Reinforcement concrete flat slab engineering essay

A flat slab is a slab (with or without drops) supported (generally without beams) by columns (with or without column heads). It is also defined as a reinforced concrete slab supported directly by concrete columns without the use of beams. Flat slabs are one of the most commonly used structural systems in residential buildings, hotels, hospitals and office buildings. Flat slabs are solid concrete slabs that transfer the load directly to columns of uniform thickness. One of the important approach systems that make flat slab systems a very attractive solution is the ease of its construction. Architects prefer the flat slab systems due to the flexibility in arrangement of partitions and columns giving architects the best use of space.

Punching shear

What is punching shear?

Punching shear is a type of failure of reinforced concrete slabs subjected to high localized forces. In flat slab structures this occurs at column support points. The failure is due to shear:

Flat slabs and punching shear: reinforcement systems

The most popular floor system used in residential car parks, buildings and many other structures (due to large span required) is reinforced concrete flat slabs. They are easy to construct floor systems to keep the height between floors and ceiling. Flat slabs are preferred to the clients and architects due to economics advantage and it is speeding up the construction process. But there is a major weakness in flat slab from structural engineering point of view that they are vulnerable to punching shear failure at the junctions of columns and columns. The major concern when using flat slabs is shear transfer from slab to the columns. Its danger for columns may punch through the slab, it is suitable to use drop panels at the column if the live loads exceed 3, if live loads exceed 6 it's suggested to use column head, in case of heavy live loads (greater than 10) it's suggested to use column head with drop panels as case of industrial buildings. When it comes to heavy loads it is preferred the flat slab floor system such as multistory car parks and multistory buildings where large spans with large areas are required. A column head or drop panel supports the flat slabs to provide the resistance to punching shear around the column. But from the architectural point of view it's not preferred to save space between floors. The most serious type of failure is the shear failure due to punching shear that will occur at the columns. A typical punching shear failure is characterized by diagonal crack starting from the bottom of the slab and making their way to the top at the angle of 20-45 degree to the horizontal leading to the separation of the slab around the column in a truncated pyramid shape. The progressive collapse of a structure is produced as one way reaction of punching shear failure. The punching shear capacity of a slab without shear reinforcement depends on the strength of concrete, depth of the slab and column size and the area of tension reinforcement. Also the shear capacity can be reduced by any openings close to the column's perimeter like services for multi storey buildings.

Uses of column heads:

Increase shear strength of slab

reducing the span to reduce the moment in the slab

if live loads exceed 6

Uses of drop panels:

Increase shear strength of slab

Increase negative moment capacity of slab at location of high negative bending and reduces the risk of shear failure

Reduce deflection by stiffen the slab

if the live loads exceed 3

Shear studs as punching shear reinforcement for flat slabs:

The use of stud systems for punching shear reinforcement is an efficient solution for concrete flat slabs where punching shear reinforcement is on the critical path where experience takes place which indicates the preferred form of shear reinforcement.

Analysis of flat slabs

Flat slab can be analyzed and designed by any methods like:

direct method

equivalent frame method

finite element (SAP) (computer model)

Neither the direct method nor equivalent frame method can solve slabs have unusual geometric configurations or the columns are spaced irregularly, therefore these special cases the floor can be analyzed by using finite element analysis, which the slab is divided into small finite elements which is connected by nodes. The element of the stiffness matrix is computed and the global stiffness matrix is constructed. The deformation at each node can be determined and the element internal forces can be obtained.

Direct method

Limitation of the direct method

To make sure that the moments at the critical sections are correct, there are design conditions that must be required

A minimum spans required is three continuous spans in each direction.

The ratio of the longer to the shorter span within a panel shouldn’t exceed 1. 3

The difference between the successive span lengths in each direction shouldn’t be more than 10%

The difference between the non-successive span lengths in each direction shouldn’t be more than 20%

Definition of column strip and field strip

The distribution of moment varies continuously across the width of the slab panel, to simplify the steel arrangement, the design moments are averaged over the width of the column strip.

The column strip width should be taken as half the sort direction for slabs without drop panels, in case of flat slab with drop panel, the column strip width equals the drop width. The width of the field strip equals the difference between span length and column strip width.

Statical Moment Mo

The direct design method is an empirical procedure for establish the design of critical sections moments. At the supports there is negative moment and at the mid span of uniform loaded beams there is positive moment.

The smallest distance at the intersection between the slab and column is D. if the sides of the rectangle are not parallel to the span or the supporting element doesn't have rectangular cross section, then it is treated as square having the same area.

The total static moment Mo is divided into a positive moment at mid span and a negative moment at the support.

Definition of D for different flat slab systems (with drop panel or with column head or both with column head and drop panel)

Distribution of Static Moment

The actual distribution of the transverse moments by two regions of constant moment. The moment is the smallest at the center strip where it is called field strip (or middle strip) and the moment is the largest at the strip in the column zones where it is called the column strip. This to simplify the analysis of the flat slab floors.

Column strips and field strips

As shown in this figure (column strips and field strips), the distribution of the moments can be explained between the field strip and the column strip. The column strip can be represented at beam A; field strip can be represented at beam B and beam C. since beam B and beam C are supported on beam A and beam A is rested directly on columns. The developed bending moment in beam A is larger than that in beam B and beam C. because all beams are subjected to uniform load (w) and beam A carries the reaction WL/2 from beam B and c in addition to the same uniform load (w). For an actual flat slab, the ratio between the field strip moment and column strip moment is variable and depends on the flexural stiffness and the rectangularity ratio of the exterior beams along the building perimeter (if any exists).

Distribution of Mo between column strip and field strip

As shown in this figure the total Statical moment (Mo) is divided into positive moment and negative moment. In the interior spans, 40% of the Mo is distributed to the negative moment and 60% of the Mo is distributed to the negative moment. This is approximately the case for a beam fixed from both ends and uniformly loaded where the positive moment is (/24) 33% of the total moment of (/8) and the negative moment is (/12) 67% of the total moment of (/8).

The distribution of the negative moment between the field strip and column strip varies according to the stiffness of the edge beam. If the edge beam depth is less than three times the slab thickness, 25% of the Mo is assigned to column strip. In the case of floors that differ in spans (within 20% difference), the negative moment section of the slab is designed for the larger of the two moments.

strip type

marginal beam

exterior bay

Interior bay

negative moment(external)

positive moment

positive moment(internal)

negative moment

positive moment

column strip

no beam

25

30

50

45

25

with beam

20

field strip

no beam

5

20

20

15

15

with beam

10

Column strip negative moment (45%)

Negative moment (60%)

Field strip negative moment (15%)

Mo (100%)

Column strip positive moment (25%)

Positive moment (40%)

Field strip positive moment (15%)

Moment distribution in inter panels (with or without marginal beam)

Column strip negative moment (35%)

Negative moment (50%)

Field strip negative moment (15%)

Mo (100%)

Column strip negative moment (30%)

Positive moment (50%)

Field strip negative moment (20%)

Moment distribution in exterior panels with marginal beam

Provision for pattern loading

If heavy live loads are subjected to the slab, negative moments shall form at mid span in addition to positive bending moments. If the live load (p) is greater than 1. 5 the dead loads (g), the negative bending in column strip in L1 direction can be estimated as following equation

M (negative) = (g -) x () x

And the negative moment in the field strip in L1 direction is

M (negative) = (g -) x () x

Where:

L1 = span in direction 1

L2 = span in direction 2

D = width of the column at slab intersection

g= uniform dead loads

p= uniform live loads

Punching shear strength of Flat Slabs

Punching shear strength is one of the most critical design aspects in demining the thickness of the flat slab. There are two shear failure mechanisms that can be encounter in a flat slab system.

One way shear

Two way shear

One way shear is similar to that in beams, this type of shear is rarely controls the flat slab floors design, the two way shear the failure surrounds the column forming a pyramid shape. The two way shear has stresses much higher than one way shear. Two way shear failure mechanism is usually encounter in footing and in flat slab. The interior columns are generally subjected to shear with negligible moment transfer from slab to columns. Interior columns moment are not obvious by the combination of shear but the combination of shear and unbalanced moment is obvious at corner and edge column locations, because of the lateral loads and unequal spans. Prevention of punching failure of column lab connections transferring moment depends on accurate calculations of shear stresses produced by the transfer of the moment. This analysis is developed by the ACI and Egyptian code of practice.

Design steps according to Direct Design Method

Choose the appropriate flat slab system according to the intensity of the live load and architectural requirements.

Assume the thickness of the slab according to the code requirements.

Calculate the total static moment to be resisted in the two directions.

Distribute the static moment between column strip and field strip.

Divide the resulting moments by strip width to obtain the moment per meter.

Design the section to select the reinforcement.

Design the slab for punching shear.

The Equivalent Frame Method

In 1948 the Equivalent Frame Method was introduced. It is used to analyze moments in any practical frame building. Equivalent Frame Method is more general than the Direct Design Method. If the buildings do not satisfy the geometrical and loading conditions or if the lateral load due to earthquake or wind exists required by the code, then the building required to be analyzed by the Equivalent Frame Method. The Equivalent Frame Method for flat slab system design is more accurate method of analysis than the Direct Design Method. A series of two dimensional frames are represented for the building, which are then analyzed for loads acting in the planes of the frames. The statical moment (Mo) in the direct method is calculated for each span and divided between negative and positive moment regions according to the code coefficients.

This method can be summarized as:

Moments are distributed at the critical sections by employing an elastic analysis. Cases of loading have to be considered for the critical loading conditions.

Dimensions or loading have no limitations.

Drop panels have to be considered in the analysis in the variations in the moment of inertia.

Equivalent frame can perform the computation of lateral analysis.

The total statical moment calculated by using the Equivalent frame method cannot exceed the moment (Mo) required by the direct design method.

Structural analysis

The slab of equivalent frames is divided into a series in two perpendicular directions. These frames consist of the slab, projected beams, drop panel and the columns above and below the considered floor. Then the frames are divided into field strips and column strips. To reach the maximum moment for the members, live load is placed at the position where it can produce maximum moment. The total strip width can calculate the inertia for the slab in case of analyzing vertical loads. While the column width plus three times the slab thickness from each side (can’t exceed span / 3) can calculate the moment of inertia for slab in case of lateral load analyses. In lateral analysis, the differences of earthquake and wind forces must be modeled of full height of the building at each level. Calculations can be simplified by the analysis of each floor and its attached column individually if the analysis is limited to gravity loads. Fixation is considered at the beginning and ending of the column at the intersection with the floor (slab). Changes in column cross section along the length of the column due to the moment of inertia of columns may be based on the gross area uncracked concrete causing difference. Resisting moment is a result from the column which equivalent to the applied torsional intensity. The torsional deformation because of the exterior ends of the slab strip rotate more than the central section. An equivalent column replaces the actual column and the transverse slab strip to account for the rotation and deformation.

Elements of the equivalent frame method

The sum of the flexibilities of the actual column and slab strip is equal to the flexibility of the equivalent column.

$= +$

The stiffness of a member is the inverse of the flexibility of that member, the above equation can be written as

$=$

$=$

From above equation can be explained by making a similarity between the system of two springs and the equivalent column. The sum of the two individual displacements equals the total deformation of both systems. If a single spring with an equivalent stiffness is being replaced by the two springs. When identical load (P) is applied at the end, the second system and the original system must deflect similarly. By equating the deflection of system one to that of the equivalent system two, it gives

Î" = +

The relation between force and displacement for a spring is P = K Î", the above equation can be expressed in terms of the stiffness and applied load (P)

K = spring stiffness

+ =

By dividing both sides with p, it gives the following equations

+ =

The above equation is similar to that of code but includes a summation sign to account for the possibility of contributions from columns at the beginning and ending of the slab. Torsional member has an approximate expression for it's stiffness, based on the results of three dimensional analysis of various slab configurations is given by the following equation

= Î£ ( )

= modulus of elasticity of concrete

= the transverse dimension of the column, equivalent column, capital

= the center to center distance measured perpendicular to the analysis direction

Cross sectional constant (C) can be explained to define torsional properties as

C = Î£ ((1-0. 63))

X = shorter dimension for the member

Y = longer dimension for the member

Torsional member consists of slab and beam; section can be divided into a number of rectangles.

moment type

percentage of moment from total moments

column strip

field strip

negative moment in interior panel

75

25

negative moment in exterior panel

80

20

positive moment

55

45

Distribution of column strip and field strip in equivalent frame method

Equivalent column and similar spring system

Column strip and field strip in the equivalent frame method

Use of computer in the equivalent frame method

The equivalent frame method was derived by assuming that the structural analysis would be carried out by using the moment distribution method, fixed end moment, stiffnesses and equivalent column stiffnesses are computed for use in such an analysis. If a standard frame analysis program based on the stiffness method is to be used. The frame must be specially modeled to get answers that agree with those obtained from the equivalent frame method. The Portland cement association has written and maintains the computer program ADOSS “ Analysis and Design of Slab Systems”.