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Comparative Study of Flat Slab Structures with Steel Bracings

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Abstract
Many past researches show that the flat slab building is weak on lateral load resistance induced due to seismic action. To enhance the seismic performance of flat slab building, it needs an effective lateral load resisting system. In this present work, G+5, G+7 and G+9 stories conventional building and flat slab building system were modelled. For lateral load resistance, various types of steel braces were modelled on flat slab structure. Equivalent static analysis method and Response spectrum analysis method were performed using IS 1893 2016. The comparative study of seismic parameters such as maximum storey displacement, drift ratio, base shear and fundamental natural time period were performed among braced and unbraced models. The study shows that, use of steel bracings as a lateral load resisting system enhances the seismic performance of flat slab system.

Keywords
Flat Slab, Steel Brace, Linear Analysis, Drift, Displacement, ETABS

1. Introduction

The term flat slab means a reinforced concrete slab with or without drops, supported generally without beams, by columns with or without flared column heads [1]. Initially CAP Turner in USA started the construction of mushroom type flat slab structure since 1906. This is also known as the beginning point of this type of construction. Most of the south European countries like Spain, Italy and Portugal adopted flat slab construction system extensively. In our neighboring country India too, flat slab system has been adopted in many places [2]. In Nepal, the construction is done with beam, column and slab which is termed as Conventional construction technique. As flat slab building structures are significantly more flexible than conventional concrete structures, thus becoming more vulnerable to seismic loading. Hence flat slab needs effective lateral load resistance system.

Lateral load resistance is the part of structural system and consist of all structural members that resist lateral inertia forces induced in the building during earthquake shaking [3]. A number of researchers have investigated various techniques such as infilling walls, adding walls to existing columns, encasing columns, and adding steel bracing to improve the strength and/or ductility of existing buildings. Some of the examples of lateral load resisting systems are Moment resisting frames, Shear walls, braced frames, dual structure system, coupled shear wall etc. This study was concerned only with application of various types of steel bracings on flat slab structure, and their seismic parameters.

In general, use of shear walls in reinforced concrete structure and use of steel bracing in steel framed structure is a normal practice of constructions. However, in recent years there has been lots of studies and application of steel braces on new built RCC structure as well as strengthening of old RCC structure. One of the earliest buildings to incorporate structural bracing is the Dewitt-Chestnut Building in 1965 in Chicago [4]. In 1981 Higashi and Endo et al. also carried out studies on the use of concentric and eccentric bracing in concrete frames [4]. In 1991, Bush et al. used a complex steel frame bracing system in a concrete frame and obtained a substantial increase in the in plane shear resistance of the frame [4]. Now days, Steel braces are used to make existing building stiffen as well as in new building to increase its lateral strength [5] . Steel diagonal braces can be added to the existing concrete frames. Braces should be arranged so that their center line passes through the centers of the beam column joints. The brace connection should be adequate against out of plane failure and brittle fracture [6].

2. Literature Reivew

Karki & Suwal[2] studied by considering traditional and flat slab building system having G+5, G+8 and G+11 stories. For lateral strengthening, perimeter beam and shear wall system was modelled in flat slab buildings. The effect of positioning of shear walls on seismic performance of flat slab building models were analyzed. Comparative study of seismic parameter (Storey Displacement, Drift, Base shear, Time period) were done. The analysis showed that with the use of shear walls and perimeter beam, flat slabs can be considered as system with an acceptable seismic risk.

Ema Coelho & Paulo Candeias [7] carried out an experimental program for flat slab building in full scale at the ELSA Laboratory, with the objective of assessing the seismic behavior of the flat slab structures. It is found that flat slab structures show relatively higher flexibility as compared to the traditional structure.

Sanjay P. N. [8] studied about the behavior of flat slab RCC structure under earthquake loading, which contains the comparative study of the seismic behavior of multi-story flat slab building with drop panels and without drop panels for different seismic zones. This study concludes that building having drop panels have more lateral load carrying capacity than without drop panels.

A. K Jain [9] study about the effect of steel bracings on RCC frame structure subjected to scaled up El Centro earthquake 1940. Inelastic seismic behavior of the RC frames with X and K bracing were analyzed and it is found that lateral displacement of building was reduced and stiffness of the structure was increased significantly.

Maheri & Shahebi [4] study about the use of steel bracings on RCC framed structure. The study is carried out through a series of tests and the objective of the tests was to determine the degree of effectiveness of various diagonal steel bracing arrangements to increase the in-plane shear strength of the concrete frame and also the relative behavior of tension and compression braces. This investigation concludes, with the proper connection between brace and frame, the steel bracing could be an alternative or supplement to shear walls in RCC frame buildings in seismically active zones.

Razak & Kong [10]reviews about the influence of various types of steel bracings to the structural and seismic performance of RCC buildings. Proper and efficient structural bracings in high rise building will lead towards the safe, sustainable and more economic construction.

3. Objectives and methodology

The general objectives of this research work is to study the effectiveness of steel bracings as a lateral load resistance system on flat slab structure. The specific objectives of this study are,

- To determine the seismic response parameters (Maximum story displacement, Maximum storey drift, Base Shear and Time period) of the flat slab buildings with steel bracing system.
- To determine the behavior of different bracing systems (i.e. Diagonal, X, V, and Chevron bracings) together with its location effects.
- To determine the most effective bracing which resist the lateral loads among all the bracings considered.

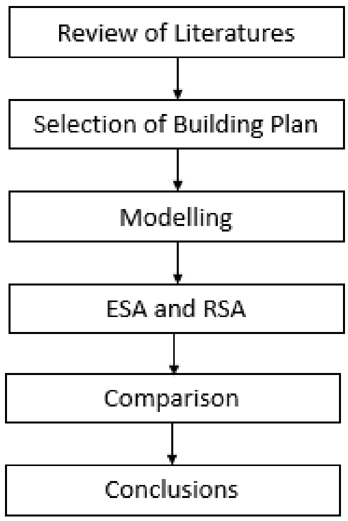

Figure 1: Methodology flowchart

Figure 1 shows the outline of methodology of study. The research begins with the extensive review of literatures including, guidelines for flat slab modelling, design, analysis; guidelines for lateral load resisting systems, types, design, analysis, their effect on building etc. and research articles and papers related to flat slab structure, steel bracings on RCC structure, seismic behavior of flat slabs etc. Then the building was modelled on ETABS V18.1.0 software with suitable size and material definition following Indian Standard Codes. Steel braces are provided on flat slab structure at different locations i.e. bays. Equivalent Static Analysis and Response Spectrum Analysis was performed following IS 1893 2016 [3]. After analysis result intrepretation as well as conclusive remarks was made.

4. Modeling and Analysis

For the analysis and the study of seismic parameters of the buildings, the mathematical modelling of the structures is required. In this study, a geometric plan with 4 bays having width 5m in x and y direction with floor height 3m are modelled by ETABS software. In Flat Slab model, 200mm thick slab and 100mm drop having 2.5x2.5m in plan is modelled, while in conventional building 150mm thick slab is taken. Column of sizes 400x400mm, 450x450mm and 500x500mm on G+5, G+7 and G+9 stories buildings respectively are modelled. Standard I section, ISHB 350-1 is taken as steel brace. Diagonal, X, V and Chevron types are applied at different locations i.e. corner bays, middle bays and all peripheral bays. For the connection of steel braces on slab, the concealed beam of depth 200mm and width 400mm were modelled peripherally. For this study, a seismic zone V, site type II and importance factor 1.2 is taken. Response spectrum function is based on IS 1893:2016 [3]. Both linear static and dynamic analysis were performed.

4.1 Building Nomenclature and Descriptions

The four different types of steel braces in vertical arrangement are modelled. The braces are provided on different bays of a building. In short form, building are nomenclatured by these words. Here, CB-B indicates Conventional Building Bare, FSWD-B indicates Flat Slab with Drop Bare model. In the simillar way DG, X, V, and CH indicates Diagonal Bracings, X bracings, V bracings and Chevron bracings respectively. Likewise CB, MB and PB indicates corner bays, middle bays and peripheral bays respectively.

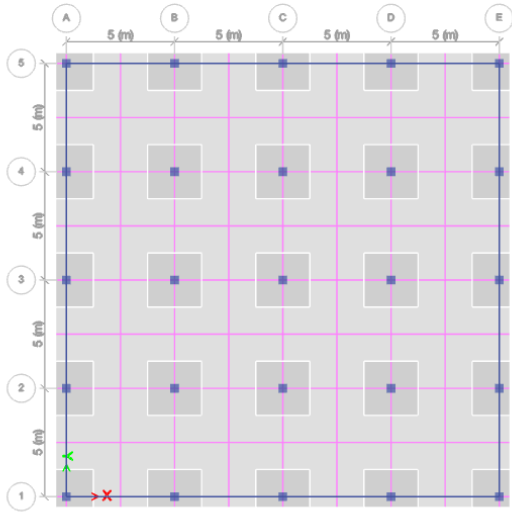

Figure 2: Flat Slab with Drop Panel and Concealed Beam Building Plan

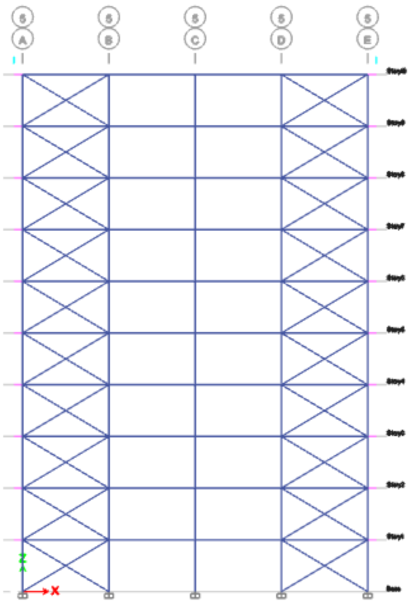

Figure 3: X Bracing at Corner Bays

Figure 3, shows X type bracings at corner bays location. In the same way, Diagonal type brace, V type brace and Chevron type brace are also modelled accordingly on corner bays, middel bays and all peripheral bays. After modelling of all models, linear seismic analysis was performed. Equivalent Static analysis (ESA) and Response Spectrum Analysis (RSA) method were performed based on IS 1893 2016 [3]. Comparative results in graphical representation are plotted and discussed. On the basis of Results and Discussion, the final conclusion of the study was made.

5. Results and Discussion

After performing linear seismic analysis, thus obtained results are plotted in graphical representation.

5.1 Maximum Storey Displacemet Between Bare Models and Braced Models

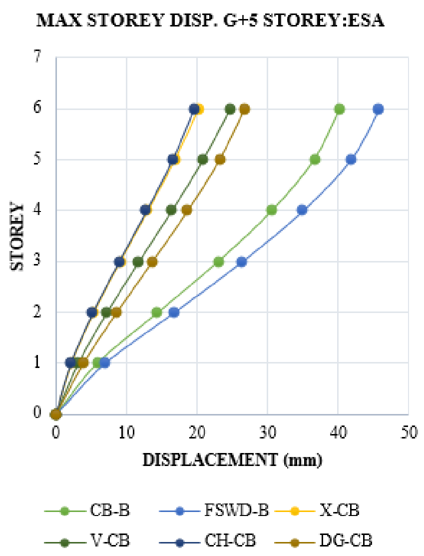

Figure 4: Maximum Storey Disp. G+5 Storey due to ESA

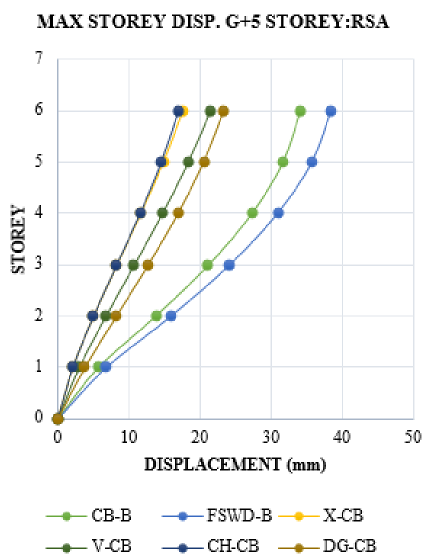

Figure 5: Maximum Storey Disp. G+5 Storey due to RSA

Figure 4 is the plot of storey displacements of G+5 stories building due to equivalent static analysis with four different types of bracings at corner bays location. The plot shows that the storey displacements of flat slab building bare model is more than simillar conventional building. After the application of diagonal steel brace on corner bays, storey displacement reduces in the range of 41% to49%. At same location, X type brace reduces the storey displacement in the range of 55% to 69%. V type braces on corner bays reduces the storey displacement by 46% to 57%. Chevron type braces also reduces the storey displacement significantly in the range of 57% to70%.

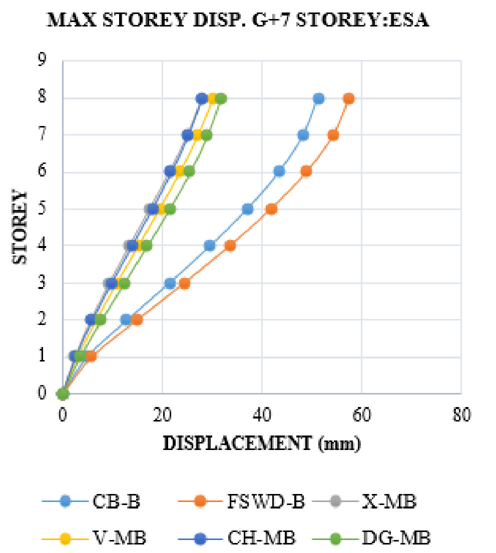

Figure 6: Maximum Storey Disp. G+7 Storey due to ESA

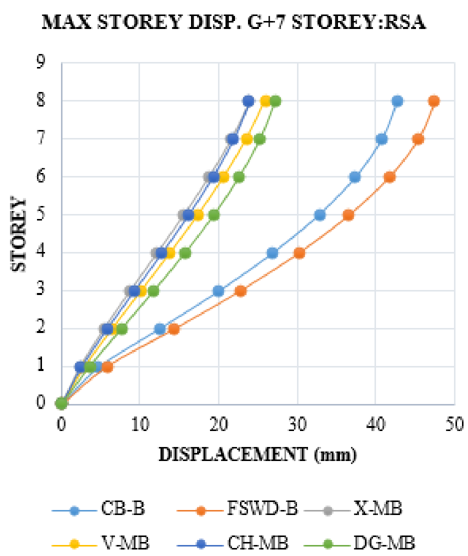

Figure 7: Maximum Storey Disp. G+7 Storey due to RSA

Figure 5 shows the plot of storey displacement for G+5 stories building due to response spectrum analysis. The displacement values for response spectrum analysis is lower than equivalent static analysis, so that the reduction percentage for this analysis is also little lower than static analysis. At corner bays location, Chevron and X type braces shows significant control in storey displacement while V and diagonal type braces shows lower values.

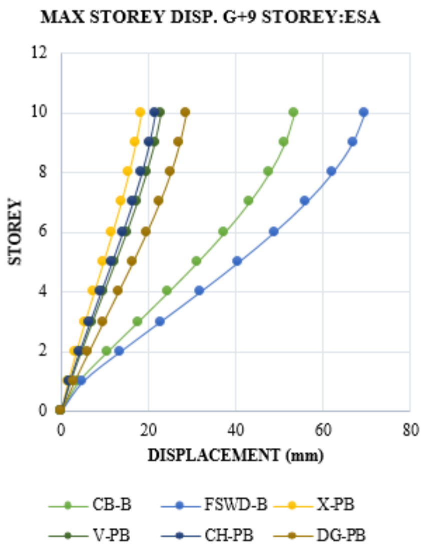

Figure 8: Maximum Storey Disp. G+9 Storey due to ESA

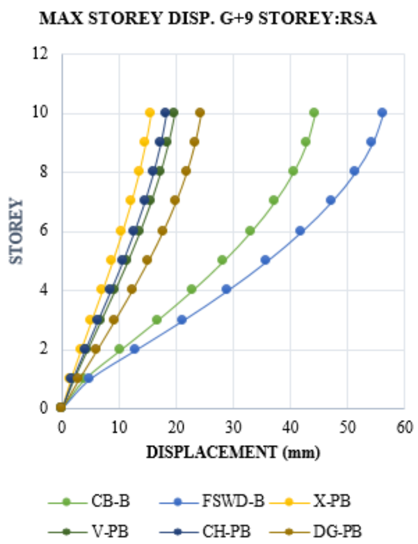

Figure 9: Maximum Storey Disp. G+9 Storey due to RSA

Figure 6 is the plot of storey displacement of G+7 stories building due to equivalent static analysis while placing the braces at middle bays. In this case the displacement values reduces more than the corner bays bracings. Diagonal type brace on middle bays of G+7 stories building shows about 44% to 50% reduction in the storey displacement. Similary X braces shows about 51% to 63%, V braces shows about 47% to56% and chevron braces shows about 51% to 61% reduction in storey displacement respectively. Keeping the number of braced bays equal, the middle bays bracings shows better results than corner bays braced models. Figure 8 and 9 is the plot of storey displacement of G+9 stories building due to equivalent static analysis and response spectrum analysis respectivelt after providing the steel braces on all peripheral bays. In this case the stiffness of structure increases more than the previous two cases, so that the displacement values highly reduces. Diagonal braces reduces maximum about 60%, X braces reduces max. about 77%, V braces reduces max. about 70% and chevron braces reduces maximum about 72% storey displacement while placing peripherally in ESA. In the case of peeripheral bracings, X bracing shows better result than other types braces.

5.2 Storey Drift Ratio Plot Between Bare Models and Braced Models

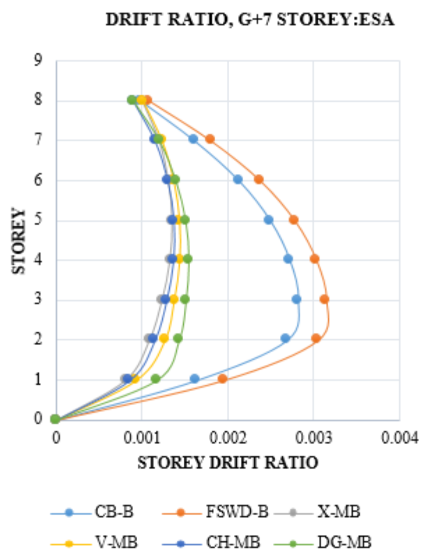

Figure 10: Drift Ratio, G+7 Storey due to ESA

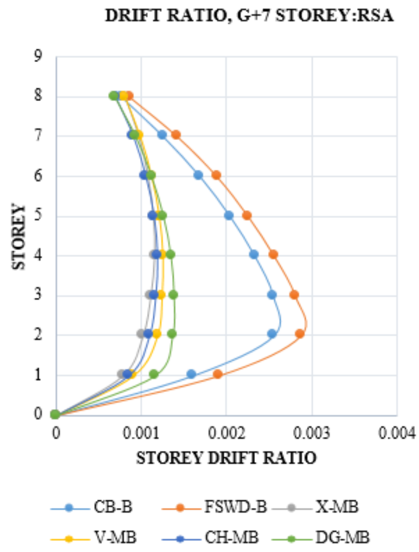

Figure 11: Drift Ratio, G+7 Storey due to RSA

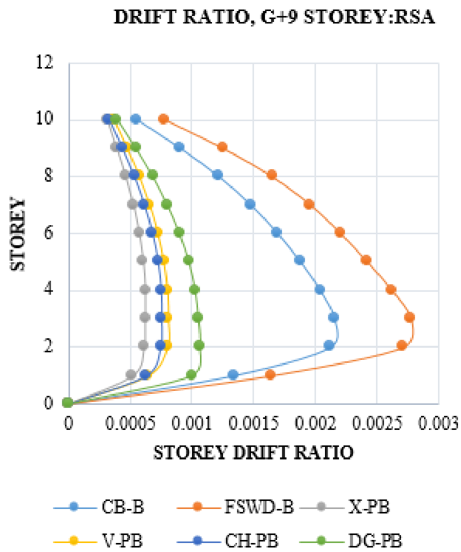

Figure 13: Drift Ratio, G+9 Storey due to RSA

Figure 10 shows the plot of inter storey drift ratio of G+7 stories building due to ESA. Figure 11 is the plot of maximum inter storey drift ratio due to RSA after the application of four different types of steel braces on middle bays. In case of unbraced models, the maximum drift ratio is above 0.003 for storey 2,3 and 4, but after providing the braces the values comes below 0.0015. The X and Chevron type braces shows more reduction than V and diagonal type braces. In case of RSA, the maximum drift ratio for storey 2,3and 4 are in the range 0.0028 and after installation of braces it becomes below 0.0013.

Figure 13 is the plot of storey drift ratio of G+9 stories building after providing braces on peripheral bays. After the application of braces, the storey drift ratio significantly reduces and its value goes below 0.001. In case of middle bays bracings, the X-bracings and Chevron bracings significantly reduce the inter storey drift ratios than the other types of bracings. It is obvious to reduce the inter storey drift ratios by peripheral bays bracings, as the bracings applied whole peripherally and structure becomes laterally more stiff, and the X-bracings shows significant reduce the inter storey drift ratios than the other types of bracings.

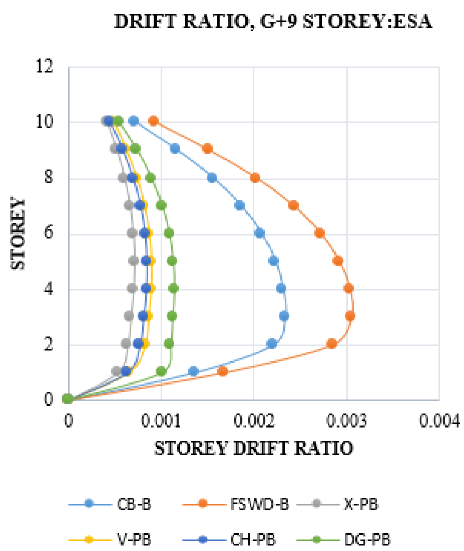

Figure 12: Drift Ratio, G+9 Storey due to ESA

5.3 Top Storey Displacement Between Bare and Braced Models

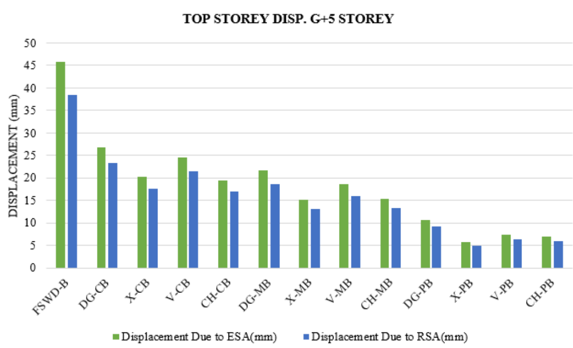

Figure 14: Top Storey Displacement, G+5 Storey

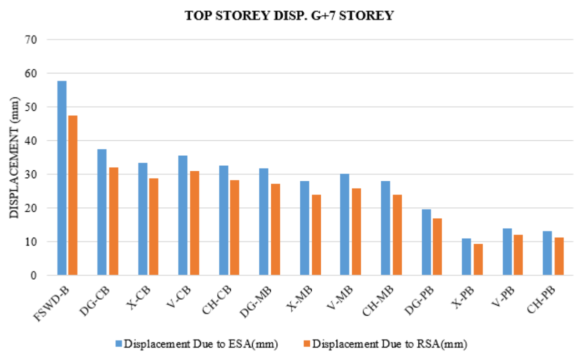

Figure 15: Top Storey Displacement, G+7 Storey

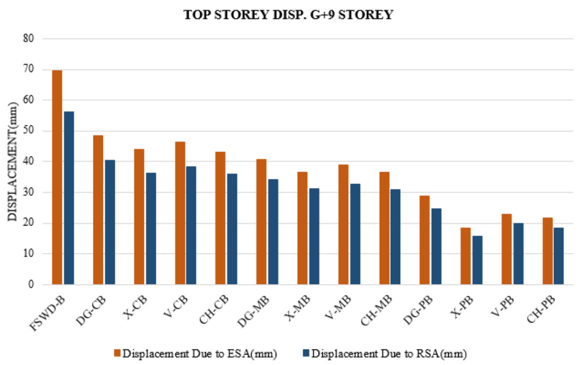

Figure 16: Top Storey Displacement, G+9 Storey

Storey Displacements are higher on flat slab system, then after providing a steel braces the story displacement values decrease significantly. Among the various types of bracings, X and Chevron type bracings are more efficient in decreasing displacement values while placings at corner bays. On middle and peripheral bays, X type braces significantly reduces the storey displacement values than other bracings. The minimum reduction is done by diagonal type steel braces.

5.4 Base Shear Between Bare and Braced Models

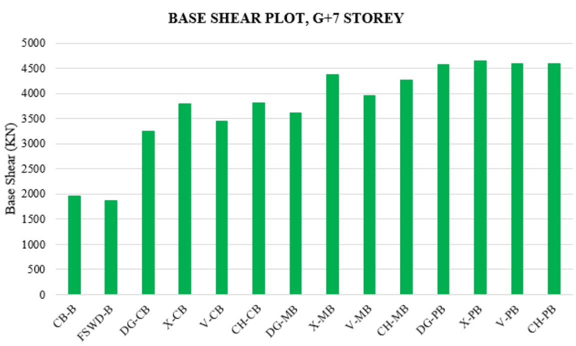

Figure 17: Base Shear Plot, G+7 Storey

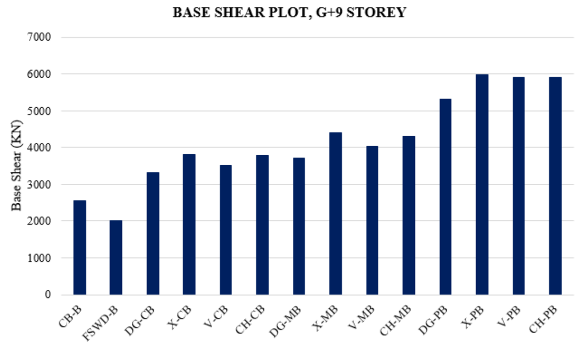

Figure 18: Base Shear Plot, G+9 Storey

Base shear values for Flat Slab Building system is lower than Conventional Type Building system. After providing bracings on flat slab system, base shear increases nearly about 150 to 300% depending upon types and number of bays braced. Among various types of bracings, the X braces plays a remarkable role to increase base shear. And minimum base shear is for diagonal type brace.

5.5 Time Period Between Bare and Braced Models

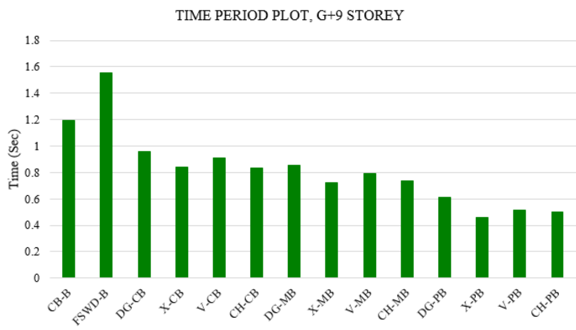

Figure 19: Time Period Plot, G+9 Storey

Figures 19 is the plot of fundamental natural time period of G+9 stories building with and without steel braces. Fundamental natural time period for flat slab building is more than conventional building system.Addition of bracings on flat slab system increases the stiffness. Hence consequently decreases the time period of structure. For G+9 stories building, at corner bays location digonal, X, V and chevron braces reduces about 38%, 45%, 41% and 46% of time period respectively. At middle bays location in same building, diagonal, X,V and chevron braces reduces about 44%, 53%,49%,52% of time period respectively. In case of peripheral bracings, these braces reduces about 60%, 70%,66% and 67% of time period respectively.

6. Conclusion

Based on Results and Discussion, this study makes following conclusions,

- On comparison to bare models, about 42% to 58% top storey displacements values are reduced by providing corner bracings in G+5 stories building. Likewise, for G+7 stories building, about 35% to 44% values decreases. Similarly, for G+9 stories building 30% to 39% displacement values reduced by providing corner bracings.
- On comparison to bare models, about 52% to 67% top storey displacements values are reduced by providing middle bays bracings in G+5 stories building. Likewise, for G+7 stories building, about 46% to 53% values decreases. Similarly, for G+9 stories building 43% to 50% displacement values reduced by providing corner bracings.
- On comparison to bare models, about 77% to 88% top storey displacements values are reduced by providing peripheral bays bracings in G+5 stories building. Likewise, for G+7 stories building, about 67% to 82% values decreases. Similarly, for G+9 stories building 61% to 75% displacement values reduced by providing peripheral bays bracings.
- On comparison to bare model, about 174% to 204% base shear increase on G+7 storied building by providing different bracings on corner bays. Likewise, for G+9 stories building 164% to 188% base shear values increases by providing corner bracings.
- On comparison to bare model, about 193% to 235% base shear increase on G+7 stories building by providing different bracings on middle bays. Likewise, for G+9 stories building 183% to 218% of base shear value increases by providing middle bays bracings.
- On comparison to bare model, about 245% to 250% base shear increase on G+7 stories building by providing different bracings on peripheral bays. Likewise, for G+9 stories building 263% to 296% of base shear values increases by providing middle bays bracings.
- In G+7 stories building, Corner bays bracing system decreases the time period nearly 43% to 53%. Similarly, middle bays bracing system reduces the time period nearly 50% to 59%. Likewise, Peripheral bays bracings system reduces 65% to 73%.
- In G+9 stories building, Corner bays bracing system decreases the time period nearly 41% to 49%. Similarly, middle bays bracing system reduces the time period nearly 48% to 56%. Likewise, Peripheral bays bracings system reduces 64% to 72%.
- Steel braces could be an possible alternative fo lateral load reistance in flat slab structure to enhance the seismic parameters.

References

[1] IS456:2000. *Plain and Reinforced Concrete Code of Practice*. IS. 2000.

[2] Milan Karki and Rajan Suwal. Comparative study of flat slab structures. In *Proceedings of IOE Graduate Conference*, 2019.

[3] IS1893:2016. *Criteria for Earthquake Resistant Design of Structure*. 2016.

[4] MR Maheri and A Sahebi. Use of steel bracing in reinforced concrete frames. *Engineering Structures*, 19(12):1018–1024, 1997.

[5] Manish Shrikhande Pankag Agrawal. *Earthquake Resistance Design of Structure*. Indian, 2014.

[6] DUDBC GoN. *Seismic Retrofitting Guidelines of Nepal-2016*. RCC. GoN, DUDBC, 2016.

[7] Ema Coelho, Paulo Candeias, Giorgios Anamateros, Raul Zaharia, Fabio Taucer, and Artur V Pinto. Assessment of the seismic behaviour of rc flat slab building structures. In *13th world conference on earthquake engineering., Vancouver, BC*, 2004.

[8] PN Sanjay, K Mahesh Prabhu, and SS Umesh. Behaviour of flat slab rcc structure under earthquake loading. *International Journal of Engineering Research and Technology*, 3(5):1386–1395, 2014.

[9] Ashok K. Jain. Seismic performance of rc frames with steel braces. *ASCE*, 1985.

[10] T.C. Kong S.M. Razak. A review of influence of various types of structural bracings to the structural performance of buildings. *Department of Civil Engineering Technology*, 2018.