Methodology for Calculating Life Expectancy of Existing Concrete Structures

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ABSTRACT

A study was conducted on four reinforced concrete buildings built in the desert region in one of the Arabian Gulf states in the late seventies to mid eighties to assess the remaining life expectancy of these buildings. Testing included core sampling, CAPO semi-destructive testing, half-cell potential measurements, cover meter, dust sampling analysis, water penetration measurements, cement content, cement type and carbonation depth evaluation.

A modification of the BS-ISO 15686 -1:2000 (Ref.1) equation for the life expectancy is presented to incorporate the role of the dominant variables in the estimation of the life expectancy of the four buildings.

Keywords : Reinforced concrete buildings, Life expectancy, Core sampling, Capo test, Half-cell potential test, Concrete cover, Dust sampling, Water permeability, Depth of carbonation penetration.

طريقة لإحتساب العمر الإفتراضي المتبقي للمنشآت الخرسانية القائمة

الخلاصة

يقدم البحث، و لأول مرة ، طريقة لإحتساب العمر الإفتراضي المتبقي لأربع بنايات مصنوعة من الخرسانة المسلحة والتي بُنيت في الفترة بين أواخر السبعينات الى منتصف الثمانينات من القرن الماضي في بيئة صحراوية في الخليج العربي. شملت الدراسة إستخدام نتائج فحوصات مختبرية لنماذج الفحص الإتلافي و فحص الكابو النصف إتلافي و فحص خلايا الجهد النصفي الكهربائي و فحوصات تقدير الغطاء الكونكريتي و الفحص الكيمياوي لغبار الخرسانة لتحديد نسب الأملاح و فحص نفاذية الماء في الخرسانة و فحص يحديد نوع الأسمنت و فحص النفاذ الكربوني.
يقدم البحث ولأول مرة طرق كمية لثوابت معادلة الكود البريطاني (ذات الطبيعة الوصفية)-BS ISO 15686 – 1 : 2000 لتحديد العمر الإفتراضي المتبقي للمنشآت الخرسانية القائمة بإستخدام النتائج المختبرية وصولاً الى تحديد العمر الإفتراضي المتبقي لها.

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INTRODUCTION

Structures, in general, undergo the process of aging. Concrete structures are highly susceptible to this process and it is becoming increasingly important to address the adverse effects of aging on concrete structures. Structural codes have been developed for new design, but they are often not appropriate for assessment since there are significant differences between design and assessment. This necessitates the need for technical rules for the structural integrity assessment of existing structures. An assignment was received to conduct structural integrity assessment on four reinforced concrete buildings which were built in the late seventies to mid-eighties in an oil production compound in an arid desert location in the Arabian Gulf Area. An anonymous reference shall be given to these buildings as buildings A1, A2, A3 & A4.

OBJECTIVE OF THIS STUDY

The objective of this paper is to provide new quantitative tools via which an evaluation of the remaining life expectancy of existing concrete structures may be achieved.

VISUAL SURVEY OF THE BUILDINGS

1) Building A1: this building consists of ground and first floor concrete frame building. It covers 44 X 13 m^2 area. Columns are spaced 7.2m apart longitudinally and 5.1 m transversely with slabs resting on beams.

The interior of building shows all the walls and staircases are very sound. No cracks were seen anywhere. Inspection of ground floor rooms showed no signs of deterioration in terms of cracking or spalling of concrete.

Roof and first floor slab show no cracks. All the columns are sound, no signs of cracks or deflection. External staircase is in a very good condition.

2) Building A2: this building is made of ground plus two floors reinforced concrete frame structure. Hollow pot slabs supported on pier walls on strip floorings. The walls are spaced 4.6m center to center.

The building was renovated in the recent past. All the plaster, paint and aluminum windows are in good condition.

Floor tiles are in medium condition. Walls do not show any signs of cracking or spalling of plaster. Door frames and false ceiling are reasonably good. Staircases are in good condition.

3) Building A3: this is a single storey steel gable frame with a reinforced concrete two storey attachment. Gable frame portion used for the training lab, measuring 18.2 m X 24 m and is approximately 6 m high. Roofing panels are made of gypsum boards with corrugated sheet cladding and is in poor condition with many roof water leakage stains.

Partitioning walls in this part are made of brick and woodwork and are all in a bad shape. Wall panels sandwich plate are in deteriorated condition.

The office building part is made of reinforced concrete 12.2m X 18m. It is recently renovated. Office portion showing good floor condition. Staircase does not show any sign of distress.

4) Building A4: This building consists of ground floor with a first floor covering part of the ground floor. The total built up area is approximately 2300m^2. It has concrete frame structure with columns spaced 4.6m transversely and longitudinally. The staircases are showing no signs of cracking or spalling of concrete. Wooden door frames are deteriorated and there are cracks visible around door frames. Main beams on the first floor do not show cracks or spalling of plaster or paint.

Significant spalling of concrete was witnessed in one of the rooms with ample rusting of the reinforcement visible to the eye. Rusting has gone through the reinforcement completely, presenting a hazardous situation to the occupants.

TESTING PROGRAM

British standard 7543 (Ref.2) provisions name the causes of deterioration of buildings to be due to the action of weathering, biological infestation, stress accumulation, chemical interactions, physical interaction and normal usage.

A test program was designed and carried out on the four buildings employing the following tests:

i. concrete coring:
   a. Visual inspection depicts grading honeycomb cracks and internal voids.
   b. Compressive strength.

ii. Half Cell Potential Survey to indicate the active reinforcement corrosion status.

iii. Dust samples for testing of ingress of chloride and sulphate ions at three incremental depths namely, (20, 40 & 60 mm) in the structural element.

iv. The depth of carbonation of concrete members is measured on exposed surfaces with the help of chemical indicator which changes its color as the pH value rises above 9.

v. Cover meter survey to determine the cover of reinforcement

vi. Opening of windows on columns and walls to verify reinforcement placing and corrosion status.

vii. CAPO Test: This is a Cut and Pull-Out test that is performed on the concrete face of a structural member. The actual pull-out force is related to the cube strength of the concrete.

viii. Cement content and type: These tests were carried out to determine the cement content in Kg/m^3 and the type of cement used.

ix. Water penetration test: This test is carried out to determinate the water penetration of concrete used. The BS 8110 and ACI 318 codes (Refs.3 &4) give various concrete cover values for various elements. These usually vary from 25 – 75mm depending on the location of the reinforced concrete elements.

Test Results:

Table (1) Test Results – 1.

Building	Core compressive strength tests	Half cell measurement	Capo tests

	No. of Tests	Result Range (N/mm^2)	%age of readings indicating no corrosion	%age of readings indicating uncertain corrosion status	%age of readings indicating definite corrosion status	No. of tests	Results Range N/mm^2
Building A1	**11**	**27.5-55.5**	**5**	**45**	**50**	**7**	**35.5-51.4**
Building A2	**30**	**10.5-51.5**	**2**	**17**	**81**	**37**	**18.9-38.7**
Building A3	**11**	**15.5-62**	**16**	**52**	**32**	**5**	**33.5-42.4**
Building A4	**21**	**11-49**	**3**	**49**	**48**	**3**	**16.8-18.2**

Table (2) Test Results – 2.

Building	Dust sample survey		Water penetration (mm)	Cement type	Cover meter		Carbonation depth	
	Average chloride ingress in %age	Average Sulphate ingress in %age			No. of Tests	Range if cover thickness (mm)	No. of Tests	Average value (mm)
Building A1	**0.42**	**< 4.0**	**145**	**OPC**	**18**	**48-80**	**18**	**15**
Building A2	**0.36**	**< 4.0**	**82-105**	**OPC**	**64**	**39-80**	**64**	**15**
Building A3	**0.39**	**< 4.0**	**62**	**OPC**	**16**	**44-80**	**16**	**13**
Building A4	**0.38**	**< 4.0**	**-**	**-**	**22**	**33-80**	**22**	**16**

LIFE EXPECTANCY EVALUATION

The form of the equation reported in the BS-IOS 15686- 1:2000 (Ref.1) is adopted here with an application pertinent to the evaluation of the deterioration parameters as follows:-

$$(ESLB)=(DLB)\ (A \times B \times C) \qquad \dots (1)$$

where :

ESLB = Expected Service Life of the Building

DLB = Design Life of the Building

A= Factor describing chloride ingress

$$B = \frac{B_1 + B_2}{2}$$

B_1 = Factor describing carbonation status.

B_2= Factor related to corrosion status of reinforcement bars.

C= Factor describing sulphate ingress in the concrete.

The form of equation (1) given by the BS-ISO 15686-1:2000 is of a qualitative nature, this paper presents quantitative means of actual evaluation leading to the estimation of the expected remaining life (in years) of concrete buildings.

Evaluation of the factors in Eqn (1) introduced in this research.

1) Factor A : This factor is given the following values:

A= 1 for the maximum allowable ingress of 0.3% as per CIRIA special Publication 31: Guide to Concrete Construction in the Gulf Region (Ref.5).

= 0.9 for ingress values between 0.31 – 0.4 %
= 0.8 for ingress values between 0.41 – 0.5 %
Then an averaging is done for these values to provide the value for factor A.
2) Factor B: This factor is the average of B_1 and B_2.
B_1: Carbonation factor was evaluated on the concept of the role of steel reinforcement protection of the value of 20 % and 80 % for the role of the concrete cover. The depth of carbonation penetration as obtained from test results averaged over the number of tests.
B_2 : Half Cell Potential Factor : This is obtained by giving a value of (1) for tests that show greater than 90 % probability of no corrosion, (0.6) for tests results of uncertain corrosion and (0.2) for test results of more than 90% probability of corrosion. These values are multiplied by their corresponding weighting factors of occurrence.
$B_2 = W_1 (1) + W_2 (0.6) + W_3 (0.2)$
Finally $B = \frac{B_1+B_2}{2}$
3) Factor C : This is the sulphate ingress given a value of (1) for sulfate content of 4% or less. The value of C shall be reduced by 10% for each increment of 1% above the limit of 4% for the sulphate content.
This procedure was employed to evaluate the percentage deterioration for the four buildings and Table (3) shows the final results.
Finally the remaining life expectancy is determined by the following equation.
Remaining life expectancy of a building (RLEB)

(RLEB) = (ESLB) – (Building Actual Age) ….. (2)

Table (3) Quantification of Factors A, B, C.

Building	Factor A Chloride ingress	Factor B Corrosion factors	Factor C	Assumed Design Life years (DLB)	ESLB Eqn. (1)	Actual age of building (years)	Expected remaining life (years)
Building A1	0.8	0.62	1.0	50	25	20	5
Building A 2	0.9	0.53	1.0	50	24	22	2
Building A 3	0.9	0.69	1.0	50	31	24	7
Building A 4	0.9	0.61	1.0	45	25	24	1

DISCUSSION AND CONCLUSIONS

The issue of estimating the remaining useful service life of a concrete structure is a very important tool to assist the decision on the fate of a certain building. A reasonably reliable assessment of the remaining service life will certainly play a dominant role on the decision of whether to demolish or to rehabilitate a certain building.

An attempt is forwarded in this study to quantify the remaining useful service life of concrete buildings based on test results to estimate the dominant factors affecting the integrity of reinforced concrete structures namely, the chloride ingress, the depth of carbonation, the corrosion status of the reinforcing bars and the sulphate ingress.

The number of tests and their locations was chosen carefully so as to enhance the credibility of the final result as much as possible. This was reflected by concentrating on the foundations and the main structural supporting elements which were decided upon based on their failure role in triggering a global failure mechanism.

Table (3) shows that the influence of corrosion of reinforcement is a prime factor in reducing the life expectancy of concrete structures and accelerating the process of their aging. Furthermore, the chloride ingress is more evident and consequently plays stronger role in affecting the aging process.

REFERENCES

[1].BS – ISO 15686 – 1: 2000, Building and Constructed Assets. Service Life Planning. General Principles, Nov. 2000.

[2].B.S. 7543: 2003 – Guide to Durability of Buildings and Building Elements, Causes and Deterioration of Buildings, Jul. 2003.

[3].B.S. 8110 – 1: 1997, Code of Practice for the Structural Use of Concrete in Buildings.

[4].ACI 318M – 08, American Building Code Requirements for Structural concrete and commentary.

[5].CIRIA – 2002, C577, ISBN 978 -0-946691-93-7, Publication 31, A Guide to the Reinforced Concrete Construction in the Arabian Gulf Region.