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Technical Note: APPLICATION OF DECISION THEORY BASED CRITERIA FOR STRUCTURAL APPRAISAL OF A BUILDING DURING CONSTRUCTION

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Abstract

In the earlier paper, a simple probabilistic model was formulated to predict the reliability of concrete in a structure during construction, a case study of laboratory block for College of Continuing Education, University of Port Harcourt, Rivers State. In this paper, the reliability of the structure is predicted using decision theory based criteria as a tool. The net probability of failure of the structure after assessment was 1.4898E-3 which exceeded the target value of probability of failure of 3.931E -6 for slabs, 4.78E-7 for beams in flexure, 1.591E-4 for beams in shear and 4.8E-5 for columns subjected to both dead and live-load combination.[1] Showing that the structure is not safe and can result in uncommon accidents to persons and damage to properties on collapse.

Keywords: probabilistic model, decision theory based criteria, target value, uncommon accidents, collapse

1. Introduction

Structural assessment of partially completed or existing buildings may be needed when there is concern about some aspect of the design or construction, including the quality of the construction materials used such as suspicion of low strength concrete in concrete slabs, beams or columns[2]. The appraisal of structural integrity of a building should be seen as a frequent task as the performance of a structure in service is a function of human intervention at every stage of the building process. This enhances the structural quality [3-7]. The appraisal of structural integrity of a building during construction has become a more frequent task for engineers both now and in the future due to increasing risk of failure during and after construction. There can be indications of ongoing deterioration in the structure during and after construction and this is a common reason for reliability assessment [8-9].

The reliability assessment of a building not only at the design stage but during construction is a necessity rather than sitting back until failure occurs resulting in the collapse of structures [10]. Wilkinson [11], in his research, discovered that the recognition of the risk magnitude would result in the determination and implementation of measures that will reduce the risk or reduce the effect of the loss or both optimally.

The use of conventional factors of safety in the design models cannot guarantee structural safety because uncertainties that occur in structural loadings. As a result of the inherent variability in most of design parameters, the concept of probability becomes a useful tool. Although the probabilistic concept may not provide answers to all issues of unknown in the design equations, it has played a very useful role in the reliability assessment of many engineering systems [12-13]. The strength as a basic variable is assumed randomly and stochastically. The reliability of concrete in the structure is assessed in terms of reliability index.

This paper highlights the application of decision-theory based criteria in the reliability assessment of a building during construction. The decision theory logic is straightforward and not mathematically cumbersome.

2. Model Derivation

Let X represents the basic variable, μ_x true coefficient of variation of X. $\overline{X}$ = mean of sample, $\overline{\delta}_x$ = coefficient of variation of sample. $\overline{X}$ and $\overline{\delta}_x$ are determined from data collected under carefully controlled conditions. $\overline{\delta}_x$ determines the inherent variability. Let the bias and coefficient of variation of uncertainties be given by $\overline{M}$ and $\overline{\delta}_x$. Then μ_x and $\overline{\delta}_x$ are obtained from the expressions:

$$\mu_x = \overline{M}\,\overline{X} \tag{1}$$

$$\delta_x = \sqrt{\bar{\overline{\delta}}_x^2 + \bar{\overline{\delta}}_M^2} \tag{2}$$

For n factors,

$$\delta_M = \sqrt{\delta_1^2 + \delta_2^2 + \ldots + \delta_n^2} \tag{3}$$

Let y represent the cube strength of concrete and X represent the concrete strength in structure. According to BS8110 [14],

$$\mu_x = 0.67\mu_y$$

Where: μ_x, μ_y = mean value of concrete strength in structure and mean value of cube strength of concrete, respectively.

(4)

To cater for uncertainties involves in testing procedure (δ_{test}) and in-situ variation of concrete strength ($\delta_{in-situ}$), the coefficient of variation of concrete strength using equation (3) can be given as:

$$\delta_x = \sqrt{\delta_y^2 + \delta_{test}^2 + \delta_{in-situ}^2} \tag{5}$$

According to Ranganathan [1],

$$\delta_{test} = \delta_{in-situ} = 0.10 \tag{6}$$

Using Equation (6), equation (5) now transforms to:

$$\delta_x = \sqrt{\delta_y^2 + 0.125} \tag{7}$$

The value of δ_y is a function of the design mix. Equation (7) represents the net variation in concrete strength.

The safety of a structure is jeopardized when the stress developed in the ith structural member exceeds the allowable stress. Therefore, the probability of failure of an ith structural member can be given as:

$$P_{fi} = P(X_i < f_a) \tag{8}$$

Where; X_i and f_a represent random variables representing the strength or resistance of the ith structural member and allowable stress of concrete in compression respectively.

According to BS8110 [14],

$$f_a = 0.34 f_{cu} \tag{9}$$

X is assumed to be normally distributed, therefore,

$$P_{fi} = \varphi\left(\frac{f_a - \mu_x}{\delta_x}\right) \tag{10}$$

Where; P_f = posteriori probability of failure which represents the probability of failure obtained after reliability assessment of a structure.

Let c_{fail} represent the algebraic sum of direct costs of failure which would be associated with the structure and c_{new} represent the estimated cost of building a new structure if the existing structure were to fail. According to Melchers [15], the expected cost for leaving the structure unchanged is given by:

$$C_1 = (c_{fail} + c_{new})P_f \tag{11}$$

Let

$$P_f \gg P_{fT} \tag{12}$$

Therefore, the existing structure is demolished and rebuilt. Where; P_{fT} = target or code specified value of probability of failure.

Using equation (12), the expected total cost for demolition and rebuilding a deteriorated structure is given by:

$$C_2 = C_{dem} + C_{new} + (C_{fail} + C_{new})P_{fT} \tag{13}$$

But

$$C_{dem} \gg C_{new} \tag{14}$$

Equation (13) now transforms to:

$$C_2 = C_{new} + (C_{fail} + C_{new})P_{fT} \tag{15}$$

Simplification of inequality $C_2 > C_1$ gives:

$$C_{new} + (C_{fail} + C_{new})P_{fT} > (C_{fail} + C_{new})P_f \tag{16}$$

Dividing both sides of equation (16) by $(C_{fail} + C_{new})$ transforms equation (16) to:

$$\frac{C_{new}}{C_{fail} + C_{new}} + P_{fT} > P_f \tag{17}$$

or

$$P_f - \frac{C_{new}}{C_{fail} + C_{new}} < P_{fT} \tag{18}$$

or

$$P_f - \frac{1}{1 + \frac{C_{fail}}{C_{new}}} < P_{fT} \tag{19}$$

Equation (19) is now the decision rule for demolition of a deteriorated structure and rebuilding of a new one, therefore will be given by:

$$P_f - \frac{1}{(1 + C_{fail})/C_{new}} \geq P_{fT} \tag{20}$$

According to CIRIA [16], the ratio $\frac{C_{fail}}{C_{new}}$ is of the order of $10^4 - -10^6$ with an average value of 5.05×10^6.

Table 2: Stochastic model [1].

Variable	**Mix**	**Specified strength**	**Mean**	**Std deviation**	**COV (%)**	**Probability distribution**	**Quality control**
Gibe strength	Grade 15	15	17.56	2.69	15.33	Normal	Design mix

Table 1: Results of non-destructive test on concrete [2].

S/No	**Location**	**Rebound Hammer readings**	**Average Rebound**	**Concrete Strength from Rebound Test (y)**
1	Middle panel	23,23	23	18
2	Edge panel	23,23	23	18
3	Beam 2	20,20	20	14
4	Slab 2	24,24	24	20
5	Slab 1	18, 19	19	8
6	Beam 1	12,12	12	5
7	Staircase	23.3, 19	21.2	15
8	Middle column	35,27	31	29
9	Corner column	27,27	27	2.5
10	Column footing	12.5,6	9	4

3. Results and Discussion

From Table 2, $\mu_y = 17.56\text{N/mm}^2$, $\sigma_y = 2.69\text{N/mm}^2$ and $\delta_y = 15.33\% = 0.1533$. Using equation (7),

$$\delta_x = \sqrt{0.1533^2 + 0.125} = 0.19$$

From equation (4),

$$\mu_x = 0.67\mu_y = 0.67 \times 17.56 = 11.76\text{N/mm}^2$$

$$\sigma_x = 0.67\delta_y = 0.67 \times 0.19 \times 17.56 = 2.24\text{N/mm}^2$$

$(\sigma_y = \delta_y \times \mu_y)$

Using equation (9),

$$f_a = 0.34 f_{cu} = 0.34 \times 15 = 5.10\text{N/mm}^2$$

From equation (10), the probability of failure of concrete is structure is:

$$P_f = \varphi\left(\frac{5.10 - 11.76}{2.24}\right) = \varphi(-2.97) = 1.49 \times 10^{-3}$$

The decision for demolition and rebuilding of a new structure is now made using equation (20):

$$1.49 \times 10^{-3} - \frac{1}{1 + 5.05 \times 10^6} = 1.4898 \times 10^{-3}$$

According to Ranganatan [1],

$$P_{fT} \text{ for slabs} = 3.391E - 6$$

P_{fT} for beams in flexure = 4.78E-7, P_{fT} for beams in shear = 1.591E-4, P_{fT} for columns under dead and live load = 4.8E-5. The calculated value of $P_f - \frac{1}{1+\frac{C_{fail}}{C_{new}}}$ exceeds P_{fT} value for slabs, beams is flexure, beams in shear and columns under dead and live-load combination implying demolition of existing structure and rebuilding of a new one.

4. Conclusion

The results of reliability-based decision model as a tool for structural appraisal of a building during construction has been presented. Using decision theory based criteria, the net value of probability of failure of the structure after assessment was 1.4898E-3 which exceeded the target value of probability of failure of 3.391E-6 for slabs, 4.78E-7 for beams in flexure, 1.591E-4 for beams in shear and 4.8E-5 for columns subjected to both dead and live-load combination [1] showing that the structure is not safe and stands the risk of serious injury to persons and damage to properties.

The structure should be carefully demolished and rebuilt. A more competent engineer should be considered for this demolition and re-construction and supervision should be more stringent.

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