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Seismic Damage Assessment and Retrofitting of Hybrid Structure

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ABSTRACT

Pakistan is seismically prone country, which has faced devastated earthquakes in the past history. The hybrid structures are very common in northern areas of Pakistan and their behavior under seismic event is very critical. The seismic response of hybrid buildings is different from other structural systems as there is discontinuity, both in the lateral and vertical load transfer mechanisms. To assess the seismic damage of hybrid building for zone 3, the pushover analysis has been carried out on a 6-storey model building with its 4 bottom stories of reinforced concrete frame and top two stories of steel frame for a maximum drift of 2.5%. Pushover analysis has been performed using commercial software SAP2000 v.15 and critical seismic deficiencies have been determined. Overall evaluation has been done using capacity curves, stages of plastic hinge levels, storey displacements and capacity spectrum. Based on the identified deficiencies in stiffness as well as the ductility a comprehensive retrofit design has been carried out. The hybrid building has been retrofitted with shear wall or steel brace to remove the deficiencies in stiffness and ductility. After retrofitting pushover analysis has been again carried out to determine the efficiency of retrofit design. The results revealed that retrofit intervention significantly improved the seismic performance of the hybrid building and increased the stiffness or lateral capacity by 47% and 42%, respectively. Moreover, lateral displacements also have been reduced by 37% and 42% by adding shear wall and steel brace respectively. The research outcome can help the local engineers and designers to properly retrofit the existing buildings in Northern Areas of Pakistan.

1. Introduction

The assessment of seismic safety of the built environment is a matter of high priority and was well realized engineers, public authorities and general public in Pakistan after October 2005 Kashmir-Hazard earthquake. Awareness of the problem has been accelerated by the disastrous effects in the recent seismic events, in terms of loss of lives, immediate and long-term economic losses. This issue is now getting importance not because of the seriousness of the problem but because of the community is moving towards improvement in the building structures. Estimating seismic demands at low performance levels requires explicit consideration of inelastic behavior of the structure. While non-linear response history analysis (RHA) is the most rigorous procedure to compute seismic demands, current civil engineering practice prefers to use the non-linear static procedure (NSP) or pushover analysis in FEMA-356 [1]. The seismic demands are computed by non-linear static analysis of the structure subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a predetermined target displacement is reached. Both the force distribution and target displacement are based on the assumption that the response is controlled by the fundamental mode and that the mode shape remains unchanged after the structure yields. Obviously, after the structure yields, both assumptions are approximate, but investigations have led to good estimates of seismic demands. However, such satisfactory predictions of seismic demands are mostly restricted to low- and medium-rise structures provided the inelastic action is distributed throughout the height of the structure. None of the invariant force distributions can account for the contributions of higher modes to response, or for a redistribution of inertia forces because of structural yielding and the associated changes in the vibration properties of the structure. To overcome these limitations, several researchers have proposed adaptive force distributions that attempt to follow more closely the time-variant distributions of inertia forces. While these adaptive force distributions may provide better estimates of seismic demands, they are conceptually complicated and computationally demanding for routine application in structural engineering practice.

In 2005, Kashmir-Hazara earthquake a devastated damage to buildings, aware the engineering experts and public authorities about the seismic assessment of the built structures. The disastrous effects of the seismic events cause loss of lives, partial/total collapse of structures, immediate and long-term economic losses. Based on materials and structural systems, buildings may be classified based on load transfer, as Masonry structures, Reinforced Concrete (RC) structures, Steel frame structures and Hybrid structures. Hybrid structures are those with two or more different lateral load-resisting systems. Hybrid buildings could be the result of modifications or expansions in existing buildings or may be conceived at the design stage itself.

Many researchers [2-7] have done research on behavior of hybrid structures. From their work, conclusions can be drawn that by proper design the hybrid structure has shown

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reasonably good seismic performance. Jiang and You [8] carried out study on high rise buildings in which the behavior of the structure was checked on linear static and nonlinear static analysis procedures. The proposed buildings were steel and hybrid buildings. They concluded that the seismic performance of buildings was quite good even in severe ground shaking. Mehanny and Deierlein [9] carried out static pushover and time history analysis of composite structure of steel beams and concrete columns. The analysis revealed that the performance levels were achieved as required by the codes. This conclusion was, however, limited to the six-storey trial design studies examined where the static over strength was large and redundant space frames were used. Oliveto and Marletta [10] proposed study in Eastern Sicily to assess the seismic vulnerability of existing buildings. They also discussed the seismic vulnerability, existing drawbacks of structures, retrofitting of structure with modern techniques, conventional methods on the applicability and the effect on the performance of the structures. They concluded that the resistance offered by the buildings after the earthquakes has improved significantly due to retrofitting. The applied lateral load patterns have been studied by many researchers [11-14] and they have concluded that plasticity theory can be extended to P-M interaction in a column, where the axial force P and the bending moment M, interact with each other. This P-M interaction should be checked properly to avoid any unforeseen failure of a structure.

An example of a hybrid system with reinforced concrete frame at the ground floor level and steel frame above in Athens, Greece shown in Fig. 1.

Fig. 1: Concrete-steel frame (Hybrid building) https://taxonomy.openquake.org/index.php/terms/hybrid-lateral-load-resisting-system-lh

In recent years a lot of seismic damage assessment and retrofit based analytical studies have been carried on load bearing masonry structures and reinforced concrete (RC) in Pakistan but the analytical studies done on seismic damage assessment of Steel-concrete hybrid structures in Pakistan is insufficient. There are many hybrid buildings in our country one of which is a famous hotel located in the heart of provincial capital of Punjab, Lahore having 5 storey concrete frame and upper 2 storey steel frame. This research can help in assessing different damage levels of steel-concrete hybrid structures and helpful to find possibilities of construction of hybrid structures in different regions of Pakistan. The proposed research will also be helpful to carry rehabilitation of hybrid structures using different retrofit measures.

2. Detail of the Structural Model

For computer modeling, a simple six storey hybrid building is selected. The building lies in occupancy groups A, B and I of BCP (2007) [15]. The plan area of building is 87×87 ft. with 11 ft. as height of each typical storey. It consists of top two stories steel frame with steel beam and column and the rest of four stories reinforced concrete frame. The connection to reinforced concrete frame to steel frame is considered as a rigid joint. The building is consisting of central elevator of concrete material having dimensions 5×5 ft. The plan area of the building consists of 5 bays both in X-direction and Y-direction. The total height of the building is 66 ft. The building is considered as a Special Moment Resisting Frame for both steel and RC frame with 6 inches thick slabs. RC Slab and shear wall were modeled as RCC shell elements. The plan of building is shown in Fig. 2. The sectional properties are given in Table 1.

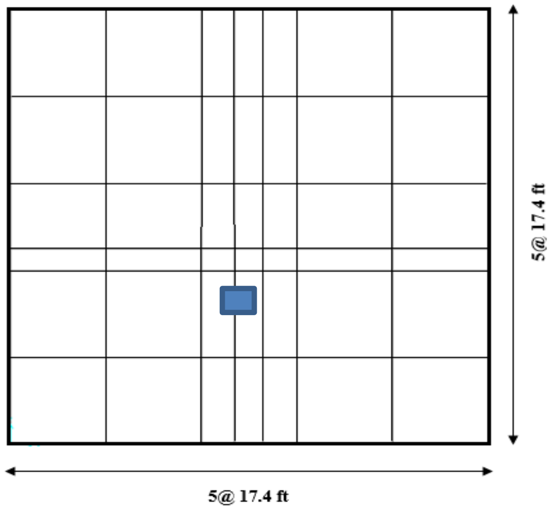


Fig. 2: Plan of hybrid model building.

Table 1: Sectional properties of model building.

Sections	Width (In)	Depth (In)	Area (In^2)	Type
B 18×12	12	18	216	Concrete beam
B 20×14	14	20	280	Concrete beam
C 12×12	12	12	144	Concrete column
C 14×14	14	14	196	Concrete column
C 15×15	15	15	225	Concrete column
C 18×18	18	18	324	Concrete column
W12×14	11.8	4	4.16	Steel beam/column
W 14×22	13.2	5	6.49	Steel beam/column
W16×26	15.7	5.5	7.68	Steel beam/column
W18×35	17.7	6	10.3	Steel column
W21×44	20.7	6.5	13	Steel column
TS 4×4×1/4	4	4	16	Steel bracing

3. Analysis Procedure / Methodology

Pushover analysis was carried out for seismic damage assessment of the modal hybrid building using SAP2000 v15 commercial software [16]. Zone 3 was selected because Pakistan is geographically located in one of the most seismically active regions of the world due to its tectonic settings. The tectonic settings of Pakistan are unique, as three major tectonic plates are converging to its location. It is exposed to very high seismic risk because of vulnerability of the built structures due to poor construction practices in the country [17]. The building was analyzed in seismic zone 3 and deficiencies were identified. Based on identified deficiencies, appropriate retrofit design was carried out and the building was retrofitted using guidelines of FEMA-356/ASCE-41/ATC-40 [1, 18, 19]. The retrofitted building was again analyzed, and results were compared with the original un-retrofitted building to study the improvement in seismic performance due to retrofit intervention. Overall seismic damage evaluation was done using capacity curves, stages of plastic hinge levels, storey displacements and capacity spectrum. The building was modeled and designed as per the provisions of ACI 318-05 [20] for RCC frames and AISC-LRFD-93 [21] for steel frames. The hybrid building was pushed to a targeted displacement (2.5% drift) and different damage levels of the building were assessed. Deficiencies in the building were identified, and appropriate retrofit strategy was developed. Based on the identified deficiencies, the model building was retrofitted with shear wall and steel braces for improving the stiffness and ductility. For Non-linear Static analysis default hinges available in SAP2000 v15 as per FEMA 356 [1] were assigned to columns and beams. Initially the hybrid building was modeled and analyzed under gravity load only. The gravity loads included self-weight of the structural members, live loads and floor finishes load taken in accordance with BCP 2007 [15]. After the building qualified for gravity loads, hinges were assigned to beams/columns and pushover analysis was carried out. The soil condition “D” was selected for zone 3 of Pakistan. Non-linear static analysis was carried out and the building was subjected to maximum of 2.5% lateral drift as per ASCE 41-06 [18]. All the materials were assigned non-linear properties. Push as a load case was defined that will start working from non- linear factored gravity load case instead of unstressed (zero) state. In Push Load Case specified monitored displacement of 19.8 inches for 2.5% of drift was assigned at top roof joint and the results were saved in multiple steps. Hinges with default properties were assigned to steel beam / columns, concrete beams / columns in accordance with FEMA-356 [1] for relative length of 0 to 1 respectively. Finally, the analysis was run for all the load cases and their results were computed for seismic damage assessment. The main parameters considered for seismic damage assessment in the model building was; (1) development of plastic hinges, (2) capacity curve, (3) storey displacements and (4) capacity spectrum.

4. Seismic Performance Levels

4.1 Operational Performance Level

This performance level associates with functionality of the structure. Generally, all systems important to normal operation are operational. Damage to the building is limited, so the overall damage is very light and hence immediate occupancy is not questionable. The structure does not experience permanent drift.

4.2 Immediate Occupancy Performance Level

The structure experiences light damages. There is no permanent drift. The building retains original strength and stiffness substantially. Minor cracking of facades, partitions, and ceilings as well as structural elements. Concrete frame experience minor hairline cracking, limited yielding on few locations.

4.3 Life Safety Performance Level

This level intended to obtain a damage condition that presents a substantially low probability of danger to life safety. Whether the danger is due to structure damage or fallen of nonstructural components of a building. The building experiences moderate overall damage. Concrete frame beams damage extensively, shear cracking and cover spall off occur in ductile columns, and minor cracking develops in non-ductile columns.

4.4 Collapse Prevention Performance Level

This level of building performance mainly relates to the vertical load carrying system and the structure need to be stable under vertical loads only. Generally, the building damage is severe. The structure retains little residual stiffness and strength. The building suffers large permanent drifts. In concrete frames, hinges and extensive cracking develop in ductile elements, non-ductile columns experience splice failure and limited cracking, and short columns damage seriously [22].

5. Identification of Deficiencies

The seismic deficiencies in the un-retrofitted hybrid building were determined based on the following parameters:

5.1 Hinge Formation

A simplified non-linear analysis provides relative qualitative data for the preliminary evaluation. The pushover analysis indicated hinge formations in the zone 3 of Pakistan in Figs. 3 (a-d). It was observed that the majority of developed plastic hinges were at life safety and some of the hinges were at collapse prevention level indicating severe damage level to the model building. Plastic hinges at life safety and collapse prevention level were mostly found at the inter-storey column level of the RC frame. However, the hinges in steel columns at fifth storey were found at life safety level (North direction). The development of plastic hinges describes potential seismic damages that may lead to unacceptable performance of the building. These potential deficiencies can even lead to collapse of the structure and require appropriate retrofit intervention to improve the seismic behavior of the building.

5.2 Capacity Curve

The capacity curve of the model building is shown in Fig. 4. The maximum lateral drift of the building recorded was 1.7% against the target displacement of 2.5% drift at a lateral load of 1859 kips. Quite low stiffness was recorded for the model building with lateral load at yielding of 1259 kips at a lateral displacement of 3.54 inches. The ultimate lateral displacement of 10.4 inches was recorded at a lateral load of 1859.8 kips. The building possesses considerable deficiencies in stiffness and ductility and needs suitable retrofit strategy to increase the stiffness in order to reduce the excessive displacement.

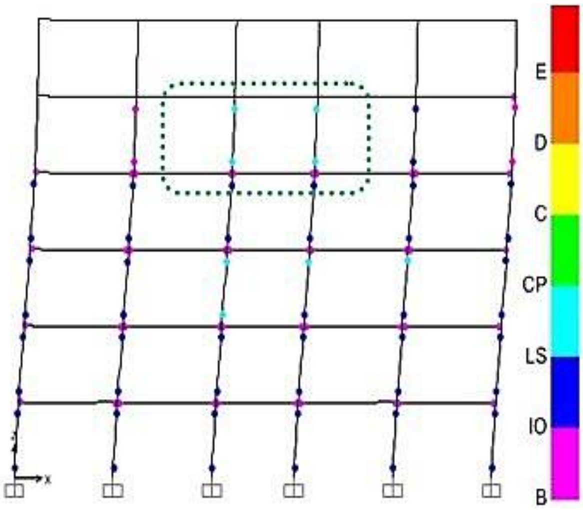


Fig. 3a: North direction.

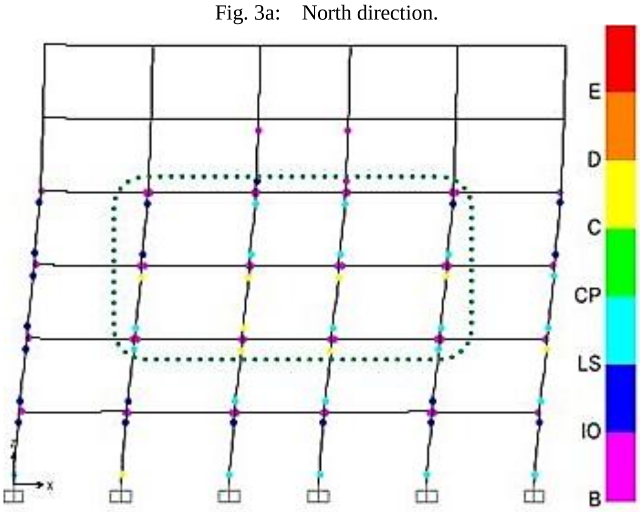


Fig. 3b: South direction.

5.3 Capacity Spectrum

After pushover analysis, capacity spectrum curve was studied to determine different parameters. The building has sustained spectral acceleration of 0.41g and spectral displacement of 0.528 at performance point as shown in Fig. 5. High spectral acceleration clearly indicates that the building experienced high inertial forces and sustained considerable damages. The performance point occurred at a lateral load of 1250 kips and lateral displacement of 2.81 ft. The performance point of the building lies between life safety and the collapse prevention indicating considerable seismic damage potential in the building requiring appropriate seismic retrofitting.

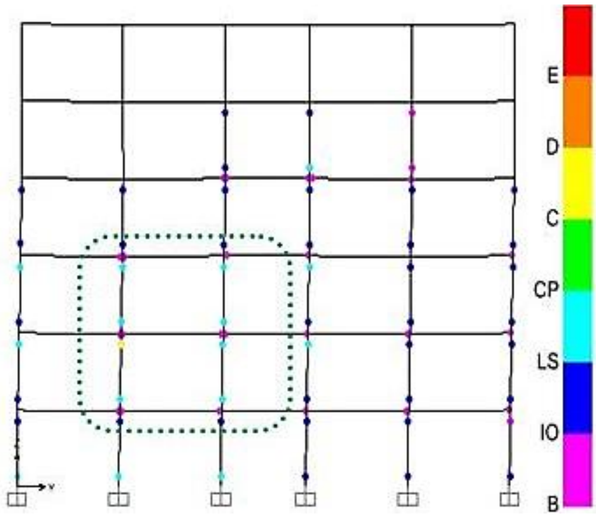


Fig. 3c: East direction.

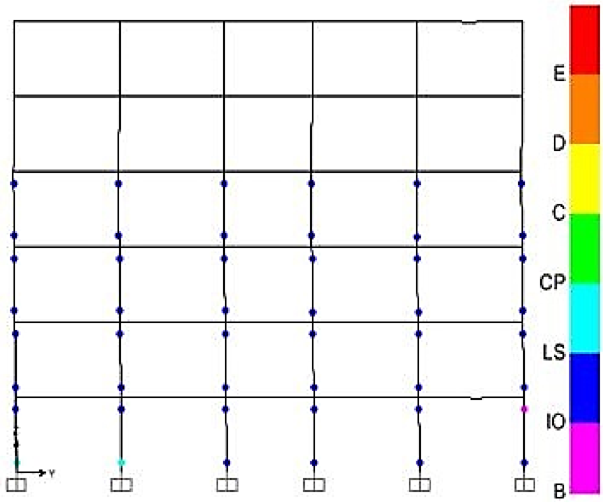


Fig. 3d: West direction.

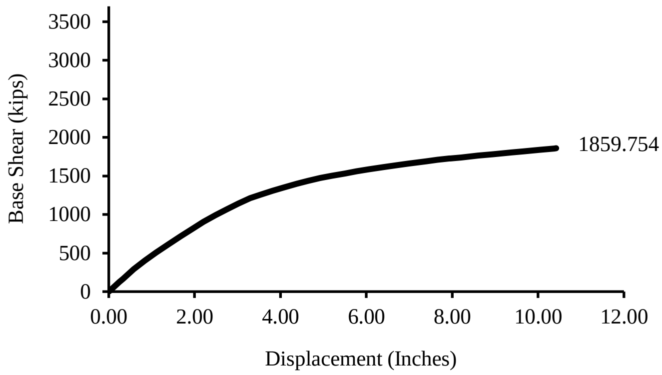


Fig. 4: Capacity curve for 2.5% drift of model building.

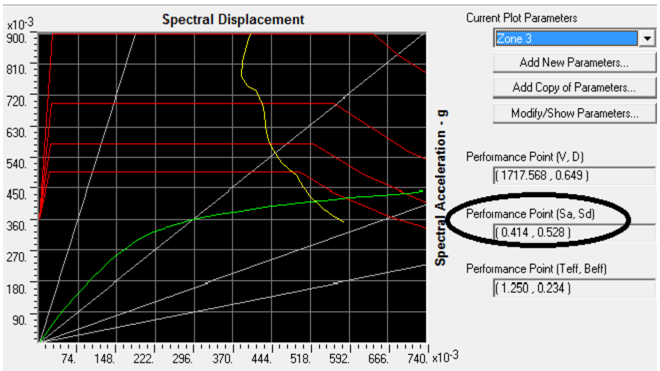


Fig. 5: Capacity spectrum of model building.

5.4 *Lateral Storey Displacement*

The recorded lateral storey drift of the building is summarized in Table 2 and graphical representation is shown in Fig. 6. It is found that the building has experienced a maximum storey drift at the top roof level which was about 1.7% in the southern direction and 1.4% in northern direction. These large displacements might lead the unacceptable performance level of the building as evident from the capacity spectrum. These unacceptable displacements can be controlled by adopting retrofit strategies which can reduce the storey drifts in the building. The seismic damage evaluation of the hybrid building revealed critical deficiencies in stiffness and energy dissipation which require an appropriate retrofit strategy for retrofit intervention. The required retrofit strategy must be based on the improving the stiffness and deformation control phenomena so that the model building has enough capacity to withstand the seismic demand. The retrofit intervention and preliminary design are selected within the context of the selected strategy.

Table 2: Lateral storey drift ratios.

Building face	Storey drift (%)						
	G	1st	2nd	3rd	4th	5th	6th
North	0.002	0.2	0.5	0.8	1.1	1.3	1.4
South	0.005	0.3	0.7	1.0	1.4	1.5	1.7

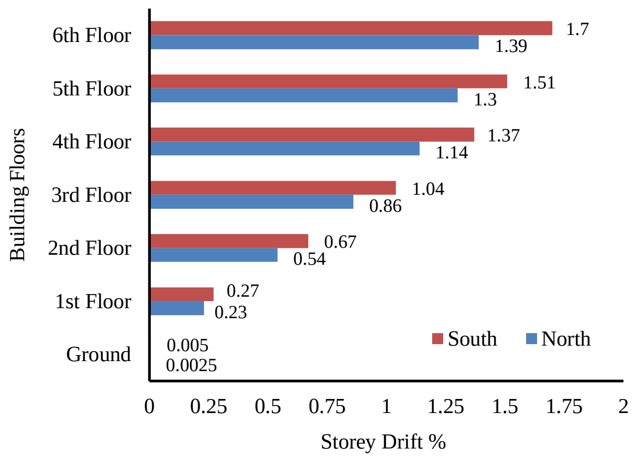


Fig. 6: Lateral storey drift ratios.

5.5 *Selection of Retrofit System*

A retrofit system is the specific method used to achieve the selected strategy of retrofit. The deficiencies found in hybrid building needs improvement in strength, stiffness and ductility which can efficiently mitigate the observed seismic damages in the building. The retrofit system selected for hybrid building was "stiffness and strength". Stiffening and strengthening retrofit strategy for the model building is typically accomplished by using the retrofit interventions like addition of braced members/shear walls. The hybrid building under consideration was strengthened by adding exterior shear wall throughout its height of the frame and by adding steel braces using ATC 40 Code [19]. In the 1st retrofit technique, the model building was retrofitted by adding shear walls to exterior side of the building in the center bay over the building height as shown in Fig. 7. The shear wall was added as a shell layer having a thickness of 12 inches. Whereas, in the 2nd retrofit technique steel braces were added at exterior side of the building in the center bay over the building height as shown in Fig. 8. For both the retrofit interventions pushover analysis was again run using same section properties/load cases and the retrofitted buildings were again evaluated for the seismic damage.

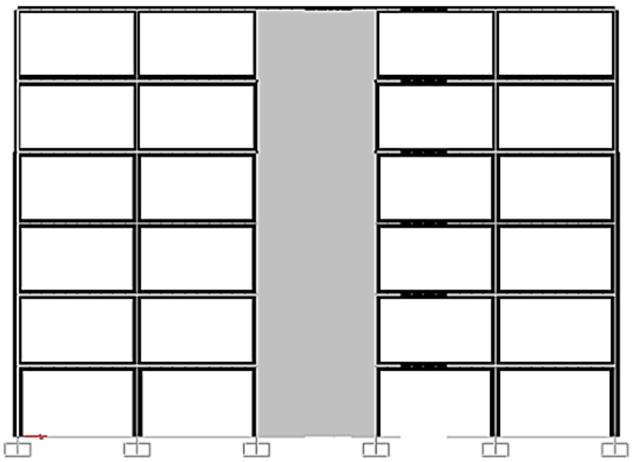


Fig. 7: Retrofitted with shear wall.

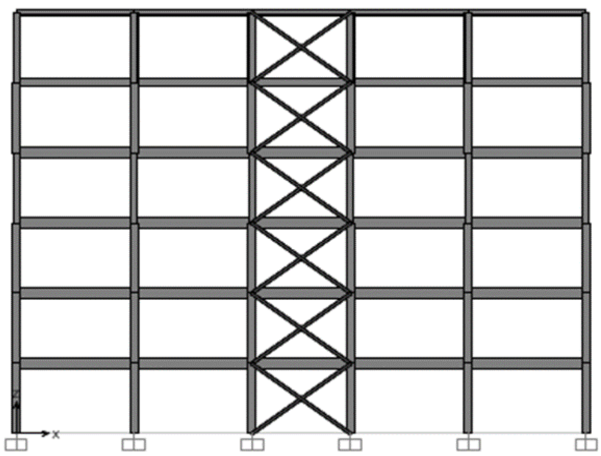


Fig. 8: Retrofitted with steel braces.

6. Discussion on Results of Retrofitted Hybrid Building

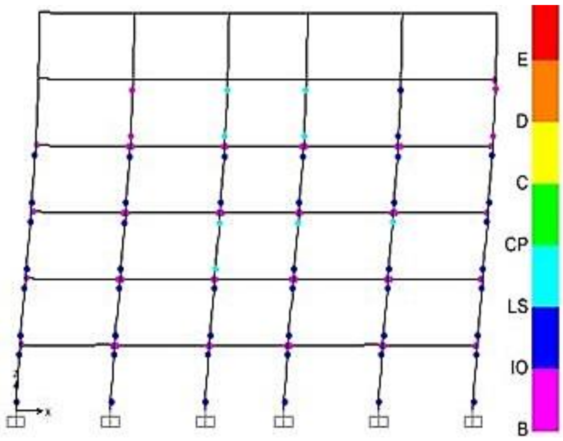
The model hybrid building was retrofitted using shear wall /steel braces and again analyzed to determine the improvement in its seismic performance. The results of retrofitted building were compared with the original un-retrofitted building and details are as under:

6.1 Comparison of Plastic Hinge Formation

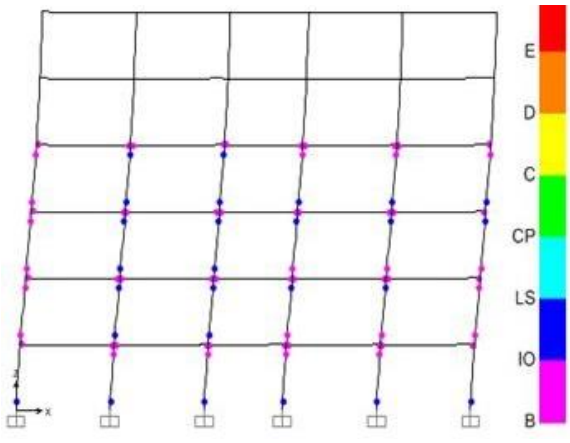
The comparison of plastic hinge development in the north grid is shown in Fig. 9. In the model building, plastic hinges were developed in all most all the beams/columns. It was observed that the majority of developed plastic hinges were at life safety and some of the hinges were at collapse prevention level indicating severe damage level to the model building. Moreover, plastic hinges were also developed at immediate occupancy/life safety levels in the steel columns at upper two stories. The plastic hinge formation improved significantly after retrofitting the building with shear wall. It was observed that plastic hinges developed in only few RCC columns/beams and the developed hinges were found at operational/immediate occupancy levels. However, no plastic hinge was developed in steel beams/columns at upper two stories and all the steel structural members remained elastic. But in case of steel braced building, large number of plastic hinges was developed in the RCC frame. However, all the developed plastic hinges were found within operational/ immediate occupancy level and none of the developed hinge crossed the life safety level. No plastic hinge was developed in upper two steel stories as was observed for building retrofitted with shear wall. Similar trend of plastic hinge development was observed in southern direction Fig. 10. In model building it was observed that the columns/beams in the RC frame were found at life safety and even collapse prevention level and plastic hinges were also found at 5th floor steel columns/beams. In the building retrofitted with shear wall, less number of plastic hinges were developed in RCC columns/beams and all the developed hinges were at operational level; whereas, no plastic hinge was in the steel frame. In seismic zone 3, in model building, the hinges in some cases have gone into collapse prevention level which is an unacceptable performance level, because it may cause loss of life and result in partial collapse of the building. The application of retrofit interventions, the developed hinges were found within operational/immediate occupancy level [23].

6.2 Comparison of Capacity Curves

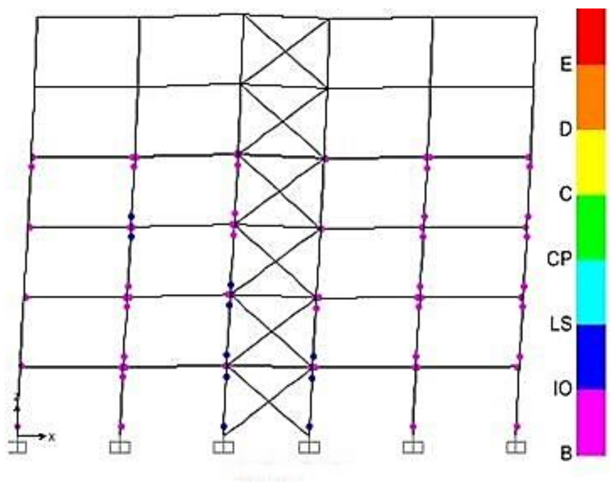
Fig. 11 shows the comparison of lateral load–lateral displacement relationship of the model and retrofitted buildings. Recorded value of base shear of model building is 1860 kips at a lateral displacement of 10.5 inches. After retrofitting with steel braces, increase in base shear is very negligible whereas the decrease in lateral displacement is quite significant as compared to model building. The recorded value of base shear is 1865 kips at a lateral displacement of 6.1 inches. Retrofitting building with shear wall has significantly increased the base shear with reduction in lateral displacement due to increase in strength and stiffness caused by shear wall. The base shear value of 2182 kips was recorded at a lateral displacement of 6.7 inches. It was observed that after retrofitted with shear wall the base shear of the building was increased significantly up to 15% and retrofitting with steel bracing the increase in base shear is about 1% which is considerably negligible. It was also observed that the lateral displacement of the retrofitted steel brace building and retrofitted with shear wall was reduced up to 36 % and 42%, respectively.



Model building

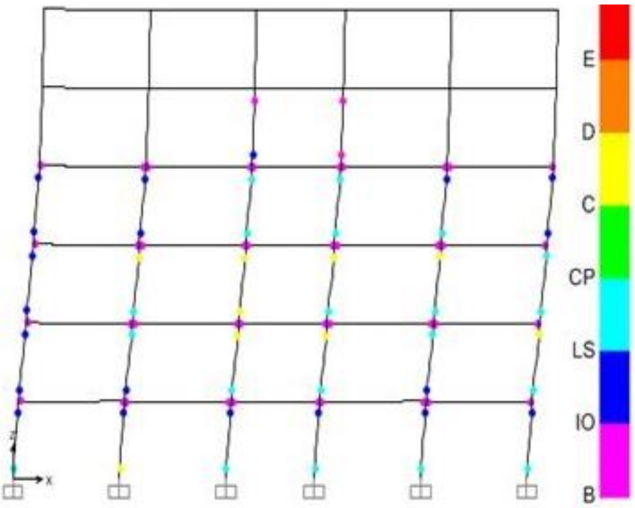


Shear wall building

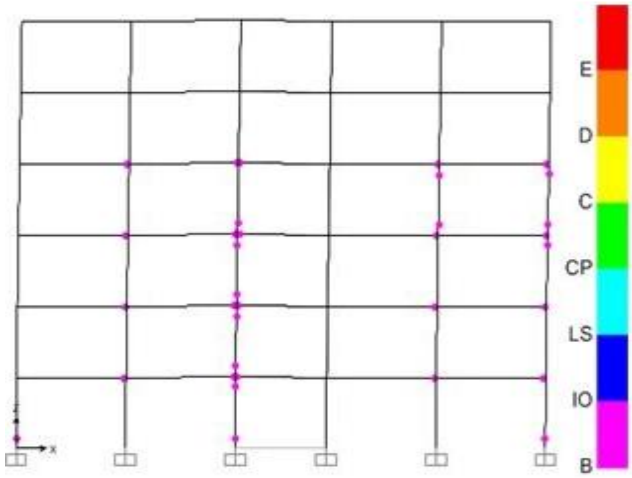


Steel brace building

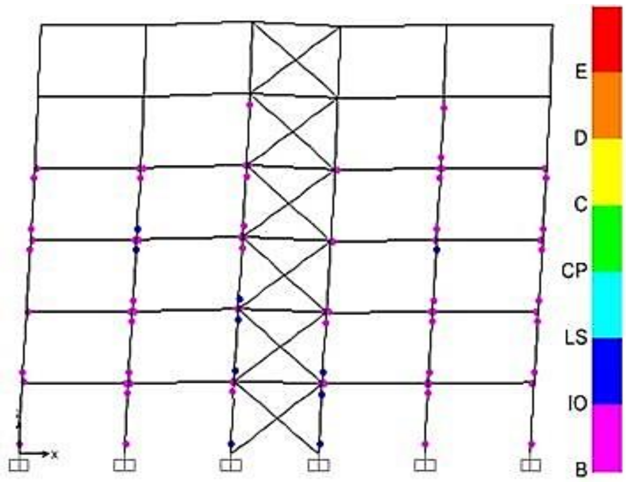
Fig. 9: Plastic hinge formation in north grid of Zone 3.



Model building



Shear wall building



Steel brace building

Fig. 10: Plastic hinge formation in south grid of Zone 3.

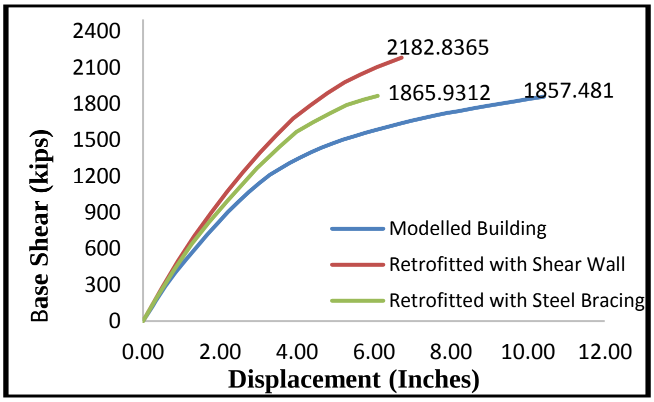


Fig. 11 Capacity Curves for 2.5% drift of Model Building and Retrofitted Building.

6.3 Comparison of Lateral Storey Displacements

Model building experienced large displacements in north/south grids as shown in Figs. 12 (a and b). After retrofitting the model building with shear wall and steel braces, the maximum lateral displacements north grid was reduced by 90% and 52%, respectively. So, it was found that both the retrofit interventions are quite effective in controlling lateral displacements.

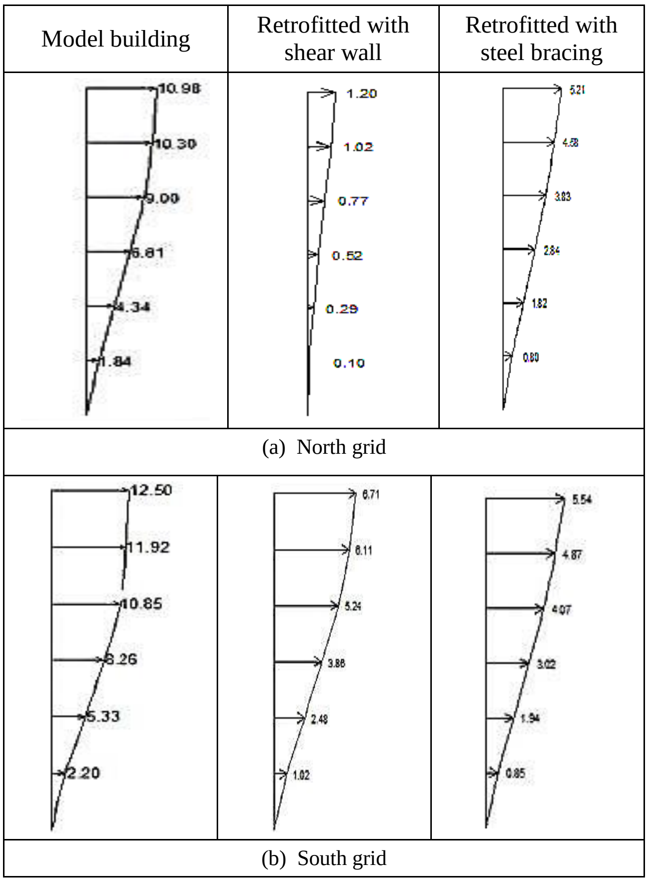
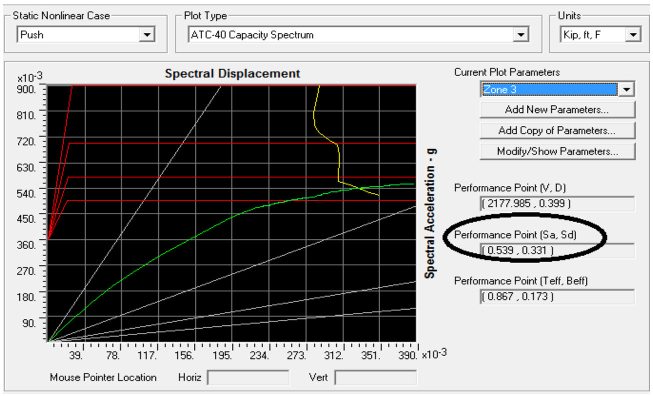


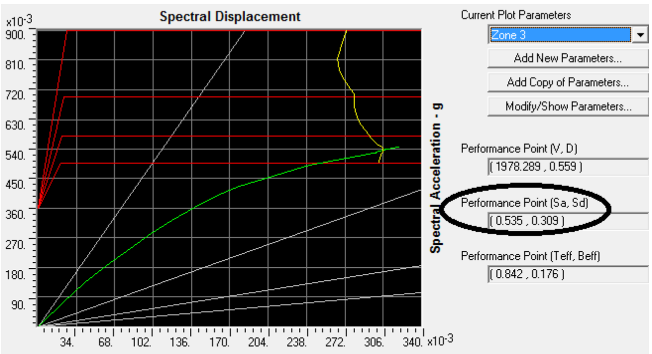
Fig. 12: Comparison of inter-storey lateral displacements of model and retrofitted building (values are in inches).

6.4 *Comparison of Capacity Spectrum*

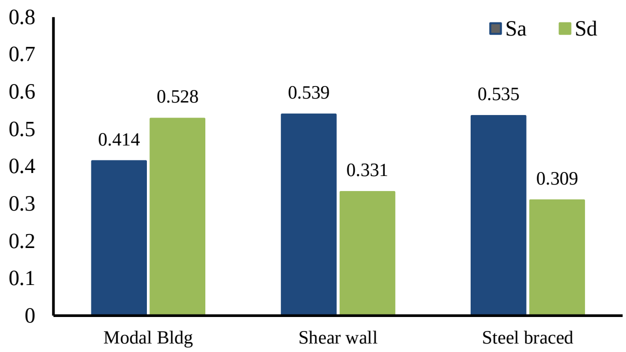
The capacity spectrum of retrofitted buildings is shown in Figs. 13 (a and b). At performance point, the spectral acceleration of 0.414g was recorded in case of original building as shown in Fig. 13c. After retrofitting with steel bracing and shear wall, building spectral acceleration increased by 23% and 22.6%, respectively. Similarly, spectral displacements in case of building retrofitted with steel bracing and shear wall decreased 42% and 37.5%, respectively. Overall the performance point improved considerably due to retrofitting and in both the cases lies in between IO-LS level. However, shear wall was more effective in improving the stiffness of building, while steel braces were comparatively more effective in improving the ductility of the building.



(a) Shear wall



(b) Steel braced



(c) Comparison of spectral values at performance point

Fig. 13: Comparison of capacity spectrum of retrofitted building.

7 Conclusions

From the present study we can conclude the following points:

1. Majority of plastic hinges developed after pushover analysis for zone 3 are crossing the collapse level. Most of the plastic hinge formation for zone 3 was within life safety/collapse prevention level which indicates significant damages to building. After retrofitting the building with shear wall and steel braces, the plastic hinge formation was found within operational/immediate occupancy level for both the zones. The retrofitting intervention significantly improved the seismic performance of the building.
2. The pushover analysis of model un-retrofitted hybrid building exhibited very low lateral capacity and the building was severely damaged after seismic activity. However, retrofitting the model building with shear wall/steel braces significantly increased the stiffness/lateral capacity and an increase of 47% and 42%, respectively was observed for retrofitted buildings as compared to model building.
3. The analysis showed very high lateral displacements in case of model building indicating higher level of damage. However, retrofitting the model building with shear wall/steel braces significantly decreased the lateral displacement by 37% and 42%, respectively.

References

[1] FEMA-356, “Prestandard and commentary for the seismic rehabilitation of buildings”, Federal Emergency Management Agency, Washington DC, USA, 2000.

[2] G. Bingnian, H. Ruikun and Z. Ning, “Experimental investigations of the dynamic characteristics of a 23-storey Steel-RC mixed structure model”, J. Build Struct., vol. 16, no. 3, pp. 37-43, 1995.

[3] D. Xiang, “Shaking table study on a model of steel-concrete hybrid structure”, J. Build Struct., vol. 22, no. 2, pp. 2-7, 2001.

[4] L. Bo, “Shaking table test of 1/10 scale model of a 12-storey Steel-RC hybrid wall system”, Master’s degree Dissertation, Xi’an University of Architecture & Technology, Shaanxi, China, 2005.

[5] H. Guangyu, C. Binlei and M. Qisong, “Design and research on composite steel and concrete frame-core wall structure”, Journal of Building Structures, vol. 27, no. 2, pp. 1-9, 2006.

[6] X. Yiming, W. Xiaoqian, “An inelastic analysis of the overall response of high-rise frame-shear wall hybrid structures”, China Civil Engineering Journal, vol. 39, no. 2, pp. 27-30, 2006.

[7] Z. Yun, L. Xiling and Q. Jiang, “Study on seismic behavior of shanghai world financial center tower”, J. Build Struct., vol. 27, no. 6, pp. 74-80, 2006.

[8] J. Jiang and B. You, “Seismic design of a super high-rise hybrid structures”, 14th World Conference on Earthquake Engineering, Beijing, China, 2008.

[9] S.S.F. Mehanny and G.G. Deierlein, “Assessing seismic performance of composite (RCS) and steel moment framed buildings”. Proc. of the Twelfth World Conference on Earthquake Engineering, Auckland, New Zealand, 2000.

[10] G. Oliveto and M. Marletta, "Seismic retrofitting of reinforced concrete buildings using traditional and innovative techniques", ISET Journal of Earthquake Technology, vol. 42, no. 2-3, pp. 21-46, 2005.

[11] M. Al-Dwaik and N.S. Armouti, “Analytical case study of seismic performance of retrofit strategies for reinforced concrete frames”, Jordan J. Civ. Eng., vol. 7, no. 1, pp. 26-43, 2003.

[12] W. Mengfu and Z. Xiyuan,, "Modified push-over analysis and seismic performance evaluation for tall building", China J. Civil Engg, vol. 36, no. 11, pp. 44-49, 2003.

[13] L. Xiling and Z. Jiejiang, "Push-over analysis of high-rise building and its influence on structural design", J. Build Struct., vol. 26, no. 6, pp. 100-107, 2005.

[14] E. Kalkan and S. K. Kunnath, "Lateral load distribution in nonlinear static procedures for seismic design", ASCE Struct Congress, Nashville, TN, USA, 2004.

[15] Government of Pakistan, "Building code of Pakistan", Pakistan Engineering Council Government of Pakistan, Islamabad, Pakistan, 2007.

[16] SAP 2000, "Advanced structural analysis program", version 15, Computers and Structures, Inc., Berkeley, CA, U.S.A.

[17] M. Waseem, S. Khan & A. Khan, M. "Probabilistic Seismic Hazard Assessment of Pakistan Territory Using an Aerial Source Model", Pure Appl. Geophys, vol. 177, pp. 3577–3597, 2020. https://doi.org/10.1007/s00024-020-02455-7

[18] ASCE 41-06, Seismic rehabilitation of existing building" American Society of Civil Engineers, ASCE, Reston, 1997

[19] ATC 40, "Guidelines for the seismic rehabilitation of buildings: Example applications", Prepared by the Applied Technology Council for the Building Seismic Safety Council and the Federal Emergency Management Agency (FEMA Publication No. 276), Washington, D.C, 1997.

[20] ACI 318, "Building code requirements for reinforced concrete, American Concrete Institute, Detroit, Michigan, 1999.

[21] AISC, "Load and resistance factor design specification for structural steel buildings", Second ed., AISC, Chicago, Illinois, 1993.

[22] "Design guide for improving school safety in earthquakes, floods and high winds, performance based seismic design, Rusk Management Publication Series, January, 2004.

[23] A. Cinitha, P.K Umesha and N.R Iyer, "Evaluation of seismic performance and review on retrofitting strategies of existing RC buildings", Asian J. Appl. Sci., vol. 7, pp. 169-181, 2014.