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REDUCTION OF LATERAL STIFFNESS DUE TO SOFT STOREY OF MULTI STOREY INFILLED FRAME

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الملخص العربى:

الهدف من البحث هو دراسه سلوك الجساءه الأفقية للمنشئات الخرسانية ذات جدار البناء المتعددة الطوابق تحت تأثير الزلازل مع الأخذ في الاعتبار وجود الطابق اللين و التي تعد من الدراسات الاكثر شيوعا حاليا و لهذا تم اجراء هذا البحث بهدف عمل دراسه خطيه و غير خطيه لهذه المباني باستخدام الطرق المختلفه للتحليل.
لذلك فقد تم دارسه العديد من النماذج مع الاخذ في الاعتبار جدار البناء تحت تأثير احمال الزلازل الافقيه لتحديد سلوك المنشأ تحت ظروف مختلفة من حيث اماكن وجود الطوابق اللينه و العناصر الانتشائية المستخدمة.

Abstract:

This study is to investigate the dynamic behavior of multi – storey rc masonry infilled frames with soft stories , noting that the study have been done with considering different levels for soft story as well as different structural system elements have been introduced to the model and designed according to the Egyptian Code. In order to present the stiffness and structural action of masonry infill walls, single equivalent strut method has been used. The seismic loads have been considered by two methods static and dynamic load (Response Spectrum). Ansys and Etab the main software have been used for the structural analysis models in the research. Storey displacements, drifts, shear storey , stiffness, overturning moments and straining actions are main parameters have been studied and analyzed in the research. The results obtained from the analysis for bare frame model tend to highly deviate from the results of other models confirming the usefulness and necessity of considering masonry infill wall action. Moreover, the absence of masonry infill action, i.e. existence of open or soft storey, causes significant and substantial changes in the obtained storey responses. After the analysis and as per the results

obtained for the structural analysis models the masonry infill have a severe impact in the structural analysis as well as the shear wall introduced to the model have a significant impact to the results, which will lead to cost saving due to the optimization in the structural elements can be done.
Key Words — masonry infill walls, single diagonal strut, soft storey, response spectrum analysis, time history analysis, moment resisting frame, ETABS programme, Ansys programme

I. INTRODUCTION

Recently, an urgent needed to use the new greener material instead of concrete requires two main characteristics;

Although the brick walls, usually used as an architectural partition in RC frame design, don't cause a lot of effects on the dead and/or live vertical loads, as well as for the lateral loads (wind or earth quicks loads).

These lateral forces can produce the critical stress in a structure, set up undesirable vibrations, and in addition, cause lateral sway of the structure which can reach a stage of discomfort to the occupants. In 1997 Uniform Building Code (UBC) [1] and several other codes (such as IBC-2003 [2] and ASCE-2002 [3]) define the soft storey as the floor of about 70% less stiffness than the floor above it. It also has inadequate shear resistance and ductility to resist the earthquake forces.

These features are highly undesirable in buildings that are constructed in seismically active areas. IS 1893:2002 [4] defines the soft story as the "one in which the lateral stiffness is less than 70% of that in the story immediately above, or less than 80% of combined stiffness of three stories above. The objectives of this thesis are discovering the effect of the existing of the soft storey, and analysis of the structure with and without soft storey, with variable resisting systems for the lateral loads.

The study performed to achieve the following main objectives:

- Simulate the structural action, stiffness of masonry infill walls and, also the effect of masonry infill walls on structural response.
- Discovering the efficiency of variable resisting systems to the lateral loads.
- Investigating the parameters that may significantly affect the response of the considered building models.
- Effect of the infill masonry on the stiffness of the 2-D frames in resisting the lateral loads.
- Investigate the single strut tie method equation accuracy.

II. Masonry Infill simulation using macro model method

The masonry infill has been represented in the model using macro model method, noting that we have 3 cases for different struts included in the model as follows:

- Case 1: where the face dimension of the columns at both sides is 600mm and the span is 6m, taking the infill layout from center column to center column as shown in Fig.1.

- Case 2: Where one column is 300mm and the other is 300mm in face dimensions and the span is 4m, taking the infill layout from center column to center column as shown in Fig. 2.
- Case 3: Where one column is 600mm and the other is 300mm in face dimensions and the span is 4m. Additionally they are located at corners. Taking the infill layout from center column to center column as shown in Fig. 3

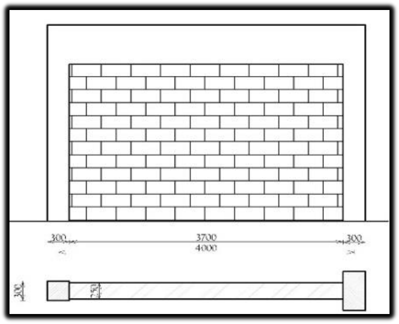

Figure. 1 (Case-1)

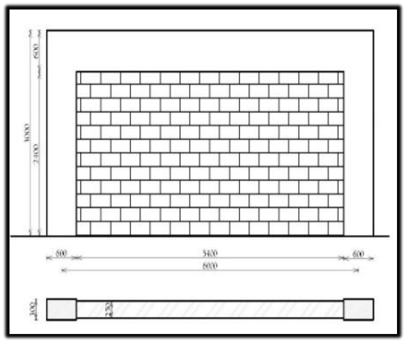

Figure. 2 (Case-2)

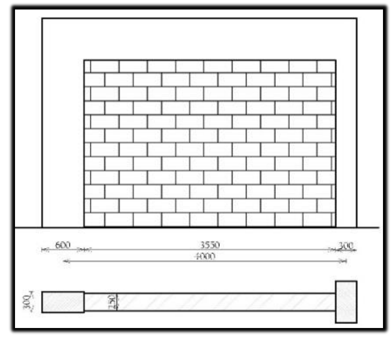

Figure. 3 (Case-3)

The following are parameters according to the orientation of the columns, geometry and dimensions of the model where:

- **L_{inf}** : Length of the infill. **L_{inf}** (1) : 5,400 mm , **L_{inf}** (2) : 3,700 mm , **L_{inf}** (3) : 3,550 mm
- **H_{col}** : Height from center column to center column. **H_{col}** : 3,000mm
- **H_{inf}** : Height of the infill. **H_{inf}** : 2,400mm

To get the respective angle according to the orientation of the column, right angle rule is used where:

$$tan\emptyset = \frac{Opposite}{Adjacent} = \frac{\text{Hinf}}{\text{Linf}}$$

$$\emptyset_1 = tan^{-1}\left(\frac{2400}{5400}\right) = 23.96^{\circ} \qquad \emptyset_2 = tan^{-1}\left(\frac{2400}{3700}\right) = 32.97^{\circ} \qquad \emptyset_3 = tan^{-1}\left(\frac{2400}{3550}\right) = 34.06^{\circ}$$

Following are the respective moment of inertia for each column orientation:

$$I = \frac{1}{12}\, bh^3$$

$$I_1 = \frac{1}{12} * 0.6 * 0.3^3 = 1.35 * 10^{-3}\, m^4 \qquad I_2 = \frac{1}{12} * 0.3 * 0.6^3 = 5.4 * 10^{-3}\, m^4 \qquad I_3 = \frac{1}{12} * 0.6 * 0.3^3 = 1.35 * 10^{-3}\, m^4$$

To calculate the length of the diagonal infill, the following formula is used:

$$r_{inf} = \sqrt{(\text{Linf})^2 + (\text{Hinf})^2}$$

$$r_{inf1} = \sqrt{(5.4)^2 + (2.40)^2} = 5.91 \qquad r_{inf2} = \sqrt{(3.7)^2 + (2.40)^2} = 4.41 \qquad r_{inf3} = \sqrt{(3.5)^2 + (2.40)^2} = 4.24$$

To calculate the coefficient which is used in calculating the equivalent width of the infill strut, the following formula is used:

$$\boldsymbol{\lambda_1} = \left[\frac{E_{me} * t_{inf} * \sin 2\emptyset^{\circ}}{4\, E_{fe} * I_{col} * h_{inf}}\right]^{\frac{1}{4}}$$

$$\boldsymbol{E_{me}} = 5.5\ GPa\ , \boldsymbol{t_{inf}} = 0.25m\ , \boldsymbol{E_{fe}} = 24\ GPa$$

$\boldsymbol{\lambda_1} = \left[\frac{5.5*0.25*\sin 2*23.96^{\circ}}{4*24*(1.35*10^{-3})*2.40}\right]^{\frac{1}{4}} = 1.34$ $\boldsymbol{\lambda_2} = \left[\frac{5.5*0.25*\sin 2*32.97^{\circ}}{4*24*(5.4*10^{-3})*2.40}\right]^{\frac{1}{4}} = 1.00$ $\boldsymbol{\lambda_3} = \left[\frac{5.5*0.25*\sin 2*34.06^{\circ}}{4*24*(1.35*10^{-3})*2.40}\right]^{\frac{1}{4}} = 1.42$

Finally, to calculate the thickness (Equivalent width) of the strut, the following formula is used:

$$\boldsymbol{\alpha} = 0.175 * (\lambda * \mathrm{Hcol})^{-0.4} * r_{inf}$$

$$\boldsymbol{\alpha_1} = 0.175 * (1.34 * 3)^{-0.4} * 5.91 = 0.593\text{ m} \quad \boldsymbol{\alpha_2} = 0.175 * (1.00 * 3)^{-0.4} * 4.41 = 0.497$$

$$\boldsymbol{\alpha_3} = 0.175 * (1.42 * 3)^{-0.4} * 4.24 = 0.416\text{ m}$$

III. ETAB MODELING (LINEAR ANALYSIS)

The system considered in this study is building of 17 floors designed according to Egyptian Code/standards. In order to investigate the behavior of the buildings with infill and without as well as different soft stories in terms of locations. Additionally, shear wall have been added to the models to check the enhancement will be occurred in the stiffens of the floors.

The floor plan in the building model has ten bays of 60 m in X-direction and eight bays of 32m in Y-direction (please refer to below figure 4)

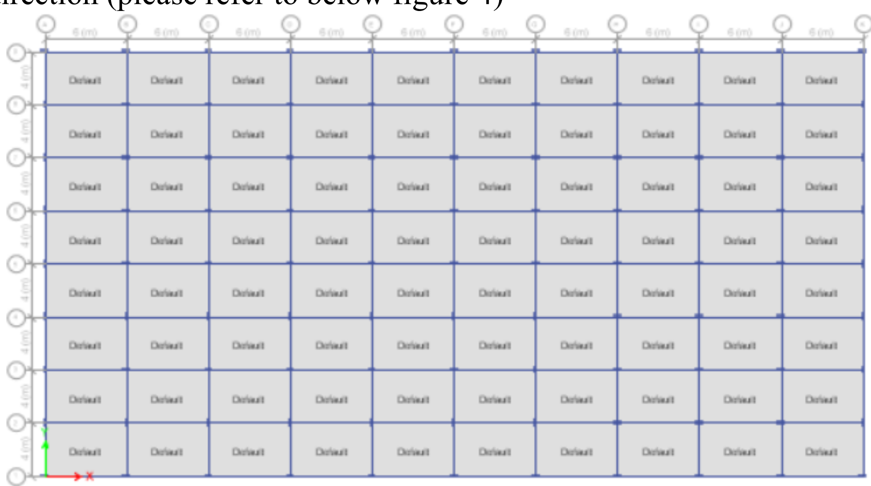

Figure 4: Typical floor plan of the storey frame building X

The selected plan is symmetric in both directions X and Y in order to avoid torsional response due to irregularity. The slab thickness considered is 140mm and concrete columns 300 * 600 mm in from base to final floor without reduction. The concrete beams sections are 300*600 mm in all floors. The floor height considered in the model is 3m.

The following are the parameters of the material used in the model:

$\boldsymbol{\Upsilon_c}$ = 25KN/m3, $\mathbf{E_c}$ = 24,099 N/mm2, $\boldsymbol{\Upsilon_m}$ =20 KN/m3 , $\mathbf{E_m}$ = 5500 N/mm2 , $\mathbf{t_m}$= 250 mm ,

υ_m= 0.15, υ_c= 0.2 , υ_s= 0.3

Section modifiers for ultimate limit state analysis for line object as follow

Columns I22=I33= 0.7 **Beams I22=I33**= 0.35

Shear wall f11=f22=f12=m11=m22=m12= 0.7 cracked or 0.35 un-cracked

Following models are analyzed in ETABS as special moment resisting frame using response spectrum analysis and time history analysis.

Model (1)	Bare frame system
Model (2)	Full Infilled frame
Model (3)	Full Infilled frame with soft storey at top level
Model (4)	Full Infilled frame with soft storey at top and bottom levels
Model (5)	Full Infilled frame with soft storey at top and bottom levels with shear wall (L-shape)
Model (6)	Full Infilled frame with soft storey at top and bottom levels with shear wall (T-shape)
Model (7)	Full Infilled frame with soft storey at top and bottom levels with shear wall (swastika – shape)
Model (8)	Full Infilled frame with soft storey at top and bottom levels with shear wall (U -shape)
Model (9)	Full Infilled frame with soft storey at top and bottom levels with shear wall (I -shape)
Model (10)	Full Infilled frame with soft storey at top and bottom level with shear wall
Model (11)	Infilled frame with soft storey at 5th floor
Model (12)	Infilled frame with soft storey at 8th floor
Model (13)	Infilled frame with soft storey at 14th floor
Model (14)	Infilled frame with soft storey at 5th floor with swastika shear wall at corners

The main parameters and results will be investigated are :

- Drift of each storey for all different models due to earthquake.

  From the results we have noticed that the masonry infill has a sever improvement in the drift of the floors except the soft stories which have a big drifts value, however these values have not exceeded the bare frame values.

  Additionally, from the results the shear wall has enhanced the drift values as well.

- Displacement of each storey for all different models due to earthquake.

  The maximum displacement occurred in the bare frame model having more than 140 mm displacement in storey 17. On the other hand, the minimum displacement occurred in model 7 which has swastika shear walls at the corners. Similar results to model 7 occurred in model 14 which has a soft storey in floor 5 and swastika shear walls at corners. A slight break occurs at soft storeys in model 11, 12 and 13. All other models shows a constant increase along ascending storeys going from bottom to top.
- Storey shear of each storey for all different models due to earthquake.

  The figure under dynamic RS analysis and when masonry infill was not considered in the analysis (i.e., bare frame model case) the response in terms of storey shear forces shows transmission of smaller shear forces to the base and superstructure than those transmitted to the building model with masonry infill.

  The presence of soft storey at base or at any other level generally decreases the transmitted shear forces to the floors of the building models compared to masonry infill frame model.
- Overturning moment of each storey for all different models due to earthquake.

  As can be seen, ignoring the masonry infill wall action underestimates the obtained bending moments which is considered as one of the main parameters during design stages, and hence may lead to unsafe design.

  The induced overturning moments for the framed building model with fully masonry infill walls and those having soft storeys at different locations show insignificant changes in the obtained values at higher storeys. However, the change in peak moments is pronounced at lower stories.

- Storey Stiffens of each storey for all different models due to earthquake.

  a major difference between the cases of considering masonry infill walls and the case of bare frame in which modeling of masonry infill is ignored.

  It can be observed from the figures that the case of ignoring infill panel (i.e., bare frame model case) show significantly underestimate stiffness values compared to those obtained by the other considered cases.

  The provision of masonry infill panel at any storey lead to increase the stiffness of that storey than the other stories that masonry infills panels not considered.

  The stiffness values for a building model with soft storey almost show values like those obtained considering masonry infill actions except at the location of soft storey where a significant decrease in the stiffness can be observed.

  According to models with soft storey at different level, it can be observed that the relative minimum stiffness values located at the storey which have no infill wall panels. This should result in the building is vulnerable to collapse at this soft storey which consider the weakest floor at the buildings.
- Straining actions (shear and bending moment) and its distribution to columns and

beams due to earthquake.

An obvious different between the bare frame model and all the other models, where struts and shear walls are taken into considerations. The stiffness in the bare frame is the weakest amongst all other models and this is obvious as it does not include any struts or shear walls. Also, it appears to be constant along the storeys from the 2nd storey to the top of the 17th. The maximum stiffness occurred in model 14 model having around 45000000 kN/m stiffness in storey 1 then it starts decreasing along the top storeys. In the models where there is no soft storey, a similar behavior is occurred where a very sudden increase in stiffness occurs in storey 1 then gets decreased with higher storeys. The stiffness is decreased at storey 1 in the following order: model 7,5,6,8,10,13 and 4 On the other hand, the minimum stiffness occurs in the bare frame model. Models with soft storeys showed similar behavior where a decrease in stiffness takes place in the soft storey and then starts increasing.

IV. RESULTS AND DISCUSSION

- Bare frame model yields higher drift values as compared to other models.
- Model with bottom soft storey have got highest storey drift values at soft stories levels, which leads to dangerous sway mechanism. Therefore providing shear wall is essential so as to avoid soft storey failure.
- There is considerable reduction in drift for models with shear wall.
- It is observed that swastika shape shear wall has least drift compared to other models in both the directions for all three analysis.
- Building with top soft storey does not showed any effect in drift when subjected to seismic loading.
- Storey drifts are found within the limit as specified by code (IS 1893-2002 Part-1).
- Effect of water tank at top soft storey is very much less during seismic lateral loading.
- Storey acceleration is maximum for model 7 along X direction for RSA and THA.
- It is concluded that inclusion of masonry infill and concrete shear wall will increase the strength and stiffness of the structure.

V. CONCLUSION

- Bare frame model (Model 1) yields higher drift values as compared to other models.
- Model with bottom soft storey have got highest storey drift values at soft stories levels, which leads to dangerous sway mechanism. Therefore providing shear wall is essential so as to avoid soft storey failure.
- There is considerable reduction in drift for models with shear wall when compared to Model 4.
- It is observed that swastika shape shear wall (Model 7) has least drift compared to other models in both the directions for all three analysis.
- Building with top soft storey does not showed any effect in drift when subjected to

seismic loading.

- Storey drifts are found within the limit as specified by code (IS 1893-2002 Part-1).
- Effect of water tank at top soft storey is very much less during seismic lateral loading.
- Storey acceleration is maximum for model 7 along X direction for RSA and THA.
- It is concluded that inclusion of masonry infill and concrete shear wall will increase the strength and stiffness of the structure.

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