A Comparative Study of Seismic Response of Flat Slab Structure and Conventional Structure

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Abstract - Flat slab is preferred as a floor system because of its architectural appearance, flexibility of flat slab RC structure, ease of construction and economy. However seismic vulnerability of flat slab building is inevitable fact. Flat slab building responds more to the earthquake loading in comparison with conventional structure. But the question is by what amount and whether it is within acceptable limits and if not what measures can be taken to reduce the seismic response of flat slab RC structure. This work aims to study seismic response of flat slab RC structure for building with variation in height as well as variation in plan.

Keywords – Dynamic analysis, Flat slab RC structure, Seismic response, Static analysis.

I. INTRODUCTION

A reinforced concrete slab is a broad, flat plate, usually horizontal with top and bottom surface parallel or nearly parallel. In conventional structures, frame construction essentially consists of columns, slab and beams. However it may be possible to undertake frame construction without providing beams. This type of frame is called flat slab RC structure.

Flat slab structure is preferred over conventional structure in construction due to their advantages in reducing storey height and construction period as compared with conventional structure, leading to reduction of construction costs. Flat slab are preferably provided with drops i.e. increased thickness of slab to provide adequate strength in shear and to reduce the amount perimeter of the critical section for shear and hence, increasing the capacity of the slab for resisting two way shear and to reduce negative bending moment at the support.

Because of change in configuration of flat slab, flat slab RC structures are essentially more flexible than conventional slab RC structure. Being flexible, flat slab RC structures are vulnerable under seismic excitation. It is well established from the previous works held on this topic that flat slab RC structures can be put into use for moderate height buildings even in seismic vulnerable areas. But with increase in height of such building, behavior of structure under seismic excitation needs to be analyzed. It is also to be seen that how the response of flat slab RC structure would be if variation in plan is met with.

The behavior of this type of structural systems with flat slab frames adopted as seismic resistant structure show some drawbacks, such as the non-dissipative features of their response to seismic excitation. Furthermore, flat slab building structures are comparatively more flexible than conventional RC frame structures, thus becoming more vulnerable under seismic excitations. Therefore, flat slab buildings constructed in earthquake prone areas demands that additional measures should be taken in order to reduce the seismic response of flat slab RC structure.

Methods of design of flat slab

There are two methods of design of flat slab

1. The direct design method
2. The equivalent frame method

The type of flat slab considered for the analysis is flat slab with drops and without column head. After design of flat slab, it is checked for the punching shear and depth turned out to be safe.

II. METHODS OF SEISMIC ANALYSIS

For seismic analysis purpose, both linear static analysis and linear dynamic analysis (Response Spectrum Analysis) is performed and results are presented separately.

B. Linear static analysis

Linear static analysis, also known as equivalent static analysis is preferred for moderate height buildings and dynamic analysis is performed for multistorey building. Since, the models analyzed in this work are both of moderate height and of high rise buildings, both linear static analysis and linear dynamic analysis is performed so as to put convenience in studying response. In this method, seismic response of structures is carried out on the principle of horizontal force assumed to be corresponding to the actual earthquake loading.

B. Linear dynamic analysis (Response Spectrum Method)

Response spectrum analysis represents an improvement over linear static analysis. The noteworthy difference between linear static and dynamic analysis is lies in the level of force and their distribution along the height of the structure being analyzed. In response spectrum method, the response of Multi-Degree-of-Freedom system is expressed as the superposition of modal response. Each modal response is then determined from the spectral analysis of Single-Degree-of-Freedom system. Both are then combined to work out total response.

III. PROBLEM FORMULATION, MODELLING AND ANALYSIS

For the purpose of analysis, following cases of multistorey buildings are considered,

Case 1)-

i. 10 storey conventional RC structure having plan dimensions 36m × 30m.
ii. 10 storey flat slab RC structure having plan dimensions 36m × 30m.
iii. 10 storey flat slab structure of same area as above but with opening at mid.

Case 2)-

i. 15 storey conventional RC structure having plan dimensions 36m × 30m.
ii. 15 storey flat slab RC structure having plan dimensions 36m × 30m.
iii. 15 storey flat slab structure of same area as above but with opening at mid.

Case 3)-

i. 20 storey conventional RC structure having plan dimensions 36m × 30m.
ii. 20 storey flat slab RC structure having plan dimensions 36m × 30m.
iii. 20 storey flat slab structure of same area as above but with opening at mid.

Above three cases i.e. 9 models are analyzed initially without any provision of shear wall to know how flat slab RC structure responds to earthquake loading in comparison with conventional one.

i. 10 storey flat slab building with shear wall.
ii. 15 storey flat slab building with shear wall.
iii. 20 storey flat slab building with shear wall.

Details of Modeling

i. Typical storey height for all the cases is 3m.
ii. Thickness of flat slab is 220mm and that of drop is 280mm.
iii. Thickness of shear wall is 150mm.
iv. Size of column varies from 350mm to 1.5m.
v. Size of beam for conventional structure varies from 300mm to 600mm.

Loading Details

i. Gravity loads- Gravity load includes dead load and live load imposed on the elements. In addition of the self weight of the elements, the superimposed load for all the floors except top is 1 kN/m^2 and that for top floor is 2kN/m^2. Live load for all the floors except at top is 3kN/m^{2}and that for top floor is 1.5kN/m^2. Superimposed load on all the beams except at top is 12kN/m and that for beams at top floor are 5kN/m.
ii. Earthquake loading-

a. Linear static analysis- The structures are assumed to be located in zone IV. The direction of earthquake excitation considered is X. Program calculated time period is assigned. Importance factor and response reduction factors are 1 and 5 respectively.

b. Response spectrum analysis- Square root of sum of squares (SRSS) method is used. Structural and function damping is 0.05. For this analysis also structures are assumed to be located in zone IV and direction of excitation considered is X.

IV RESULTS

1. Base shear comparison- Base shear is the total design lateral force VB along any principal direction, which is determined by following expression

$$V_B = A_h W$$

Where

A_h = Design horizontal acceleration spectrum

W = Seismic weight of building.

TABLE I BASE SHEAR COMPARISON

Model	Linear static analysis	Response spectrum analysis
Case 1- 10 storey building		
Conventional	2764.91 kN	2396.26 kN
Flat slab	1772.25 kN	1591.79 kN
Flat slab + opening	1682.90 kN	1516.32 kN
Case 2- 15 storey building		
Conventional	3963.94 kN	3339.52 kN
Flat slab	2978.21 kN	2556.87 kN
Flat slab + opening	2830.70 kN	2439.52 kN
Case 3- 20 storey building		
Conventional	6215.97 kN	4967.64 kN
Flat slab	4889.42 kN	3591.43 kN
Flat slab + opening	4646.84 kN	3555.44 kN

The comparison of base shear clearly shows the flexibility of flat slab RC structure in comparison with conventional one.

2. Storey drift-

Storey drift is the total lateral displacement that met in a single storey of a high-rise building. It is one of the predominantly important engineering response quantity and indictor of structural performance, in particular for multi-storey buildings. Storey drift is considered as unique standard for structural behavior conclusion.

IS 1893 (Part 1): 2002 laid out standards for maximum allowable storey drift as *"shall not exceed 0.004 times the storey height under consideration."* For all the cases analyzed in this work, storey height considered is 3m. Therefore, maximum allowable storey drift in this case is 12mm.

The analytical results shows that flat slab structures does not exceed maximum allowable storey drift for moderate height structure, but with increase in height necessitates the provision of lateral load resisting element as storey drift is likely to exceed the allowable limit. In this case, storey drift exceeds for with 20 storeys.

Comparison of Storey Drift for different cases

1. **Case 1-** 10 storey structure

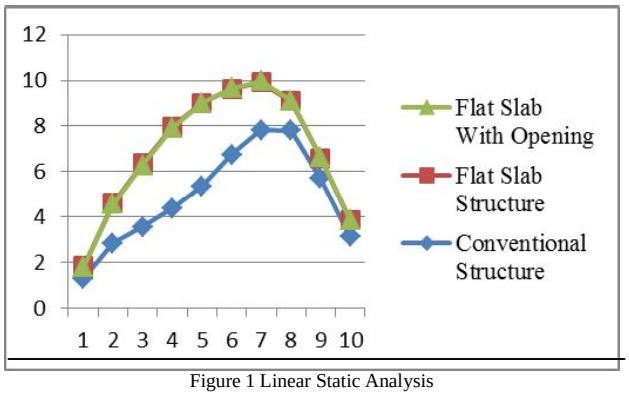

Figure 1 Linear Static Analysis

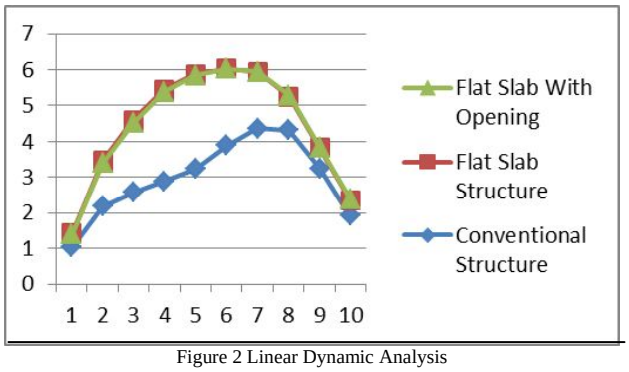

Figure 2 Linear Dynamic Analysis

Figure 1 and 2 shows performance (Storey Drift) of flat slab structure and flat slab structure with opening in comparison with conventional slab structure by linear static analysis and Linear Dynamic Analysis.

Case 2- 15 storey structure

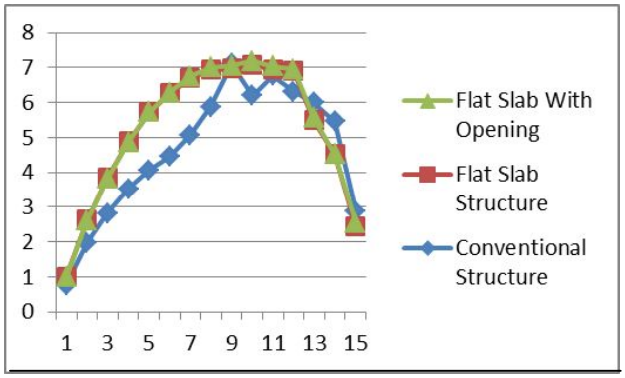

Figure 3 Linear Static Analysis

Figure 3 shows performance (Storey Drift) of flat slab structure and flat slab structure with opening in comparison with conventional slab structure by linear static analysis.

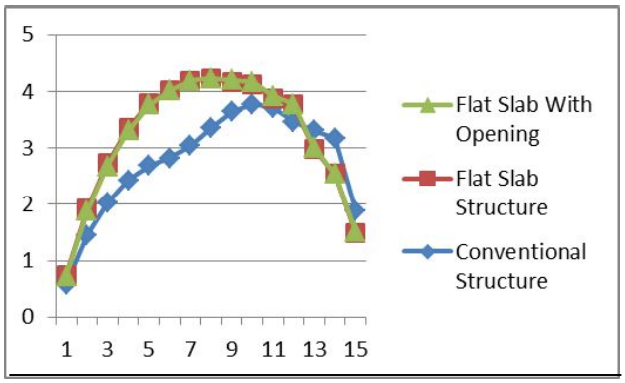

Figure 4 Linear Dynamic Analysis

Figure 4 shows performance (Storey Drift) of flat slab structure and flat slab structure with opening in comparison with conventional slab structure by response spectrum analysis.

Case 3- 20 story structure

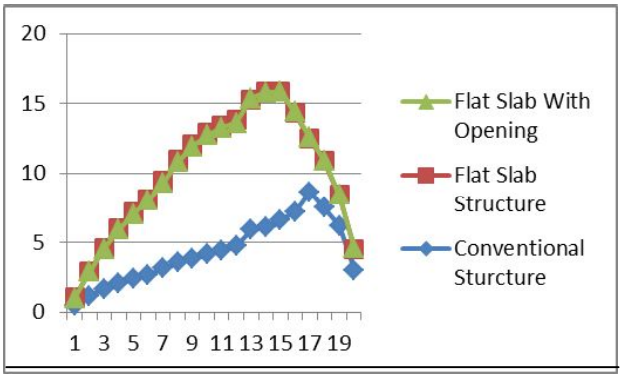

Figure 5 Linear Static Analysis

Figure 5 shows performance (Storey Drift) of flat slab structure and flat slab structure with opening in comparison with conventional slab structure by linear static analysis.

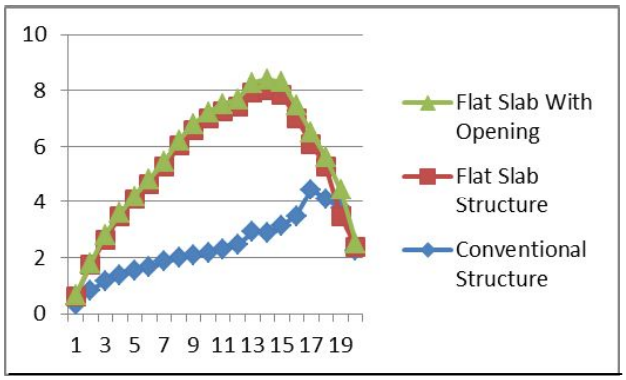

Figure 6 Linear Dynamic Analysis

Figure 6 shows performance (Storey Drift) of flat slab structure and flat slab structure with opening in comparison with conventional slab structure by response spectrum analysis.

Case 4- Flat slab structure of 10, 15 and 20 storey's with and without shear wall.

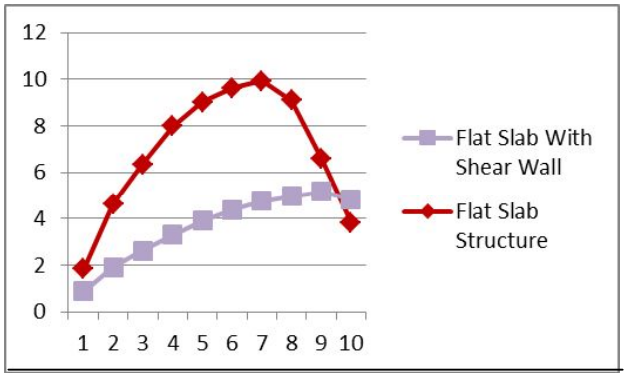

Figure 7 Linear Static Analysis

Figure 7 shows performance (Storey Drift) of flat slab structure with shear wall and without shear wall by linear static analysis.

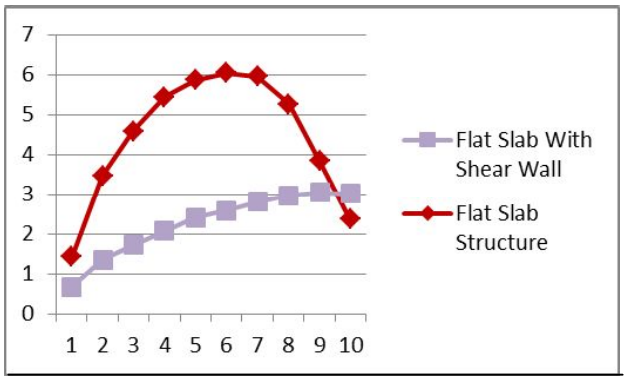

Figure 8 Linear Dynamic Analysis

Figure 8 shows performance of flat slab structure with shear wall and without shear wall by response spectrum analysis.

15 storey flat slab structure with and without shear wall.

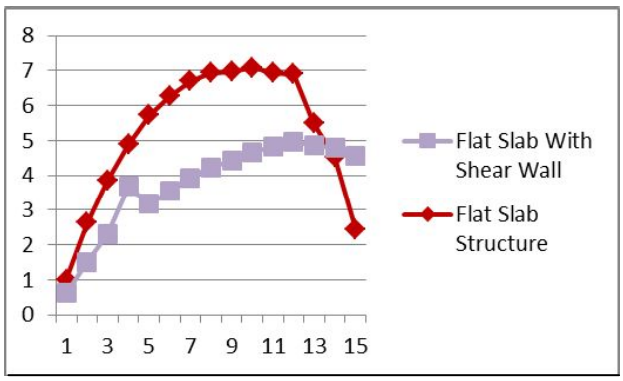

Figure 9 Linear Static Analysis

Figure 9 shows performance (Storey Drift) of flat slab structure with shear wall and without shear wall by linear static analysis.

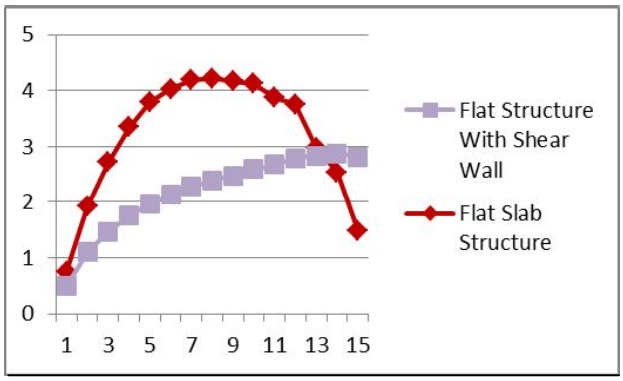

Figure 10 Linear Dynamic Analysis

Figure 10 shows performance (Storey Drift) of flat slab structure with shear wall and without shear wall by response spectrum analysis.

20 storey flat slab structure with and without shear wall.

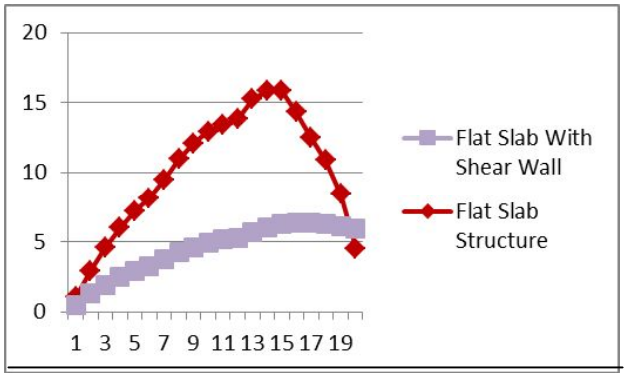

Figure 11 Linear Static Analysis

Figure 11 shows performance (Storey Drift) of flat slab structure with shear wall and without shear wall by linear static analysis.

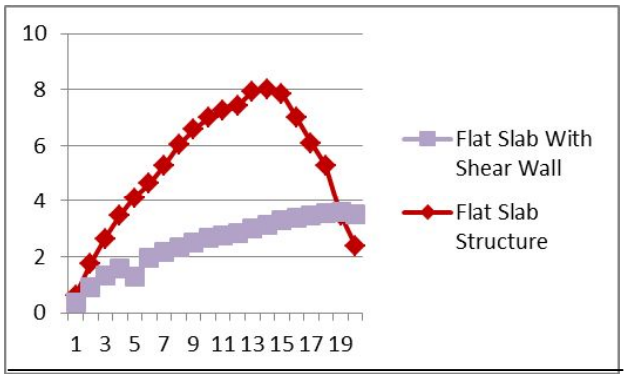

Figure 12 Linear Dynamic Analysis

Figure 12 shows performance of flat slab structure with and without shear wall by response spectrum analysis.

V. CONCLUSION

1. For all case, the base shear of flat slab structure is less than that of conventional one.
2. Storey drift follows a parabolic path with higher value somewhere at the middle to leaning towards upper storey.
3. Storey drift for flat slab structures is within allowable limit up to 15 storey structures but exceeds in case of 20 storey structure necessitating provision of lateral load resisting element.
4. Flat slab structure with opening at mid does not differ much in performance (storey drift) from flat slab structures.
5. The provision of shear wall as a lateral load resisting element to the flat slab structure helps to bring the parameters like maximum displacement and storey drift within acceptable limit.

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