

Effect of soft storey on multistoried reinforced concrete building frame

M.R. Amin

Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

P. Hasan

University of Asia Pacific, Dhaka, Bangladesh

B.K.M.A. Islam

Bangladesh Water Development Board

ABSTRACT: In an attempt to investigate the effect of soft storey for multistoried reinforced concrete building frame, four building models (3, 6, 9 and 12 storey) with identical building plan were analyzed. Equivalent diagonal struts were provided, as suggested in FEMA-273, in place of masonry to generate infill effect. Earthquake load was provided at each diaphragm's mass centre as a source of lateral load as set forth by the provision BNBC (1993). Soft storey level was altered from ground floor to top floor for each model and equivalent static analysis was carried away using ETABS 9.6.0 analysis package. Results show a general changing pattern in lateral drift irrespective to building height and location of soft storey. Inter-storey drift ratio was found increasing below the mid storey level and maximum ratio was obtained where the soft storey was located. The rate of increase in drift ratio at any particular floor (kept soft) for different building height increases linearly from bottom to top floor. As the building height increases, location of soft storey goes downwards from mid storey level to produce maximum lateral drift.

1 INTRODUCTION

Reinforced concrete frames with masonry infills are a popular form of construction of high-rise buildings in urban and semi urban areas around the world. The term infilled frame is used to denote a composite structure formed by the combination of a moment resisting plane frame and infill walls. The masonry can be of brick, concrete units, or stones. The behavior of masonry in filled frame structures has been studied in the last four decades in attempts to develop a rational approach for design of such frames (Al-Chaar, 2002). Present code of practice does not include provision of taking into consideration the effect of infill. It can be understood that if the effect of infill is taken into account in the analysis and design of frame, the resulting structures may be significantly different. Therefore, a study is undertaken which will involve the finite element analysis of the behavior of reinforced concrete (RC) frame with brick masonry infill. Again when a sudden change in stiffness takes place along the building height, the story at which this drastic change of stiffness occurs is called a soft story. According to BNBC (1993), a soft story is the one in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stores above. Social and functional needs like vehicle parking, shops, reception etc are compelling to provide soft storey in high rise building. Soft storey can form at any level of a high rise building to fulfill required functional necessity and serve various purposes. The common practice of building design considers infill as non structural elements and building is designed as framed structures without regard to structural action of masonry infill walls. The soft storey effect and presence of infill in any building changes the behavior of frame action due to the relative changes of stiffness and lateral load distribution mechanism and thus may induce changes in phenomenon like lateral displacement and inter-storey drift ratio.

In the present study, seismic performance of 3D building frame with intermediately infilled frame was studied. Performance of R.C. frame was evaluated varying storey level and location of the soft storey. The main objective of the study was to investigate the behavior of multistory, multi-bay soft storey infilled frames and to evaluate their performance levels when subjected to earthquake loading.

2 BUILDING STUDIED

The typical building plan layout of 3D reinforced concrete moment resisting building frame was studied as shown in Fig 1. The building is deliberately kept symmetric in both orthogonal directions in plan to avoid torsional response under pure lateral forces. Further, the columns are taken to be square to keep the discussion focused only on the soft storey effect, without being distracted by the issues like orientation of columns. Number of storey was varied from three, six, nine and twelve but the plan was unaltered. The effect of unreinforced masonry infill was generated using equivalent strut model according to FEMA-273 (1997) and FEMA- 306 (1999). Soft storey level was altered for every storey level and then analysis was performed. The soft storey effect was produced by providing no infill in a particular storey level, whereas other level had proper infill effect.

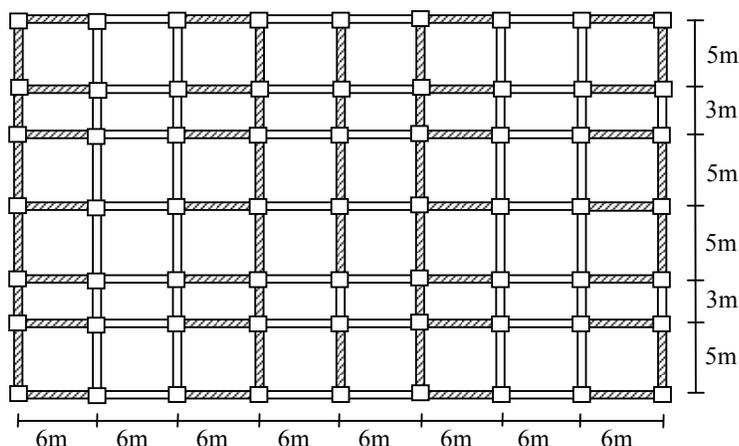


Figure 1. Typical Building Plan of three, six, nine and twelve storied building

3 DESCRIPTION OF STRUCTURAL MODEL

Significant experimental and analytical research is reported in the literature since four decades, which attempts to understand the behavior of infilled frames. Different types of analytical models based on the physical understanding of the overall behavior of an infill panels were developed over the years to mimic the behavior of infilled frames. The available infill analytical models can be broadly categorized as i) Macro Model and ii) Micro models. The single strut model is the most widely used as it is simple and evidently most suitable for large structures (Das and Murthy, 2004). Thus RC frames with unreinforced masonry walls can be modeled as equivalent braced frames with infill walls replaced by equivalent diagonal strut which can be used in rigorous nonlinear pushover analysis. Using the theory of beams on elastic foundations (Smith et al, 1969) suggested a non dimensional parameter to determine the width and relative stiffness of diagonal strut. Mainstone (1974) suggested another model representing the brick infill panel by equivalent diagonal strut. FEMA- 273 adopted Mainstone (1974) suggested model to calculate strut area which was followed here. According to FEMA-273 and FEMA-306, the strut area A_c is given by following expression

$$A_s = \alpha t_{inf} \quad (1)$$

$$\alpha = 0.175(A_1 I_{col}) - 0.4 r_{inf} \quad (2)$$

$$A_1 = \left[\frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fc} I_{col} h_{inf}} \right]^{\frac{1}{4}} \quad (3)$$

where a = equivalent width of infill, in; h_{col} = column height between centerlines of beams, in; h_{inf} = height of infill panel, in. E_{fc} = expected modulus of elasticity of frame material, psi; E_{me} = expected modulus of elasticity of infill material, psi; I_{col} = moment of inertial of column, in⁴; r_{inf} = diagonal length of infill panel, in; t_{inf} = thickness of infill panel and equivalent strut, in and θ = angle whose tangent is the infill height-to-length aspect ratio, radians.

$$\theta = \tan^{-1} \left(\frac{h_{inf}}{L_{inf}} \right)$$

where L_{inf} = Length of infill panel, in.

In this study, four different models for three, six, nine and twelve storey building symmetrical in the plan was considered. Usually in a building 40% to 60% presence of masonry infills are effective as the remaining portion of the masonry infills are meant for functional purpose such as doors and windows openings (Pauley and Priestley, 1992). In this particular study, buildings were modeled using 40 % masonry infills in an arrangement as shown in the Fig 1.

4 PROPERTIES OF BUILDINGS

In modeling plane frame, the following material properties and geometrical properties was used for beam, columns, masonry infill. Normal weight concrete was chosen for finite element analysis of building frames. Value of elastic moduli of concrete and masonry was 24,820 MPa and 700 MPa respectively. Poisson's ratio

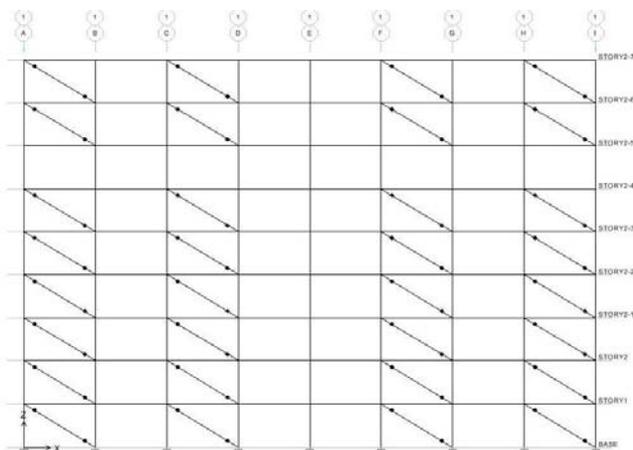


Figure 2. A Nine Storied Building Frame with soft storey at 7th floor

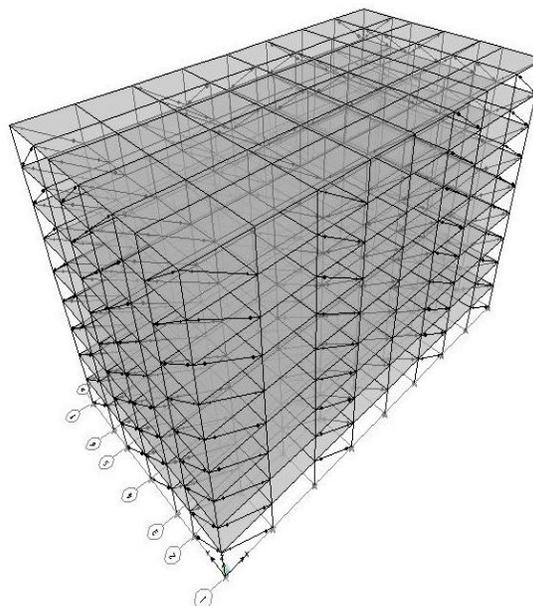


Figure 3. 3D view of a Nine Storied Building Model

was 0.2 and 0.3 respectively for concrete and masonry. The unit weights of concrete and masonry was taken as 23.56 kN/m³ and 18.88 kN/m³. The floor finish and random wall on the floors are 1 kN/m². The live load on floor was taken as 1 kN/m². All beams and columns had same cross-sectional area e.g. 45 cm × 30 cm and 70 cm × 70 cm respectively. Infill walls and slabs were modeled as 20 cm and 15 cm thick respectively throughout all the building models.

5 ANALYSIS OF BUILDING

Linear elastic analysis was performed for the nine models of the building using ETABS 9.6.0 analysis package. The frame members were modeled with rigid end zones, the walls were modeled as equivalent struts, and the floors were modeled as diaphragms rigid in-plane. Linear elastic analyses of the building were carried out using the equivalent static method. This method was appropriate as the building is vertically regular, and modal analyses show that despite the presence of infill panels, the building could be classed as horizontally regular. In the present investigation, earthquake load was chosen as a source of lateral loading on the building frame as set forth by the provision of Bangladesh National Building Code (BNBC, 1993). The total share force due to the seismic load was applied in the centre of mass of all diaphragms with additional eccentricity ratio of all diaphragms. Earthquake load was applied at every storey level of individual models. Modeling of strut was carried out by releasing the end moment of the strut throughout the analysis period and thus simulating pin supported connection with strut and frame members as prescribed by FEMA-273.

6 LATERAL DRIFT AND INTER-STOREY DRIFT RATIO

Lateral drift and inter-storey drift are commonly used damage parameter in structural analysis. In this study, lateral drift of the 3D building frame was analyzed for earthquake load coming from long direction. Inter-storey drift was also evaluated and tabulated which is defined by

$$SDI = \frac{\delta_i - \delta_{i-1}}{h_i}$$

where, $\delta_i - \delta_{i-1}$ = relative displacement between successive storey and h_i = storey height.

7 RESULT AND DISCUSSION

From the models of three (3), six (6), nine (9) and twelve (12) storied buildings, data of lateral drift was collected for a particular 2D frame in long direction for seismic loading from that particular direction. Inter-storey drift ratio was calculated from lateral drift and compared for all building models. Changing pattern of lateral drift and inter-storey drift ratio was compared with building height and location of soft storey.

7.1 Drift pattern at different storey level:

More or less for all the buildings irrespective to their height and location of soft storey level, a general lateral pattern was generated. From Figure 3., Figure 4., Figure 5. and Figure 6., it can be remarked that initially the rate of drift is less as in the initial portion the curve is convex, the rate of drift then increases and the curve takes a concave shape at the middle portion, but in the end portion it takes convex shape again referring to a decrease in lateral drift at in the top floors. This pattern directly indicates the physical deflection shape of a building frame due to earthquake loading and it also indicates a higher rate of lateral deflection occurring at the middle portion of a building.

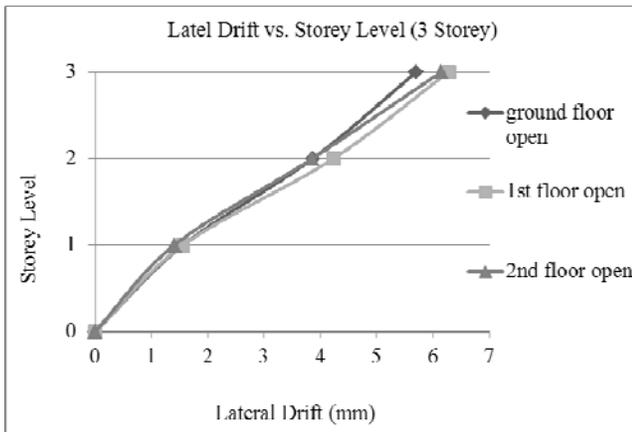


Figure 4. Total Lateral Drift of a Three (3) Storey Building

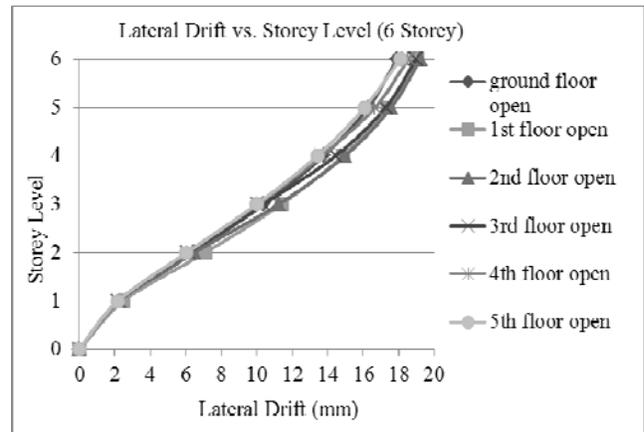


Figure 5. Total Lateral Drift of a Six (6) Storey Building

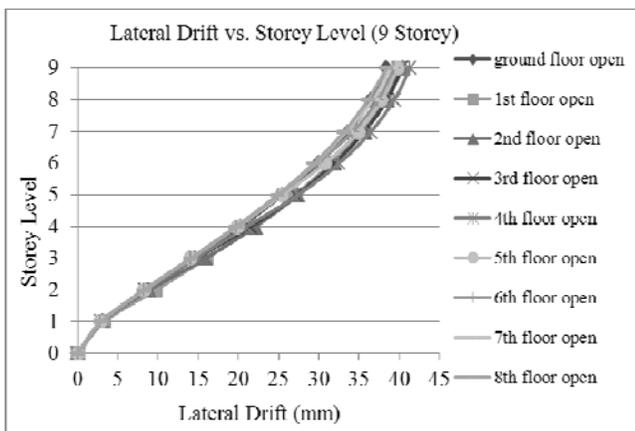


Figure 6. Total Lateral Drift of a Nine (9) Storey Building

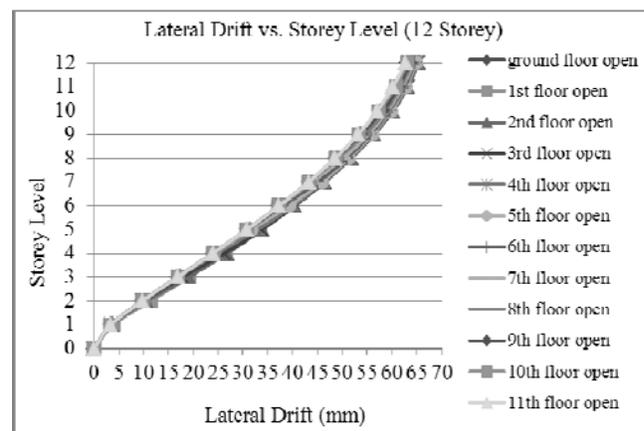


Figure 7. Total Lateral Drift of a Twelve (12) Storey Building

7.2 Inter-storey drift ratio at different storey level

Inter-storey drift ratio was plotted against storey levels for each location of soft storey. From Figure 7., Figure 8., Figure 9. and Figure 10., it can be concluded that inter-storey drift ratio increases at the middle stories and shows a parabolic pattern reaching maximum value between 2nd and 5th floor (for twelve storey). This pattern was found independent of the location of soft storey and building height. But for any particular floor level, maximum value was obtained when that particular floor was kept open. For a twelve storey building, if the 2nd and the 3rd floor is kept open then it shows an average of 18.2% and 17.6% more drift respectively at that floor level compared to drift at that level if other floors are kept soft. This feature is also prominent especially in the mid-storey zone and it also varies with the building height. Same values reduce to 17.1% and 16.6% respectively for 2nd and 3rd floor for a nine storey building. For the 6th and 7th floor these values are 16% and 15.5% respectively for twelve storey building and 15.2% and 14.7% for nine storey building.

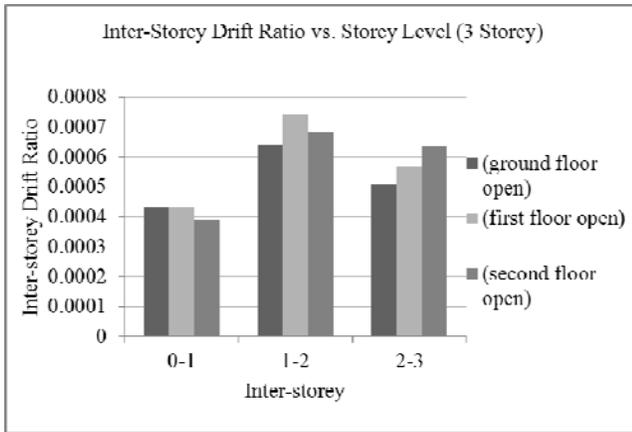


Figure 8. Inter-Storey Drift Ratio (Three Storey Building)

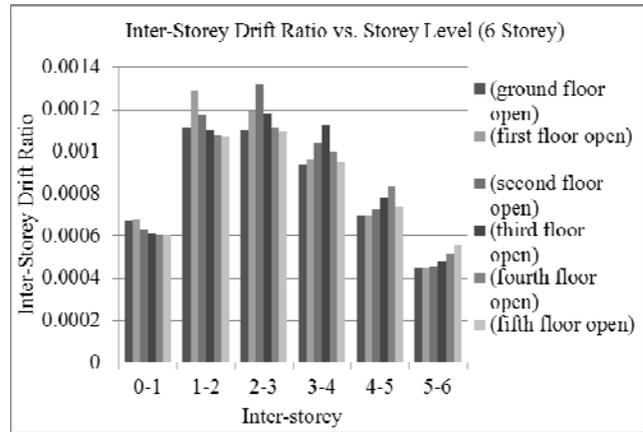


Figure 9. Inter-Storey Drift Ratio (Six Storey Building)

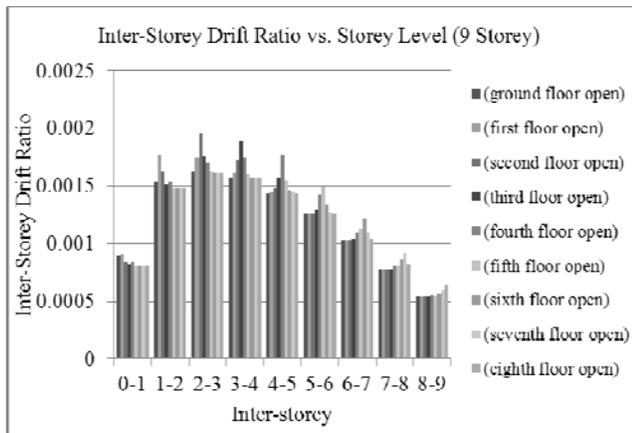


Figure 10. Inter-Storey Drift Ratio (Nine Storey Building)

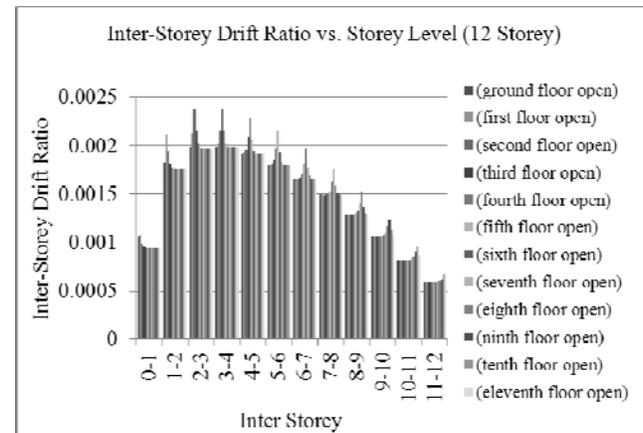


Figure 11. Inter-Storey Drift Ratio (Twelve Storey Building)

7.3 Inter-storey drift ratio and soft storey location

When all the soft storey's drift ratio data were plotted in a graph (Figure 11.), a regular distribution pattern was visible that shows a parabolic changing pattern supporting the analogy previously claimed and bolstering the fact that the drift ratio value are greater near the middle floor levels.

From Table 1. it can be concluded that the rate of increase in drift ratio at any particular floor (kept soft) for two different building height increases linearly from bottom to top floor. In the upper floors, drift ratio increases more rapidly in the taller structure if that floor is kept open.

7.4 Effect of location of soft storey on maximum lateral drift:

A trend line was plotted in an attempt to locate position of soft storey for maximum lateral drift (Figure 12.). From the plot, it is clear that for the location of soft storey below mid height, maximum lateral drift takes place. As the building height increases, location of soft storey goes downwards from mid storey level.

Table 1. Comparison of percent increase in drift ratio at different soft storey levels.

Comparison between buildings	Increase in height (%)	GF open (%)	1 st Floor open (%)	2 nd Floor open (%)	3 rd Floor open (%)	4 th Floor open (%)	5 th Floor open (%)	6 th Floor open (%)	7 th Floor open (%)	8 th Floor open (%)
3 and 6 Storey	100.00	55.10	74.26	107.83	-	-	-	-	-	-
6 and 9 Storey	50.00	33.04	37.69	47.77	67.46	112.40	168.07	-	-	-
9 and 12 Storey	33.33	17.51	18.85	21.44	25.76	28.63	43.29	60.90	91.08	133.96

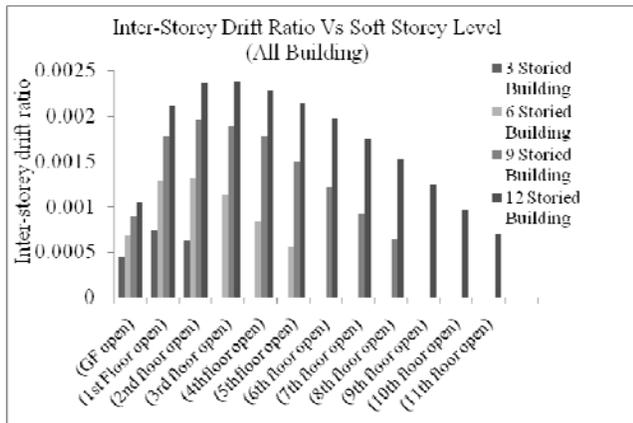


Figure 12. Inter-Storey Drift Ratio at soft storey (All Building)

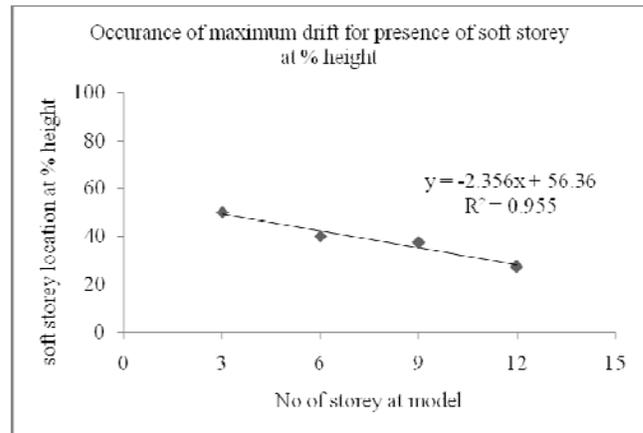


Figure 13. Maximum Drift for presence of soft storey at percent height Soft Storey location

8 CONCLUSION

This analysis is only a case study of a RCC building with a fixed amount of infill at a particular floor level. Detailed analysis could be performed using various percentages of infill in each floor level and different orientations considering soil-foundation-structure interaction.

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