Analytical Study of Different Types of Flat Slab Subjected to Dynamic Loading

R.S.More[1], V. S. Sawant[2], Y. R. Suryawanshi[3]

[1]M.E.Structure student of ICOER Pune, Savitribai Phule University of Pune

[2, 3]Assistant Professor of civil Engineering Department ICOER Pune, Savitribai Phule University of pune

Abstract: ***A popular form of concrete building construction uses a flat concrete slab (without beams) as the floor system. This system is very simple to construct, and is efficient in that it requires the minimum building height for a given number of stories. Unfortunately, earthquake experience has proved that this form of construction is vulnerable to failure, when not designed and detailed properly, in which the thin concrete slab fractures around the supporting columns and drops downward, leading potentially to a complete progressive collapse of a building as one floor cascades down onto the floors below. Although flat slabs have been in construction for more than a century now, analysis and design of flat slabs are still the active areas of research and there is still no general agreement on the best design procedure. The present day Indian Standard Codes of Practice outline design procedures only for slabs with regular geometry and layout. But in recent times, due to space crunch, height limitations and other factors, deviations from a regular geometry and regular layout are becoming quite common. Also behavior and response of flat slabs during earthquake is a big question. The lateral behavior of a typical flat slab building which is designed according to I.S. 456- 2000 is evaluated by means of dynamic analysis. The inadequacies of these buildings are discussed by means of comparing the behavior with that of conventional beam column framing. Grid slab system is selected for this purpose. To study the effect of drop panels on the behavior of flat slab during lateral loads, flat plate system is also analyzed. Zone factor and soil conditions -- the other two important parameters which influence the behavior of the structure, are also covered. Software ETABS is used for this purpose. In this study relation between the number of stories, zone and soil condition is developed.***

Keywords: Flat slab, Flat plate, Grid slab, Storey drift, punching shear, ETABS**.**

1. Introduction

The horizontal floor system resists the gravity load (dead load and live load) acting on it and transmits this to the vertical framing systems. In this process, the floor system is subjected primarily to flexure and transverse shear, where as the vertical frame elements are generally subjected to axial compression, often coupled with flexure and shear. The floor also serves as a horizontal diaphragm connecting together and stiffening the various vertical frame elements. Under the action of lateral loads, the floor diaphragms behave rigidly (owing to its high in plane flexural stiffness) and effectively distribute the lateral load to the various vertical frame elements and shear walls. In cast in situ reinforced concrete construction the floor system usually consists of one of the following

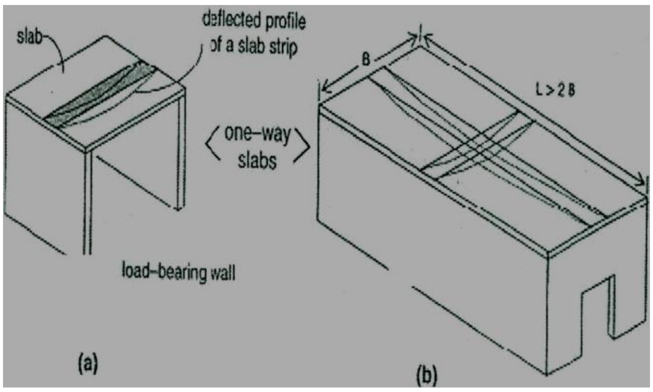


Figure 1.1: Wall Supported slab systems

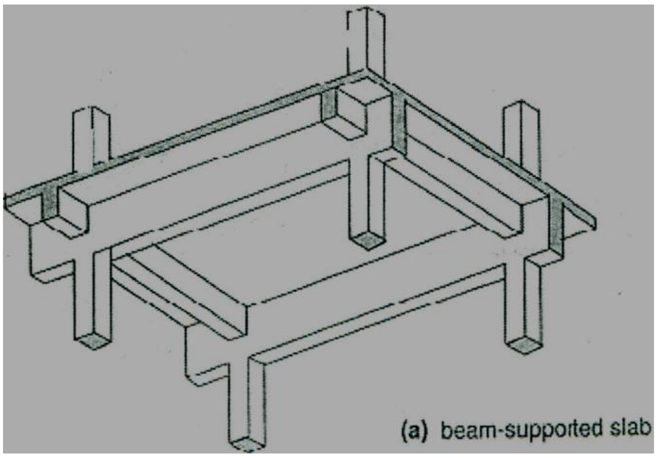


Figure 1.2: Beam Supported Slab System

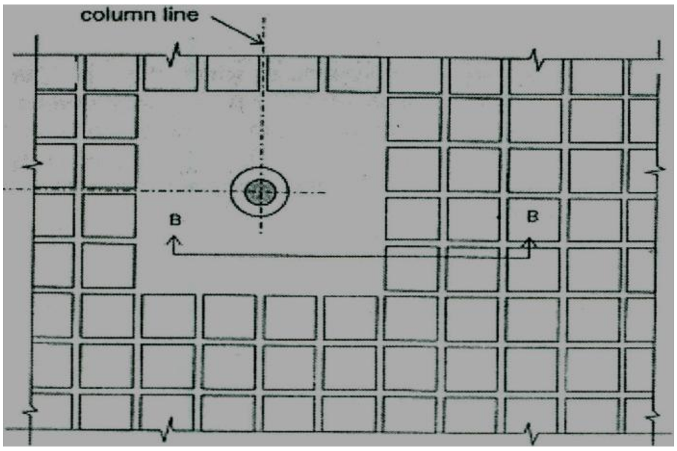


Figure 1.3: Two way ribbed (waffle) slab system

1.1 Flat slab system

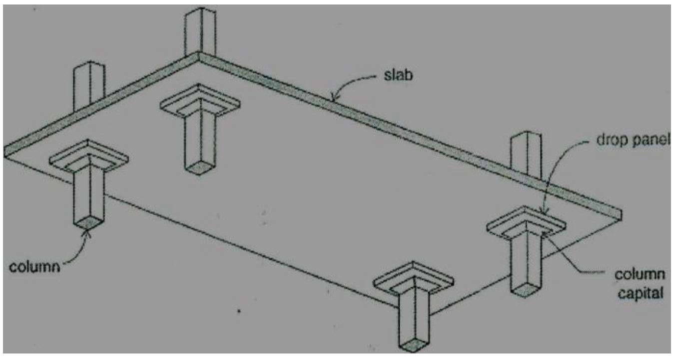


Figure 1.4: Flat Slab Systems

RC slabs with long spans extended over several bays and only supported by columns, without beams known as flat slab. Flat slab system is very simple to construct and is efficient in that it requires the minimum building height for a given number of stories.

Such structure contains large bending moment and vertical forces occur in a zone of supports. This gives a very efficient structure which minimizes material usages and decreases the economic span range when compared to reinforced concrete. Post-tensioning improves the structural behavior of flat slab structure considerably.

This is more acceptable concept to many designers. It is adopted in some office buildings. The flat slabs are plates that are stiffened near the column supports by means of 'drop panels' and/or 'column capitals' (which are generally concealed under 'drop ceilings'). Compared to the flat plate system, the flat slab system is suitable for higher loads and larger spans, because of enhanced capacity in resisting shear and hogging moments near the supports. The slab thickness varies from 125 mm to 300 mm for spans of 4 to 9m. Among the various floor systems, the flat slab system is the one with the highest dead load per unit area.

In general, in this type of system, 100 percent of the slab load has to be transmitted by the floor system in both directions (transverse and longitudinal) towards the columns. In such cases the entire floor system and the columns act integrally in a two- way frame action.

Some terminologies involved

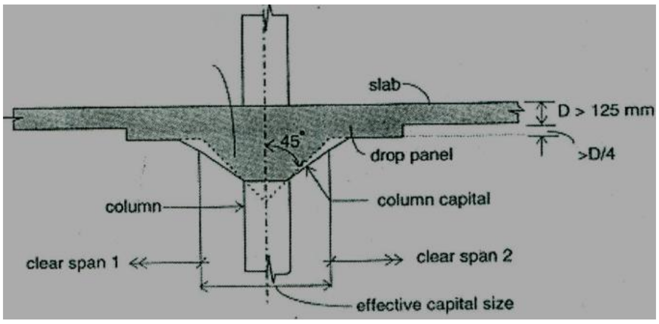


Figure 2.1: Drop panel and column capital

Drop Panels: The 'drop panel' is formed by the local thickening of the slab in the neighborhood of the supporting column. Drop panels or simply drops are provided mainly for the purpose of reducing shear stress around the column supports. They also help in reducing the steel requirements for the negative moments at the column supports. The code recommends that drops should be rectangular in plan, and have length in each direction not less than one third of the panel length in that direction. For exterior panels, the length measured perpendicular to the discontinuous edge from the column centerline should be taken as one half of the corresponding width of drop for the interior panel.

Column Capital: The column capital or column head provided at the top of a column is intended primarily to increase the capacity of the slab to resist punching shear. The flaring of the column at top is generally done such that the plan geometry at the column head is similar to that of the column.

The code restricts the structurally useful portion of the column capital to that portion which lies within the largest (inverted) pyramid or right circular cone which has a vertex angle of 90°, and can be included entirely within the outlines of the column and the column head. This is based on the assumptions of a 45° failure plane, outside of which enlargement of the support is considered ineffective in transferring shear to the column.

Some evident of flat slab failure:

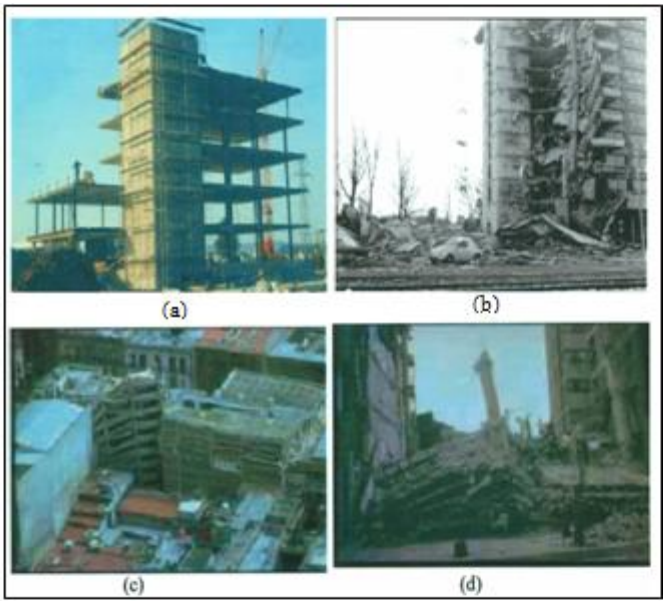


Figure 2.2: Some evident of flat slab failure

a) In this new skeleton building with flat slabs and small structural columns designed to carry gravity loads, the only bracing against horizontal forces and displacements is a reinforced concrete elevator and stairway shaft, placed very asymmetrically at the corner of the building. There is a large eccentricity between the centres of mass and resistance or stiffness. Twisting in the plan, lead to large relative displacements in the columns furthest away from the shaft and, this implies the danger of punching shear failure.

b) Punching Shear Failure in the Main Roof at corner Column.
c) This multi-floor parking garage collapsed like a stack of cards while some of the neighbouring buildings remained undamaged. Flat slab construction was the most vulnerable construction type with 85 total collapses during the 1985 quake at Germany.
d) In this building as in many others, the load-bearing column forced through the concrete floors as they collapsed around it. Severe resonance oscillations of the buildings caused strain at the juncture between columns and ceiling slabs; the concrete structure was destroyed and the steel reinforcements were strained until they failed. The vertical columns were compressed or (as in this picture) punched through the heavy floors that collapsed around them.

1.2 Advantages of flat slab

- Increases speed of construction
- The construction is simple and economical because of the simplified form work, the ease of placement of reinforcement.
- The plain ceiling gives an attractive and pleasing appearance; in absence of beams, provision of acoustical treatment is easy.
- In general flat slab construction is economical for spans up to 10m and relatively light loads.
- Compare to the RCC less self weight, which results in reduced dead load, which also has a beneficial effect upon the columns and foundations
- Reduces the overall height of buildings or enables additional floors to be incorporated in buildings of a given height.

1.3 Major problems in flat slab

- Slab column connection does not possess the rigidity of the beam column joint.
- Shear concentration around column is very high due to the possibility of the column punching through the slab.
- Deflections tend to be very large due to lesser depth of slab.

2. Methods of Analysis of Flat Slab

Behavior of two-way slab system under gravity and lateral loads is complex. In the case of beam supported two way slabs, 100% of gravity loads on the slabs are transmitted to the supporting columns in both longitudinal at transverses directions. The mechanism of load transfer from slab to columns is achieved by flexure, shear & torsion in various elements. The slab beam columns system behaves integrally as a three dimensional system, with the involvement of all the floors of the building, to resist not only gravity loads, but also lateral loads. However a rigorous three dimensional analysis of the structure is complex, & not warranted except in very exceptional structures. Unlike the planer frames, in which beam moments are transferred directly to columns, slab moments are transferred indirectly, due to tensional flexibility of the slab. Also slab moments from gravity can leak from loaded to unloaded spans; this must be accounted for, in the analysis.

Presently, the Indian Standard Codes provide the guidelines for design of flat slabs. These are basically empirical and are supported by the vast experimentation. But since the standard experimentation has been done on standard layouts and configuration of the slabs; these design procedures are limited in their scope and applicability. Nowadays, irregular layouts are becoming common, and it is in this light that standard codal procedures seem Inadequate.

Code definition of flat slabs

"The term flat slab means a reinforced concrete slab with or without drops, supported generally without beams, by columns with or without flared heads. A flat slab may be solid slab or may have recesses formed on the soffit so that a soffit comprises a series of ribs in two directions. The recess may be formed of permanent or removable filler blocks. A flat slab is reinforced concrete flat slab reinforced in two or more directions to bring the load acting normal to its plane directly to supporting columns without the help of any beam or girder." The above definition is very broad and encompasses the various possible column supported two-way slabs mentioned earlier. As mentioned earlier the code procedure is based on the elastic analysis of equivalent frames under the gravity loads and follows closely the 1997 version of the ACI code. However unlike the unified code procedure, there is no elaboration in the I.S code for the particular case of two way slab with beams along column lines.

Design Philosophy

There are three methods of analysis of flat slabs viz.
1 Direct Design Method (DDM)
2 Equivalent Frame Method (EFM)
3 Finite Element Method (FEM)
Out of this, first 2 methods are recommended by the I.S. code for determining the bending moments in the slab panel (approximate methods); either method is acceptable (provided the relevant conditions are satisfied).These methods are applicable only to two way rectangular slabs (not one way slabs), and in the case of direct design method the recommendations apply to the gravity loading condition alone (and not to the lateral load condition).

Finite element method:

The structures having irregular types of plans with which the EFM has limitations in analysis can be analyzed without any difficulties by the FEM. FEM is a powerful tool used in the analysis of flat slabs. Most finite element programs are based on elastic moment distribution and material that obey Hooke's Law. This works for steel plates but reinforced concrete is an elasto-plastic material and ones it cracks its behavior is non linear. As a consequence the support moments tend to be overestimated and the deflection of the slab is under estimated. Currently, one of the main criticisms of the FEM analysis is its reliance on the elastic solutions that result in high peaked support moments over the column. These support moments are unlikely to be realized under service loads due to cracking and thus the service span moments will be correspondingly increased. While using

finite element method following considerations are important.
1)Choice of a proper finite element.
2)Degree of disceretisation
3)Overall computational economy.

Hence various finite element models are possible for the same problem. A model which can take into account all the important structural effects at the least computational cost is called as the best model.
Dynamic Analysis
1. Coefficient Method
2. Response Spectrum method
3. Time History Method

3. Behavior of Flat Slab under Lateral Loading

3.1 General Building Behavior

The behavior of a building during earthquake is a vibration problem. The seismic motion of the ground does not damage a building by impact, or by externally applied pressure, but by internally applied pressure and internally generated inertial forces caused by vibration of building mass. It can cause buckling or crushing of columns and walls when the mass pushes down on a member bent or moved out of plumb by the lateral forces. This effect is known as the 'P-ʌ'effect and Greater the vertical forces, the greater the movements due to 'P-ʌ'. It is almost the vertical load that causes the building to fall down. The distribution of dynamic forces caused by the motion and the duration of motion are of concern in seismic design. Although the duration of motion is an important issue, we do not consider it for seismic design.

In general tall buildings respond to seismic motions differently than low rise buildings. The magnitude of inertia force induced in an earthquake depends on the building mass, ground acceleration, the nature of the foundation, and the dynamic characteristics of the structure. For a structure that deforms slightly, the force 'F' tends to be less than the product of mass and ground acceleration. Tall buildings are invariably more flexible than low rise buildings, and in general, experience much lower accelerations than the low rise buildings. But a flexible building subjected to ground motions for prolonged period may experience much larger forces if its natural period is near that of ground period. Thus the magnitude of earthquake force is function of the acceleration of the ground, the type of structure and its foundation.

3.2 Building Behavior

Tall buildings respond to seismic motions differently than low rise buildings. The magnitude of inertia force depends on the building mass, ground acceleration, the nature of foundation, and the dynamic characteristics of the structure. Tall buildings are invariably more flexible than low rise buildings, and in general experiences much lower accelerations than low rise buildings. The magnitude of earthquake force is not a function of the acceleration alone, but influenced to a great extent by the type of response of the structure and its foundation. This interrelationship of building behavior and seismic ground motion also depends on the time period. Some factors which affect the building behavior are discussed here.

3.2.1 Influence of soil

The seismic motion that reaches a structure on the surface of the earth is influenced by local soil conditions. Low to mid-rise buildings have time period between 0.1 to 1 sec range, while taller more flexible buildings have periods between 1to 5 sec or greater. Harder soils, and bed rock transmit short period vibrations (caused by near field earthquake) while filtering out longer period earthquakes (caused by distant earthquakes), whereas softer soils will transmit longer period vibrations.

3.2.2 Structural response

If the base of structure is moved suddenly, the upper part of the structure will not respond instantaneously, but will lag because of inertial resistance and flexibility of the structure. Because earthquake ground motions are three dimensional, building deforms in a same manner. But inertia forces generated by horizontal components of ground motions required greater considerations for seismic design since adequate seismic resistance to vertical seismic loads is provided by member capacities required for gravity load design.

3.2.3 Load Path

Buildings are generally composed of vertical and horizontal structural elements. A complete load path is a basic requirement for all buildings. Seismic forces originating throughout the building, mostly in the heavier mass elements such as diaphragms, are delivered throughout the connections to diaphragm; the diaphragm distributes these forces to vertical force resisting system such as shear walls and frames. Through frame these forces are transferred to foundation; and foundation transfers these forces to supporting soil. Interconnecting, members needed to complete the load path is necessary to achieve good seismic performance.

3.3 Flat slab building behavior under lateral loading

The behaviour of flat slab structures for gravity loads is well established. However, behavior under lateral displacement is not well understood and lateral design methods are not well established. Frame action provided by flat slab and column is generally insufficient for buildings taller than 10 stories. The lateral behavior of flat slab structures is in doubt because of the relative flexibility of the connections when compared with beam column joints. A flat slab column framing is generally inadequate as a primary lateral load resisting system for multi-storey structures in high seismic risk zones because of problems associated with excessive drift. A system consisting of shear walls and flat slab with proper bracing systems is usually recommended for high rise buildings. Even there is a concern as to whether the connection possesses sufficient lateral displacement capacity to survive lateral deformations which can be reasonably expected. The stiffness of the typical wall or frame system is insufficient to protect the slab column connection from yield. Hence attention must be given to its inelastic seismic response. I.S. 1893-2002 says that "Since the lateral load resistance of the slab column connection system is small, flat slabs are often designed only for gravity loads, while the seismic force is resisted by shear walls. Even though slabs and columns are not required to share the lateral forces, these deforms with rest of the structure under seismic excitation. The concern is that under such deformations, the slab column system should not lose its vertical load capacity."

The slab column connections are subjected to gravity shear and unbalanced moment during earthquake. Transfer of shear and unbalanced moments is critical in flat slab behaviour, especially for horizontal loading which requires substantial unbalanced moment to transfer between slab and column. Unbalanced moment is transferred by combination of flexure, torsion and shear in the flat slab around the periphery of column faces. The shear from the unbalanced moment transfer is added to the gravity shear at connections. When combined shear becomes too large, a brittle punching failure will occur. If the connections are not properly detailed, punching failure may lead to progressive collapse. The concrete will provide a certain level of shear resistance around the columns but this may need to be supplemented by punching shear reinforcement arranged on concentric perimeters. Thus during transfer of loads either due to gravity or due to earthquakes, behavior of flat slab building depends on strength and behavior of slab connection.

3.4 Structural Dynamic behavior of Multiple-degree-of-freedom (MDOF) systems

3.4.1 Degree of freedom

Any mass can undergo six possible displacements in space - three translation and three rotations about an orthogonal axis system. The number of independent displacement required to define the displaced position of all the masses relative to their original position is called number of degree of freedom (DOFS) for dynamic analysis.

1 Single Degree of Freedom System
2 Multi Degree of Freedom System
3 Continuous System

3.4.2 Classification of vibration

1 Free and forced vibration
2 Undamped and damped vibrations
3 Linear and non-linear vibration

1 Free and forced vibrations

If a system, after an initial disturbance is left to vibrate on its own, the ensuing vibration is known as free vibrations. No external force acts on the system. The oscillation of a simple pendulum is an example of free vibration. If a system is subjected to an external force (often a repeating type of force) the resulting vibration is known as a forced vibration. The oscillation is known as forced vibration. The oscillation that arises in machines such as diesel engines is an example of force vibration. If the frequency of the external of the external force coincides with one of the natural frequencies of the system, a condition known as Resonance occurs and the system undergoes dangerously large oscillation, failures of such structures as building, bridges, turbines and airplane wings have been associated with the occurrence of Resonance.

2 Undamped and damped vibrations

If no energy is lost or dissipated in friction or other resistance during Oscillation, the vibration is known as Undamped Vibration. If any energy is lost in this way, however, it is called Damped vibration. In many physical systems, the amount of damping is so small that it can be disregarded for most engineering purposes .however consideration of damping becomes extremely important in analyzing vibratory system near resonance.

3 Linear and non-linear vibrations

If all the basis component of a vibratory system, the spring, the mass and the damper behave linearly the resulting vibration is known as linear vibration. If however, any of the basic component behave nonlinearly the vibration is called non linear vibration.

4. Analysis of Flat Slab

The seismic analysis and design of buildings are traditionally focused on reducing the risk of loss of life in the largest expected earthquake. Building codes are based on their provisions on the historic performance of buildings and their deficiencies and have developed provisions round life safety concerns i.e. to prevent the collapse under the most intense earthquake expected at site during the life of the structure. These provisions are based on the concept that the successful performance of buildings in areas of high seismicity depends on combination of strength, ductility manifested in the details of construction, and the presence of the fully interconnected, balanced, and complete lateral force resisting system.

4.1Advantageous Features of ETABS (Version 9.7.2)

Software ETABS (Extended Three Dimensional Analysis of Building Structures) is used for seismic analysis and to study the behaviour of flat slab buildings. ETABS is the Integrated Software for Analysis, Design, and Drafting of Building Systems. ETABS is very useful for linear as well as nonlinear analysis of buildings. Input for buildings becomes very easy and also 'user interface' explains us various modelling and analysis procedures. Engineering News Record has also declared that ET ABs as the only reliable software for seismic analysis of buildings.

For nearly 30 years ET ABS has been recognized as the industry standard for Building Analysis and Design Software. Today, continuing in the same tradition, ETABS has evolved into a completely Integrated Building Analysis and Design Environment. The System built around a physical object based graphical user interface, powered by targeted new special purpose algorithms for analysis and design, with interfaces for drafting and manufacturing, is redefining standards of integration, productivity and technical innovation.

The integrated model can include Moment Resisting Frames, Braced Frames, Staggered Truss Systems, Frames with Reduced Beam Sections or Side Plates, Rigid and Flexible Floors, Sloped Roofs, Ramps and Parking Structures, Mezzanine Floors, Multiple Tower Buildings and Stepped

Diaphragm Systems with Complex Concrete, Composite or Steel Joist Floor Framing Systems. Solutions to complex problems such as Panel Zone Deformations, Diaphragm Shear Stresses, and Construction Sequence Loading are simplified by ETABS.

4.1.1Useful characteristics of ETABS

1) ETABS is the solution for designing a simple 2D frame or performing a dynamic analysis of a complex high-rise structure that utilizes non-linear dampers for inter-story drift control.
2) Useful for Design of Buildings with Moment Resisting Frames, Braced Frames, Shear Wall Systems, Sloped Roofs, Ramps and Parking Structures, Multiple Tower Buildings, or Stepped Diaphragm Systems with Concrete Floors, Composite Steel Decks or Steel Joist Floor Framing Systems.
3) ETABS has been developed specifically for multi-story building structures, such as office buildings, apartments and hospitals. Also modeling of any kind of slab like grid / waffle slab, flat slab, ribbed slab becomes very easy with the help of this software.
4) For earthquake analysis ETABS has inbuilt IS 1893 spectrum. This simplifies the definition of earthquake load.
5) Input tables help in viewing 'Auto Seismic load' to Diaphragms and stories.
6) Static and dynamic analysis of any kind of buildings becomes easy. Also it has inbuilt design load combinations for analysis and design as per specified code.
7) Design output results clearly show the steps of design.

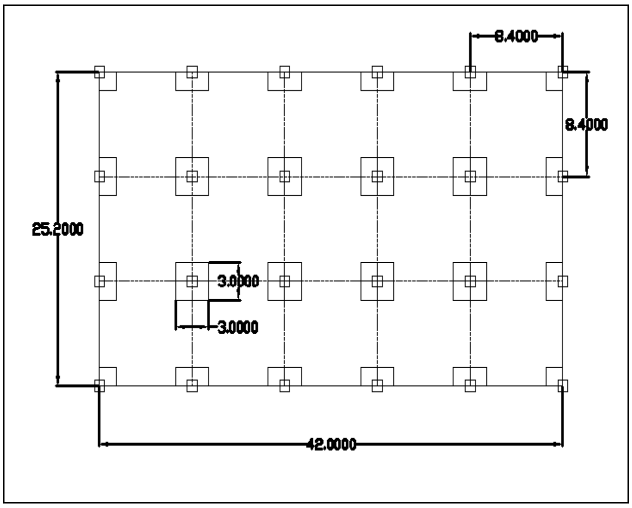
4.2 Modelling steps

As a case study, plan of existing flat slab building for commercial building is selected which is located near Pune (zoneIII and soil type II i.e. medium soil condition). Same building is analyzed for other zones and soil conditions and their storey drifts are compared. Existing structure consists of two buildings connected together. One part consists of only offices and other part includes all utilities like staircase, lifts, washrooms etc. The part which consists of offices only is built with flat slabs while other is beam column frame structure. For the simplification in the analysis, the part which consists of offices is selected. Software ET ABS is used for the analysis. For this, Plan dimensions of an existing flat slab building are taken as fixed dimensions.

1) With the same loading conditions, requirement of column free space, greater floor to floor height and number of stories of that of existing building, three different types of slabs viz. grid slab, flat slab and flat plate slab are designed.
2) Models of all buildings are prepared in ETABS with given loading conditions. To compare the behaviour of the floor diaphragm of the flat slab, grid slab and flat plate building during lateral condition, stiffness of columns is kept same. Columns are assumed to have the same size at the particular storey level.
3) Edge beams of the same dimensions are provided along the periphery of the flat slab and flat plate building:
4) Thickness of the slab is provided according to the deflection requirement and to resist the one way and two way punching shear.
5) Dynamic analysis is carried out by placing three buildings in all four zones and with three soil conditions.
6) Response reduction factor '5', and importance factor' 1', is assumed.
7) Column size is reduced after every three stories as per requirements of gravity loads and it is checked for punching shear.

Details of flat slab building:

1.	Plan Dimensions	25.2 m X 42 m(C/C dist)	
2.	Length in X- direction	42m	
3.	Length in Y- direction	25.2 m	
4.	Floor to floor height	4.2m	
5.	No. of Stories	9	
6.	Total height of Building	37.8m	
7.	Slab Thickness	250 mm	
8.	Thickness of the drop	100mm	
9.	Width of drop	3000 mm	
10.	Edge Beam	400 X 900	Mm
11.	Size of the Column	1-3 story	850 X 850 mm
		4-6 storey	750X 750 mm
		7-9 storey	600 X 600 mm
12.	Grade of concrete	M25	
13.	Grade of Steel	Fe 415	
14.	Panel Dimensions	8.4 X 8.4 m	
15.	Width of middle strip	4200 mm	
16.	Width of column strip	4200 mm	
17.	Loading	Terrace	Remaining FLR.
	A) Live load	1.5 kN/ m^2	4 kN/ m^2
	B) Dead load	3 kN/ m^2	2.7 kN/ m^2



Details of Grid Slab Building:

1.	Plan Dimensions	25.2 m X 42 m(C/C) dist.	
2.	Length in X- direction	42m	
3.	Length in Y- direction	25.2 m	
4.	Floor to floor height	4.2m	
5.	No. of Stories	9	
6.	Total height of Building	37.8m	
7.	Slab Thickness	250 mm	
8.	Thickness of the drop	100mm	
9.	Width of drop	3000 mm	
10.	Edge Beam	400X900	Mm
11.	Size of the Column	1-3 story	850X850 mm
		4-6 storey	750X750 mm
		7-9 storey	600X600 mm

All parameters except mentioned below are same as that of flat slab building.

1. Slab thickness 125mm
2. Size of the beam i. 300 X 750 mm
ii. 230 X 600 mm

4.3 Load Combinations Considered

Since wind is not governing load in this case its combination is not considered.
Following 21 combinations are considered for the analysis as per mentioned in IS 1893 - 2002

1 1.5 (D.L. + L.L.)
2 1.2 (D.L. + L.L. ± EQ x)
3 1.2 (D.L. + L.L. ± EQ y)
4 1.5 (D.L. ± EQ x)
5 1.5 (D.L. ± EQ y)
6 0.9 (D.L.) ± 1.5 (EQ x)
7 0.9 (D.L.) ± 1.5 (EQ y)
8 1 (D.L. + L.L. ± EQ x)
9 1 (D.L. + L.L. ± EQ y)
1 1 (D.L. ± EQ x)
1 1 (D.L. ± EQ y)

Since plan is symmetrical about both axis earthquake in negative direction of X and Y are not considered in the analysis. Out of these combinations, 1.5 (D.L. + EQ x / EQ y) has the maximum displacement in the specified direction. But as per I.S. 1893 design combinations for partial safety factor of 1 are only considered. Partial load factor of unity implies service load conditions, which is required for 'serviceability design'.

5. Result

5.1 Building Drift

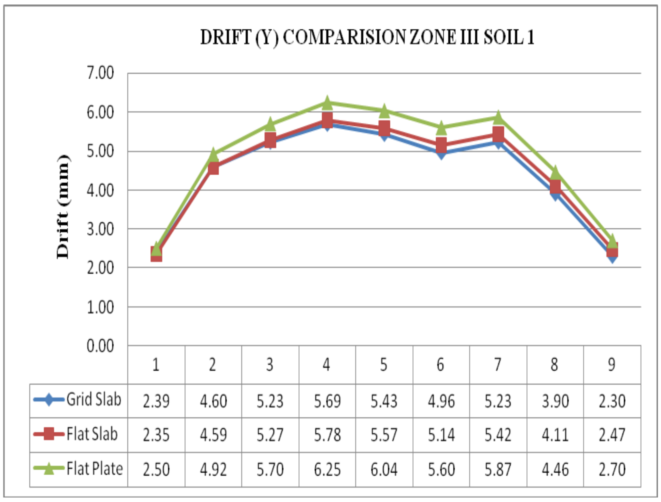
Storey drift is defined as difference between lateral displacements of one floor relative to the floor below.

I.S. 1893-2002: The storey drift in any storey due to the minimum specified design lateral force with partial load factor 1.00 shall not exceed 0.004 times the storey height. In this case storey height is 4200 mm. Therefore limited storey drift is calculated as

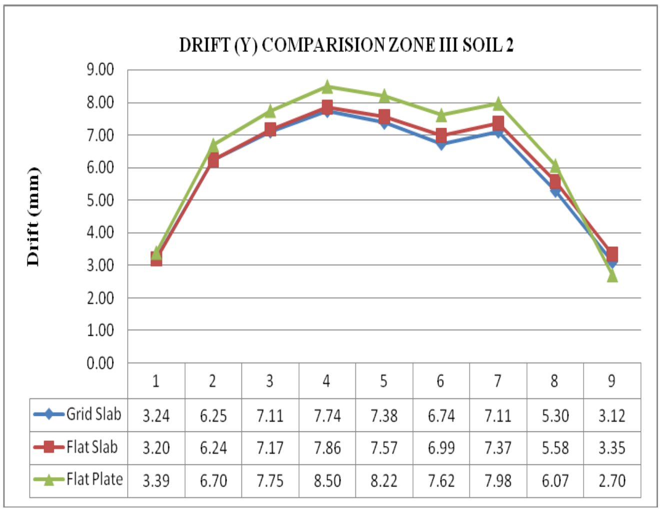
Storey drift = 0.004
4200

Therefore Limiting storey drift = 0.004 X 4200 = 16.8 mm

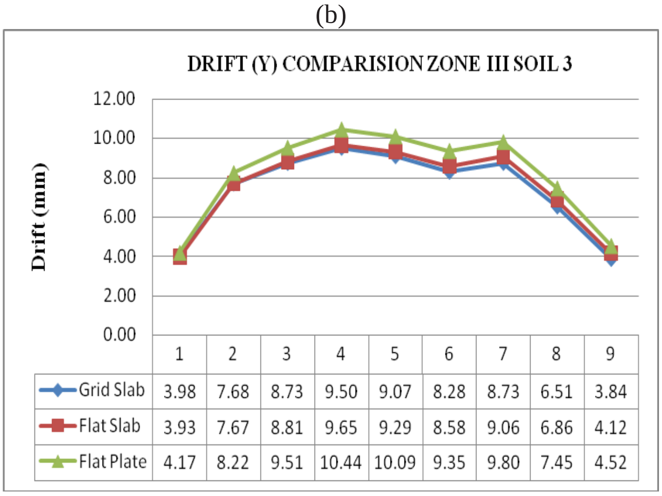
Soil 1	Type 1	Rock or hard soil
Soil 2	Type 2	Medium soil
Soil 3	Type 3	Soft soil



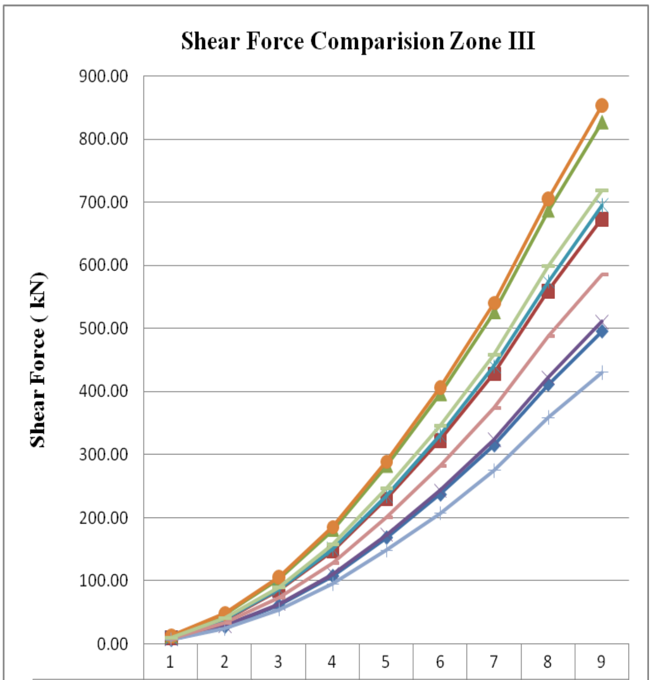
(a)



(b)



(c)



	1	2	3	4	5	6	7	8	9
FLS Soil 1	7.03	28.12	62.01	108.2	169.0	237.1	314.9	411.2	495.2
FLS Soil 2	9.56	38.24	84.34	147.1	229.9	322.5	428.2	559.3	673.5
FLS Soil 3	11.74	46.95	103.6	180.7	282.3	396.0	525.8	686.8	827.0
FLP Soil1	7.16	28.63	63.27	110.6	172.7	242.9	323.2	422.1	510.9
FLP Soil2	9.73	38.94	86.04	150.3	234.9	330.3	439.6	574.1	694.8
FLP Soil3	11.95	47.82	105.7	184.6	288.5	405.6	539.7	705.0	853.1
GS Soil1	6.17	24.69	54.36	94.77	148.1	207.3	275.0	359.1	430.7
GS Soil2	8.39	33.57	73.94	128.9	201.4	281.9	374.0	488.4	585.7
GS Soil3	10.31	41.22	90.79	158.3	247.3	346.1	459.2	599.8	719.3

(d)

Abbreviation used:
FLS –Flat Slab System
FLP – Flat Plate System
GS – Grid Slab

6. Conclusion

Conclusions from graphs (a to c)

1) All graphs clearly show that drift of flat plate is maximum than grid floor slab and flat slab. Grid slab has less drift compared to others. Drift of top storey of flat plate slab is about 18 % more than that of top storey of grid slab, and for flat slab it is about 8% more than that of grid slab. Drift or relative displacement of a storey is the ratio of base shear experienced by that storey to total stiffness of columns at that storey. Since stiffness of columns for a given storey is same for all three types of slabs, maximum drift indicates maximum base shear for flat plate slab.
2) Drifts of flat slabs and grid slabs are approximately equal up to storey 4.
3) All slabs deflect within the limit when strata is of type one i.e. rock, or hard soil.
4) Comparing strata conditions, building on soft soil (Type 3) deflects more.
5) Storey four and seven experiences maximum drift. Storey four has the largest displacement. This shows that column stiffness requirement of storey four and seven is greater than that of remaining stories.

Conclusions from graphs (d)

1) Flat plate experiences maximum shear force, whereas grid slab experiences less shear force. Shear force experienced by flat plate is 17 % higher and that of flat slab is 14 % higher than that of grid slab for all soil conditions.
2) There is definite correlation between increase in shear force and storey drift with change in soil condition for particular type of slab. For e.g. Flat slab building in medium soil condition experiences 36 % more drift and 36 % more shear force than building located on harder strata, where as for Flat slab building on soft soil condition both of them are 67 % more. Similar is the case for Grid slab and Flat plate building.

References

[1] Hyun-Su Kim1, Dong-Guen Lee2, “Efficient Seismic Analysis of Flat Plate System Structures” (13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 680) (2004)
[2] Suzanne King, Norbert J. Delette (February, 2004) "Collapse of 2000 Commonwealth Avenue: Punching Shear Case study" journal of performance of constructed facilities
[3] Carla M. Ghannoum, “Effect Of High-Strength Concrete On The Performance Of Slab-Column Specimens” Department of Civil Engineering and Applied Mechanics, McGill University Montréal, Canada (November 1998)
[4] Simon Brown1, Walter Dilger2, “Design Of Slab-Column Connections To Resist Seismic Loading” (13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 680) (2014)
[5] H. S. Kirn, D. G. Lee (October, 2005) "Efficient analysis of flat slab structures subjected to lateral loads", Engineering structures 27
[6] Megally, S. and Ghali, A, 2000. "Seismic Behavior of Slab-column Connections", Canadian Journal of Civil Engineering, Vo1.27, No.l, pp. 84-100.
[7] E. K. Jones & J. Morison (April, 2005) "flat slab design: past, present & future" structures & buildings 158 issue SB2
[8] U. Prawatwong, C.H. Tandian and P. Warnitchai “Tests Of Interior Flat Slab-Column Connections Transferring Shear Force And Moment”
[9] IS 1893 (Part 1):2002 Criteria For Earthquake Resistant Design Of Structures
[10] IS 456: 2000 Plain & reinforced concrete code of practice
[11] IS 4326 : 1993 (Reaffirmed 2003) Edition 3.3 (2005-01)
[12] Illustrated Design of Reinforced concrete Buildings - Karve & Shah
[13] P. Agarwal and M. Shrikhande – Earthquake Resistant Design of Structures, Prentice- Hall Publications.