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Seismic Strengthening of Steel Buildings using Bracings

Harsha C. S.[1], **Nikhil R.**[2]

[1]PG Student, Department of Civil Engineering, Universal Engineering College, Thrissur, Kerala, India
[2]Assistant Professor, Department of Civil Engineering, Universal Engineering College, Thrissur, Kerala, India

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Abstract - *Engineers are always in search for more advanced techniques for resisting seismic force because of the hazardous effect of seismic activity on building structures. The buckling restrained braced frames are an effective predictable method developed for resisting highly unpredictable seismic forces. Generally, buildings with lateral force resisting system having more resistance against high seismic forces than rigid systems. The buckling restrained braced frame is a more ductile frame choice than conventional lateral force resisting systems. The brace yielding in both compression and tension provides the ductility to the bracing. As the use of BRBF has increased, it is essential to know more about the member and behaviour of buckling restrained braced frame under seismic loads. In this paper, seismic performance of buildings with floating column strengthened using buckling restrained brace was evaluated using pushover analysis. The buildings were modeled using different configurations of bracings. The different configurations of bracings studied were inclined bracing, inverted V bracing and X bracing. Analyses of buildings were carried out using ETABS 17 software. These all building performance was compared with corresponding moment resisting frames with same building configurations.*

Key Words: **Buckling Restrained Braces, Seismic Strengthening, Pushover Analysis, Floating Column, Base Shear**

1. INTRODUCTION

Earthquakes can cause significant amount of losses to human lives and infrastructure. So they are considered as one of the major natural disasters on earth. Structural engineers are always in search for more advanced techniques for resisting seismic force because of the hazardous effect of seismic activity on building structures. During the past few years, various techniques like shear wall buildings, braced frames, base isolation etc. are implemented to improve the performance of moment resisting frames. Sufficient performance for various types of structures can be achieved by following the proper design guidelines provided by different design codes.

The structural damage during severe seismic events can be reduced by proper design of steel structures. The typical design objective is to limit material yielding to specific locations and to provide enough ductility in the system to prevent collapse. Specially detailed braced frames and moment frames can be used to obtain such a design. A special type of ductile braced frame system called buckling restrained braced frame (BRBF) is discussed in this project. A Buckling Restrained Braced Frame (BRBF) is a special type of Concentrically Braced Frame (CBF). It is more popular in the United States and is used as a substitute for conventional steel braced frame as it does not buckle in compression and exhibits stable hysteretic behavior. Japan was the first country to develop the concept of buckling restrained braces (BRBs) in 1980s.

The buckling-restrained braced frame has been developed during the past decade as a seismic force-resisting system. The concept of BRBs was developed in Japan at the end of the 1980s. It appeared in the United State after the Northridge earthquake in 1994 and it is now accepted with its design regulated in current standards as a displacement dependent lateral load resisting solution. BRBFs have enlarged capacity of withstanding severe earthquakes. But the potential for large residual drifts in this system reduces the practical feasibility of repairing the building after an earthquake and it is financially very costly. These problems implicit a need for developing a system capable in minimizing the structural damage following an earthquake and can be restored to its initial condition with reasonable effort. The clear cost savings of the overall system and the simplicity of design and erection have led to the expeditious growth in the use of BRB.

The use of buckling-restrained braces as a means of resisting lateral seismic loading has significantly increased in recent years. This is because they have significant advantages over special concentric braces, which suffer loss of strength and stiffness after the braces buckle in compression .In the past, many experimental and analytical studies were done on the behaviour of BRBs. But a parametric study is needed, inorder to identify and compare the behaviour of buckling restrained braced frame over conventionally using moment resisting frames. Hence, it is essential to investigate the improvement in the base shear capacity of a steel structure with buckling restrained braces as compared to a moment resisting frame. The floating columns are highly useful in increasing the functional area of a structure. So the investigation is carried out in steel structures with floating columns.

The objectives of the study are to conduct seismic analysis of buildings with floating column strengthened using buckling restrained braces and to find the effect of height of building and locations of floating column in seismic strengthening of buildings with floating column

1.1 BUCKLING RESTRAINED BRACES

Before Buckling-restrained braces (BRBs) do not show any unfavorable behavior characteristics of conventional braces. The compression yielding and tension yielding behavior of BRBS are similar. So they show full, balanced hysteretic behavior. This is attained by the decoupling of the stress resisting and flexural-buckling resisting aspects of compression strength. The steel core resists axial stresses. Uniform axial strains are developed across the section because the steel core is restrained from buckling. The plastic hinges related with buckling do not form in perfectly designed and detailed BRBs. Very high compression strength can be permitted by the BRB. Because of instability, there is no reduction in the available material strength. Thus the effective length of the core can be considered as zero. Great ductility can be achieved by confining inelastic behaviour to axial yielding of the steel core. The ductility of the steel material is achieved throughout the brace length.

Thus the hysteretic performance of the material of the steel core and that of braces are similar. If the core materials have significant core hardening, then the braces will also show strain hardening. The braces can dissipate large amounts of energy because the strains are not concentrated in a limited region such as a plastic hinge. Test results shows that the braces have low-cycle fatigue life. When the demands established from nonlinear dynamic analysis was considered, this capacity was found to be well in excess. The analyses also showed that very good performance of the systems can be established by using braces with this type of hysteretic behavior. Drifts are expected to be significantly lower than the special concentric braced frame (SCBF) due BRBs behavior. Due to the BRBs behavior, the drifts are also found to be appreciably lower than the special concentric braced frame (SCBF). Due to the ability to provide uniform brace demand-to capacity ratios, inelastic demands are distributed over multiple stories. The maximum ductility demands of the BRB can be estimated by conducting analytical studies of the response of the BRB. The design and detailing of the BRBs must be proper in order to accommodate the inelastic deformations and not permitting undesirable modes of behavior, like overall instability of the brace or bearing of the non-yielding zones of the core on the sleeve.

2. MODELING AND ANALYSIS

The geometrical modeling and analysis was carried out using ETABS 17 software. The safe sections for beams and columns were found to be ISMB 450 for 3 storied buildings and ISMB 600 for 6 storied building. The typical bay width used is 3.5 m and typical storey height is 3.6 m. The buildings considered were under the category of mercantile building and the design loads were taken as per IS 875 – 1987 recommendations. The live load taken was 4 kN/m^2 and the dead load included wall load and slab load. Wall load was taken as 14.3 kN/m. Displacement controlled pushover analyses were conducted for all the models.

2.1 THREE STORIED SQUARE BUILDING

The three storied square building consist of 4 number of bays in both X and Y direction. 4 models of three storied square building were created each having different configurations of bracings. The different configurations of bracings used were inverted V bracing, X bracing and inclined bracing and they were compared with building without bracing. The sections used for braces were StarBRB_2.0, StarBRB_1.5 and StarBRB_1.0 in ground, first and second stories respectively. The floating column was provided along the joint 1C.

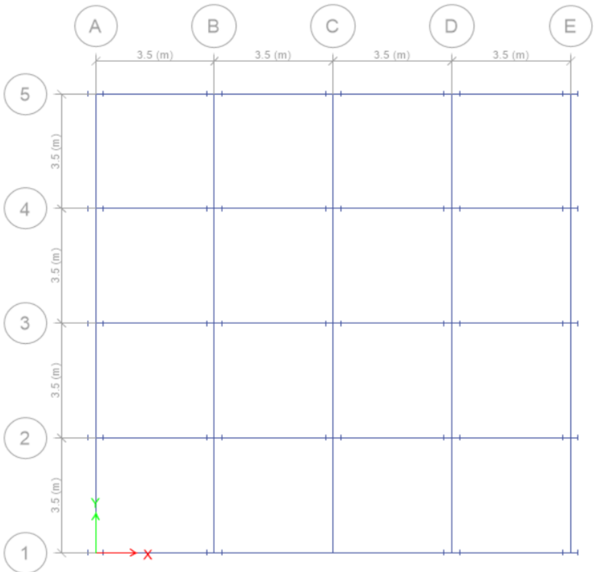

Fig -1: Plan View of a Three Storied Square Building

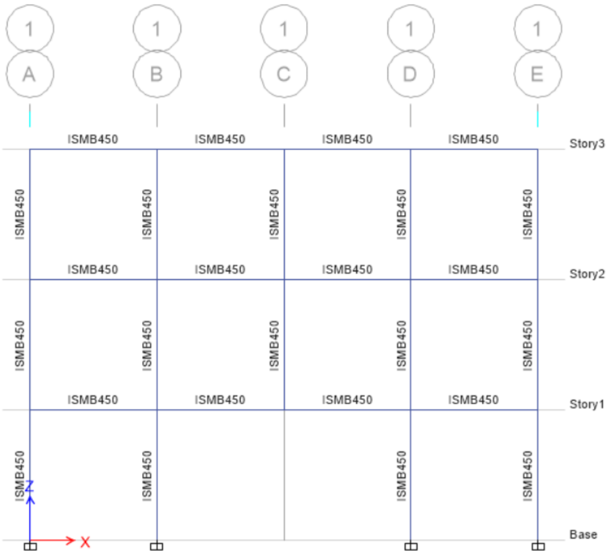

Fig -1: Elevation View of a Three Storied Square Building without Bracing

2.2 SIX STORIED SQUARE BUILDING

The six storied square building consist of 4 number of bays in both X and Y direction. 4 models of six storied square building were created each having different configurations of bracings. The different configurations of bracings used were inverted V bracing, X bracing and inclined bracing and they were compared with building without bracing. The sections used for braces were StarBRB_3.5, StarBRB_3.0 and StarBRB_2.5, StarBRB_2.0, StarBRB_1.5 and StarBRB_1.0 in ground, first, second, third, fourth and fifth stories respectively. The floating column was provided along the joint 1C.

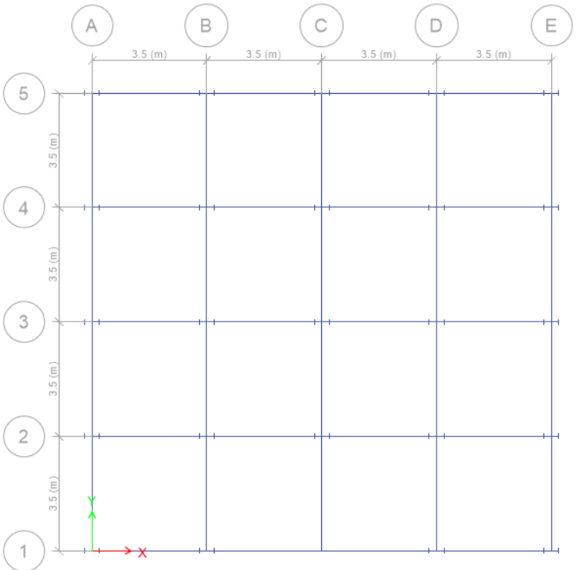

Fig -1: Plan View of a Six Storied Square Building

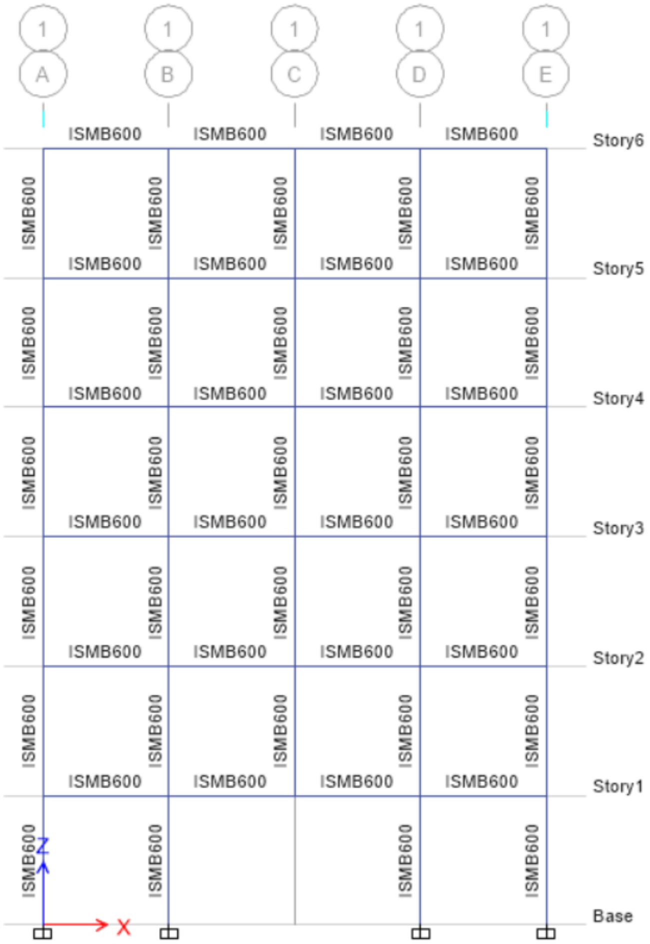

Fig -1: Elevation View of a Six Storied Square Building without Bracing

2.3 THREE STORIED L SHAPED BUILDING WITH EXTERNAL FLOATING COLUMN

The three storied L shaped building consist of 5 number of bays in both X and Y direction along the exterior and 3 number of bays along the interior. 4 models of three storied L shaped building were created each having different configurations of bracings. The different configurations of bracings used were inverted V bracing, X bracing and inclined bracing and they were compared with building without bracing. The sections used for braces were StarBRB_2.0, StarBRB_1.5 and StarBRB_1.0 in ground, first and second stories respectively. The floating column was provided along the joint 6C.

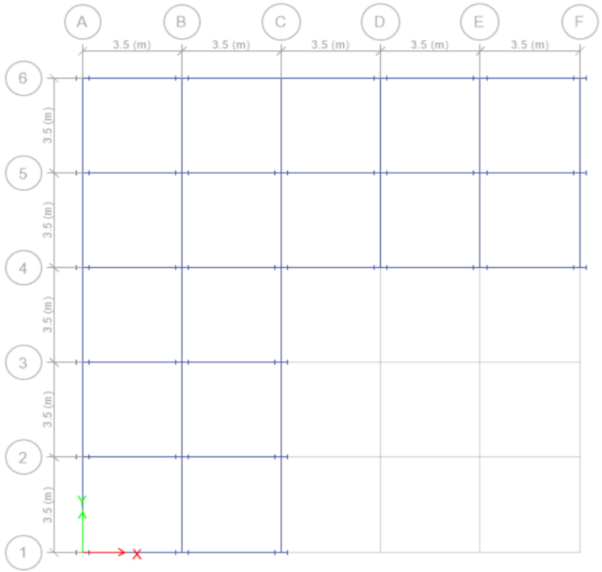

Fig -1: Plan View of a Three Storied L Shaped Building with External Floating Column

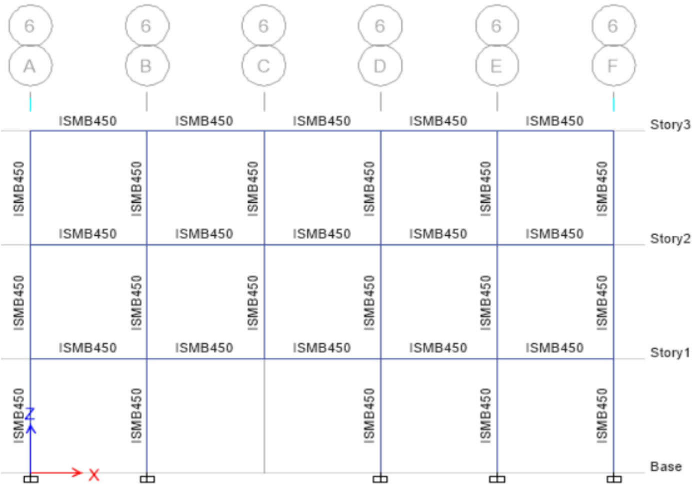

Fig -1: Elevation View of a Three Storied L Shaped Building with External Floating Column without Bracing

2.4 THREE STORIED L SHAPED BUILDING WITH INTERNAL FLOATING COLUMN

The three storied L shaped building consist of 5 number of bays in both X and Y direction along the exterior and 3 number of bays along the interior. 4 models of three storied L shaped building were created each having different configurations of bracings. The different configurations of bracings used were inverted V bracing, X bracing and inclined bracing and they were compared with building without bracing. The sections used for braces were StarBRB_2.0, StarBRB_1.5 and StarBRB_1.0 in ground, first and second stories respectively. The floating column was provided along the joint 2C.

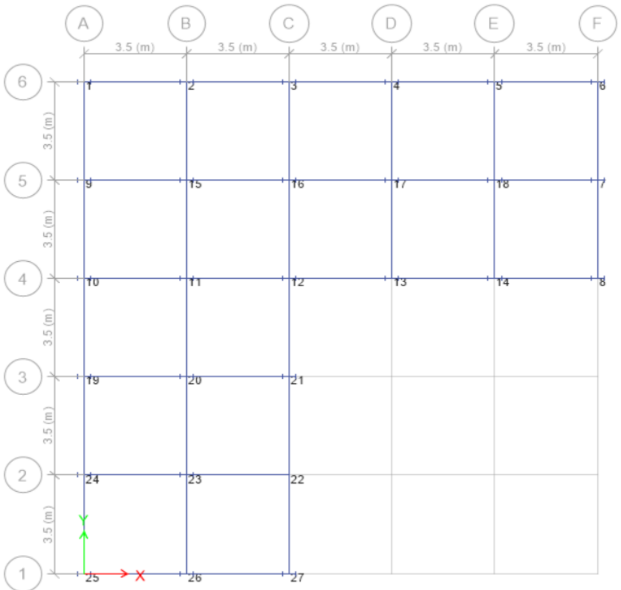

Fig -1: Plan View of a Three Storied L Shaped Building with External Floating Column

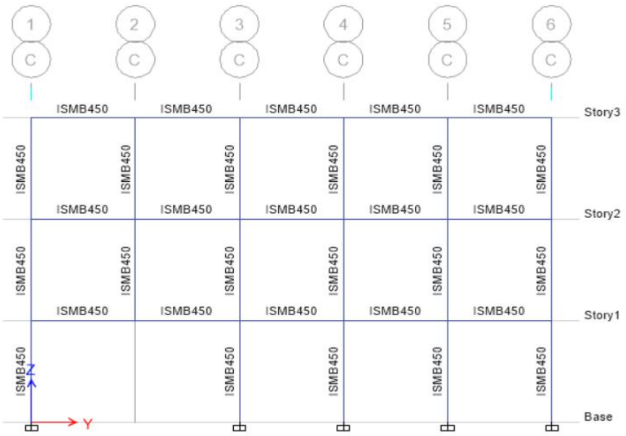

Fig -1: Elevation View of a Three Storied L Shaped Building with External Floating Column without Bracing

3. EFFECT OF HEIGHT OF BUILDING

To find the effect of height of building, a three storied square building and a six storied square building were analyzed and their percentage improvement in the base shear capacity was compared.

3.1 THREE STORIED SQUARE BUILDING

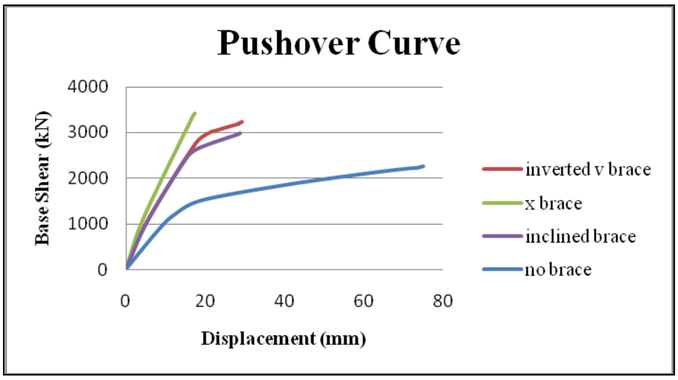

Chart -1: Combined Pushover Curve for a Three Storied Square Building

Table -1: Comparison of Maximum Base Shear and Displacement Values for Different Configuration of Bracings in a Three Storied Square Building

BUILDING	MAXIMUM BASE SHEAR (kN)	DISPLACEMENT (mm)
3 storied square building without bracing	2254.619	74.897
3 storied square building with inverted V bracing	3235.332	29.162
3 storied square building with X bracing	3412.281	17.347
3 storied square buiding with inclined bracing	2986.556	28.768

3.2 SIX STORIED SQUARE BUILDING

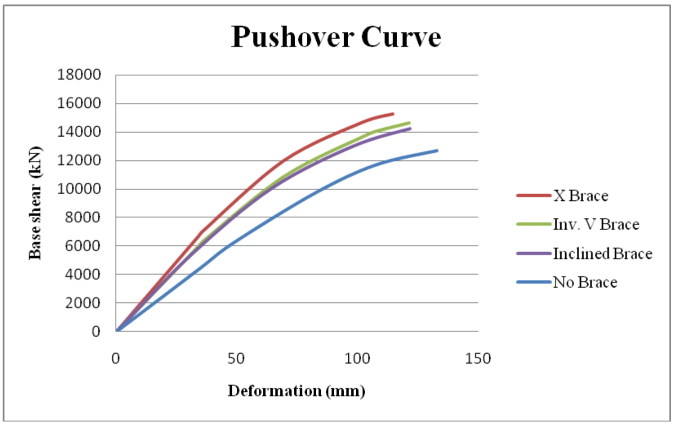

Chart -1: Combined Pushover Curve for a Six Storied Square Building

Table -1: Comparison of Maximum Base Shear and Displacement Values for Different Configuration of Bracings in a Six Storied Square Building

BUILDING	MAXIMUM BASE SHEAR (kN)	DISPLACEMENT (mm)
6 storied square building without bracing	12658.994	132.948
6 storied square building with inverted V bracing	14605.168	121.646
6 storied square building with X bracing	15278.000	114.721
6 storied square buiding with inclined bracing	14207.300	122.064

The percentage improvements in the base shear capacity while using an inverted V brace was found to be 43.49 % in three storied building and 15.37 % in six storied building. The percentage improvements in the base shear capacity while using an X brace was found to be 51.34 % in three storied building and 20.68 % in six storied building. The percentage improvements in the base shear capacity while using an inclined brace was found to be 32.46 % in three storied building and 12.23 % in six storied building. The percentage improvement in the base shear capacity is more for 3 storied building compared to the 6 storied building in all configurations of bracings.

4. EFFECT OF LOCATION OF FLOATING COLUMN

To find the effect of location of floating column, a three storied L shaped building with an external floating column and a three storied L shaped building with an internal floating column were analyzed and their percentage improvement in base shear capacity was compared. The external floating column is provided along the X direction and the internal floating column is provided along the Y direction.

4.1 THREE STORIED L SHAPED BUILDING WITH EXTERNAL FLOATING COLUMN

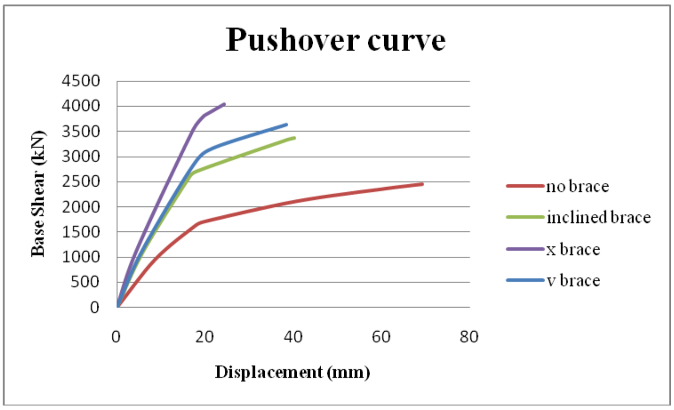

Chart -1: Combined Pushover Curve for a Three Storied L Shaped Building with External Floating Column

Table -1: Comparison of Maximum Base Shear and Displacement Values for Different Configuration of Bracings in a Three Storied L Shaped Building with External Floating Column

BUILDING	MAXIMUM BASE SHEAR (kN)	DISPLACEMENT (mm)
3 storied L shaped building without bracing	2444.889	69.383
3 storied L shaped building with inverted V bracing	3635.494	38.467
3 storied L shaped building with X bracing	4046.867	24.330
3 storied L shaped buiding with inclined bracing	3372.797	40.323

4.2 THREE STORIED L SHAPED BUILDING WITH INTERNAL FLOATING COLUMN

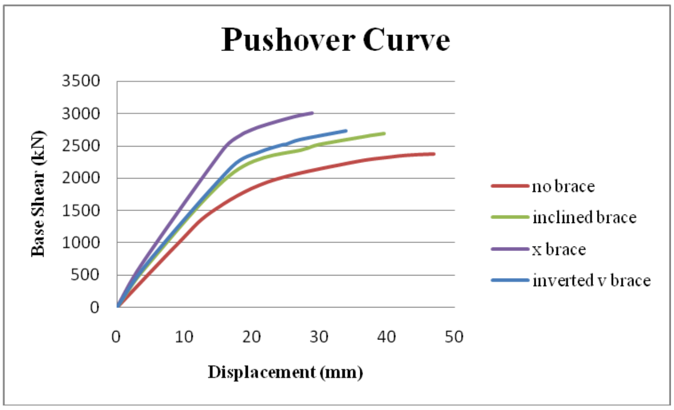

Chart -1: Combined Pushover Curve for a Three Storied L Shaped Building with Internal Floating Column

Table -1: Comparison of Maximum Base Shear and Displacement Values for Different Configuration of Bracings in a Three Storied L Shaped Building with Internal Floating Column

BUILDING	MAXIMUM BASE SHEAR (kN)	DISPLACEMENT (mm)
3 storied L shaped building without bracing	2373.594	46.966
3 storied L shaped building with inverted V bracing	2733.097	33.857
3 storied L shaped building with X bracing	3003.832	28.946
3 storied L shaped building with inclined bracing	2690.587	39.563

The percentage improvements in the base shear capacity while using an inverted V brace was found to be 48.69 % for building with external floating column and 15.14 % for building with internal floating column. The percentage improvements in the base shear capacity while using an X brace was found to be 65.52 % for building with external floating column and 26.55 % for building with internal floating column. The percentage improvements in the base shear capacity while using an inclined brace was found to be 37.95 % for building with external floating column and 13.35 % for building with internal floating column. The percentage improvement in the base shear capacity is more for external floating column provided along the X direction compared to the internal floating column provided along the Y direction in all configurations of bracings. So the bracings are more effective when the floating column comes in the X direction.

5. CONCLUSIONS

The overall base shear capacity of building with floating column can be improved significantly by using buckling restrained braces. The pushover analysis of all the building types showed that the X bracing configuration is the most effective method of bracing in improving the base shear capacity of the building and also minimising the displacement. The maximum improvement in the base shear capacity was observed while using the X bracing. The percentage improvement in the base shear capacity is more for 3 storied building compared to the 6 storied building in all configurations of bracings. So the seismic strengthening of small buildings will be more than multi-storeyed building by using buckling restrained braces. The maximum percentage improvement in the base shear capacity in a three storied building was found to be 51.34 % while using an X bracing whereas it was only 20.68 % in a six storied building. The percentage improvement in the base shear capacity is more for external floating column provided along the X direction compared to the internal floating column provided along the Y direction in all configurations of bracings. So the bracings are more effective when the floating column comes in the X direction. The maximum percentage improvement in the base shear capacity in a three storied L shaped building with external floating column along X direction was found to be 65.52% whereas it was only 26.55% in a three storied L shaped building with internal floating column provided along the Y direction.

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