RESEARCH ARTICLE OPEN ACCESS

Non-Linear Static Analysis of G+6 Storeyed RC Buildings with Openings in Infill Walls

Praveen Rathod*, Dr. S. S. Dyavanal**
*(PG Student Department of Civil Engineering, BVBCET, Hubli, India)
** (Professor Department of Civil Engineering, BVBCET, Hubli, India)

ABSTRACT
Masonry infill walls are commonly used in the RC frame structure buildings. Openings are inevitable part of the infill walls. Openings in infill walls significantly decrease the lateral strength and stiffness of RC frames. In the present study two-dimensional seven storeyed reinforced concrete (RC) building models are considered with of (5%, 25%, and 35% openings Bare frame and soft storey buildings are modeled considering special moment resisting frame (SMRF) for medium soil profile and zone III. Concrete block infill walls are modeled as pin-jointed single equivalent diagonal strut. Pushover analysis is carried out for both default and user defined hinge properties as per FEMA 440 guidelines using SAP2000 software. Results of default and user defined hinge properties are studied by pushover analysis. The results of ductility ratio, safety ratio, global stiffness, and hinge status at performance point are compared with the models. Authors conclude that as the percentage of openings increases, vulnerability increases in the infill walls. The user-defined hinge model is better than the default-hinge model in reflecting nonlinear behavior. The misuse of default-hinge properties may lead to unreasonable displacement capacities for existing structures. However, if the default-hinge model is preferred due to simplicity, the user should be aware of what is provided in the program and should avoid the misuse of default-hinge properties.
***Keywords* -** Openings, Default and User defined hinges, Pushover analysis, Performance levels, Ductility ratio, Safety ratio, Global stiffness

I. INTRODUCTION

Earthquake causes the random ground motions in all directions, radiating from epicenter. These ground motions causes structure to vibrate and induces inertia forces in them [1]. In India majority of the existing RC structures do not meet the current seismic code requirements as these are primarily designed for gravity loads only. However they can resist certain amount of lateral forces due to earthquake of small magnitude, due to the effects of stiffness of the masonry infill walls [2].

In India, majority of RC multistoreyed buildings with masonry infill are constructed. The presence of infill walls in RC frame structures significantly enhances the strength and stiffness [3]. During the design of structures masonry infill walls are considered as non-structural elements. The special characteristic in many buildings constructed in urban India is that they have open ground storey to facilitate the vehicle parking. Therefore, such buildings are called as soft storey buildings. Thus the upper storeys of the building with infill walls-have more stiffness than the open ground storey. Most of the lateral displacement of the building occurs in the open ground storey. Collapse of many buildings with the open ground storey during the 2001 Bhuj earthquake emphasizes that such buildings are extremely vulnerable under the earthquake shaking [2]. Window and door -openings are inevitable part of the infill walls. However, the presence of openings in infill walls decreases the stiffness and lateral strength of the RC frame building [3]. Further if the openings are provided in the infill walls of the soft storey buildings, it proves to be critical condition [2]. Indian seismic code recommends no provision regarding the stiffness and openings in the masonry infill wall. Whereas, clause 7.10.2.2 and 7.10.2.3 of the "Proposed draft provision and commentary on Indian seismic code IS 1893 (Part 1) : 2002" [4], [Jain and Murty] [5] defines the provision for calculation of stiffness of the masonry infill and a reduction factor for the opening in infill walls.

II. BUILDING DESCRIPTION

In the present paper 2D seven storeyed RC frame building models are considered. The plan and elevation of the building models are shown in Fig 1, Fig 2, and Fig 3. The bottom storey height is 4.8 m, upper floors height is 3.6 m and bay width in longitudinal direction is considered as 6 m [2]. The building is assumed to be located in zone III. M25 grade of concrete and Fe415 grade of steel are considered. The stress-strain relationship is used as per IS 456 : 2000 [6]. The concrete block infill walls are modeled as pin-jointed equivalent diagonal struts. M3 (*Moment*), V3 (*Shear*), PM3 (*axial force with* *moment*), and P (*Axial force*) user defined hinge properties are assigned at rigid ends of beam, column, and strut elements. The density of concrete block is 22kN/m^3 [7]. Young's modulus of concrete block is 2272 MPa [8]. Poison's ratio of concrete is 0.3 [9]. 15%, 25%, and 35% [2] of central openings are considered and four analytical models developed are,

Model 1 - Building has no walls and modeled as bare frame, however masses of the walls are considered.

Building has no walls in the first storey and walls in the upper floors and modeled as soft storey with varying central opening of the total area, however stiffness and masses of the walls are considered.

Model 2 - 15%.

Model 3 - 25%

Model 4 - 35%

Models are designed for 1.2(*DL+LL+EQ*) and 1.2(*DL+LL+RS*) are carried out for equivalent static and response spectrum analysis respectively [4].

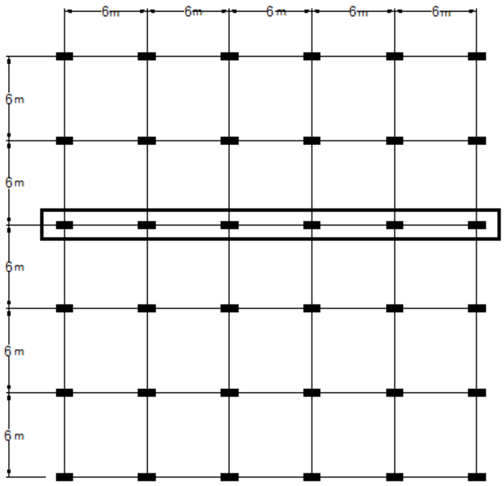

Fig 1. Plan of the building

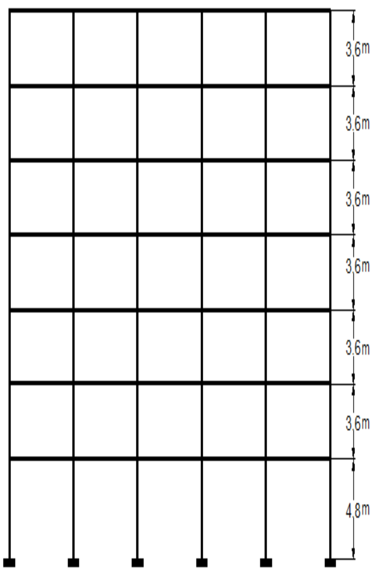

Fig 2. Elevation of bare frame and building model

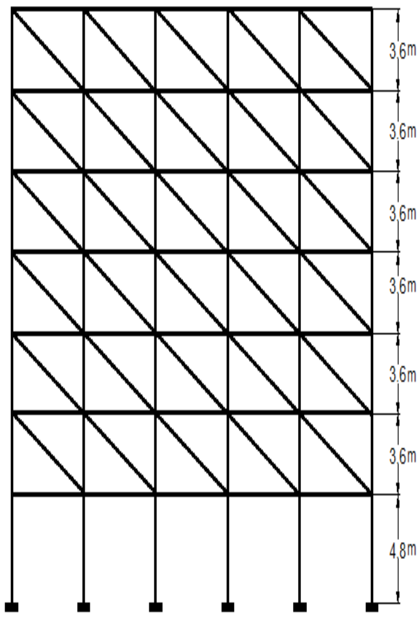

Fig 3. Elevation of soft storey building models

III. METHODOLOGY OF THE STUDY

3.1 User Defined Hinges

The definition of user-defined hinge properties requires moment–curvature analysis of beam and column elements. Similarly load deformation curve is used for strut element. For the problem defined, building deformation is assumed to take place only due to moment under the action of laterally applied earthquake loads. Thus user-defined M3 and V3 hinges for beams, PM3 hinges for columns and P hinges for struts are assigned. The calculated moment-curvature values for beam (M3 and V3), column (PM3), and load deformation curve values for strut (P) are substituted instead of default hinge values in SAP2000.

3.1.1 Moment Curvature for Beam Section

Following procedure is adopted for the determination of moment-curvature relationship considering unconfined concrete model given in stress-strain block as per IS 456 : 2000 [6].

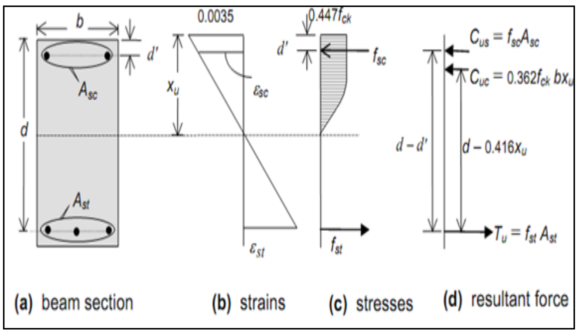

Fig 4. Stress-Strain block for beam [9]

1. Calculate the neutral axis depth by equating compressive and tensile forces.
2. Calculate the maximum neutral axis depth x_{umax} from equation 1.

$$\frac{0.0035}{x_u} = \frac{\left(\frac{f_y}{E_s} + 0.002\right)}{(d - x_u)} \quad .. (1)$$

3. Divide the x_{umax} in to equal laminae.
4. For each value of x_u get the strain in fibers.
5. Calculate the compressive force in fibers corresponding to neutral axis depth.
6. Then calculate the moment from compressive force and lever arm (C×Z).
7. Now calculate the curvature from equation 2.

$$\phi = \frac{\varepsilon_s}{d - x_u} \quad ……………..… (2)$$

8. Plot moment curvature curve. Figure 5 shows the moment curvature curve for beam.

Assumption made in obtaining moment curvature curve for beam and column

[1] The strain is linear across the depth of the section (Plane sections remain plane).
[2] The tensile strength of the concrete is ignored.
[3] The concrete spalls off at a strain of 0.0035 [6].
[4] The point 'D' is usually limited to 20% of the yield strength, and ultimate curvature, θ_u with that [10].
[5] The point 'E' defines the maximum deformation capacity and is taken as $15\theta_y$ whichever is greater [10].
[6] The ultimate strain in the concrete for the column is calculated as 0.0035-0.75 times the strain at the least compressed edge (IS 456 : 2000) [6]

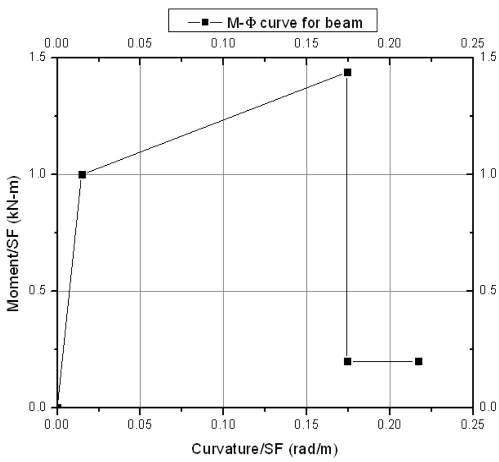

Fig 5. Moment curvature curve for beam

3.1.2 Moment Curvature for Column Section

Following procedure is adopted for the determination of moment-curvature relationship for column.

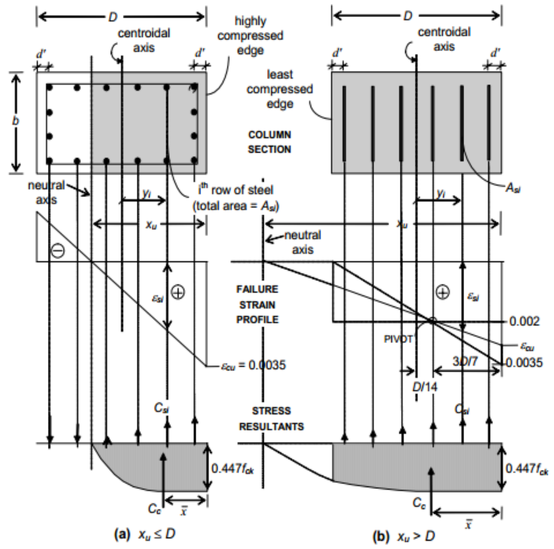

Fig 6. Analysis of design strength of a rectangular section under compression [9]

1. Calculate the maximum neutral axis depth x_{umax} from equation 3.

$$\frac{0.0035}{x_u} = \frac{\left(\frac{f_y}{E_s} + 0.002\right)}{(d - x_u)} \quad ………….. (3)$$

2. NA depth is calculated by assuming the neutral axis lies within the section.
3. The value of x_u is varied until the value of load (P) tends to zero. At P = 0 kN the value of x_u obtained is the initial depth of NA.
4. Similarly, NA depth is varied until the value of moment tends to zero. At M = 0 kN-m the value of x_u obtained will be the final depth of NA.
5. The P-M interaction curve is plotted in Figure 7.
6. For the different values of x_u, the strain in concrete is calculated by using the similar triangle rule.
7. The curvature values are calculated using equation 4,

$$\phi = \frac{\varepsilon_c}{x_u} \quad ……………………… (4)$$

8. Plot the moment curvature curve. Moment curvature curve shown in Fig 8.

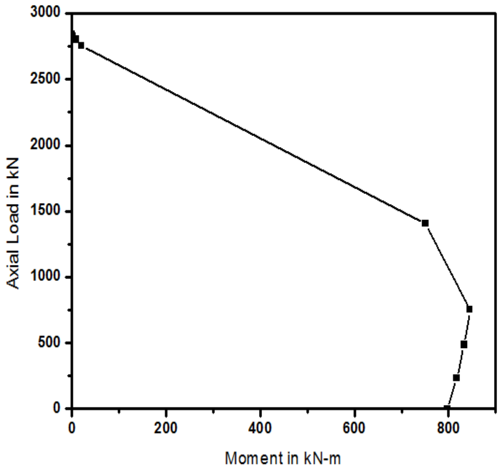

Fig 7. P-M interaction curve

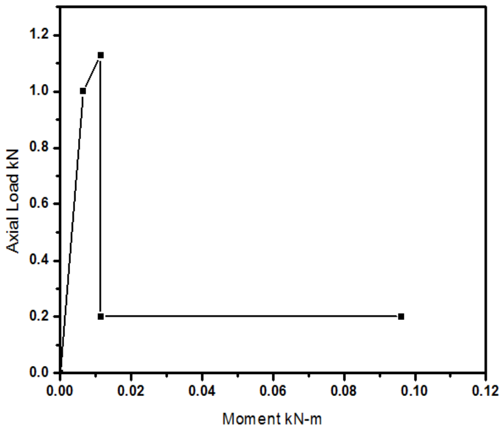

Fig 8. Moment curvature curve for column

3.2 Pushover Analysis

Pushover analysis is a static non-linear procedure in which the magnitude of the lateral load is incrementally increased maintaining a predefined distribution pattern along the height of the building. With the increase in the magnitude of loads, weak links and failure modes of the building can be found. Pushover analysis can determine the behavior of a building, including the ultimate load and the maximum inelastic deflection. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve for that structure. Pushover analysis as per FEMA 440 [11] guide lines is adopted. The models are pushed in a monotonically increasing order in a particular direction till the collapse of the structure. The models are pushed in a monotonically increasing order in a particular direction till the collapse of the structure. 4% of height of building [10] as maximum displacement is taken at roof level and the same is defined in to several steps The global response of structure at each displacement level is obtained in terms of the base shear, which is presented by pushover curve. Pushover curve is a base shear -versus roof displacement curve. The peak of this curve represents the maximum base shear, i.e. maximum load carrying capacity of the structure; the initial stiffness of the structure is obtained from the tangent at pushover curve at the load level of 10% [12] that of the ultimate load and the maximum roof displacement of the structure is taken that deflection beyond which the collapse of structure takes place.

IV. RESULTS AND DISCUSSIONS

4.1 Performance Evaluation of Building Models

Performance based seismic evaluation of all the models is carried out by non linear static pushover analysis (i.e. *Equivalent static pushover analysis and Response spectrum pushover analysis*). Default and user defined hinges are assigned for the seismic designed building models along the longitudinal direction.

4.1.1 Performance point and location of hinges

The base force, displacement and the location of the hinges at the performance point for both default and user defined hinges, for various performance levels along longitudinal direction for all building models are presented in the below Table 1 to Table 4.

Table 1. Performance point and location of hinges by equivalent static pushover analysis with default hinge

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	82.56	618.06	216	8	0	0	0	224
	Ultimate	336.85	890.49	177	20	18	0	9	224
2	Yield	31.26	1176.75	277	7	0	0	0	284
	Ultimate	122.64	1865.35	260	3	10	9	2	284
3	Yield	32.38	1161.26	275	9	0	0	0	284
	Ultimate	126.8	1782.91	259	5	12	5	3	284
4	Yield	33.8	1146.81	271	13	0	0	0	284
	Ultimate	133.62	1731.02	258	3	10	7	6	284

Table 2. Performance point and location of hinges by response spectrum pushover analysis with default hinge

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	80.12	653.98	216	8	0	0	0	224
	Ultimate	325.62	892.36	178	19	16	0	11	224
2	Yield	31.48	1520.55	276	8	0	0	0	284
	Ultimate	120.69	1876.36	256	5	8	11	4	284
3	Yield	32.74	1489.56	278	6	0	0	0	284
	Ultimate	126.31	1833.26	259	6	10	4	5	284
4	Yield	33.62	1476.00	275	9	0	0	0	284
	Ultimate	130.52	1816.29	262	2	12	0	8	284

Table 3. Performance point and location of hinges by equivalent static pushover analysis with user defined hinge

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	80.12	591.45	192	16	6	0	10	224
	Ultimate	316.25	848.32	132	52	18	0	22	224
2	Yield	35.85	1173.8	262	12	4	1	5	284
	Ultimate	114.66	1766.4	245	11	14	4	10	284
3	Yield	35.05	1153.7	261	10	4	2	7	284
	Ultimate	122.86	1698	245	11	14	0	14	284
4	Yield	34.25	1127	260	8	4	2	10	284
	Ultimate	131.06	1654.3	240	10	12	3	19	284

Table 4. Performance point and location of hinges by response spectrum pushover analysis with user defined hinge

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	79.69	631.26	192	16	4	0	12	224
	Ultimate	287.65	848.16	132	51	14	0	27	224
2	Yield	36.79	1448.1	261	10	4	2	7	284
	Ultimate	109.88	1765.2	241	11	12	5	15	284
3	Yield	37.59	1430.9	260	8	4	2	10	284
	Ultimate	118.08	1750.2	240	10	12	2	20	284
4	Yield	38.39	1413.8	258	8	4	2	12	284
	Ultimate	126.28	1735.2	238	10	11	0	25	284

The base force at performance point and ultimate point of the building depends on its lateral strength. It is seen in Table 1, Table 2, Table 3, and Table 4 that, as the openings increase the base force at ultimate point reduces by 1.077 and 1.033 times by equivalent static and response spectrum pushover analysis method in model 4 compared to model 2 with default hinges. Similarly base force reduces in model 4 compared to model 2 by 1.068 and 1.017 times by equivalent static and response spectrum pushover analysis method with user defined hinges. As the stiffness of infill wall is considered in the soft storey buildings, base force is more than that of the bare frame building. The stiffness of the building -decreases with the increase in percentage of central openings.

In most of the models, plastic hinges are formed in the first storey because of open ground storey. The plastic hinges are formed in the beams and columns. From the Table 1 and Table 2 it is observed that, in default hinges the hinges are formed within the life safety range at the ultimate state is 95.98%, 99.30%, 98.94%, and 97.89% in model 1 to 4 respectively by equivalent static pushover analysis (ESPA). Similarly 95.09%, 98.59%, 98.24%, and 97.18% hinges are developed in the models 1 to 4 respectively by response spectrum pushover analysis (RSPA). Similarly from the Table 3 and Table 4 it is observed that, in user defined hinges the hinges are formed within the life safety range at the ultimate state is 90.18%, 96.48%, 95.07%, and 93.31% in model 1 to 4 respectively by equivalent static pushover analysis (ESPA). Similarly 87.95%, 94.72%, 92.96%, and 91.20% hinges are developed in the models 1 to 4 respectively by response spectrum pushover analysis (RSPA). These results reveal that, seismically designed multistoreyed RC buildings are safe to earthquakes.

It is further observed that in default hinges, the hinges formed beyond the CP range at the ultimate state is 4.02%, 0.70%, 1.06%, and 2.11% in the models 1 to 4 respectively by ESPA. Similarly 4.91%, 1.41%, 1.76%, and 2.82% hinges are developed in the models 1 to 4 respectively by RSPA. Similarly in user defined hinges, the hinges formed beyond the CP range at the ultimate state is 9.82%, 3.52%, 4.93%, and 6.69% in the models 1 to 4 respectively by ESPA. Similarly 12.05%, 5.28%, 7.04%, and 8.80% hinges are developed in the models 1 to 4 respectively by RSPA. As the collapse hinges are few, retrofitting can be completed quickly and economically without disturbing the incumbents and functioning of the buildings.

From the above results it can be conclude that, a significant variation is observed in base force and hinge formation mechanism by ESPA and RSPA with default and user defined hinges at the ultimate state. The user-defined hinge models are more successful in capturing the hinging mechanism compared to the models with the default hinge. However, if the default hinge model is preferred due to simplicity, the user should be aware of what is provided in the program and should avoid the misuse of default hinge properties.

4.2 Ductility Ratio

The ratio of collapse yield (CY) to the initial yield (IY) is called as ductility ratio [13].Ductility ratio (DR) for building models are tabulated in the Table 5.

Table 5. Ductility ratio by ESPA and RSPA

Model No.	**Equivalent Static Pushover Analysis**			**Response Spectrum Pushover Analysis**		
	IY	**CY**	**DR**	**IY**	**CY**	**DR**
Default hinges						
1	82.56	336.85	4.08	80.12	325.62	4.06
2	31.26	118.65	3.8	31.48	120.69	3.83
3	32.38	123.59	3.82	32.74	126.31	3.86
4	33.8	129.64	3.84	33.62	130.52	3.88
User defined hinges						
1	80.12	316.25	3.95	79.69	287.65	3.61
2	35.85	114.66	3.2	36.79	109.88	2.99
3	35.05	122.86	3.51	37.59	118.08	3.14
4	34.25	131.06	3.83	38.39	126.28	3.29
Note: IY: Initial Yield, CY: Collapse Yield, and DR: Ductility Ratio,						

It is seen in Table 5 that, the ductility ratio of the bare frame is larger than the soft storey models, specifying stiffness of infill walls not considered. In default hinges, DR of all models i.e. model 1, model 2, model 3, and model 4 are more than the target value equal to 3 by ESPA. Similar results are observed in all models i.e. model 1, model 2, model 3, and model 4 by RSPA. Similarly in user defined hinges, DR of model 1, model 2, model 3, and model 4 are more than the targeted value which is equal to 3 by ESPA. Similar results are observed in model 1, model 3, and model 4 by RSPA. These results reveal that, increase in openings increases the DR more than the target value for both default and user defined hinges.

4.3 Safety Ratio

The ratio of base force at performance point to the base shear by equivalent static method is known as safety ratio. If the safety ratio is equal to one then the structure is called safe, if it is less than one than the structure is unsafe and if ratio is more than one then the structure is safer [14].

It is observed in Table 6 that, in default hinges SR of model 2 to model 4 is 1.28 to 1.36 and 1.29 to 1.43 times safer compared to the model 1 by ESPA and RSPA respectively. Similarly in user defined hinges SR of model 2 to model 4 is 1.27 to 1.37 and 1.26 to 1.42 times safer compared to the model 1 by ESPA and RSPA respectively. Therefore, these results indicate that seismically designed soft storey buildings are safer than the bare frame buildings for both default and user defined hinges.

Table 6. Safety ratio by ESPA and RSPA

Model No.	Equivalent Static Pushover Analysis			Response Spectrum Pushover Analysis		
	BF at PP	**BS by ESM**	**SR**	**BF at PP**	**BS by ESM**	**SR**
Default hinges						
1	890.49	471.5	1.89	892.36	471.5	1.89
2	1865.4	772.5	2.41	1876.36	772.5	2.43
3	1782.9	722.8	2.47	1833.26	722.8	2.54
4	1731	673.1	2.57	1816.29	673.1	2.70
User defined hinges						
1	848.32	471.5	1.80	852.16	471.5	1.81
2	1766.4	772.5	2.29	1765.16	772.5	2.28
3	1698	722.8	2.35	1750.16	722.8	2.42
4	1654.3	673.1	2.46	1735.16	673.1	2.58

Note: BF at PP: Base Force at Performance Point, BS by ESM: Base shear by Equivalent Static Method, SR: Safety Ratio

4.4 Global stiffness

The ratio of performance force shear to the performance displacement is called as global stiffness [14]. Global stiffness (GS) for ten storeyed building models are tabulated in the Table 7.

It is seen in Table 7 that, in frames defined with default hinges as the openings increases global stiffness reduces slightly by ESPA and ESPA. The global stiffness of model 2 increases by 5.75 and 5.67 times compared to the model 1 by ESPA and RSPA respectively. In user defined hinges as the openings increases global stiffness reduces marginally by ESPA and ESPA. The global stiffness of model 2 increases 5.75 and 5.43 times compared to the model 1 by ESPA and RSPA respectively. These results reveal that, multistoreyed RC buildings designed considering earthquake load combinations prescribed in earthquake codes are stiffer to sustain earthquakes.

Table 7. Global stiffness by ESPA and RSPA

Model No.	Equivalent Static Pushover Analysis			Response Spectrum Pushover Analysis		
	BF at PP	**Disp. at PP**	**GS**	**BF at PP**	**Disp. at PP**	**GS**
Default hinges						
1	890.49	336.85	2.64	892.36	325.62	2.74
2	1865.4	118.65	15.72	1876.36	120.69	15.5
3	1782.9	123.59	14.42	1833.26	126.31	14.5
4	1731	129.64	13.35	1816.29	130.52	13.9
User defined hinges						
1	848.32	316.25	2.68	852.16	287.65	2.96
2	1766.4	114.66	15.41	1765.16	109.88	16.1
3	1698	122.86	13.82	1750.16	118.08	14.8
4	1654.3	131.06	12.62	1735.16	126.28	13.7

Note: BF at PP: Base Force at Performance point, Disp. at PP: Displacement at Performance Point, GS: Global Stiffness

V. CONCLUSION

Based on the results obtained by analyses for the various building models, the following conclusions are drawn.

1. RCC framed multi-storeyed buildings must be designed considering methods mentioned in earthquake codes to reduce vulnerability to earthquake shaking.
2. As the percentage of openings increases the base force at performance point decreases for both default and user defined hinges.
3. A significant variation is observed in hinge formation mechanism by ESPA and RSPA with default and user defined hinges at the ultimate state.
4. The user-defined hinge models are more successful in capturing the hinging mechanism compared to the default hinge models.
5. The default-hinge model is preferred due to simplicity, the user should be aware of what is provided in the program and should avoid the misuse of default-hinge properties.

6. The models considered in this paper are safer, ductile, and stiffer.

REFERENCES

[1] C.V.R. Murthy (2002), "*What are the Seismic Effects on Structures*?" Earthquake tip 05, IITK –BMTPC.
[2] B.G. Prashanta and S.S. Dyavanal (2007), "Performance Based Seismic Evaluation of Multistoreyed Buildings with the Openings in U M Infill Walls", *RDSE-2007, Manipal Institute of Technology*, Manipal. 30-31st August.
[3] G. Mondal and S.K. Jain, "Lateral Stiffness of Masonry Infilled Reinforced Concrete (RC) Frames with Central Opening", *Earthquake Spectra, Vol 24, No 3, pages 701-723,* Indian Institute of Technology, India, 2008.
[4] IS 1893 (Part 1): 2002, "*Criteria for Earthquake Resistant Design of Structures*", Bureau of Indian Standards, New Delhi 110002.
[5] S.K. Jain, and C.V.R. Murty, *Proposed draft provision and commentary on Indian Seismic Code IS 1893 (Part 1),* Department of Civil Engineering, Indian Institute of Technology Kanpur.
[6] IS 456:2000, "*Code of Practice for Plain and Reinforced Concrete*", Bureau of Indian Standards, New Delhi, India.
[7] Dr.H.J. Shah, "*Reinforced Concrete*", 9th ed., vol. 1. Charotar Publication 2012.
[8] Rihan Maaze "*Seismic Evaluation of Multistorey Buildings with Soft Storey Assigned with User Defined Hinges*", M.Tech Thesis, B.V. Bhoomaraddi College of Engineering & Technology, Hubli, 2013.
[9] Pillai and Menon, "*Reinforced Concrete Design*", Tata McGraw-Hill Education 2003
[10] Applied Technology Council (1996), "*Seismic Evaluation and Retrofit of Concrete Buildings*", Vol.1& 2, California.
[11] Federal Emergency Management Agency, FEMA-440 (2005), "*Improvement of Nonlinear Seismic Analysis Procedures*". California.
[12] FEMA 356, 2000 "*Pre-standard and commentary for the seismic rehabilitation of buildings*", ASCE for the Federal Emergency Management Agency, Washington, D.C.
[13] R. Park and T. Paulay, "*Reinforced Concrete Structures,*" Christ church, New Zealand, Aug, pp. 270-343, 1974.
[14] V.B. Karkatti, "*Seismic Evaluation and Retrofitting of Soft Ground RC Multistorey Buildings*", M.Tech Thesis, B.V. Bhoomaraddi College of Engineering & Technology, Hubli, 2006.
[15] Praveen Rathod, S S Dyavanal, *"Seismic Evaluation of Multistorey RC Building With Openings in Unreinforced Masonry Infill Walls with User Defined Hinges",* ICMBME, IRAJ Research Forum, Bengaluru, 5th july 2014.
[16] Praveen Rathod, S.S Dyavanal, "*Performance Based Seismic Evaluation of G+9 RC Buildings with Openings in Infill Walls*", *IJARSE, Vol. No.3, Issue No.7*, July 2014.
[17] Praveen Rathod, S.S Dyavanal, "*Pushover Analysis of Ten Storeyed RC Buildings with Openings in Infill Walls*", International Journal of Advanced Scientific and Technical Research, IJAST, Issue 4, Volume 4: July-August 2014.
[18] Praveen Rathod, S.S Dyavanal, "*Non-Linear Static Analysis of G+3 Storeyed RC buildings with Openings in Infill walls*", *IJERT, Vol. No.3, Issue No.8,* August 2014.
[19] Praveen Rathod, S.S Dyavanal, "*Pushover Analysis of Seven Storeyed RC buildings with Openings in Infill walls*", *IJETT, Volume 14, Number 3,* August 2014.
[20] Praveen Rathod, S.S Dyavanal, "*Performance Based Seismic Evaluation of G+3 RC Buildings with Openings in Infill Walls*", *IJIRAE, Volume 1, Issue 7, August 2014.*