

Effect of Additional Reinforcement Length in Beams on Base-Shear Capacity in Performance-based Design of Low-Rise Buildings

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Abstract Most of the existing low rise RCC buildings with 4 to 6 floors were constructed pursuant to the code provisions without detailed Earthquake analysis. To comply with the revised code provisions, it is essential to build up the seismic resistance of the existing buildings. International building safety agencies such as NEHRP, FEMA, and ATC etc., formulated the Performance-based design methods to verify the seismic resistance of the existing buildings and also recommend the retrofit the building to achieve the targeted performance. Pushover method (nonlinear static analysis) is one of the methods. This paper describes the increase of seismic capacity of structure with the additional steel contribution from 25 % to 75% increase in the beams near the beam-column joints. Moreover, this additional steel is placed up to 0.2L, 0.25L and 0.3L of the beam span. To accomplish the above parameters, 4-storey, 5-storey and 6-storey rectangular framed structures are analyzed with the pushover analysis. The seismic capacity curves in terms of base shear versus displacement are illustrated. It is found that 10 to 25% of base shear is increased when beams are provided with additional reinforcement from 25% to 75% @0.2L. In this case of increasing the additional steel length from 0.20L to 0.3L, nearly 5% increase of the base shear is observed in width direction but no augmentation is observed in the

length direction of the building.

Keywords Pushover Analysis, Base Shear Capacity, Seismic Demand, Hinge

1. Introduction

Buildings in urban India are predominantly observed from 4 to 6 floors which were constructed long back as per the code provision applicable at that point of time. The codal provisions for the seismic design are being updated/revised based on the research done in the field of seismic engineering. About thirty earthquakes occurred in India during the last 50 years. It was estimated that more than one lakh people died and more than two lakh people injured in the last 20 years due to the damages occurred to the buildings and other structures during the earthquakes in the Indian subcontinent.

To reduce the human loss and property damage in future, it is essential to provide the adequate seismic capacity to the existing buildings. In this context, a lot of research work is being carried out in the USA and other developed countries. Guidelines were formulated in

NEHRP, FEMA, ATC, and ASCE codes with performance-based design procedures to verify the seismic resistance of the existing buildings and also demonstrated to retrofit the structure to satisfy the targeted performance [1-4]. The commonly adopted retrofit methods in the present context are the construction of shear walls, connecting the joints with bracings, columns confinements, steel jacketing etc.

Demand and capacity are the key elements of a performance-based design procedure. Demand is a representation of the earthquake ground motion. Capacity is the structure's ability to resist seismic demand.

Pushover analysis is the Non-linear static analysis and generates the "pushover" or capacity curve. This represents the lateral displacement as a function of the lateral force applied to the structure.

Pushover analysis (PA) can be useful for two situations. In the first instance, to find the deficiencies in the existing building due to the improper seismic design, and secondly to retrofit the existing structure to comply with the provisions of revised versions of the seismic codes. This method is generally applied to all lifeline structures including water tanks, bridges, low rise and tall buildings also. The revised Indian earthquake code provisions water tanks, high rise bundled tube structures and buildings on hill slopes are studied only linear elastic method only [5-7]. Nonlinear hinge properties and their assumed location in the beams/ column members of the structure have a primary role in the nonlinear analysis of the building. These are the points on the structures where expected cracking and yielding occurs. The hinges are flexural, shear and axial load characteristics. These represent the localized force-displacement relationships through elastic and inelastic ranges under seismic loads. The effects of plastic hinge properties in nonlinear analysis of buildings are studied [8]. Pushover analysis with column retrofitting of the school buildings was demonstrated in [9]. The effects of providing additional reinforcement in beams and columns near beam-column joints are examined [10].

In this work, an attempt is made to prepare design methodology to retrofit the existing RCC buildings by providing additional reinforcement in beams near beam-column joints. It is a new method. It studied the enhancement of the seismic demand in terms of the Base shear capacity and the roof displacements by providing varied lengths of additional reinforcement in beams near beam-column joints. The whole analysis is carried out by pushover analysis. E-TABS software is used for the analysis of three-dimensional modelling of RCC building [11]. Under some circumstances, instead of Pushover analysis, Push under analysis is proposed [12,13]. The revised Indian seismic codes and safety of tall building code recommended the pushover analysis for unconventional building category high rise buildings only [14-16].

2. Description of the Structure

Three RCC structures i.e., four, five and six storied buildings are examined to represent low-rise buildings for this study. And the properties of the structure are shown in the table 1.

Table 1. Properties of the Structures.

Type of structure	Multi-storied moment resistance frame
Size of the Building	Length 24 m Width 18 m
Number of stories	4storey, 5 storey and 6 storey buildings of 3 models
Height of Storey	3.0 m
Concrete Grade & steel	M 25 Fe 415
Wall thickness considered for load	The external wall thickness of 230 mm The internal wall thickness of 115 mm
Column size	250 mm x 500 mm
Beam size	250 mm x 400 mm
Slab thickness	150 mm
Unit weight of RCC	25 kN/m ³
Unit weight of Wall	20 kN/m ³
Live Load	3 kN/m ²
Floor finish	1 kN/m ²

2.1. Methodology

Fundamentally the pushover method is applied when the fundamental period of building is less than 1Sec. The computed values are found less than 1 sec for the selected models. E-TABS software is adopted for the analysis of structures. The geometric configuration of the buildings is shown in the table 1. A 3Dimensional model is created for each structure to carry out the non-linear static analysis. The Plan and Sectional elevation are shown in the figures 1 and 2. Beam and Column members are modelled as non-linear frame members consisting of plastic hinges at both ends and other selected locations. The beam and column members are divided into three parts with central part being 0.4 to 0.6 times span of the beam/height of the column. 0.2 to 0.3 times span of the beam on either side of the beam-column joint is strengthened by providing additional reinforcement.

The beam reinforcement near the joints is increased by 25%, 50% and 75 % for a length of 0.20L for each model in this study. The initial reinforcement in beams and columns is obtained from the elastic analysis as per IS 456-2000 code recommendations without considering seismic loads and wind loads [17]. The required reinforcement details are shown in the figure 3. Suitable combinations of different diameter bars are provided consistent with the equivalent area of required reinforcement. The percentage increase in beam reinforcement is above the reinforcement area required as

per the elastic analysis.

Six non-linear plastic hinges are provided to allow the nonlinear failure mechanism for each column and beam as shown in figure 4. The length of the beam member for which additional reinforcement is provided is further increased to $0.25L$ and $0.30L$ and the pushover analysis is performed to find out the increase in base shear. Default hinge properties are provided in line with (FEMA356) ASCE 41-13. They are PMMHinges in columns and M3 hinges in beams. Table 2 and 3 show the reinforcement

provided for beams and columns.

In pushover analysis, the model is subjected to gravity loading and simultaneous representative lateral loading. The lateral loads are applied proportional to the model displacement with the default provision in ETABS software. Twelve models were generated for each of the 4, 5 and 6 storied building model. Pushover analysis is performed and pushover curves for displacement in the length direction (and width direction) versus base shear are obtained.

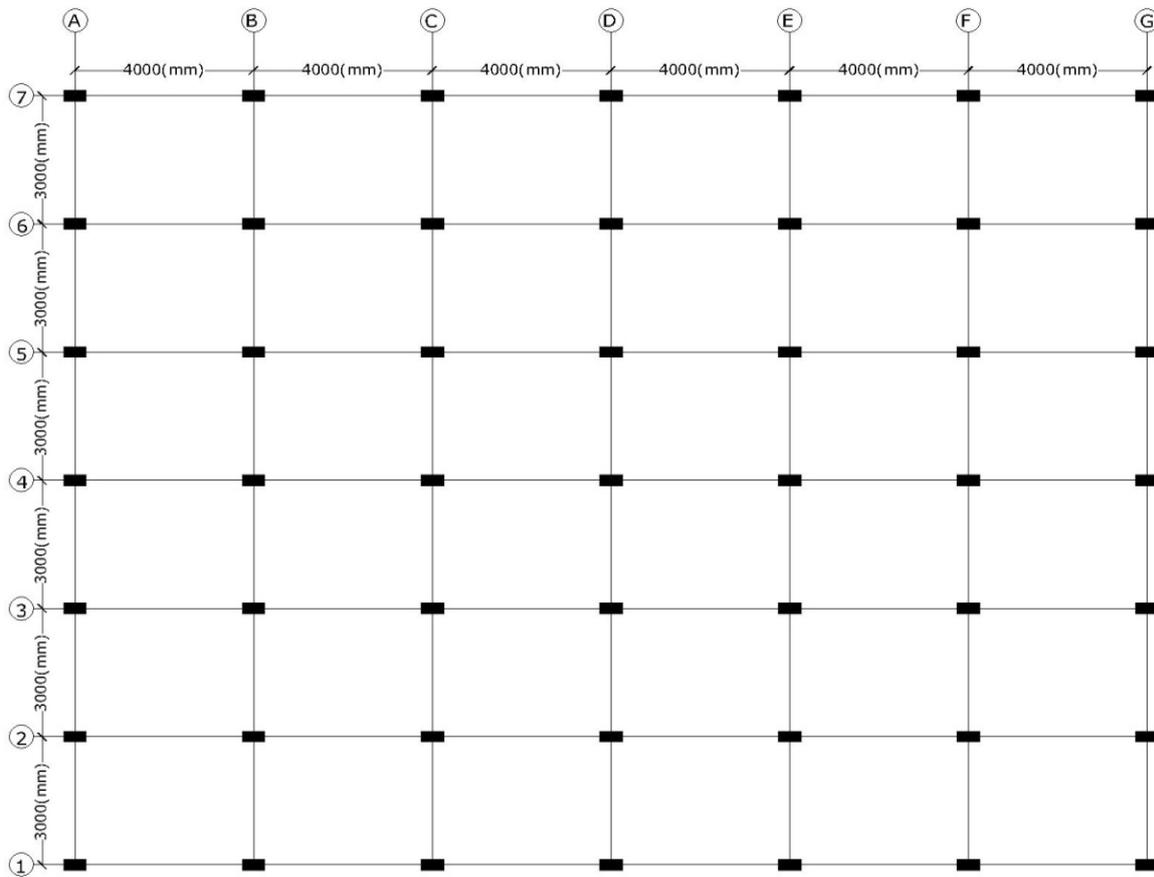


Figure 1. Plan of RCC structure of all stories

Effect of Additional Reinforcement Length in Beams on Base-Shear Capacity in Performance-based Design of Low-Rise Buildings

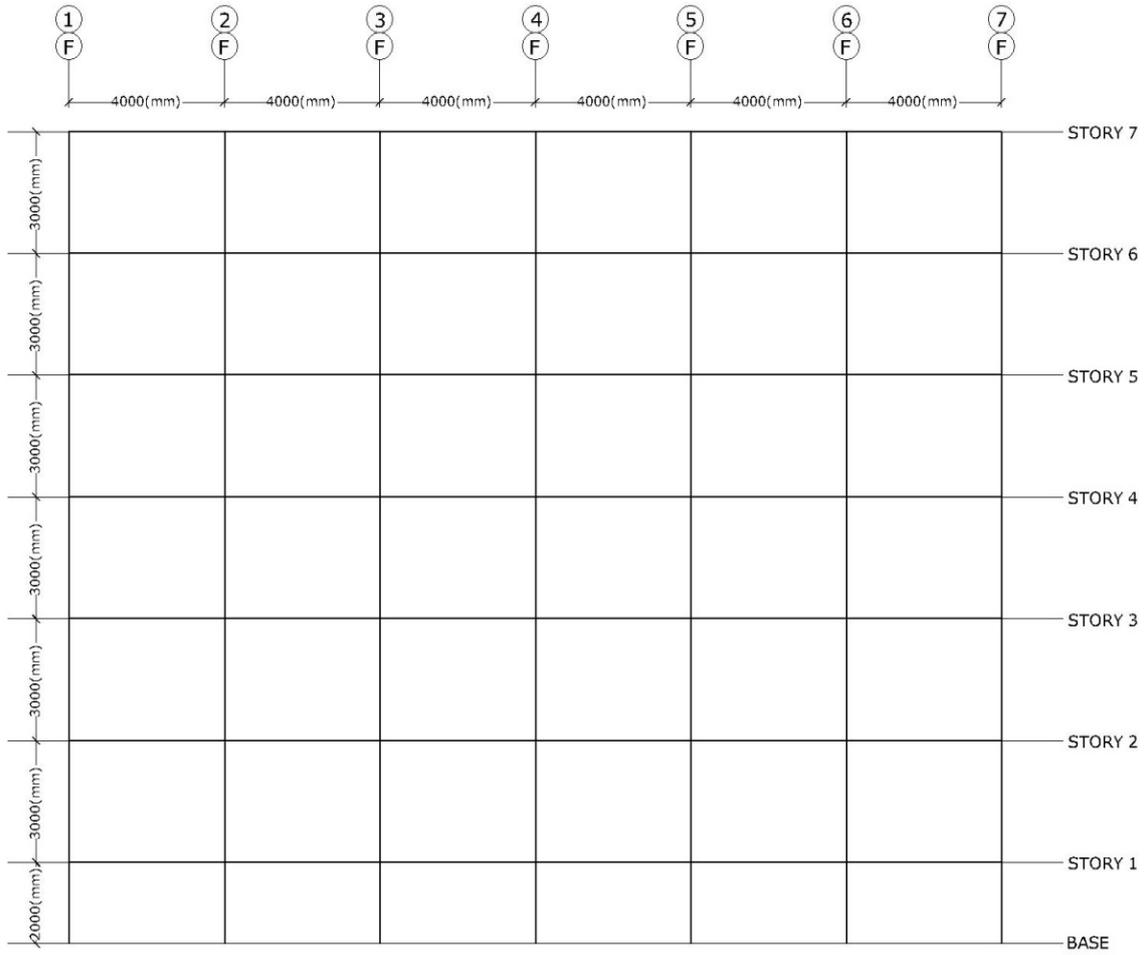


Figure 2. Elevation of 6 Storey structure

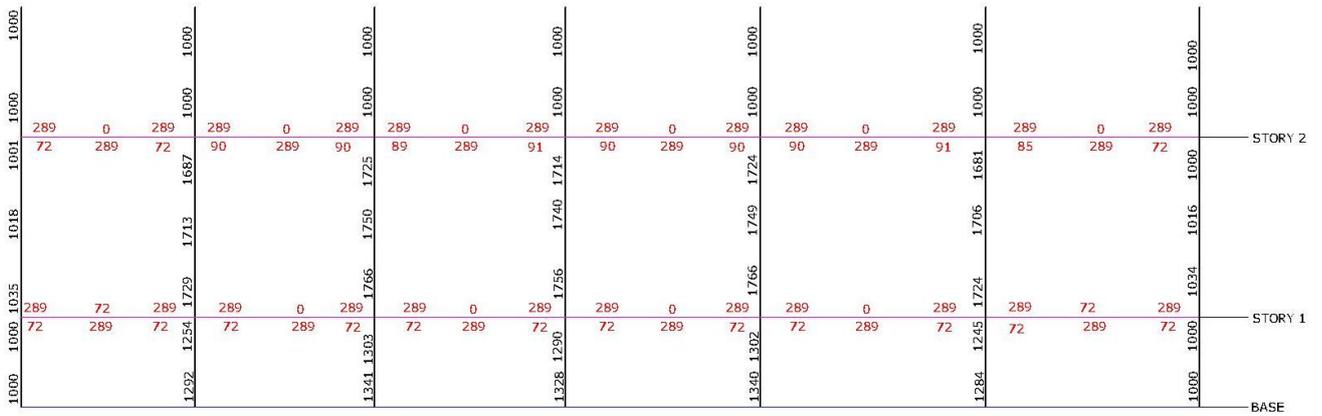
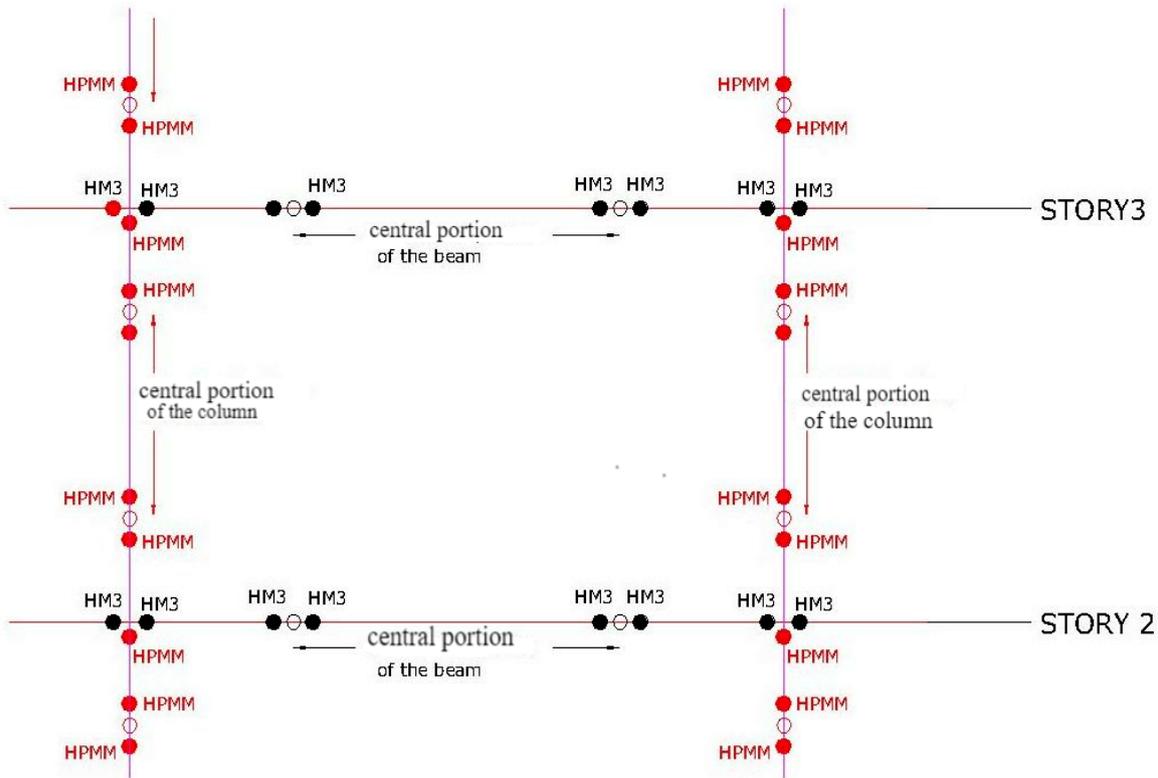


Figure 3. Designed Longitudinal Reinforcement area (mm²) for 6 Storey structure



Foot note: HPMM=Hinge in the column, HM3=Hinge in the beam

Figure 4. Plastic Hinge location near beam-column joint

Table 2. Longitudinal Reinforcement provided in Beams

Area increasedby	4 storey		5 storey		6 storey	
	Top	Bottom	Top	Bottom	Top	Bottom
0%	2 Nos 16 ϕ	2 Nos. 16 ϕ	2 Nos 16 ϕ	2 Nos. 16 ϕ	2 Nos 16 ϕ	2 Nos. 16 ϕ
25%	2 Nos 16 ϕ + 1No 12 ϕ	2 Nos. 16 ϕ + 1No. 12 ϕ	2 Nos. 16 ϕ + 1No. 12 ϕ	2 Nos. 16 ϕ + 1No. 12 ϕ	2 Nos. 16 ϕ + + 1No. 12 ϕ	2 Nos. 16 ϕ + 1No. 12 ϕ
50%	3 Nos. 16 ϕ	3 Nos. 16 ϕ				
75%	2 Nos. 16 ϕ + 1No. 20 ϕ	2 Nos. 16 ϕ + + 1No. 20 ϕ	2 Nos. 16 ϕ + 1No. 20 ϕ			

Table 3. Longitudinal Reinforcement provided for Columns

4 storey	5 storey	6 storey		
All floors	All floors	Column base and ground floor		Other floors
All Columns	All Columns	External Columns	Internal Columns	All Columns
4Nos. 12 ϕ + 4Nos. 14 ϕ	4Nos. 12 ϕ + 4Nos. 14 ϕ	4Nos. 12 ϕ + 4Nos. 16 ϕ	4Nos. 16 ϕ +4Nos. 20 ϕ	4Nos. 12 ϕ + 4Nos. 14 ϕ

3. Results and Discussions

The three models each corresponding to 4, 5 and 6 storeys are analyzed using “ETABS” software and the maximum displacement versus base shear values are tabulated below. (Table 4 to Table 6).

Effect of Additional Reinforcement Length in Beams on Base-Shear Capacity
in Performance-based Design of Low-Rise Buildings

Table 4. 4 Storey building

Name of the Model	Strengthening Ratio (Ls/L) **	Deflection in x-direction (in mm)	Base shear in the x-direction (in KN)	Deflection in Y-direction	Base shear in Y-direction (in KN)
B 1.00 C 1.00	0.20	97.48	55164*	33.14	50913
B 1.25 C 1.00	0.20	90.56	60646	73.21	56008
B 1.50 C 1.00	0.20	98.44	64439	64.68	58893
B 1.75 C 1.00	0.20	101.12	68899	60.13	63531
B 1.00 C 1.00	0.25	112.04	54244	33.14	47654*
B 1.25 C 1.00	0.25	94.79	59480	70.99	56878
B 1.50 C 1.00	0.25	93.79	63500	65.17	60530
B 1.75 C 1.00	0.25	96.75	68093	51.16	64532*
B 1.00 C 1.00	0.30	113.14	53788*	34.70	48918*
B 1.25 C 1.00	0.30	130.96	59338	70.38	58381
B 1.50 C 1.00	0.30	112.26	63180	64.09	61805
B 1.75 C 1.00	0.30	97.66	68063	58.46	66219

* The iteration process has not converged for these results, B=Beam,C= Column., 1.00=no increase of steel, 1.25=25% increase, 1.50=50% increase

**Ls: strengthening length on each end of the beam/column, X-Direction is Length direction and Y-Direction is Width direction.

L: Total length of the beam/column

Table 5. 5 Storey Building

Name of the Model	Strengthening Ratio (Ls/L)**	Deflection in x-direction (in mm)	Base shear in the x-direction (in KN)	Deflection in Y-direction	Base shear in Y-direction (in KN)
B 1.00 C 1.00	0.20	32.46	49240*	40.67	55334
B 1.25 C 1.00	0.20	139.25	66888	69.89	65139
B 1.50 C 1.00	0.20	61.32	67174*	47.19	68604*
B 1.75 C 1.00	0.20	42.68	68057*	46.12	70623*
B 1.00 C 1.00	0.25	156.34	61332	40.03	56318*
B 1.25 C 1.00	0.25	147.66	68214	82.24	67580
B 1.50 C 1.00	0.25	136.73	71772	51.35	70596*
B 1.75 C 1.00	0.25	61.57	70998*	44.52	70321
B 1.00 C 1.00	0.30	28.75	47654*	41.53	58753*
B 1.25 C 1.00	0.30	94.49	64900*	81.93	69627
B 1.50 C 1.00	0.30	137.53	71610	47.07	70423*
B 1.75 C 1.00	0.30	76.86	72056	43.44	69882*

* The iteration process has not converged for these results

**Ls: strengthening length on each end of the beam/column

L: Total length of the beam/column

Table 6. 6 Storey Building

Name of the Model	Strengthening Ratio (Ls/L)**	Deflection in x-direction (in mm)	Base shear in the x-direction (in KN)	Deflection in Y-direction	Base shear in Y-direction (in KN)
B 1.00 C 1.00	0.20	36.37	55969*	47.66	66208
B 1.25 C 1.00	0.20	164.05	75626	50.00	73003*
B 1.50 C 1.00	0.20	162.61	79872	44.50	72566*
B 1.75 C 1.00	0.20	70.33	81431*	43.99	72194
B 1.00 C 1.00	0.25	172.84	68719	51.45	68350*
B 1.25 C 1.00	0.25	180.47	75294	47.21	72072*
B 1.50 C 1.00	0.25	25.32	56852*	44.80	73046
B 1.75 C 1.00	0.25	69.85	81057*	44.29	73046*
B 1.00 C 1.00	0.30	35.77	55259*	55.35	68639
B 1.25 C 1.00	0.30	169.71	75141	46.99	72196*
B 1.50 C 1.00	0.30	142.13	79547*	48.36	75822
B 1.75 C 1.00	0.30	72.67	81201*	43.82	72063

* The iteration process has not converged for these results

** : Ls: strengthening length on each end of the beam/column

L: Total length of the beam/column

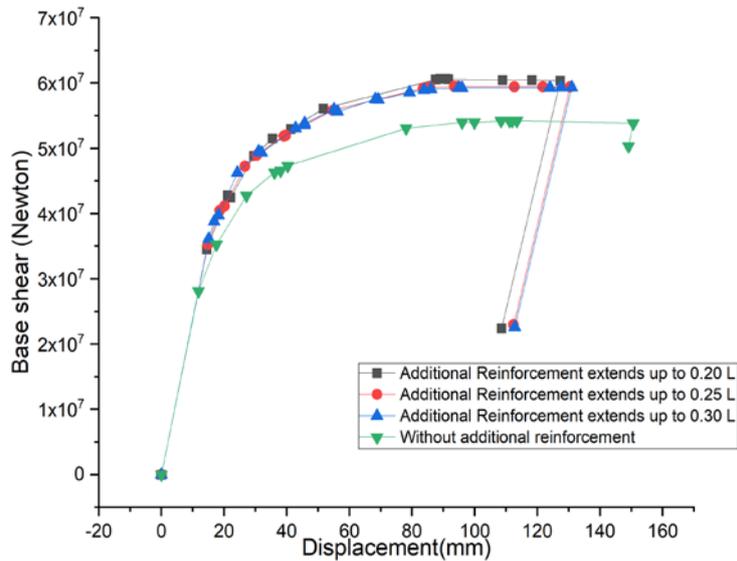


Figure 5. Base shear capacity of 4 storey building with a 25% increase of steel in the length direction

Effect of Additional Reinforcement Length in Beams on Base-Shear Capacity in Performance-based Design of Low-Rise Buildings

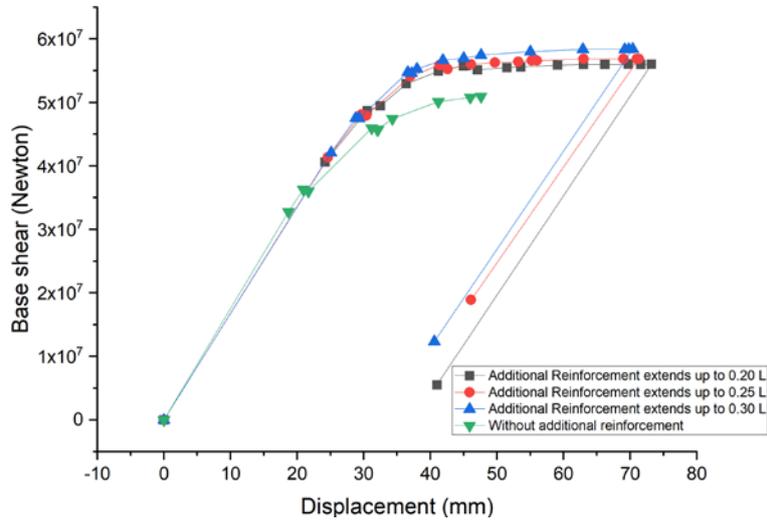


Figure 6. Base shear capacity of 4 storey building with a 25% increase of steel in the width direction

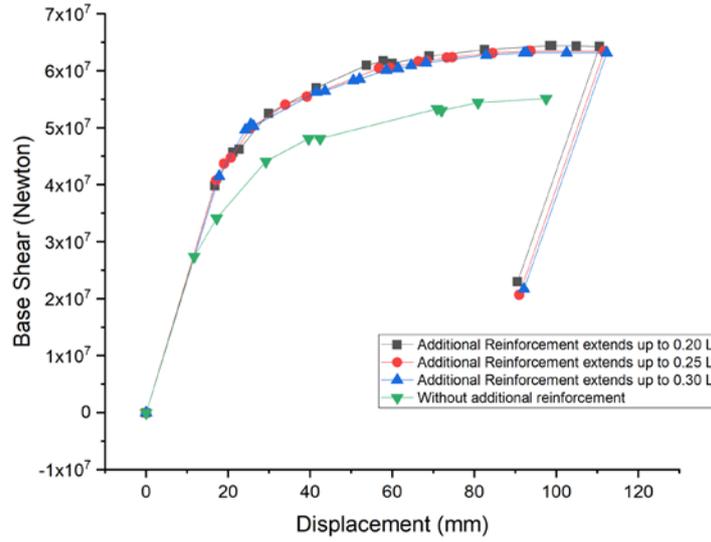


Figure 7. Base shear capacity of 4 storey building with a 50% increase of steel in the length direction

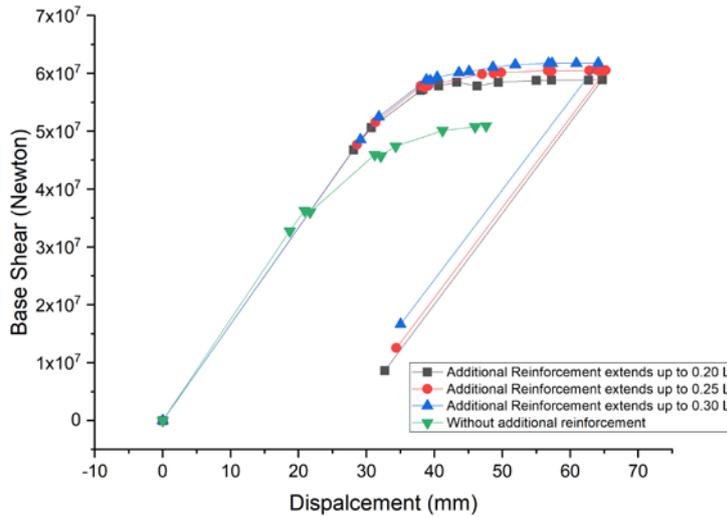


Figure 8. Base shear capacity of 4 storey building with a 50% increase of steel in the width direction

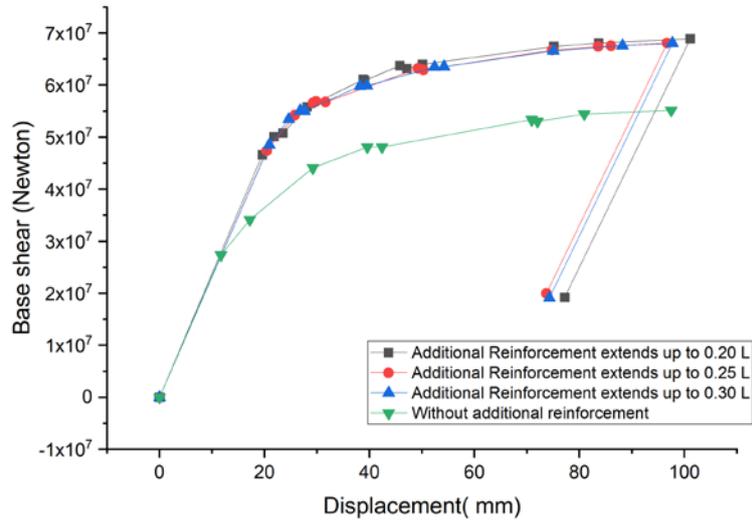


Figure 9. Base shear capacity of 4 storey building with a 75% increase of steel in the length direction

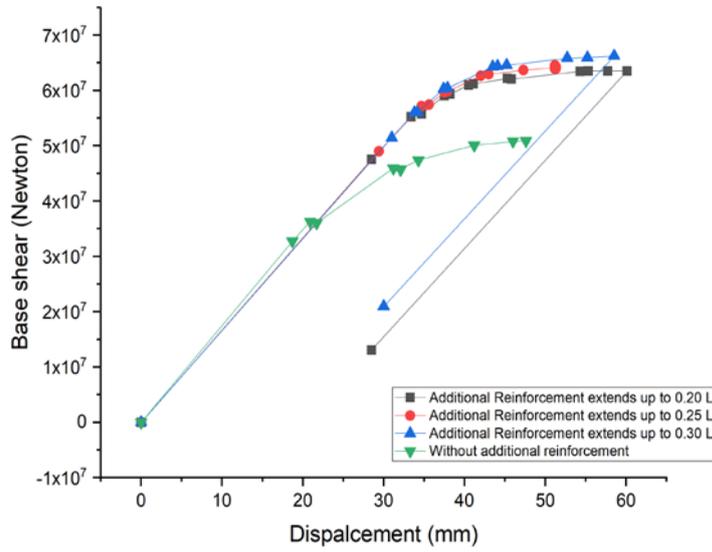


Figure 10. Base shear capacity of 4 storey building with a 75% increase of steel in the width direction

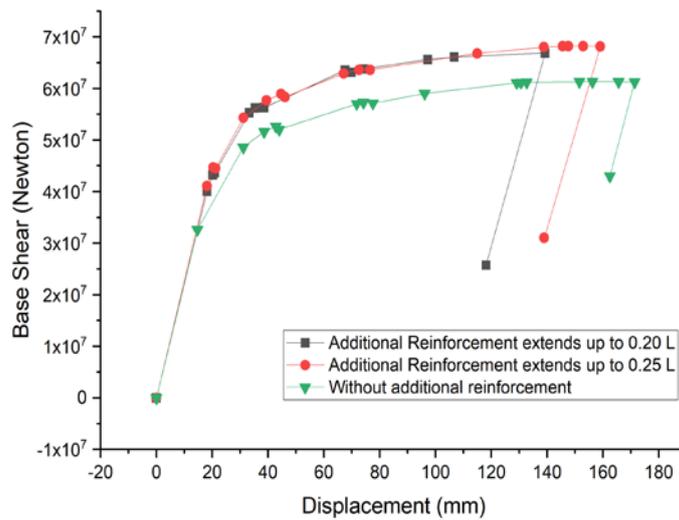


Figure 11. Base shear capacity of 5 storey building with a 25% increase of steel in the length direction

Effect of Additional Reinforcement Length in Beams on Base-Shear Capacity in Performance-based Design of Low-Rise Buildings

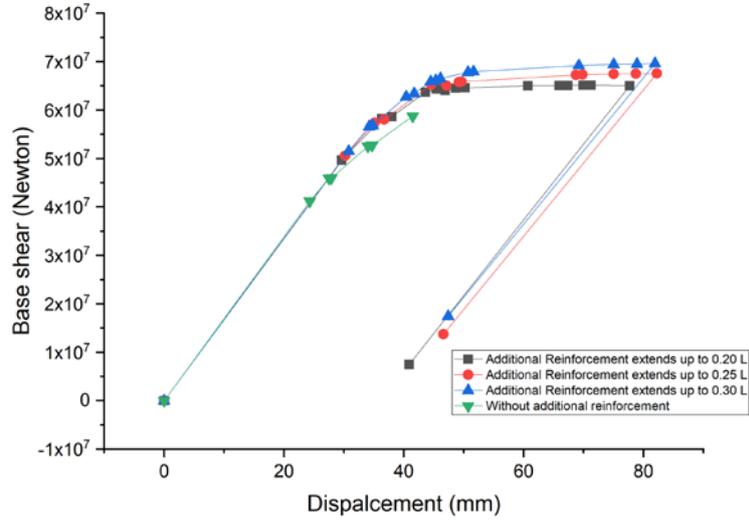


Figure 12. Base shear capacity of 5 storey building with a 25% increase of steel in the width direction

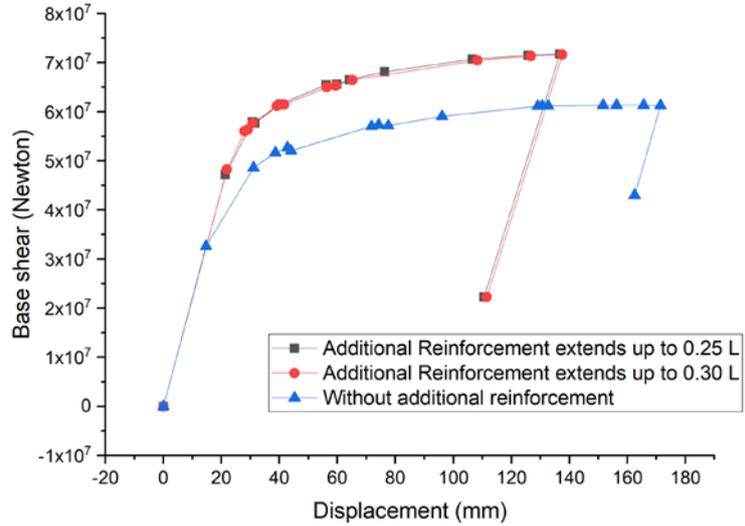


Figure 13. Base shear capacity of 5 storey building with a 50% increase of steel in the length direction

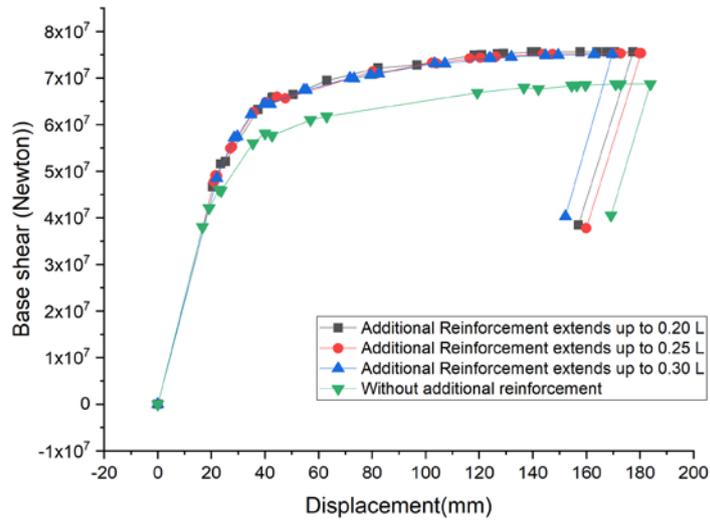


Figure 14. Base shear capacity of 6 storey building with a 50% increase of steel in the width direction

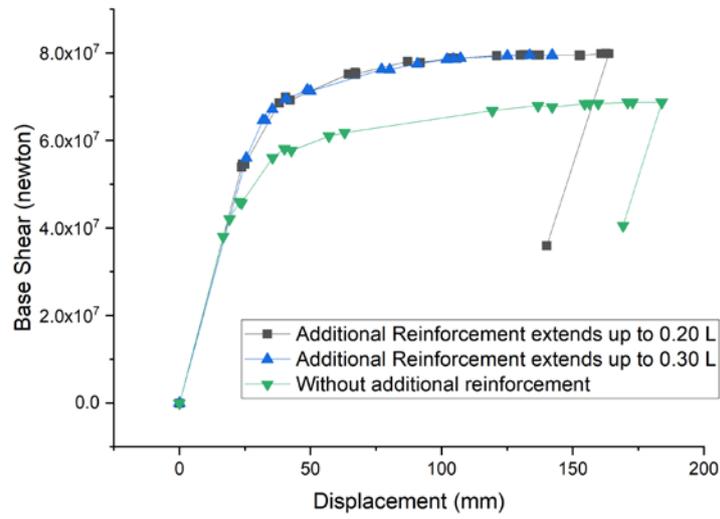


Figure 15. Base shear capacity of 6 storey building with a 50% increase of steel in the length direction

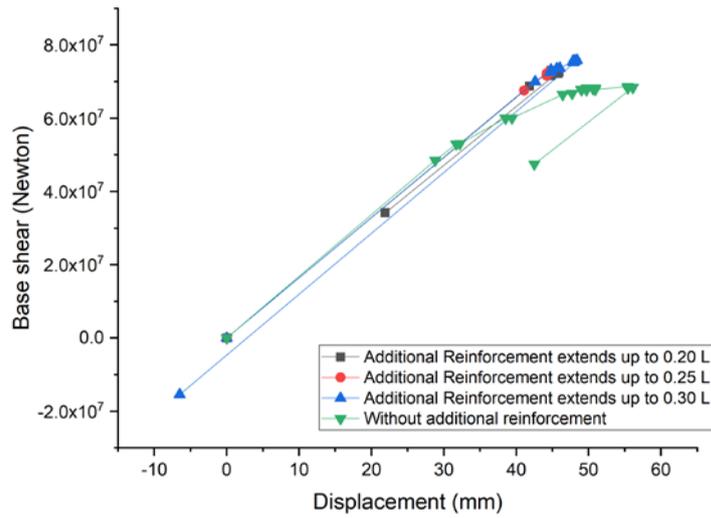


Figure 16. Base shear capacity of 6 storey building with a 50% increase of steel in the width direction

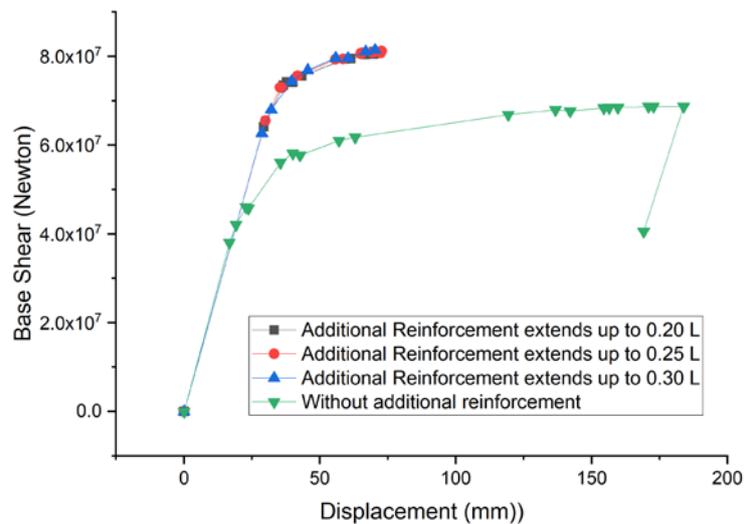


Figure 17. Base shear capacity of 6 storey building with 75% increase of steel in the length direction

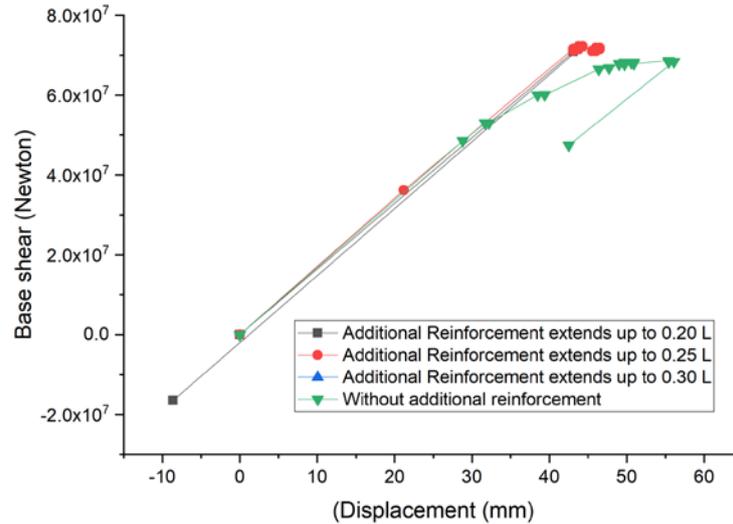


Figure 18. Base shear capacity of building with 75% increase of steel in the width direction

3.2. Observations

The following observations are made from the results obtained

3.2.1. 4 storey building (Table 4)

- 1) Long span direction, for 25% additional reinforcement - Fig. 5
 - a. Nearly 10% base shear capacity is increased in x-direction when the reinforcement is increased by 25% in beams for a length of 0.25L near beam-column joints.
 - b. A small change in base-shear is observed when strengthening length is increased from 0.20L to 0.25L and 0.30L.
- 2) Short span direction, for 25% additional reinforcement – Fig. 6
 - a. Nearly 10% base shear capacity is increased when reinforcement is increased by 25% in beams for a length of 0.20L near beam-column joints.
 - b. Nearly 1.5% increase in base shear capacity is observed when strengthening length is increased from 0.20L to 0.25L and 4% increase in base shear capacity is observed when strengthening length is increased from 0.20L to 0.30L.
- 3) For a 50% increase in reinforcement in long-span direction - Fig. 7
 - a. Nearly 17% of base shear capacity is increased. Very little change is observed in base shear capacity when strengthening length is increased from 0.20L to 0.25 L and 0.30L.
- 4) In short span direction for 50% additional reinforcement - Fig. 8
 - a. Nearly 16% increase in base shear capacity when 50% of additional reinforcement is provided for a length of 0.20L.

- b. Nearly 2.5% increase in base shear is observed when the strengthening length is increased from 0.20 L to 0.25L and nearly 5% increase in base shear is observed when strengthening length is increased from 0.20L to 0.30L.
- 5) In the long-span direction for a 75% increase in reinforcement - Fig. 9
 - a. Nearly 25% increase in base shear capacity is observed when 75% of additional reinforcement is provided for a length of 0.25L in beams near beam-column joint.
 - b. Very little change in base shear is observed when the strengthening length is increased from 0.20L to 0.25L and 0.30L.
- 6) In short span direction for a 75% increase in reinforcement - Fig. 10
 - a. Nearly 25% increase in base shear capacity is observed when 75% of additional reinforcement is provided for a length 0.20L in beams near beams -column joint.
 - b. Nearly 4% increase in base shear capacity in the y-direction is observed when the strengthening length is increased from 0.20L to 0.30L.

3.2.2. 5 storey building (Table 5)

- 1) In Long span direction, for a 25% increase in reinforcement - Fig.11
 - a. When reinforcement is increased to 25%, nearly 11% of base shear capacity is increased.
 - b. No increase in base shear is observed when the strengthening length is increased from 0.20L to 0.30L.
- 2) short span direction for 25% increase in reinforcement –Fig. 12
 - a. Nearly 18% of the base shear increase is observed when compared with non-converged base shear.

The base shear capacity is increased by 4% when strengthening length is increased from 0.20L to 0.25L.

- b. Nearly 7% base shear is increased when strengthening length is increased from 0.20L to 0.30L.
- 3) In short span direction, for a 50% increase in reinforcement- Figure-13
 - a. Nearly 17% of base shear capacity is increased when 50% of beam reinforcement is increased.
 - b. No increase of base shear is observed when strengthening length is increased from 0.25L to 0.30L.

3.2.2.6 storey building (Table-6)

- 1) In short span direction, 25% increase in reinforcement - Fig -14
 - a. The base shear capacity is increased by 10% when 25% of additional reinforcement is provided when strengthening length is 0.25L.
 - b. There is no increase is observed when strengthening length is increased from 0.20L to 0.30L.
- 2) In long-span direction, 50% increase in reinforcement - Figure -15
 - a. The base shear capacity is increased by nearly 16% when 50% of additional reinforcement is provided.
 - b. No increases are observed when strengthening length is increased from 0.20L to 0.3L.
- 3) In short span direction -Figure-16
 - a. Nearly 10% increase in base shear is observed when 50% of additional reinforcement is provided for a length of 0.30L.(not fully convergent results are compared).
 - b. Around 4% increase in base shear is observed when strengthening length is increased from 0.25L to 0.30L.
- 4) In the long-span direction, a 75% increase in reinforcement - Fig 17
 - a. Nearly 18% increase in base shear is observed when 75% of additional reinforcement is provided.
 - b. No increase in base shear is observed when strengthening length is increased from 0.20L to 0.30L (not fully convergent results are compared).
- 5) In short span direction - Fig 18

Nearly 9% increase in base shear is observed when 75% of additional reinforcement is provided (not fully convergent results are compared).

4. Conclusions

- 1) The base shear capacity of the low rise buildings in both long span and short span is substantially increased (ranging from 10% to 25 %) by providing additional reinforcement in beams(25 % to 75%) near beam-column joints.
- 2) No increase of base shear is observed in long-span direction due to the subsequent increase of strengthening length (by providing additional reinforcement) from 0.20 L to 0.30 L.
- 3) Nearly 5% increase in base shear is observed in short span direction due to the subsequent increase of strengthening length from 0.20 L to 0.30L.
- 4) The effect of strengthening is varied for long span direction and short span direction. One of the reasons may be due to the change of stiffness of columns and building in short span direction. As the location and properties of the nonlinear hinges in beams and columns have a major role in a nonlinear pushover analysis, further study with more number of plastic hinges with different locations is required.
- 5) Ultimately, how the targeted seismic resistance can be achieved with the additional reinforcement and its required length in each direction is demonstrated to the practical engineers without rigorous analysis

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