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Structural Analysis and Design of a Primary School Building (4 Storey) in Savar upazila, Dhaka

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Abstract
The school buildings are critical pieces of infrastructure in every country. Several aspects, including structural safety, utility, and economic feasibility, must be carefully considered while creating these structures. The goal of this study is to look at the available research on the structural analysis and design of primary school buildings, particularly four-story structures, in Savar Upazila, Dhaka. This project paper presents the analysis and design of a four-story RCC school building at Dhorenda, Savar, Dhaka, for which we have designed the structural components (beam, column, slab, and foundations). Our building has a total area of 7.68 Katha. The site is located in Savar upazila near Dhaka. It is located about 12 meters South-East from the Dhaka-Aricha national highway. And about 100 meters South-East of Nabinagor market. The principal objective of this venture is to develop a 4 story school building to increase school capacity and accommodate more facilities for students. The BNBC Code and ACI 318 is followed during designing this project. Moreover, the alternative floor plans for the project is analyzed with respect of withstanding seismic and wind load according to the geological condition of the site. The project emphasizes the study's two primary components: structural analysis and design. The structural analysis entails applying the Load and Resistance Factor Design (LRFD) approach to evaluate the loads (self-weight, live load owing to occupancy, and wind load) and establishing the size of the structural elements to assure the building's stability. The ETABS software which is a finite element technique (FEM) is used to study and verify the structure under various loads. The design component of the research addresses the selection and size of structural elements (reinforced concrete columns, beams, and slabs). The output of the study is very helpful understand the difficulties of design and construction of a building and given a direction to smooth of the design process.

Keyword: Structural Analysis, Design, Etabs, Primary School Building, Savar upazila

Introduction

Primary school construction is an important infrastructure development activity in every country. Due to fast population expansion and urbanization, there is a strong need for elementary school buildings in Bangladesh. The structural design of primary school buildings must take into account a number of aspects, including occupant safety, building functioning, and project economic feasibility. So the designing of this building must be optimal to cover all these aspects in order to provide a safe environment for the students as well as to be economically viable. In order to do this multiple floor plans with different layout arrangements must be designed and analyzed to get the best option to serve these purposes. Moreover that design has to be safe and reliable against the earthquake and wind loads. Here we have analyzed a four-story school building which is located in a suburban area in Dharenda, Savar. The principal objective of this venture is to develop a 4 story school building in that area which has moderate seismic activity which is safe to withstand the lateral loads and will be economic as well as environmentally sustainable.

Two floor plans were considered as shown in fig 1 and fig 2 which is analyzed using finite element analysis using the ETABS software. There were few factors considered before analyzing the models. One of them was site condition. As our site class was SC according to the soil report for incorporating its effect into the model we consider the soil type was F where the Fa be 1.15 and Fv be 1.725 according to the ASCE 7-16 which provide the same value for SC site according to BNBC 2020. Another was the wind speed for Dhaka was 65.7 m/s and the exposure condition was B for suburban areas according to BNBC but in model it was considered to be ASCE 7-16 to be C. As well as the concrete is made up of brick chips to make the structure light weighted and cost effective. These parameters were kept constant along with the live and superimposed dead loads for both models to check there performance other than changing the numbers of members resisting these loads. The resisting members in model 1 have 24 columns and 8 beams where model 2 has 15 columns and 5 beams keeping the beam dimension (12”x18”) same in both plans but changing the column dimensions keeping the total surface area same.

Literature review

Bangladesh lies in a high-risk seismic hazard zone, according to historical records, geological data, and current earthquake patterns. A natural disaster such as an earthquake has a direct and immediate impact on people's lives and communities. The research in the Savar study region, which also represents a low degree of satisfaction with earthquake preparedness factors (8.91 out of 25). Approximately 43% of buildings have no damage condition, 10% have lightly damaged possibility, 28% have reduced probability of collapse, 15% have moderate possibility of collapse, and approximately 4% have severe possibility of collapse(Rahaman,2021). Previous earthquake experience, fast urbanization, high population growth rates, high density, and the development of economic infrastructure all enhance seismic risk(CDMP, 2014).As cities develop in population, more people are exposed to natural hazards. Cities house 35.86% of Bangladesh's overall population(Statista, 2019). So it is very important to assess the risk of earthquakes of building design with respect to the Bangladesh geological and social condition.

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Etabs 2020 is used to build and plan a structure by computing forces, bending moments, stress, strain, and deformation or diversion for a complicated underlying framework. The structure was developed in accordance with Indian Codes for seismic loads for IS:1893-2016.The primary goal of our literature study is to provide a complete assessment of past studies in the field of seismic design, and employing this software will result in greater accuracy of the analysis(Dhomne, A. K. 2021). This software can be used to incorporate different shapes and dimensions of the structural members to analyze seismic and economic performance without having to use more tedious methods (MHASKE, N. 2021). In today's fast growing globe, software utilized in the construction sector is an essential requirement in order to match the speed of infrastructural growth. The primary goal of the research is to determine the computability of the results. The final stage in the process is the study and design of Reinforced Concrete structures. Construction business to complete projects on schedule and within budget(Sindhur, V. S., & Ramya, B. V.,2022).

Methodology

The methodology section focus on addressing the methods used to examine the structural integrity of the primary school building structural members and construct a safe and efficient four-story primary school building with two alternative floor plans to determine which one performs better in both earthquake and wind load based on the BNBC 2020 guideline and its site condition, which is incorporated in the Etabs model for the detail analysis. We have 24 columns and 8 beams in the first configuration, three of which are intermediate beams that go across the middle of the room. The second plan, by contrast, has 15 columns and 5 beams, with the intermediate beams removed keeping the room dimension same as seen in figures 1 and 2.

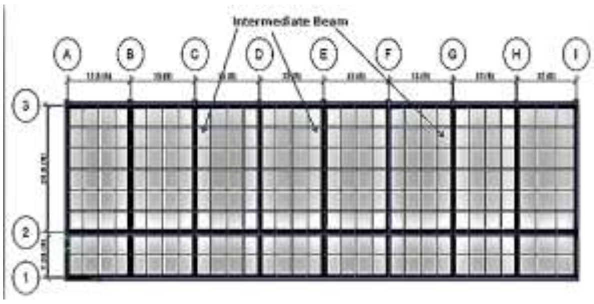

Fig 1

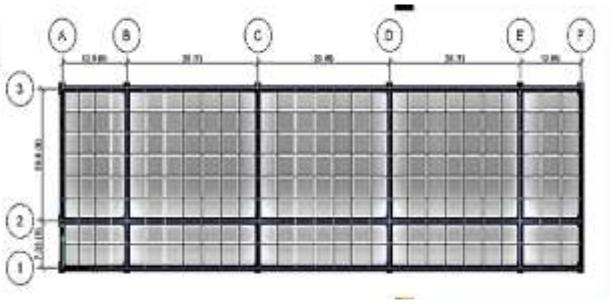

Fig 2

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 table1.

Table 1: Column cross sectional areas

Layout 1 24 columns	Column1(sft)	Column2(sft)	Total
	1x1.64 = 1.64sft	1x1.23 = 1.23sft	36.84 sft
	1.64x16 = 26.24sft	1.23x8 = 9.84sft	
Layout 2	Column1(sft)	Column2(sft)	Total

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15 columns	1.25x2 = 2.5 sft	1.25x1.8 = 2.25 sft	36.25 sft
	2.5x10 = 25 sft	2.25x5 = 11.25 sft	

The structural analysis comprises estimating the loads and sizes of the structural elements in order to ensure the stability of the structure. This research includes the self-weight of the building, the live load owing to occupancy, and the wind load as well as the seismic load. The self-weight of the structure is the total weight of all structural pieces, whereas the live load is the weight of the people and their belongings. The wind load is the force exerted by the wind on the structure's surfaces. This study's data collection techniques were mostly based on structural engineering design requirements, standards, and best practices. The primary school building was developed in compliance with the Bangladesh National Building Code (BNBC 2020), which specifies rules for building structural construction in Bangladesh. Building codes principal objective is to establish minimum requirements to protect public health, safety, and the general welfare in the construction and occupation of buildings and structures. According to the BNBC's seismic zone-2, the construction is designed to resist earthquake loads. Wind loads are estimated for exposure condition B using a base wind speed of 65.7 m/s at a height of 10 meters above ground level. The Dhaka Imarat Nirman Bidhimala 2008 and ACI 318 code is used for extra assessments. The unit weights of the materials used for analysis are shown in tables 2 and 2.1 below.

Table 2.0: 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 2.1: Unit Weight of Basic Materials for construction

Materials	Unit Weight (kN/m3)	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 analysis of the building behavior is performed using the finite element method and the ETABS software. Using the LRFD approach, the study demonstrates that the structure is safe and efficient in terms of structural performance and cost-effectiveness against zone 2 earthquakes and wind loads at a height of 10 meters above ground level. The site for understanding the soil condition which is used in the ETABS model for design and analysis. This program is generally used to design multi-story buildings. The foundation hinge support is considered the shallow foundation as suggested by the soil report. The research identified the structure's maximum stresses, deflections, and drifts along with bending and shear forces under all loads. Also, determine which design produces the greatest results for the structural members' specified dimensions. The distribution of stress at crucial parts is also evaluated to verify that it is within acceptable limits. This will confirm the selected dimension for the plan is adequate for the sustainability of the structure. The governing equations are as follows:

$$D + L \tag{1}$$

$$1.2D + 1.6L \tag{2}$$

$$1.2D + 1.6W + L \tag{3}$$

$$1.2D + 1.0E + 1.0L \tag{4}$$

$$\text{Maximum allowable deflection} \leq \frac{L}{500} \tag{5}$$

$$\text{Maximum beam deflection} = \frac{Span\ length}{360} \tag{6}$$

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

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

$$Ps = \lambda KztIPs30 \tag{9}$$

Where, D is the Dead load, L is the Live load, W is the Wind load and E is the Earthquake. The simplified procedure is used to find out the wind load. The zone was Savar, Dhaka where the speed of wind was 236.52 km/h for the exposure type was B. Where the topographic factor kzt was 1. The importance factor I was 1.15. Ps30 is the simplified design wind pressure. And λ is the Factor adjusting for building height and exposure is 1.5456 for mean height of 14.48m. The Gust Factor, G and Directionality Factor, Kd was 0.85.

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

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

To find out earthquake load we have to use this equation, where V is the design base shear. The seismic zone is zone 2, where seismic intensity is moderate. Occupancy category is 3, I importance factor is 1.25, where the structural period Ct is 0.0466, m is 0.9 and natural period T is 0.517. For proper analysis of the site condition in the model we have use Fa be 1.15 and Fv be 1.725 for the site class F according to ASCE 7-16 where in the BNBC 2020 the site class

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is SC. As our structure is a MOMENT RESISTING FRAME SYSTEMS with no shear wall, so Response Modification, R is 8, System Overstrength, ⍵ is 3 and Deflection Amplification, Cd is 5.5.

Result and Discussion

Etabs was used to simulate the floor plan layouts depicted in figure 1 and figure 2. The number of beams and columns are changed by removing the beams and columns that are passing through the middle of the room keeping in mind that the total cross sectional area of the column in both plans is unchanged as shown in table 1. Whereas the beam and slab dimensions are kept constant even though there numbers have been changed. The drifting and deflection values obtained after modeling for both plans against the lateral loads like earthquake and wind load provides us a clear view on there response to the change in layouts with respect to the surrounding condition stated by BNBC 2020. Also incorporating the site condition of the project, the deflection and drift response is shown in table 3.

Table 3: 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	0.0004785	0.0004895

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direction		
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 results imply that the model 2 which has less resisting frame members has higher deflection and drift than the model 1. From the data it is found that the subforce direction of the earthquake in the opposite axis has less effect on the structure. For example, the Eqx whose primary force along the x axis has a higher deflection and drift effect than its subforce of Eqx in the y axis. Same can be observed in both Eqy whose primary force direction in y axis has higher deflection and drift effect than its subforce direction of Eqy in x axis. Same trend is observed for Wx and Wy forces. This trend is the same for both models irrespective of its numbers of force resisting members. So for our analysis we are avoiding subforce effects in our analysis. And will only consider the primary force direction is that particular axis. This means if we are dealing with Eqx we will take the effect on the x axis direction only. From the data it is also found that the structure with a larger number of resisting frames has better performance in resisting the earthquake and wind load. Thus increasing the survivability and safety of the structure during the catastrophic time. Moreover these results suggest the reinforcement and the concrete structure will face less stress. As model 1 has more load bearing members so less shear and bending moment will be generated so less reinforcement will be required as majority of the bending moment and shear force will be absorbed by the concrete thus making the model 1 more economical than model 2. This hypothesis is further supported by the graphs and tables below.

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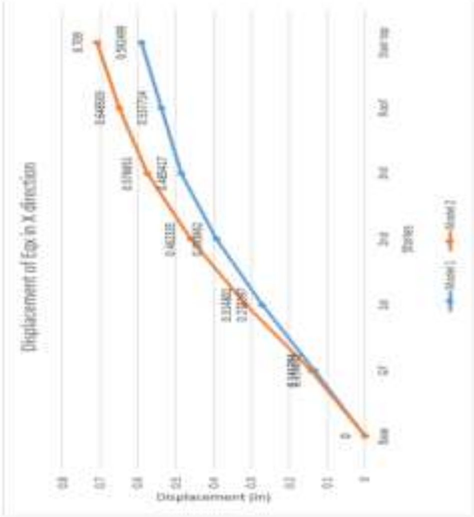

Fig 3

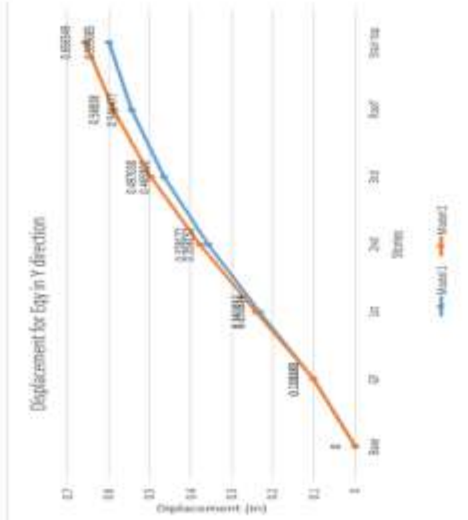

Fig 4

The deflection value from figure 3 and figure 4 suggests the serviceability performance of the structure with respect to the earthquake. According to BNBC-2020, the maximum allowable deflection should be $\leq \frac{L}{500}$ where L is the height of the building in inches. The total height of the building is 40 ft = 480 in. So total deflection limit of the building is $\frac{480}{500}$= 0.96 in. From the graph we can see that the deflection of model 2 is alway higher than model 1 In X direction for Eqx the model 1 has maximum deflection of 0.59 in where model 2 has 0.7 in which is very close to the max limit. Same trend can be observed for Eqy in Y direction. This suggests that model 1 performs better in earthquakes than model 2 because it has a larger number of members to resist earthquake force.

The drifts are plotted in figure 5 and figure 6 for the earthquake. The mean earthquake pressures are mainly affected in the leading edge side, irrespective of the numbers of members. The magnitude is mainly controlled by the leading edge side pressure distribution. In the leading edge side the majority force is applied so its drift is higher than the non leading edge side as shown in figures below.

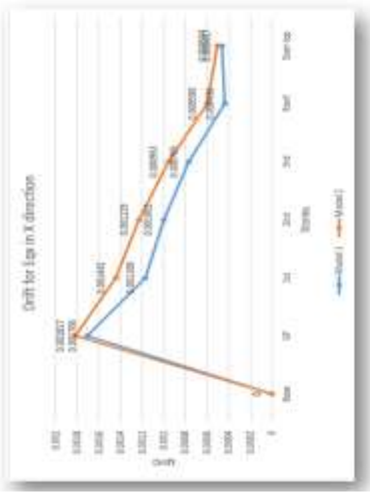

Fig 5

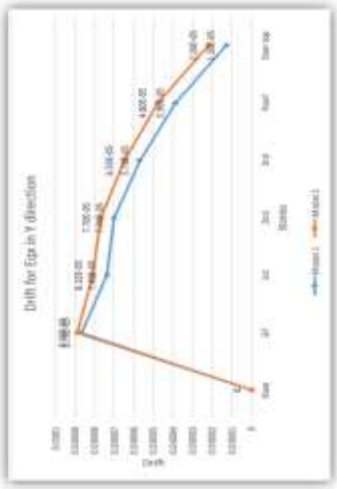

Fig 6

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

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is 1 and Cd value is 5.5 the drift ratio limit is < 0.02hsx for earthquakes. For Eqx the drift of model 1 is 0.00713 where model 2 is 0.011 as shown in figure 7 and 8. Same thing can be observed for Eqy.

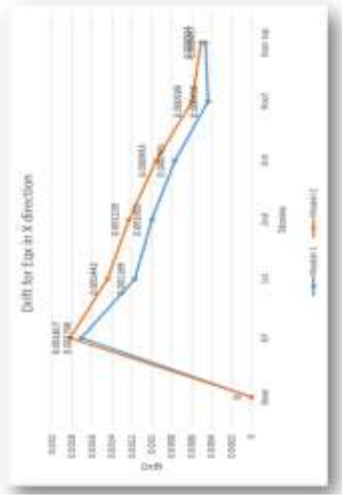

Fig 7

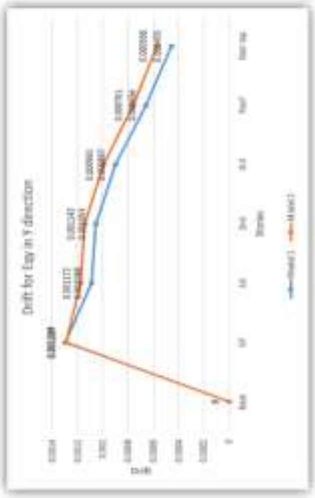

Fig 8

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 ≤0.005h for natural period T<0.7. As shown in figure

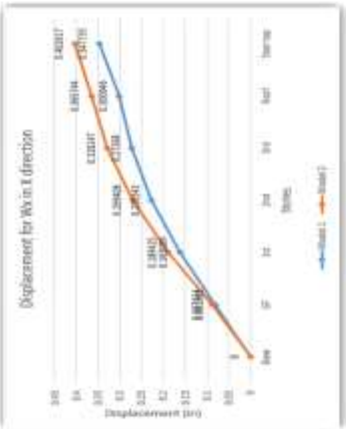

Fig 9

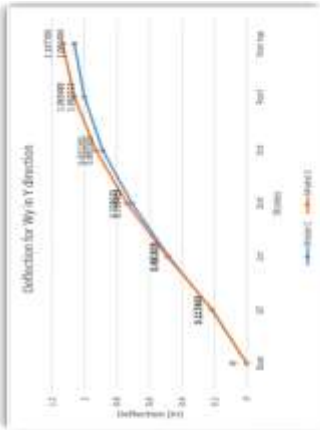

Fig 10

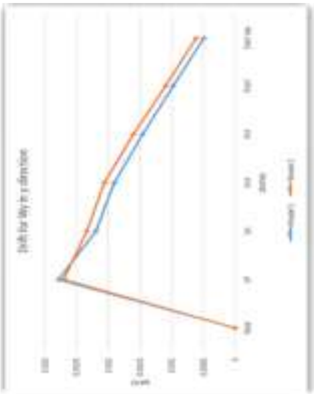

Fig 11

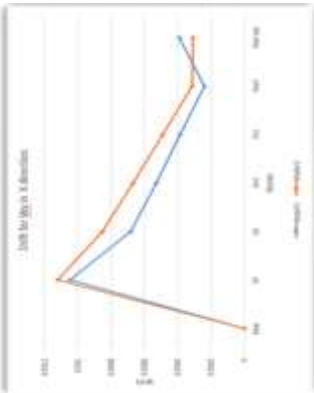

Fig 12

From all the graphs we can see that model 1 performs better model 2 in all conditions. This statement is further reinforced by the bending moment and shear force value generated by the

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models. The more the stress generated in the beams the more reinforcement required to cope up the stress as the concrete will not be able to withstand the stress. Thus making the model less economic and sustainable. The increase in demand for the reinforcement will eventually increase the mining of the metals which will eventually increase the environmental cost of the project. The bending moment and shear values for the models suggest that even though model 1 has more members than model 2 its stress is less so less reinforcement is required which makes it more economic and sustainable as shown in table 4 and table 5.

Table 4 : 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
1AB	12x18	Combo2	GF	-13.00	-1.67	11.87	-13.87	22.47	-22.82
1AB	12x18	Combo2	1st	-10.02	-2.09	11.01	-13.56	21.62	-19.17
1AB	12x18	Combo2	2nd	-10.31	-2.38	10.72	-14.75	21.92	-17.18
1AB	12x18	Combo2	3rd	-10.54	-2.62	10.48	-15.86	22.20	-15.51

Table 5 : 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
1AB	12x18	Combo2	GF	-32.51	0.638	33.79	-134.8	91.44	-150.6
1AB	12x18	Combo2	1st	-31.32	0.57	32.46	-130.4	87.86	-144.6
1AB	12x18	Combo2	2nd	-31.29	0.60	32.49	-129.8	88.09	-144.7
1AB	12x18	Combo2	3rd	-31.30	0.59	32.48	-130.2	87.94	-144.8

Conclusion

This paper presents the structural analysis and design of a four-storey primary school building in Savar Upazila, Dhaka, with different floor plans. Static calculation involves load evaluation and component determination, while design involves selecting components and their dimensions. The structural system is a reinforced concrete frame structure, the model 1 has 24 columns and 8 beams, and the model 2 has 15 columns and 5 beams. The analysis ensures that the building is safe and stable under all loads, withstands seismic and wind loads, and provides a safe and comfortable learning environment for students. It was found that model 1 performed better than model 2. The results show that the designed model 1 is safe and efficient in terms of structural performance and cost effectiveness even though it has more structural members. The designs presented in this document can be used as a reference for similar constructions in the future.

Acknowledgments

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