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STUDY ON VULNERABILITY ASSESSMENT AND SEISMIC UPGRADATION OF OLD SCHOOL BUILDINGS IN KHULNA

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ABSTRACT

Bangladesh lies in an earthquake hazardous zone. A large number of existing reinforced concrete buildings are incompetent to withhold design seismic loads as per BNBC 2020. RC buildings, especially some primary and high school buildings, designed with past regulations could be vulnerable in times of earthquake. This research deals with seismic analysis of such 10 existing school buildings in Khulna city, Bangladesh. Linear equivalent static analysis was carried out to analyze those school buildings by using structural analysis software (ETABS 2018). Among them 2 buildings were found to exceed their maximum allowable deflection. A retrofitting technique involving diagonal steel bracing was investigated for those vulnerable buildings to control their deflection. The diagonal bracing consisted of HSS 4 X 4 X ½ steel section. Research results yielded that the retrofitting technique could be conveniently and cost effectively applied to such type of low-rise buildings to avoid the hazards due to earthquake.

Keywords: *Seismic, Vulnerable, Retrofitting, Diagonal Bracing, Storey Displacement*

1. INTRODUCTION

Bangladesh is an earthquake-prone country and many of the buildings here are at severe seismic vulnerability. Bangladesh is facing a high risk of moderate to sturdy earthquakes which may end in widespread loss and damage of thousands of lives. Five geological break lines run through the country, exposing it to extremely vulnerable of a serious earthquake by the specialists. The fateful effects of the earthquakes that occurred in Bangladesh throughout the recent years didn't depend upon their significant seismic intensity solely, but also on high population density in several areas and poor attention paid to building seismic-resistant buildings. A huge number of existing reinforced concrete buildings are insufficient to withstand design seismic loads as prescribed by BNBC 2020. RC buildings that were designed in the past are usually far from the proper illustration of their dynamic behaviour, usually exhibit an ill performance that may result in sudden collapse and a low load-bearing capability.

Khulna, a coastal district of south-western part of Bangladesh, lies in earthquake active zone-1. However, there are many old primary and high school buildings that can be hazardous in times of earthquake, since the small children and the women are the most helpless ones. Such 10 primary schools and high schools were inspected around 5 km radius of Khulna University of Engineering & Technology (KUET). Aim was to assess the seismic capacity of those school buildings and to upgrade the vulnerable ones through steel braced retrofitting to withstand earthquakes hazards.

Braced frame, a structural system widely used in structures subject to lateral loads such as seismic and wind pressure. Generally, members in a braced frame are made of structural steel that can work effectively both in compression and tension. The bracing system carries the lateral loads and the beams and columns that form the frame carry vertical loads. The placing of braces, however, can be problematic as they can interfere with the design of the facade and the position of openings. Bracings

can be used both as an internal or external design feature. In the external bracing system, existing buildings are retrofitted by attaching a global or local steel bracing system to the outside frames. A scaled model test reported by (Bush et al., 1991) showed the effectiveness of the method in increasing the shear resisting capacity of the building. Successful retrofits of existing buildings by indirect internal bracing using different forms of K, X and V eccentric and concentric braces had been reported by (Maheri & Akbari, 2003). In this paper, diagonal steel bracing is executed to analyse the vulnerable school buildings. Several tests were performed to increase the load resisting capacity of an existing reinforced concrete school building situated in the district of Naples, Italy. The school was reconstructed with different intervention techniques, namely steel concentric, eccentric and buckling restrained braces, reinforced concrete walls and steel shear panels whose non-linear behaviour under seismic actions in terms of performance point detection have been evaluated and compared using the Capacity Spectrum Method (Formisano et al., 2017). Tests on two full-scale, four-storey reinforced concrete frames were reported by (Pinto & Taucer, 2006). Without any strengthening interventions, high vulnerability to seismic loads was observed to the frame. Through the use of steel braces, it was found that the energy dissipation capacity and the seismic response of the strengthened frame were significantly improved. In previous years, the effective use of steel bracing in RC frames had also been indicated by several reports. In this paper, equivalent static analysis is carried out because the buildings are low-rise and no sign of significant twist in the previous earthquakes.

The objectives of the current research are as follows-

- To collect the construction details of 10 nos. school buildings around 5 km radius of KUET.
- To assess the structural capacity of those buildings through modelling in ETABS and to determine if these school buildings can withstand safely without causing any significant damages in terms of earthquakes by analyzing maximum allowable deflections.
- To propose and design an appropriate retrofitting method and compare the deflection variations after installing steel bracing.
- To estimate the cost for establishing steel braced retrofitting.

2. STRUCTURAL MODELLING

The present study consists of the selection, study and modelling of ten vulnerable govt. primary schools and high schools around Khulna city which could be hazardous in times of earthquake. Different parameters were used to identify these schools like location, soil condition, no. of storey, reinforcement condition, no. of people affiliated, age of the building, deflection, cracks, beam-columns current condition etc. The schools were surveyed thoroughly to measure all the possible dimensions. In those cases where the plans were not directly available, relevant plans were prepared from survey data and national building code BNBC. The surveyed schools along with necessary dimensions are shown in Table 1.

Table 1: Plan details of surveyed schools

Surveyed Schools	No of Storey	Storey Height (ft)	Floor Area (ft x ft)	Beam Size (ft x ft)	Column Size (ft x ft)
1. Afiluddin Primary & High School	4	45	70 x 46	B1 (12 x 12) B2 (22 x 12)	C1 (12 x 12)
2. Binapani Sarkari Prathamik Bidyalay	3	35	79 x 25	B1 (16 x 11)	C1 (11 x 11)
3. Collegiate Govt. Primary School	2	25	70 x 20	B1 (20 x 10)	C1 (16 x 10)
4. Fulbari B.K Govt. Primary School	4	45	72 x 30	B1 (16 x 12)	C1 (12 x 12)
5. Govt. Laboratory School	2	27	320 x 120	B1 (16 x 12)	C1 (12 x 12) C2 (Circular dia-10')

6. Government Muhasin Boys' High School	2	25	86 x 30	B1 (16 x 12)	C1 (12 x 12)
7. KUET School	2	25	123 x 25	B1 (12 x 12)	C1 (12 x 12) C2 (Circular dia-8.6')
8. Moheswarpasha Govt. Primary School	3	35	72 x 30	B1 (16 x 12)	C1 (12 x 12)
9. Nayabati Govt. Primary School	4	45	79 x 27	B1 (20 x 12)	C1 (16 x 12)
10. Nayabati Hazi Soriutllah High School	3	35	142 x 28	B1 (20 x 10)	C1 (20 x 10)

2.1 Development of Models in ETABS

At first, the as-built layout plans of the school buildings were made with appropriate dimensions. Then the layout plan was plotted in ETABS along with the gravity loads i.e., dead loads and live loads as per BNBC 2020 and survey data. The compressive strength of concrete was taken as 2000 psi for all the schools as they were established a long time ago. Compressive strength was considered as low as possible to maximize the factor of safety in times of earthquake. Strength of rebar was taken as 40 grades. Reinforcement detailing and other required data were taken according to BNBC manual within the allowable range. Earthquake and wind load both were considered in analysis to be safe against any unfavourable situation. Khulna, a coastal sub-division of Bangladesh, falls in earthquake zone-1. Though it is a mild earthquake zone, a medium level earthquake could be catastrophic in old poorly designed buildings. The seismic zone factor for Khulna is 0.12 as per code. Soil site coefficient SC is used for seismic calculations. Value of Ct for reinforced concrete moment resisting frame is 0.0466 in S.I. units. Other coefficient values were calculated as per BNBC guidelines.

The wind speed for Khulna is 73.3 m/s ≈ 163.97 mph. Exposure Type – A. The Windward and Leeward coefficients are calculated according to the BNBC 2020.

Maximum allowable deflection = L/240 due to all sustained loads and any additional live loads as per BNBC 2020, where L = height of the building.

After providing necessary dimensions and gravity loads to the models, the following load combinations were carried out for the analysis of all school buildings according to the BNBC 2020 code.

1. 1.4D
2. 1.2D+ 1.6L
3. 1.2D+ 1.0L
4. 1.2D± 0.5W
5. 1.2D+ 1.0L± 1.0W
6. 1.2D+ 1.0L± 1.0E, where, $E=E_h+E_v$
7. 0.9D± 1.0W
8. 0.9D± 1.0E, where, $E=E_h-E_v$

Then all the plans were analyzed by ETABS-2018 to evaluate if the existing school buildings can withstand safe in future earthquake by analyzing maximum deflection limit of these buildings.

2.2 Maximum and Allowable Storey Displacements

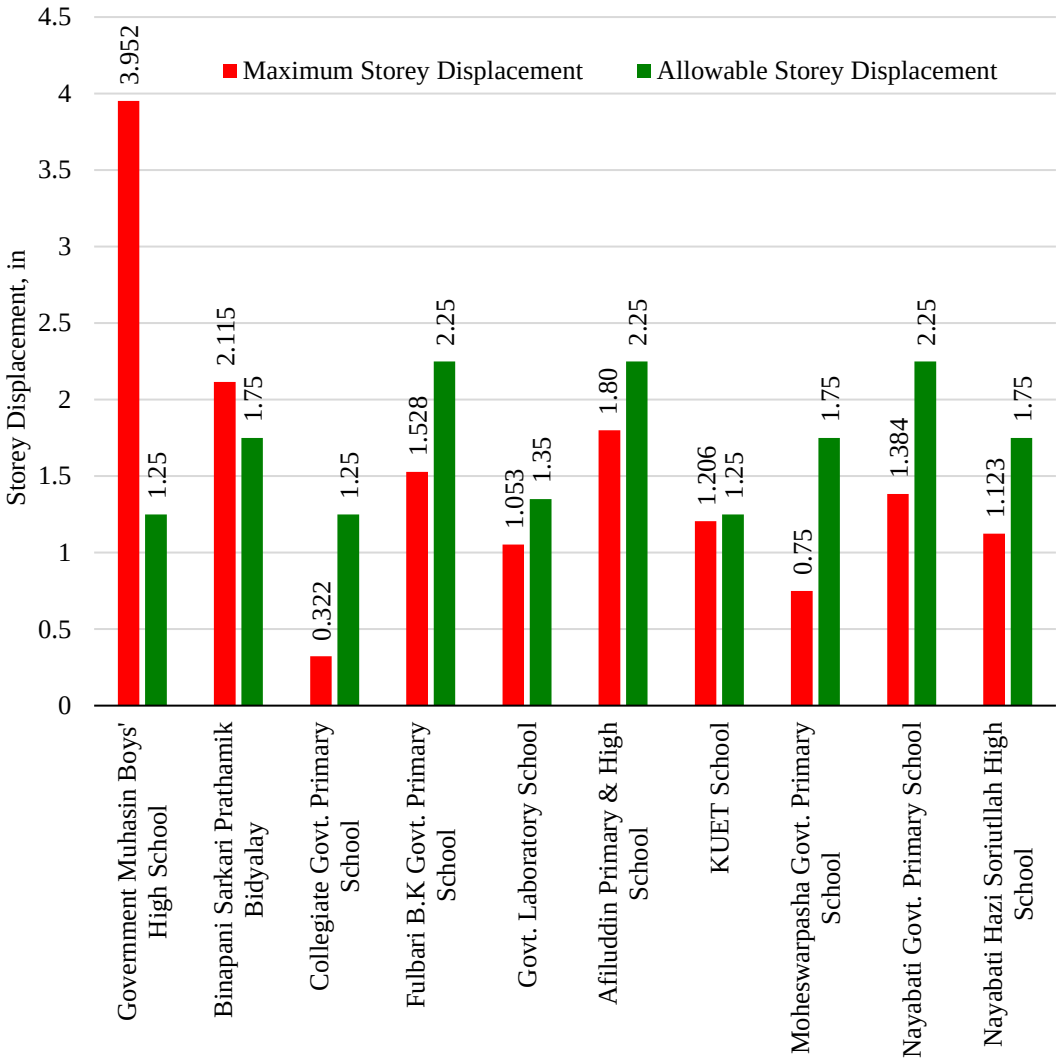


Figure 1: Maximum and allowable storey displacements for 10 school buildings

The analysis results of the maximum and allowable storey displacements of the surveyed school buildings are showed in
Figure *1*. From the analysis of 10 school buildings, two of them were found to exceed their allowable displacement limit. Those 2 schools are as follows:

1. Government Muhasin Boys' High School.
2. Binapani Sarkari Prathamik Bidyalay.

2.3 Analysis and Design for Seismic Strengthening

Vulnerable two schools-Government Muhasin Boys' High School and Binapani Sarkari Prathamik Bidyalay were strengthened by retrofitting techniques since their displacements were above the allowable limits.Government Muhasin Boys' High School is one of the oldest schools located in Daulatpur, Khulna. It was established in 1867 and is a 2-storey school building with a floor height of 10 ft as erected in 1995. The conditions of the building are poor. There were significant cracks seen in beams and columns and spalling of plasters. The conditions of the slabs, walls, stairways and plumbing system were also poor. Reinforcements were exposed in several places. A plan was prepared after surveying the whole school shown in Figure 2. There were 7 bays in X- direction. The length in X-

direction was86 ft. and in Y- direction was 30 ft. The allowable deflection is L/240 = (25 X 12) / 240 =1.25 in, whereas the maximum storey displacement for this school is 3.592 in. on the 2nd floor.

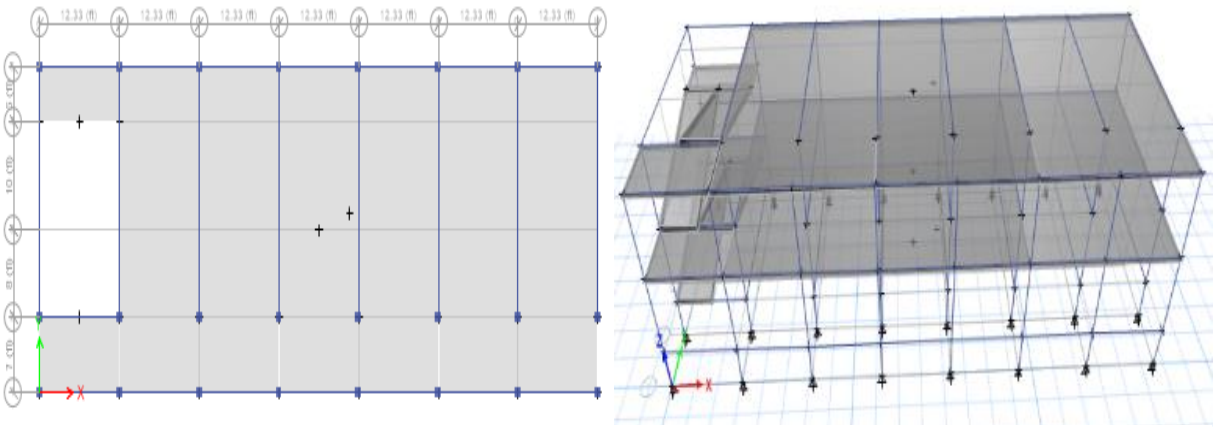


Figure 2: Plan and 3D model of Government Muhasin Boys' High School

Binapani Sarkari Prathamik Bidyalay, a 3-storey building located in Daulatpur, Khulna was established in 1926. But its academic building was constructed in the 90's. The overall conditions of the building were not satisfactory. There were significant cracks. Reinforcements came out in different places. It had 8 bays in X- direction and 2 bays in Y- direction as shown in Figure 3. The length in X- direction was 79 ft. and in the Y- direction was 25 ft. A plan was prepared after surveying the whole school. The maximum storey displacement for this school is 2.115 in. in the Y-direction on the 3rd floor where the allowable deflection is 1.75 in. The maximum storey displacements for Government Muhasin Boys'

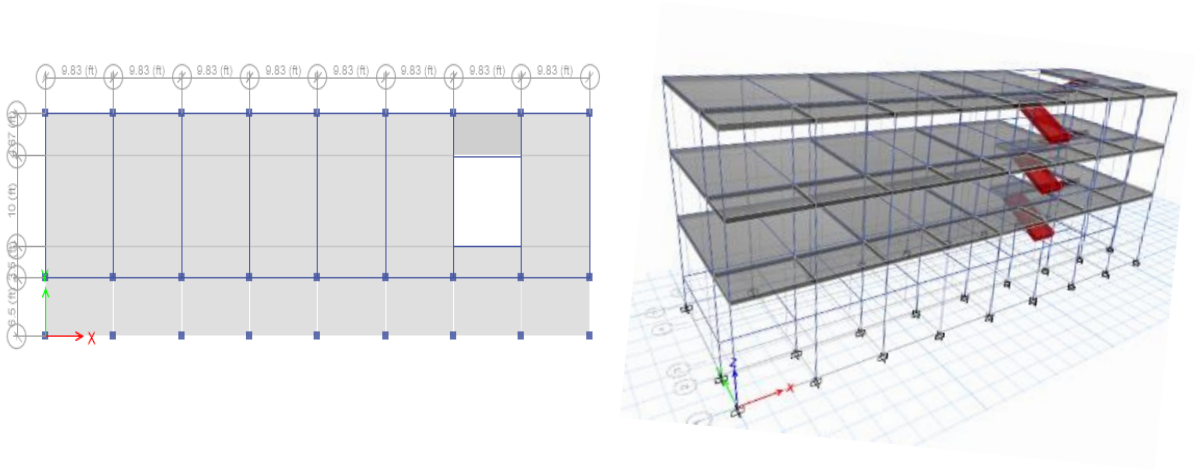


Figure 3: Plan and 3D model of Binapani Sarkari Prathamik Bidyalay

High School and Binapani Sarkari Prathamik Bidyalay are 3.592/1.25=2.874 and 2.115/1.75=1.692 times greater with respect to their allowable limits.

The maximum storey displacements of these two schools were analysed after providing retrofitting. Among different types of retrofitting techniques- diagonal, cross, K, V, eccentric, zipper, CSB bracings etc. simple diagonal bracing steel bracing is discussed briefly in this paper. Hollow rectangular GI A36 steel HSS 4 X 4 X ½ section is used as steel braced retrofitting. It is because, HSS type of steels are quite available in the local markets and their cost, strength and durability are better. Diagonal types of bracings are easy to construct and the cost required is comparatively low. The handling and setting of beam-column connection for diagonal bracing are easier than other types.

Steel bracing was provided at the both extreme corners of the building for both Government Muhasin Boys' High School and Binapani Sarkari Prathamik Bidyalay as the maximum deflection lies on that portion. Hinge type of connections were considered between the joints of steel bracings and concrete elements for retrofitting. After providing bracing, deflections were lowered due to the increase of stiffness. Thus, the rise of lateral load-bearing capacities had been noted significantly.

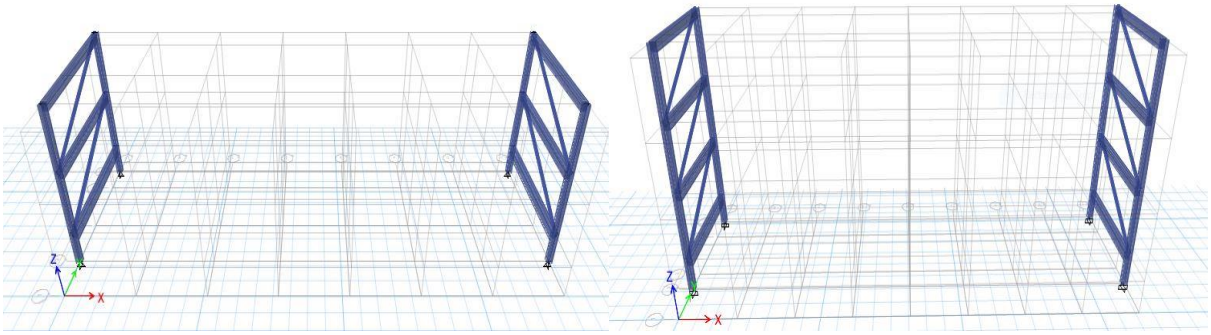
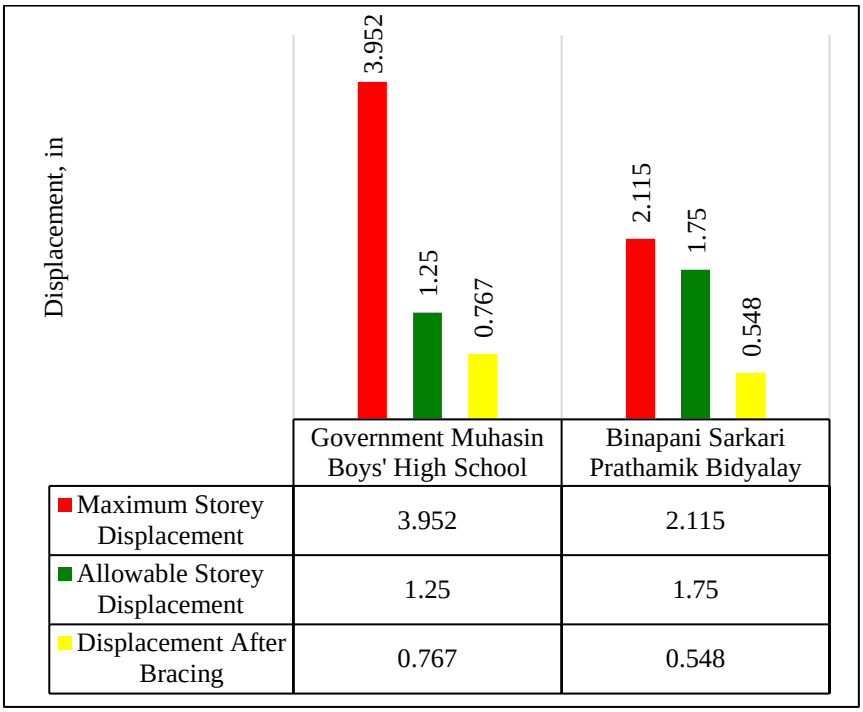


Figure 4: Position of steel bracing of Government Muhasin Boys' High School (Left) and Binapani Sarkari Prathamik Bidyalay(Right)



	Government Muhasin Boys' High School	Binapani Sarkari Prathamik Bidyalay
Maximum Storey Displacement	3.952	2.115
Allowable Storey Displacement	1.25	1.75
Displacement After Bracing	0.767	0.548

Figure 5: Change of displacements after proving steel bracing

Comparison of maximum and allowable displacements, before and after providing diagonal bracing is shown in
Figure 5. After installation of bracings, the storey displacements were below the allowable limits. These bracings were provided in such a way that the cost due to retrofitting be minimal as possible. In this paper diagonal bracings are provided to the vulnerable frames to study the after-effects of retrofitting. A relative cost analysis was performed to check if it is cost-efficient and safe to repair the buildings rather than reconstruct them. According to BNBC, replacement of existing unsafe buildings or damaged buildings by reconstruction is, generally, avoided due to higher costs than retrofitting or strengthening, conservation of historical architecture and sustaining the functional cultural and social environment. Mostly, the comparative cost of reconstruction to retrofitting concludes the decision. As a thumb rule,

if the seismic strengthening and repair cost is less than about 50% of the reconstruction cost, retrofitting is accepted. Approximate reconstruction cost was calculated for vulnerable two schools following the PWD Schedule of Rates for Civil Works 2014.

Table 2: Approximate reconstruction and retrofitting cost

Vulnerable Schools	Reconstruction Cost Taka (BDT)	Retrofitting Cost Taka (BDT)
1. Government Muhasin Boys' High School	12,636,480	287,456
2. Binapani Sarkari Prathamik Bidyalay	14,053,531	366,872

For Government Muhasin Boys' High School bracing the installation cost was 2.27% of the reconstruction cost which is undoubtedly cost-efficient. For Binapani Sarkari Prathamik Bidyalay, installation cost was 2.62% compared to its reconstruction costs. So, it can be said without any confusion that the installation of steel diagonal bracing is cost-effective and time saving.

3. CONCLUSION

Many existing buildings do not meet the seismic strength requirements due to original structural inadequacies and material degradation due to time or alterations carried out during use over the years. Their earthquake resistance can be upgraded by appropriate seismic retrofitting techniques.

- This research deals with the seismic analysis of 10 existing school buildings in Khulna city.
- By analysing and comparing with the allowable deflection limits seismic hazardous buildings were identified.
- A guideline of retrofitting technique has been shown in the 2 vulnerable schools- Government Muhasin Boys' High School and Binapani Sarkari Prathamik Bidyalay.
- By providing steel bracing at the both extreme corners maximum deflection is reduced from 3.952 in. to 0.767 in. for Government Muhasin Boys' High School and 2.115 in. to 0.548 in. for Binapani Sarkari Prathamik Bidyalay.
- Research results yield that diagonal steel braced retrofitting technique can be conveniently and cost-effectively applied to such type of low-rise buildings to avoid the hazards due to earthquakes.

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