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STUDY ON SESMIC PERFORMANCE OF RC BUILDING USING PUSHOVER ANALYSIS

Deepa.T[1], Chandrashekar V.C[2]

[1,2]Assistant Professor, Dept. of Civil Engineering,

Dayananda Sagar College of Engineering Bangalore, Karnataka, (India)

ABSTRACT

Earthquake is one of the major natural event to make the structures to collapse now a days. India is divided into four seismic zones, structures situated in high seismic zone experiences huge damage when earth shakes, hence to prevent these harms, seismic design is also taken into consideration while designing the structure located in any of the seismic zone. To design the structures for seismicity, there are many methods of analysis, one of the popular method is nonlinear static analysis procedure. In present study, the building of plan dimension (30x18) m assumed to be located in different parts of Karnataka state and response of the structure to ground motion for both code defined and user defined response spectra is compared and plotted, and also present study consists of applying lateral load, in a determined pattern to the structure in small percentage increase, that is pushing the modeled structure or structural element and plotting the whole functional shear force and related lateral displacement at each step, until the structure attains collapse condition. Seismic resistant design philosophy incorporates the non-linear response of the structure by using appropriate response reduction factor (R). The value of R is directly related to the ductility level provided in the structure. Greater the assumed value of R, greater will be the ductility in the structure. Use of higher values of R is encouraged because of significant reduction in base shear leading to more economic structure. SAP2000 analytical tool is used for the analysis. It is found that, lateral displacement in case of user defined response spectra is less as compared to code defined response spectra, and also performance point of user defined spectra is less than code defined spectra.

***Keywords:* Diagonal Strut, Nonlinear Static Analysis, Pushover analysis, Response Spectra, Redundancy factor, Response reduction factor, SAP2000.**

I. INTRODUCTION

1.1 General

In the past few decades, major losses have been observed due to violent action of earth and other Natural hazardous. Many building in those past days are of good construction but poor resistance to lateral forces. Due to this lacking in lateral force resisting design, structures experience huge damages. Ground motion due to earthquake is mainly depends on seismic zoning of area and soil site condition. In present study some major cities of Karnataka state are considered, variation of soil types in these cities are taken in terms of spectral acceleration vs time period graph.

Karnataka state has two zones (II, III) and different types of soil condition, major soils are red and black cotton soil. Major cities like Bangalore, Belgaum, Bellary, Gulbarga, Hubli, Kaiga, Mangalore and Mysore are considered. Response spectrum graph (Sa vs T) are taken for the above cities and Response spectrum graph defined in Indian

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seismic code is also taken, and pushover analysis is done to see the behavior of structures for these two response spectra and compare the result. There has been a considerable increase in the construction of tall buildings both residential and commercial and the modern trend is towards more tall and slender structures. Thus the effects of lateral loads like wind loads, earthquake loads and blast forces are attaining increasing importance and almost every designer is faced with the problems of providing adequate strength and stability against lateral loads. In the present study an RC building is analyzed by varying plastic hinge length and its location for bare and in filled frames.

1.2 User Defined Response Spectra

User defined response spectra taken from the previous investigation by T.G. Sitharam on seismic hazards of different parts of Karnataka State.

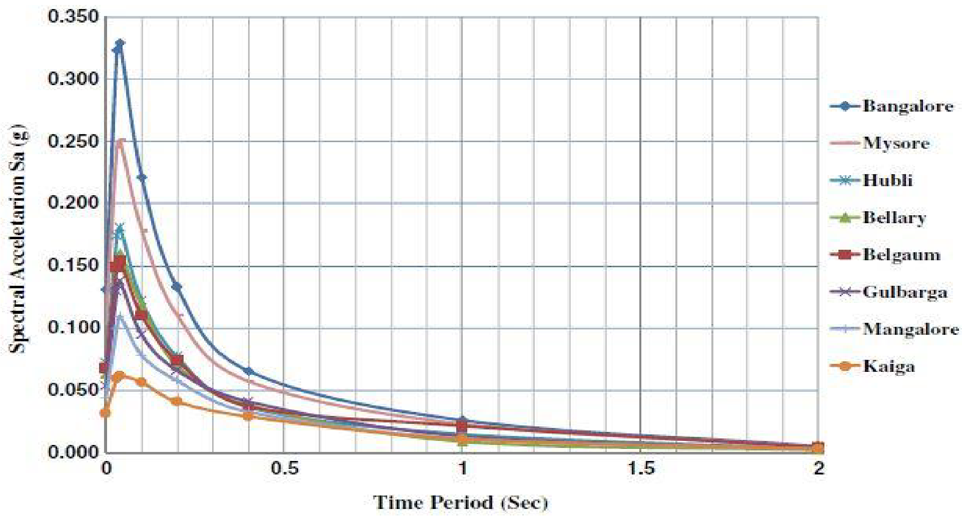

Fig 1: User Defined Response Spectra (Developed by Researchers)

1.3 Response Reduction Factor

Response reduction factor (R) is characterized diversely in various nations for various sorts of basic frameworks. In Indian seismic code, IS1893:2002, estimation of R for strengthened solid structure is indicated taking into account, Ordinary Moment Resisting Frame (OMRF) and Special Moment Resisting Frame (SMRF). The estimation of R changes from 3-5 in IS code according to kind of opposing edge, however the current writing does not give data on what premise R qualities were considered Response reduction factor consists of majorly three parameters; strength, redundancy,ductility.

$$\mathbf{R = R_s * R\mu * R_R}$$

Where R_S, R_R, and R_μ represents over strength, redundancy and ductility factors, respectively.

The strength factor (R_S) is a measure of the built-in over strength in the structural system and is obtained by dividing the ultimate base shear (V_u) by the design base shear (V_d). The ductility factor (R_μ) is a measure of the global nonlinear response of a structural system in terms of its plastic deformation capacity. The redundancy factor, (R_R) is measure of redundancy in a lateral load resisting system. The redundancy factor Rd for redundant structures is taken as 1.0.

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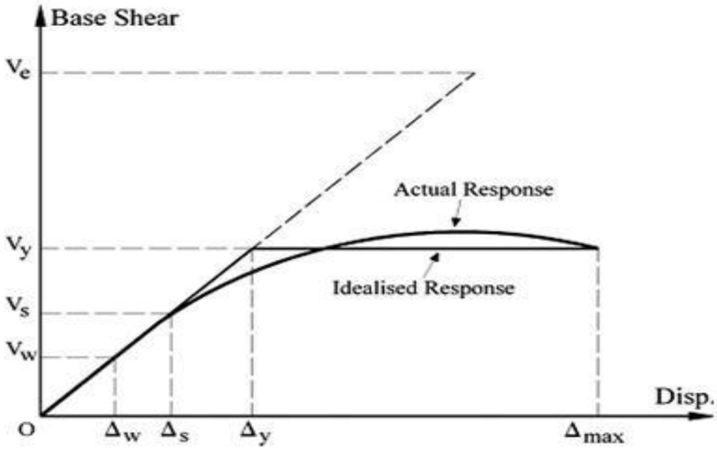

Fig: 2 Typical Pushover response curve for evaluation of response reduction factor, R

1.4 Pushover Analysis

A stagnant nonlinear pushover examination is a system used to gage seismic structural deformation. In this system the connected shear power and the corresponding displacements are plotted by applying monotonically expanding even loads in a prearranged way on the structure, until the structure accomplishes the disappointment criteria. SAP defines plastic hinge properties as per FEMA-356.Hinge property defined in the form of force curve with five points labelled A, B, C, D, and E shown in fig3. The value of these points obtained from moment curvature relationship of element depends on the type of geometry, material property, longitudinal reinforcement, shear reinforcement and loads subjected to particular member

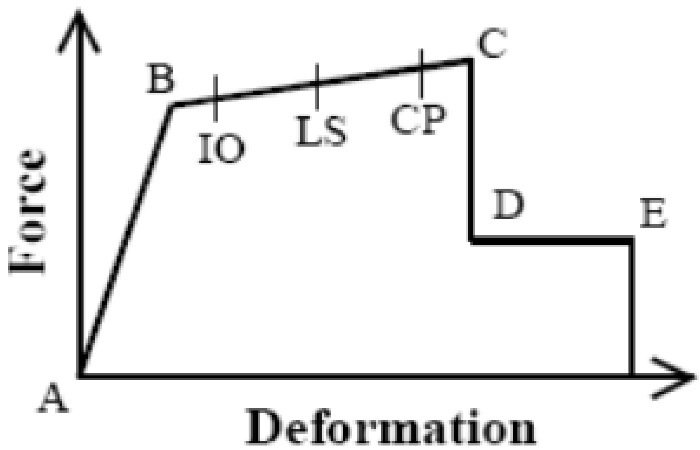

Fig -3: A-B-C-D-E Curve for Force vs. Deformation

For the present study a two dimensional model of each structure was modelled in SAP to perform Non-Linear Static analysis. Equivalent Loads from third dimension were applied on considered frame. For pushover analysis 100% dead load and 25% of live load were considered as initial load. Reinforcement in the members were defined using Auto hinges with hinge type PM3 and M3 hinges were assigned to columns and beams, respectively. Shear hinge is assigned to beam and columns of brittle type, the calculation of shear calamity can be referred.

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II. METHODOLOGY

Seismic analysis of the RC building generally includes calculation of storey drift, time period, lateral displacement and nonlinear static analysis includes the formation of hinges and performance point. To determine these factors, SAP2000 analytical tool is used.

2.1 Building Description

The plan dimension of the building is (30x18) m. G+4 3D model of building with each floor height is 3m and 5 bays along X-direction and 3 bays along Y-direction with 6 m spacing for both direction is modelled in SAP2000. Building is modelled as soft storey and infill walls are modelled as equivalent diagonal strut, width of the strut is calculated and assigned as infill panels.

2.2 Material Property

The basic material properties used for the analysis of RC building are as follows.

Table -1: Material Property

Concrete Grade	M30 N/mm^2
Grade of Steel	Fe415 N/mm^2
Elastic Modulus of Steel	$2x10^8$ kN/m^2
Elastic Modulus of Concrete	$2x10^5$ kN/m^2
Elastic Modulus of Brick Masonry	$13.2x10^6$ kN/m^2
Density of Concrete	25 kN/m^2
Density of Masonry	20 kN/m^2

2.3 Section Properties and Loads

Table -2: Section Property and Loads

SECTION	PROPETIES
Beam	(250X500) mm
Interior Column	(500X500) mm
Exterior Column	(250X500) mm
Thickness of Slab	100 mm
Thickness of Wall	250 mm
Storey Height	3 m
Floor finish, DPC	2 kN/m^2
FBBM	15 kN/m^2
PPT	4.5 kN/m^2
Live Load	3 kN/m^2

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2.4 Building Model

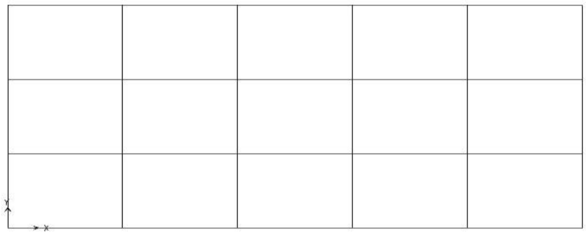

Fig 4: Plan of the Building

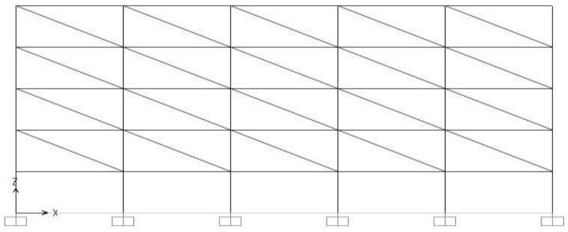

Fig 5: Elevation of Infill frame

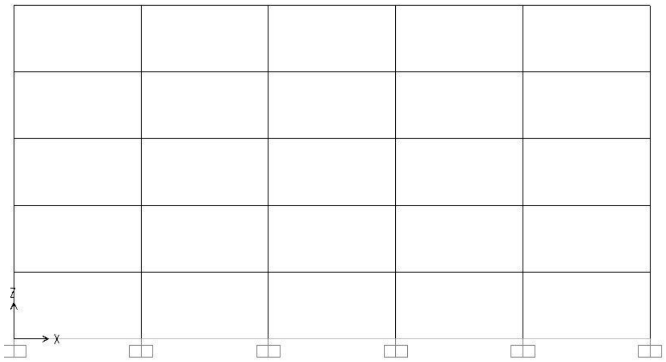

Fig 6: Elevation of Bare frame

2.5. Strut width calculation

Stafford Smith equation for calculation of equivalent diagonal strut width is considered. Stiffness of the masonry walls is considered.

$$\textbf{Smith and Henry,} \quad w = \frac{1}{2}\sqrt{\alpha^2{}_h + \alpha^2{}_L}$$

2.6 Plastic Hinge length calculation

Table-3: Calculation of plastic hinge length using above formulae for beam and column

Researchers	Formulation	Plastic hinge length	
		Beam	Column
Sawyer	Lp = 0.25d+0.075L	0.58	0.35
Mattock	Lp = 0.5d+0.05L	0.55	0.40
Priestley & Park	Lp = 0.08L+db	0.48	0.24
Paulay & Priestley	Lp = 0.08L+0.022dbfsy	0.63	0.39
Berry	Lp=0.05L+((0.01dbfsy)/(sqrt(fc)))	0.42	0.27

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III. RESULTS AND DISCUSSION

3.1 Natural Time Period

It is the time of undamped free vibration of the building. Natural period obtained from SAP2000 for the building located in different cities of Karnataka State are plotted and tabulated.

Table- 4:Natural Period along longitudinal direction

Mode	Natural Time Period (S)	
	Infill frame	Bare frame
1	0.6	1.045
2	0.553	0.947
3	0.538	0.915
4	0.151	0.327

Table-5: Natural Period along transverse direction

Mode	Natural Time Period (S)	
	Infill frame	Bare frame
1	0.639	1.277
2	0.611	1.172
3	0.523	1.063
4	0.153	0.402

Due to the presence of infill stiffness the natural period gets reduced as compared to bare frame natural period. The natural period directly affects the spectral acceleration Sa/g, it can be observed in Fig.2 of IS: 1893(Part1)-2002, where the spectral acceleration coefficient increases as the time period reduces.

3.2 Lateral Deformation

When horizontal loads are applied to the structures along its height, it deforms laterally. The amount of deformation obtained from SAP2000 for both infilled and bare frame model along transverse and longitudinal direction are plotted and tabulated.

Table-6: Lateral displacement (mm) along longitudinal direction(Located in Bangalore)

Storey No.	Code defined response spectra		User defined response spectra	
	Infill	Bare	Infill	Bare
5	2.03	4.23	0.4	0.8
4	1.96	3.80	0.389	0.71
3	1.85	3.06	0.366	0.57
2	1.71	2.04	0.338	0.38
1	1.47	0.87	0.292	0.17
0	0	0	0	0

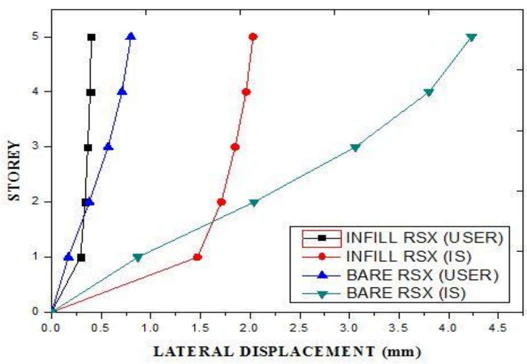

Fig: 7 Deformation profile along longitudinal direction (Located in Bangalore)

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Storey No.	Code defined response spectra		User defined response spectra	
	Infill	Bare	Infill	Bare
5	3.24	8.31	0.227	0.47
4	3.14	7.47	0.220	0.428
3	2.96	6.01	0.207	0.344
2	2.74	4	0.191	0.231
1	2.36	1.71	0.165	0.1
0	0	0	0	0

Table -7: Lateral displacement (mm) along Longitudinal direction (Located in Mangalore)

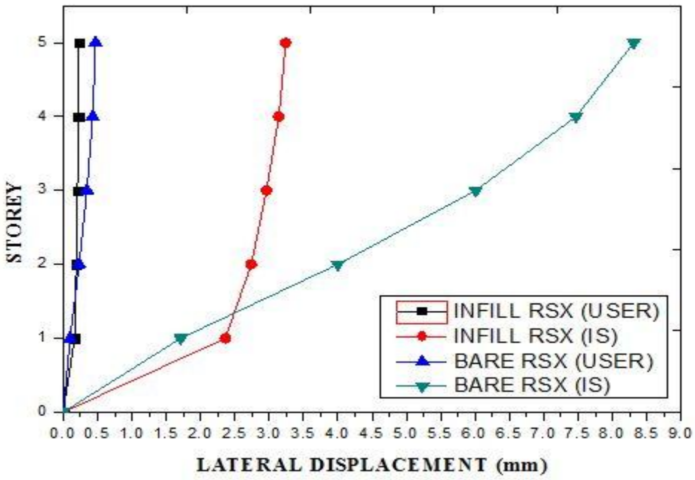

Fig: 8 Deformation profile along longitudinal direction (Located in Mangalore)

3.3 Storey Drift

As per Clause: 7.11.1 of IS: 1893 (Part 1): 2002 the storey drift for RC building is limited to 0.004 times the storey height, that is 0.4% of storey height.

Table -8: Inter Storey Drift for Both Longitudinal and Transverse Direction

Storey No.	**Displacement (mm)**		**Storey No.**	**Displacement (mm)**	
	Infill	**Bare**		**Infill**	**Bare**
5	1.84	2.49	5	0.07	1.21
4	3.73	4.62	4	0.12	2.57
3	5.78	6.86	3	0.15	4.17
2	7.45	8.62	2	0.26	5.68
1	6.15	7.04	1	4.28	6.18

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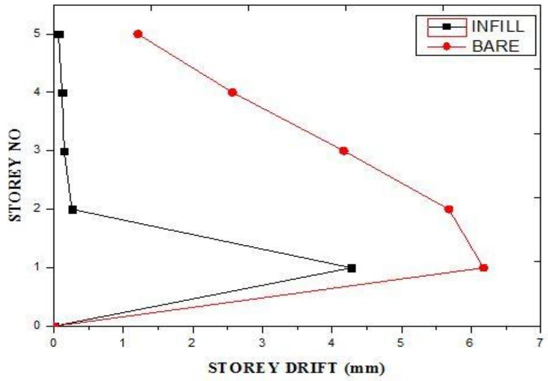

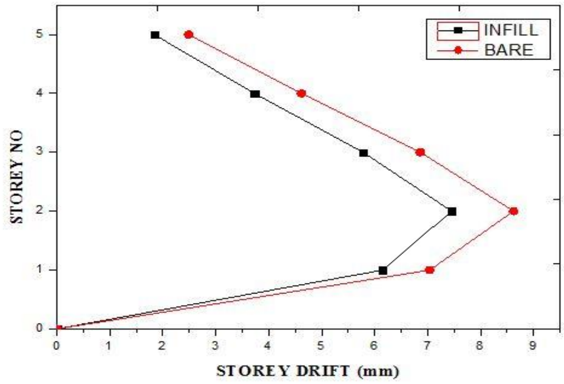

Fig: 9 Storey drift profile in transverse direction **Fig: 10 Storey drift profile in longitudinal direction**

3.4 Formation of Hinges and their Location

Table-8: Formation and location of hinges

MODELS	Performance point		Hinge location								
	D In mm	V In kN	A - B	B - IO	IO - LS	LS - CP	C P - C	C - D	D - E	> E	Total
I	180	5739	528	180	111	66	0	39	0	0	924
II	142	5289	410	106	104	0	0	0	0	0	620
III	151	2008	912	12	0	0	0	0	0	0	924

Model I - Infill along Longitudinal Direction

Model II - Bare along Longitudinal Direction

Model III - Infill along Transverse Direction

Mode IV - Bare along Transverse Direction

Table -9: Base shear and Displacement values

Models	Base shear (kN)	Displacement(mm)
Model 1	5530.212	122
Model 2	6670.024	97
Model 3	5535.196	122
Model 4	6313.000	94

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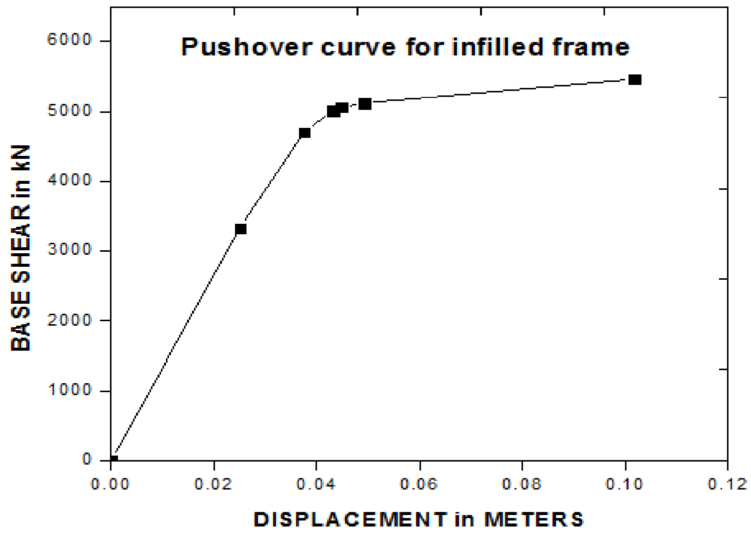

Fig 11: Correlation Pushover Curve for Infill Frame

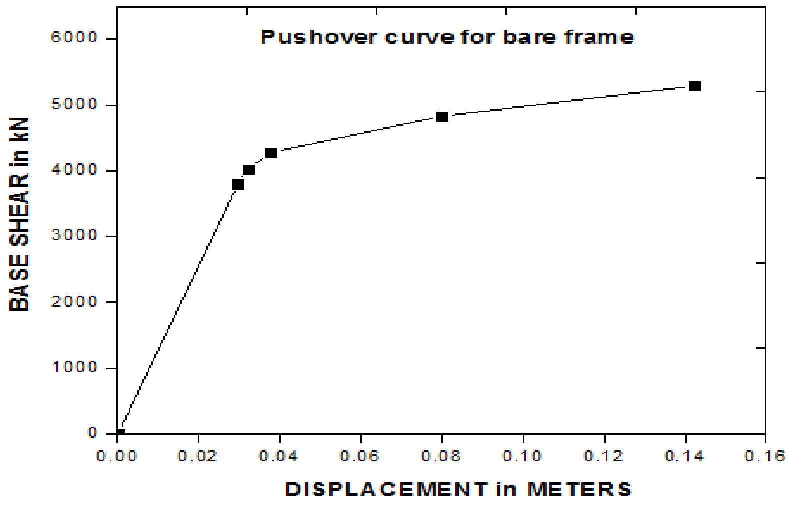

Fig 12: Correlation Pushover Curve for Bare Frame

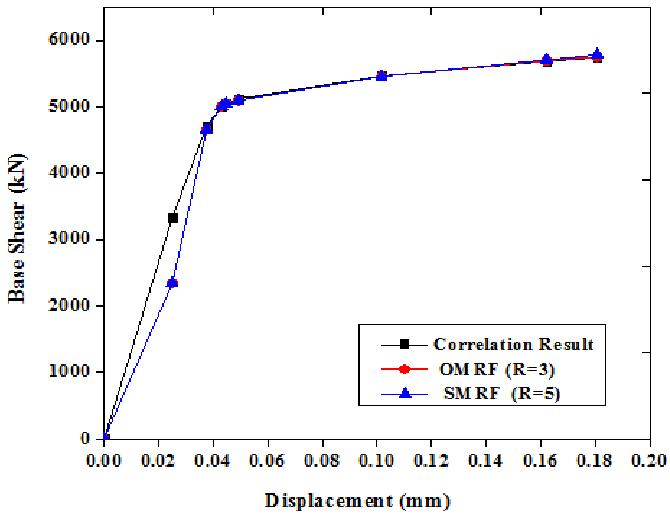

Fig 13: Comparison of correlation results with infill frame in longitudinal direction

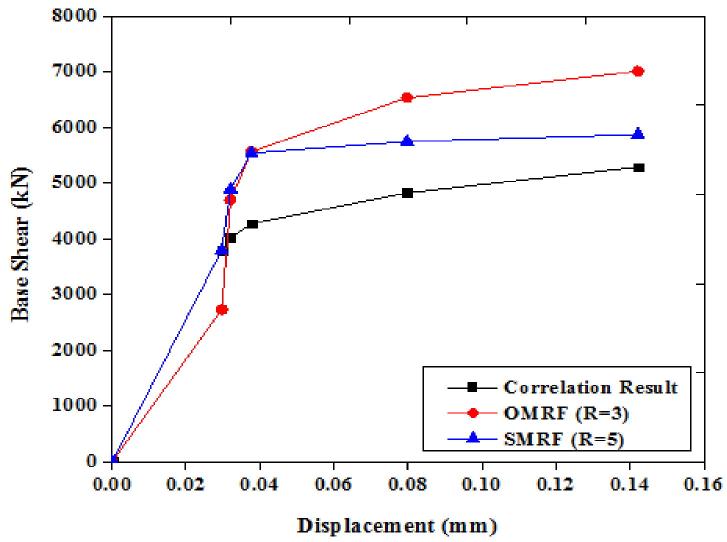

Fig 14: Comparison of correlation results with bare frame in longitudinal direction

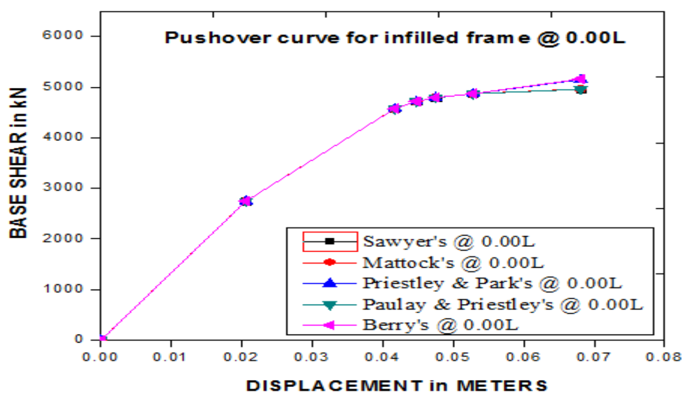

Fig 15: Comparison of pushover curves for infill frame with hinges of different hinge length formulations.

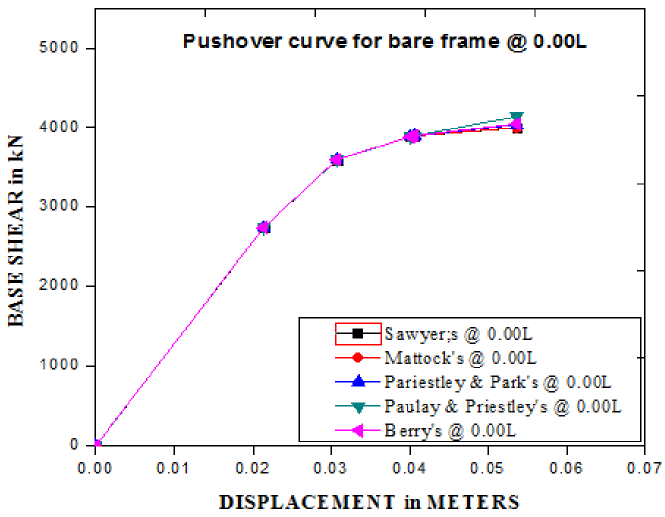

Fig 16: Comparison of pushover curves for bare frame with hinges of different hinge length formulations

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Table-10: Base shear and displacement values for bare frame

Hinge location from support / Formula	0.0L	0.05L	0.10L	0.15L	0.20L
Sawyer's	P =5295.106 Δ = 0.109	P =5337.330 Δ =0.108	P =5513.903 Δ =0.105	P =5655.171 Δ =0.104	P =5778.147 Δ =0.103
Mattock's	P =5295.106 Δ =0.109	P =5321.638 Δ =0.108	P =5523.496 Δ =0.105	P =5689.622 Δ =0.104	P =5817.650 Δ =0.102
Priestley & Park's	P =3054.968 Δ =0.025	P =3058.890 Δ =0.025	P =3060.415 Δ =0.026	P =3078.035 Δ =0.026	P =3088.892 Δ =0.026
Pauley-Priestley's	P =5294.827 Δ =0.109	P =5315.530 Δ =0.108	P =5575.122 Δ =0.105	P =5661.175 Δ =0.104	P =5818.163 Δ =0.103
Berry's	P =5304.071 Δ =0.109	P =5357.553 Δ =0.108	P =5511.384 Δ =0.105	P =5703.080 Δ =0.104	P =5792.974 Δ =0.103

Table-11: Base shear and displacement values for Infilled frame

Hinge location from support / Formula	0.0L	0.05L	0.10L	0.15L	0.20L
Sawyer's	P =5182.752 Δ = 0.132	P =5258.494 Δ =0.130	P =5361.687 Δ =0.137	P =5497.955 Δ =0.128	P =5504.566 Δ =0.136
Mattock's	P =5188.060 Δ =0.132	P =5264.336 Δ =0.131	P =5366.876 Δ =0.137	P =5411.756 Δ =0.128	P =5515.832 Δ =0.136
Priestly& Park's	P =5237.392 Δ =0.131	P =5487.195 Δ =0.112	P =5571.463 Δ =0.105	P =6033.760 Δ =0.116	P =6213.760 Δ =0.117
Paulay-Priestley's	P =5763.537 Δ =0.136	P =5769.047 Δ =0.124	P =5884.248 Δ =0.122	P =5972.970 Δ =0.118	P =6443.781 Δ =0.128
Berry's	P =5462.273 Δ =0.113	P =5495.949 Δ =0.112	P =5545.105 Δ =0.101	P =5848.243 Δ =0.107	P =5937.513 Δ =0.106

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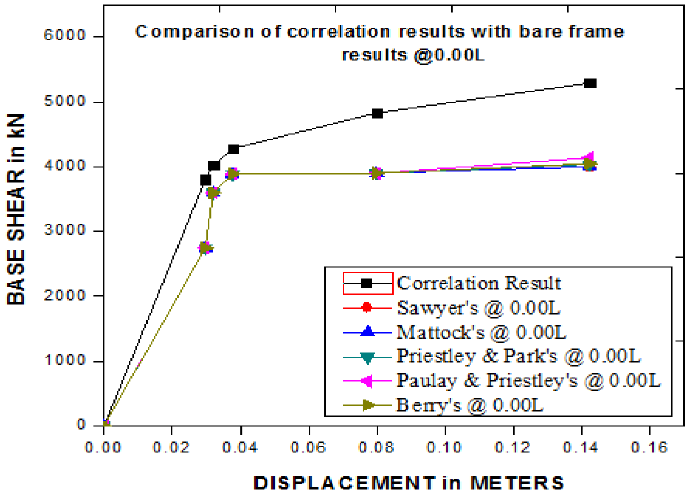

Fig 17: Comparison of correlation result with bare frame result at 0.00L

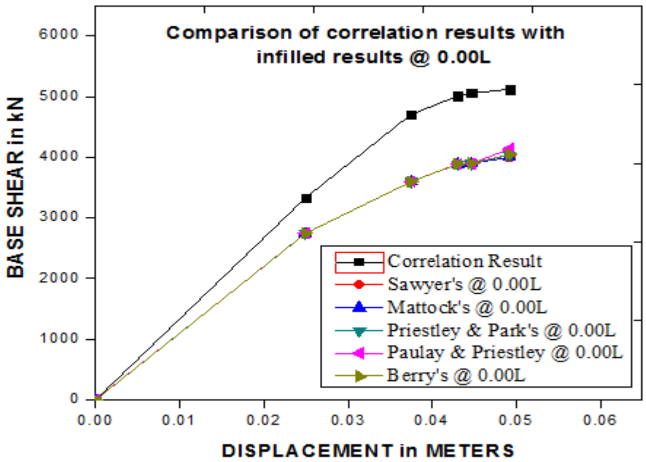

Fig 18: Comparison of correlation result with infill frame result at 0.00L

IV. CONCLUSIONS

[1] On the basis of present work, following conclusion are drawn,

[2] Lateral displacement for code defined spectra is 5.07 times the user defined spectra.

[3] The analytical natural time period do not agree with time period obtained using empirical expression of the code for all the cities considered, there high degree of dynamic analysis should be carried out to design such type of buildings.

[4] The inter storey obtained for the building located in different cities are within permissible limit prescribed by Indian Standards.

[5] Bare frame structures are having highest R value as compared to the infill frame structure.

[6] There is significant difference between the value of the Response reduction factor given in the IS code and that obtained from analysis.

[7] Compared between two models model-1 shows more displacements for little amount of base shear which is opposite in other model with infill walls

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[8] Performance point is very close for modal, FEMA and IS-1893-2002 loading. This is due to the close similarity between the load patterns.

[9] Considering infill frame and bare frame, infilled frames have the more stiffness than the bare frame.

[10] Base shear increases with the increases in length of the hinge location.

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BIOGRAPHICAL NOTES

	Prof. Deepa T is working as assistant professor in department of civil engineering from last year in DSCE Bangalore, she also worked as assistant professor in SJMIT Chitradurga for 3 years and she worked as lecturer for 2 years in Prasanna college of engineering Ujire. She received her M.Tech in Civil Engineering with specialization in CAD Structures from Visvesvaraya technological university. Her research is in the field of Earthquake resistant structures, Structural engineering.
	Prof. Chandrashekar V C is working as assistant professor in department of civil engineering for last 2 years in DSCE Bangalore and he also worked as a Lecturer in SIET Tumkur for 1 Year. He received his M.Tech in Civil Engineering with specialization in CAD Structures from Visvesvaraya technological university. His research is in the field of Structural engineering and Concrete Technology.