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# EVALUATION AND STRENGTHENING OF SOFT STOREY BUILDING

Dhadde Santosh *
* Assistant Professor, Department of Civil engineering, BKIT, Bhalki
Email: santoshdhadde660@gmail.com

***Abstract*— Most of the low/medium rise buildings are often build with irregularities such as soft/weak, torsional irregularity, vertical, and plan irregularity, unsymmetrical layout of in-fill walls etc. Hence these irregularities are needs to be retrofitted by evaluating their performance. In this paper R.C.C framed building (G+7) with soft storey irregularity is considered for the current study. Nonlinear pushover analysis is conducted to the building models using ETABS. The performance evaluation is carried for non-retrofitted normal buildings and retrofitting methods are suggested like infill wall, increase of ground story column stiffness and shear wall at central core. The comparison is established for existing soft storey at ground, intermediate and top story level and retrofitted models. The results in terms of lateral deformation, storey shear, and hinge status are compared for the different building models considered in the investigation. All the building models are designed as per IS: 456-2000 and their performance based seismic investigation is assessed by the acceptance criteria presented in FEMA 356 and ATC 40 It is concluded that the performance of the retrofitting models is more compare to an existing soft storey models.**

***Index Terms*— Soft storey, Pushover Analysis, Performance evaluation, Retrofitting, Storey drifts Hinge status.**

## I. INTRODUCTION

Post earthquake studies show that the most of the reinforced concrete buildings having such irregularities were severely damaged under strong seismic ground motion. Soft story irregularity is one of the main reasons of the building damage during past earthquakes and has been mentioned in almost all reconnaissance reports. Soft story due to increased story height is a well-known subject but soft story may also arise due to abrupt changes in amount of infill walls between stories, which are usually not considered as a part of load bearing system [1]. This study investigates soft story behavior due to increased story height, lack of infill amount at ground story and existence of both cases using nonlinear static and dynamic response history analyses for mid-rise reinforced concrete buildings. The draft Indian seismic code classifies a soft storey as one whose lateral stiffness is less than 70% of the storey above or below [Draft IS: 1893, 2002][2]. Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first storey, to be “buildings with soft first storey.” Whereas the total seismic base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height.

## II PERFORMANCE EVALUATION

The objective of performance-based analysis is to produce structures with predictable seismic performance. Performance based engineering is not new concept. Automobiles, Airplanes, and turbines have been designed and manufactured using this approach for many decades. But the applications of the same, to the buildings were limited. In order to utilize performance-based analysis effectively and intelligently, one need to be aware of the uncertainties involved in both structural performance and seismic hazard estimations. A key requirement of any meaningful performance based analysis is the ability to assess seismic demands and capacities with a reasonable degree of certainty.

## II. CAPACITY

The overall capacity of a structure depends on the strength and deformation capacity of the individual components of the structure. In order to determine capacities beyond the elastic limits, some form of nonlinear analysis, such as the pushover procedure, is required. This procedure uses a series of sequential elastic analysis, superimposed to approximate a force displacement capacity diagram of the overall structure. A lateral force distribution is again applied until additional components yield. This process is continued until the structure become unstable or until a predetermined limit is reached.

## III. DEMAND

Ground motion during an earthquake complex horizontal displacement patterns in the structures. It is impractical to trace this lateral at each time-step to determine the structural design parameters. The traditional design methods use equivalent lateral forces to represent the design condition. For nonlinear methods it is easier and more direct to use a set of lateral displacements as the design condition. For a given structure and ground motion, the displacement demand is an estimate of the maximum expected response of the building during the ground motion. Once, a capacity curve and demand displacement, are defined, a performance check can be done.

## V. PUSHOVER ANALYSIS

The static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new

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structures. The expectation is that the pushover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components. The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces.

## VI. OBJECTIVES AND SCOPE

To study the performance of the soft storey buildings, study the weaker points in the structure with help of total base shear and target displacement, Study of elastic and plastic hinges formed in RCC framed building, to evaluate and compare the variation of the values of soft storey irregularities after the retrofitting of the building.

In this study an attempt has been made to understand the structural behavior of buildings with soft storeys. Most of the low/medium rise residential buildings are often built with irregularities such as soft/weak storey, torsional irregularity, vertical and plan irregularity, unsymmetrical layout of in-fill walls etc. Post earthquake studies show that the most of the reinforced concrete buildings having such irregularities were severely damaged under strong seismic ground motion. Soft story irregularity is one of the main reasons of the building damage during past earthquakes and has been mentioned in almost all reconnaissance reports. Hence the aim of performance evaluation is to fulfill the seismic vulnerable requirement of structure.

## VII. RESULTS AND DISCUSSIONS

### *A. Buildings Studied*

The plan layout of the reinforced concrete ordinary moment resisting frame building of eight storied is shown in fig 7.3 to 7.5, building with open ground storey as soft storey is considered, and the soft story is shifted to top floors. The plan is similar for all building models as shown in fig 7.2. And the existing soft storey is retrofitted with four retrofitting models as shown in fig 7.6 to 7.9. In the first retrofitting model i.*e.* model RM1 is retrofitted with 230mm thick infill as equivalent diagonal strut at soft storey in ground floor, in second retrofitting model RM2 is retrofitted with increase in column stiffness of ground storey by 450x900 instead of 350x700, in the third model RM3 is retrofitted with central core 230mm infill wall as double diagonal and in model RM4 a central core of shear wall is added. The storey height of 3m is kept for all the storeys, bay dimensions in both x and y directions are kept as 4.5m and 3m respectively.

The masonry infill is modelled as equivalent diagonal strut in the upper storey. The equation for calculation of equivalent diagonal strut width is considered from Rahul P. rathi and Dr. P.S Pajgade [3] paper.

The width is given by

W= 0.175 (λ H)$^{-0.4}$ D……………….……. (7.1)

Where $\lambda_h = \sqrt[4]{\dfrac{E_i t \sin 2\theta}{4 E_c I_c H_i}}$ ………………… (7.2)

λ =Stiffness reduction factor
Ei = the modules of elasticity of the infill material, N/mm2
Ef= the modules of elasticity of the frame material, N/mm2
Ic = the moment of inertia of column, mm4
t = the thickness of infill, mm
H = the Centre line height of frames
h = the height of infill
L = the centre line width of frames
l =the width of infill
D = the diagonal length of infill panel
θ = the slope of infill diagonal to the horizontal.

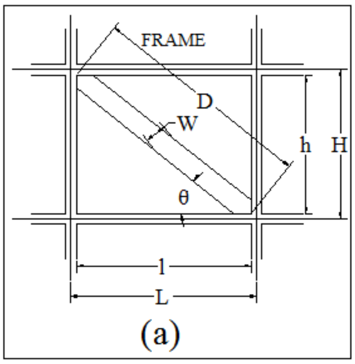


Fig 7.1 shows equivalent diagonal strut model

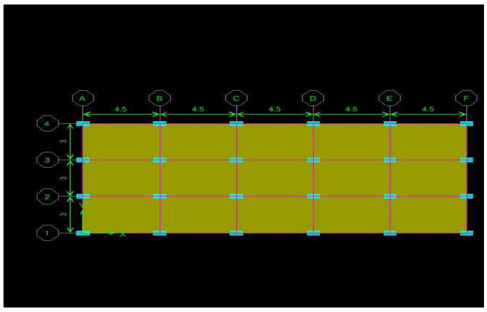

Fig 7.2: Plan of the soft storey buildings

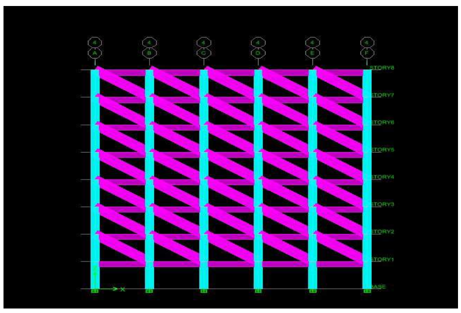

Fig 7.3: Model I

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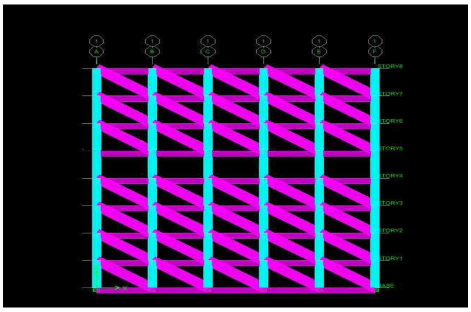


Fig 7.4: Model II

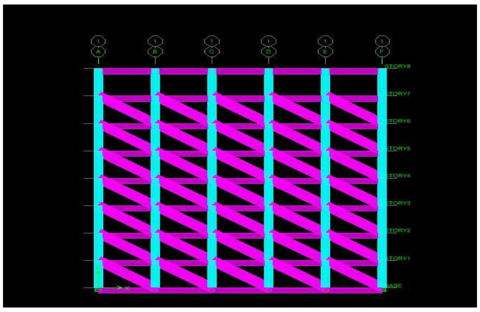


Fig 7.5: Model III

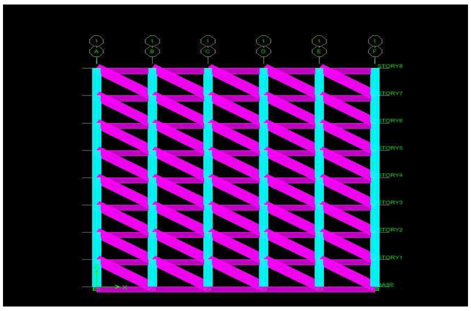


Fig 7.6: Retrofitting Model (RM 1)

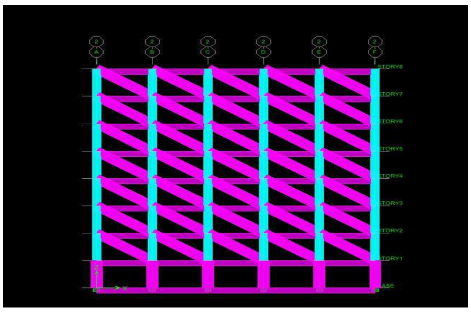


Fig 7.7 Retrofitting Model (RM)

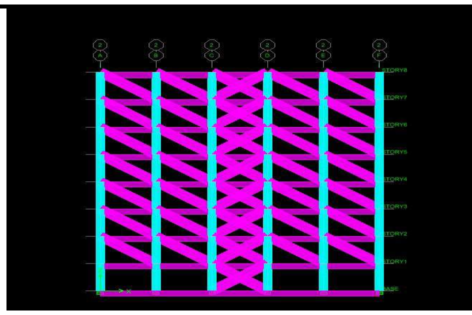


Fig 7.8: Retrofitting Model (RM 3)

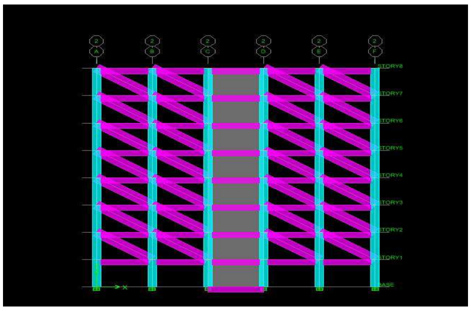


Fig 7.9: Retrofitting Model (RM 4)

B. *Base Reaction and Roof Displacement at the Performance Point*

The design base shear for models obtained from manual calculation match with those obtained by using ETABS analysis, which validates the models in ETABS, can be used for further analysis. Base shear and roof displacement at performance point for ideal soft storey building and retrofitting building models is calculated as shown in table 7.1.

The Seismic Performance Evaluation is comprises of comparison between some of the 'demand' that earthquake places on Structure to measure of the 'capacity' of the building to resist. Base Shear (total horizontal force at the lower level of the building) is the normal parameter that is used for this purpose. The Base Shear demand that would be generated by a given earthquake or intensity of ground motion and compare this to the base shear capacity of the building.
It observed that the base reaction and displacement at performance point in soft storey building models that base reaction is more in model I as compare to models II and model III when earthquake in X -direction. Whereas in Y –direction base reaction and displacement at performance point that in model III and model I respectively. When these models are compared with retrofitting models their performance is more, in resisting maximum base shear with less roof displacement. For better compatibility graphs are shown in below fig 7.1 & 7.2 respectively.

TABLE 7.1: Performance Of The Soft Storey And Retrofitting Buildings

| Models | Performance point | | | |
|---|---|---|---|---|
| | Base reaction at collapse(KN) | | Displacement at collapse(M) | |
| | X | Y | X | Y |
| I | 7415.653 | 5300.320 | 0.014 | 0.033 |
| II | 6233.260 | 5107.151 | 0.012 | 0.025 |
| III | 6991.209 | 5997.358 | 0.011 | 0.023 |
| RM 1 | 7282.857 | 6249.051 | $9.33X10^{-3}$ | 0.018 |
| RM2 | 7585.373 | 5871.420 | 0.011 | 0.023 |
| RM3 | 7383.237 | 6891.625 | 0.011 | 0.022 |
| RM4 | 8257.170 | 7557.137 | $8.35X10^{-3}$ | 0.018 |

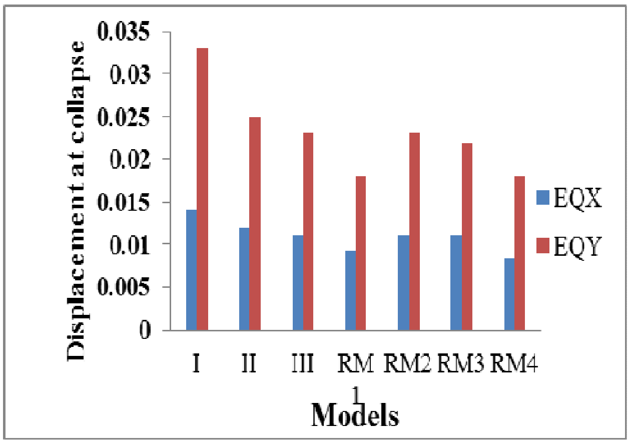
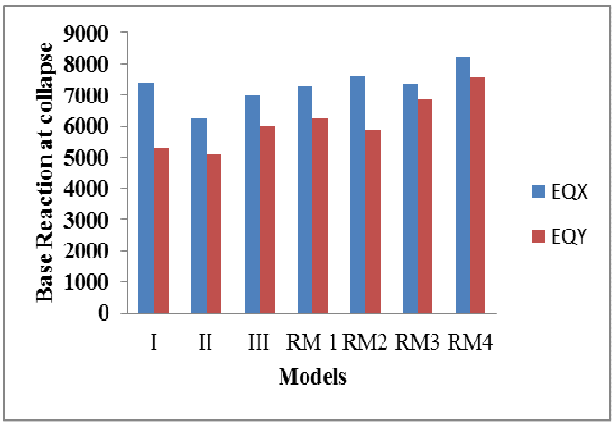



Fig 7.10: Base reaction at collapse

Fig 7.11: Displacement at collapse




C. *Lateral Displacements or Storey Drift*

The lateral displacement of models considered for study is the displacement of centre of mass. The maximum displacement at each floor level with respect to ground for all models along X and Y directions obtained from pushover analysis are shown in Tables 7.2. For better comparability the displacement for each model along X and Y-directions of ground motion are plotted in graphs as shown in Fig 7.3 & Fig7.4.

It observed both in X and Y direction of earthquake that storey drift in model I, model II, and model III which are having soft storey at ground, intermediate and top storey as a soft storey. The maximum values of storey drift is found at the soft storey itself then it goes on decrease to the top. When the soft storey values compared with retrofitting models, where it is maximum at the lower storey and gradually it decrease to the top storey in all retrofitted models as shown in above table 7.2. In overall comparison, storey drifts in retrofitting model about 50% less than the soft storey buildings.

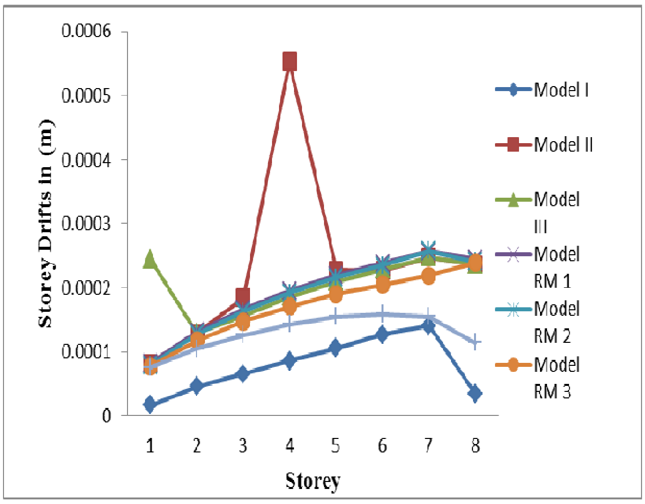



Fig 7.12: Storey drifts comparison in (EQX)

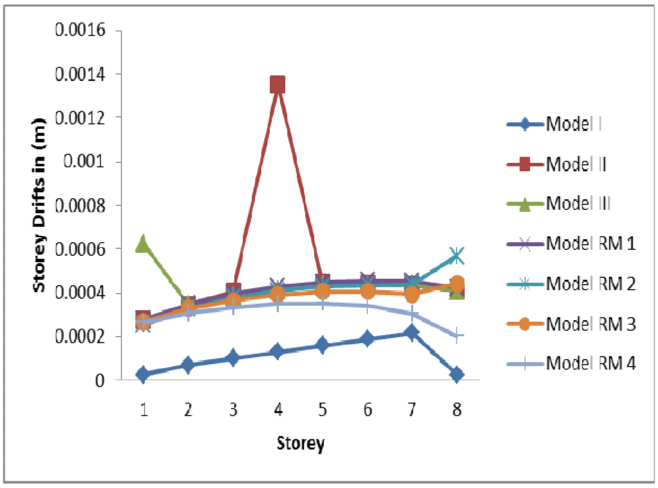



Fig 7.13: Storey drifts comparison in (EQX)

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TABLE 7.2: Storey Drifts Comparison in (EQX)

| Storey | Storey Drift(m) in X (EQX) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Model I** | **Model II** | **Model III** | **Model RM 1** | **Model RM 2** | **Model RM 3** | **Model RM 4** |
| 8 | 0.000017 | 0.000083 | **0.000244** | 0.000083 | 0.000079 | 0.000078 | 0.000076 |
| 7 | 0.000046 | 0.000129 | 0.000130 | 0.000131 | 0.000128 | 0.000118 | 0.000105 |
| 6 | 0.000066 | 0.000184 | 0.000157 | 0.000166 | 0.000163 | 0.000148 | 0.000126 |
| 5 | 0.000086 | **0.000553** | 0.000186 | 0.000195 | 0.000192 | 0.000171 | 0.000143 |
| 4 | 0.000106 | 0.000228 | 0.000210 | 0.000219 | 0.000216 | 0.000190 | 0.000155 |
| 3 | 0.000127 | 0.000227 | 0.000229 | 0.000238 | 0.000235 | 0.000205 | **0.000159** |
| 2 | **0.000141** | 0.000247 | 0.000247 | **0.000257** | **0.000258** | 0.000219 | 0.000155 |
| 1 | 0.000035 | 0.000236 | 0.000236 | 0.000245 | 0.000241 | **0.000239** | 0.000114 |

TABLE 7.3: Storey Drifts Comparison in (EQY)

| Storey | Storey Drifts (m) in Y (EQY) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Model I** | **Model II** | **Model III** | **Model RM 1** | **Model RM 2** | **Model RM 3** | **Model RM 4** |
| 8 | 0.000026 | 0.000275 | **0.000625** | 0.000277 | 0.000257 | 0.000269 | 0.000265 |
| 7 | 0.000070 | 0.000346 | 0.000343 | 0.000349 | 0.000329 | 0.000328 | 0.000307 |
| 6 | 0.000100 | 0.000405 | 0.000382 | 0.000395 | 0.000376 | 0.000366 | 0.000334 |
| 5 | 0.000129 | **0.001352** | 0.000414 | 0.000428 | 0.000409 | 0.000392 | 0.000351 |
| 4 | 0.000159 | 0.000445 | 0.000434 | 0.000448 | 0.000429 | 0.000405 | **0.000354** |
| 3 | 0.000189 | 0.000440 | 0.000441 | **0.000455** | 0.000436 | 0.000405 | 0.000340 |
| 2 | **0.000217** | 0.000436 | 0.000436 | 0.000451 | 0.000440 | 0.000393 | 0.000305 |
| 1 | 0.000026 | 0.000408 | 0.000408 | 0.000422 | **0.000568** | **0.000442** | 0.000203 |

### *D. Hinge Status at Performance Point*

Performance point determined from pushover analysis is the point at which the capacity of the structure is exactly equal to the demand made on the structure by the seismic load. The performance of the structure is assessed by the state of the structure at performance point. This can be done by studying the status of the plastic hinges formed at different locations in the structure when the structure reaches its performance point. It is therefore important to study the state of hinges in the structure at performance point. The status of hinges at performance point for different models considered for the analysis.

From BELOW TABLE 7.5 table it is observed that in soft storey models, most of the hinges are formed at reasons at IO-LS, LS-CP and C-D and some of hinges at D-E, which indicates the failure of those elements so the structural elements required to retrofitting. Whereas in retrofitting models it observed that hinges formed at reasons IO-LS, LS-CP, and C-D and some hinges at D-E, is less.

## VIII CONCLUSIONS

Based on the present study following conclusions are drawn.

1) Performance of the soft storey buildings, it is observed that soft fist storey has more base reaction and more roof displacement compare to all other models. Storey drift values for soft storey models maximum values is attained at soft storey itself when compare to other storey's. Then the values of storey drift decreases gradually up to the top. Whereas in retrofitting models story drift is uniform compare to existing models.
2) The building studied plastic hinges are more at the soft storey only. Plastic hinges formed in retrofitting model are less compared to existing soft storey models.
3) The overall performance of retrofitting model is more compare existing models both in base reaction and roof displacement. Among four retrofitting models, RM4 model has more performance in base reaction and roof displacement compare to other retrofitted models.

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