EC2 – DURABILITY AND QUALITY CONTROL

Concrete lack of durability, a worldwide problem, involves the expenditure of vast sums of money on inspection maintenance and repair. This is mainly attributed to inadequate attention to the problem at the design and construction stages. Attention being applied both the extrinsic and intrinsic causes. The former is environmentally related and can be assessed by a thorough examination of the ambient conditions in which the concrete will pass the best part of its life span.

The durability of concrete or its ability to withstand the ravages of time and environment is as essential as the requirement that it must be strong enough to carry the intended loads and as such must be properly integrated at the initial stages of a building project (together with strength, stability, cost and buildability).

It is accepted that concrete compressive strength reflects most of the other properties of this material to the extent that several, mainly empirical relationships, have been developed to correlate compressive strength to most other properties. This is somewhat fortunate in that compressive strength is one of the easiest, least complicated, least costly and most used (even if often abused!) test that can be applied to the material. Indeed the cube is king! – or is it? European design codes are based on compressive strength measured by testing 150 mm by 300 mm cylinders when the normal test specimen is the cube. Since the producers could not persuade the designers to use the cube and the designers could not persuade most concrete producers to use the cylinder, the compromise is dual classification of strength.

Durability is no different than other properties. It is well documented that the stronger the concrete the greater its durability. In EC2 this has been developed to the extent of durability grades. One principle of the mix design of concrete mixes is the requirement that the proposed mix should satisfy the requirements of both strength and durability. With the introduction of durability grades this can be carried out at the onset and the target mean strength or for that matter the choice of prescribed mix chosen prior to the start of calculations. It must also be kept in mind that the quality of the material alone does not guarantee durability. Workmanship combined with lack of adequate supervision is also a major factor.

Although the new standard covers the same ground as BS5328 with regards to specification, production and conformity of concrete, it is more extensive in its coverage of concrete durability or its performance in service. In fact the introduction of durability provisions in EC2 represents the most significant revision of durability requirements for structural concrete since the replacement of CP110 buy BS8110 in 1985. The requirements are intended to ensure that concrete structures are designed and constructed so that they maintain their required durability and performance for a sufficiently long period of time – in excess of fifty years. The code covers all ordinary type structures with foreseeable environmental conditions and expected normal service lives. It is admitted that situations might arise when different requirements may be necessary and are not catered for, examples being complex structures such as viaducts, large dams or the use of new constituent materials.

Modern durability technology has been built up from engineering models incorporating knowledge and experience from a wide range of technical disciplines such as:

- Statics (structural behaviour)
- Materials technology
- Design (codes, structural form, design traditions)
- Execution (workmanship, local traditions)
- Statistics
- Economy

Based on the above, clause 2.4. in EC 2, states that to ensure adequate durability one should consider the following inter related factors:

- The expected environmental conditions
- The use of the structure
- The required performance criteria
- The composition, properties and performance of the materials
- The shape of the members and structural detailing
- The quality of workmanship and level of control
- The particular protective measures
- The likely maintenance during the intended life

These factors are practically the same as those considered under clause 4.1.1 – General, which in section P4 of the same clause states that for most buildings the general provisions in the code will ensure a satisfactory life with the proviso that the required level of performance and it duration be considered at an early stage in the design.

A study of clauses 4.1.2.2, Environmental conditions, 4.1.2.3 Chemical attack and 4.1.2.4 Physical attack leads to the conclusion that like its predecessors, EC2 deals primarily with the four main deterioration mechanisms namely:

- Corrosion of reinforcement
- Alkali-silica reaction
- Chemical attack (such as sulphates)
- Freeze-thaw

The first primarily attacks and destroys the reinforcement resulting in cracking and spalling of the concrete. The other three attack the concrete directly. All require the presence of water. Water, essential for hydration, turns from hero to villain. It is well documented that rate of deterioration diminishes with the relative dryness of the concrete. This is quite evident from the fact that indoor concrete is much less susceptible to damage even if all other conditions required for development of the particular mechanism are present.

In the local contest it is reinforcement corrosion and to a lesser extent chemical attack that are of significance.

The environment is taken to mean those chemical and pysical actions to which the structure or any part thereof is exposed, the consequences of which are not envisaged in the structural design. (Cl. 4.1.2.2)

The environment and exposure condition classes according to Table 3.2 of B.S. 8110; 1985 are shown in Table 1 whilst Table 2 shows the corresponding exposure classes according to EC2 Table 4.1. The classification according to 8110 appears more simplistic but open to a certain amount of interpretation whilst that in EC2 is more specific – once more emphasising the importance of the durability aspect in design.

Class one still covers the large majority of interior concrete used in practice. The interpretation of footnote 1 as to what constitutes ‘a prolonged period of time’ is left to common sense and is locally of little significance..

Class two covers the majority of external concrete with the main limitation being no salt exposure.

Class three mainly covers land-based concrete exposed to salts.

Class four covers all marine concrete.

Class five covers chemical attacks form gaseous, liquid or solid substances as defined by ISO classifications and covers solely chemical aggressivity to the concrete itself and not to substances only aggressive to any embedded steel once it is reached. Deterioration of concrete by chemical attack can be caused by contact with gases or solutions of many chemicals, but it is generally the result of exposure to acidic solutions or to solutions of sulphate salts. This contact (Cl. 4.1.2.3) can also result from the use of the building as well as from an aggressive environment.

The resistance of concrete to degradation both from chemical and physical (Cl 4.1.2.4) causes must be obtained through the two processes of design and execution to achieve a dense impermeable concrete (Cl. 4.1.2.3 [4]). To achieve this any designer must take account of the proper choice of materials, proportions, desired mechanical properties, and mixing placing compacting and curing of the concrete.

Modern cements are more finely ground and show a marked increase in the C_3S/C_2S ratio resulting in marked increase in concrete strengths most noticeable at early ages. The long-term strength has also shown an increase although the proportion of this strength development after 28 days has also decreased. This in effect means that strength specifications can now be met with lower cement contents and higher w/c ratios. Leading to higher permeability and consequently lower durability capabilities. To this end EC2 as for that matter BS 8110 addresses this problems by relating concrete grades to cement content and w/c ratio. These are shown in Table 3.

Carbonation and corrosion rates are affected in very different ways by humidity. The rate of carbonation is fastest in a dry environment and is negligible under wet conditions. In contrast, steel corrosion requires both moisture and oxygen. It is negligible in dry conditions owing to lack of moisture and also negligible under water owing to the restricted availability of oxygen. Corrosion of steel proceeds fastest under conditions of high humidity, particularly where fluctuations around 100% RH give rise to periodic condensation.

Concrete being a porous material, the rate of ingress of atmospheric CO_2 through the pores into the interior can only be controlled through reducing the porosity. W/c, good compaction and good curing are the major factors involved in reducing porosity grouped together as the factor *k* in the equation, depth of carbonation = $k(t)^{1/2}$, *t* being time expressed in years.

It is quite obvious that depth of carbonation and hence the loss of the alkaline environment essential for the protection of the steel depends on both the quality and the depth of the concrete cover. Generally, increased depth and quality of cover delay carbonation reaching the steel. They also reduce fluctuations of humidity around the steel, which reduces the rate of corrosion, and provide increased mechanical resistance to cracking. As in the case of BS 8110: 1985, EC2 relates the depth of cover required to exposure class, cement content and w/c. The requirements of BS 810 are shown in Table 4 whilst those of EC2 are shown in Table 5. The use of spacers to achieve these depths with adequate tolerances cannot be over-emphasized. These values are intended for rebar protection from corrosion but greater depths of cover may be warranted for ensuring bond strength, fire protection, large maximum aggregate sizes and to prevent spalling.

It is well proven that the potential for rebar corrosion is enhanced in the presence of chloride ions. To this end, EC2, as does BS8110, bans the use of calcium chloride based admixtures in any concrete incorporating embedded metal. The 0.4% limit on chloride ions by weight of cement still applies. Table 6 shows a summary of the potential for corrosion based on BRE Digest No.264 (1982). The presence of the chloride ion will manifest itself within a few years in the medium to high-risk category particularly if associated with concretes of low cement content and high permeability in a moist environment. The need to specify high-strength concrete with the right constituents and adequate cover cannot be over-emphasised in such conditions. The use of blended cements (GGBS, PFA or microsilica) will give enhanced resistance to chloride ingress at lower strength grades and cover. EC2

The quality of the appropriate cover is an essential factor in the protection of the concrete from re-bar corrosion. Apart from proper compaction of the appropriate concrete of the right grade and w/c, curing is the main factor affecting the quality of the skincrete. Blocking of the surface capillaries and thus producing discontinuity and low porosity is dependent on w/c. Table 7 demonstrates the relationship between w/c and curing time for the blocking of capillaries thereby greatly reducing the risk of ingress of deleterious substances. EC2, as in BS8110, recommends a minimum but varying curing period. These requirements of BS 8110 are shown in Table 8. It can be ascertained that these periods, for a temperature range between 5 and 25^o are related to cement type, ambient conditions after casting and concrete surface temperature. The need for thorough curing and protection for an adequate period is stressed. Clause 10.6.3 of ENV 206, The European Standard for Concrete on which EC2 is based, states that the required curing time depends on the rate at which a certain impermeability or resistance to penetration of gases and liquids, of the surface zone is achieved. It further recommends that curing times should be determined by either maturity, local requirements or in accordance with the minimum periods given in table 12. In this table, minimum curing times in days for exposure classes 2 to 5a are dependent on whether concrete strength development is rapid, medium or slow as governed by w/c (table 13 of Env206, as well as concrete temperature and ambient conditions during curing.

The provision of an impermeable cover is seriously impaired should the structure or any element crack. This is referred to in EC" (Cl. 4.1.2.5) as 'Consequential indirect effect'. The formation of such cracks can be minimised by following the general requirements in the code for durability, cracking, deformation, detailing, strength etc. as detailed in other sections of the same code. The code also recommends the consideration in design and detailing (Cl.4.1.3.1) of adoption of structural forms that minimise exposure to moisture and the detailing of elements or structures such as to promote good drainage.

The role played by 'the man on site' in achieving the right durability cannot be overemphasised and the standard of workmanship should ensure that the planned durability is achieved. The combination of materials and procedures should be such as to ensure satisfactory resistance to aggressive media to both concrete and the steel. Adequate measures through supervision and quality control should ensure this.

EC2 specifies Cl 7.1) the minimum necessary control measures for the design and construction of concrete structures and comprise essential actions and decisions as well as checks to be made in compliance with specifications and standards to ensure that these are met. The code goes much further than BS

8110 and is more stringent. It identifies three basic control systems (Cl. 7.2.1 – 7.2.3) each exercised by a different party with different objectives. These are:

- Internal control
- External control and
- Conformity control.

Internal control is effected by the designer, sub/contractor or supplier each within the scope of his specific task and is carried out on his own initiative or according to 'external' requirements by the client.
External control comprises all measures for the client and is carried out by an independent organisation employed by the client. This normally consists in the verification internal control measures required by external specifications and additional checking procedures independent from internal control systems.
Conformity control, normally part of the external control, is exercised to ascertain that a particular service or function has been carried out in accordance with specifications.

The frequency and intensity of control depend on the consequences ensuing from mistakes and errors in the various stages of construction (Cl. 7.3). These stages (Cl. 7.4) may be distinguished as

- Control of the design
- Control of the production and construction
- Control of the completed structure.

Control of design (7.5 shall conform with appropriate CEC or National Administrative procedures (Cl. 7.5)
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Control of production and construction (Cl. 7.6) comprises all measures necessary to maintain and regulate the quality of the materials and of the workmanship in conformity with specified requirements. It naturally involves inspections, tests and assessment of test results (Cl. 7.6.1). Its objectives (Cl. 7.6.2 – Table 7.2) are shown in Table 9.

Controls (Cl. 7.6.3) include initial tests and checking procedures such as a check that the intended structure can be constructed satisfactorily using the proposed materials, equipment and construction methods (Cl. 7.6.4). Checks during construction include (Cl. 7.6.5) general requirements (Cl. 7.6.5.1):

- A permanent system of verification as to dimensions, properties of materials and equipment.
- The checking, upon arrival on site of all materials and components with the terms of the original order
- The filing of written reports on important findings, best kept in the site journal. The latter shall also contain the relevant information on concrete (as defined in ENV 206 Section 10.3) as well as the following minimum information :

- time required for each operation (e.g. placing concrete; removal of formwork
- delivery of construction materials and components
- the results of tests and measurements
- observations and measurements on the position of rebars and tendons
- description of extraordinary occurrences.

Clause 7.6.5 also lists the requirements for compliance control at delivery to the site (Cl. 7.6.5.2) covering delivery notes (for ready mixed as per Section 10.3.2 of ENV 206) and pre-cast units as well as delivery tickets for reinforcement and the information to be included therein. The same clause also lists controls prior to concreting (ENV 206 – Section 11.2.3) and during prestressing .

In clause 7.6.6 the Code defines conformity control as the combination of actions and decisions to be taken in order to verify that all requirements, criteria and conditions laid down previously are met completely which in turn implies completing relevant documentation for all materials.

Clause 7.7 deals with the control and maintenance of the completed structure which requires that a planned control programme should specify the inspections to be carried out in service where long term compliance with the basic requirements for the project is not adequately ensured It also specifies the requirement for all relevant information for the structure's utilisation in service and its maintenance should be passed to the whoever becomes responsible.

The handbook to CP114:1957 first emphasized the great importance to be attributed to the protection of the reinforcement especially in concrete exposed to the weather through an adequate cover of good quality, well compacted concrete. Both B.S. 110 and BS 8110 quantified this recommendation, introduced the idea of exposure classes and laid the first emphasis on quality control. EC 2, following the experience gained, developments in materials, and the wider use of concrete for a variety of functions under very diverse environmental conditions, has further developed theses concepts. It has gone a step further in answering the question 'Good – but will it last?' The answer lies in proper attention at the design and construction stage to the five 'Cs', namely constituents, cover, compaction curing and control.

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