Response of Different RC Slab Systems in Buildings to Seismic Excitations

Ramakant Azad¹, Saraswati Setia²

Civil Engineering Department, National Institute of Technology Kurukshetra

Kurukshetra

ramakantazad025@gmail.com

Abstract. In the current study, the response of flat, grid and conventional slab against seismic excitation is studied and comparative analysis is performed to establish which among the three slab system would be most effective and safe in an earthquake scenario. The parameter such as storey displacement, drift, shear, and base shear of each slab arrangement is extracted from ETABS which is general structural design software for comparison. In the analysis, three different building specimen with the aforementioned slab type having length, width and height of 40m, 30m and 30m respectively are designed as per Indian design code IS: 456:2000 and analyzed as per IS:1893:2016.

Keywords: Storey displacement, Seismic force, Storey drift, Storey shear, Base shear, ETABS.

1. Introduction

The population of the world is increasing day by day. Besides this increase in population, housing requirements are also increasing [1]. Urbanization is the displacement of people from rural areas to urban areas which helps to decrease the proportion of the rural population. Nowadays, people are facing problems due to land scarcity and the cost of land. Therefore, there is required for vertical development of the building [2]. Due to urbanization, the construction of high-rise buildings is very frequent. But, the tall buildings are not properly constructed and designed for the resistance of earthquake loads [3]. In earlier days, only gravity loads are considered for the design of buildings, but nowadays both gravity and lateral loads are considered for the design of buildings. Before the actual erection of the high-rise buildings, it should be analytically or numerically analyzed for seismic loads. Earthquake load is the most important reason for the failure of many tall building structures worldwide [4].

The storey shear force, storey deflection, storey drift ratio and shear at base play a crucial role to judge the building against the earthquake load [2]. Storey displacement is defined as the lateral displacement of the storey level to the ground floor. The difference between the lateral displacement of the successive floor is known as storey drift and the ratio of storey drift to the height of that floor is called storey drift ratio [5]. Storey shear is defined as the lateral force acting on each storey due to lateral force. It is a lateral force maximum at the bottom storey of the building and minimum at the top of the building. The total lateral load acting at its base is known as the base shear [6]. From the last twenty years, there is a substantial rise in the number of tall buildings and the development is towards these types of structures due to congestion in cities. The lateral loads are the primary concerns in these buildings.
1.1 Conventional Slab System
The conventional slab is directly sustained on columns and beams. The depth of the beam is large and the thickness of the conventional slab is small. The weight of the slab is moved from slab to beams and beams to columns. The conventional slab needs more formwork as compare to a flat slab.

1.2 Flat Slab System
The flat slab is directly supported by columns or column head. Generally, it doesn’t have beams. A flat slab is also known as a beam-less slab. The slab Loads are directly transmitted to columns and the columns to the footing. The flat slab requires less formwork. In this type of slab system, a flat ceiling is obtained gives a good aesthetic appearance. The flat slab is easy to construct as compared to other slabs.

The rectangular portion provided below the slab and above the column in the drop panels. The contact surface area between the column and slab increased in the drop panel, which helps to distribute the load from slab to column. The shear strength and negative moment capacity increase in the drop panel. By stiffening the flat slabs, the drop panel decreases deflection [9].

1.3 Grid/ Waffle Slab System
A grid slab is a concrete structure in which beams are provided at square or rectangular intervals in the perpendicular direction with slabs. These slabs are used at the entrance of the auditorium, theatre, showrooms, restaurants, malls, for good aesthetic view and also used for lighting, where column-free space is required. The waffle slab is stronger as compared to other slabs [10].

A waffle slab is employed where large spans are essential to escape a lot of columns prying with space. It is generally suitable for greater than 12 m spans. A large number of loads are held by using waffle slabs compare to conventional concrete slabs.

1.4 Research Objectives
The main objectives of current work are summed as under:
1. To study the performance of (G+9) multistoried building for slab systems under the earthquake load condition i.e. 1.5(DL+EQx) and 1.5(DL+EQy) for earthquake zone IV as per IS 1893-2016 part-1: Criteria for Earthquake resistant structure.
2. To study the seismic behaviour of different slab systems for various responses like storey displacements, base shear, story drift ratio and storey shear, and using ETABs software.
3. To compare the earthquake response of (G+9) multistoried building for different slab systems under different seismic load conditions in terms of several aforementioned parameters.

2. Method of Analysis

2.1 Methodology
The analysis of different slab system which considered has been done by using ETABS software. There are mainly three parts for structure using ETABS software.
1. Modelling
2. Analyzing
3. Designing
1. In the modelling parts, first define the material properties, section properties, diaphragm, load pattern, load combinations, mass source, after that draw column, beam, slab, drop, etc., and in last part of modelling is assign the frame loads, shell load, diaphragm, restraints, and auto floor mess.

2. After the modelling part, analyze the check model to find errors. To check the model, no warning message will create, then go for run analysis.

3. After the analysis, we extract the followings results parameter like storey shear, storey drift, storey deflection, for comparing the behaviour of flat slab, waffle slab, and conventional slab arrangements.

2.2 Building Specification

Consider G+9 multistoried RC building with each floor height of 3m and has 5 bays of 8m in the longitudinal direction and 6m in the and transverse direction. The slab thickness of each floor is considered 250 mm. The dimension of the beam taken for ten stories is 300 x 250mm. The column size taken for ten stories is 900 x 900 mm.

| S.N O. | SPECIFICATION NS | TYPES OF SLAB SYSTEM |
|--------|------------------|---------------------|
|        |                  | Conventional Slab   |
|        |                  | Flat Slab           |
|        |                  | Waffle Slab         |
| 1      | Plan Dimension of building | 40m × 30m | 40m × 30m | 40m × 30m |
| 2      | Grid Length in longitudinal direction | 8m | 8m | 8m |
| 3      | Grid Length in transverse direction | 6m | 6m | 6m |
| 4      | Total number of storey level | 10 | 10 | 10 |
| 5      | Height of each floor | 3m | 3m | 3m |
| 6      | Depth of slab | 0.25m | 0.25m | 0.25m |
| 7      | Cross-section of Beam | 0.30m × 0.25m | 0.30m × 0.25m |
| 8      | Cross-section of Column | 0.90m × 0.90m | 0.90m × 0.90m |
| 9      | Size of Ribs | 125 mm × 125 mm |
| 10     | Spacing of Ribs | 1400 mm |
| 11     | Grade of Concrete | M25 | M25 | M25 |
| 12     | Grade of Steel | Fe-415 | Fe-415 | Fe-415 |
2.3 Loading Condition

During the analysis of the multistoried building, the loads are considered as

1. **Dead load**: It is calculated as per IS-875 (Part 1) : 1987
   a) Plate load = Concrete density × Slab thickness
      \[ = 25 \text{ KN/m}^3 \times 0.25 \text{ m} = 6.25 \text{ KN/m}^2 \]
   b) Masonry load = 1 KN/m²
   c) Floor finishing load = 1.5 KN/m²
   Total weight of slab = 8.75 KN/m²

2. **Seismic load**: It is taken as according to IS-1893 (part 1): 2016
   Seismic zone: IV (Z=0.24)
   Response reduction factor: 5
   Importance Factor: 1.5 (Very Important Building)
   Rock and Soil Site Factor: 1 (Medium Soil Building)
   Type of Structure: 1
   Damping of structure: 5% (0.05)
   Type of soil: II (Medium soil)

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**Fig.1** Plan of G+9 models of Conventional slab

**Fig.2** Elevation of (G+9) model Conventional slab

**Fig.3** 3-Dimensional view of Conventional Slab System

**Fig.4** 3-Dimensional view of Flat Slab System
3. Results and Discussions

The results are provided in the form of a chart in the subsequent figures after analyzing all the three buildings using the software. The earthquake load patterns of $1.5(DL+EQ_x)$ and $1.5(DL+EQ_y)$ are considered.

3.1 Effect of storey displacement for different slab system

Maximum storey displacement is calculated for the two load patterns are $1.5(DL+EQ_x)$ and $1.5(DL+EQ_y)$ in longitudinal and transverse direction correspondingly. In fig.3.1 and fig.3.2, the abscissa denotes the storey level, and the ordinate denotes the maximum displacement. It can be concluded that the displacement is increasing from the ground level to the top storey level of the building.

Fig.5 3-Dimensional view of waffle slab system

Fig.6 Storey displacement for $1.5(DL+EQ_x)$ in X-axis direction
3.2 Effect of Storey Drift for different slab system

Maximum storey drift is finding for the load patterns are 1.5(DL+EQx) and 1.5(DL+EQy) in longitudinal and transverse direction correspondingly. In fig.3.3 and fig.3.4, the abscissa denotes the storey level, and the ordinate denotes the maximum drift. It can be concluded that the Storey drift is increasing first and after that decreasing from bottom to top of the building. The storey drift is observed highest at the fifth storey for each slab system.
3.3 Effect of Storey Shear

Maximum storey shear is calculated for the two load patterns are 1.5(DL+EQx) and 1.5(DL+EQy) in longitudinal and transverse direction correspondingly. In fig.3.5 and fig.3.6, the abscissa denotes the storey level, and the ordinate denotes the maximum storey shear. It can be concluded that the Storey shear is decreasing from bottom to top of the building. The storey shear force is decreasing from the ground level to the top storey level of the building.
3.4 Effect of Base Shear

In fig.3.7, the abscissa denotes the types of the slab, and the ordinate denotes the base shear. It clearly shows that the base shear is higher for waffle slab arrangement compare to flat slab and conventional slab arrangement.

Fig.11 Storey Shear for 1.5(DL+EQ_y) in Y-axis direction

Fig.12 Base shear for different slab under loading condition of 1.5(DL+EQ_x) and 1.5(DL +EQ_y)
4. Conclusions

- The storey deflection is minimum for waffle slab and maximum for conventional slab for the similar dimensional area of the building. The story displacement is rising with a rise in height of the storey.
- The maximum storey deflection for the conventional slab arrangement is 44.44% higher than the waffle slab arrangement and 58.81 % higher than the flat slab arrangement in the longitudinal direction.
- The storey drift is minimum for waffle slab arrangement and maximum for conventional slab arrangement for the similar plan area of the building. The storey drift ratio is increasing first and after decreasing with an increase in storey height. The maximum storey drift is found at the fifth storey of the building for considered loading condition for the slab system.
- The maximum storey drift for a conventional slab is 11.56% more than the flat slab and 57.2% more than the waffle slab system in the longitudinal direction.
- The storey shear force is maximum for waffle slab arrangement and minimum for flat slab arrangement.
- The maximum storey shear force for a waffle slab system is 47.4% more than the flat slab system and 31% more than the conventional slab system in the longitudinal direction.

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