

Comparison of Reliability Based Design (RBD) With Eurocode 2 for A Singly Reinforced Concrete Beam

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ABSTRACT

This research compares the Reliability-Based Design (RBD) method with the Eurocode 2 (EC2) for a singly reinforced concrete beam. Advanced First Order Second Moment (AFOSM) was used and the equation for the ultimate limit state design consideration for Moment of resistance and Applied moment was applied. The parameters which were all functions of the Ultimate load, G were replaced respectively with variables and their derivatives $G(x)$ obtained with being the characteristic strengths of concrete and the yield stress of steel respectively. Given the original vector space and the transformed reduced vector space, the Taylor series was used to expand the reduced vector space and thus reliability index β_x expressed. The procedure was then coded using JAVA to produce the Reliability Index and Probability of failure for respective steel ratio. The required probability index of 3.9 corresponds to 0.048% of the steel ratio. Typical analysis of a singly reinforced beam according to EC2 for $b=300\text{mm}$, $h=500\text{mm}$, $d=447\text{mm}$, cover of 40 mm, gave a steel ratio of 1.31 %. Comparing this to the reliability-based design of 0.048%, the code provision exceeded the RBD output by 2000 times and 63 times the minimum reinforcement requirement by the code.

Keywords: Reliability Based Design (RBD), Advanced First Order Second Moment (AFOSM), First Order Reliability Method (FORM), Eurocode 2 (EC2).

INTRODUCTION

Civil engineering structures such as bridges, buildings, power plants, dams, and offshore platforms are projected to contribute to the aids and value of life. Therefore, such amenities must be planned to be economically effective and realize the necessities with respect to safety [1]. In structural design, functional and structural requirements must be satisfied respectively. A structure must be able to perform its intended purposes (functional) and also must be able to withstand all the imposed load applied on it (structural) i.e. safely transmits all the load from the topmost down to the foundation without appreciable settlement.

Such structures must also satisfy other requirements like the ability to withstand vibration, cracking, thermal resistance, and exposure to attacks and must also maintain adequate appearance throughout its life span. The aforementioned are states which structures reach before they are declared unfit for use. The idea is to ensure that those limits are not reached at all. Hence, Limit states design concept focuses on the acceptable probability that a structure will not be declared unfit for use throughout its lifespan by satisfying certain

design criteria based on probability theory. i.e. (Normal Probability Distribution)

Two limits states exist which are the ultimate limit state (ULS) and Serviceability limit state (SLS). ULS deals with shear and bending from loading while SLS deals with appearance, exposure condition, vibration, cracking, thermal resistance, deflection and durability.

ULS uses factor of safety for loads and material strengths due to several design and construction uncertainties, errors, constraints, and variations etc. According to John (2004), design failures of structures could arise if the Ultimate Limit States, Conditional Limit States and Serviceability Limit State are not accurately measured in the process of structural design.

The ultimate limit states relate to the maximum load-carrying capacity which can be associated with the development of an instrument in the structure, extreme plasticity, breaking owing to fatigue, and instability (buckling) [2]. The provisional limit states relate to the load-carrying capacity if a local part of the structure has collapsed, and this can be instigated by unintentional act or fire. While the serviceability limit states relate to the ordinary use of the

structure such as unwarranted deflection, local damage, and extreme vibrations.

For countless years, loads used in the design of structural components have constantly been expected to be deterministic; this notion permits the engineer to govern the strength of a member by multiplying the load applied to the structure with a satisfactory brim often stated as a factor of safety.

This factor of safety is commonly measured to be an actual degree of determining the consistency of the structure and differs depending on the code of practice being adopted. Since variations are existing in engineering design built on this deterministic method, integration of uncertainties in engineering design is usually essential. The reliability-based design process offers a hypothetical background for considering uncertainties in the engineering result structure [3]. Owing to these uncertainties, John (2004) observed that it is tough to measure the complete safety of a structure using deterministic investigation.

A recent study has revealed that poor performance of structures is as a result of the uncertainties in the loads' estimate, inadequate evaluation of the strengths of materials, exposure condition variability and poor modeling of the systems, poor workmanship, poor project supervision during construction and also natural effects such as seismicity, etc. These variabilities in recent times have led to the continual failure of structures globally.

Reliability-based design has constituted the foundation of safety assessment in current engineering projects. There is a necessity to balance safety, serviceability, and economy in our immediate environment when designing structures, safety being of dominant importance.

There are allowances for some insecure and unwanted performances in a genuine state which is reserved as total safety because it necessitates a massive sum of properties and statistics which may not be accessible. The Probabilistic method to structural safety has been a rising debate and focus matter in recent years, and the procedures used in the investigation and design have been developed. Various researchers have investigated the concept of Reliability-Based Design (RBD) in engineering particularly in the field of civil engineering.

According to John (2004), reliability is considered as the possibility that the structure

under reflection has an appropriate performance during its entire lifespan.

Reliability is defined reliability as the probability that a structure or system can accomplish an obligatory purpose under a definite service state through a specified period and equally, the failure probability is the probability that a structure does not perform suitably within an agreed period [4].

Reliability is the likelihood that a structure can be used without collapse for a specific period, under definite functioning situations [5].

Reliability is the probability that a structure can accomplish under definite service state throughout a period, they opined that reliability can be accessed by the possibility of the structure in the safe domain P_s and that the corresponding probability is the Failure Probability P_f . They Resolved that

$$P_s + P_f = 1 \dots\dots\dots (1)$$

LITERATURE REVIEW

According to [6], reliability is the probability of an element executing its intended purpose over a specified period under functioning settings met. Structural Reliability is defined as a measure of the ability of the structure to function, or be capable of accomplishing a required purpose without collapse under a quantified condition for a definite period on unit of action [7].

Basic Random Variables, Limit State Functions and Reliability Index are the three elementary expressions governing Reliability study.

Input uncertain variables that oversee the efficacy of the structure are the Basic Random Variables and are used to establish mathematical prototype to produce the efficiency of the structure [8].

According to [9], Limit State Function was expressed as the state of a structure beyond which it no longer satisfies the pertinent standard of its performance. The Limit State equation is generally characterized by the expression:

$$G(x) = R - S \dots\dots\dots (2)$$

Where R is the resistance of the structure or member, S is the load applied on the structure and G(x) is known as the Limit State Function or Performance Function. R and S are also known as the Basic Random Variables governing the failure Modes. According to Huang et al. (2016), Reliability Index is the value used to denote the safe working of the

structure gotten from the solution of the Limit State equation. Cornell Index which has a demerit due to lack of invariance for equivalent performance functions and Hasofer-Lind Index which overpowers this demerit are the two categories of Reliability Index. The Probability of failure is also being assessed together with the reliability index and this is the probability of existence of structural failure.

Hence for a characteristic reliability problem, the performance function is stated as:

$$Z = G(X) = (X_1, X_2, X_3, \dots, X_n) \dots \dots \dots (3)$$

Where $Z = G(X) > 0$ indicates that the structure is in a safe condition and $Z = G(X) < 0$ implies the state of failure.

$X_1, X_2, X_3, \dots, X_n$ are the basic arbitrary variables.

The Reliability Index can be gotten from the expression,

$$\begin{aligned} p_f &= P(Z \leq 0) = \int_{-\infty}^0 f_z(z) dz \\ &= \int_{-\infty}^0 \frac{1}{\sqrt{2\pi}\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{z - \mu_z}{\sigma_z}\right)^2\right] dz \dots \dots \dots (4) \\ &= \Phi\left(-\frac{\mu_z}{\sigma_z}\right) = \Phi(-\beta_c) \end{aligned}$$

Where $\Phi(\cdot)$ is the CDF standard normal distribution, and $\beta_c = \frac{\mu_z}{\sigma_z}$ is the Reliability Index.

The reliability test was performed by [10] on reinforced concrete slabs subjected to failure modes in flexure, shear, and deflection with thickness ranging from 100 mm to 250 mm using First Order Reliability Method (FORM). FORM5 reliability software was used for Continuous slabs of equal span as a case study. For several failure modes, Limit State equations were developed and the results showed that the margins of safety suggested were similar to the probability of failure stated as 1×10^{-6} for singly reinforced concrete slabs according to BS 8110 and EC2 codes. The reliability levels were however not regular showing that the design assumptions were not safe and dependable as suggested. Safety criterium was violated by a reliability design index for 100 mm to 125 mm thick slabs. The probability of failure for bending was only 0.022 and it matched an indirect safety level of 2.015. The conclusion showed that review must be made on the code formulations to conform to accepted structural safety set out by the Joint Committee of Structural Safety (JCSS).

The reliability-based design of reinforced concrete two-way solid slab under Euro code2 was conducted by [11]. Formula Translation (FORTRAN) based program for the reliability design was produced considering suitable variables and designed the reliability index. It was observed that FORM design was more efficient given the steel area required and the final section depth with a reliability index of 3.0.

The structural reliability of a system under fire was examined by [12] putting into consideration the reservations that occur in the system. The structural behavior which was exposed to the realistic fire was assessed by mathematical simulations using Latin Hypercube Simulations, Subset simulations, and the First and Second-Order Reliability Method. Categorizing and describing the input constraints, probabilistic analysis of the thermo-mechanical impacts on the structure, and assessing reliability with suitable limit state functions were the steps adopted in the reliability analysis. Their research pointed out the precision and efficacy as well as the shortcomings.

[13] Examined the 3-D time-dependent reliability analysis of reinforced concrete slab bridges under representative traffic loadings. The 3-D variables for the structural resistance considered were cover, compressive strength, and arbitrary variables including pit depths and model faults. Forecasting the outstanding lifespan of a rusting structure, and the spatial variability related to the material, dimensional, and environmental properties were the areas of focus of study. A two-dimensional random field was produced where the load and time constraints resistance were evaluated for each fraction of the field and the outcome gotten from the reliability analysis showed that the 3-D correlated resistance amounted to a minor increase in the probability of failure.

Reliability-based design of a two-way solid slab about design based on BS 8110 (1997) Part 1: Structural Use of Concrete was performed by [14]. FORM method was adopted for designing the slabs to an expected margin of safety level using a FORTRAN program formed and related to FORM5 reliability software. Both the reliability and deterministic based designs each made an acceptable performance with a typical reliability indexes of 3.20 and 1.48 for Flexure and serviceability respectively. 10% economic design was found using the reliability-based design while the deterministic design resulted in an unacceptable outcome that exposed the

shortfalls in the deterministic design as a result of short-span (Continuous Edge).

The reliability of slender reinforced concrete columns having uniform cross-sections was studied by [15]. The main input constraints used examined were loads, compressive strength, and yield strength of steel, concrete cross-section dimensions, reinforcement ratio, and the position of steel settlement. The analysis was performed with a risk analysis program and the impact of eccentricity on the reliability index of the slender column was observed. The results extracted from the reliability analysis showed that the performance of slender columns is enhanced by good quality control and improves the reliability index of the slender column.

Reliability analysis on an I-section beam profile I 254 (10") x 37.7 with a design strength of MR250 was investigated by [16] using the Monte Carlo method exposed to an applied bending moment. The resolution was to evaluate the constituent stress handling characteristics to precise scheme stress according to the Brazilian setting. An applied bending moment of 83.0kNm was used, expected reliability index was gotten from records of Joint Committee of Structural Safety (JCSS) which were shown in a table in the research work and a value of 3.9 was adopted as the expected reliability index below modest failure modes and this was a constraint for a design working life suggestion of 50years. A probability of failure of 3.2×10^{-5} and a reliability index of 3.98 was generated after performing the analysis using the Monte Carlo technique. Since the attained reliability index was superior to the expected reliability index, the practicality of the beam was established and the constituent was measured to be huge and the structure can be exposed to superior stresses without conceding structural safety and harming the global structure.

[17] studied the structural reliability of reinforced concrete beam and columns under concurrent static loads and steel reinforcement corrosion and it was observed that corrosion in concrete is the main problem adversely affecting the structural lifespan of the structure. The variables considered for the reliability analysis were thickness, dimensions, the strength of materials and reinforcement and the result was obtained based on numerous corrosion models produced after the analysis was performed on a 2D frame at each time to estimate the mass loss of steel reinforcement as a result of corrosion and the prompt load-bearing capacity of each

element was evaluated. It was established from the outcome that the corrosion process impairs negatively on the strength of structural elements drastically.

Reliability analysis on reinforced concrete beams using finite element models under four points bending test was studied by [18]. The first model adopted the SOLID65 component for modeling concrete joining William-Warke and Von Mises criteria, while the second component adopted the SOLID185 element and micro plane philosophy. The steel reinforcement was modeled by LINK180 fundamentals in both scenarios. The models engaged in the reliability analysis of RC beams subjected to various load levels were standardized using investigational outcomes. Based on supreme allowable displacements, a limit state function was assumed. The outcomes gotten from the reliability analysis disclosed that only the micro-plane model was suitable for RC structures since the SOLID65 encountered a lot of difficulties related to convergence.

[19] Investigated reliability analysis on the raft foundation with uniformly random soils causing the randomness in the input variables. The variables examined were the elastic modulus of the raft, modulus of subgrade reaction of the soil, and loading on the raft. Point Estimate Method (PEM), FOSM, and FORM were adopted for the analysis to get the probability of failure and reliability index-linked with the settlement of the raft foundation. It was observed that the reliability index for FORM was lower and dependable than PEM and FOSM. Parametric study indicating changes in modulus of subgrade reactions was also carried out and loadings affected the settlement reliability limit state of the raft the most, while the modulus of elasticity of the raft was discovered to be indifferent to this limit state. Reliability evaluation of reinforced concrete beams with implanted PVC pipes below neutral axis was conducted by [14]. The research was carried out in three phases which were the investigational method, deterministic method, and the reliability analysis. The Reliability approach was carried out using a FORTRAN program link to FORM5 reliability software. Rectangular beams with a number of PVC pipes (one, two, and three) were injected and beams with one, two, and three PVC pipes in accordance with ASTM C 293 standard. The results showed that beams with PVC pipes required more reinforcement to meet the reliability i and one PVC pipe injected achieved

acceptably. While the results gotten from the reliability assessment shown an area of reinforcement of 38.9 % for beams with no PVC and one PVC pipes injected with a reliability index ranging from 3.3 to 4.4 satisfying the criteria of the code.

The reliability evaluation of the Ejigbo Campus Library Building at Osun State University was investigated by [20]. Findings revealed that the

Table 1. Table showing the Tentative Targeted Reliability Indices and associated Failure Rates related to a one-year inference period and Ultimate Limit State.

1	2	3	4
Relative Cost of Safety Measure	Minor Consequences of Failure	Moderate Consequences of Failure	Large consequences of Failure
Large (A)	$\beta = 3.1$ (Pf $\approx 10^{-3}$)	$\beta = 3.3$ (Pf $\approx 5 \times 10^{-4}$)	$\beta = 3.7$ (Pf $\approx 10^{-4}$)
Normal (B)	$\beta = 3.7$ (Pf $\approx 10^{-4}$)	$\beta = 4.2$ (Pf $\approx 10^{-5}$)	$\beta = 4.4$ (Pf $\approx 5 \times 10^{-5}$)
Small (C)	$\beta = 4.2$ (Pf $\approx 10^{-5}$)	$\beta = 4.4$ (Pf $\approx 5 \times 10^{-6}$)	$\beta = 4.7$ (Pf $\approx 10^{-6}$)

Source: Joint Committee of Structural Safety (2000)

The guiding principle stated in the code should be followed in order to make the right selections in the Table 1. Shown above.

METHODOLOGY

The methodology used in this study is the Advanced First Order Second Moment (AFOSM) as detailed in [20]. The ultimate limit state design consideration is given by:

$$G = M_R - M_A \tag{5}$$

Where M_R the Ultimate Moment of resistance and M_A is the applied moment. A safe design stipulates $M_R \geq M_A$.

Hence using the Limit State Equation for bending as stated in EC2 for a singly reinforced rectangular concrete beam in eqn. (1):

$$G(f_{ck}, f_y, b, d, h, \gamma, M_A) = 0.4533 f_{ck} b \left\{ 2.5d - \frac{2.874 M_A}{(f_y \gamma b h)} - M_A \right\} \tag{6}$$

Where, $\gamma A_s b d$ (7)

Let $x_1 = b, x_2 = d, x_3 = h, x_4 = M_A$

Hence, eqn.(2) can be rewritten as

$$G(x_1, x_2, x_3, x_4) = 0.4533 f_{ck} x_1 \left\{ 2.5x_2 - \frac{2.874 x_4}{\gamma f_{ck} x_1 x_3} \right\} - x_4 \tag{8}$$

At the boundary of the design surface where $G = 0$

$$x_4 = - \frac{2.258 f_{ck}^2 \gamma x_1^2 x_2 x_3}{x_1 x_3 \gamma f_{ck} - 1.303} \tag{9}$$

The partial derivatives of $G(x)$ with respect to x

$$\frac{\partial G}{\partial x_1} = 1.13 f_{ck} x_2 \tag{10}$$

university library was in a dreadful situation and was inhabitable. Physical inspection was done at the preliminary stage and it was discovered that the stress distribution in the structural elements was discovered to be 10 % below design strength. Their reliability analysis showed that the safe reliability was on the low side since about 2.2 % of steel ratio was required and only 1.5% was provided.

$$\frac{\partial G}{\partial x_2} = 1.13 f_{ck} x_1 \tag{11}$$

$$\frac{\partial G}{\partial x_3} = \frac{1.3 f_{ck} x_4}{\gamma f_y x_3^2} \tag{12}$$

$$\frac{\partial G}{\partial x_4} = - \left(1 + \frac{1.3 f_{ck}}{\gamma x_1 x_3} \right) \tag{13}$$

If the original vector space is given as $\{x\} = \{x_1, x_2, x_3, x_4\}$ then the transformed reduced vector space

$\{x'\} = \{x'_1, x'_2, x'_3, x'_4\}$ is given by:

$$x'_i = \frac{x_i - \mu}{\sigma} \quad i = 1 \text{ to } 4 \tag{14}$$

The initial values for the original vector space are given by their densities and the last variable is calculated.

$$\begin{aligned} x_1 &= \mu_{x1}, x_2 = \mu_{x2}, x_3 = \mu_{x3} \\ x_4 &= - \frac{2.258 f_{ck}^2 \gamma x_1^2 x_2 x_3}{x_1 x_3 \gamma f_{ck} - 1.303} \end{aligned} \tag{15}$$

Using Taylor series to expand the reduced vector space, then the reliability index β_x can be expressed as follows:

$$\beta_x = [A]^T [x_i'] / \sqrt{[A]^T [A]} \tag{16}$$

Where:

$$[A] = \begin{bmatrix} (\partial g / \partial x_1^i) = (\partial g / \partial x_1) \sigma_{x1} \\ (\partial g / \partial x_2^i) = (\partial g / \partial x_2) \sigma_{x2} \\ (\partial g / \partial x_3^i) = (\partial g / \partial x_3) \sigma_{x3} \\ (\partial g / \partial x_4^i) = (\partial g / \partial x_4) \sigma_{x4} \end{bmatrix}$$

The directional cosine which is the transformation vector $\{\alpha\}$ is given as

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$$\{q_i\} = [A] / \sqrt{([A]^T[A])} \quad (17)$$

Now the reduced vector space $\{x_i\}$ is given as

$$\{x_i\} = \beta_x [q_i] \quad (18)$$

Then we can calculate the original vector space from the reduced vector space using the relationship

$$\{x_i\} = \mu_{x_i} + x_i' \sigma_{x_i} \text{ where } i = 1 \text{ to } 4 \quad (19)$$

The error to converge the iteration is given by

$$\text{Error} = \left| \frac{(\beta_{i+1} - \beta_i)}{\beta_i} \right|$$

The above procedure is coded in Java and the results are discussed in the following section.

RESULTS AND DISCUSSION

The results of the program developed for the reliability index and probability of failure are shown in figures 1 and 2 respectively. It is clear from figure 1 that the required probability index of 3.9 corresponds to 0.048% of the steel ratio. This is far from the minimum reinforcement of 0.13% of the code requirement.

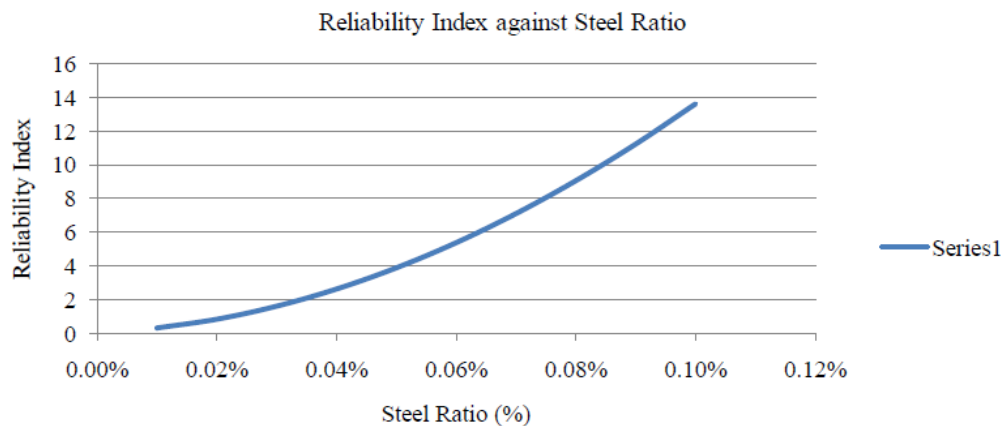


Figure1. Variation of Reliability Index with Steel ratio.

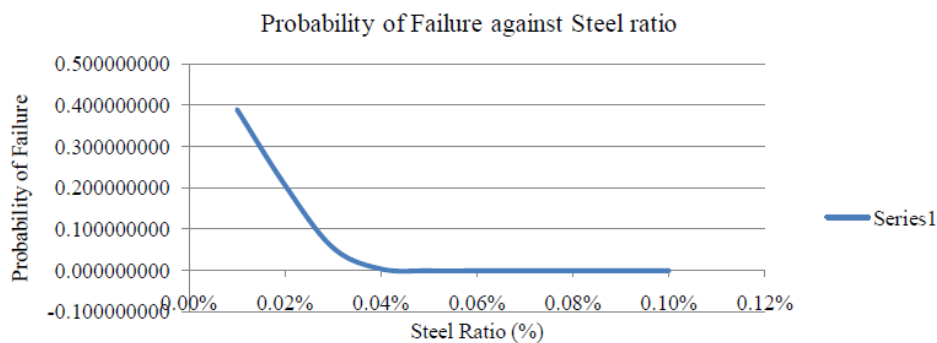


Figure2. Corresponding Probability of failure with increasing steel ratio

For a typical analysis of a singly reinforced beam according to EC2, the steel ratio % can be calculated thus given the following parameters:

Cover to reinforcement = 40 mm

Effective depth, d, is

$$d = h - \text{cover} - \phi/2 = 500 - 40 - 25/2 = 447 \text{ mm}$$

$$K_0 = \frac{M}{f_{ck} b d^2} = \frac{M}{25 * 300 * 447^2} \quad (20)$$

$$z = d \left[\left(0.5 + 0.25 - \frac{k_0}{3.4} \right)^{\frac{1}{2}} \right] \quad (21)$$

$$= 447 \left[0.5 + \left(0.25 - 3 * \frac{M}{3.4 * 25 * 300 * 447^2} \right)^{\frac{1}{2}} \right] \quad (22)$$

$$A_s = \frac{M}{0.87 f_{yk} z} = 1960 \text{ mm}^2 \quad (23)$$

This is about 1.31 % of the steel ratio. Comparing this to the reliability-based design of 0.048 %, the code provision is more than 2000 times the RBD output. Even if we take the minimum to reinforce recommended by the code there is about 63 times the calculated output using EC2 provisions.

CONCLUSION

The Reliability Index increases as the Steel ratio also increases from figure 1 showing the variation of Reliability Index with the steel ratio. The required probability index of 3.9 corresponds to 0.048 % of the steel ratio from

figure 1. This exceeds the minimum reinforcement of 0.13 % of the code requirement. The results obtained from the comparison between the Reliability-Based Design and the Local Design i.e. Euro Code 2 (EC2) clearly show that the Reliability-Based Design is by far more economical than the Local Design using EC2. Therefore, the method of Reliability-Based Design is highly cost-effective compared to the Orthodox design method used since time immemorial.

REFERENCES

- [1] John Dalsgaard Sørensen. (2004). Structural Reliability theory and risk analysis. Institute of Building Technology and Structural Engineering, Aalborg University, Sohngaardsholmsvej, 57, DK-9000 Aalborg, Denmark.
- [2] Bastidas-Arteaga, E. and Soubra, A. H. (2014). Reliability Analysis Methods. ALERT Doctoral School -Stochastic Analysis and Inverse Modeling, 53-77.
- [3] Hsin Yu Low and Hong Hao. (2001). Reliability Analysis of Reinforced Concrete Slabs under Explosive Loading”, School of Civil and Structural Engineering, Nanyang Technological University, Singapore 639798, Singapore, 0167-4730/01/\$ - see front matter Elsevier Science Ltd.
- [4] Lemaire M. Structural reliability. John Wiley & Sons.
- [5] Kassem Fidaa. (2015). Reliability of reinforced concrete structure: case of slab subjected to impact, PHD Thesis, École doctorale: Mécanique, Energétique, Génie Civil, Acoustique.
- [6] Goutham, D. R. and Dr. K. Manjunath. (2016) Reliability Analysis of Grid Floor Slabs. International Research Journal of Engineering and Technology (IRJET), 3(6). E-ISSN: 2395 -0056, www.irjet.net p- ISSN: 2395-0072.
- [7] Wasiu John and S A Raji. (2015). Reliability Based Design of Two-Way Slab in Comparison with Design Based on BS 8110 (1997), Journal of Multidisciplinary Engineering Science and Technology (JMEST), 2(6).ISSN: 31590040.
- [8] Choi, S. K., Grandhi, R. and Canfield, R. A. (2006). Reliability-based structural Design. Springer Science and Business Media.
- [9] El Hami, A. and Radi, B. (2013). Incertitudes, optimization et fiabilité des structures. Hermès science Publications.
- [10] Abejide, O. S. (2014). Reliability Analysis of Bending, Shear and Deflection Criteria of Reinforced Concrete Slabs. Nigerian Journal of Technology (NIJOTECH), 33(3), 394-400. Copyright© Faculty of Engineering, University of Nigeria, Nsukka, ISSN: 1115, www.nijotech.com http://dx.doi.org/10.4314/njt.v33i3.18.
- [11] Abubakar I and Ma’aruf A. 2014. Reliability-Based Design of Reinforced Concrete Two Way Solid Slab using Eurocode2. Nigerian Journal of Technology (NIJOTECH), 33(4) Copyright© Faculty of Engineering, University of Nigeria, Nsukka, ISSN: 1115 http://dx.doi.org/ 10.4314/njt.v33i4.3.
- [12] Guo, Qianru. (2015). Structural Reliability Assessment under Fire. A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Civil Engineering) in the University of Michigan.
- [13] Hajializadeh Donya, Mark G Stewart, Bernard Enright and Eugene O Brien (2015). Spatial Time-Dependent Reliability Analysis of Reinforced Concrete Slab, Bridges Subject to Realistic Traffic Loading, Structure and Infrastructure Engineering, DOI: 10.1080/15732479.2015.1086385.
- [14] Wasiu John and Adedeji, A.A. (2018). Reliability Assessment of Reinforced Concrete Beam with Embedded PVC Pipes below the Neutral Axis, International Journal of Multidisciplinary Sciences and Engineering, 9(1).
- [15] Ahmed Metwally Abdel Aziz, Ahmed Shaban Abdel Hay Gabr and Inas Mohamed Saleh. (2016) Reliability of Slender Reinforced Concrete Columns, World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering 10 (7).
- [16] Beatriz Gonçalves Klink and Lara Alves da Silva. (2016) Reliability Analysis of a Steel Beam Using the Monte Carlo Method Centro Universitário de Brasília UniCEUB SEPN 707/907 Asa Norte 70790-075 DF Proceedings of the XXXVII Iberian Latin-American Congress on Computational Methods in Engineering, Suzana Moreira Ávila (Editor), ABMEC, Brasília, DF, Brazil.
- [17] Tarighat Amir, Zehtab Behnam. (2016). Structural Reliability of Reinforced Concrete Beams/ Columns under Simultaneous Static Loads and Steel Reinforcement Corrosion, Arab J Sci Eng 41:3945–3958, DOI 10.1007/s13369-016-2033-6.
- [18] Wellison José de Santana Gomes. (2017). Reliability analysis of reinforced concrete beams using finite element models, Center for Optimization and Reliability in Engineering (CORE), Department of Civil Engineering, Federal University of Santa Catarina. Conference Paper, DOI: 10.20906/CPS/CILAMCE2017-0145, https://www.researchgate.net/publication/321633064.
- [19] Kuriakose Bennet, Anju Krishnan, Dodagoudar G.R and Rao B.N. 2017 Reliability Analysis of Raft Foundation on Uniformly Random Soils, Department of Civil Engineering, Indian Institute of Technology Madras, Journal of Structural Engineering, 43(6), 568-579.

Comparison of Reliability Based Design (RBD) With Eurocode 2 for A Singly Reinforced Concrete Beam

[20] Olawale S O A, Tijani M.A, Folayan O I and Bolaji E. O 2018, Reliability Assessment of Ejigbo Campus Library Building at Osun State University, Osogbo, Department of Civil

Engineering, Osun State University, Osogbo, Journal of Research Information in Civil Engineering, **16**(1), 2511-2526.

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