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Appraisal and Repair of Existing Concrete Structures

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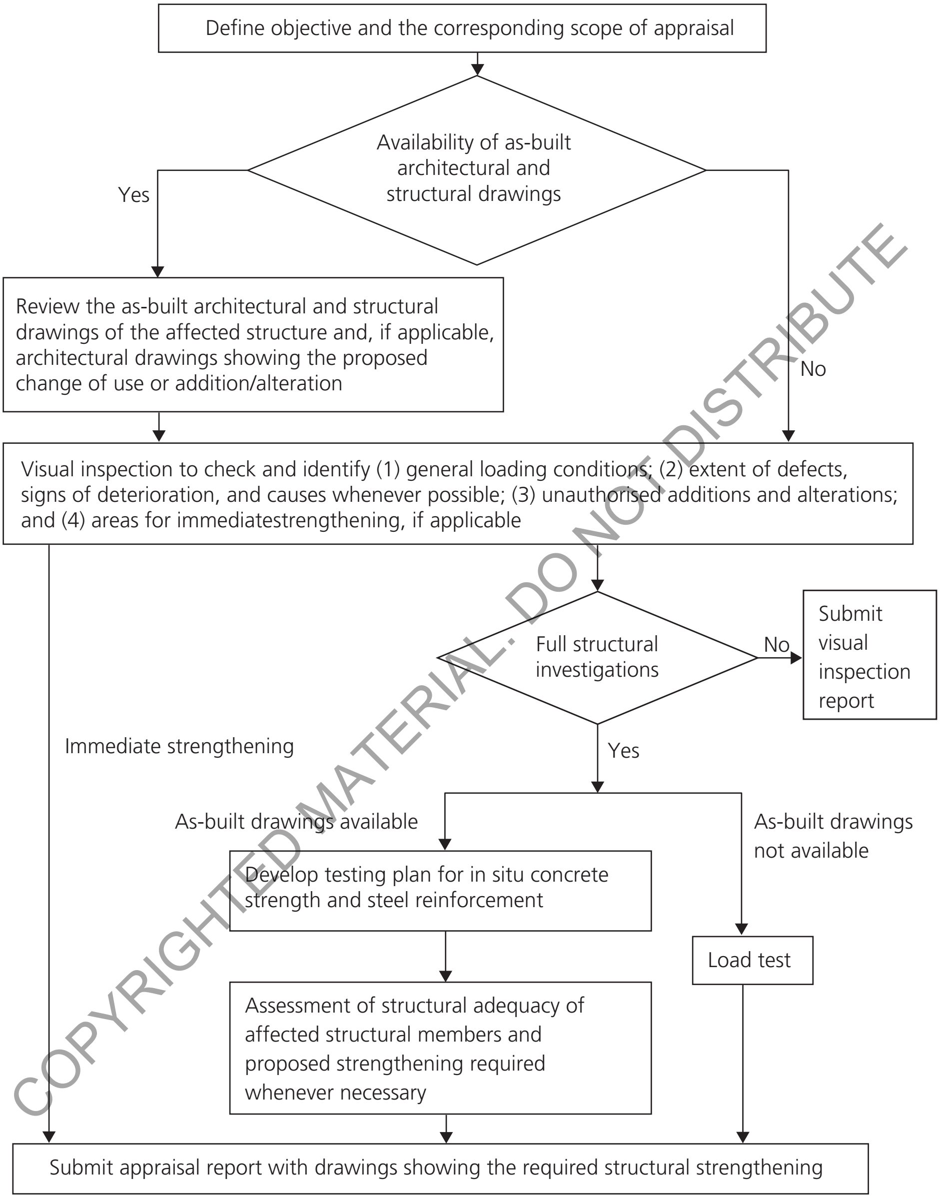
Figure 1.1 Stages of structural appraisal of existing concrete structures



If the as-built structural drawings are not available, one of the other methods to appraise the existing structure is to load test its structure. This approach is best illustrated in the case study reported by Kog (1989), discussed in Chapter 11. A fuller discussion of the load testing of existing concrete structures is presented in Chapter 11. Another possible method of appraisal is to reconstruct the structural drawings by site measurement of various dimensions and steel reinforcement bars used in the construction. However, this will be very costly.

characteristics of the concrete. This form of deterioration is detected during the visual inspection. Scaling severity is rated on the basis of the depth of its defect, categorised as follows:

- Light scaling does not expose any coarse aggregate.
- Moderate scaling is approximately up to 3 to 10 mm in depth from the surface and exposes some coarse aggregates.
- Severe scaling has an even larger depth of flaking in which the coarse aggregates become very noticeable and there may be some mortar loss surrounding the aggregate.
- Very severe scaling is greater than 20 mm in depth, with the loss of coarse aggregate particles, surface mortar and surrounding aggregate.

Table 3.2 summarises the common defects for different causes and their ages of appearance. Information on the types of defect and their ages of appearance provides some useful hints on the probable cause of the defects. Tables 3.1 and 3.2 are useful to identify the cause of the defects recorded during the visual inspection.

3.3. Types of cracks

Cracking of concrete is common in some reinforced concrete structures. Engineers need to determine the extent and severity of cracks. Two parameters are often used by engineers to characterise cracks, namely crack width and crack depth. Preliminary evaluation of existing surface cracks is normally done during the visual inspection of structures. A crack on the surface of concrete is normally measured using a crack gauge, as shown in Figure 3.7. Depending on the width of cracks on the surface, cracks can be categorised as follows: a fine crack of less than 1 mm, a medium crack of 1 to 2 mm, and a wide crack greater than 2 mm. In terms of depth of crack, there are three categories as follows: on the surface,

Table 3.2 Common defects appearing in existing concrete structures for different causes (after Higgins, 1981)

Cause	Defects			Age of appearance	
	Cracking	Spalling	Erosion	Early	Long term
Structural deficiency	X	X		X	X
Reinforcement corrosion	X	X			X
Chemical attack	X	X	X		X
Frost damage	X	X	X	X	
Fire damage	X	X		X	
Internal reactions	X	X			X
Thermal effects	X	X		X	X
Shrinkage	X			X	X
Creep	X	X			X
Rapid drying	X			X	
Plastic settlement	X			X	
Physical damage	X	X		X	X

ICE Publishing

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ISBN 978-0-7277-6693-9
https://doi.org/10.1680/arecs.66939.083

Chapter 6

Estimating the in situ strength of existing concrete structures

Abstract

For the structural adequacy assessment of existing concrete structures, one of the most important tasks is to estimate f_{ck} of the existing concrete structures. A series of NDTs and core tests on the existing structure have to be carried out to estimate the in situ compressive strength of concrete. The in situ compressive strength, f_{ck}, of existing concrete structures can be estimated using a lower and upper bounds approach using a combination of the rebound hammer test or Windsor probe test and UPV test or core test. In the lower and upper bounds approach, a bias factor for the core test and each of the NDTs is needed to account for the overestimation of characteristic in situ compressive strength by rebound hammer test and Windsor probe test and underestimation of characteristic in situ compressive strength by UPV test and core test. Ranges of each of these bias factors have been derived from in situ concrete testing results of 34 existing concrete structures aged 4 to 73 years. Illustrative examples of using this lower and upper bounds approach to estimate f_{ck} of existing concrete structures are presented.

6.1. Introduction

For the structural adequacy assessment of existing concrete structures, one important task is to estimate f_{ck} of the existing concrete structures by carrying out a series of NDTs and core tests on the existing structure in accordance with BS EN 13791 (BSI, 2007a) and BS 6089 (BSI, 2010). These NDTs are the Windsor probe test in accordance with ASTM C803/C803M-18 (ASTM, 2018c), the pull-out test in accordance with BS 1881-207 (BSI, 2020a) and EN 12504-3 (BSI, 2005a), the rebound hammer test in accordance with BS 1881-207 (BSI, 2020a) and BS EN 12504-2 (BSI, 2012b), and UPV test in accordance with BS EN 12504-4 (BSI, 2004a). BS 6089 (BSI, 2010: p. 18) stated that 'the confidence with which it is possible to assess in-situ strength of concrete increases with the number of assessments made'.

In situ compressive strength of concrete structures can be estimated using the calibrated indirect method (Windsor probe, UPV and rebound hammer test) or cores in accordance with BS EN 13791 (BSI, 2007a). A correlation relationship between the Windsor probe, UPV or rebound hammer test and core test is required when the Windsor probe, UPV or rebound hammer test is used. For assessing in situ strength of concrete in a structural element, core tests are the most direct method according to BS 6089 (BSI, 2010). BS EN 13791 (BSI, 2007a) requires that a specific correlation relationship between the core test results and the test results by Windsor probe, UPV or rebound hammer test be based on at least 18 pairs of test results. The 18 pairs of test results mean 18 core test results and 18 NDT results, covering the range of interest. A pair of test results is a core test result and the corresponding Windsor probe, UPV or rebound hammer test result from the same test location. According to BS EN 13791 (BSI, 2007a), the in situ compressive strength of existing concrete structures can also be estimated from an established correlation relationship between core and Windsor probe, UPV or rebound hammer test results.

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ISBN 978-0-7277-6693-9
https://doi.org/10.1680/arecs.66939.121

Chapter 9
Testing plan for the durability assessment of existing concrete structures

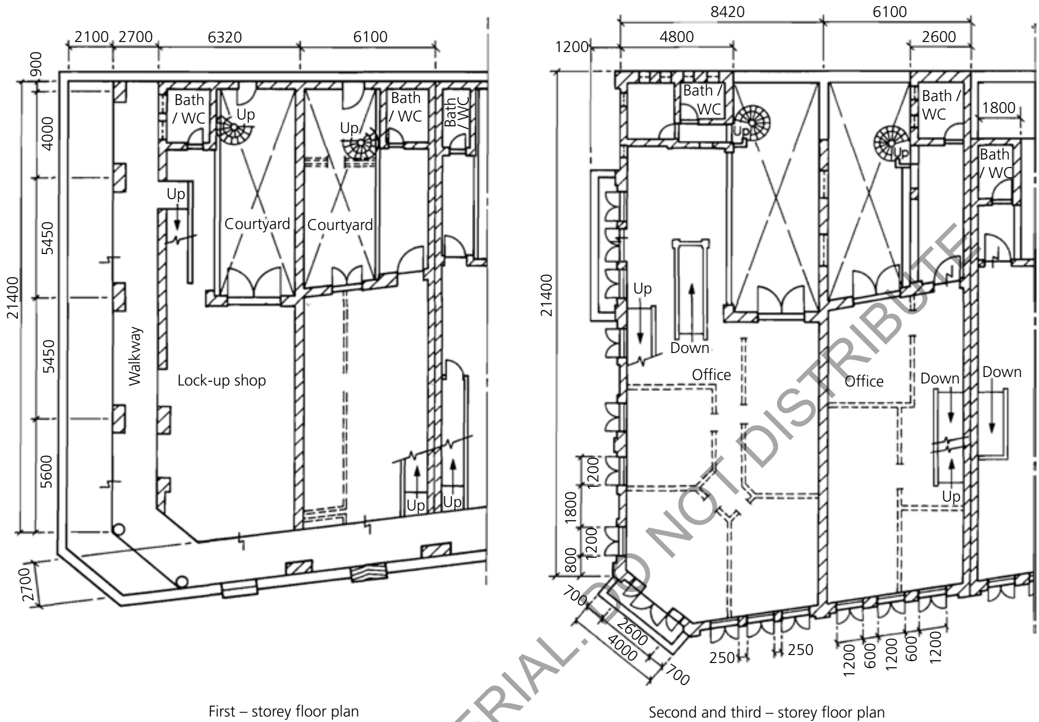
Abstract
The durability assessment is an essential component in the appraisal process of existing concrete structures. Different nominal design lives for various categories of structure are recommended in codes of practice. The difference between the nominal service life and the actual service life of the existing structure will be discussed. The conditions of the existing concrete structure to be appraised have to be determined from visual inspection and a testing plan for various in situ tests. The various issues, such as the types of test, the number and locations of the tests, will be discussed.

9.1. Introduction
Beside the structural adequacy assessment, the durability assessment is an essential component in the appraisal process of existing concrete structures. Durability is concerned with the duration over which the existing concrete structure will be serviceable with routine servicing and maintenance. Buildings, bridges and other infrastructural projects are designed to serve for different intended periods, depending on the owner's and developer's requirements. Consequently, durability has become one of the most important requirements for concrete structures. The durability of a concrete structure is characterised as its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration that will adversely affect the service performance of the concrete structure. A proper understanding of the deterioration agents and mechanisms causing concrete deterioration is essential for the durability assessment of existing concrete structures.

The durability assessment starts with gathering all necessary information on the condition of the existing concrete structure from visual inspection and in situ concrete testing. From signs of defects and deterioration observed during visual inspection, the probable causes of deterioration can be identified using Concrete Society (2000) so that appropriate in situ concrete testing can be selected. A testing plan can then be drawn up for the durability assessment of the existing concrete structure that includes types of in situ concrete test, number of tests required for each type of in situ test, and their test locations. An illustrative example of the testing plan for a durability assessment is presented in Appendix A.

9.2. Nominal design life and actual service life
The nominal design life (or nominal design service life) of a concrete structure is the period of use when the structure remains fit for purpose with routine servicing and maintenance, as intended by the design engineer. It is of interest to note that the design lives of BS EN 1990 (BSI, 2002a), UK National Annex for Eurocode 0 (BSI, 2002d) and BS 1881-124 (BSI, 2015a), as summarised in Tables 9.1, 9.2 and 9.3, respectively, are generally consistent, albeit they differ slightly.

Figure 11.1 First, second and third storey of the existing three-storey building (after Kog, 1989)



11.2. Approach to the appraisal

The design and details of the concrete structure must satisfy ultimate and serviceability limit states, as well as other requirements pertaining to durability, fatigue (for cyclical imposed load) and fire resistance. The ultimate limit state encompasses the considerations for structural stability, robustness and the effects of special hazards, while the serviceability limit state considers the effects of temperature, creep, shrinkage, sway, settlement, deflection, cracking, response to wind load, vibration and cyclic loading, as appropriate.

Existing structures must comply with the limit states and other requirements that apply to new structures, according to the latest codes of practice. Therefore, the appraisal of the existing concrete building was carried out in accordance with BS 8110-1 (BSI, 1985a) for the ultimate and serviceability limit states and requirements for the durability and fire resistance. Fatigue appraisal was not thought to be necessary because the imposed load due to the structure's use as offices is not cyclical in nature.

11.3. Load tests of an existing concrete building

As explained earlier, a load test and several visual inspections for the whole three-storey building and the foundations had to be carried out in accordance with BS 8110 (BSI, 1985a and 1985b), which was the most current code then, to comply with the ultimate and serviceability limit states. The visual inspections were performed before, during and after the load test.