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FAULT TREE–BASED RELIABILITY ANALYSIS OF REINFORCED CONCRETE ELEMENTS IN AN INSTITUTIONAL BUILDING

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Abstract
There are so many causes of reinforced concrete building collapse, and therefore, it is very important to know the root cause(s) through some engineering analysis. This paper evaluated fault tree-based reliability analysis of failure of reinforced structural elements of an institutional building. The compressive strength of each of the structural elements of the building (slab, column and beam) was analysed with first order reliability method (FORM) by reliability software called CalREL (a coded algorithm). The reliability indices and probabilities of failure were further analysed using fault tree analysis (FTA), which is a valuable tool for understanding and analyzing the reliability and failure modes of complex systems. Seven criteria of failure (failure of beams due to concrete, steel, shear and deflection; failure of slab due to applied moment and deflection; and failure due to columns) were considered. Qualitative and quantitative analysis (Boolean algebra) techniques were deployed. The results showed that for the entire building system, the reliability of the elements was 96.5% and about 4% of the elements may fail. Critical examination of the system showed that the columns need to be scheduled for corrective maintenance to avoid eventual collapse.
Keywords: *compressive strength, reliability indices, probability of failure, Boolean algebra, fault-tree analysis*

Introduction

The failure of reinforced concrete building elements whether in service or during construction may be accompanied by various consequences ranging from destruction of parts or entire building elements, death and hazardous environmental effects (Hamma-Adama, and Kouider, 2017). The reason is that structures generally undergo reduction in their life span over time (Bussa, *et al.,* 2025). This may be due to moisture movement within the material matrix of the structure, fluctuation in the temperature, vibration and strain. The physical inspection method may not expose concealed faults or damages in the structure and therefore, structural health monitoring (SHM) is widely employed for this purpose for structures (towers, bridges, buildings, etc.) in service (Dinesh, *et al.,* 2022, Victor *et al*, 2024). SHM is the process of evaluating the conditions of structures over a period of time using equipment like sensors (Atoyebi, *et al*, 2019). Fundamentally, data acquisition with sensors, most especially smart sensors, makes data analysis faster for quick decision about the condition of the structures that are investigated. The smart sensors use cutting-edge technologies such as wireless network connections, more accurate data interpretation and digital surveillance systems which assist quick maintenance plan of action (Liu, 2024, Mayank, *et al*., 2022), and this is because it has on-board microprocessor, sensing capabilities, wireless communication, battery powered, and low cost. Some of the smart sensors commonly used are piezoelectric smart sensors and fiber optic sensors (Agarwal, 2018). Apart from monitoring the integrity of structures using sensors, non-destructive testing (NDT) could also be used. NDT ensures that the tested members are not destroyed after testing (Abdollahi-Mamoudan *et al*., 2025). Using this method, each member can be tested individually and performing inspection on the member over a given period of time is possible. With NDT in reinforced concrete, flaws can be detected, concrete homogeneity can be evaluated, measurement of the thickness and the size of reinforcement can be ascertained as well as cover depth to members and the microstructure characterization. It can be used to evaluate in-situ concrete compressive strength, and also to detect cracks (Akingbonmire *et al*., 2021, Akingbonmire, 2022, Abu *et al*., 2025, Muzammil and Shaikh, 2021). The commonly used NDT methods are Schmidt rebound hammer test, penetration resistance, pull-off testing, ground penetrating radar, half-cell potential, radiographic testing, ultrasonic pulse velocity, acoustic emission, impact –echo test, laser scanning, infrared thermography, visual inspection, electrical resistivity, vibration-based methods, and computer tomography (Belay and Abrham, 2025, Saravanakumar, *et al*., 2024, Pan Panjehpour 2025, Patel *et.al*, 2022, Gupta and Khan, 2021). However, data from the structural health monitoring needs to be analysed. One of such methods is structural reliability techniques. Structural reliability is a method used to analysis load and resistance uncertainties at a particular period in the lifespan of the structure. Here, probabilistic analysis is used to evaluate a particular limit state or performance function of the member so as to know the probability of failures and their reliability indices (Rosowsky 1999, Xiangi, 2019, Omoya *et al.,* 2019, Radon and Zabojszcza, 2025, Uche and Afolayan, 2008, Akingbonmire and Afolayan, 2023). As explained by Sule and Okere (2020), the safety indices responded to the load ratio, beam span, effective depth and imposed load when a singly reinforced concrete beam was analysed in respect of limit state deflection, shear and bending in accordance with BS 8110, Part 1, 1997 design provisions. Also, Idris *et al.,* (2025) worked on flat slab using sine-cosine algorithm, and found out that 9.03% of the design cost was reduced. So, reliability-based approach has been used as a tool in analysing parameters of concerns in structural systems. However, FTA helps to identify the cause and mode of failure (Waghmode and Patil, 2013, Patil, *et al*., 2013). FTA can be used as reliability tools and analysis of risk in engineering systems. It outlines a graphical means by which system fails commencing from interconnected basic events which lead to the failure of the system called the top event i.e. it breaks down the failure of the system into smaller components till the root cause of failure is identified (Sharma and Singh, 2015, Frederick, *et. al.,* 2022). It starts from defining the failure, analyse the system, break down the failure into different components, narrowing down the components and then identify the root cause by which corrective measures can be applied in order to prevent the reoccurrence of the failure.

FTA was developed in 1962 at Bell laboratory by H.A Watson under a contract from the U.S. Air Force Ballistic Systems Division to assess the Minuteman I intercontinental ballistic missile (ICBM) launch control system (Mohammad *et al*., 2011, Odeyar, *et al*., 2022). All the events and conditions are connected with logical symbols. Figure 1 presents the symbols used in FTA. Fault tree can be evaluated using qualitative and quantitative analysis. The events are described using Boolean logic. Minimal cut sets are obtained using Boolean expressions in qualitative analysis while the quantitative analysis uses probability of occurrence of the logic gates. The probability of “OR” Gate is expressed in equation 1 while the probability of “AND” gate is presented in equation 2 (Sharma and Singh, 2015, Makarov, 2025).

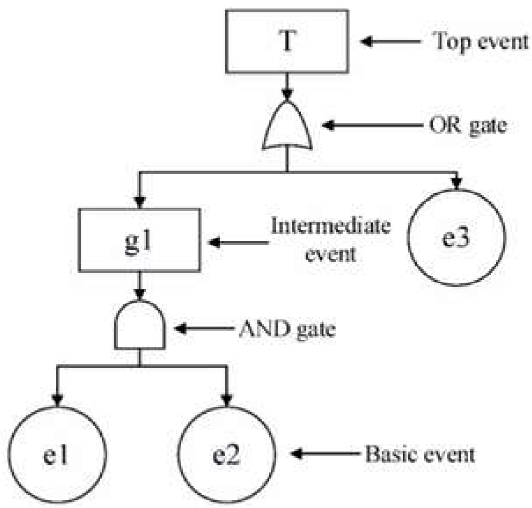

Figure 1. Fault trees symbols (Odeyar, *et al.,* 2022)

$$P = 1 - \sum_{i=1}^{n}(1 - p_i) \quad (1)$$

$$P = \sum_{i=1}^{n} p_i \quad (2)$$

where P is the top event probability; p_i is the basic event probability; and n is the number of basic event gates.

FTA has been useful to study the integrity of structures. Efe *et al.* 2021 used FTA to evaluate integrity of mine cage conveyance, while Marco *et al.* 2025 used FTA to understudy the integrity of gas pipelines. Due to the usefulness of FTA in pin pointing causes of failure, it is therefore employed to evaluate the status of the structural members of an institutional building in Akure, Ondo State, Nigeria.

Methodology

The structural layout of the institutional building being investigated is presented in Figure 2. The layout consists of identified forty eight (48) beams, seventy two (72) first floor columns and eighteen (18) slab panels. All these elements were subjected to reliability analysis. Table 1 shows the criteria of failure of the structural members.

Table 1: Criteria of failure of structural elements

S/N	Criteria	Code
1	Ultimate resistance of the beams based on concrete failure	S_1
2	Ultimate resistance of the beams based on steel failure	S_2
3	Ultimate resistance of the beams based on shear	S_3
4	Failure of the beams due to deflection	S_4
5	Failure of the slabs under applied moments	S_5
6	Failure of the slabs due to deflection	S_6
7	Failure of columns	S_7

The values of the reliability indices and the probabilities of failure were computed using CalREL (Pei-ling et al., 1989), which is a coded algorithm capable of analysing limit state functions using:

i. First-order reliability method (FORM)
ii. Second-order reliability method (SORM)
iii. Directional simulation with exact or approximate surfaces; and
iv. Monte Carlo simulation

The performance function is generally represented using equation 3

$$G = R - L \quad (3)$$

Where R represents the resistance and L denotes the applied load

Equation 4 is the performance function for columns subjected to small eccentricity. For biaxial columns, equation 5 gives the limit state function, and for beams and slabs, equations 6, 7, 8 and 9 are the limit state equations of failure due to concrete, steel, shear and deflection respectively.

$$g = \{0.4b(d + 0.5\emptyset + \emptyset_{links} + c)[f_{cu} + 0.002f_y\sigma]\} - \alpha N_A \quad (4)$$

$$g_{(x)} = 1 - \propto \left(\frac{M_c}{M_{uz}} - \frac{N_A}{N_{uz}}\right) \quad (5)$$

$$g = 0.156 f_{cu} bd^2 - \varphi M \quad (6)$$

$$g = 0.95 f_y A_s Z - \varphi M \quad (7)$$

$$g = 0.74575\, f_{yv} d + 0.91bd - \omega\, V_A \quad (8)$$

$$g = \left[\frac{11M + 89.4bd^2 - 0.16667bd^2 f_s}{M + 0.9bd^2}\right] - \frac{L}{d} \quad (9)$$

Where b is the width, d is the effective depth, $\emptyset$ is the diameter of the main bar, $\emptyset_{links}$ is the diameter of the links, c is the cover depth, f_{cu} is the characteristics strength of the concrete, f_y is characteristics strength of the reinforcement, σ is the steel ratio, α is the percentage of applied axial load, N_A is the applied axial load, M_c is the applied moment, M_{uz} is the design ultimate moment, N_{uz} is the design ultimate capacity of a section, φ is the percentage of applied moment, M is the applied moment, A_s is the cross sectional area of tension reinforcement, Z is the lever arm, f_{yv} is the characteristic strength of the links, ω is the percentage of shear, V_A is the applied shear, f_s is the design service stress, and L is the actual span.

The results from FORM were used for the computation of probability of failures (P(F)) of the reinforced concrete elements of the building using equation (10) (Patil *et al.* 2013):

$$P(F) = 1 - [(1 - S_1)(1 - S_2)(1 - S_3)(1 - S_4)(1 - S_5)(1 - S_6)(1 - S_7)] \quad (10)$$

Applying Boolean algebra, the quantitative values of all the criteria are computed using equations 11 – 17, while the reliability of beams and slabs were expressed using equations 18 and 19 respectively:

$$S_1 = B_1 \cap B_2 \cap B_3 \cap \ldots B_{48} \quad (11)$$

$$S_2 = B_1 \cap B_2 \cap B_3 \cap \ldots B_{48} \quad (12)$$

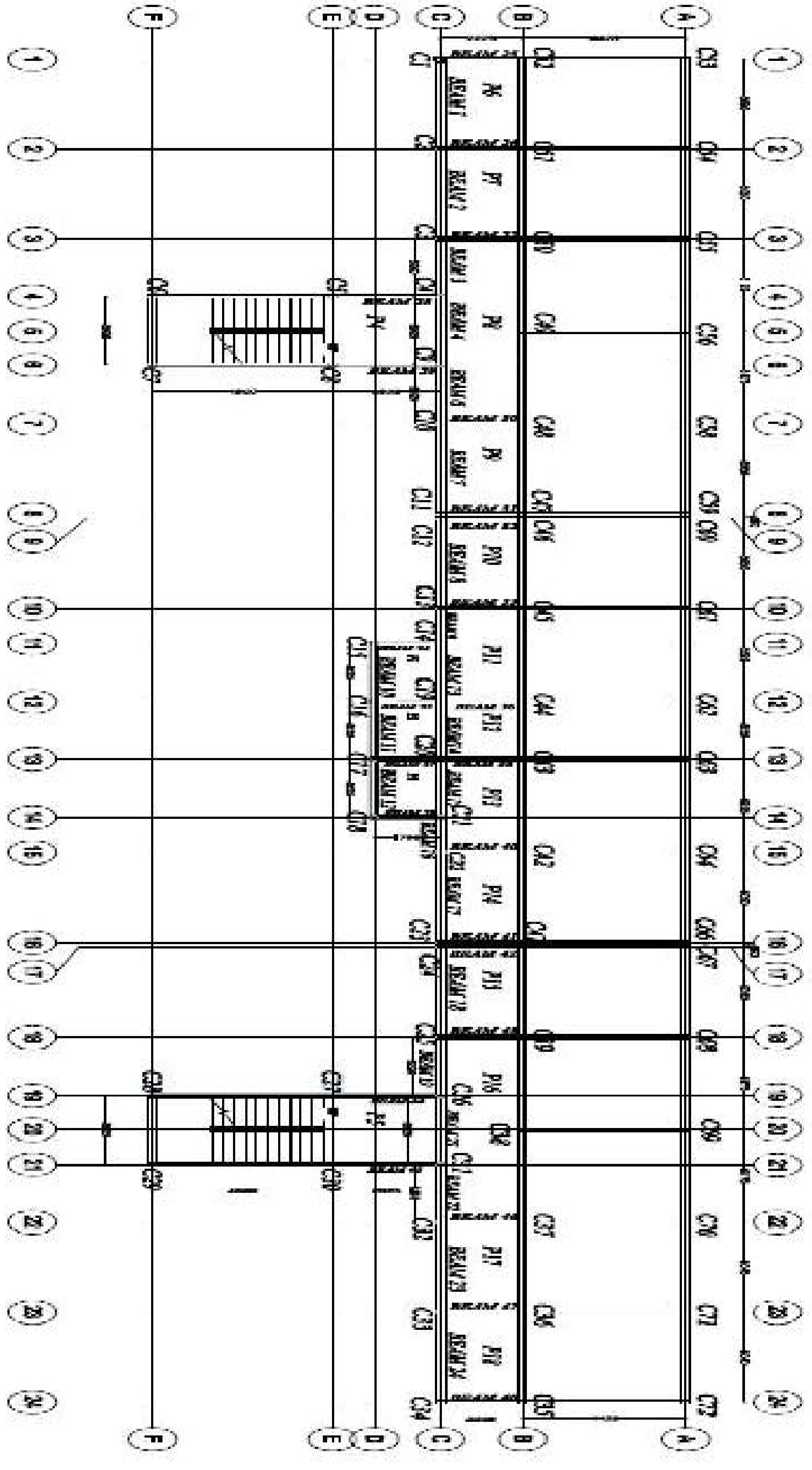

Figure 2: Structural layout of the investigated institutional building

$$S_3 = B_1 \cap B_2 \cap B_3 \cap \ldots B_{48} \quad (13)$$

$$S_4 = B_1 \cap B_2 \cap B_3 \cap \ldots B_{48} \quad (14)$$

$$S_5 = P_1 \cap P_2 \cap P_3 \cap \ldots\ldots P_{18} \quad (15)$$

$$S_6 = P_1 \cap P_2 \cap P_3 \cap \ldots\ldots P_{18} \quad (16)$$

$$S_7 = C_1 \cap C_2 \cap C_3 \cap \ldots\ldots C_{72} \quad (17)$$

Where B_1, B_2, …. B_{48}, $P_1, P_2 \ldots. P_{48}$, C_1, C_2, C_{72} are their probabilities of failure in appendices 1 – 7 respectively. The failures of due beams and slab are given in equations 18 – 19.

$$Reliability\ of\ beams = S_1 \cap S_2 \cap S_3 \cap S_4 \quad (18)$$

$$Reliability\ of\ slabs = S_5 \cap S_6 \quad (19)$$

The reliability indices and the probability of failures were obtained from previous studies (Akingbonmire, 2022). Figure 3 gives the fault tree diagram for the building.

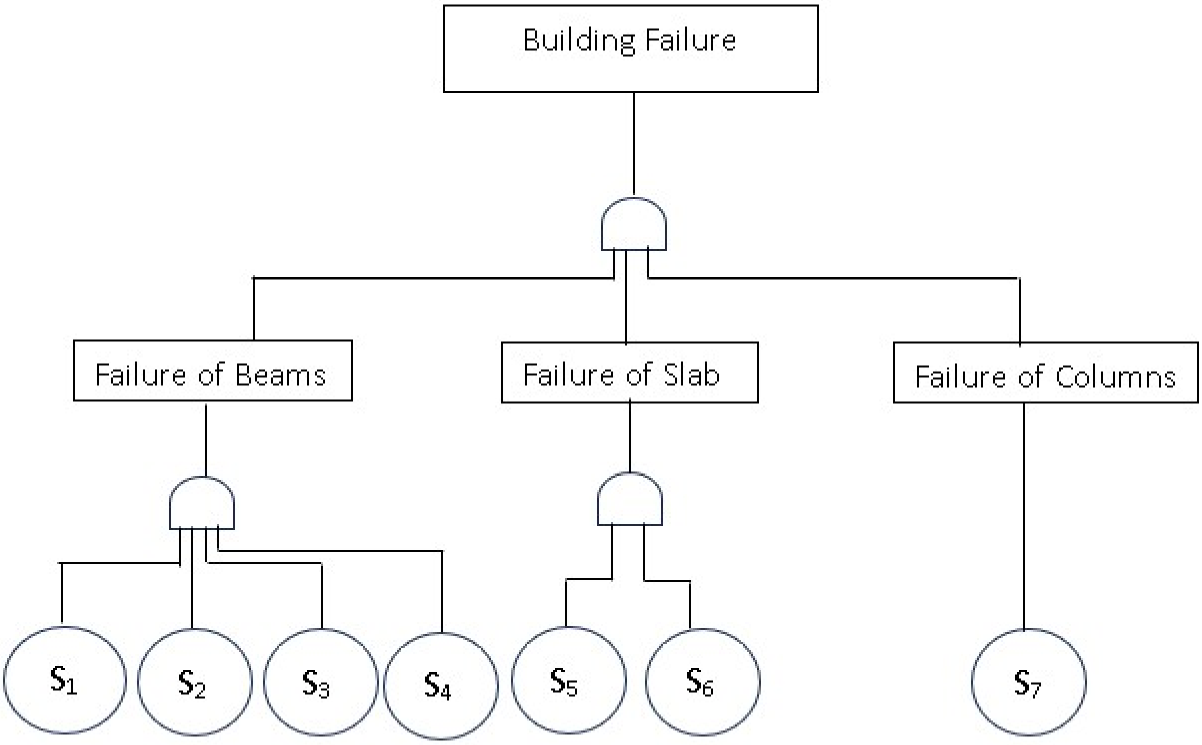

Figure 3: Fault tree diagram for the failure of the building

Figure 4: Values of Reliability for all the Failure Criteria of the Structural Elements

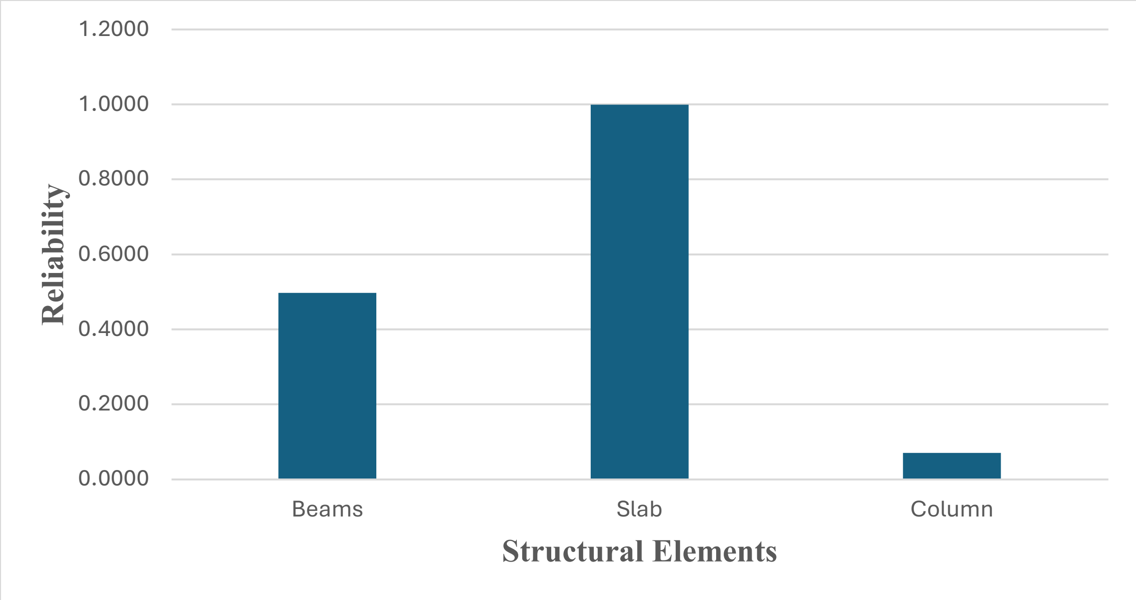

Figure 5: Values of Reliability of the Structural Elements

Results and Discussion

Appendices 1 – 7 shows the probabilities of failure and reliabilities for the structural members in their respective criteria of failure. It could be observed that the probabilities of failure are very low but with high reliability indices for almost all the structural members except columns. This implies that the structural members of the investigated buildings can still effectively performed their intended functions. Quantitatively, Figures 4 - 5 gives the summary of the reliabilities of the structural elements for all the criteria. It can be deduced that the slab possesses reliability greater than the beams and column. The reliability of columns is very poor owing to their high probabilities of failure**.** The low reliabilities may be due to the inadequate provisions of their main bars that will could resist loadings. Therefore, efforts should be made for corrective maintenance as any delay in doing this may result into the total collapse of the building.

The probability of failure (PF) of the entire structural elements is

$PF = 1 - (0.4971 \times 0.9989 \times 0.070696) = 0.03510$; and;

Overall reliability (R) = $1 - PF = 1 - 0.03510 = 0.9649$

This implies that the reliability of the entire structural members of the building is 96.5%, and approximately four elements in the building may fail to perform their intended functions.

Conclusions

The reliability analysis of the structural elements of an institution building was evaluated using fault tree analysis. Based on the findings, the total probability of failure of the system was 3.5% while the reliability of the structural elements is 96.5%. Critical examination of the system showed that the columns need to be scheduled for corrective maintenance to avoid eventual collapse.

References

Abdollahi-Mamoudan, F., Ibarra-Castanedo, C., and Maldague, X. P. V. (2025). Non-Destructive Testing and Evaluation of Hybrid and Advanced Structures: A Comprehensive Review of Methods, Applications, and Emerging Trends. *Sensors*, 25, 3635.

Abu, S. M., Manisha, P., and Bonisha, B. (2025). Condition Assessment of Reinforced Concrete Structures using Non-Destructive Testing. Proceedings of the International Conference on Smart Systems and Social Management, Smart Systems Tracks. *Advances in Intelligent Systems Research,* 40 – 54.

Agarwal, V. (2018). Smart Sensors for Structural Health Monitoring- Overview, Challenges and Advantages. *Sensors and Transducers*, 221 (3), 1-8.

Akingbonmire, S. L., (2022). Assessment of concrete quality of reinforced concrete structural elements of university buildings using Schmidt Hammer. *International Journal of Engineering, Romania*, 89 – 96.

Akingbonmire, S. L. (2022). Reliability-Based Prediction of the Structural Integrity of Selected Buildings at the Federal University of Technology, Akure, Nigeria, unpbl

Akingbonmire, S. L. and Afolayan, J. O, (2023). Structural integrity of reinforced concrete slabs of some selected existing buildings based on field assessment. *Journal of Civil Engineering and Environmental Sciences*, 9(2): 046-051.

Akingbonmire, S. L**.**, Afolayan, J. O., Olanitori, L. M. and Ikumapayi, C. M. (2021). Quality Assessment of Reinforced Concrete Structural Elements of some selected University Buildings using Ultrasonic Pulse Velocity Test. *Journal of Multidisciplinary Engineering Science Studies*. 7(12), 4162-4169,

Atoyebi, O. D., Afolayan, J. O. and Arum, C. (2019). Analyses and Interpretation of Structural Health Monitoring Data on Reinforced Concrete Buildings: A Critical Review. *Journal of Engineering and Applied Sciences*, 14(24), 9657 – 9666.

Belay, B. T., and Abrham, G. T. (2025). Non-Destructive Testing Techniques for Condition Assessment of Concrete Structures: A Review. *American Journal of Civil Engineering*, 13 (1), 10 – 31.

Bussa, S. K., Boppana, N. K., and Gunda, K. (2025). A literature review of approaches to structural integrity assessment using FBG and PZT sensors. *Discover Sensors*, 1 (15), 1 – 20.

Dinesh, A., Karthick, A., and Ramkumar, S. (2022). Structural Health Monitoring of Infrastructures using Sensors as Smart Materials– Review and Perspective. *Sustainable Materials and Smart Practices,* 255- 268.

Efe, P. I., Olutayo, O. O., and Isaque, M. G. (2021). Managing the Integrity of Mine Cage Conveyance using Fault Tree Analysis. *International Journal of Engineering Research andTechnology*, 10 (6), 743 - 747

Frederick, O. E., Olufemi O. K., Abubakar S. N., Lateef, O. A., and Ikeola S. O. (2022). Fault Tree Analysis and its Modifications as Tools for Reliability and Risk Analysis of Engineering Systems – An Overview. *International Journal of Research Publication and Reviews*, 3 (1), 383 – 396.

Gupta. M., and Khan, M. A. (2021). Advances in Applications of Non-Destructive Testing (NDT): A Review. *International Research Journal of Engineering, IT & Scientific Research*, 7 (3), 76 – 86.

Hamma-Adama, M., and Kouider, T. (2017). Causes of Building Failure and Collapse in Nigeria: Professionals' View. *American Journal of Engineering Research*, 6 (12), 289-300.

Idris, U., Erondu M., and Baba M. K. (2025). Reliability Based Optimum Design of Reinforced Concrete Flat Slab. *Journal of Built Environment and Geological Research*, 10 (4), 214 – 226.

Ijaseun, D. (2023). Ikoyi building collapse: New insights expose real cause, Bussiness Day Newspaper**,** https://businessday.ng/news/article/the-root-cause-behind-the-collapse-of-21-storey-building-in-ikoyi/. Retrieved 25th April, 2026

Liu, Z. (2024). Smart Sensors for Structural Health Monitoring and Nondestructive Evaluation. *Sensors*, 24, 1 - 8.

Makarov, A. N., Monakhov, B. E., Mozaffari, M. A. (2025). Methodology for Calculating the Risk of Defects in Multi-Story Construction Using Fault Tree Analysis. *International Journal of Engineering Trends and Technology,* 73 (6), 302-308

Marco, A. S., Jose, A., and Alysson, H. S. B. (2025). Development of a Fault Tree Analysis (FTA) for Structural Integrity Assessment of Gas Pipelines: A Literature-Based Approach. *Revista de Gestão Social e Ambiental*, 1 – 22.

Mayank, M., Paulo, B., and Ramana. G. V. (2022). Structural health monitoring of civil engineering structures by using the internet of things: A review. Journal of Building Engineering, 48.

Mohammad, S. J., Azim N., and Ali, M. (2011). Fault Tree Analysis Approach in Reliability Assessment of Power System. *International Journal of Multidisciplinary Sciences and Engineering*, 6 (2), 46 – 60.

Muzammil F., and Shaikh M. (2021). Non-Destructive Testing on RCC Structure. *International Journal of Research in Engineering and Science*, 9 (7), 50-55

Odeyar, P., Apel, D.B., Hall, R., Zon, B., and Skrzypkowski, K. (2022). A Review of Reliability and Fault Analysis Methods for Heavy Equipment and Their Components Used in Mining. *Energies*, 15, 1 – 27.

Omoya, O. A., Papadopoulou, K. A. and Lou, E. (2019). Reliability Engineering Application to Pipeline Design. *International Journal of Quality and Reliability Management*, 36 (9), 1644-1662.

Pan Panjehpour (2025). Exploring Non-Destructive Testing in Reinforced Concrete Structures: An In-Depth Review. *Civil Engineering and Architecture*, 13(3A), 2382-2395

Patel, R., Patel, D. and Meshram, D. (2022). A Review on Non-Destructive Testing (NDT) Techniques: Advances, Researches and Applicability. *International Journal of Current Science Research and Review*, 5 (4), 1342-1355.

Patil, R. B., Waghmode, L. Y., Chikali, P. B. and. Mulla, T. S. (2013). An Overview of Fault Tree Analysis (FTA) Method for Reliability Analysis and Life Cycle Cost (LCC) Management. *IOSR Journal of Mechanical and Civil Engineering*, 14-18

Pei-ling, L., Hong-Zong, L., and Armen, D. K. (1989). Structural Engineering Mechanics and Materials, *CalRel User Manual, Department of Civil Engineering*. University of California, Berkeley, California.

Radon, U., and Zabojszcza, P. (2025). The Application of Structural Reliability and Sensitivity Analysis in Engineering Practice. *Applied Science*, 15, 342.

Rosowsky, D. V. (1999). Structural Reliability" Structural Engineering Handbook Ed. Chen Wai-Fah Boca Raton: CRC Press LLC

Saravanakumar, R., Elango, K. S., Venkatesh, S. G., and Saravanaganesh, S. (2024). Evaluation of Structural Stability of Four-Storied building using Non-Destructive Testing Techniques. *International Research Journal of Multidisciplinary Technovation*, 6 (4), 1 – 7.

Sharma, A. and Singh, A. (2015). Overview of Fault Tree Analysis, *International Journal of Engineering Research and Technology*, 4(3), 337 – 340.

Sule, S. and Okere, C. E. (2020). Reliability analysis of a singly reinforced concrete rectangular beam with uncertain parameters. *International Journal of Engineering*, 3,75 – 84.

Uche, O. A. U. and Afolayan, J. O. (2008). Reliability-Based Rating for Reinforced Concrete Columns, *Journal of Engineering and Technology*, 3 (10), 1 – 20.

Victor, P. O, Alan R., and José, A. A. (2024). Assessing the Evolution of Structural Health Monitoring through Smart Sensor Integration, *Procedia Structural Integrity*, 64, 653-660

Waghmode L. Y., and Patil, R. B. (2013). An Overview of Fault Tree Analysis (Fta) Method or Reliability Analysis. *Journal of Engineering Research and Studies*, 1- 3

Xianqi D. (2019). Structural reliability model considering mixed probabilistic and interval variables. *Latin American Journal of Solids and Structures*, 17(1): 1 – 9.

Appendix 1: Probabilities of failure for Beams under ultimate moment of resistance based on failure of concrete

Beams	Probability of failure P(F)	1-P(F)	Beams	Probability of failure P(F)	1-P(F)
B1	0.0044	0.996	B27	0.00033	1.0000
B2	0.00341	0.997	B28	5.93E-06	1.0000
B3	2.34E-06	1.000	B29	5.39E-06	1.0000
B4	1.78E-05	1.000	B30	0.00035	1.0000
B6	1.37E-05	1.000	B31	2.09E-05	1.0000
B7	0.00225	0.998	B32	2.1E-05	1.0000
B8	0.00217	0.998	B33	0.00037	1.0000
B9	6.14E-06	1.000	B34	1.00E-10	1.0000
B10	7.62E-08	1.000	B35	1.00E-10	1.0000
B11	5.48E-08	1.000	B36	0.00051	0.9990
B12	2.78E-08	1.000	B37	1.00E-10	1.0000
B13	9.57E-07	1.000	B38	0.0006	0.9990
B14	9.57E-07	1.000	B39	1.00E-10	1.0000
B15	1.12E-06	1.000	B40	0.00034	1.0000
B16	5.75E-06	1.000	B41	1.91E-08	1.0000
B17	0.00216	0.998	B42	2.16E-05	1.0000
B18	0.00228	0.998	B43	0.00031	1.0000
B19	1.41E-05	1.000	B44	6.99E-06	1.0000
B22	1.88E-05	1.000	B45	5.39E-06	1.0000
B23	2.28E-05	1.000	B46	0.00042	1.0000
B24	0.00342	0.997	B47	0.00045	1.0000
B25	0.0046	0.995	B48	1.68E-05	1.0000
B26	0.000161	1.000			
	Total Product				0.9720

Appendix 2: Probabilities of Failure of Beams due to steel under Ultimate Moment of Resistance

Beams	Probability of failure P(F)	1-P(F)	Beams	Probability of failure P(F)	1-P(F)
B1	1.00E-10	1	B26	1.00E-10	1.0000
B2	1.00E-10	1	B27	1.00E-10	1.0000
B3	1.00E-10	1	B28	1.00E-10	1.0000
B4	1.00E-10	1	B29	1.00E-10	1.0000
B6	1.00E-10	1	B30	1.00E-10	1.0000

Appendix 2: Probabilities of Failure of Beams due to steel under Ultimate Moment of Resistance

Beams	Probability of failure P(F)	1-P(F)	Beams	Probability of failure P(F)	1-P(F)
B7	1.00E-10	1	B31	1.00E-10	1.0000
B8	1.00E-10	1	B32	1.00E-10	1.0000
B9	1.00E-10	1	B33	1.00E-10	1.0000
B10	1.00E-10	1	B34	1.00E-10	1.0000
B11	1.00E-10	1	B35	1.00E-10	1.0000
B12	1.00E-10	1	B36	1.00E-10	1.0000
B13	1.00E-10	1	B37	1.00E-10	1.0000
B14	1.00E-10	1	B38	1.00E-10	1.0000
B15	1.00E-10	1	B39	1.00E-10	1.0000
B16	1.00E-10	1	B40	1.00E-10	1.0000
B17	1.00E-10	1	B41	1.00E-10	1.0000
B18	1.00E-10	1	B42	1.00E-10	1.0000
B19	1.00E-10	1	B43	1.00E-10	1.0000
B20	1.00E-10	1	B44	1.00E-10	1.0000
B22	1.00E-10	1	B45	1.00E-10	1.0000
B23	1.00E-10	1	B46	1.00E-10	1.0000
B24	1.00E-10	1	B47	1.00E-10	1.0000
B25	1.00E-10	1	B48	1.00E-10	1.0000
	Total Product				1.0000

Appendix 3: Probabilities of Failure for Shear criteria of Beams

Beams	Probability of failure P(F)	1-P(F)	Beams	Probability of failure P(F)	1-P(F)
B1	0.0619	0.9381	B26	0.00405	0.9960
B2	0.0186	0.9814	B27	0.00398	0.9960
B3	0.0016	0.9984	B28	0.00138	0.9986
B4	0.04	0.96	B29	0.00138	0.9986
B6	0.000869	0.9991	B30	0.00412	0.9959
B7	0.0408	0.9592	B31	0.000429	0.9996
B8	0.04	0.96	B32	0.000429	0.9996
B9	0.00004	1.000	B33	0.00433	0.9957
B10	0.000671	0.9993	B34	6.76E-08	1.0000
B11	0.000161	0.9998	B35	7.84E-08	1.0000
B12	8.03E-05	0.9999	B36	0.00528	0.9947
B13	0.00419	0.9958	B37	1.39E-07	1.0000
B14	0.00285	0.9972	B38	0.00637	0.9936
B15	0.00434	0.9957	B39	7.75E-07	1.0000
B16	3.31E-05	1.000	B40	0.00405	0.9960
B17	0.04	0.96	B41	0.000429	0.9996

Appendix 3: Probabilities of Failure for Shear criteria of Beams

Beams	Probability of failure P(F)	1-P(F)	Beams	Probability of failure P(F)	1-P(F)
B18	0.0408	0.9592	B42	0.00044	0.9996
B19	0.00129	0.9987	B43	0.00372	0.9963
B21	0.0404	0.9596	B44	0.0005	0.9995
B22	0.00153	0.9985	B45	0.00138	0.9986
B23	0.043	0.957	B46	0.00471	0.9953
B24	0.162	0.838	B47	0.00495	0.9951
B25	0.0382	0.9618	B48	0.000347	0.9997
	Total Product				0.5172

Appendix 4: Probabilities of Failure for the Deflection of Beams

Beams	Probability of failure P(F)	1-P(F)	Beams	Probability of failure P(F)	1-P(F)
B1	0.00185	0.9982	B26	4.98E-10	1.0000000
B2	0.00141	0.9986	B27	4.79E-10	1.0000000
B3	8.93E-07	1.0000	B28	6.68E-09	1.0000000
B4	7.67E-07	1.0000	B29	6.68E-09	1.0000000
B6	5.62E-08	1.0000	B30	4.98E-10	1.0000000
B7	0.000982	0.999	B31	1.97E-10	1.0000000
B8	0.000982	0.999	B32	1.97E-10	1.0000000
B9	6.62E-10	1.0000	B33	1.56E-09	1.0000000
B10	4.11E-09	1.0000	B34	1.00E-10	1.0000000
B11	5.78E-09	1.0000	B35	1.00E-10	1.0000000
B12	2.57E-09	1.0000	B36	6.61E-10	1.0000000
B13	4.65E-08	1.0000	B37	1.00E-10	1.0000000
B14	4.94E-08	1.0000	B38	7.60E-09	1.0000000
B15	5.01E-08	1.0000	B39	1.00E-10	1.0000000
B16	0.00087	0.9991	B40	4.86E-10	1.0000000
B17	0.000828	0.9992	B41	1.00E-10	1.0000000
B18	0.00087	0.9991	B42	2.00E-10	1.0000000
B19	4.19E-09	1.0000	B43	4.47E-10	1.0000000
B20	2.5E-06	1.0000	B44	6.67E-09	1.0000000
B22	8.69E-08	1.0000	B45	6.67E-09	1.0000000
B23	0.00137	0.9986	B46	5.70E-10	1.0000000
B24	0.00195	0.9981	B47	1.67E-10	1.0000000
B25	1.02E-09	1.0000	B48	6.04E-09	1.0000000
	Total Product				0.988938

Appendix 5: Probabilities of Failure of the Slabs under Applied Moment

Slab	Probability of failure P(F)	1-P(F)	Slab	Probability of failure P(F)	1-P(F)
P1	1.14E-10	1.0000	P10	1.27E-08	1.0000
P2	1.14E-10	1.0000	P11	1.14E-10	1.0000
P3	1.14E-10	1.0000	P12	1.14E-10	1.0000
P4	1.8E-07	1.0000	P13	1.14E-10	1.0000
P5	1.8E-07	1.0000	P14	1.27E-08	1.0000
P6	1.27E-08	1.0000	P15	1.27E-08	1.0000
P7	1.27E-08	1.0000	P16	4.29E-08	1.0000
P8	4.29E-08	1.0000	P17	1.27E-08	1.0000
P9	1.27E-08	1.0000	P18	1.27E-08	1.0000
	Total Product				1.0000

Appendix 6: Probabilities of failure of the Deflection of Slab

Slab	Probability of failure P(F)	1-P(F)	Slab	Probability of failure P(F)	1-P(F)
P1	1.21E-08	1.00000	P10	3.44E-06	1.0000
P2	1.21E-08	1.00000	P11	2.37E-07	1.0000
P3	1.21E-08	1.00000	P12	2.37E-07	1.0000
P4	0.000515	0.99949	P13	2.37E-07	1.0000
P5	0.000515	0.99949	P14	3.44E-06	1.0000
P6	3.44E-06	1.00000	P15	3.44E-06	1.0000
P7	3.44E-06	1.00000	P16	7.18E-06	1.0000
P8	7.18E-06	0.99999	P17	3.44E-06	1.0000
P9	3.44E-06	1.00000	P18	3.44E-06	1.0000
	Total Product				0.99893

Appendix 7: Probabilities of Failure of Columns of the Building

Columns	Probability of failure P(F)	1-P(F)	Columns	Probability of failure P(F)	1-P(F)	Columns	Probability of failure P(F)	1-P(F)
C1	1.20E-10	1.00000	C29	9.04E-10	1.00000	C24	2.82E-08	1.00000
C3	2.22E-06	1.00000	C30	3.89E-05	0.99996	C25	2.38E-06	1.00000
C4	6.64E-06	0.99999	C31	6.76E-06	0.99999	C26	6.76E-06	0.99999
C5	3.83E-05	0.99996	C32	2.2E-06	0.99999	C27	3.89E-05	0.99996
C6	8.77E-10	1.00000	C33	0.00588	0.99412	C28	9.04E-10	1.00000
C7	8.77E-10	1.00000	C34	1.00E-10	1.00000	C58	0.071	0.92900
C8	3.88E-05	0.99996	C35	0.000227	0.99977	C59	2.24E-06	1.00000
C9	6.81E-06	0.99999	C37	0.209	0.79100	C60	1.09E-07	1.00000
C10	2.38E-06	1.00000	C38	0.143	0.85700	C61	0.0803	0.91970
C11	2.61E-08	1.00000	C39	0.249	0.75100	C62	6.83E-05	0.99993
C12	2.61E-08	1.00000	C40	0.000227	0.99977	C63	6.83E-05	0.99993
C13	5.37E-07	1.00000	C41	0.0001	0.99990	C64	0.0805	0.91950
C14	2.58E-08	1.00000	C42	0.21	0.79000	C52	0.000228	0.999772

Appendix 7: Probabilities of Failure of Columns of the Building

Columns	Probability of failure P(F)	1-P(F)	Columns	Probability of failure P(F)	1-P(F)	Columns	Probability of failure P(F)	1-P(F)
C15	1.00E-10	1.00000	C43	0.00205	0.99795	C53	2.12E-06	0.999998
C16	6.06E-07	1.00000	C44	0.00205	0.99795	C54	0.0652	0.934800
C17	3.44E-07	1.00000	C45	0.21	0.79000	C55	0.0513	0.948700
C18	1.00E-10	1.00000	C46	0.000217	0.99978	C56	0.0837	0.916300
C19	7.07E-06	0.99999	C47	0.000217	0.99978	C66	1.09E-07	1.000000
C20	7.07E-06	0.99999	C48	2.81E-81	1.00000	C67	2.24E-06	0.999998
C21	1.75E-08	1.00000	C49	0.166	0.83400	C68	0.071	0.929000
C22	4.61E-07	1.00000	C50	0.238	0.76200	C69	0.0514	0.948600
C23	2.82E-08	1.00000	C51	0.281	0.71900	C70	0.0633	0.936700
C71	0.0652	0.93480	C72	2.24E-06	0.99998			
Total Product								0.0706960