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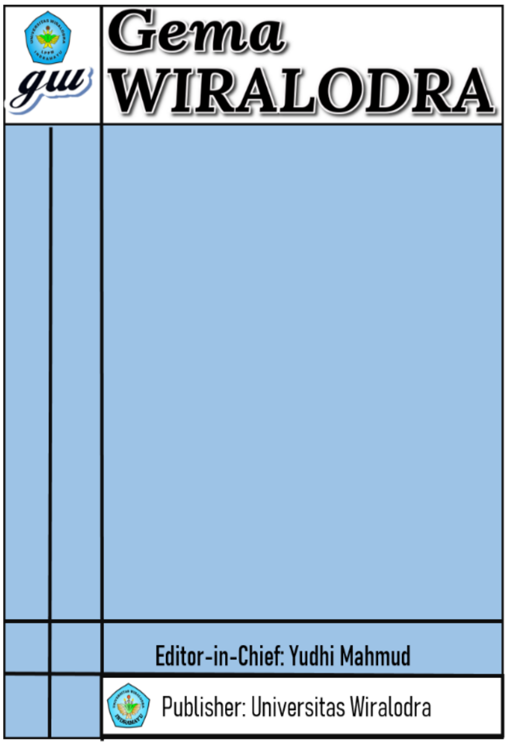

Reliability Analysis of Reinforced Concrete Beams in Lecture Buildings

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Reliability Analysis of Reinforced Concrete Beams in Lecture Buildings

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Abstract
During its service life, a building structure must be capable of withstanding the applied forces, which refers to its structural capacity. Beyond capacity, the structure must also be evaluated in terms of its probability of failure under loading conditions, a concept known as structural reliability. This study aims to analyze the reliability of reinforced concrete beam elements in buildings functioning as lecture facilities. The First Order Second Moment (FOSM) method was selected due to its effectiveness in incorporating statistical uncertainty into structural analysis, particularly for engineering problems involving variability in loads and resistance. The research was conducted through numerical analysis, which involved several key stages: (1) determining internal forces (bending and shear) from structural analysis, (2) collecting and assigning statistical parameters—namely, the mean and standard deviation—of dead loads, live loads, and material resistance, and (3) computing the reliability index for each beam element using the FOSM approach. The input data were derived from structural design specifications and relevant statistical references for load and material properties. The analysis results show that the maximum flexural reliability index values for beams B1, B2, RB, and SL are 8.29, 7.92, 7.62, and 8.34, respectively, while the maximum shear reliability index values are 3.96, 3.80, 4.29, and 4.28. All calculated values exceed the target reliability indices of 3.75 for new buildings and 2.75 for existing buildings, both for flexural and shear capacities. These findings indicate that the structural reliability of the analyzed beams is within a high and acceptable safety range.
Keywords: Reliability Index, Probability of Failure, FOSM.

1. Introduction

The ability of a structure to receive the working load is called the capacity of the structure. In order to have a service function, the building must meet the capacity according to each function of the building. In buildings with public or social services such as shopping centers, libraries, and school buildings , the loads that work are adjusted to the function of the building. This is different from other buildings such as *warehouses* , warehouses or factories where the activities in the building are not entirely carried out by humans. Thus, the capacity of the structure to receive the load from each function of the building become a safety requirement for a building, or referred to as a strength requirement.

In general building design, the approach used is deterministic, where capacity is determined based on the fulfillment of certain requirements. Meanwhile, another design method that can be used is probabilistic design. In the probabilistic method, design is carried out by involving several parameters that have uncertainty. In reality, uncertainty in the value of the material can occur in the fulfillment of the quality of construction materials. For example, in the tensile strength of reinforcing steel, the tensile strength value can vary even though the rods are produced in one production *batch* , so the tensile strength value used is the average value of the tensile strength. In addition, in structural loading such as dead and live loads, there is also an element of uncertainty. In the probabilistic method, basic statistical values that describe the distribution of data and its probability are used in calculations to measure structural reliability. Thus, reliability can be interpreted as the magnitude of the structure's ability not to fail during loading.

p – ISSN: **1693 - 7945**
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Orginal Article

Several studies have been conducted on the reliability analysis of reinforced concrete buildings using field data and various analytical methods. Reliability analysis plays a crucial role in the design and evaluation of reinforced concrete structures, including beams in lecture buildings. (Ellingwood, 1978) emphasizes the importance of reliability methods based on probability theory in determining the safety of reinforced concrete design. These methods help in understanding how uncertainties in resistance and loads impact design safety and how they should be controlled in building standards. (Lu et al., 1994) specifically focus on the reliability evaluation of reinforced concrete beams, highlighting the significance of assessing the structural integrity of such elements. (Chiu & Jean, 2013) delve into the seismic reliability analysis of reinforced concrete framed buildings deteriorated by chloride ingress. Their study proposes an evaluation method to analyze the time-dependent seismic reliability of RC buildings in corrosive environments with high seismic hazard. By developing models to estimate corrosion initiation and rate, as well as analyzing structural capacity, the study provides insights into the seismic evaluation of RC framed buildings. (Da Silva Barbosa, 2019) conducts a reliability analysis of concrete beams reinforced with carbon fiber-reinforced polymer bars, focusing on residential building beams. By utilizing the First Order Reliability Model (FORM) and Monte Carlo Simulation, the study calculates reliability indexes, probabilities of failure, and sensitivity factors with reference to ultimate and service limit states. This analysis aids in understanding the performance and safety of reinforced concrete beams in various scenarios. Moreover, (Thi et al., 2015) investigate the flexural behavior of fire-damaged reinforced concrete slabs repaired with carbon fiber-reinforced polymer rods. Their numerical investigation evaluates the mechanical performance and ductility of concrete beams reinforced by fiber-reinforced polymer and steel tension reinforcement. This study highlights the importance of considering factors such as reinforcement ratio, location, type, and concrete strength in assessing the mechanical performance of reinforced concrete beams. In conclusion, the literature on reliability analysis of reinforced concrete beams in lecture buildings underscores the significance of probabilistic methods, seismic evaluations, and material considerations in ensuring the structural integrity and safety of such elements. These studies provide valuable insights into the assessment and enhancement of reinforced concrete beams for sustainable and resilient construction practices.
Another studies have been conducted on the reliability analysis of reinforced concrete buildings. A study in Tehran tested the seismic performance of various reinforced concrete structural systems, and found that the dual system (shear walls and moment frames) outperformed moment frames alone in reducing earthquake damage (Amirkardoust et al., 2020) (Amir Kardoust et al., 2021). Another study assessed the reliability of rehabilitated RC frames with eccentrically supported frames, using nonlinear static pushover analysis and comparing various reliability methods (Safaei et al., 2020). In addition, a study on the reliability analysis of RC frames using the Finite Element Method with implicit state limit functions compared various numerical methods, including MVFOSM, FORM, SORM, and Monte Carlo simulations. This study found that the reliability results were sensitive to the analysis method used and that geometric parameters had a greater impact than material characteristics in the nonlinear region (Grubišić et al., 2019).

This study is designed to address the following research question: "What is the reliability level of reinforced concrete beam elements in lecture buildings when analyzed using a probabilistic approach, particularly the First Order Second Moment (FOSM) method?" Based on this question, the primary objective of the study is to conduct a reliability analysis of reinforced concrete beams by considering statistical variations in load and resistance parameters. Furthermore, the study aims to calculate the reliability index and the probability of failure for each beam element, and to provide recommendations for structural strengthening strategies or

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

risk mitigation measures in the event that the obtained reliability index does not meet the predetermined criteria.

2. Method

Reliability analysis is done by calculating the load and resistance values obtained deterministically. The deterministic load value is obtained by modeling the structure in SAP2000 software for analysis which will produce the internal force value. The internal forces obtained are in the form of axial, shear, and moment forces. In addition, other parameters related to the value of deviation, deflection and others are obtained from the structural analysis using SAP2000. Structural modeling is done in three dimensions with a finite element analysis *(FEA) approach* where the structure has stiffness in all three directions of the structure.
Finite Element Analysis (FEA) is a numerical technique used to find solutions to engineering and physics problems by dividing its geometry into smaller elements. The basic concept of FEA involves modeling a structure as a combination of small elements that have the same shape and properties. By doing this, we can more easily analyze stability, strength, and other structural behaviors under various loading conditions.
The system of equations underlying FEA can be expressed as:

$$[[K] \cdot d = F] \tag{1}$$

Where:
[K] is the total stiffness matrix of the system,
d is the displacement vector,
F is the force vector applied to the structure.
Several things that must be defined in SAP2000 are: model, material strength, cross-section of structural elements. In addition, loading is also defined on the structure so that structural analysis can be carried out perfectly. The outcomes of structural analysis by SAP 2000 were internal forces, such as moment, shear, and axial load. It also known as ultimate forces.
Ultimate forces in the context of structures are the maximum forces that can be accepted by structural elements before experiencing failure or collapse. Ultimate forces are usually calculated based on a combination of various loads that may act on the structure, including dead loads, live loads, and additional loads like wind or earthquakes. As explained in the literature, the internal ultimate forces are forces caused by external loads (Layang, 2014). This indicates that the analysis of ultimate forces not only considers one type of load but also the interactions between various factors that can affect the stability and safety of the structure.
The analysis stages were carried out as follows:

1. Structural analysis of the lecture building was performed to determine the internal forces within the structure.
2. Internal forces such as moments, axial forces, and shear forces were considered as ultimate loads, while the structural capacities were calculated using capacity equations.
3. Reliability analysis was conducted by assigning statistical parameters to both loads and resistances, according to the function of each beams.
4. Reliability analysis was further conducted using the First Order Second Moment (FOSM) approach.
5. Reliability indices and failure probabilities were measured for each beam element.

2.1 Structural model

The structure of the building reviewed is a building with a lecture function of 3 floors. The building has a configuration as shown in Figure 1 below. The structural system used is a concrete frame structure with a steel roof frame.

p – ISSN: **1693 - 7945**
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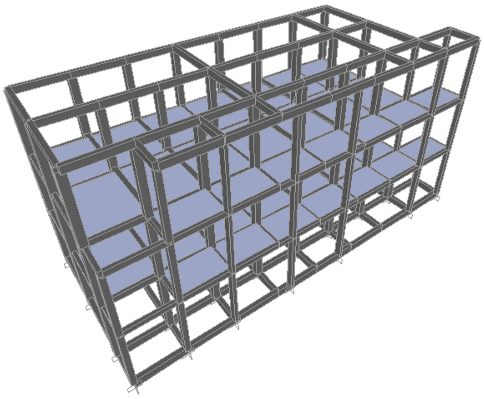
Figure 1
Lecture Building



The function of building is for lecture building. It consists of 3 floors with typical geometric and connected by RC (reinforced concrete) stairs to each floor. The roof's system is a cold-formed truss along the x-bay on the 3rd floor.

While the cross-section of the structural elements can be seen in table 1.

Table 1.
Cross-Section of Structural Elements

Structural elements	Cross-sectional dimensions (m)	
	Width (b)	Height (h)
Column, K1	0.40	0.40
Column, K2	0.30	0.30
Column, K3	0.20	0.40
Beam, B1	0.35	0.65
Beam, B2	0.25	0.35
Beam, RB	0.24	0.40
Sloof, SL	0.20	0.40
Plate	-	0.15

The columns of the building consist of 3 types of sections, the smallest of which has a cross-section length of about 0.20 m on columns K3. The biggest cross section of the column is on K1, with the size of each side being 0.40 m. Each column in the model is on the 1st floor until the 3rd floor. There are 4 types of beams, and 2 of the beams are in the bottom and top of the building. The 2 beams were ring balk (RB) and Sloof (SL), and the other beams are on the 1st floor and 2nd floor as floor beams. The plate's thickness is 0.15 m, and it's on the 1st and 2nd floors with the function of a lecture building.

2.2 Loading

The loading on the building is arranged based on gravity load and earthquake load. Gravity load consists of dead and live loads according to loading regulations (DPU, 1987)and loading (BSN, 2020).

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Table 2.
Dead Load of Floor

Type	Thickness (m)	Self Weight (kg/m³)	Dead Load (kg/m²)
Ceiling Hanger Weight (DPU, 1987)	1	7	7
Floor Finishing Weight (DPU, 1987)	0.02	2100	42
Ceramic Weight (DPU, 1987)	0.01	2400	24
Ceiling Weight (DPU, 1987)	1	11	11
Total Dead Load, Qd			84

The dead load consists of the structural weight of material applied on the model. The material of the structural member affects the weight of the model. in the building, there were ceramic, concrete, and stone members affecting its weight as in table 2 above. The constant value of some weight is tabled in building load standard.
The strength of the modeled structural material is the material strength (quality) of concrete and steel reinforcement as in table 3 below.

Table 3
Strength of Structural Materials

Material	Quality (Mpa)	Density (kg/m³)
Concrete	21	2400 (DPU, 1987)
BJTD	390	7850 (DPU, 1987)
BJTP	240	7850 (DPU, 1987)

The strength of material of each is about 21 to 390 MPa. The strength compression (f’c) of concrete is 21 Mpa and 390 MPa for yield strength (fy) of steel reinforcement for flexure. Meanwhile, the yield strength of shear steel reinforcement (fys) is 240 MPa. So, the concrete strength of its material such as columns, beams, and plates is 21 MPa, and the fy and fys fo its members are 390 and 240 MPa, respectively, for flexure and shear.
Meanwhile, the live load acting on the floor according to loading standards can be seen in table 4 below.

Table 4.
Floor Live Load

Weight Type	Live Load (kg/m²)
Lecture/Classroom	195 (BSN, 2020)
Corridor	195 (BSN, 2020)

The load applied in building the model was noted by the rule and Indonesian standard of building load standard. The living load was noted as per the function of the designed building in the Indonesian standard. The standard mention about the living load of a classroom is about 195 kg/m². Furthermore, the above values of live load are used to compile a model in SAP2000 software. Hereafter, the analysis results obtained are then used to calculate the reliability value of the beam structure.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

2.3 Structural Reliability Index Value

The reliability index value indicates how reliable the structure is in receiving the load. The higher the index value, the more capable the structure is in receiving the load and vice versa, the structure will fail if it cannot meet the required index value. The reliability index value can be calculated using several methods, including the *First Order Second Method* (FOSM). FOSM is a method that takes into account the second moment of statistical parameters, namely the mean and standard deviation. The reliability index value (β) of the beam element can be arranged using the following equation.

$$\beta = \frac{\mu_Z}{\sigma_Z} \quad (2)$$

$$\beta = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}} \quad (3)$$

The mean values of R (μR) and S (μS) as well as the standard deviation of R (σR) and the standard deviation of S (σS) can be calculated using the following equations.

$$\mu R = \lambda R \cdot Rn \quad (4\ .a)$$

$$\mu S = \lambda S \cdot Sn \quad (4.\ b)$$

$$\sigma R = V \cdot Rn \quad (5\ .a)$$

$$\sigma S = V \cdot Sn \quad (5.\ b)$$

Where

β = reliability index
Φ = cumulative probability distribution function (CDF)
μR, μS = average resistance and load
σR = standard deviation of resistance
σS = standard deviation of load
λ = bias factor
V = coefficient of variation

The values of the bias factor and coefficient of variation in beams for resistance and load according to Ellingwood et al (Nowak, 2017) have values as in table 5 below.

Table 5.
Bias Factor Values and Coefficient of Variation

Type	Bias factor (λ)	Coefficient of variation (V)
Flexure	1.08	0.14
Shear	1.00	0.19
Dead load	1.05	0.10
Live load	1.00	0.18

The values of bias factor (l) and coefficient of variation (V) are in various numbers depending on another statistical parameter of resistance and load factor. (Nowak, 2017) mentioned that the biggest value of l was on the resistance value of flexure; meanwhile, the smallest bias factor was by the live load value. The bias factor describes the bias of value to the mean. Meanwhile, the coefficient of variation value of each resistance and load value describes the division of the standard deviation to the mean value.

2.4 Reliability Index Target Value

According to (Kaszynska, 2011) and (Ghasemi, 2014) , the target reliability index value for beams, plates and columns is considered against the risk of failure of the structural components. Based on the level of failure consequences, flexure in beams is considered as a structural

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

component with quite high ductility. Failure in columns is more dangerous than beams, so the target reliability index value must be higher.

Table 6.
Target Reliability Index Value

Level of interest	New design	Existing	Historical
Low	3.00 - 3.50	2.00 - 2.50	3.25 - 3.50
Medium	3.50 - 4.00	2.50 - 3.00	3.50 - 4.50
High	3.75 - 4.50	3.75 - 3.50	3.75 - 4.75

In existing structures, the target reliability index value is allowed to be lower for economic reasons. The target reliability index value according to the level of importance for new building structures, existing structures, and structures with historical value can be seen in Table 6. Based on table 6, the reliability index value of the new design of the building is about 3.00 to 4.50. Meanwhile, for the existing building, the index value is about 2.00 to 3.50. Furthermore, the index reliability value of historical buildings must have a value of about 3.25 to 4.75.

2.5 Probability of Failure

The probability of failure of a structure refers to the likelihood that a structure will not perform as expected or function. In the context of structural engineering, the probability of failure is often measured as the likelihood that the loads applied to a structure exceed its capacity or resistance. It can be calculated using various reliability analysis methods, such as probability analysis, normal distribution, and log-normal distribution. (Zacoeb, 2015)

The probability of failure is indicated by the relationship between the resistance value and the value of the structural load effect that exceeds the ultimate strength limit condition. The probability of failure can also be determined by calculating the number of samples that do not meet the requirements with the magnitude of the probability of failure in relation to the reliability index can be expressed in the following equation:

$$Pf = \Phi[-\beta] \tag{6}$$

So the reliability index can be expressed in the following equation:

$$\beta = -\Phi^{-1}[P_f] \tag{7}$$

Where :
Pf = probability of failure
β = reliability index
Φ = cumulative probability distribution function (CDF)
ϕ= density distribution function (PDF)

2.6 Flexural Capacity of Beam

In flexible components, reliability analysis considers two boundary conditions, namely: flexural limit strength and shear limit strength. The flexural resistance of beam components can be calculated according to the following equation:

$$Mn = (As - As') \cdot \text{fy} \cdot \text{d} \cdot \left(1 - \frac{As \cdot fy}{1.7 \cdot f'c \cdot b \cdot d}\right) + As' \cdot fy \cdot (d - d') \tag{8}$$

Where:
As = area of reinforcement
fy = yield strength of reinforcement
f'c = concrete compressive strength
b = cross-sectional width
d = effective cross-sectional height

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

2.7 Shear capacity of beam

The shear resistance of the beam components can be calculated using the following equation:

$$Vn = Vc + Vs \quad (9)$$

$$V_c = \left(\frac{1}{6} f'_c\right) \cdot b_w \cdot d \quad (10)$$

$$V_s = A_v \cdot f_y \left(\frac{d}{s}\right) \quad (11)$$

$$A_v = \left(\frac{b_w \cdot s}{3 \cdot f_y}\right) \quad (12)$$

Where :
Vu = shear force of the block
Vn = shear resistance of the beam
Vc = shear resistance of concrete beam
Vs = shear resistance of reinforcement
b w = width of beam cross-section
f'y = yield strength of reinforcement
f'c = concrete compressive strength
As = area of tensile reinforcement
As' = area of compression reinforcement
d = distance from edge to tensile reinforcement
d' = radius of compression edge to tensile reinforcement
Av = minimum shear reinforcement area
S = distance between shear reinforcement

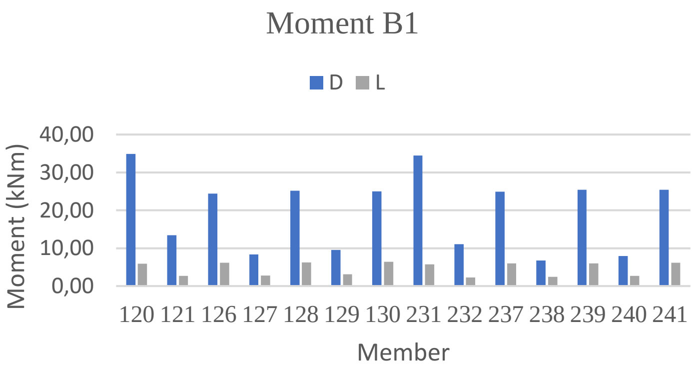
3. Results and Discussion

Based on the modeling and structural analysis carried out with SAP2000 v.14 software, each internal force in the beam and column structural elements is obtained. In the context of the analysis of the reliability of the beam structure, the internal forces of each beam structure can be seen in Figure 2 to Figure 9 below.

3.1 Internal Force of Beam B1

In beam B1, the force values in moment and shear are obtained as in figure 2. The largest moment value in the beam is obtained at 35 kNm for dead load and 6 kNm for live load. In addition, the shear force values in the member of beam B1 can be seen in figure 3.

Figure 2.
Force in Moment B1



The Moment B1 graph displays two types of data, namely moment D and moment L, presented in the form of bar charts. The horizontal axis of the graph shows categories consisting of

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

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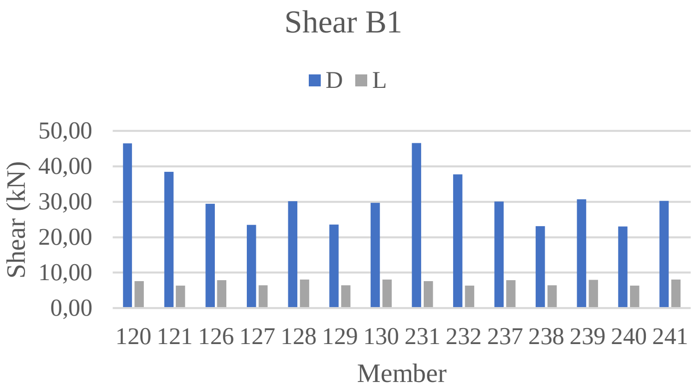
different numbers, while the vertical axis indicates the measured moment values. From this graph, it can be seen that moment D has a significant peak, particularly at categories 120 and 240, indicating a concentration of load or strong influence at these points. Meanwhile, the moment L values tend to be lower with less significant fluctuations compared to moment D. This can be interpreted to mean that the conditions measured by moment L may not be subject to the same level of heavy load as those measured by moment D. Therefore, it is crucial to evaluate the context behind these data to identify the factors influencing these differences. For further analysis, it would be very useful to conduct additional experiments that can support or challenge existing hypotheses. In conclusion, this graph provides important insights into the behavior of the structures or materials being investigated. Paying attention to the significant differences between moment D and moment L will assist researchers in taking strategic steps toward optimal design development and further research on factors affecting load.

The shear force of member beam B1 ranges between 23 kN and 46.58 kN as shown in Figure 3 below.

Figure 3.

Shear Force B1



The Shear B1 graph illustrates two distinct sets of data represented by shear forces denoted as D and L across various members identified by numerical categories (120, 121, 126, 127, 130, 231, 232, 237, 239, 240, and 241). The vertical axis quantifies the shear forces measured in kilonewtons (kN), while the horizontal axis categorizes the various members of the structure under consideration. Upon analysis of the graph, it is apparent that the shear force D exhibits noticeable peaks, particularly at members 231 and 240, suggesting that these members experience significant shear loads. In contrast, the shear force L appears to maintain a relatively lower and more stable range throughout the categories, indicating that these members may be subject to less variation in shear force compared to their counterparts in D. The consistent disparity between D and L prompts critical reflection on the structural design and load distribution across these members. Furthermore, the considerable values of shear D could imply potential vulnerability in these areas, warranting further investigation into the factors contributing to these pronounced loads. Such insights are essential for engineers when assessing structural integrity and determining the need for reinforcement or redesign. Overall, the Shear B1 graph serves as a vital tool for understanding the shear behavior within the structure, guiding subsequent analysis and ensuring that safety and performance criteria are met effectively. Evaluating these shear forces allows for more informed decision-making in structural design, ensuring resilience under various loading conditions.

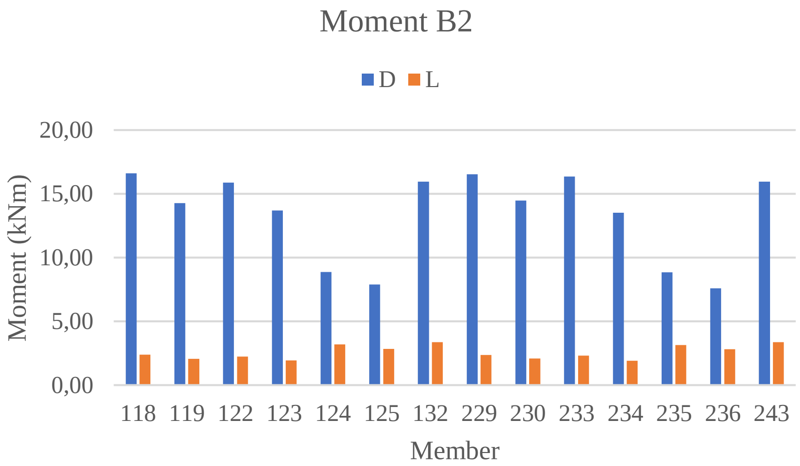
p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Based on the calculation results using SAP2000 software, the internal forces in the form of moments and shear in beam B1 obtained minimum and maximum bending values of 3 kNm and 35 kNm and minimum and maximum shear values of 6 kN and 47 kN respectively.

3.2 Internal Force of beam B2

The internal forces on the members of beam B2 can be seen in Figures 4 and 5 as follows. The moment value on the beam with a minimum and maximum dead load of 7.58 kNm to 16.53 kNm and due to live load between 2.81 kN and 3.36 kN.

Figure 4.
Moment B2

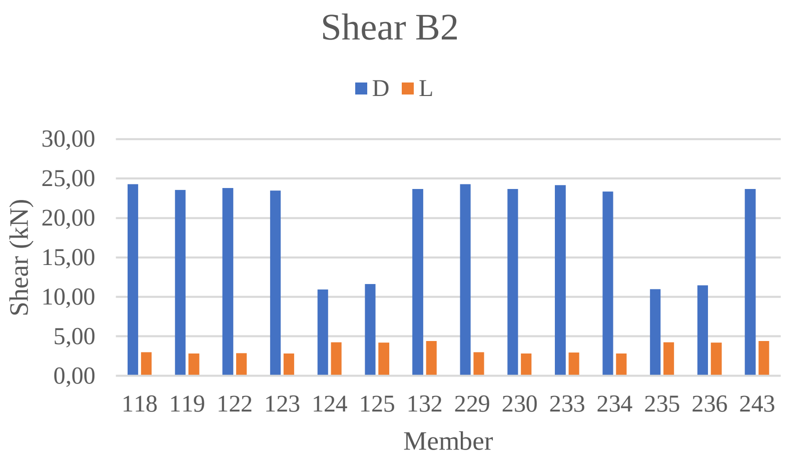


The Moment B2 graph depicts two sets of moment data represented as D and L across various members identified by numerical categories (118, 119, 122, 123, 126, 229, 230, 234, 236, and 243). The vertical axis quantifies the moments measured in kilonewton-meters (kNm), while the horizontal axis indicates the specific members being evaluated. Upon examining the graph, it becomes evident that moment D consistently shows higher values compared to moment L across most members, with peaks notably at members 123 and 236, suggesting that these members are under significant bending moments. The pronounced difference between D and L indicates a higher magnitude of stress and potential vulnerability in these areas, highlighting crucial points of interest for structural stability. Additionally, the relatively lower and more uniform values of moment L imply that these members might experience less bending stress, possibly due to design considerations or varying load conditions. This consistent pattern between the two moments raises important questions regarding load distribution, structural efficiency, and overall design integrity. The presence of high moment D values emphasizes the need for careful analysis to ensure that the structure can withstand these forces without compromising safety. Therefore, the insights gained from the Moment B2 graph are essential for engineers and designers when making informed decisions about structural reinforcement, material selection, or other design modifications to enhance resilience and performance. This analysis ultimately guides effective engineering practices in achieving both safety and functional efficacy in structural design.

Meanwhile, the shear force on beam B2 can be seen in Figure 5 below with a range of values due to dead load between 11 kN and 24 kN and due to live load between 2.8 kN and 4.4 kN.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Figure 5.
Shear B2



The Shear B2 graph presents two distinct shear force measurements, designated as D and L, across various members categorized by numerical identifiers (118, 119, 122, 123, 124, 125, 132, 229, 230, 233, 234, 236, and 243). The vertical axis shows the shear forces in kilonewtons (kN), while the horizontal axis corresponds to the specific members being assessed. From a detailed examination of the graph, it is apparent that shear force D exhibits a significant range of values, with pronounced peaks at multiple members, especially around members 123 and 124. This trend indicates that these members experience considerable shear loads, which may have implications for their structural integrity under applied forces. Conversely, shear force L displays consistently lower values throughout the members, suggesting a more stable and less variable shear condition. The distinct disparity between D and L raises critical considerations regarding the load distribution within the structure. The higher shear forces observed in D may signify areas of potential weakness or critical stress, necessitating further investigation to ensure that these members are adequately designed to bear their respective loads without failure. Additionally, understanding the relationship between these shear forces is crucial for optimizing structural design, reinforcing critical areas, and anticipating stress concentrations that could affect the performance and safety of the overall structure. In conclusion, the Shear B2 graph offers valuable insights into the shear behavior of the structure, enabling engineers and designers to make informed decisions about potential reinforcements or design changes to enhance resilience against load demands.
In addition, the moments due to dead load on the RB beam members are between 19 kNm and 39.7 kNm and live load is between 0.14 kN and 0.33 kN.

p – ISSN: **1693 - 7945**
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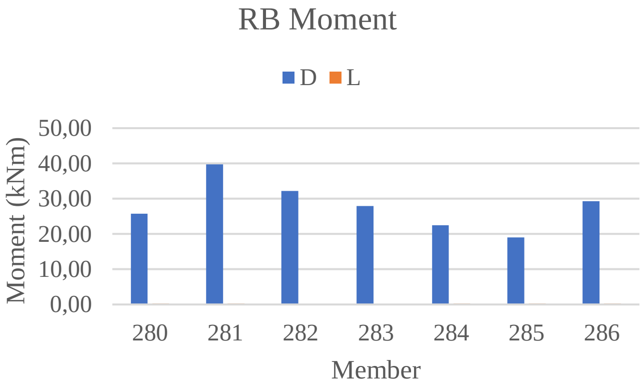
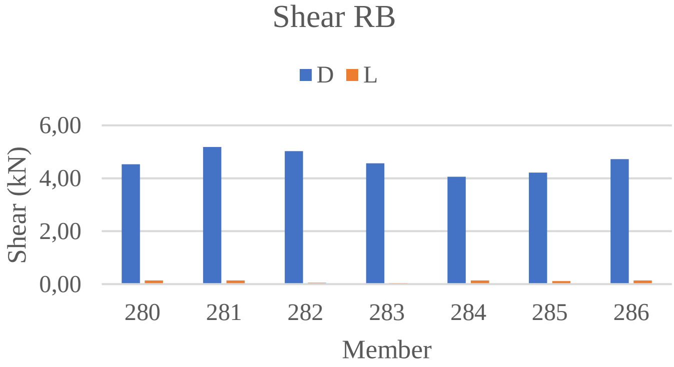
Figure 6.
Moment RB



The RB Moment graph illustrates the moment data represented as D and L across various members labeled from 280 to 286. The vertical axis quantifies the moments measured in kilonewton-meters (kNm), while the horizontal axis indicates the specific members being evaluated. Upon analyzing the graph, it is clear that moment D consistently demonstrates higher values across nearly all members, particularly peaking at member 281 with a significant load of approximately 50 kNm. This high moment suggests that member 281 is subjected to considerable bending forces, potentially indicating a critical region within the structure that requires careful structural consideration. In contrast, moment L remains markedly lower, illustrating minimal fluctuation across the assessed members, which infers that these members experience much less stress under the given loading conditions. The notable disparity between the magnitudes of moments D and L highlights the importance of understanding how loads are distributed within the structural system. The elevated moments of D could point to areas where additional reinforcement may be needed to prevent structural failure or excessive deflection. This analysis is crucial for engineers in informing design decisions, especially in determining which members might require enhanced support or alternative materials to ensure long-term stability and safety. In conclusion, the RB Moment graph provides valuable insights into the structural behavior of the members under review, guiding engineers towards strategies for optimizing design and ensuring adequate performance in response to applied loads.
Furthermore, the shear force RB due to dead load is between 4 kN and 5.19 kN and due to live load is between 0.05 kN and 0.15 kN.

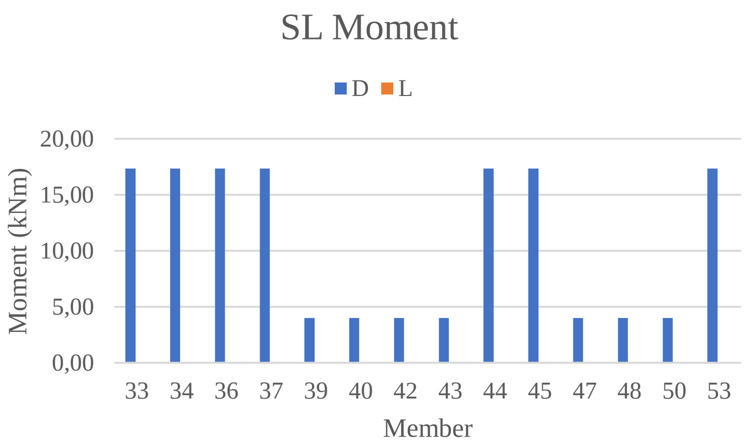
Figure 7.
Shear RB



p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

The Shear RB graph illustrates the shear force measurements denoted as D and L across a series of structural members labeled from 280 to 286. The vertical axis quantifies the shear forces in kilonewtons (kN), while the horizontal axis represents the specific members being assessed. Upon careful examination of the graph, it is evident that shear force D displays relatively consistent and substantial values across all members, with peak measurements around 5 kN for members 280 and 281. This indicates that these members are experiencing considerable shear loads, which is critical for maintaining the structural integrity of the system under various conditions. On the other hand, shear force L remains notably lower and constant, suggesting minimal contribution to the shear loads on these members. The difference between D and L raises important considerations regarding load distribution within the structure. The relatively uniform values of shear force L indicate that these members may be designed to operate under lighter loading conditions, or they may be less critical in terms of shear resistance compared to those represented by shear force D. Understanding this shear behavior is essential for engineers, as it informs the necessary precautions to ensure that structural members can adequately bear applied forces without risking failure. The consistency of the higher shear values in D implies that additional analysis and potential reinforcement may be necessary for the affected members to enhance safety and performance. Overall, the Shear RB graph serves as a valuable tool in assessing the shear behavior of the structure, guiding engineering decisions regarding design optimization and structural reliability.
In addition, the moment of the SL sloof due to dead load has a value between 4 kNm and 17.34 kNm as shown in the following graph 8.

Figure 8.
SL Moment

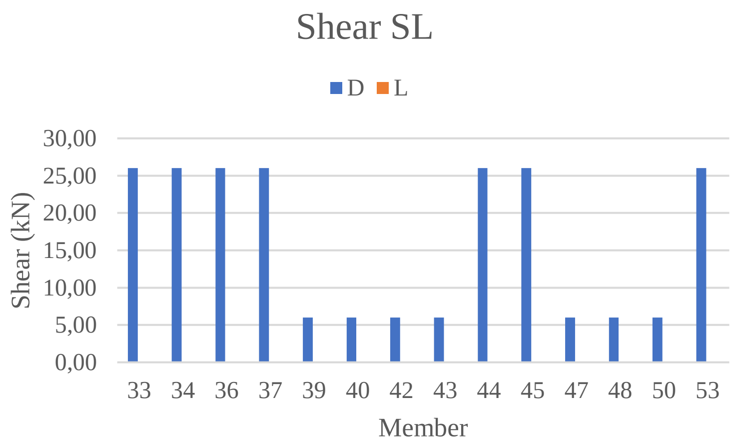


The SL Moment graph illustrates the moment data represented by D and L across various members identified by numerical categories ranging from 33 to 53. The vertical axis quantifies the moments measured in kilonewton-meters (kNm), while the horizontal axis indicates the specific members being assessed. Upon analyzing the graph, it becomes apparent that moment D consistently demonstrates higher values across most of the members, with notable peaks around members 33 and 41, where moments reach approximately 16-17 kNm. This trend suggests that these particular members are subjected to significant bending moments, highlighting them as critical components within the structural system that must be carefully considered during the design process. In contrast, moment L remains consistently lower across the assessed members, indicating that these members perhaps endure less stress under the given loading conditions. The distinct disparity between moments D and L raises essential considerations regarding the distribution of loads and the potential vulnerabilities in the

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

structural design. The relatively high values of moment D may indicate areas that could benefit from reinforcement to ensure they can safely accommodate the applied forces without compromising structural integrity. Therefore, engineers must pay particular attention to these critical members as they plan for potential design modifications or reinforcements. The insights gained from the SL Moment graph are invaluable for guiding engineering decisions, ensuring that members are adequately designed to withstand the expected loads while maintaining overall structural performance.
In addition, the shear force of the SL sloof due to dead load is between 6 kN and 26 kN.

Figure 9.
Shear Force SL



The Shear SL graph displays the shear force data represented by D and L across various structural members labeled from 33 to 53. The vertical axis quantifies the shear forces in kilonewtons (kN), while the horizontal axis corresponds to the specific members being analyzed. Upon examining the graph, it is evident that shear force D exhibits substantial and relatively consistent values across all members, with peak measurements at members 33 to 37, each reaching around 25 kN. This indicates that these members are experiencing considerable shear loads, which is crucial for understanding the structural behavior and ensuring adequate safety measures are in place. In contrast, shear force L remains markedly lower and more stable, with values consistently below 10 kN across the assessed members. The significant difference between shear forces D and L suggests varying load distribution and structural demand on each respective member. The elevated shear forces from D indicate potential critical zones that require closer inspection, as these members may be more susceptible to shear failure if not properly supported or reinforced. It is essential for engineers to take these findings into account while designing the structure to ensure it can adequately resist the applied forces. The Shear SL graph thus serves as a vital resource for evaluating the shear behavior within the structure, guiding engineers in making informed decisions about potential reinforcements or adjustments needed to enhance structural integrity and safety.
Based on the results of the structural analysis that produces internal forces in the form of moments and shear on the beam. Furthermore, the value of the reliability index of the beam element can be calculated by considering the resistance and load variables. The beam resistance variable can be calculated using equation 7 for bending resistance and equation 8 for shear resistance.
Next, the reliability index value of the flexural and shear beams can be calculated using equation 2. The reliability index value is calculated by considering the average value and standard deviation of each flexural and shear resistance and the flexural and shear load values.

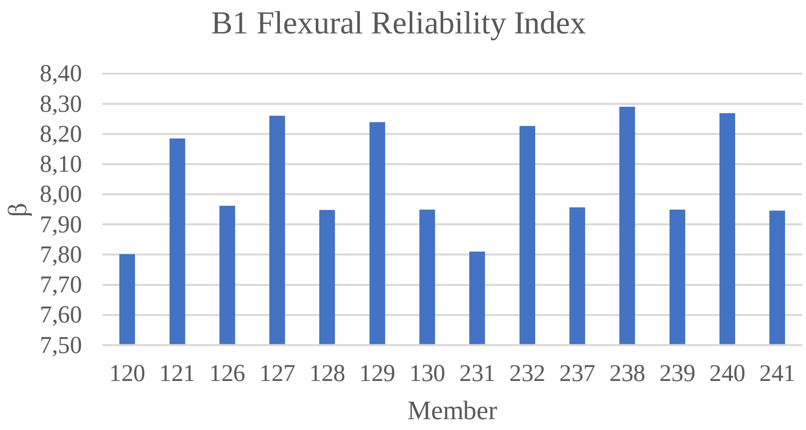
p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

In addition, the values of μ R and σR are calculated by considering the bias factor value (λ) and the coefficient of variation (V) respectively according to the values in table 5.

3.3 Reliability Index (β) of beam B1

Based on the structural analysis and calculation of the reliability index value, the flexural reliability index value of beam B1 can be seen in the following figure.

Figure 10.
Flexural Reliability Index B1



The value β of beam B1 ranges between 7.80 and 8.30, while the shear reliability index value of beam B1 can be seen in Figure 11 below. The β value of all B1 beams is in reliable condition because the β value is greater than the β target of all types of buildings.

The B1 Flexural Reliability Index graph displays the flexural reliability index (β) measured across various structural members categorized numerically from 120 to 241. The vertical axis represents the values of the flexural reliability index (β), while the horizontal axis indicates the members being evaluated. An analysis of this graph reveals that the values of β vary among the studied members, with most values ranging between 7.80 and 8.20. The highest peaks of the reliability index are observed in members 126 and 231, each reaching 8.20. This indicates that these members have a higher reliability level against flexural loads compared to the others, suggesting a better structural performance in resisting applied forces.

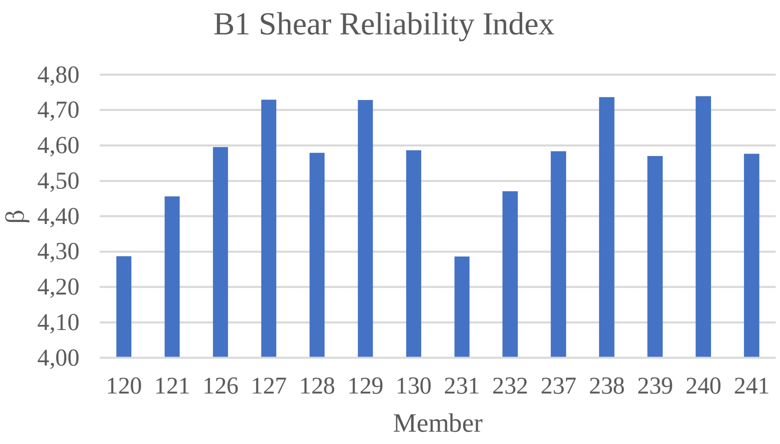
Conversely, members 240 and 241 display lower β values, around 7.70, indicating that these members may be more susceptible to failure under flexural loads. The observed differences in reliability index values provide essential insights into how each member may perform under real-world conditions. This observation is crucial for the design and evaluation process of the structure, as lower β values in certain members could signal engineers to consider reinforcement, modifications, or further evaluations of their structural designs.

Overall, the B1 Flexural Reliability Index graph serves as a valuable analytical tool for understanding the resilience of members to flexural loading, guiding accurate decision-making in the development of safer and more efficient designs.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Orginal Article

Figure 11.
Shear Reliability Index B1

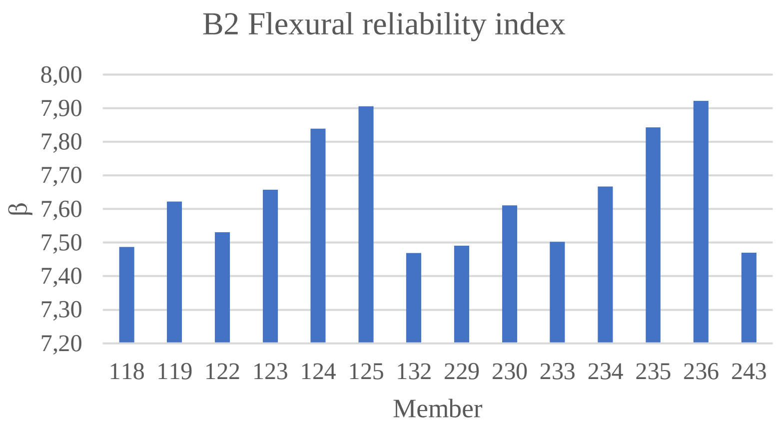


The reliability index value (b) of shear in B1 is between 4.28 and 4.73, so the beam is declared safe in receiving shear forces because the value exceeds the b target value. The minimum requirement of the reliability index for building is about 3.00 on a new design, and the maximum value is about 4.75, so the shear index value is in a reliable condition.
The B1 Shear Reliability Index graph illustrates the shear reliability index (β) measured across various structural members identified by numerical categories ranging from 120 to 241. The vertical axis represents the values of the shear reliability index (β), while the horizontal axis indicates the specific members being assessed. An analysis of the graph reveals that the values of β exhibit a range between approximately 4.20 and 4.80, displaying some variability among the members. Notably, members 126 and 231 achieve the highest reliability index values, reaching around 4.80, which signifies that these members possess a higher level of reliability in resisting shear forces compared to others in the set.
In contrast, members such as 120 and 125 exhibit lower reliability index values, hovering around 4.20, suggesting that these particular members may be more vulnerable to shear failure under applied loads. The discernible differences in shear reliability index values across the members underscore the importance of careful structural analysis when evaluating load-bearing capacities and overall performance. The higher values of β for certain members indicate a more robust design that can better withstand shear stresses, which is essential for ensuring structural integrity. These insights are invaluable for engineers and designers, as they can utilize this data to inform decisions regarding necessary reinforcements or modifications to members at risk of exceeding their shear capacity.
Ultimately, the B1 Shear Reliability Index graph serves as a critical tool for understanding the shear capacity and safety margins of various structural elements. By analyzing this index, engineers can make informed decisions to enhance the durability and resilience of the overall structure.

Furthermore, the flexural reliability index value of beam B2 can be seen in Figure 12 below. The reliability index (β) flexural value of beam B2 ranges between 7.49 and 7.92. bases on the analysis, the B2 Beam is in reliabile condition for the flexural reliability. Meanwhile, the reliability index value of shear in B2 beam can be seen in Figure 13 below.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Figure 12.
Flexural Reliability Index B2



The β value on beam B2 ranges between 3.25 and 3.80. Based on this value, beam B2 is declared safe in receiving shear loads because the value b is between the values 3.0 and 4.75. The target value of β is between 3.00 and 4.00 for the new design; meanwhile, the β value of the existing building is about 2.00 to 3.50.

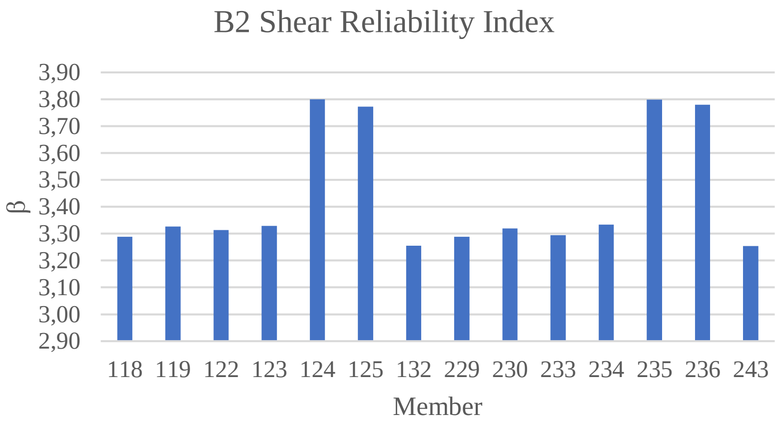
The B2 Flexural Reliability Index graph illustrates the flexural reliability index (β) for various structural members categorized by numerical labels ranging from 118 to 243. The vertical axis quantifies the index values, while the horizontal axis represents the specific members being analyzed. Upon examining the graph, it is evident that the values of β vary significantly among the members, with most values falling between 7.30 and 8.00. The peaks in the reliability index are observed at members 236 and 243, which reach values close to 8.00, indicating that these members exhibit a higher level of reliability in terms of flexural capacity compared to others in the set.

In contrast, members such as 118, 119, and 125 show lower reliability index values ranging around 7.30 to 7.50, suggesting a reduced capacity to handle flexural loads adequately. The variation observed in the reliability index highlights critical considerations regarding the performance and safety of the structure under operational loads. Members with a high flexural reliability index are likely to perform better under bending stresses, reducing the risk of failure and ensuring structural stability.

The insights gained from the B2 Flexural Reliability Index graph are paramount for engineers during the design and assessment process. Identifying members with lower β values can prompt further investigation and potential design modifications or reinforcements to enhance their performance. This proactive approach is essential for maintaining overall structural integrity and safety, particularly in applications subjected to significant loads. Overall, the B2 Flexural Reliability Index graph provides valuable information for optimizing structural designs, ensuring that all members are capable of effectively resisting applied forces while maintaining reliability and safety throughout their operational lifespan.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Figure 13.
Shear Reliability Index B2



The B2 Shear Reliability Index graph visualizes the shear reliability index (β) for different structural members categorized by numerical identifiers ranging from 118 to 243. The vertical axis represents the values of the shear reliability index, while the horizontal axis designates the specific members being evaluated. Analyzing the graph reveals that the β values generally fall within the range of approximately 2.90 to 3.90, indicating a moderate level of variability among the members. Notably, members 123 and 236 stand out with the highest reliability index values of around 3.90, suggesting that these members possess a superior capacity to resist shear forces compared to their counterparts.

Conversely, some members, such as 118 and 125, exhibit lower β values close to 3.00, which may imply a higher susceptibility to shear failure under applied loads. This discrepancy highlights the importance of understanding the shear capacities of various members, as it directly impacts the overall structural performance and safety. The lower reliability index values can signal potential weaknesses within the design, prompting engineers to consider necessary reinforcements or alternative design strategies to mitigate risks associated with shear loading.

The variations in the shear reliability index provide crucial insights for engineers engaged in structural analysis and design. By recognizing which members have lower β values, engineers can prioritize those areas for further assessment and potential enhancement, ensuring that the structure can adequately withstand the anticipated shear forces during use. Ultimately, the B2 Shear Reliability Index graph serves as an essential tool for evaluating the shear behavior of the structure, guiding informed decision-making to bolster the integrity and resilience of the overall construction.

Furthermore, the flexural reliability index value of the RB beam can be seen in Figure 14 below. The value of b flexural on the RB beam ranges between 6.71 and 7.62. The b value of RB on flexural reliability exceeds the target value in the level target of the building, so that the beams are reliable in their flexural behavior on accepting loads.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

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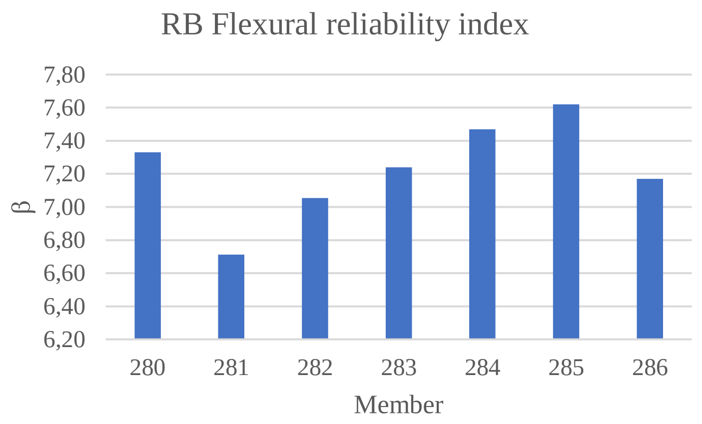
Figure 14.
Flexural Reliability Index RB



The RB Flexural Reliability Index graph depicts the flexural reliability index (β) for various structural members identified by numerical categories ranging from 280 to 286. The vertical axis quantifies the values of the flexural reliability index, while the horizontal axis denotes the specific members under assessment. A careful analysis of the graph reveals a range of β values primarily between 6.60 and 7.80, showcasing a moderate level of variability among the members. The highest reliability index is observed in member 281, which peaks at approximately 7.80. This suggests that member 281 exhibits a superior capacity to withstand flexural loads compared to the other members, indicating its significance in the overall structural performance.

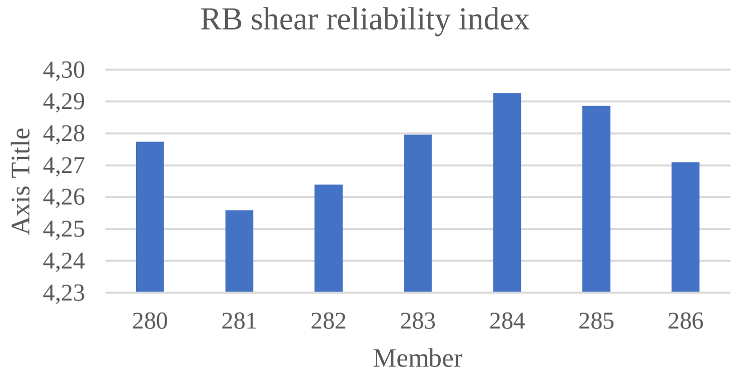
In contrast, members 280 and 284 display lower β values, around 6.60 to 6.80, indicating that these members have a relatively reduced capacity to resist bending stresses. The variations in the flexural reliability index underscore critical points for structural analysis, as members with lower β values may require additional examination to assess their ability to handle applied loads safely. Engineers may need to consider potential reinforcements or design modifications for these members to enhance their flexural capacity and ensure overall structural integrity.

Understanding the implications of the flexibility reliability index is vital for informed decision-making during the design and evaluation processes. By identifying the members with higher and lower reliability indices, engineers can prioritize their efforts in assessing the structural design strategies. Overall, the RB Flexural Reliability Index graph serves as a valuable resource for evaluating the performance of various members under flexural loading, guiding engineers in crafting designs that maximize safety and effectiveness while minimizing the risk of structural failure.

Meanwhile, the shear reliability index value of the RB beam can be seen in Figure 15 below. The b value of the RB beams is about 4.26 to 4.29. These values exceed the minimum index target on new designs and existing buildings, which is valued at about 2.00 to 4.75.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Figure 15.
Shear Reliability Index RB



The RB Shear Reliability Index graph illustrates the shear reliability index (β) for various structural members labeled numerically from 280 to 286. The vertical axis represents the values of the shear reliability index, while the horizontal axis indicates the specific members being evaluated. A detailed analysis of the graph shows that the β values range from approximately 4.23 to 4.30, indicating a relatively narrow band of variability among the members. Notably, members 284 and 286 achieve the highest reliability index values of around 4.30, suggesting that these members exhibit a strong capacity to resist shear forces effectively.
Conversely, the other members, including 280, 281, and 283, display β values closer to 4.24 to 4.27, indicating slightly lower shear reliability. While all analyzed members demonstrate reasonable reliability, the subtle differences in their indices may highlight distinctions in their capacities to handle shear loads. Understanding these differences is essential for assessing potential vulnerabilities in the structure, especially under dynamic or high-load conditions.
The RB Shear Reliability Index provides valuable insights for engineers and designers as they conduct structural analyses. By recognizing the members with higher and lower reliability indices, engineers can prioritize their design modifications, reinforcements, or further evaluations to ensure that all members are equipped to handle the anticipated shear forces without risking structural integrity or performance.
Overall, the RB Shear Reliability Index graph serves as a critical tool in evaluating the shear behavior of various structural elements, guiding informed decisions in optimizing design strategies to enhance safety and durability throughout the lifespan of the construction.
Furthermore, the flexural reliability index value of the SL beam can be seen in Figure 16 below. The b flexural value of the SL beam ranges between 8.04 and 8.34. These values are so high and exceed the target index value. In other words, the beams would say effective but less efficient because the difference to the minimum target index value is large. Furthermore, there were more strategies to achieve the efficiency of building design; one of them is to reduce the cross section of the beam so that the index value can be set to a suitable value.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

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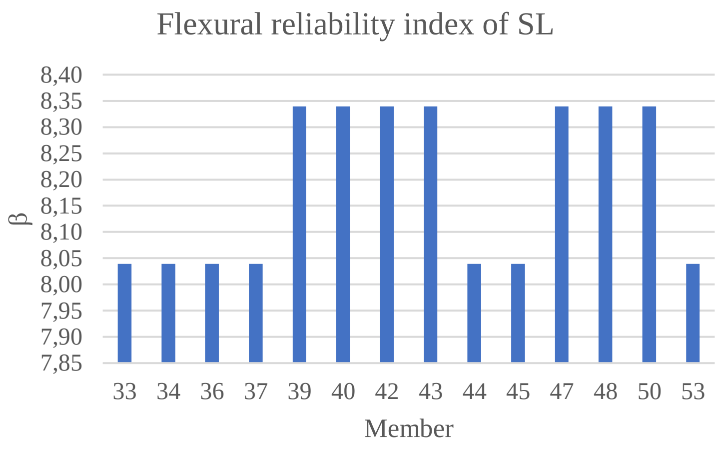
Figure 16.
Flexural Reliability Index SL



The Flexural Reliability Index of SL graph presents the flexural reliability index (β) for various structural members identified by numerical labels ranging from 33 to 53. The vertical axis quantifies the values of the flexural reliability index, while the horizontal axis denotes the specific members being assessed. Upon analyzing the graph, it is apparent that the β values exhibit a range primarily between 7.85 and 8.40, indicating a degree of variability in the flexural capacity among the members.

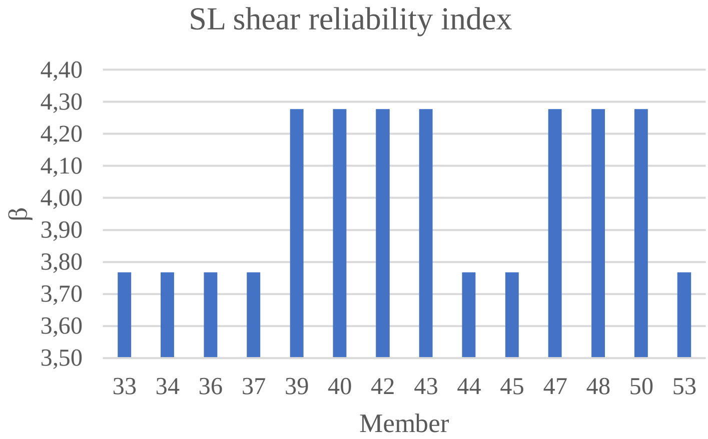
Notably, members 39 and 52 stand out with peak reliability index values around 8.35 to 8.40, signifying that these members have superior flexural performance and can withstand greater bending moments compared to others in the group. In contrast, members such as 33 and 50 display lower β values, hovering around 7.85 to 8.00, which suggests that these members may have a relatively reduced ability to resist flexural stresses under applied loads.

The significant differences observed in the reliability indices among the members highlight critical considerations for structural design and analysis. Higher values of β represent members that can better endure flexural loads, thus playing a pivotal role in maintaining overall structural integrity. Conversely, members with lower β values signal potential vulnerabilities, necessitating further examination or reinforcement to ensure they can effectively support the anticipated loads.

Overall, the Flexural Reliability Index of SL graph serves as an important analytical tool that helps engineers evaluate the flexural performance of various structural elements. By identifying members with both high and low reliability indices, engineers can make informed decisions regarding design modifications, reinforcements, and materials, thus optimizing structural safety and durability. Meanwhile, the shear reliability index value of the SL beam can be seen in Figure 17 below. The β index value of shear is about 3.77 to 4.28. The minimum value was on beams 33 to 37, 44, 45, 53 and the maximum value is on beams 39 to 43, and 47 to 50.

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Figure 17.
Shear Reliability Index SL



The SL Shear Reliability Index graph displays the shear reliability index (β) for various structural members categorized by numerical labels ranging from 33 to 53. The vertical axis represents the values of the shear reliability index, while the horizontal axis indicates the specific members being analyzed. An examination of the graph reveals that the β values generally range from approximately 3.70 to 4.40, reflecting a moderate level of variability among the members.
Notably, members 39 and 50 achieve the highest reliability index values at around 4.40, indicating a robust capacity of these members to resist shear forces effectively. In contrast, members 33 and 43 exhibit lower β values, hovering around 3.70, suggesting that these members may be more vulnerable to shear failure under applied loads. The discernible differences in the shear reliability index highlight critical considerations for structural analysis, as the reliability index directly correlates with the member's ability to withstand shear stresses. The variability observed in the shear reliability indices indicates areas of potential concern within the structure. Members with lower β values, such as 33 and 43, could benefit from additional scrutiny and possible reinforcement to ensure adequate load-bearing performance. Overall, understanding the shear reliability index is crucial for engineers in evaluating the structural integrity and safety of the construction, guiding them toward informed decision-making regarding design adjustments or reinforcements that may be necessary.
In summary, the SL Shear Reliability Index graph serves as an essential tool in analyzing the shear behavior of different structural members. By recognizing the members with varying levels of reliability, engineers can effectively prioritize their focus on those that may require enhancements to maintain safety and performance across the structural system.

4. Conclusion

In conclusion, this comprehensive study on the reliability analysis of reinforced concrete structures, particularly focusing on beams and their responses to various loads, underscores the critical importance of employing probabilistic design methods in architecture and engineering. The analysis demonstrated how structures must be capable of supporting various functional loads, especially in educational facilities where public safety and structural integrity are paramount. The methodologies adopted, including finite element analysis with SAP2000 and the application of statistical reliability indices, allowed for a thorough assessment of each structural member.
The findings indicate that many structural elements, such as beams B1, B2, and SL, surpassed the required reliability index values, confirming their capacity to withstand flexural and shear

p – ISSN: **1693 - 7945**
e – ISSN: **2622 - 1969**

Orginal Article

forces. Moreover, significant attention was drawn to members displaying lower reliability indices, suggesting that further examination or reinforcement could enhance overall safety. The research highlighted critical insights into load distribution, structural performance, and the impact of design parameters on the reliability of reinforced concrete buildings.

By integrating methodical approaches to reliability analysis and emphasizing the necessity of accounting for uncertainties in material strengths and loading conditions, this study provides valuable guidance for engineers and designers. It reinforces the need for adaptive design strategies to ensure that structures not only meet safety requirements but also achieve greater efficiency and resilience in their operational lifespans. The adoption of these insights will facilitate informed decision-making in future design modifications, ultimately contributing to more robust and sustainable construction practices.

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