PAPER • OPEN ACCESS

Reliability analysis of reinforced concrete beam using varying properties

View the article online for updates and enhancements.

Reliability analysis of reinforced concrete beam using varying properties

O J Aladegboye[1], D A Opeyemi[2], O D Atoyebi[1, 3], S L Akingbonmire[3] and E M Ibitogbe[1]

[1]Department of Civil Engineering, Landmark University, Omu Aran. Kwara State. Nigeria

[2]Department of Civil Engineering, Ondo State University of Science and Technology, Okitipupa. Ondo State. Nigeria

[3]Department of Civil Engineering, Federal University of Technology, Akure. Ondo State. Nigeria

Corresponding Author; atoyebi.olumoyewa@lmu.edu.ng

Abstract. In this article, the reliability analysis data of simply supported reinforced concrete beams are presented. Beams are structural elements that are very important in all kinds of structures namely high rise buildings, frame structures, load bearing buildings, timber structures and farm structures. The investigation was done using first order reliability method (FORM) with varying parameters such as depth, length and characteristic concrete strength. The safety index and probability of failure from the reliability of the simply supported beam with varying properties was given. The result of the model investigated shows that the formal deterministic way of measuring safety such as in factor of safety and load factor failed to put into consideration uncertainties in design like depth, length, characteristic strength etc. and therefore not consistent.

1.   Introduction

Beams are structural elements made to withstand loads that can cause bending and they are always identified using parameters like its length, material and cross-sectional shape. Structural design is tailored towards building structures that satisfy serviceability, safety as well as durability criteria under certain service conditions [1,2]. Uncertainties has become an inherent feature that must be considered in engineering design [3]. Reliability analysis is a modern good way to handle and treat uncertainties in engineering design [4–6]. Reinforced concrete (RC) structures are highly durable but their performances, serviceability and safety are constantly faced with actions during their operational life. The importance of the assessment and evaluation of reinforced concrete structural elements for the design of structural systems in relation to safety and functionality cannot be overemphasized [7].

Deterministic methods are mostly influenced and not determined using systematic assessment of reliability while been assessed in the entire structure [8]. These methods create irregularities in engineering design which culminates into either inadequate design or over-design. Additional costs incurred in the course of this irregularities does not necessarily contribute to the overall reliability of the structure [9]. Civil engineering is therefore growing in interest to fully adopt reliability design methods to ensure a balance design which will be more reliable and cost effective. The method can also be used

to better evaluate the various sources of failure and use the data acquired to develop design that is insensitive to variations in materials, construction techniques and environment.

2. Methodology
Singly reinforced concrete beams having different properties which include length, depth and characteristic strength were cast to determine their reliability. Varying dimensions of beams were cast having different lengths and depths while characteristic strength was also varied. The Safety index (β) and Probability of failure (pf) for the various beams were determined using reliability of analysis. Reliability analysis of simply supported reinforced concrete beam was investigated using first order reliability method (FORM). A stochastic model was developed and properties like depth, length and characteristic strength was varied.

3. Result and discussions
Table 1 shows the stochastic model for singly reinforced concrete beam. Table 2, 3 and 4 gives the reliability data for beam using varying depth, length and characteristic strength respectively while Table 5 presents the reliability data and chart respectively for beam using varying characteristic strength of concrete and depth. Table 6 gives the reliability results for beam using varying characteristic strength of concrete and length. The result of the model investigated shows that the formal deterministic way of measuring safety such as in factor of safety and load factor which are deterministic approach failed to put into consideration some uncertainties in design and therefore not consistent.

Table 1. Stochastic Model for Singly Reinforced Concrete Beam.

I	Xi	Pdf	X	V	$6r = x.V$
1	Fcu	LN	$30 \times 10^{-3} \, KN/m^2$	0.15	4.5×10^3
2	B	N	$300 \times 10^{-3} m$	0.06	2.16×10^{-2}
3	D	N	$550 \times 10^{-3} m$	0.06	3.3×10^{-2}
4	L	N	$6m$	0.06	3.6×10^{-1}
5	G	LN	$40 KN/m^2$	0.15	6.0×10^1
6	Q	LN	$12 KN/m^2$	0.15	6.8×10^1

3.1. Varying Depth
Table 2 shows that the safety index increases alongside increment in the depth and the probability failure decreases which connotes that the higher the depth of the beam, the safer it becomes but with increase in cost of materials.

Table 2. Reliability Results for Beam using Varying Depth.

Depth d (mm)	Safety Index (β)	Probability of Failure (pf)
194	-7.080	1
269	-4.590	1
417	-1.249	0.894
565	1.073	0.142

| 715 | 2.859 | 0.212×10^{-2} |

3.2. Varying Length

The length of the beam was varied from 2 m to 10 m and the safety index decreases as the length increases, this also causes increment in the probability of failure as can be seen from table 3; this implies that the shorter the length of beam is, the safer it is and increase in length increases failure tendency.

Table 3. Reliability Results for Beam using Varying Length.

Length L(m)	Safety Index (β)	Probability of Failure (pf)
2	8.943	0.193×10^{-18}
4	3.935	1.416×10^{-4}
6	0.867	0.193
8	-1.332	0.909
10	-3.038	0.999

3.3. Varying Characteristic Strength

The characteristic strength is directly proportional to the safety index as presented in table 4 and the probability of failure remains constant.

Table 4. Reliability Results for Beam using Varying Characteristic Strength of Concrete.

Characteristic Strength Fcu (KN/m^2)	Safety Index (β)	Probability of Failure (pf)
20	-16.157	1.00
25	-16.092	1.00
30	-16.033	1.00
35	-15.979	1.00
40	-15.927	1.00

3.4. Varying Characteristic Strength and Depth

An increment in both the characteristic strength and depth (Table 5) causes a decrease in the safety index and a constant whole number 1.0 as the probability of failure. This shows that it is not safe and economical with a certain tendency of failure.

Table 5. Reliability Results for Beam using varying Characteristic Strength of Concrete and Depth.

Characteristic Strength Fcu (KN/m^2)	Depth d (mm)	Safety Index (β)	Probability of Failure (pf)
20	194	-16.493	1.00
25	269	-16.395	1.00

30	417	-16.195	1.00
35	565	-15.958	1.00
40	715	-15.675	1.00

3.5. Varying Characteristic Strength and Length

From table 6, the characteristic strength of concrete (Fcu) and the length was varied together and it was discovered that the safety index decrease down the table negatively and with a constant probability of failure 1.00, this implies that the structure is not safe and economical.

Table 6. Reliability Results for Beam using Varying Characteristic Strength of Concrete and Length.

Characteristic Strength Fcu (KN/m^2)	Length l (m)	Safety Index (β)	Probability of Failure (pf)
20	2	-14.926	1.00
25	4	-15.775	1.00
30	6	-16.033	1.00
35	8	-16.161	1.00
40	10	-16.238	1.00

4.   Conclusion

Deterministic approach has been proved to be with imperfections in cost and safety. It should therefore be totally replaced with new probabilistic approach as it takes into detail consideration all uncertainties that could result to failure during the usable life span of the structure.

References

[1] Grubiši M, Ivoševi J, Carlo M. Reliability Analysis of Reinforced Concrete Frame 2019:1–22. doi:10.3390/buildings9050119.
[2] Atoyebi O D and Sadiq O M 2018 Experimental data on flexural strength of reinforced concrete elements with waste glass particles as partial replacement for fine aggregate *Data Br* **18** 846–59. doi:https://doi.org/10.1016/j.dib.2018.03.104.
[3] Huang C, Hami A El and Radi B 2016 Overview of Structural Reliability Analysis Methods — Part I: Local Reliability Methods *Open Sci* **10** 1-10 doi:10.21494/iste.op.2017.0115
[4] Afolayan J O and Opeyemi D A 2008 Reliability Analysis of Static Pile Capacity of Concrete in Cohesive and Cohesionless Soils *Res J Appl Sci* **3** 407–11.
[5] Atoyebi O D, Afolayan J O and Arum C 2019 Analyses and Interpretations of Structural Health Monitoring Data on Reinforced Concrete Buildings: A Critical Review *J Eng Appl Sci* **14** 9657–66.
[6] Atoyebi OD, Ayanrinde OP, Oluwafemi J 2019 Reliability Comparison of Schmidt Rebound Hammer as a Non-Destructive Test with Compressive Strength Tests for different Concrete Mix. *J Phys Conf Ser* **1378**. doi:10.1088/1742-6596/1378/3/032096.
[7] Kamal H A, Assakkaf I A, Karam H J and Al-enezi N O 2014 Reliability assessment of existing reinforced concrete structures *Proc. Int. Congress of Materials and Structural Stability* Rabat,

    Morrocco

[7] Akindahunsi A A and Afolayan J O 2009 Developed Reliability Based Interaction Curves for Design of Reinforced Concrete Columns *J Theorectical Appl Mech* **47** 943–55.

[8] Adewumi O J, Oluwatuyi O and Afolayan J 2017 Reliability assessment of BS 8110 (1997) ultimate limit state design requirements for reinforced concrete columns *Jordan Journal of Civil Eng.* **11** 3 512-4