Analysis & Design of Beamless Slab

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Abstract
The flat slab system now-days is largely used in construction. It allows architectural flexibility, more clear space, less building height, easier formwork and less construction time. Flat slab is defined as one sided or two-sided support system with shear load of the slab being concentrated on the supporting columns and a square slab called 'drop panels' This paper presents computational analysis and design of flat slabs supported directly on column. To carry out an extensive parametric study, three-dimensional finite element analysis has been carried out by using STAAD.pro. The study contains the design of G+8 storey building where the height of top floor was exceeding the permissible height and simultaneously the construction was to be done in designed time frame. The behaviour of stresses in flat slab and design for safe shear are aimed by providing additional shear reinforcement. Space analysis of the achieved results are found to be under permissible limits and design is carried out as per the relevant IS codes.

Introduction
As in many other types of civil engineering structures, construction of flat slab preceded its theory of analysis and design. C.A.P Turner constructed flat slabs in U.S.A as early as in 1996 mainly using intuitive and conceptual ideas. This was the start of these types of construction. Many slabs were load-tested between1910-20 in U.S.A. It was only in 1914 that Nicholas proposed a method of analysis of these slabs based on simple statics. This method is used even today for the design of flat slabs and is known as the direct design method. [4]
Flat slab structures are very flexible and undergo huge deflection under lateral load induced by earthquakes. [1] Susceptibility of this type of structures to progressive collapse is very high, as the load re-distribution is not significant due to absence of beams. [5] Flat slabs generally fail in punching shear mode, which is a weak mode of failure, and in past earthquakes flat slab buildings have experienced sudden collapse due to punching shear failure.

Flat slab is a reinforced concrete slab supported directly on columns without the use of beams. Flat slab is defined as one sided or two-sided support system with shear load of the slab being concentrated on the supporting columns and a square slab called drop panels. A flat slab can be constructed in the following ways.

1. As solid slabs or ribbed slabs or ribbed slabs resting on walls or on beams and columns.
2. As flat plates resting directly on columns.
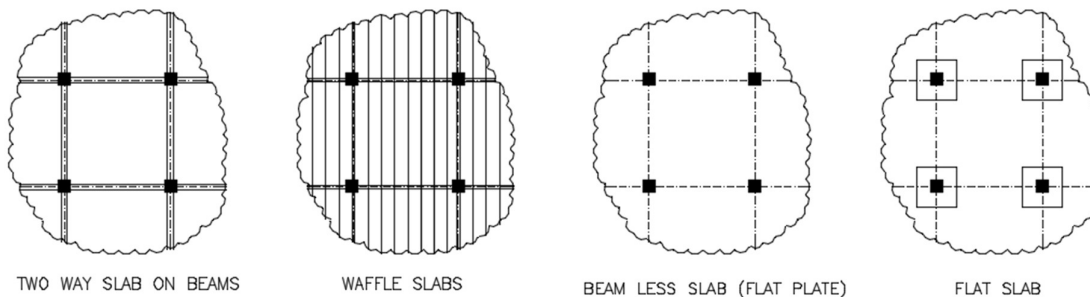3. As flat slabs with or without drops supported on columns with enlargements. (Column Heads)

TWO WAY SLAB ON BEAMS   WAFFLE SLABS   BEAM LESS SLAB (FLAT PLATE)   FLAT SLAB

Fig. 1: Different Types of Slab

Advantages of Flat Slabs:
1. Lowering in the total height required for each storey, thus increasing the number of floors that can constructed in a defined height.
2. Saving in materials of construction.
3. More uniform access to natural light of the day and easier accommodation of the various ducts in the building.

Disadvantage of Flat Slabs:

The main disadvantage of flat slabs is their lack of resistance to lateral loads, such as those due to high winds and earthquakes. Hence, special features like shear wall must be always provided if they are to be used in high-rise constructions or in earthquake regions.

Major concern with the flat slab is that unless any special/specific measures are adopted, the shear capacity at the column-slab connection is low after punching failure which can generate a horizontal propagation of failure and subsequently the slab can fall onto the next lower floor. The propagation of failure (horizontally and vertically) is influence by the dynamic effect which can notably increase the shear demand in the slab-column connections. As indicated by Vlassis et al. [8], modelling the connection behaviour precisely is critical towards providing alternative load paths and achieving continuity and ductility in the structure.

The difference in the actions of flat slab from those of conventional two-way slab is shown below fig. 2, in flat slabs the load on the slab are directly transferred by plate action to columns, whereas in conventional slabs with beams, the loads are first transferred from slabs to the beams and then from beams to the columns. A good appreciation of this load-transfer mechanisms (or load path) is necessary for a clear understanding of the analysis of these structures. [4]
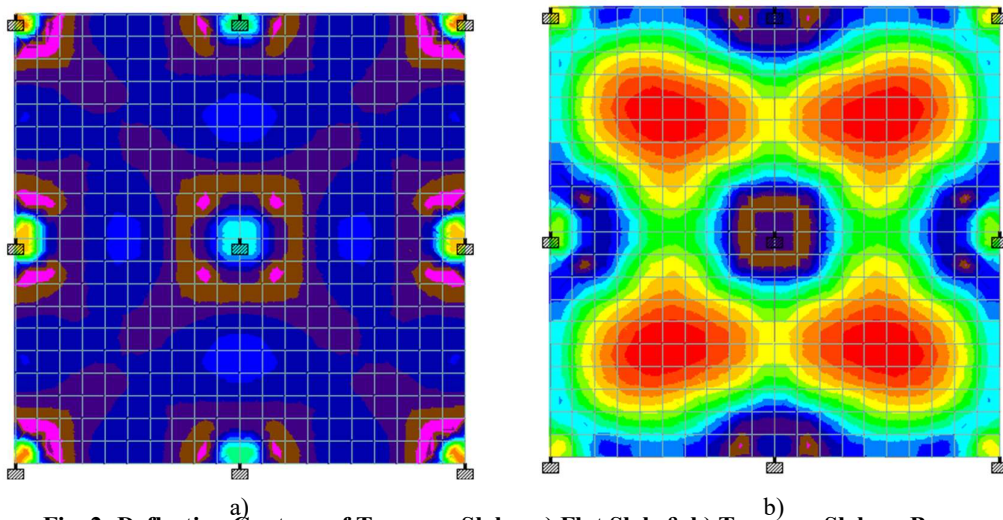

a)   b)

Fig. 2: Deflection Contour of Two-way Slabs: a) Flat Slab & b) Two-way Slab on Beams

A flat slab with 6.3 x 5.3m maximum panel size has a slab thickness of 175mm, is to be designed for the 8th floor where the floors beneath the top floor is designed as normal two way slab and the restrictions to be faced while designing the 8th floor flat slab the height should be less than the height of normal slab simultaneously the construction of whole structure should not be delayed.

Objectives

Following are the main objectives of the current study:

1. To analyse the behaviour of flat slab supported on column for a defined structure.
2. To study the vulnerability of flat slabs resting on column under different factors such as shear stress and bending moment near the supporting column.
3. Three-Dimensional modelling is to be carried out by finite element method using STAAD.PRO
4. Design of flat slab for safe shear by providing additional shear reinforcement.

Methodology

The finite element analysis software STAAD.PRO is used to create 3-D model of flat slab supporting on column and run the linear static analysis for the following data:

 i.   Building type – Flat Scheme G+8 (Residential Building)
 ii.   Live Load = 2 kN/Sqm
 iii.   Floor Finish = 1 kN/Sqm
 iv.   Wall Load = 1 kN/Sqm [3]
 v.   Grade of concrete for building M30
 vi.   Grade of Steel Fe415
 vii.   Maximum panel size = 6.3m x 5.3m
 viii. Thickness of slab = 175mm
 ix.   Maximum column size = 230 x 1200 mm
 x.   Analysis = Space Frame Analysis
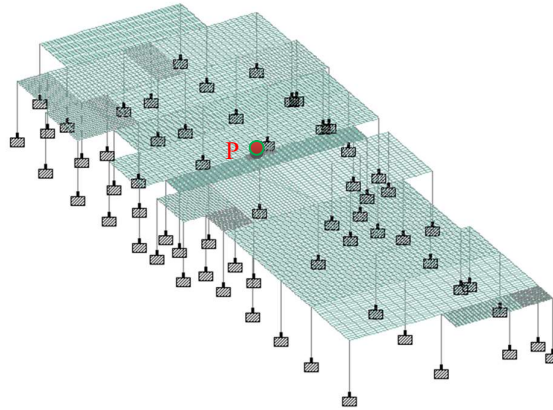 xi.   Design Philosophy = Working Stress Method

Fig. 3: Model of Structure

Results

After analysis the model we have to find the design forces i.e. stress and bending in slab to design the flat slab. Fig. 4 shows the stress contour developed in the slab after the analysis.
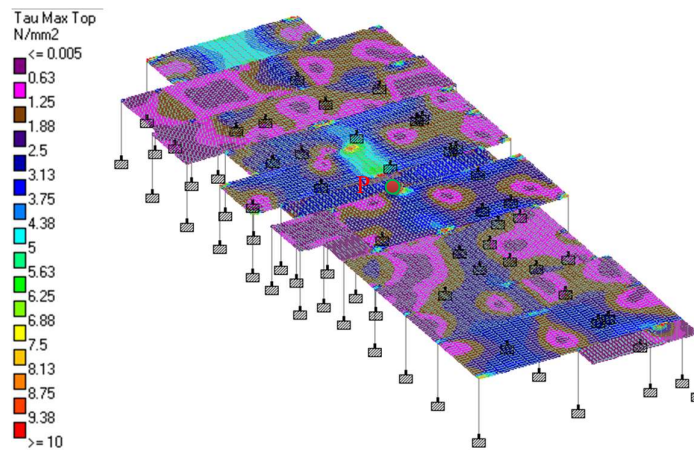

Fig. 4 Stresses in Flat Slab

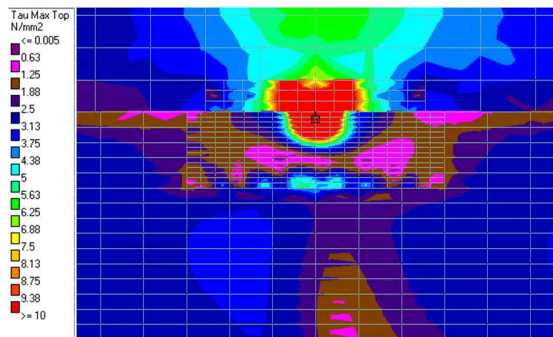As point P is located at the centre of the column, maximum forces will be developed as shown below
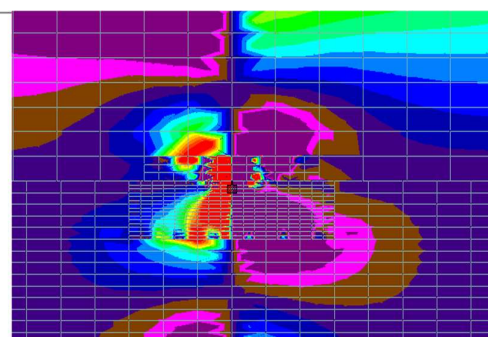

Fig. 5: Stresses at Point "P"   **Fig. 6: Moments at Point "P"**

Design for Shear Stress

Generally, flat slabs (with drops) can be made safe in punching shear without extra shear steel by increasing the thickness of the slab near the columns as drop panels. But this increases the cost of shuttering and, in addition,

drops are also not very pleasing to the eyes. In flat plates, however, punching shear becomes critical and extra reinforcements to cater for punching shear will be found necessary.

Value of punching shear, v_p	Type of shear reinforcement
$v_p \leq \tau_p$	No special steel needed
$v_p > \tau_p$ but $\leq 1.5\tau_p$	Provide designed bar reinforcements
$v_p > \tau_p$ but $\leq 1.75\tau_p$	Provide designed fabricated-shear head reinforcement
$v_p > 1.75\tau_p$	Redesign the slab

Table 1 : Design for Punching Shear

Where $\tau_p = 0.25\sqrt{f_{ck}}$ in limit state method of design and $0.16\sqrt{f_{ck}}$ in working stress method of design

Note: When providing steel for shear assume concrete takes only $0.5\tau_p$

The critical section of the for-shear stress shall be at distance d/2 from periphery of column. [2]
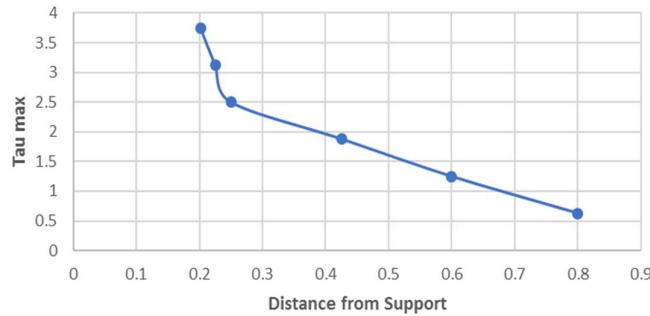

Fig. 7: Stresses Variation at Point

Considering average of values given in graphs in fig. 6 up to the shear stirrups is to provided. i.e. 700mm from the face of column.

$\tau_{avg} = 2.1 N/mm^2 > \tau_p = 0.16\sqrt{30} = 0.88 N/mm^2$ so that providing additional shear reinforcement.

$Tensile\ Force\ T = 2.1 \times 230 \times 175 = 84.52\,kN$

$Ast = \dfrac{T}{\sigma_{st}} = \dfrac{84.52 \times 10^3}{230} = 367.5 mm^2$

$T = 2.1 \times 1200 \times 175 = 441\,kN$

$Ast = \dfrac{T}{\sigma_{st}} = \dfrac{441 \times 10^3}{230} = 1917.39 mm^2$

$i.e.\Pr oviding\ shear\ stirrups\ 12mm\phi\ 2-legg\ @100mm\ c/c\ up\ to\ the\ 700mm\ from\ face\ of\ column.$

Design for Bending Moments
Bending moments at face of column M_{max}= 18.8 kNm

$Ast = \dfrac{18.8}{0.207 \times 0.15} = 605 mm^2$

Bending moments at 700mm from face of column M_{max}= 6.25 kNm

$Ast = \dfrac{6.25}{0.207 \times 0.15} = 201 mm^2$

$i.e.\Pr oviding\ 8mm\phi\ @200mm\ c/c\ double\ mess.$
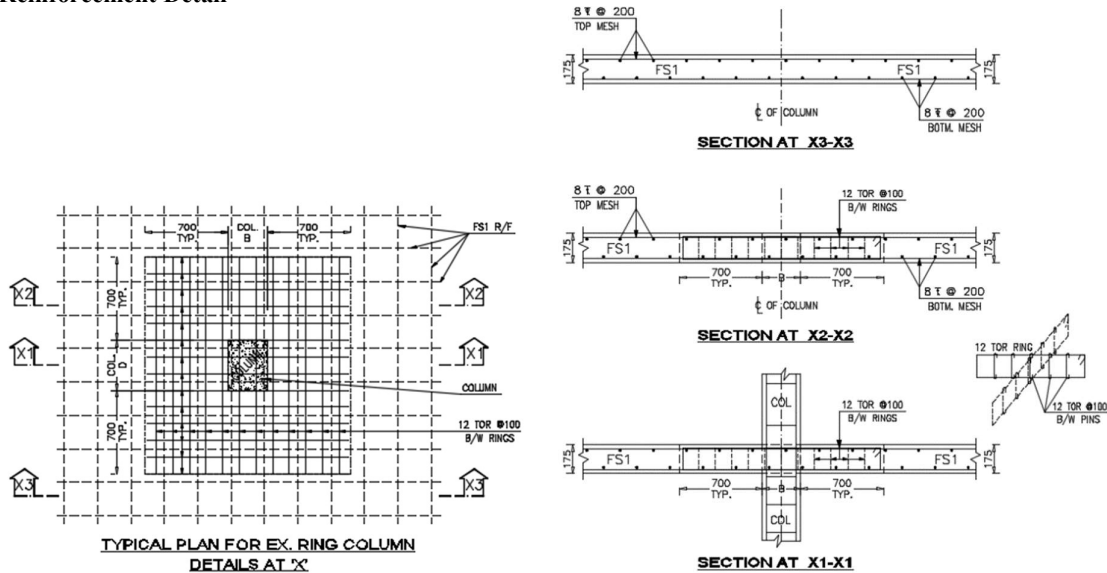
Reinforcement Detail

Fig. 8: Reinforcement Detail of Beamless Slab (Flat Slab)

Conclusion

1. Analysis of the behaviour of flat slab supported on column for a defined structure is successfully performed.
2. Shear stress for the critical column in the maximum sized panel i.e. 6.3 x 5.3m is found to be $\tau_{avg} = 2.1 N/mm^2 > \tau_p = 0.16\sqrt{30} = 0.88 N/mm^2$ so that providing additional shear reinforcement.
3. The shear stress calculated for the maximum sized panel is well within the permissible limits of IS 456:2000.
4. Three-Dimensional modelling is carried out by finite element method using STAAD.PRO is successfully performed and desired bending moments have been incorporated in above results which are well shown in graphical contours.
5. Analysis and design work helped in optimising the construction cost as well as cost of shuttering is reduced by a marginal amount and the desired work is also completed well within the time frame.

References

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