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REVIEW

Structural Analysis and Design of a Seismically Resilient Multi-Story Primary School Building in Rural Bangladesh

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ABSTRACT

School buildings play a vital role in the development of a country's infrastructure, serving as key facilities for education and community growth. These structures must fulfill essential criteria, including structural safety, functionality, and cost-effectiveness. This study explores the structural analysis and design of a four-story primary school building located in Dhorenda, Savar Upazila, Dhaka. The site, encompassing 7.68 Katha, is approximately 12 meters southeast of the Dhaka-Aricha National Highway and 100 meters southeast of Nabinagor market. The primary goal of the project is to develop a multi-story school building that enhances student capacity and provides improved facilities. Various floor plan configurations are evaluated to ensure optimal performance under these forces. The study is organized into two main components: structural analysis and structural design. For structural analysis, the Load and Resistance Factor Design (LRFD) method is applied to determine the impact of various loads, including self-weight, live loads, and wind forces, on the building. Finite element software, ETABS, is utilized to simulate the structure's behavior and validate its response to these loads. The structural design involves determining the dimensions and reinforcements of key components, such as beams, columns, slabs, and foundations, to ensure the stability and strength of the building. This research highlights the complexities involved in designing and constructing a robust educational facility and offers recommendations for improving the efficiency of similar projects in the future. The findings serve as a resource for professionals seeking to implement sustainable and resilient designs in school infrastructure development.

Keywords: Infrastructure Development; School Building; Structural Analysis; Planning Process

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1. Introduction

Primary school construction is a crucial aspect of infrastructure development in any country. In Bangladesh, the rapid expansion of the population and increased urbanization have created a significant demand for new primary school buildings. These facilities play a vital role in ensuring access to quality education, particularly in suburban and rural areas. However, the structural design of such buildings involves addressing several critical factors, including the safety of occupants, functional requirements, economic feasibility, and environmental sustainability. Achieving an optimal design requires a meticulous approach that balances these considerations to provide a safe and conducive learning environment for students. Designing a primary school building demands careful planning and analysis, especially in regions prone to natural disasters such as earthquakes and strong winds. Structural integrity and reliability under these loads are paramount to ensure the safety of students and staff. Additionally, economic considerations must be balanced to make the project viable without compromising safety and functionality. This paper analyzes the design and performance of a four-story primary school building located in Dharenda, Savar, a suburban area in Bangladesh with moderate seismic activity. The primary goal of this study is to develop a structure that is safe, cost-effective, and environmentally sustainable, meeting the requirements of both functionality and resilience. This involves examining site conditions, structural layouts, and material properties to create an optimized design solution that adheres to local building codes and international standards.

Education is a cornerstone of national development, and primary schools serve as the foundation of a child's academic journey. The quality of the learning environment directly impacts students' academic performance and overall well-being. Therefore, primary school buildings must be designed to provide a safe, comfortable, and stimulating environment that fosters learning and creativity. In densely populated countries like Bangladesh, where land resources are limited, multi-story school buildings are often the most practical solution to accommodate the growing number of students. However, this approach introduces additional design challenges, particularly in ensuring structural stability and resilience. One of the primary concerns in designing multi-story school buildings is the potential impact of natural disasters. Bangladesh is located in a region that experiences moderate to high seismic activity due to its proximity to tectonic plate boundaries. Earthquakes pose a significant threat to the structural safety of buildings, particularly those that house large numbers of occupants, such as schools. In addition, strong winds associated with cyclones and other weather events can also impose significant lateral loads on buildings. To address these challenges, the design of primary school buildings must incorporate advanced engineering techniques and materials that enhance their ability to withstand such forces. Economic feasibility is another critical factor in the construction of primary school buildings. In developing countries like Bangladesh, financial resources for infrastructure projects are often limited. As a result, it is essential to develop cost-effective designs that maximize the use of available resources without compromising safety or quality. This requires careful consideration of construction materials, building layouts, and structural systems. Lightweight materials, such as brick chip concrete, can reduce the overall weight of the structure, thereby lowering construction costs and improving seismic performance. Optimized layouts and efficient use of structural members can further enhance the cost-effectiveness of the design. The design process follows the Bangladesh National Building Code (BNBC) [1] and ACI 318 [2] standards to ensure safety, durability, and compliance. Additionally, the building is assessed for its ability to resist seismic and wind loads based on the site's geological and environmental conditions.

Environmental sustainability is increasingly recognized as a key consideration in building design. The construction industry is a major contributor to greenhouse gas emissions and resource depletion, making it imperative to adopt sustainable practices in all aspects of construction. For primary school buildings, this means using environmentally friendly materials, minimizing waste, and incorporating energy-efficient features. In the context of this study, the use of recycled materials, such as brick chips, not only reduces environmental impact but also aligns with the principles of sustainable development. The site-specific conditions in Dharenda, Savar, played a significant role in shaping the design of the primary school building analyzed in this study. The area's soil properties, wind conditions, and seismic activity were carefully evaluated to ensure that the proposed design would be safe and effective. According to the soil report, the site was classified as SC, which corresponds to a soft clay soil profile. This classification required the use of site-specific amplification factors, Fa and Fv, to account for the effects of soil-structure interaction on seismic performance. These factors were derived from the ASCE 7-16 [3] guidelines and cross-referenced with the Bangladesh National Building Code (BNBC) 2020 to ensure consistency with local standards. Wind conditions were another important consideration in the design process. The design wind speed for Dhaka, which includes Dharenda, was determined to be 65.7 m/s based on BNBC 2020. This value represents the maximum wind speed that the building is expected to withstand during its lifetime. The exposure condition for the site was classified as B, indicating a suburban area with moderate levels of wind turbulence. However, for modeling purposes, the exposure condition was considered as C, as per ASCE 7-16, to account for potential variations in wind intensity. This conservative approach ensured that the design would remain robust under a range of wind conditions. The structural design of the building involved the development and analysis of two floor plans, referred to as Model 1 and Model 2. Both models were designed as four-story structures with reinforced concrete frames. The primary difference between the two models lay in the number and arrangement of structural members. Model 1 featured 24 columns and 8 beams, while Model 2 had 15 columns and 5 beams. The dimensions of the beams were kept constant at 12”x18” in both models, but the column dimensions were adjusted to maintain the same total surface area. This approach allowed for a direct comparison of the performance of the two layouts under identical loading conditions.

The analysis of the two models was conducted using ETABS software, which provides a comprehensive platform for finite element analysis of structural systems. The software allowed for the simulation of various load scenarios, including seismic, wind, and gravity loads. For seismic analysis, response spectrum analysis was performed using site-specific seismic coefficients and amplification factors. The wind loads were applied as lateral pressures based on the design wind speed and exposure condition. Gravity loads included the self-weight of the structure, live loads, and superimposed dead loads. Several key performance metrics were evaluated during the analysis, including lateral displacements, story drifts, internal forces in columns and beams, and foundation reactions. These metrics provided insights into the stability, strength, and overall behavior of the two models under different loading conditions. Additionally, the natural frequencies and mode shapes of the structures were analyzed to assess their dynamic behavior and vulnerability to resonance effects. The results of the analysis highlighted the strengths and weaknesses of each floor plan. Model 1 demonstrated superior stability and load distribution, with lower lateral displacements and story drifts compared to Model 2. This performance can be attributed to the increased number of structural members in Model 1, which provided greater redundancy and reduced stress concentrations. However, Model 2 offered significant advantages in terms of cost and material efficiency. The reduced number of columns and beams in Model 2 resulted in lower construction costs and minimized material usage, making it a more economical option.

The choice between the two models ultimately depends on the priorities of the project. In regions with higher seismic activity or greater exposure to strong winds, Model 1 would be the preferred option due to its enhanced stability and safety. Conversely, Model 2 may be more suitable for areas with lower seismic and wind risks, where cost efficiency is a higher priority. Regardless of the chosen model, the use of lightweight concrete and other sustainable practices ensures that the building meets modern standards of environmental responsibility. The design of primary school buildings in Bangladesh requires a holistic approach that addresses safety, functionality, cost, and sustainability. The analysis presented in this study demonstrates the importance of site-specific considerations and the benefits of using advanced engineering tools like ETABS to optimize structural performance. By carefully balancing these factors, it is possible to develop primary school buildings that provide a safe, conducive, and sustainable environment for learning, contributing to the long-term development of the nation.

2. Literature review

Bangladesh is located in a region of high seismic risk, as evidenced by historical earthquake records, geological studies, and ongoing seismic activity. Earthquakes, along with other natural disasters, can cause devastating impacts on communities, leading to significant loss of life and property. In the Savar region, studies reveal a low level of earthquake preparedness, with an average satisfaction score of just 8.91 out of 25 [4]. Structural evaluations in the area highlight varying levels of risk: around 43% of buildings are deemed safe from damage, 10% exhibit a slight risk of damage, 28% show a reduced likelihood of collapse, 15% are categorized as being at moderate risk of collapse, and 4% face a severe risk of collapse [5]. Contributing factors to this vulnerability include past earthquake experiences, rapid urban expansion, high population density, and the growth of economic infrastructure (CDMP, 2014). With 35.86% of the population residing in urban areas, it is critical to evaluate the earthquake resilience of building designs, considering the country’s unique geological and socio-economic conditions.

Beyond seismic risks, additional research has focused on natural hazards such as rainfall-induced landslides. For instance, Hasan [6] conducted case studies in the hilly regions of Bangladesh to examine slope stability under heavy rainfall. Moreover, soil chemical properties have been extensively studied by Hore [7-11] to gain insights into how soil conditions affect the design of earthquake-resistant embankments. These interdisciplinary studies are vital for developing a comprehensive understanding of natural hazards and for improving infrastructure resilience against disasters. Advances in modern structural analysis tools, such as ETABS 2020, have revolutionized the evaluation and design of buildings subjected to seismic forces. This software facilitates detailed modeling of forces, bending moments, stresses, strains, and deformations in complex structures, ensuring accuracy while reducing dependence on manual calculations [12–16]. ETABS complies with regional and international codes, such as IS:1893-2016, to guarantee that structural designs meet stringent seismic requirements. Its efficiency and precision have made it an indispensable tool in the construction industry, enabling faster, cost-effective designs to address the rising demand for resilient infrastructure [17–21]. Hore [21] also analyzed the seismic performance of wrap-faced retaining wall embankments constructed with local sands, providing insights into geotechnical properties under seismic forces. The challenges of earthquake resilience in Bangladesh are multifaceted, requiring the integration of structural engineering, urban planning, and disaster management strategies. Talukder [22] found that while urban populations are generally more aware of earthquake risks, rural communities often lack access to critical information and resources. This disparity underscores the need for targeted education campaigns and training programs to enhance preparedness across all regions of Bangladesh. Additionally, the integration of traditional knowledge with modern engineering practices can provide valuable insights into designing resilient structures that are both culturally appropriate and cost-effective. Research on the geotechnical aspects of earthquake resilience has also gained significant attention. The behavior of soils under seismic loads is a critical factor in determining the stability of foundations and retaining structures. The chemical properties of soils in earthquake-prone regions, providing valuable data for the design of earthquake-resistant embankments [23–28]. The study revealed that soil stabilization techniques, such as the use of lime and cement, can significantly enhance the bearing capacity and shear strength of soils, reducing the risk of foundation failure during seismic events.

Another area of focus has been the impact of climate variability on seismic resilience. The time-series analysis to simulate recent temperature and rainfall data, highlighting the potential for climate change to exacerbate existing vulnerabilities [29–33]. For instance, increased rainfall intensity can lead to soil saturation and reduced stability, making structures more susceptible to seismic-induced landslides. These findings emphasize the need for an integrated approach that considers both seismic and climatic factors in infrastructure planning. In addition to structural analysis, significant research has been conducted on the broader issues of earthquake resilience and infrastructure development in Bangladesh. The study of assessed the state of water, sanitation, and hygiene infrastructure found that many rural communities lack access to basic amenities, which increases their vulnerability to natural disasters [34-37]. By incorporating resilient infrastructure into development plans, it is possible to mitigate the impacts of earthquakes and improve the overall quality of life for these communities. The use of advanced materials and construction techniques has also been explored as a means of enhancing seismic resilience The Comprehensive Disaster Management Programme (CDMP) in Bangladesh has played a pivotal role in raising awareness, providing training, and supporting research initiatives related to disaster risk reduction. According to CDMP (2014), one of the key challenges in promoting resilience is the lack of coordination among various stakeholders. By fostering collaboration between government agencies, academic institutions, and local communities, it is possible to develop more effective strategies for disaster risk management.

Urban planning and land-use management are also critical components of earthquake resilience. In many cities, unplanned urbanization has led to the construction of buildings on unsuitable land, such as floodplains and reclaimed areas. These locations are inherently more vulnerable to seismic activity due to poor soil conditions and high water tables. The implementing strict zoning regulations and promoting sustainable urban development practices can significantly reduce the risks associated with earthquakes [38-41]. Education and capacity building are essential for fostering a culture of resilience in Bangladesh. Universities and research institutions play a vital role in advancing knowledge and developing innovative solutions to address seismic challenges. For instance, the Bangladesh University of Engineering and Technology (BUET) has been at the forefront of seismic research, conducting studies on structural retrofitting, performance-based design, and disaster risk reduction. By investing in education and training, it is possible to build a skilled workforce capable of implementing advanced engineering practices and improving overall resilience. Community-based approaches to earthquake resilience have gained traction in recent years. These approaches emphasize the active involvement of local communities in disaster risk reduction efforts, ensuring that solutions are tailored to their specific needs and contexts. For example, participatory vulnerability assessments and risk mapping exercises can help communities identify their vulnerabilities and develop appropriate mitigation strategies.

The integration of technology into disaster risk management has opened up new possibilities for enhancing earthquake resilience. Geographic Information Systems (GIS) and remote sensing technologies are increasingly being used to assess seismic hazards, map vulnerabilities, and monitor infrastructure conditions. The technologies have the potential to revolutionize disaster risk management by providing real-time data and facilitating informed decision-making. Additionally, advancements in structural health monitoring systems have enabled engineers to continuously assess the condition of buildings and identify potential issues before they become critical. The addressing the challenges of earthquake resilience in Bangladesh requires a multidisciplinary approach that integrates engineering, urban planning, and community engagement [42-46]. By leveraging advanced technologies, promoting education and awareness, and fostering collaboration among stakeholders, it is possible to develop infrastructure that is not only safe and reliable but also sustainable and inclusive. The studies reviewed in this paper highlight the importance of site-specific considerations, innovative materials, and holistic planning in achieving this goal. As Bangladesh continues to urbanize and develop, ensuring the resilience of its infrastructure will be essential to safeguarding the well-being of its people and supporting sustainable growth.

3. Methodology

The methodology focuses on evaluating the structural integrity of the primary school building's structural components and designing a safe, efficient four-story structure. Two alternative floor plans are analyzed to determine which configuration performs better under earthquake and wind loads, following the BNBC 2020 guidelines and considering the specific site conditions. These conditions are incorporated into the detailed analysis conducted using the ETABS software.In the first floor plan, the structure features 24 columns and 8 beams, including three intermediate beams that span across the center of the room. In contrast, the second floor plan consists of 15 columns and 5 beams, with the intermediate beams removed while maintaining the same room dimensions. **Figures 1** and **2** illustrate these configurations, highlighting the differences in structural layout. The comparative analysis assesses the performance of both plans in terms of stability, strength, and suitability for the building's functional requirements.

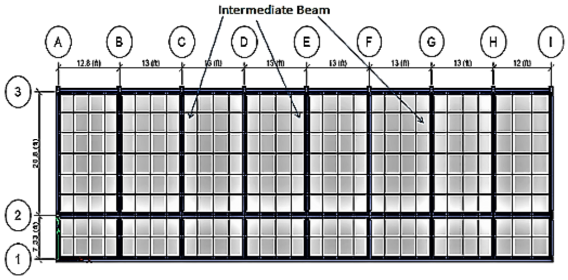

Figure 1. Layout 1 of the model.

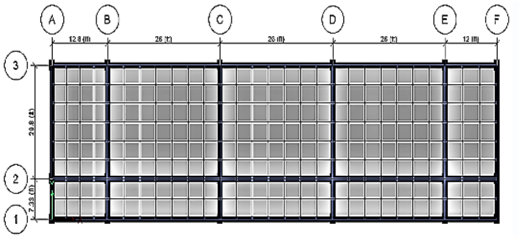

Figure 2. Layout 2 of the model.

The beam and slab dimensions the same in both designs to comprehensively is analyzed the plan, the column dimension is changed due to keep the overall cross section area of the columns the same in both plans, as indicated in the **Table 1**.

Table 1. Column cross sectional areas.

Layout 1 24 columns	Column 1(sft) 1 × 1.64 = 1.64sft 1.64 × 16 = 26.24sft	Column 2(sft) 1 × 1.23 = 1.23sft 1.23 × 8 = 9.84sft	Total 36.84 sft
Layout 2 15 columns	Column 1(sft) 1.25 × 2 = 2.5 sft 2.5 × 10 = 25 sft	Column 2(sft) 1.25 × 1.8 = 2.25 sft 2.25 × 5 = 11.25 sft	Total 36.25 sft

The structural analysis of the primary school building involves evaluating various loads and determining appropriate dimensions for structural elements to ensure stability and safety. This study considers different types of loads, including self-weight, live loads, wind loads, and seismic loads. The self-weight encompasses the combined weight of all structural components, while live loads account for the weight of occupants and their belongings. Wind loads refer to the forces exerted by wind on the building's surfaces.

The analysis follows established structural engineering design standards, guidelines, and best practices. The design complies with the Bangladesh National Building Code (BNBC 2020), which specifies minimum construction requirements to safeguard public health, safety, and overall structural integrity. The building is designed to withstand earthquake forces as per the seismic zone-2 classification defined in BNBC. Additionally, wind loads are assessed based on exposure condition B, with a base wind speed of 65.7 m/s, measured at a height of 10 meters above ground level. To further enhance reliability and performance, supplementary references include the Dhaka ACI 318. These codes provide additional guidelines to ensure structural resilience. The material unit weights used in the analysis are detailed in **Tables 2** and **3**.

Table 2. Weight of Construction Materials.

Materials	Strengths f'c (psi)	Strengths f'c (MPa)
Concrete for foundation M25 (1:1:2)	4000	27.57903
Concrete for super-structure M20 (1:1.5:3)	3000	20.68427
Grade 60 rebar	60000	413.68544

Table 3. Unit Weight of Basic Materials for construction.

Materials	Unit Weight (kN/m^3)	Unit Weight (lb/ft3)
Brick	18.9	120.315
Cement	14.7	93.578
Sand, dry	15.7	100
Concrete - stone aggregate (unreinforced)	22.8*	145.142
Brick aggregate (unreinforced)	20.4*	129.864
Steel	77.0	490.2

The structural behavior of the building was analyzed using the finite element method with ETABS software. The Load and Resistance Factor Design (LRFD) approach was employed to evaluate the structural performance, demonstrating that the design is both safe and cost-effective under zone-2 earthquake conditions and wind loads at a height of 10 meters above ground level. The soil conditions at the site were incorporated into the ETABS model to ensure accurate design and analysis. ETABS, widely used for designing multi-story buildings, served as the primary tool for this study. The foundation was modeled as a shallow foundation with hinge support, as recommended by the soil report. The research assessed the structure's maximum stresses, deflections, drifts, bending moments, and shear forces under various loading conditions. Additionally, the study compared the performance of the two design configurations to determine which yielded the most effective results for the specified dimensions of the structural members. Stress distribution at critical points was analyzed to ensure it remained within permissible limits, confirming that the selected dimensions are sufficient to maintain the structure's stability and sustainability. The following governing equations were used in the analysis:

$$D + L \quad (1)$$

$$1.2D + 1.6L \quad (2)$$

$$1.2D + 1.6W + L \quad (3)$$

$$1.2D + 1.0E + 1.0L \quad (4)$$

$$\text{Maximum allowable deflection} \leq \frac{L}{500} \quad (5)$$

$$\text{Maximum beam deflection} = \frac{Span\ length}{360} \quad (6)$$

$$\text{Max drift ratio in X-direction } \delta x = \frac{Cd * \delta xe}{I} < 0.02hsx \quad (7)$$

$$\text{Max drift ratio in Y-direction } \delta y = \frac{Cd * \delta ye}{I} < 0.02hsx \quad (8)$$

$$Ps = \lambda KztIPs30 \quad (9)$$

Here's a revised version to ensure originality and clarity:

In this analysis, D represents the dead load, L stands for the live load, W denotes the wind load, and E refers to the earthquake load. A simplified procedure was employed to calculate the wind load. The site, located in Savar, Dhaka, experiences a wind speed of 236.52 km/h under exposure type B conditions. The topographic factor (kzt) was taken as

1, and the importance factor (I) was set to 1.15. The simplified design wind pressure (Ps30) was determined, incorporating the adjustment factor for building height and exposure (λ), which was calculated as 1.5456 for a mean building height of 14.48 meters. Additionally, the Gust Factor (G) and Directionality Factor (Kd) were considered, with values of 0.85 each. These parameters were combined to ensure accurate wind load estimation in compliance with relevant guidelines and standards.

$$V = Sa \text{ X } W \tag{10}$$

$$Sa = \left(\frac{2ZI}{3R}\right) \text{ x } Cs \tag{11}$$

To determine the earthquake load, the design base shear (V) is calculated using the specified equation. The structure is located in seismic zone 2, which is characterized by moderate seismic intensity. The occupancy category is 3, and the importance factor (I) is 1.25. The structural period constants include Ct as 0.0466, m as 0.9, and the natural period (T) as 0.517. For an accurate analysis of site conditions, the parameters Fa and Fv were used, with values of 1.15 and 1.725, respectively, based on site class F as per ASCE 7-16. In the BNBC 2020 guidelines, the corresponding site class is identified as SC. Since the structure is designed as a Moment Resisting Frame System without shear walls, the following factors were applied: Response Modification Factor (R) of 8, System Overstrength Factor (φ) of 3, and Deflection Amplification Factor (Cd) of 5.5. These parameters ensure the design accurately reflects the structure's seismic resilience and complies with the relevant standards.

4. Result and Discussion

ETABS was utilized to simulate the floor plan layouts illustrated in **Figures 1** and **2**. The layouts were modified by removing beams and columns passing through the center of the room, while ensuring that the total cross-sectional area of the columns in both designs remained constant, as outlined in **Table 1**. The dimensions of the beams and slabs were kept consistent, despite changes in their number. The analysis evaluated the deflection and drift values for both configurations under lateral loads such as earthquakes and wind, providing insight into how these layouts respond to changes based on the surrounding conditions specified in BNBC 2020. Additionally, the deflection and drift responses were assessed by incorporating the specific site conditions of the project, and the results are presented in **Table 4**.

Table 4. Earthquake and wind load results.

Parameters	Model 1	Model 2
Max Deflection for Eqx in X direction	0.5924 in	0.709 in
Max Deflection for Eqx in Y direction	0.0371 in	0.0419 in
Max Deflection for Eqy in X direction	0.033 in	0.039 in
Max Deflection for Eqy in Y direction	0.599 in	0.656 in
Max Deflection for Wx in X direction	0.347 in	0.402 in
Max Deflection for Wx in Y direction	0.021 in	0.023 in
Max Deflection for Wy in X direction	0.016 in	0.013 in
Max Deflection for Wy in Y direction	1.061 in	1.138 in
Max Drift ratio for Eqx in X direction	0.009383	0.019935
Max Drift ratio for Eqx in Y direction	0.0004785	0.0004895
Max Drift ratio for Eqy in X direction	0.000352	0.000385
Max Drift ratio for Eqy in Y direction	0.007139	0.0070785
Max Drift ratio for Wx in X direction	0.005753	0.00616
Max Drift for Wx in Y direction	0.000275	0.000286
Max Drift ratio for Wy in X direction	0.0001925	0.0001485
Max Drift ratio for Wy in Y direction	0.0153	0.0149

The analysis results reveal that Model 2, with fewer force-resisting frame members, exhibits greater deflection and drift compared to Model 1. This finding underscores the significance of increasing the number of structural members to enhance stability and reduce deformation under lateral loads. Furthermore, the data show that the subforce direction of seismic and wind loads, acting perpendicular to the primary force direction, has a comparatively lesser impact on the structure. For instance, earthquake loads in the x-axis direction (Eqx) cause more significant deflection and drift along the x-axis than the subforce component acting in the y-axis. Similarly, for earthquake loads in the y-axis direction

(Eqy), the primary force along the y-axis has a greater effect than its subforce in the x-axis. A similar pattern is observed for wind loads (Wx and Wy), reinforcing the conclusion that subforce effects are relatively less critical in the overall structural behavior. Based on these observations, the analysis focused on the primary force directions, simplifying the evaluation process without sacrificing accuracy. For example, when analyzing Eqx, only its effects along the x-axis were considered, while the minimal impact of its subforce on the y-axis was disregarded. This streamlined approach allowed for a more targeted evaluation of structural behavior under seismic and wind forces.

The findings clearly demonstrate that structures with a greater number of force-resisting members, such as Model 1, exhibit superior performance in resisting seismic and wind loads. The increased number of columns and beams in Model 1 results in a more even distribution of forces, reducing stress concentrations and enhancing the structure's ability to withstand catastrophic events. This improved resilience ensures greater occupant safety and reduces the likelihood of structural failure under extreme conditions. Additionally, the data reveal that structures with more resisting members experience lower stresses in both reinforcement and concrete. In Model 1, the higher number of load-bearing elements helps distribute bending moments and shear forces more evenly, allowing the concrete to absorb most of these forces. As a result, the demand for reinforcement is reduced, optimizing material usage without compromising structural integrity. This contributes to the economic efficiency of Model 1, making it a more cost-effective option for construction. The superior performance of Model 1 is further supported by accompanying graphs and tables that illustrate its advantages in terms of deflection, drift, and stress distribution. The study highlights the importance of designing structures with an adequate number of force-resisting members to improve their performance against seismic and wind loads. Model 1's enhanced stability, safety, and cost-effectiveness make it the preferred choice for primary school construction in regions with moderate seismic activity. These findings provide valuable insights for future infrastructure projects, fostering the development of resilient and economically viable structures.

The deflection values illustrated in **Figures 3** and **4** highlight the serviceability performance of the structure under earthquake loads. According to BNBC-2020, the maximum allowable deflection is limited to ≤L/500, where L represents the height of the building in inches. For this structure, the total height is 40 ft = 480 inches, resulting in a maximum permissible deflection of 480/500 = 0.96 inches. The graphs show that the deflection of Model 2 is consistently higher than that of Model 1 in the X direction under earthquake load (Eqx). Specifically, Model 1 has a maximum deflection of 0.59 inches, whereas Model 2 exhibits a deflection of 0.7 inches, which approaches the allowable limit. A similar trend is observed in the Y direction under Eqy, further indicating that Model 1 performs better during earthquakes due to its larger number of structural members that effectively resist seismic forces.

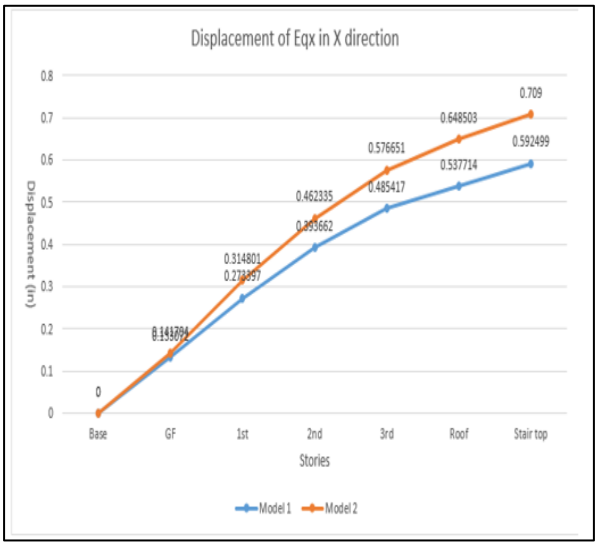

Figure 3. Deflection values (X Direction).

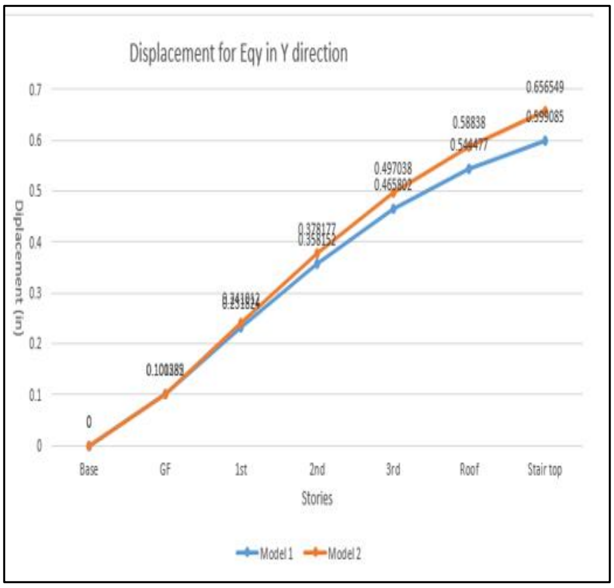

Figure 4. Deflection values (Y Direction).

Figures 5 and **6** depict the drift values for the earthquake analysis. The results indicate that the mean earthquake pressures primarily affect the leading edge side of the structure, regardless of the number of structural members. The magnitude of the drift is predominantly governed by the pressure distribution on the leading edge, where the majority of the force is applied. Consequently, the drift values are higher on the leading edge side compared to the non-leading edge side, as demonstrated in the figures. This analysis confirms that Model 1 outperforms Model 2 in terms of deflection and drift during earthquakes. The increased number of structural members in Model 1 ensures better resistance to seismic forces, contributing to improved stability and serviceability.

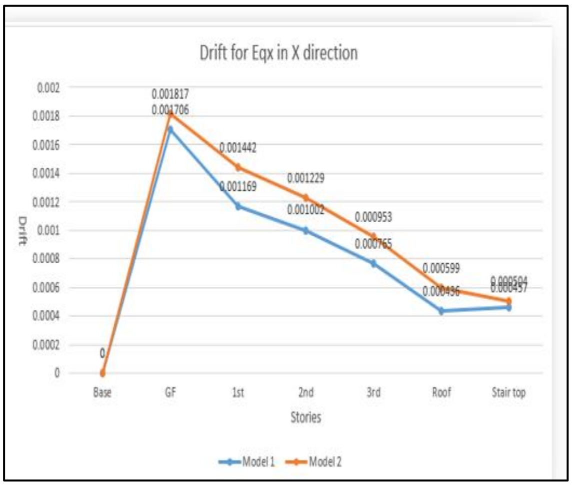

Figure 5. Values for the earthquake analysis (X Direction).

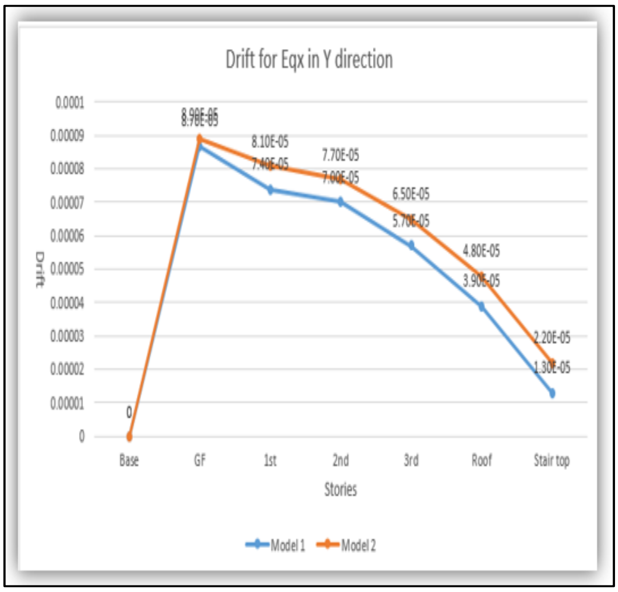

Figure 6. Values for the earthquake analysis (Y Direction).

As we check the deflection limit of these models we can see that model 1 has better value than model 2. As we know that our building occupancy category is 3 and its Importance factor is 1 and Cd value is 5.5 the drift ratio limit is <0.02 hsx for earthquakes. For Eqx the drift of model 1 is 0.00713 where model 2 is 0.011 as shown in **Figures 7** and **8**. Same thing can be observed for Eqy.

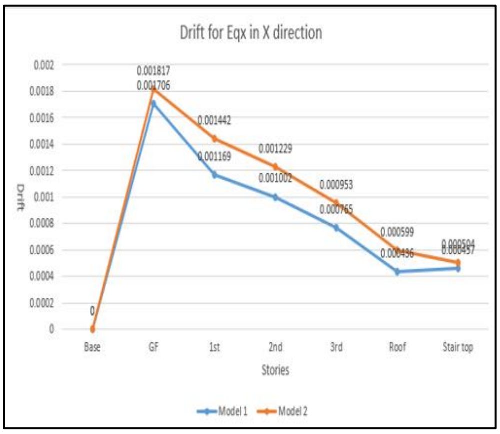

Figure 7. Values for the earthquake analysis (Pattern 3).

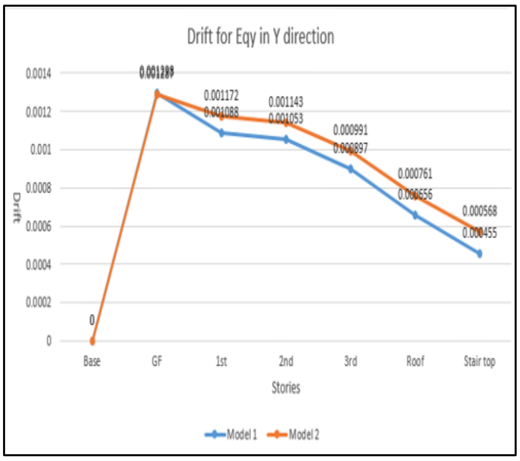

Figure 8. Values for the earthquake analysis (Pattern 4).

For better understanding we also plotted the deflection and drift graph of the wind load, we can see the same trend where the deflection limit is $\leq \frac{L}{500}$ = 0.98 in and drift limit is ≤0.005 h for natural period T < 0.7 is shown in **Figures 9–12**.

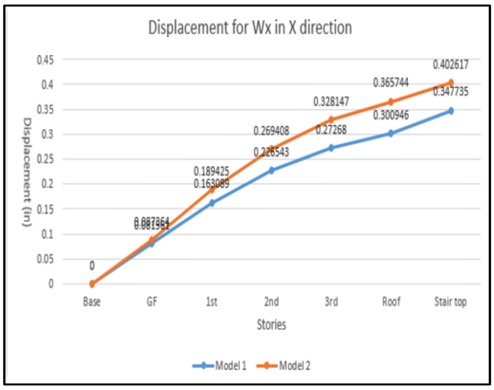

Figure 9. Analysis result 1.

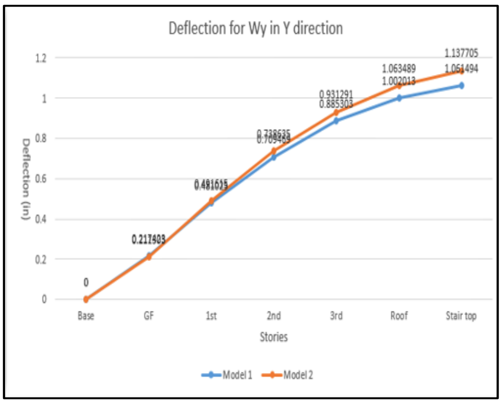

Figure 10. Analysis result 2.

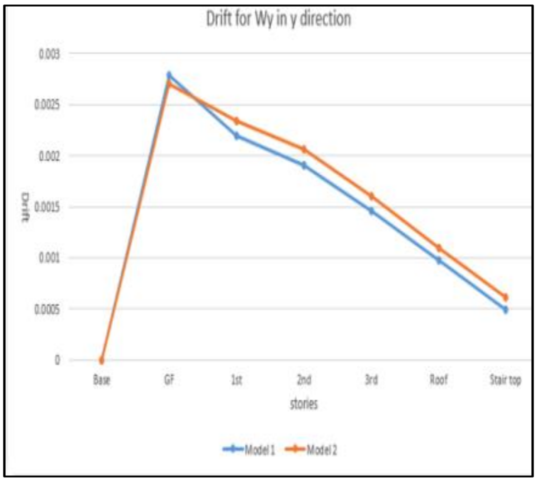

Figure 11. Analysis result 3.

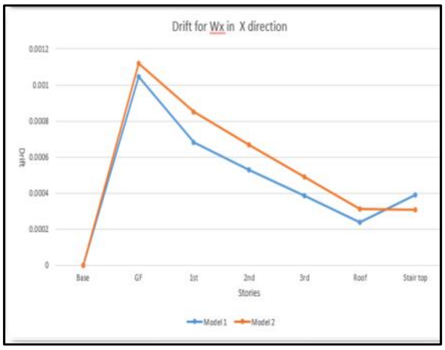

Figure 12. Analysis result 4.

The analysis results, as shown in the accompanying graphs, consistently indicate that Model 1 performs better than Model 2 under all assessed conditions. This conclusion is further validated by the bending moment and shear force values obtained for both models. These values are critical in assessing the structural requirements for reinforcement. Increased stress in the beams requires additional reinforcement to resist these forces, as concrete alone cannot endure excessive stress. As a result, this has implications for both the economic and environmental aspects of the project. Higher reinforcement demands lead to greater material consumption, which in turn increases costs and environmental impact.

In structural design, reducing stress levels in load-bearing members is essential for achieving cost-effective and sustainable construction. Model 1, despite having more structural members than Model 2, exhibits lower bending moment and shear force values. This indicates that the stresses within its beams and columns are more evenly distributed. As a result, the requirement for reinforcement in Model 1 is significantly reduced compared to Model 2. This not only minimizes the construction costs but also contributes to environmental sustainability by reducing the demand for steel and other reinforcement materials. The environmental implications of increased reinforcement demand cannot be overstated. The production and mining of metals for reinforcement materials involve substantial energy consumption and emissions, contributing to environmental degradation. By optimizing structural designs to lower stress levels and reinforcement requirements, projects like Model 1 can reduce their overall environmental footprint. In this context, Model 1 stands out as a more sustainable choice, aligning with global efforts to minimize the environmental impact of construction activities. **Tables 5** and 6 provide quantitative evidence supporting these observations. The bending moment and shear force values for Model 1 are significantly lower than those for Model 2, underscoring its superior performance in handling loads efficiently. This translates into reduced reinforcement needs, as the structural members in Model 1 are less stressed and can rely more on concrete's inherent strength. In contrast, Model 2, with its fewer structural members, experiences higher stress concentrations, necessitating increased reinforcement to maintain safety and stability. This trade-off highlights the importance of considering not only the number of structural members but also their configuration and distribution in the overall design. The comparative analysis of the two models emphasizes the advantages of Model 1 in terms of structural performance, cost-effectiveness, and environmental sustainability. By distributing stresses more effectively across its increased number of members, Model 1 achieves a balance between safety, economic feasibility, and environmental responsibility. These findings reinforce the importance of comprehensive structural analysis and design optimization in achieving resilient and sustainable infrastructure. The insights gained from this study can serve as a valuable reference for future construction projects, particularly in regions where cost and environmental considerations are critical factors in decision-making.

Table 5. Bending Moment and Shear Force value for Beams in Model 1.

Beam Id (Grid)	Beam Section	Load Combo	Story Level	Beam Shear (kips)			Beam Moment (kips-ft)		
				End	Mid	End	End	Mid	End
1 AB	12 × 18	Combo 2	GF	−13.12	−1.67	11.87	−13.88	22.47	−22.82
1 AB	12 × 18	Combo 2	1st	−10.04	−2.09	11.01	−13.57	21.62	−19.18
1 AB	12 × 18	Combo 2	2nd	−10.31	−2.38	10.72	−14.75	21.92	−17.19
1 AB	12 × 18	Combo 2	3rd	−10.55	−2.62	10.48	−15.87	22.21	−15.51

Table 6. Bending Moment and Shear Force value for Beams in Model 2.

Beam Id (Grid)	Beam Section	Load Combo	Story Level	Beam Shear (kips)			Beam Moment (kips-ft)		
				End	Mid	End	End	Mid	End
1 AB	12 × 18	Combo 2	GF	−32.54	0.638	33.79	−134.8	91.44	−150.6
1 AB	12 × 18	Combo 2	1st	−31.35	0.57	32.46	−130.4	87.86	−144.6
1 AB	12 × 18	Combo 2	2nd	−31.30	0.60	32.49	−129.8	88.09	−144.7
1 AB	12 × 18	Combo 2	3rd	−31.30	0.59	32.48	−130.2	87.94	−144.8

5. Conclusions

This paper presents a detailed structural analysis and design of a four-story primary school building located in Savar Upazila, Dhaka, considering two distinct floor plans. The objective was to evaluate and compare the structural performance, stability, and cost-effectiveness of the two models under various loading conditions, including seismic and wind loads, while ensuring a safe and conducive learning environment for students. The structural analysis was performed using static calculations to evaluate the loads and determine the required structural components. This process involved assessing live loads, dead loads, and lateral loads due to wind and seismic activities. The design phase focused on selecting appropriate dimensions and configurations for the structural components, ensuring compliance with relevant codes and standards. The primary structural system employed in the design is a reinforced concrete frame structure, which is widely recognized for its strength, durability, and adaptability in multi-story construction.

Model 1, with 24 columns and 8 beams, was compared against Model 2, which consisted of 15 columns and 5 beams. While both models utilized the same beam dimensions of 12” × 18”, the column dimensions were varied to maintain the same total surface area across the two designs. The analysis incorporated critical parameters such as soil type, wind speed, and exposure conditions, as outlined by ASCE 7-16 and BNBC 2020 standards. For instance, the soil type was classified as SC, with Fa and Fv values of 1.15 and 1.725, respectively. Wind speed for Dhaka was considered at 65.7 m/s with an exposure condition of B for suburban areas. Additionally, the use of lightweight brick chip concrete contributed to reducing the overall structural weight, enhancing both stability and cost-effectiveness. The comparative analysis of the two models revealed that Model 1 outperformed Model 2 in terms of structural stability and load distribution. Despite having more structural members, Model 1 demonstrated superior performance under seismic and wind loads, effectively mitigating the risks of excessive deformation and instability. The additional columns and beams in Model 1 contributed to a more uniform distribution of loads, reducing stress concentrations and enhancing the overall safety and durability of the structure. Moreover, the increased number of structural members in Model 1 did not significantly impact cost efficiency, as the design optimized material usage and construction practices to balance performance with affordability. Model 2, while having fewer structural members, exhibited higher stress levels and less favorable load distribution, indicating a potential compromise in safety and longevity. This highlights the importance of prioritizing structural integrity and occupant safety over minimalistic designs, especially in regions with moderate seismic activity like Savar Upazila. The results of this study underscore the critical role of comprehensive structural analysis and design in ensuring the safety and functionality of educational buildings. The optimized design of Model 1 serves as a robust reference for future school construction projects, offering valuable insights into balancing performance, safety, and cost-effectiveness. By adhering to stringent design standards and leveraging advanced analysis tools like ETABS, it is possible to develop infrastructure that meets the growing demands of urbanization while safeguarding the well-being of its users. Ultimately, this research contributes to the broader goal of enhancing disaster resilience and educational infrastructure in Bangladesh.

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Data Availability Statement

Not applicable.

Conflict of Interest

There is no conflict of interest.

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