# Points to Ponder in Specifying Concrete and Designing of Pile and Shallow Foundations

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## Abstract

*Correct practice is the dominant characteristic of a successful structural design. The approach and use of the correct and relevant references are the main factors to be considered by the designer. In this paper, the use of the BS 8500-1:2015+A1:2016 and BS EN 197 are discussed in detail with special reference to specifying concrete and cement/cement combinations, the durability of structures, and limitations of chloride content. In addition, the pile foundation design aspect for seismic consideration and the method of evaluating the minimum depth of excavation for the foundation are discussed in detail.*

## 1. Introduction

Carrying out structural design correctly following the relevant guidelines and directives stipulated in the standards is one of the responsibilities of the structural engineer. Being well aware of design and construction practices, guidelines and specifications relevant to the structural analysis, design, and detail is a must to complete a project successfully.

During the design stage, it is required to consider the durability of the structure, fire rating, material specifications, applicable laws, the performance of the structure, etc. The important aspects that a structural designer should be aware of are discussed in this paper.

- Classification of Cement BS 8500-1:2015+A1:2016
- Selection of Grade of Concrete according to BS 8500-1:2015+A1:2016
- Maximum chloride ion content
- Vital Facts in Pile foundation design
- How to calculate the depth of excavation of footings

## 2. Classification of Cement

Specification, performance, production, and conformity of the concrete would be in accordance with BS EN 206 [1]. The relevant standards to be referred to in connection with this standard to carry out design according to the Eurocode 2 are indicated in Figure 1. Accordingly, BS EN 197 [2] is to be referred for compliance requirements of the cement in addition to BS EN 206.

BS EN 197 provides a comprehensive guideline on the type of cement to be used in the construction depending on the different applications. According to BS EN 197-1:2011, there are five types of cement categories namely CEM I, CEM II, CEM III, CEM IV and CEM V under which it specifies 27 types of cement. The combination of clinker with one of the additives such as blast furnace slag, silica fume, pozzolana, fly ash, burnt shale and limestone are done to produce 27 types of cement/cement combinations.

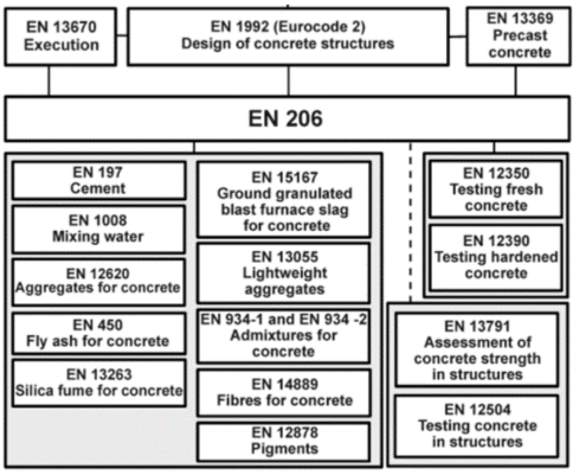


Figure 1: Relevant Standards to be referred connection with BS EN 206 (BS EN 206)

BS 8500-1:2015+A1:2016 Concrete-Complementary British Standard to BS EN 206, Part 1: Method of specifying and guidance for the specifier [3] has further developed the classification of the cement in line with the selection of the grade of concrete, water cement ratio, and minimum cement, etc. Based on the exposure class, cover to the reinforcement and design life of the structure is selected to comply with the durability requirements. The cement type CEM V is no longer used in this standard; however, most of the cement types are included in this standard and it appears that no

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significant change from the BS EN 197.

## 3. Selection of Concrete Grade

The grade of the concrete represents the ability of structures to stand against the applied loads, compatibility with the durability requirements, satisfy serviceability requirements, fire resistance, etc. In old design codes, the selection of the concrete strength class was done with more emphasis on the strength and serviceability requirements. However, with the experience gathered after following the guidelines/design standards for many years, it has now changed the method of specifying the concrete for reinforced concrete structures. Today the main concern in specifying the concrete is connected with the durability of concrete and the design life.

Accordingly, the exposure classes, aggressive chemical environment for concrete exposure class, cover to the reinforcement, cement/cement combination type, water cement ratio, and minimum cement content are required to be considered together in selecting the grade of concrete. This process makes sure the structure meets the durability requirements. In addition to this, depending on the applied loads or induced stresses in the structure, the selection of a suitable grade of concrete can be done while comparing it with the grade of concrete selected to meet the durability aspects.

*3.1 Exposure Classes*

Eurocode 2, as well as BS 8500-1:2015+A1:2016, specifies seven exposure conditions that the structure would be subjected. The corrosion induced by carbonation, chlorides, freeze-thaw attack, and chemical attack is included in the exposure conditions. Firstly, the selection of the applicable exposure class shall be done.

*3.2 Chemical Attack*

Structures built on the aggressive ground can be subject to chemical attack if preventive measures such as the selection of suitable concrete including the specifying suitable cement/cement combination are not being taken.

Table A.2 of BS 8500-1:2015+A1:2016 classifies the aggressive chemical environment for concrete exposure classes (ACEC class) based on the Sulfate, Magnesium and pH values of water/soil samples or groundwater. Depending on the ACEC class, a concrete design class can be selected referring to Table A.10 and A.12.

*3.3 Design Life*

The purpose of constructing the structure and the degree of importance are considered in determining the design life. Generally, the buildings are designed for 50 years and the structures such as dams, long-spanning bridges, etc. are designed for 100-120 years. Since the design life is directly related to the durability of concrete, suitable concrete having the cement/cement combinations shall be selected in accordance with Table A.4 and A.5 of BS 8500-1:2015+A1:2016.

*3.4 Steps to be Followed in Specifying Concrete*

The basic procedure to be followed in determining the concrete grade and relevant parameters are discussed herein in accordance with BS EN 8500-1:2015+A1:2016. Figure 2 indicates the overall procedure that could be followed when specifying the concrete. Some of the important steps are as follows.

- Find the applicable exposure class from Table A.1
- Check the applicable aggressive chemical environment for concrete exposure class from Table A.2 based on the sulfate and magnesium content and pH value.
- Find the minimum cover to the reinforcement as per the requirements of bonding of steel, fire resistance, and rebar detailing requirements. The requirement of cover depending on the durability considerations can be decided when the grade of concrete is selected.
- Refer to the Table A.4 and A.5 to find the grade of concrete, maximum water-cement ratio, minimum cement/cement combination content for normal weight concrete based on the design life, maximum aggregate size (20mm), and nominal cover to the reinforcement and exposure class. Tables A.4 and A.5 specify the concrete based on the cement/cement combination and its classification is given in Table A.6 according to the cement type with limiting values of additives such as fly ash, ground granulated blast furnace slag, limestone, and silica fume.
- Table A.12 and other applicable tables shall also be referred to obtain the cement/cement combination to comply with ACEC class and shall be compared with the cement and cement combination obtained from Table A.4 and A.5 to select the most suitable concrete grade.

In addition to the above, for maximum water-cement ratio and minimum cement content for the maximum aggregate size other than 20 mm is to be obtained from the Table A.7. Limiting values of composition for unreinforced concrete in contact with seawater (exposure class XAS) and cement and combination types shall be in accordance with Table A.13. Designers shall not solely depend on the process indicated in Figure 2 and relevant Clauses of in connection with specifying the concrete shall be referred in the same and other standards.

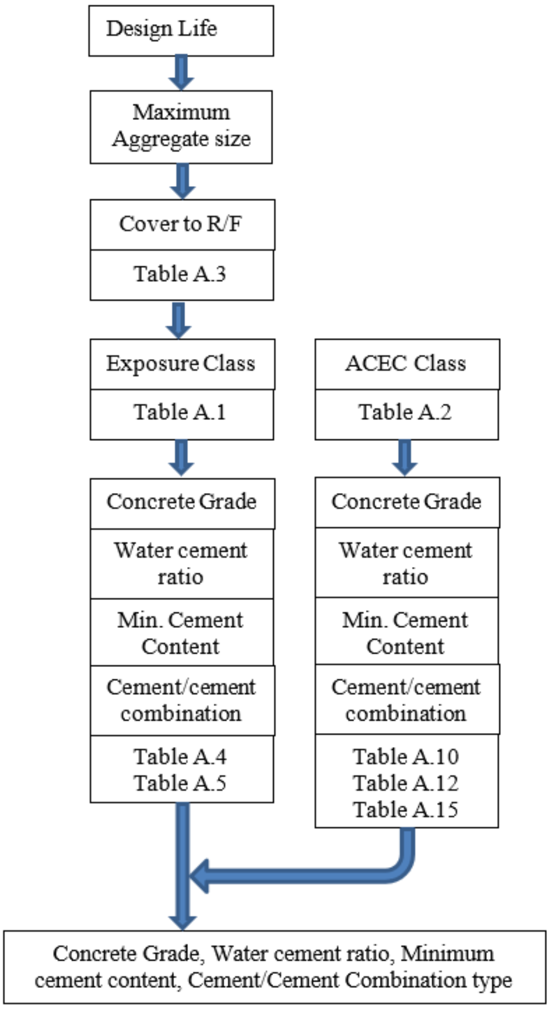


Figure 2: Steps in specifying concrete as per BS 8500-1:2015+A1:2016

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## 4. Maximum Chloride Ion Content

Reaching chloride to the reinforcement together with Oxygen causes corrosion of reinforcement, and cracks are the commonly identified cause of Chloride diffusion in concrete. Micro cracks having a width of about 0.024 mm have been recorded facilitating the penetration of the Chloride and observed that the rate of penetration decreased with the increase of crack width. Due to the self-healing and obstructions made with the formation of the rust, impacts of the micro-cracks on the corrosion of the reinforcements are not significant.

However, a crack within the range of 0.06 - 0.08 mm can be considered critical and a further increase in the crack width can adversely affect the durability of the structure. Research studies are yet to be done to confirm the impact of the crack width and depth on the Chloride induce corrosion. A recent study by A. Poursaee and B. Ross [4] reveals that 64% of the research considered for their study have found the crack width has an impact on the chloride diffusion in the concrete whereas 36% of studies have reported that the influence of the crack width and depth of the crack can be disregarded. Therefore, there is certainly doubt that needs to be clarified with further research as there is no firm justification. Since it is well-known fact that chlorides induce corrosion, taking necessary steps to avoid corrosion if the structure has to be built in a chloride environment is a must. In addition, it appears that the corrosion of the reinforcement is significant when the width of the crack is around 0.2 mm or greater.

A considerable variation in the specified limiting crack width in the different codes of practice was not observed. Specifying different crack widths could be due to the exposure conditions of that particular country and as per the findings from the local research. Table 1 indicates the specified crack width for Eurocode 2, BS 8110 and ACI code.

Table 1: Comparison of crack widths

| Code | Exposure condition | Crack width (mm) |
|---|---|---|
| Eurocode 2 | All exposure classes except X0 and XC1 | 0.30 |
| | Exposure class X0 and XC1 | 0.40 |
| BS 8110 | No risk of corrosion | 0.40 |
| | Water retaining structures | 0.10/0.20 |
| | All other conditions | 0.30 |
| ACI committee 224 | Water retaining structures | 0.10 |
| | Contact with seawater | 0.15 |
| | Humidity, moist air, soil | 0.30 |
| | Dry air or protective membrane | 0.41 |

While limiting the crack width to control the corrosion of the reinforcement due to environmental impacts, it is a must to have a certain limitation on the content of Chlorides within the concrete. Water used for the mixing of concrete and curing, admixtures, and cement may have a certain percentage of chloride that is eventually added into the concrete mix could lead to corrosion of reinforcement with the presence of Oxygen at the reinforcement. BS 8500-1:2015+A1:2016 (Table A.8) specifies the allowable percentage of maximum Chloride ion content based on the mass of cement or cement combinations as indicated in Table 2.

The content of chloride allowed for non-heat cured concrete for different exposure conditions and types of concrete such as mass concrete, reinforced concrete, pre-tensioned and pre-stressed concrete shall be as per the relevant code of practices and project specification. According to BS 8500-1:2015+A1:2016, in reinforced concrete structures, it is required to limit the content of chloride in the range of 0.3-0.4 % by mass of cement or cement combination depending on the exposure condition. In the standard, no limitations have been made based on the type of cement or the type of structure to be constructed.

Table 2: Maximum Chloride Ion Content

| Concrete use | Maximum Chloride ion content (% mass of cement or combination) |
|---|---|
| Pre-tensioned and pre-stressed concrete | 0.10 |
| Reinforced concrete structures not exposed to a significant amount of external chlorides (Exposure classes XS or XD) | 0.30 |
| Reinforced concrete structures subjected to XC exposure classes | 0.40 |
| Post-tensioned concrete structures subjected to XC1 exposure classes | 0.10/0.20 |
| Unreinforced Concrete | 1.00 |

## 5. Vital Facts to Consider in Pile Foundation Design

Having awareness on of the condition of soils that the piles are driven or constructed is very important especially when they are constructed in an earthquake-prone area having the risk of soil liquefaction, and reduction in soil stiffness than that of anticipated in the design. Piles may be subjected to buckling failures due to the loss of the lateral restrain with the reduction of soil stiffness and may be subjected to shear and bending failures when there are soil layers that could undergo liquefaction. Therefore, having found all the properties of the soil other than evaluating the soil stiffness with the Cone Penetration Test (CPT) or Standard Penetration Test (SPT) at the time of pile foundation design would avoid the risk of failure of foundation in an exceptional event.

Mostly the bucking of the piles causes the failure in addition to the additional shear stresses developed in the pile with the liquefaction effects. Special attention shall be made by the designers when selecting the effective height of the piles.

*5.1 Axial Response of Pile*

Variation of the axial load of a pile due to the changes in the soil strata seems not been considered in some of the designs. Excessive increases in the pile axial forces could lead to excessive settlement of the pile foundation or may be subjected to severe structural hazards.

- Lateral and vertical movement of the ground induced by a seismic event could cause the settlement of soil to develop negative skin friction. Compressible soils are more susceptible to occurring failures of this nature.
- The pile friction on the soil is developed by the horizontal effective stress between the pile and the soil. There could be possibilities of reducing the effective stress of the soil with the increase in the pore water pressure due to an earthquake. It would lead to reducing the pile geotechnical capacity causing the safety margin of the pile to a lower level.

*5.2 Pile Buckling*

Phenomenon such as soil liquefaction causes the loss of the lateral support on the pile. Though the pile designs are done to resist buckling failures, the following suggestions are made by Harry G. Poulos in his book Tall Building Foundations [5].

- The ratio between pile axial load and critical buckling load is to be limited to about 1/3 to have a safer margin for buckling failures.
- Slenderness ratio of the pile within the buckling zone shall be less than 50 for avoiding buckling instability. The slender ratio is denoted by SR = L/(I/A)0.5, where L is the effective pile length within the liquefiable layer, I is the minimum moment of inertia and A is the pile cross-sectional area.

*5.3 Correct Estimation of Soil Lateral Stiffness*

During the modeling, the correct estimation of the soil lateral stiffness is very important to assess the pile-soil interaction. Depending on the lateral stiffness of the soil, lateral deformation of the pile head, bending and shear forces developed will be varying significantly. There are different methods to model the piles and the method given in the book Foundation Analysis and Design [6] is used most of the time. The soil can be represented by the modulus of the subgrade reaction during the modeling of the pile and the average end area formula can be used to model the piles.

$$K_i = \frac{BL}{6}\left(2k_{s,i} + k_{s,i-1}\right) \; or \; \frac{BL}{6}\left(2k_{s,i} + k_{s,i+1}\right)$$

$$k_s = \frac{E_s}{B(1-\nu^2)}$$

$$E_s = 650N$$

The above equations would be used to estimate the soil subgrade reaction to model the piles in the conventional method or software having the facility to model the soil on its own could also be used.

## 6. How to Calculate Depth of Excavation of Footings

There is a rule to follow when figuring out the depth excavation for the foundation, and it cannot be done by looking at the state of soil because it's linked to many other variables. The following are some crucial factors that must be taken into account while deciding where to place the footing.

- Adequate bearing capacity of soil
- Minimum settlement of the foundation
- Impact of the groundwater table on design and construction
- Free from organic matters

The minimum depth to be excavated to place the foundation can be calculated from Rankin's formula.

$$D = \frac{P}{\gamma}\left[\frac{1 - sin\theta}{1 + sin\theta}\right]^2$$

Where D is the depth of footing, P is the applied pressure of allowable bearing capacity of the soil, γ is the density of soil and θ is the angle of repose.

Both the allowable soil bearing capacity and the applied soil pressure can be used to calculate the minimum excavation depth of footings. The applied pressure could be used to calculate the excavation depth as it will give a low depth when compared to the excavation depth calculated considering the allowable pressure. In addition, the calculated minimum depth is to be checked with other key aspects discussed in this paper when finalizing the excavation depth of the foundations.

## 7. References

[1] BS EN 206:2013: Concrete – Specification, performance, production and conformity, British Standards, UK, 2014.

[2] BS EN 197-1:2011: Cement, Part1: Composition, specifications, and conformity criteria for common cements, British Standards, UK, 2011

[3] BS 8500-1-20015+A1:2016: Concrete – Complementary British Standard to BS EN 206, Part 1: Method of specifying and guidance for the specifier, British Standards Institution, London, UK, 2016

[4] A. Poursaee and B. Ross, "The Role of Cracks in Chloride-Induced Corrosion of Carbon Steel in Concrete-Review," Journal Corrosion and materials degradation, no. 3, pp. 258-269, June 2022.

[5] H.G. Poulos, Tall Building Foundation Design, CRC Press, 2017.

[6] J. E. Bowles, Foundation Analysis and Design, 5th ed. The McGraw-Hill Companies, Inc. 1997.