix) 'M' beams (webs and tops of bottom flanges should be treated before erection).

Material

3 (i) Silane is a toxic material and is an irritant to human tissue. Containers must be retained in a safe and secure facility and quantities used must be carefully monitored. Access for sampling of opened containers and at the spraying equipment must be provided for the Employer's Personnel.

(ii) Silane hydrolyses with moisture in the atmosphere. The contents of any opened containers should be used in accordance with sub-Clause 8 of this Clause within 48 hours or discarded

(iii) Silane can be contaminated with substances such as paraffin or white spirit without any visual indications. It is important to test for such contamination by measuring the refractive index of the silane and taking the necessary actions as indicated in sub-Clause 1709.2.

Spraying Equipment

4 The type of nozzle used and spraying distance should be in accordance with the manufacturer's instructions.

Protective Measures

5 (i) Silane may have deleterious effects that need to be controlled during the application of the material. Prior to application, protective measures must be implemented to prevent contamination of watercourses and damage to humans, animals, vegetation and vehicles.

(ii) Impregnation over or adjacent to watercourses will require protective sheeting or complete encapsulation beneath the structure to be impregnated.

(iii) Impregnation on structures over or adjacent to roads will require protective sheeting or complete encapsulation. Consideration should also be given to the introduction of appropriate traffic management and safety measures.

(iv) Vegetation that could be subject to spray, needs to be covered or otherwise protected, and the protective covering must be maintained in position and in good condition.

(v) Silane has a softening effect when it comes into contact with elastomeric bearings, painted steel surfaces, bituminous materials and joint sealants, and these items should be protected during application. The protective measures must be maintained in position and in good condition. On completion of the impregnation process the masking materials should be removed and disposed of in accordance with sub-Clause 8 of this Clause.

Surface Condition

6 (i) It should be ensured that curing membranes and release agents, where they have been used, have fully degraded before impregnation is carried out. This is particularly important to check when silane is to be applied less than a month after the concrete was placed.

(ii) Water jetting or steam cleaning should not in general be used to remove contamination, solid deposits or curing membranes. In exceptional circumstances, where there is substantial contamination, these methods may be used with care, subject to a satisfactory trial being undertaken. However, impregnation should not commence for a minimum of 48 hrs from completion of the cleaning works, and remains subject to the other application and surface condition requirements, particularly the need for a period of surface dryness of the concrete substrate for a period of 24 hours in advance of the impregnation operation.

(iii) Silane should not be applied until the concrete surface has been dry for 24 hours because absorption of silane will be restricted if damp, reducing its effectiveness. Artificial drying of the concrete surface is not permitted, as this may lead to increased moisture at the surface by capillary action from within the concrete, when the drying equipment is removed.

Application

7 (i) Depending on climatic conditions, it may be necessary to protect surfaces to be treated to ensure that they are surface dry before impregnation.

(ii) The required coverage of each coat at 300 ml/m^2 must be regularly monitored by determining the quantities of silane material used on particular areas of each structure. Achieving the required rate may result in some loss of material, by run down and evaporation. Application of silane can be judged by a characteristic ‘wet look’ to the concrete.

(iii) It is important to apply the silane before the concrete receives its first exposure to salts, subject to the prior degradation of any curing membranes, because a substantial amount of contaminants can enter the concrete by capillary adsorption during this initial exposure. This may be particularly important in a marine environment.

Disposal

8 Given the toxic nature of silane, the contents of all containers that have been opened for more than 48 hrs, contaminated materials, sheeting etc, must be disposed of appropriately at an approved disposal facility.

Quantities of materials must be monitored on site and materials kept in safe and secure facilities.

Materials Testing

9 (i) It is essential that volumes of impregnation material delivered to site, used on site and for disposal, are accurately monitored.

(ii) Samples of impregnation material (refer to sub-Clause 1709. 2(vi)) should be tested to confirm compliance with the requirements of sub-Clause 1709. 2(ii).

NG 1710 Concrete – Construction General

Construction Joints

1 The number of construction joints should be kept as few as possible consistent with reasonable precautions against shrinkage and early thermal movement. Concreting should be carried out continuously up to construction joints.

Where it is necessary to introduce construction joints, careful consideration should be given to their exact location, which should be shown either on the drawings or determined by the Contractor in accordance with the specified criteria. Construction joints should be at right angles to the general direction of the member and should take due account of shear and other stresses.

The use of retarding agents painted onto formwork is not permitted because they tend to migrate into the concrete under the action of vibration.

When open mesh permanent formwork is proposed, its suitability should be supported by sufficient information about its stiffness, strength, method of use and performance.

Concrete should not be allowed to run to a feather edge and vertical joints should be formed against a stop end. The top surface of a layer of concrete should be level and reasonably flat unless design requirements are otherwise. Joint lines should be so arranged that they coincide with features of the finished work.

If a kicker (i.e. a starter stub) is used, it should be at least 70mm high and carefully constructed. Where possible, the formwork should be designed to facilitate the preparation of the joint surface, as the optimum time for treatment is usually a few hours after placing.

Particular care should be taken in the placing of the new concrete close to the joint. This concrete should be particularly well compacted.

Formwork

2 (i) Design and construction. It should be ensured that all permanent or temporary formwork, including supports, is adequate for the proper construction of the Works.

Before any formwork is constructed, the Contractor should prepare detail drawings, including details of external vibrators where proposed and the depth of lifts to be concreted where appropriate. The drawings should be supported by calculations which show the adequacy of the proposals.

Requirements for permanent formwork, for either internal or external use, should be described in Appendix 17/4; due regard being given to the conditions to which it is likely to be exposed and to its function in the structure. The material selected for external use must be durable, particularly at exposed edges or joints.

(ii) Projecting reinforcement. Special care should be taken when formwork is struck to avoid the risk of breaking off the edge of concrete adjacent to any projecting reinforcement.

Transporting, Placing and Compacting

3 Concrete should be transported from the mixer to the formwork as rapidly as practicable by methods that will prevent the segregation or loss of any of the ingredients and maintain the required workability. It should be deposited as near as practicable to its final position to avoid rehandling.

All placing and compacting should be carried out under the direct supervision of a competent member of the Contractor's (or manufacturer's) staff. Concrete should normally be placed and compacted soon after mixing, but short delays in placing may be permitted provided that the concrete can still be placed and effectively compacted without the addition of further water.

A cohesive concrete mix that does not segregate may be allowed to fall freely provided that special care is taken to avoid displacement of reinforcement or movement of formwork, and damage to faces of formwork. In massive sections it is necessary to consider the effect of lift height on the temperature rise due to the heat of hydration.

Concrete should be thoroughly compacted by vibration, pressure, shock or other means during the operation of placing to produce a dense mass having the required surface finish when the formwork is removed.

Whenever vibration has to be applied externally, the design of formwork and disposition of vibrators should receive special consideration to ensure efficient compaction and to avoid surface blemishes.

The mix should be such that there will not be excess water on the top surface on completion of compaction. It may be necessary to reduce the water content of batches at the top of deep lifts to compensate for water gain from the lower levels, but this can be avoided by designing the mix, checking with preliminary trials and accurately controlling the mix proportions throughout the work.

Spillages of concrete onto other parts of the permanent structure, e.g. structural steelwork, should be removed immediately they occur to avoid damage to finishes. When air entrained concrete is used, reference should also be made to NG 1702.3(ii).

For the time being it should be noted that self-compacting concrete (SCC) is not explicitly permitted under the Specification, as concrete is required to be compacted. However, where SCC is considered to be the preferred option then agreement should be sought under NRA BD 2 Technical Acceptance of Structures on Motorways and Other Roads and amendments agreed to Specification Clauses, dealing with quality control, materials, testing and construction requirements. In particular attention should be given to the type of testing proposed, such as slump flow table, and setting target flow values, to be used as part of the quality control procedures. Also important are specification and limitation of admixture dosage rates, both at the batching plant and at the point of delivery. From experience it may be necessary to undertake trial panels to ensure that the specified concrete finishes are achieved and that any necessary controls over the method and rate of placement of SCC can be assessed and instigated.

Striking of Formwork

4 (i) General. The time at which formwork is struck is influenced by the following factors:

(a) concrete strength;

(b) stresses in the concrete at any stage in the construction period, which in the case of precast units includes the stresses induced by disturbance at the casting position and subsequent handling;

(c) curing (see NG 1710.5);

(d) subsequent surface treatment requirements;

(e) presence of re-entrant angles requiring formwork to be removed as soon as possible after concrete has set to avoid shrinkage cracks;

(f) requirements of any deflection profile.

The formwork should be removed slowly, as the sudden removal of wedges is equivalent to a shock load on the partly hardened concrete.

(ii) Striking period for cast in situ concrete.

Field conditions for control cubes may be simulated by temperature-matching curing or other methods. In the absence of control cubes, reference should be made to the specialist literature, e.g. "Formwork Striking Times-Methods of Assessment" prepared by CIRIA (Report No. 67) for appropriate guidance.

The periods given in Table 17/5 of the Specification are not intended to apply where accelerated curing or slip forms are used. Where it is not practicable to ascertain the surface temperature of concrete, air temperatures may be used though these are less precise. In cold weather the period should be increased according to the reduced maturity. For example, for soffit formwork it would be appropriate to increase the value by half a day for each day on which the concrete temperature was between 2^{O}C and 7^{O}C, and by a whole day for each day on which the concrete temperature was below 2^{O}C.

When formwork to vertical surfaces such as beam sides, walls and columns is removed in less than 12 hours, care should be exercised to avoid damage to the concrete, especially to arrises and features. The provision of suitable curing methods should immediately follow the removal of the vertical formwork at such early ages, and the concrete should be protected from low or high temperatures by means of suitable insulation (see NG 1710.5).

Curing

5 (i) Curing Methods. The method of curing and its duration should be such that the concrete will have satisfactory durability and strength and the member will suffer a minimum of distortion, be free from excessive efflorescence and undue cracking. To achieve these objectives it may be necessary to insulate the concrete so that it is maintained at a suitable temperature, or so that the rates of evaporation of water from the surfaces are kept to appropriate values, or both. Different curing or drying treatments are appropriate to different members and products. Where necessary, special care should be taken to ensure that similar components are cured as far as possible under the same conditions.

Curing usually consists of maintaining the formwork in place and covering the concrete with a material such as polythene sheet or a curing compound or with an absorbent material that is kept damp for a period of time.

Where formwork is struck before curing is complete some other form of protection should be used.

Where structural members are of considerable depth or bulk or have an unusually high proportion of cement or are precast units subjected to special or accelerated curing methods, the method of curing should be specified in detail in Appendix 17/4. Some special cases are cited as examples in NG 1710.5(iii).

The higher the rate of development of strength in concrete, the greater the need to prevent excessive differences in temperature within the member and too rapid a loss of moisture from the surface. Alternate wetting and drying should be avoided, especially in the form of cold water applied to hot concrete surfaces. In order to avoid surface cracking, cold water should not be applied to relatively massive members immediately after striking the formwork while the concrete is still hot.

(ii) Accelerated curing. Accelerated curing (which includes steam curing) consists of curing the concrete in an artificially controlled environment, in which the humidity and the rate of temperature rise and fall are controlled, to speed up the rate of increase in strength.

(iii) Additional Considerations. The principal reasons and recommendations for curing concrete are given in (i) and (ii) above. The following parts of this sub-Clause are intended to amplify the factors that should be considered. The recommendations are based on the assumption that the concrete temperature during the curing period will not fall below 2^{O}C. Particular precautions to be taken when concreting at low air temperatures are given in NG 1710.6.

(a) Strength of concrete. The effect of admixtures on curing should be considered. The higher the rate of development of strength of the concrete (and hence of heat of hydration of the cement), the more care should be taken during the early period after casting to prevent excessive differences in temperature within the concrete and excessive loss of moisture from the pour.

The rate of gain of strength is also increased if the temperature of the concrete is raised. An approximate guide of the development of strength at different temperatures can be obtained by using the concept of 'maturity', which may be defined as the area under a curve of the concrete temperature (in degree Celsius) plotted against time (in hours) calculated from a basis of -10^{O}C. Curing by means of damp absorbent materials is likely to cause a lowering of the temperature of the concrete as a result of the evaporation from the material, and in some circumstances the effect can be significant.

The rate of development of strength diminishes as the concrete dries out; hence excessive evaporation of water from all surfaces may need to be prevented.

(b) Distortion and cracking. The concrete should b cured so that internal stresses within the member, whether due to differences in temperature or differences in moisture content within the concrete, are not sufficient to cause distortion or cracking. The disposition of reinforcement will affect the restraint to the strains, and hence it will have an effect on any distortion and cracking.

In assessing the likely temperature variation within the concrete, the following factors apply:

- rate of heat evolution (related to rate of development of strength);
- size and shape of member;
- different insulation values of curing media (e.g. wooden moulds or water spray);
- external temperature.

For example, surface cracking may occur as a result of variation in temperatures due to applying a cold water spray to a relatively massive member immediately after stripping the moulds while the concrete is still hot.

In assessing the likely variation in moisture content within the concrete. The rate of evaporation will be higher with atmospheric conditions encouraging evaporation (e.g. low relative humidity, high wind speed, concrete surface hotter than air), especially if the rate of migration of water through the concrete is greater than the rate of evaporation from the surface, e.g. for:

- members of high surface/volume ratio;
- concrete at early age or lower strength class of concrete.

For example, cracking may occur due to varying shrinkage in members with sudden changes in section that affect the surface/volume ratio appreciably; especially if the more massive section is reinforced and the more slender section is not.

Further information can be obtained from CIRIA Report No. 91, "Early-age Thermal Crack Control in Concrete".

If the shrinkage of units after they are built into the structure is likely to lead to undesirable cracking at the ends of the unit, curing aimed at preventing the loss of water from the unit should be continued no longer than is necessary to obtain the desired durability and strength; thereafter the concrete should be given the maximum opportunity to dry out consistent with the limitation of the variation in moisture content as already outlined.

(c) Durability and appearance. As deterioration is most likely to occur as a result of the concrete providing inadequate protection for the reinforcement, or because of frost attacking the surface concrete, all vulnerable surfaces of concrete should be protected against excessive loss of water by evaporation that would result in a weak, porous surface layer.

Where it is important to prevent the formation of efflorescence, especially in cold weather, the atmosphere adjacent to the surface of the concrete should be maintained at a constant relative humidity approaching 100% for the time given in Table 17/5 of the Specification. Concrete should be protected from wetting and drying cycles.

(iv) Curing liquids, compounds and membranes. Before curing liquids, compounds and membranes are accepted for use on surfaces on which waterproofing systems are to be laid they should be shown to be completely removable by natural or mechanical means.

It should be noted that proprietary liquid curing membranes may take a long time to disintegrate and may affect the appearance of permanently visible surfaces as well as the bond of any waterproofing layer.

Only film type membranes that fully degrade by exposure to ultra-violet light should be used where concrete surface impregnation is specified, as other curing liquids, compounds or membranes may leave residues which prevent satisfactory application of the treatment. Sufficient interval should be allowed for the film to fully decompose before impregnation commences (see NG 1709.6). To achieve optimum breakdown of the membrane the manufacturer's recommendations for prior wetting or dampening of the concrete surfaces and the rate of application of the membrane material should be closely followed.

Cold Weather Work

6 (i) General. Before placing concrete, the formwork, reinforcement, prestressing steel and any surface with which the fresh concrete will be in contact should preferably be at a temperature close to that of the freshly placed concrete. Special care should be taken where small quantities of fresh concrete are placed in contact with larger quantities of previously cast concrete at a lower temperature. Any concrete damaged by frost should be removed from the work.

Concrete temperatures should be measured at the surface at the most unfavourable position.

(ii) Concrete Temperature.

The raising of the temperature of the concrete may be achieved in a number of ways including the following:

(a) By heating the mixing water and aggregate. If the water is heated above 60^{O}C, it is advisable to mix the water with the aggregate before adding the cement.

(b) By increasing the top cement content of the mix or by using a more rapid hardening cement.

(c) By covering the top face of slabs and beams with adequate insulating material.

(d) By providing wind breaks to protect newly placed concrete from cold winds.

(e) By using a heated enclosure, completely surrounding the freshly placed concrete or using heated formwork panels. In either event care should be taken to prevent excessive evaporation of water from the concrete.

Formwork should be left in place as long as possible to provide thermal insulation; timber formwork provides better insulation than steel. Further guidance on this subject can be obtained from the Cement and Concrete Association Publication No. 45.007 "Winter Concreting".

Hot Weather Work

7 In hot weather, the incidence of cracking and loss of workability may be reduced if measures are taken to cool the constituent materials. Aggregates can be kept cool by protecting them from direct sunlight and by spraying with water, making due allowance for the moisture content of the mix. Water pipes particularly if long should preferably be shaded and if possible insulated.

Surface Preparation of Precast Concrete Units

8 Laitance is the dusty milky cement compound which can be removed after the concrete has hardened using a stiff brush.

Handling and Erection of Precast Concrete Units

9 (i) Manufacture off the Site. The designer should show on the drawings the type of preparation of the surfaces of concrete members which will subsequently receive in situ concrete.

Supervision of workmanship and materials for factory-made concrete units is as important for Site work and is most satisfactorily carried out by a resident inspector or by making frequent visits during manufacture.

To monitor control during production, test results should be readily available. This should help to encourage careful manufacture. Where exceptional circumstances prevent proper supervision being exercised, visual inspection and measurement of the completed units can determine some of the important properties. Reference should also be made to NG 1727. To benefit from manufacturer's normal practice, it is recommended that for factory-made pretensioned beams, the designer should be prepared to accept alternative types and positions of tendons. Where the size and position of the tendons is shown on the drawings, the words "or equivalent" should be added and the force before transfer and its eccentricity should be given. The designer should ensure that the losses from the type of tendons proposed are not greater than those taken into account in the design.

(ii) Storage. Indelible identity, location and orientation marks should be put on the member end where necessary. The designer should in all cases specify the points of support during storage, and these should be chosen to prevent unacceptable permanent distortion and lack of fit of the units. In order to minimise the stresses induced, supporting arrangements that permit only small settlements are to be preferred.

The accumulation of trapped water and rubbish in the units should be prevented. The freezing of trapped water can cause severe damage.

Where necessary, precautions should be taken to avoid rust stains from projecting reinforcement and to minimise efflorescence.

(iii) Handling and transport. Precast units should resist, without permanent damage, all stresses induced by handling and transport. The minimum age for handling and transport should be related to the concrete strength, the type of unit and other relevant factors.

The position of lifting and supporting points, the method of lifting, the type of equipment, the minimum age for handling, and transport to be used should be as specified by the designer.

Care should be taken to ensure that lifting details are practicable and can be used safely, and that no damage results from the lifting equipment.

During transport the following additional factors require consideration

(a) Distortion of the transporting vehicles.

(b) Centrifugal force due to cornering.

(c) Oscillation. A slim member may flex vertically or horizontally sufficiently to cause damage.

(d) The possibility of damage due to chafing.

(iv) Assembly and erection. Where the method of assembly and erection is part of the design, it should be stated in Appendix 17/4.

In order to ensure compliance with sub-Clause 1710.8(iv)(a) of the Specification, it may be advisable to have the camber of precast beams measured at the factory so that they can be placed in the correct order.

The object of preventing lateral movement of precast beams in composite slab bridges is to prevent differential movement between beams, which may occur if the concrete is placed in longitudinal strips. This is particularly important when the beams are supported on flexible bearings.

(v) Forming structural connections. The precast units should be inspected to ensure that the design requirements of the structural connection can be met.

The precast units should be free from irregularities which may cause damaging stress concentrations. When reliance is placed on bond between the precast and in situ concretes, the contact surface of the precast units should have been suitably prepared. If frictional resistance is assumed to be developed at a bearing, the construction should be such that this assumption can be realised. Particular care should be given to checking the accurate location of reinforcement and any structural steel sections in the ends of precast members, and to introducing any additional reinforcement needed to complete the connection.

(a) Concrete or mortar packing. When joints between units, particularly the horizontal joints between successive vertical lifts are load-bearing and are to be packed with mortar or concrete, tests should be carried out to prove that the material is suitable for the purpose and the proposed method of filling results in a solid joint (for bedding mortar see Clause 2601).

(b) Other packing materials. Where epoxy resin bonding agents for segmental deck construction are to be used the designer should prepare additional specification requirements based on the manufacturer's recommendations. Reference should also be made to Federation Intrernatinoale de la Precontrainte (FIP) publication FIP/9/2, available from the British Cement Association.

The composition and water/cement ratio of the in situ concrete or mortar used in any connection should be as specified.

Care should be taken to ensure that the in situ material is thoroughly compacted.

The manufacturer's recommendations as to the application and method should be strictly followed.

Careful consideration should be given to the proposed methods for removing levelling devices such as nuts and wedges.

(vi) Protection. The degree and extent of the protection to be provided should be sufficient for the surface finish and profile being protected, bearing in mind its position and importance. This is particularly important in the case of permanently exposed concrete surfaces, especially arrises and decorative features. The protection can be provided by timber strips, hessian, etc. but should not be such as will damage, mark or otherwise disfigure the concrete.

Measurement of Precast Concrete

10 Units may be measured at any convenient time but not less than 7 days after casting, provided that the alternative time proposed by the Contractor is supported by calculations to demonstrate the dimensions predicted for 28 $\pm$ 2 days.

NG 1711 Concrete – Grouting and Duct Systems for Post-tensioned Tendons

General

1 The Specification allows for the designer to call for full-scale trials to be carried out to demonstrate that the grouting will provide adequate protection to the tendons. This requirement should be specified in Appendix 17/6 and fully detailed on the Contract drawing, including trial beam size, concrete strength class, cover to reinforcement and tendons, reinforcement for testing and investigation. The designer should recognise that the purpose of the trial is to test the Contractor's systems and methods and personnel proposed for the permanent works and should incorporate any particular requirements pertaining to the construction sequence and duct configurations. Requirements for subsequent disposal of the trial beam should be specified.

Feedback from previous Contracts has shown that there are very significant benefits for all parties in undertaking a full-scale trial. In the circumstances it is advocated in all but very minor post-tensioning and grouting operations.

The trials should be carried out well in advance of the planned need for use of post-tensioning in the permanent works (56 days is the default period in the Specification). In particular, any proposals for untried systems should be given due time for acceptance.

Successful completion of the trials and materials tests will allow commencement of the grouting in the permanent Works.

Grouting techniques such as vacuum grouting and void grouting (undertaken as a remedial measure) are available from some suppliers and can be considered either to be demonstrated as suitable in trials or for remedial works as appropriate.

Grout Material

2 Composition of the grout is classified in sub-Clause 1711.2. The grout may be supplied as a proprietary manufactured pre-bagged material, to which water must be added, or as a designed site batched blend of cement, admixtures and water. Both materials have identical performance requirements. Performance of the grout will in all cases be assured by suitability testing, irrespective of whether full-scale grouting trials have been specified.

Where bagged cement is used in site batched grout the Employer's Representative should be aware that variations in cement type, age, chemical composition, fineness and temperature can have significant effects on the performance of the grout.

Ducting

3 Sub-Clause 1711.3 requires the ducting to form an air and water resistant protective barrier as an additional defence against corrosive contaminants. This follows the philosophy adopted in Concrete Society Technical Report TR47 'Durable Bonded Post-tensioned Concrete Bridges' 2nd edition, of multi-layer corrosion protection. The duct system should comply, as a minimum with the International Federation for Structural Concrete *(fib)* recommendations (Technical Report, Bulletin No. 7) for 'Corrugated plastic ducts for internal bonded post-tensioning'. Polyethylene and polypropylene are suitable materials for ducting but other materials may also be suitable.

Debate continues over the minimum wall thickness of ducting, and over the air-pressure test requirements.

The minimum manufactured wall thickness of ducting for internal tendons should be 2mm. The duct rigidity and type and spacing of fixings and supports should be such as to maintain line, position and cross section shape during concreting. Local deformation of the duct at supports should be avoided.

For external tendons the minimum wall thickness should be 4mm for durability, or such thicker wall as required to withstand grouting pressures of the particular duct configuration. It is important to anticipate any sagging of the duct due to the weight of grout, particularly for tendons stressed after grouting, and appropriate temporary duct support should be provided during the grouting operation.

Minimum wall thickness of the ducting after tensioning should be considered by the designer and appropriate requirements specified in Appendix 17/6, taking account of minimum radii of curvature of the tendons which will tend to bite into the duct wall. Type and spacing of duct supports also need careful attention to avoid this. Manufacturers' and suppliers' data should be referred to.

The internal diameter of vents should be as large as possible but designers should bear in mind the sizes included within available systems. The vents, connections and taps should be sufficiently robust to withstand full grouting pressure.

For most applications a minimum vent height of 500mm above the highest point on a duct is recommended to help entrapped air and water to escape. For some configurations of tendons this will not be appropriate and the designer should specify an alternative in Appendix 17/6.

There are circumstances where the requirement for a sealed ducting system will be difficult e.g. in segmental construction. The designer should consider the options. Sealing of ducts at joints in segmental construction is an issue which remains to be satisfactorily resolved, and consequently such a form of construction using internal grouted tendons is not currently permitted.

The purpose of air testing is to demonstrate, first, that the system provides an adequate degree of resistance to contaminants and, second, that the system is correctly assembled and has no significant leaks. The pressure testing requirements make reference to compliance testing before installation and duct assembly verification testing. It is expected that all currently available systems can pass the latter test, but designers should seek the prestressing supplier's guidance before completing Appendix 17/6.

Grouting Equipment

4 The mixing equipment should be of a type capable of producing a homogeneous grout by means of high local turbulence while imparting only a slow motion to the body of the grout.

Injecting Grout

5 The volume of the spaces to be filled by the injected grout should be compared with the quantity of grout injected.

Grouting should be undertaken from one end of the duct only, to avoid the risk of voids. In exceptional situations such as looped vertical ducts this may be undertaken from both ends, but the methods should be assessed in full scale trials.

The rate of grout injection should be defined in Appendix 17/6. Grout injection should not normally result in more than 10m of duct being grouted per minute. For certain applications where ducts are outside the normal range of size (i.e. not multi-strand tendons in 80mm – 125mm ducts), this limit may be increased to 15m of duct per minute.

Grouting During Cold Weather

6 The grout materials may be warmed within the limits recommended for concrete (see NG 1710.6).

Testing

7 The requirement for bond length is given as 50-100 diameters of the duct in line with *fib* recommendations. If the designer wishes to give an alternative, this should be specified in Appendix 17/6.

The mandatory Duct Assembly Verification Test included in the Specification is intended to demonstrate that the system has been correctly assembled. If the system fails to meet the criteria required by the Test, it should be dismantled, any damaged items replaced, and the system reassembled and re-tested. If it still fails to comply, sealing of joints with the addition of a suitable sealant may improve matters. Acceptance would then be subject to the results of re-testing.

Appendix A of TR47 describes additional tests to measure the effectiveness of seal provided by the duct system, which the designer may wish to consider adopting in appropriate circumstances. These methods require further experience and development before adoption as a specification requirement.

The fluidity of the grout during the injection period should be sufficiently high for it to be pumped effectively and adequately to fill the duct, but sufficiently low to expel the air and any water in the duct. The time during which fluidity is maintained will need to be assessed but a target of 90 minutes is a sensible upper limit.

The grout should be sufficiently stable to bleed very little and so the materials segregate and settle to a minimal extent.

The Employer's Representative should adopt a pragmatic approach to the size of acceptable voids in ducts. The limits given in sub-Clause 1711.1 would normally be acceptable at a crest in the duct where the steel tendons are embedded in grout in the lower part of the duct and the vents are properly filled and sealed, and the surface is waterproofed.

It is recommended that where the system includes end caps at anchorages intended to be left in place, these are left undisturbed and completeness of grouting is tested by sounding and visual examination of vent holes in order to avoid disturbing the seals.

It has been observed that the type of belled test currently specified in most national codes, and in the first edition of TR47, failed to identify potentially unstable grouts. The important feature missing from these tests is the destabilising effect of the 'wick action' caused by the strands. This shortfall has been addressed by LCPC Appendix A, clause A7 in France by the development of an inclined tube test, which is included in Appendix A7 of TR47 as an acceptable alternative test. It has also been addressed in a BRITE Euram Project 'QA of grouting', clause 9.3 by the development of a 1.5m vertical test. The latter test is simpler, quicker and more economical, and is incorporated in TR47, and is recommended for general use.

It has also become evident that specifications that require bleed water to be reabsorbed in 24 hours have no logical basis. If bleed water develops, reabsorption will merely create an air void. Likewise, requirements to measure the bleed water after three hours are not necessarily relevant to modern thixotropic grouts.

Admixtures

8 Expanding grout admixtures are supplied as powders which expand to ensure that there is no overall decrease in the volume of grout at the end of the hardening period.

Non-expanding grout admixtures are supplied in liquid or powder form.

Both types of grout admixture may also permit a reduction in water/cement ratio, improve fluidity, reduce bleeding and retard the set of the grout.

Grouting

9 Normally, grout injection should not exceed the rate of 10m of duct per minute. For certain applications, where ducts are outside the normal range of size (i.e. not multi-strand tendons in 80-125mm ducts0, this may be increased to 15m of duct per minute.

To minimise the risk of blockages of pumping equipment or delivery hoses or of lumps forming in the grout, it is advisable to wash out equipment with water at least every three hours. This is especially recommended before grouting very long tendons and in warm weather.

In cold weather it is necessary to measure the temperature of the concrete structure (for internal tendons) or the air void around the ducts (for external tendons) to comply with specifications to avoid freezing the grout. Air temperature measurement is straightforward but measuring the temperature of the structure can be more difficult.

Recommended procedures are to seal the ducts, say, 12 hours before grouting and measure the air temperature inside the ducts, or to form a small pocket in the concrete, fill it with water, again, say 12 hours before grouting and measure the temperature of this water.

Grouting plant should be located as close as practical to the point of injection to keep supply lines short.

NG 1712 Reinforcement – Materials

Stainless Steel Reinforcement

1 Advice on stainless steel reinforcement is given in BA 84 (DMRB 1.3). Since there are a multiplicity of grades of stainless steel, it is essential that supplied steel is clearly designated with its strength and chemical grade, and that care is taken to ensure that the correct materials are utilised.

NG 1713 Carbon Steel Reinforcement and Stainless Steel Reinforcement – Bar Schedule Dimensions – Cutting and Bending

1 Bending of reinforcement should not be carried out when the temperature of the steel is below $5^{O}C$. If necessary, reinforcement may be warmed to a temperature not exceeding $100^{O}C$.

Where it is necessary to bend reinforcement projecting from concrete, the radius of the bend should be not less than that specified in BS 8666, and there should be a clear distance of 4d between the concrete face and the start of the bend. Embedded couplers should be used wherever practicable to avoid damage to concrete and reinforcement.

2 Where the Contractor or precast manufacturer opts to cut and bend reinforcement on the Site, or in the precasting works respectively, even through the CARES fabricators offer this service, it should be ensured that any fabricated reinforcement not covered by a third party certified product certification scheme such as CARES is assessed by acceptance tests carried out by an independent testing laboratory as specified in BS 8666.

NG 1714 Reinforcement – Fixing

1 Cover blocks and spacers should be of such materials and designs that they will be durable, will not lead to corrosion of the reinforcement, and will not cause spalling of the concrete cover.

Cover and spacer blocks made from cement, sand and fine aggregate should match the mix proportions of the surrounding concrete as far as is practicable with a view to being comparable in strength, durability and appearance. The Concrete Society Report CS 101 “SPACERS” provides standardised methods of achieving the specified nominal cover and gives standard performance requirements and methods of testing spacers and chairs.

Non-structural connections for the positioning of reinforcement should be made with stainless steel wire or tying devices or by welding (see NG 1717). Care should be taken to ensure that projecting ends of ties or clips do not encroach into the concrete cover.

The cover and position of reinforcement should be checked before and during concreting; particular attention being paid to the position of top reinforcement in cantilever sections. The support of reinforcement to achieve the correct location, cover and spacing is the Contractor’s responsibility and supports should not be shown on the drawings and bar schedules.

The concrete cover to reinforcement should be confirmed as soon as possible after the removal of formwork by the use of non-destructive methods of testing (see NG 1727.2(ii)(d)). A record of this survey should be retained for inclusion in the as-build drawings.

NG 1715 Reinforcement – Surface Condition

1 Normally handling prior to embedment in the concrete is usually sufficient for the removal of loose rust and scale from reinforcement; otherwise wire-brushing of sand-blasting should be used. The sand used for blasting should comply with BS 1199 and BS 1200.

NG 1716 Reinforcement – Laps and Joints

General Requirements

1 Where continuity of reinforcement is required through the connection, the jointing method used should be such that the assumptions made in analysing the structure and critical sections are realised. The following methods may be used to achieve continuity of reinforcement:

(i) lapping bars;

(ii) mechanical joints;

(iii) threaded reinforcing bars;

(iv) welding (see NG 1717).

Such connections should occur, where possible, away from points of high stress and should be staggered. The use of any other jointing method not listed should be confirmed by test evidence.

Lapping of Bars

2 Where straight bars passing through the joint are lapped, the requirements of BS 5400 : Part 4 apply. When reinforcement is grouted into a pocket or recess, an adequate shear key should be provided on the inside of the pocket.

Where continuity over a support is achieved by having dowel bars passing through overlapping loops of reinforcement, which project from each supported member, the bearing stresses inside the loops should be in accordance with BS 5400 : Part 4.

Jointing of Bars

3 A number of systems are available for jointing reinforcing bars, which are capable of transmitting the tensile and compressive forces in the bar; these are as follows:

(i) swaged couplers;

(ii) tapered threaded bars and couplers;

(iii) upset bar ends with parallel threads and couplers;

(iv) couplers fixed to the bars with studs for transmitting compressive forces only;

(v) sleeves with tapered closers that align the square sawn ends of bars for transmitting compressive forces only.

Mechanical Joints should have a current British Board of Agrément Roads and Bridges or CARES Certificates.

Mechanical joints for stainless steel reinforcement should have equivalent durability to the reinforcement itself. They require specific approval from the Engineer in respect of the technical design requirements.

NG 1717 Reinforcement – Welding

General

1 Welding should be avoided whenever possible. Very significant loss in fatigue strength of reinforcement can occur as a result of welding. Location welds (track welds used for locating bars) pose a

particular fatigue risk (see BS 5400 : Part 10) and any welding to shear stirrups requires careful assessment.

Welding may only be undertaken where suitable safeguards, supervision and techniques are to be employed. Where it is acceptable in the design and to BS 5400 : Part 4 and Part 10 it should be checked that where cyclic loading occurs, the Class of weld given in Table 17 of BS 5400 : Part 10 has been achieved.

Where, notwithstanding the above, welding is to be used, and the fatigue effects of the welds have been taken into account in the design it should if possible be carried out under controlled conditions in a factory or workshop. The competence of the operators should be demonstrated prior to, and periodically during, welding operations.

In such circumstances welding may be considered for:

(i) Fixing in position, e.g. by welding between crossing or lapping reinforcement or between bars and other steel members. Metal-arc welding or electric-resistance welding may be used on suitable steels.

(ii) Structural welds involving transfer of load between reinforcement or between bars and other steel members. Butt welds may be carried out by flash butt welding or metal-arc welding.

The manual metal-arc process is used on Site or in fabrication shops for making joints of every configuration. In particular it is the only process available for making tee joints between bars and anchorage plates and lapped joints between bars. It is emphasised that operators should be trained and possess sufficient skill for producing good welded joints. The flash butt welding process is restricted to fabrication shops where it can produce sound butt welds more rapidly than manual metal arc welding. The resistance welding process for cross bar joints can be used on Site or in fabrication shops, through for work on Site it is more usual to use manual metal-arc welding. Further guidance on metal-arc welding of reinforcing bars is given in BS 7123.

2 Flash butt welding is carried out by clamping the reinforcing steel bars in water-cooled copper shoes which introduce a large current to the bars. The bar faces are moved slowly towards each other and, when in close proximity, arcing of flashing occurs at those parts of the two faces in closest contact. The arcing or flashing results in intense heating of the bars. This flashing period can be extended to further preheat the joint before completing the weld which is performed by forcing the hot faces together, metal being forced from the hot faces during the actual welding stage to form a collar. Advice on the correct combination of flashing, heating, upsetting and annealing should be obtained from the reinforcement manufacturer.

3 Manual metal-arc welding is a form of fusion welding in which heat for welding is obtained from an arc struck between a consumable stick electrode and the joint faces. The stick electrode consists of a metal core and a flux covering, the flux forming a protective shield for the molten metal in the weld pool, protecting it from atmospheric contamination. In addition the flux includes constituents that can slag off some harmful contaminants that may present in the joint prior to welding.

4 Other methods such as resistance welding may be used for forming butt welds. This is a similar operation to flash butt welding, contact of the bar faces creating intense heat due to electrical resistance at the interface. After a predetermined period, sufficient to heat the bar faces into a plastic state, the current is turned off, the bars faces are pressed together under great pressure and a welded joint made, with less material upset than arises in flash butt welding. It is, however, necessary to have cleaner bar faces for resistance butt welding than for flash butt welding.

Resistance welding is rarely used for butt welding of reinforcing steel bars, but resistance spot welding finds wide application for joining wire bars in cross welds configurations. Large automatic machines with multiple pairs of electrodes are used for simultaneously welding many wires and smaller diameter bars to form mesh. In addition portable guns with single pairs of electrodes are used for tack welding bars of smaller diameter.

Should fabricators wish to use other processes, reference should be made to the reinforcement manufacturer for guidelines in developing satisfactory procedures.

NG 1718 Prestressing Tendons – Materials

1 The characteristic strengths of prestressing tendons are given in the appropriate British Standards.

NG 1720 Prestressing Tendons – Surface Condition

1 All prestressing tendons and internal and external surfaces of sheaths or ducts should be free from loose mill scale, loose rust, oil, paint, grease, soap or other lubricants, or other harmful matter at the time of incorporation in the structural member. Slight surface rusting is not necessarily harmful and may improve the bond. It may, however, increase the loss due to friction.

Cleaning of tendons may be carried out by wire brushing or by passing them through a pressure box containing carborundum powder. Solvent solutions should not be used for cleaning.

NG 1722 Prestressing Tendons – Cutting

1 In post-tensioning systems the heating effect on the tendon due to cutting should be kept to a minimum both to avoid damage to the anchorage or bond of the tendon, and to avoid any undesirable metallurgical effects in the tendon steel within the concrete member. Where tendons between beams on long line prestressing beds are to be cut, the yielding of steel in burning imparts less of a shock load to the beam ends than any cold cutting method and is, therefore, to be preferred.

NG 1723 Prestressing Tendons – Positioning of Tendons, Sheaths and Duct Formers

1 The method of supporting and fixing the tendons (or the sheaths or duct formers) in position should be such that they will not be displaced by heavy or prolonged vibration, by pressure of the wet concrete, by workmen or by construction traffic. The means of locating prestressing tendons should not unnecessarily increase the friction where they are being tensioned.

Sheaths and extractable cores should retain their correct cross section and profile and should be handled carefully to avoid damage. Extractable cores may be coated with release agent and should not be extracted until the concrete has hardened sufficiently to prevent it being damaged.

Damage can occur during the concreting operation, and if the tendon is to be inserted later, the duct should be dollied during the concreting process to ensure a clear passage for the tendon. Inflatable rubber duct formers are not suitable for this purpose.

Should the profile of any empty duct be in doubt after the concrete has been cast a technique has been developed of drawing a radioactive source through the duct and plotting its path.

NG 1724 Prestressing Tendons – Tensioning

General

1 Tendons may be stressed either by pretensioning or by post-tensioning according to the particular needs of the form of construction. In each system different procedures and types of equipment are used, and these govern the method of tensioning, the form of anchorage and, in post-tensioning, the protection of the tendons.

Safety Precautions

2 A tendon when tensioned contains a considerable amount of stored energy which, in the event of any failure of tendon, anchorage or jack, may be released violently. All possible precautions should be taken during and after tensioning to safeguard persons from injury, and equipment from damage, that may be caused by the sudden release of this energy. Guidance on the precautions which should be taken is given in Appendix C to BS 5400 : Part 8.

Pretensioning

3 The transfer of stress should take place slowly to avoid shock that would adversely affect the transmission length.

Post-tensioning

4 (i) Arrangement of tendons. Tendons, whether in anchorage systems or elsewhere should be so arranged that they do not pass around sharp bends or corners likely to provoke rupture when the tendons are under stress.

(ii) Anchorage system. The anchorage system in general comprises the anchorage itself and the arrangement of tendons and reinforcement designed to act with the anchorage. The form of anchorage system should facilitate the even distribution of stress in the concrete at the end of the member, and should be capable of maintaining the prestressing force under sustained and fluctuating load and under the effect of shock. Provision should be made for the protection of the anchorage against corrosion.

(iii) Tensioning procedure. The measured tendon force should be compared with that calculated from the extension, using the Youngs Modulus (E) value for the tendon obtained by measuring the load-extension relationship in a calibrated testing machine with an extensometer of 1m gauge length. This provides a check on the accuracy of the assumption made for the frictional losses at the design stage; if the difference is significant, corrective action should be taken.

Where a large number of tendons or tendon elements are being tensioned and the full force cannot be achieved in an element because of breakage, slip or blockage of a duct, and if the replacement of that element is not practicable, the designer should consider whether a modification in the stress levels can still comply with the design requirements.

The designer should specify the order of loading and the magnitude of the load for each tendon.

NG 1725 Prestressing Tendons – Protection and Bond

General

1 It is essential to protect prestressing tendons from both mechanical damage and corrosion. Protection may also be required against fire damage.

It may also be an important design requirement for the stressed tendon to be bonded to the structure.

Protection and Bond of Internal Tendons

2 Internal tendons may be protected and bonded to the member by cement grout in accordance with Clause 1711. Alternatively the tendons may be protected by other materials such as bitumen or petroleum-based compounds, epoxy resins, plastics and the like, provided that bond is not important.

Protection and Bond of External Tendons

3 A tendon is considered external when, after stressing and incorporation in the work but before protection, it is outside the concrete section. It does not apply, for example to a slab comprising a series of precast beams themselves stressed with external tendons and subsequently concreted or grouted in so that the prestressing tendons are finally contained in that filling with adequate cover.

Protection of external prestressing tendons against mechanical damage and corrosion from the atmosphere or other aspects of the environment, should generally be provided by an encasement of dense concrete or dense mortar of adequate thickness. It may also be provided by other materials hard enough and stable enough in the particular environment.

In determining the type and quality of the material to be used for the encasement, full consideration should be given to the differential movement between the structure and the applied protection that arises from changes of load and stress, creep, relaxation, drying shrinkage, humidity and temperature. If the applied protection is dense concrete or mortar and investigations show the possibility of undesirable cracking, then a primary corrosion protection system should be used that will be unimpaired by differential movement.

If it is required that external prestressing tendons be bonded to the structure, this should be achieved by suitable reinforcement of the concrete encasement to the structure.

NG 1727 Inspection and Testing of Structures and Components

General

1 This Clause indicates methods for inspecting, and where necessary, testing whole structures, finished parts of a structure, or structural components to ensure that they have the required components to ensure that they have the required standards of finish dimensional accuracy, serviceability and strength. Where inspection or results of other tests (see NG 1727.2) lead to doubt regarding the adequacy of the structure, loading tests may be made following the procedure set out in NG 1727.6.

In this Clause, deflection means the maximum amount of movement under load of the component being tested, relative to a straight line connecting its points of support. The load tests described in this Clause may not be suitable for:

(i) model testing when used as a basis of design;

(ii) development testing of prototype structures;

(iii) testing to prove the adequacy of a structure owing to change of use or loading.

Where the Contractor or manufacturer uses a quality control method, and maintains records of the entire process of manufacture (subject to these records being certified by a Chartered Engineer or a person who has a recognised equivalent qualification of another state of the European Economic Area) which show that the products meet the requirements of the Specification, such records may be accepted as confirming that the required quality has been reached. This in no way precludes the designer specifying such tests as he requires.

Testing requirements should be fully described in Appendix 17/4 and scheduled in Appendix 1/5 and/or Appendix 1/6.

Check Tests on Structural Concrete

2 (i) General. The testing of concrete specimens to establish whether the concrete used in the structure complies with the Specification as a structural material is described in Clause 1707 and the additional cube tests for special purposes are dealt with in NG 1707.6. The tests described in sub-Clause (ii) below are applicable to hardened concrete in the finished parts of a structure or in precast units. They may be used in routine inspection and for quality control. They are also of use when concrete is found defective from visual inspection and when assessing the strength of the concrete used. Details of procedures are contained in British Standards and advice is provided in the Concrete Bridge Development Group Technical Guide No. 2 "Testing and Monitoring the Durability of Concrete Structures" (TG2).

(ii) Types of check tests

(a) Cutting cores. In suitable circumstances the compressive strength of the concrete in the structure may be assessed by drilling and testing cores from the concrete. The procedure used should comply with BS 1881 : Part 201. Such cores may also be cut to investigate the presence of voids in the compacted concrete. Core cutting should, whenever possible, avoid reinforcement.

(b) Gamma radiography. Gamma radiography has been used to test concrete up to 450mm thick for the presence of local voids in the concrete and the efficiency of the grouting of ducts in prestressed members; the presence and location of embedded metal may also be determined. The testing should be carried out in accordance with the recommendations in BS 1881 : Part 205. Further information about gamma radiography testing is contained in Post-tensioned Concrete Bridges published in 1999 by Thomas Telford, specifically Chapter 8. Special precautions are necessary to avoid contamination from the radioactive source.

(c) Ultrasonic test. If an ultrasonic apparatus is regularly used by trained personnel and if continuously maintained individual charts are kept that show, for a large number of readings and the strength of cubes made from the same batch of concrete, such charts may be used to obtain approximate indications of the strength of the concrete in the structure.

In the cases of suspected lack of compaction or low cube strengths, ultrasonic tests carried out on adjacent suspect and acceptable sections of the structure may provide useful comparative data.

(d) Electromagnetic cover measuring devices. The position of reinforcement or tendons may be verified to depths of about 70mm by an electromagnetic cover measuring devices as described in BS 1881 : Part 204. The position of reinforcement and ducts/tendons may be verified to depths of up to 500mm using an inductive probe as described in TG2.

(e) Rebound hammer test. If a rebound hammer is regularly used by trained personnel and if continuously maintained individual charts are kept that show, for a large number of readings, the relation between the readings and the strength of cubes made from the same batch of concrete, such charts may be used in conjunction with hammer readings to obtain an approximate indication of the strength of the concrete in a structure or element. An accuracy of $\pm$ 3 N/mm^2 could be expected when used by trained personnel in these circumstances.

Rebound hammer tests are usually preformed on a grid over a defined test area. 12 measurements are obtained around each grid point. Abnormal readings should be discarded and the rebound number determined as the mean of the remaining numbers. (TG2). Readings should not be taken within 25mm of the edge of concrete members. It may be necessary to distinguish between readings taken on a trowelled face and those taken on a moulded face. When making the test on precast units, special care should be taken to bed them firmly against the impact of the hammer.

Surface Finish

3 The surface of the concrete should be inspected for defects, for conformity with the Specification and, where appropriate, for comparison with approved sample finishes.

Subject to the strength and durability of the concrete being unimpaired, the making good of surface defects may be permitted, but the standard of acceptance should be appropriate to the strength class and quality of the finish specified and should ensure satisfactory performance and durability. On permanently exposed surfaces great care is essential in selecting the mix proportions to ensure that the final colour of the faced area blends with the parent concrete in the finished structure.

Dimensional Accuracy

4 The methods of measurement of dimensional accuracy, making allowance for specified tolerances, if any, should be agreed in advance of manufacture.

The effect of temperature, shrinkage and imposed load should be taken into account.

The positions of bars, tendons or ducts should be checked where these are visible or ascertainable by simple means (reference sub-Clause 2(ii) (d) of this Clause).

In the case of precast units, the checking of twist, bow squareness and flatness may entail removal of the unit from its stacked position to a special measuring frame. Extensive checking of units in this manner may materially affect the cost. The frequency and scope of measurement checks should therefore be strictly related to the production method, the standard of quality control at the place of casting, and the function that the unit has to fulfil.

When checking the camber or upward deflection due to prestress, the precast unit should be placed on proper bearings at full span and a central reference point should be provided level with the bearings. The amount of upward deflection to be expected at any stage should be assessed as described in BS 5400 : Part 4. Alternative methods of checking include the use of dial gauges or measurements from a thin wire stretched across the bearings and tensioned sufficiently to take out the sag. Upward deflection is preferably measured on the underside.

Load Tests on Individual Precast Units

5 (i) General. The load tests described in this Clause are intended as checks on the quality of the units and should not be used as a substitute for normal design procedures. Where members require special testing, such special testing procedures should be described in Appendix 17/4 and scheduled in Appendix 1/5.

Test loads should be applied and removed incrementally.

(ii) Non-destructive test. The unit should be supported at its designed points of support and loaded for 5 minutes with a load equivalent to the sum of the nominal dead load plus 1.25 times the nominal imposed load. The deflection should then be recorded. The maximum deflection measured after application of the load should be in accordance with the requirements defined by the designer. The recovery should be measured 5 minutes after the removal of the applied load and the load then reimposed. The percentage recovery after the second loading should be not less than that after the first loading nor less than 90% of the deflection recorded during the second loading. At no time during the test should the unit show any sign of weakness or faulty construction in the light of a reasonable interpretation of relevant data.

(iii) Destructive test. The unit should be loaded while supported at its design points of support and should not fail at its ultimate design load within 15 minutes of the time when the test load becomes operative. A deflection exceeding one-fortieth of the span is regarded as a failure of the unit.

(iv) Special test. For very large units or units not readily amenable to tests (such as columns, the precast parts of composite beams, and members designed for continuity or fixity) the testing arrangements should be agreed before such units are cast.

(v) Load testing of pretensioned beams. Load testing is not normally required and should only be embarked upon when the adequacy of the beams is in serious doubt. When testing is required, the appropriate loading should be agreed with both the Employer’s Representative and Specialist responsible for the design, taking account of any composite action in the permanent works.

Load Tests of Structures or Parts of Structures

6 (i) General. The tests described in this Clause are intended as a check on structures other than those covered by NG 1727.5 where there is doubt regarding serviceability of strength.

Test loads should be applied and removed incrementally.

(ii) Age at test. The test should be carried out as soon as possible after the expiry of 28 days from the time of placing the concrete. When the test is for a reason other than the quality of the concrete in the structure being in doubt, the test may be carried out earlier provided that the concrete has already reached its specified characteristic strength.

When testing prestressed concrete, allowance should be made for the effect of prestress at the time of testing being above its final value.

(iii) Test loads. The test loads to be applied for deflection and local damage are the appropriate design loads, i.e. the nominal dead and imposed loads. When the ultimate limit state is being considered, the test load should be equivalent to the sum of the nominal dead load plus 1.25 times the nominal imposed load and should be maintained for a period of 24 hours. If any of the final deal load is not in position on the structure, compensating loads should be added as necessary.

During the tests, struts and bracing strong enough to support the whole load should be placed in position, leaving a gap under the members to be tested, and adequate precautions should be taken to safeguard persons in the vicinity of the structure.

(iv) Measurements during the tests. Measurements of deflections and crack width should be taken immediately after the application of load and, in the case of the 24-hour sustained load test, at the end of the 24-hour loading period, after removal of the load and after 24-hour recovery period. Sufficient measurement should be taken to enable side effects to be taken into account. Temperature and weather conditions should be recorded during the test.

(v) Assessment of results. In assessing the serviceability of a structure or part of a structure following a loading test, the possible effects of variation in temperature and humidity during the period of the test should be considered.

The following recommendations should be met

(a) For reinforced concrete structures the maximum width of any crack measured immediately on application of the test load for local damage should not be more than two thirds of the value for the serviceability limit state of cracking given in BS 5400 : Part 4. For prestressed concrete structures or elements considered under Class 1 of Class 2, no visible cracks should occur under the test load for local damage.

(b) For members spanning between two supports, the deflection measured immediately after application of the test load for deflection should be not more than the specified value. Limits should be agreed before testing cantilevered portions of structures.

(c) If, within 24 hours of the removal of the test load for the ultimate limit state as calculated in NG 1727.6(iii), a reinforced concrete structure does not show a recovery of at least 75% of the maximum deflection shown during the 24 hours under load, the loading should be repeated. The structure should be considered to have failed to pass the test if the recovery after the second loading is not at least 75% of the maximum deflection shown during the second loading.

(d) If, within 24 hours of the removal of the test load for the ultimate limit state as calculated in NG 1727.6(iii), a prestressed concrete structure or member, considered under Class 1 or Class 2 does not show a recovery of at least 85% of the maximum deflection shown during the 24 hours under load, the loading should be repeated. The structure or member should be considered to have failed to pass the test if the recovery after the second loading is not at least

85% of the maximum deflection shown during the second loading.

NG SAMPLE APPENDIX 17/1: SCHEDULE FOR THE SPECIFICATION OF DESIGNED CONCRETE

These mixes below shall be supplied as designed mixes in accordance with the relevant clauses of I.S. EN 206-1				
1. Mix reference				
2. Strength class				
3. Nominal maximum size of aggregate, in mm (D)				
4. Types of aggregate Coarse Other *[specify requirements]* Fine Other *[specify requirements]*	IS EN 12620 IS EN 12620			
5. Sulphate class *[ring as appropriate]*	XA 1 XA 2 XA 3			
6. Cement type(s) or combinations complying with *[ring those permitted]* CEM I N IS EN 197-1 CEM I R IS EN 197-1 CEM I SR B.S. 4027 Others *[specify requirements]*	CEM I N CEM I R CEM I SR			
7. Exposure Class (As in IS EN 206-1) (or combinations)	X0 XC1, XC2, XC3, XS1, XS2, XS3, XD1, XD2, XD3, XF1, XF2, XF3 XA1, XA2, XA3			
8. Chloride Class	Cl 1,0 C1 0,30 Cl 0,20 Cl 0,10			
9. Minimum cement content, kg/m^3				
10. Maximum free water/cement ratio				
11. Quality assurance requirements		(1)	(1)	(1)
12. Rate of sampling intended by the purchaser for strength testing (for information)		(2)	(2)	(2)
13. Other requirements *[alkali, colour, etc. as appropriate]*				

In the case of fresh concrete the following shall be completed by the purchaser					
14. Consistence	*[Choose one method]* Slump Class Vebe Class Compaction Class Flow Class	S1, S2, S3, S4, S5 V0, V1, V2, V3, C0, C1, C2, C3 F1, F2, F3, F4,			
15. Method of placing (for information)					
16. Other requirements by the purchaser of fresh concrete *[only if appropriate]*					

[Notes to compiler:

(1) Cross-reference should be made to Appendix 1/24 and /or 1/25 as appropriate.

(2) Cross-reference should be made to Appendix 1/5 and/or 1/6 as appropriate.]

NG SAMPLE APPENDIX 17/2: CONCRETE – IMPREGNATION AND COATING SCHEDULE

[Notes to compiler: Areas to be impregnated, or impregnated and coated should be scheduled. If considered preferable the schedule can be placed on a drawing and this Appendix should cross-refer].

NG SAMPLE APPENDIX 17/3: CONCRETE – SURFACE FINISHES

[Note to compiler: Include here]

1. Requirements for trial panels *[1708.1].*

2. Requirements for Contract-specific surface finishes *[1708.4] [cross-referring to the drawings as appropriate].*

3. Positions where internal ties are permitted (other than in rebates) for Class F4 finish *[1708.4(i)].*

4. Locations where a regular pattern of formwork joints is unnecessary *[1708.4(i)].*

NG SAMPLE APPENDIX 17/4: CONCRETE – GENERAL

[Note to compiler: This should include]

1. Requirements for concrete if different from the requirements of sub-Clause 1701.1.
2. Whether the use of cement other than to Clause 1702.1 is permitted.
3. Requirements for lightweight aggregate if different from the requirements of sub-Clause 1702.2.
4. Requirements for admixtures if different from the requirements of sub-Clause 1702.3.
5. Requirements for sampling and testing if different from the requirements of sub-Clause 1707.1. Whether identity testing is required *[1707.2]. [Cross-reference should be made in Appendix 1/5 and/or Appendix 1/6 as appropriate].*
6. Requirements for construction joints *[1710.1].*
7. Whether retarding agents may be used *[1710.1(ii)].*
8. Requirements for permanent formwork [1710.2(iv].
9. References to drawings which show lifting and support points *[1710.8(ii) and (iii)].*
10. Requirements for assembly and erection of precast concrete members *[1710.8(iv].*
11. Whether welding or reinforcement other than steel fabric reinforcement is permitted *[1717.1].*
12. Requirements for tolerance if different from the requirements of sub-Clause 1723.1.
13. Requirements for time of stressing if different from the requirements of sub-Clauses 1724.3(ii) and 1724.4(iv).
14. Requirements for protection of prestressing tendons *[1725.1].*
15. Requirements for inspection and testing of structures and components *[1727.1]. [Guidance is given in NG 1727. Tests should be scheduled in Appendix 1/5 and Appendix 1/6].*
16. Requirements for particular curing methods for deep / bulky elements, elements containing unusually high proportion of cement or precast units subject to special or accelerated curing methods. *[1710.5 and NG1710.5].*

NG SAMPLE APPENDIX 17/5: NOT USED

NG SAMPLE APPENDIX 17/6: GROUTING AND DUCT SYSTEMS FOR POST-TENSIONED TENDONS

TENDON REFERENCE:

[Note to compiler: complete this for each different group or type of tendons]

GROUT DEFINITION:

Grout type:	*Grout*	*[Common]*	*[Special]*
Maximum water/cement ratio:	Not specified	*[0.40]*	*[0.35]*

REQUIREMENTS FOR TRIALS/TESTS:

Drawing Reference:
[full details including location of cuts should be defined on drawing]

Time at which trials are to be carried out (days before planned use in the permanent works: *[56 days]*

[Note to compiler: Optional additional testing requirements to prove protection against ingress of contaminants are given in Section 8 of the Concrete Society Technical Report 47, 2nd Edition – Durable Bonded Post-Tensioned Concrete Bridges. Availability of compliant duct components should be discussed with manufacturers, and tests interpreted in accordance with Section 3.2A of the report].

Required duct assembly testing pressure: *[0.01 N/mm²]*
Minimum duct wall thickness as manufactured: *[2.0mm] [4.0mm for external tendons]*
Minimum duct wall thickness after tensioning: *[1.5mm]*
Minimum duct to concrete ultimate bond length: *[50-100 diameters]*

REQUIREMENTS FOR DUCT SYSTEM:

Distance beyond crests to next vent: *[Horizontally, to the point where the duct is half the diameter lower than at the crest, or 1m, whichever is the lesser]*

Maximum vent spacing *[15m]*
Minimum vent height above highest point *[500mm]*
Other requirements *[-]*

Requirements for Grouting:

Maximum rate of grouting of ducts *[10m/min]*
Minimum volume of grout expelled after visual test *[5 litres]*

[Note: Default values shown in brackets]