Understanding The Behavior of Flat Slab by Linear and Nonlinear Finite Element Analysis

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ABSTRACT

In the present situation of building construction around the world, Flat slab is becoming widely popular in the multi-storied buildings due to its advantage and ease of construction over the slabs. However, during past earthquakes, many building with flats have performed poorly. This is mainly due to inadequate resistance for punching shear under the earthquake loading. Many codes that are available for the design are for the analysis of flat slab under gravity loading. Some provisions exist for punching shear resistance, however, they are inadequate.

To understand the behavior of building with flat slab subjected lateral loads, a numerical study is performed. A three-dimensional finite element method is used to perform the analysis. A flat slab along with the columns is modelled. Nonlinear constitute equations are used to model material, i.e., concrete. Parametric study is performed for understanding the nonlinear behavior of flat slab subjected to lateral loads.

Keywords: Flat Slab, Lateral loading, Finite Element Method, Material Nonlinearity.

1. INTRODUCTION

In the present situation of building construction, the flat slab is widely popular throughout the world and it is being used but its behavior under lateral load is not clearly understood. This system has many advantages over the slab such as ease of construction, Increases speed of construction, the construction is simple and economical because of the simplified formwork, In absence of beams, it has got plain ceilings which gives an attractive and pleasant appearance. Also, this system reduces total height and weight of a structure.

Despite its many advantages, Flat slab structure has vulnerability under the lateral force. The performance of flat slab is poor under the lateral load as compared to frame structure which is due to lack of frame action, so it has an excessive amount of lateral deformation. These lateral deformations produce moment at the slab-column joint and due to its limitation in the rigidity of moment transfer, increases the possibility of punching shear failure. Advent of technology has reduced the complexity of the problem. A numerical study is performed by modelling slab along with columns as a single unit and understanding its behavior under lateral loading.

The work in this research paper presents the three-dimensional finite element model of flat slab along with column and modeling is done by writing mesh-generation and finite element method code with suitable boundary conditions and its behavior under lateral loading is studied in both linear as well as in nonlinear cases. Effect of increase in column size on the displacement of the slab in a nonlinear case is also studied.

2. LITERATURE REVIEW

The literature shows the study on the flat slab buildings under seismic excitation.

Subhajit Sen and Yogendra Singh, “Seismic Performance of Flat Slab Buildings”, In this paper performance of flat slab buildings designed as per guidelines of Indian code, ACI code, Eurocode and New Zealand code guideline have been evaluated under earthquake loading. Equivalent frame approach is used to model the flat slab as beam members of equivalent width. Torsional members are provided to account for the unbalanced moment under lateral loading. It can be seen that torsional portion of unbalance moment at the exterior support causes excessive punching shear stress, and design of flat slab is governed by punching shear failure.

C.S. Garg, Yogendra Singh, studies the performance of flat slab under lateral loading using pushover analysis. In this analysis, a parabolic lateral load has been applied according to IS 1893(part 1) to a flat slab building along its height. The lateral loads applied are increased until it's any member shows yield and then the stiffness of the structure is changed, considering the stiffness of the yielded member. This process is continued until the top deformation of the building reaches to defined deformation or it becomes unstable.

3. PUNCHING SHEAR FAILURE

Punching shear is that failure which occurs when a flat slab is subjected to high localized forces around the column; this failure is due to shear. This failure is so important because no prior sign is visible before failure. In flat slab structure, this occurs at the slab and column support point and this result in cracks failure around the column in the slab. A model is created as shown in Figure 1 to show its effects around column under Lateral loading

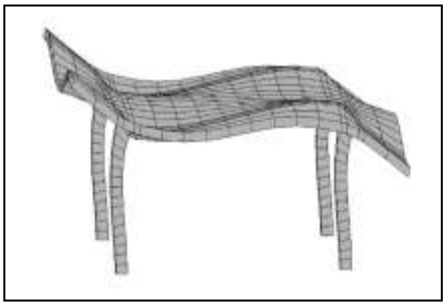

Figure 1: Punching shear of slab around column

4. NUMERICAL MODELLING

A flat slab along with the four columns is taken as a structure model on which three-dimensional finite element analysis is performed. In this method of analysis slab and columns are divided into fine meshes to form finite elements. This method of analysis subdivides the large problem into smaller. Meshing is such that it provides well know eight noded hexahedral elements. Only 3 degrees of freedom is considered for each node i.e., along x, y and z-direction displacement. Nodal coordinate matrix, element connectivity matrix, stiffness matrix and strain matrix are formed. After applying boundary conditions at the column bottom node by making rigid, FEM model is run by following governing equation (1) to calculate displacement from a force applied and global stiffness matrix.

$$F = K\,U \qquad (1)$$

F = force applied, K = global stiffness matrix, U =displacement at the nodes.

5. NONLINEAR ANALYSIS

As stress-strain behavior in concrete is nonlinear, to encounter cracks in concrete behavior nonlinear analysis is done. To perform the analysis incremental Newton-Raphson method is applied. In this method of analysis Externally applied load is divided into small number of load increment defined by user and for each load increment iteration process is started to make residual force so small such that convergence is achieved and simultaneously tangent stiffness matrix are calculated and updated with previous iteration stiffness matrix, next increment is performed as shown in Figure 2.

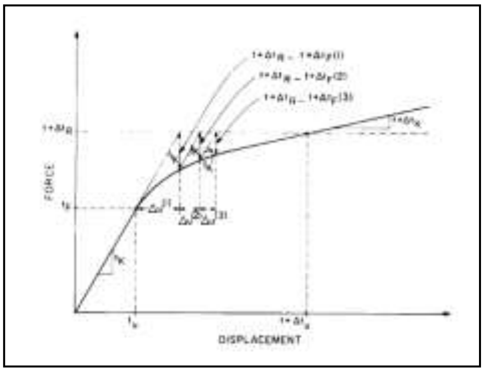

Figure 2: Convergence

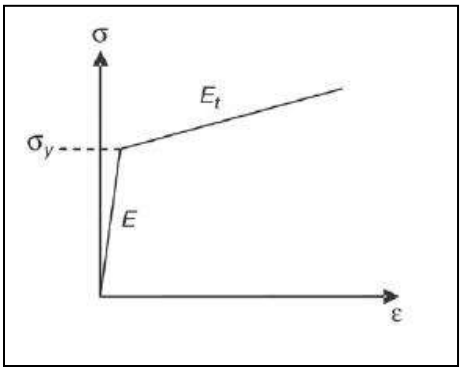

Figure 3: Bilinear model of concrete

Where residual force are calculated by equation

$$F_{residual} = F_{external} - F_{internal} \quad (2)$$

$F_{external}$ = Applied load
$F_{internal}$ = Internal force generated due to internal stress.

In this study material nonlinearity is considered by considering the bilinear model of stress and strain of concrete as shown by Figure 3 and equation 3 and 4.

$$\sigma_y = E \times \varepsilon \text{ for } \varepsilon <= 0.002 \quad (3)$$
$$\sigma_y = E_t \times \varepsilon \text{ for } 0.002 < \varepsilon <= 0.0035 \quad (4)$$

Where σ_y is stress value and ε is strain value and E is modulus of elasticity of concrete in linear state and E_t is modulus of elasticity of concrete in nonlinear state.

6. NUMERICAL EXAMPLE

6.1 Data

Flat slab of length l = 7500 mm, breadth b = 7500 mm, thickness t = 200 mm, interior panel of slab length = 5000 mm, breadth = 5000mm, four column of length = 500 mm, breadth = 500 mm and height h = 3000 mm. Material properties of slab and columns are: maximum compressive strength of concrete f_c = 25 N/mm^2. Modulus of elasticity of concrete E = 2.5 × 10^4 N/mm^2, modulus of elasticity of concrete after yielding point E_t = 5 × 10^3 N/mm^2, Density of concrete density ρ = 2.5 × 10^{-6} Kg/mm^3, Poisson's ratio = 0.18.

6.2 Design of Flat slab designed as per IS code

Thickness (t) = 200 mm
Effective depth (d) = 175 mm
Gravity load (weight) = $t \times \rho \times g$ (5)
= 4.9 × 10^{-3} N/mm^2
Factored load (W) = 1.5 × weight (6)
= 7.35 × 10^{-3} N/mm^2
Clear span (L_n) = 5000-500 = 4500 mm
Total design load W = 7.35 × L_2 × L_n (7)
= 165375 N
Moments
Panel moment $M_o = \frac{WL_n}{8}$ = 93.02344 9 × 10^6 N-mm
Panel negative moment = 0.65 × 93.02 × 10^6 = 60.46 × 10^6 N-mm
Panel positive moment = 0.35 × 93.02× 10^6 = 32.56 × 10^6 N-mm

Distribution of moments into column strip and middle strip can be shown in Table 1

Table 1: Moment distribution into the strips

	Column strip in N-mm	Middle Strip in N-mm
Negative moment	$0.75 \times 60.46 \times 10^6 = 45.34 \times 10^6$	$0.75 \times 60.46 \times 10^6 = 15.11 \times 10^6$
Positive moment	$0.6 \times 32.56 \times 10^6 = 19.54 \times 10^6$	$0.4 \times 32.56 \times 10^6 = 13.02 \times 10^6$

$$b = 0.5 \times 5000 = 2500 \text{ mm}$$

Checking the thickness selected $M_{u\ lim} = 0.138 \times f_c \times b \times d^2$ (8)

$$M_{u\ lim} = 0.138 \times 25 \times 2500 \times 175^2 = 264.1 \times 10^6 \text{ N-mm}$$

Where $M_{u\ lim}$ is the maximum limiting value of moment and b is the width of column strip. As Limiting moment is more than moment coming on strip, so thickness provided is satisfactory.

7. FLAT SLAB FEM MODELLING AND ANALYSIS

Flat slab and columns are considered as a combined structure, same as numerical data mentioned in the section 5.1 is being used to model this system.

7.1 Coordinate System

Considered coordinate system used in the modeling is represented by the figure 4

7.2 Mesh formation

By taking consideration of mesh sensitivity, flat slabs are divided into 15 × 15 × 1 hexahedral elements along x, y and z-direction respectively. Four columns each are divided into 1 × 1 × 15 hexahedral elements along x, y and z direction respectively.

7.3 Model

3D model is shown in Figure 5.

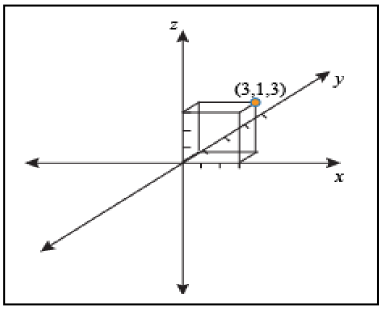

Figure 4: Coordinate system

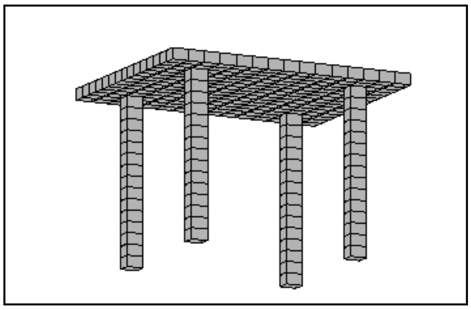

Figure 5: 3D Model of flat slab structure

7.4 Methodology

After mesh creation, each hexahedral element has got the property of concrete assigned, and stiffness matrix is calculated. As every element are connected to each other at the nodes, so combined nodal coordinate matrix, element connectivity matrix and global element stiffness matrix are formed. To provide the suitable boundary conditions, the bottom nodes of the columns can be fixed by making displacement at that node equal to 0.

Three models are taken, in first model gravity load is only applied and in second model gravity as well as lateral load of 0.8 N/mm^2 is applied in positive x-direction on left face of the slab and its linear analysis is done. In the third model gravity as well as lateral load is applied and material nonlinearity is performed. In this model lateral load is applied and increases from 0 with the increment of lateral load value of 0.1 N/mm^2 until the element goes into the nonlinear state.

7.5 Results

Top surface deformation contour and stress concentration contour in z-direction are shown in the figures. Model 1 shows the considered model is safe against gravity as reaction at the column base is equal to weight of the structure.

7.5.1 Model 1

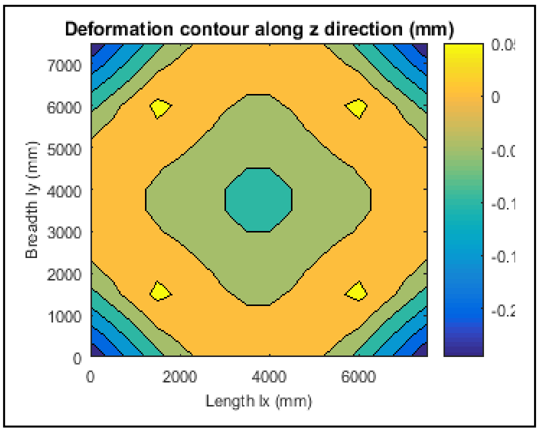

Figure 6: Top deflection of slab

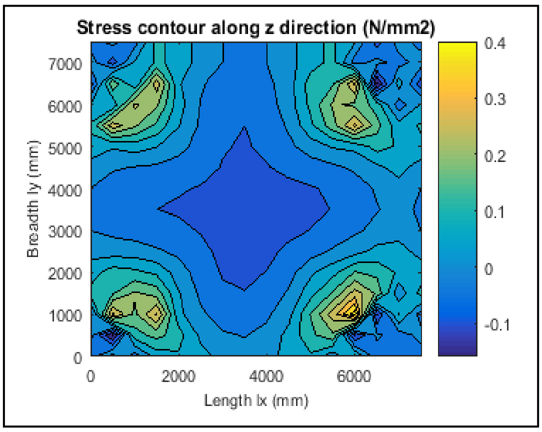

Figure 7: Stress concentration on the slab

7.5.2 Model 2

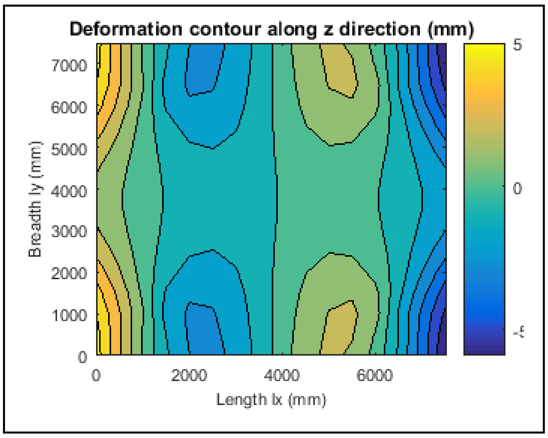

Figure 8: Top deflection of slab

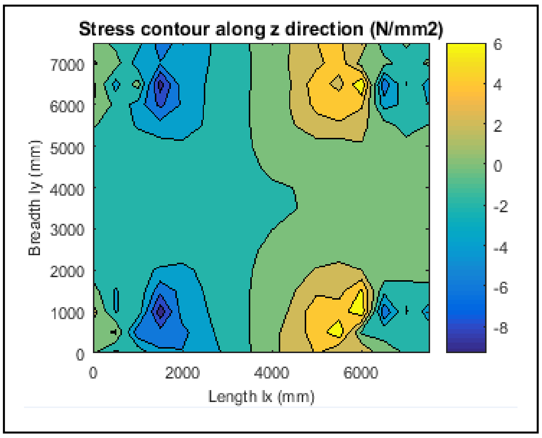

Figure 9: Stress concentration on the slab

7.5.3 Model 3

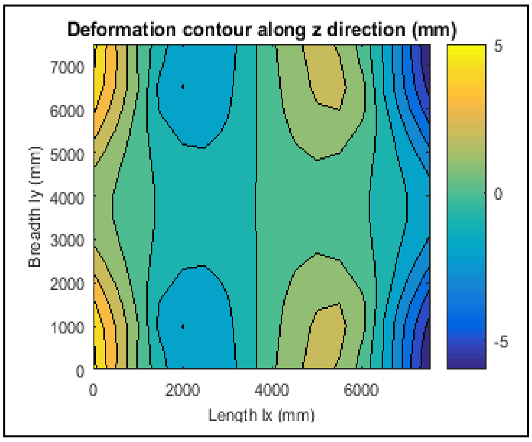

Figure 10: Top deflection of slab

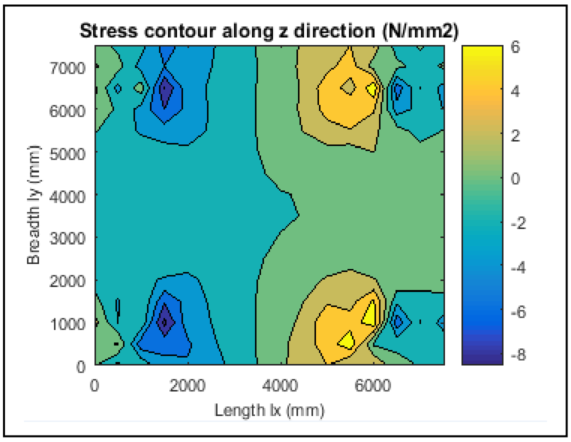

Figure11: Stress concentration on the slab

In this analysis, at the 9th increment i.e. at lateral load = 0.8 N/mm^2, 12 elements out of 285 shows nonlinear behavior and shows yielding. This nonlinear behavior can be seen at the slab and column connections.

8. CONCLUSION

The results of this test describe about the behavior of flat slab under different loading condition. As from model 1 and model 2 it can be understood about deformation and how the stress is distributed on the flat slab due to gravity and lateral loading. In model 1 due to gravity load positive stress develops in the slab at the column location while the negative stress is on the rest part of the slab. Considering model 2, model 3 both positive and negative stresses develop in the slab around the column position. To understand the behavior under lateral loading more accurately, Model 3 was performed i.e., nonlinear analysis. As for the same final lateral load of 0.8 N/mm^2 applied on model 3 shows the correct behavior under lateral load as it consider the material nonlinearity of model.

Design of slab should be done such that it takes into account both type of stress behavior. Special attention should be given at the slab and column sub assemblage as the complete change in stress behavior of slab is at the column location.

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