

Optimum Design of Reinforced Concrete Flat Slab with Drop Panel

Kiran S. Patil, N.G.Gore, P.J.Salunke

Abstract— In this present study optimum design of reinforced concrete flat slab with drop panel according to the Indian code (IS 456-2000) is presented. The objective function is the total cost of the structure including the cost of slab and columns. The cost of each structural element covers that of material and labour for reinforcement, concrete and formwork. The structure is modelled and analysed using the direct design method. The optimization process is done for different grade of concrete and steel. The comparative results for different grade of concrete and steel is presented in tabulated form. Optimization for reinforced concrete flat slab buildings is illustrated and the results of the optimum and conventional design procedures are compared. The model is analysed and design by using MATLAB software. Optimization is formulated is in nonlinear programming problem (NLPP) by using sequential unconstrained minimization technique (SUMT).

Keywords—Flat slab, Reinforced concrete, Structural optimization, Punching shear stress, slab size, drop panel size.

I. INTRODUCTION

Common practice of design and construction is to support the slabs by beams and support the beams by columns. This may be called as beam slab construction. The beams reduce the available net clear ceiling height. Hence in ware houses, offices and public halls sometimes beams are avoided and slabs are directly supported by columns. These slabs which are directly supported by columns are called flat slab shown in “Fig. 1”

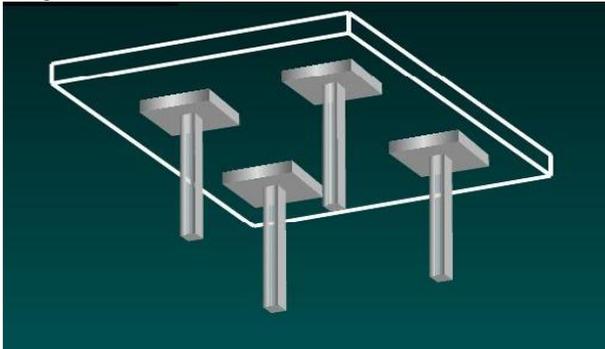


Fig.1 Typical shape of flat slab with drop panel

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A reinforced concrete slab supported directly by concrete columns without the use of beams. Flat slabs are highly versatile elements widely used in construction, providing minimum depth, fast construction and allowing flexible column grids. The term flat slab means a reinforced concrete slab with or without drops, supported generally without beams, by columns with or without flared column heads. A flat slab may be solid slab or may have recesses formed on the soffit so that the soffit comprises a series of ribs in two directions. The recesses may be formed by removable or permanent filler blocks. Gupta et al. (1993) described computer aided design of flat slab-column-footing structure. Ronaldo et al. (1999) proposed a theoretical model for analyzing the punching resistance of reinforced flat slabs with shear reinforcement for concentric loading. M.G. Sahab et al. (2005) had presented Cost optimization of reinforced concrete flat slab buildings according to the British Code of Practice (BS8110). Vikunjetal. (2011) presented cost comparison between flat slabs with drop and without drop in four storey lateral load resisting building. Galebet al. (2011) presented optimum design of reinforced concrete waffle slabs. Adedeji(2011) had presented application: simplifying design of RC flat slab using taboo search.

II. STRUCTURAL ANALYSIS

The structural analysis of flat slab systems can be carried out using the direct design method and adopted by Indian code (IS 456-2000).

In direct design method, a flat slab building having a rectangular column layout is divided into a series of longitudinal and transverse plane. Each frame consists of a row of equivalent columns and beams representing columns and strips of slabs bounded laterally by centre lines of panels adjacent to columns. In each direction, edge and middle equivalent frames are structurally analyzed to obtain the total bending moments and shear forces at different sections of slabs. These slab panels are loaded with the full uniform gravity dead and imposed loads over the width of panels. It is assumed that the width of beams is divided into two strips, namely column and middle strips. The average bending moment over each strip is obtained as a percentage of the total bending moment at each section. The required reinforcement in each slab section is calculated according to the design bending moment obtained in each section of column and middle strips as shown in “Fig. 2”

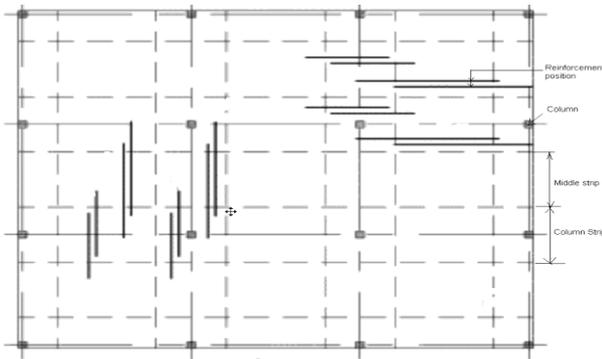


Fig.2 Typical arrangement of column and drop panel

It should be noted that the current analysis is restricted to rectangular plan form buildings. In case of an irregular plan form, the direct design method cannot be used and other more accurate techniques such as the finite element method should be applied instead. In addition, geometrical non-linearity in the form of interaction between axial loads and deflections of columns is negligible as the height of flat slab buildings considered in the present study is small.

III. DESIGN VARIABLES AND CONSTRAINTS

A. Design variables

A design alternative option, which defines a complete design of a flat slab with drop panel, includes the following decision variables:

- X1= Effective depth of slab.
- X2=Overall depth of drop from top of slab=Dd.
- X3=No. of span required in longer direction.
- X4=No. of span required in shorter direction.

B. Constraint equations

The restrictions that must be satisfied to produce an acceptable design are called design constraints.

- No of span constraint in x direction $G1 = (2/X3) - 1 < 1$
- No of span constraint in y direction $G2 = (2/X4) - 1 < 1$
- Length constraint $G3 = (Ly / (2 * Lx)) - 1 < 1$
- Minimum depth constraint $G4 = (Ly / (26 * X1)) - 1 < 1$
- Depth constraint $G5 = (125 / St) - 1 < 1$
- Load constraint $G6 = wl / (3 * wd) - 1 < 1$
- Stiffness check in y direction $G7 = (aymin / ay) - 1 < 1$
- Stiffness check in x direction $G8 = (axmin / ax) - 1 < 1$
- Moment constraint in slab $G9 = (Mposmax / Mslab) - 1 < 1$
- Moment constraint in drop $G10 = (Mnegmax / Mdrop) - 1 < 1$
- Constraint of shear check in slab $G11 = (Tvn / Tvper) - 1 < 1$
- Constraint of shear check in drop $G12 = (Tvn1 / Tvper1) - 1 < 1$
- Constraint of check of punching $G13 = (Pact / Pper) - 1 < 1$

Where Lx =span in shorter direction, Ly = span in longer direction, St =Overall depth of flat slab, wl =Total live load, wd =Total dead load, ay = stiffness coefficient in longer direction, ax = stiffness coefficient in shorter direction, $Mposmax$ =Max. Positive bending moment, $Mslab$ =Provided moment in slab, $Mnegmax$ =Max. negative bending moment, $Mdrop$ =Provided moment in drop, tvn = Nominal shear stress for slab, $tvper$ = Permissible shear stress for slab, $tvn1$ = Nominal shear stress for drop, $tvper1$ = Permissible shear stress for drop, $Pact$ = Actual Punching shear, $Pper$ =Permissible Punching shear.

IV. DESIGN OPTIMIZATION PROCEDURE

Definition: “The process of finding the conditions that gives the maximum or minimum value of the function”.

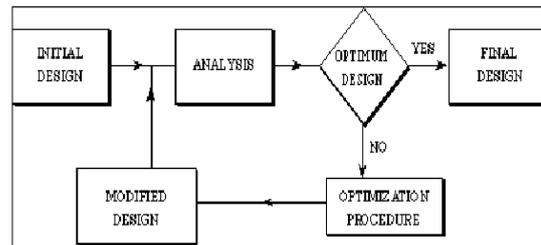


Fig.3 Structural Optimization Flow Chart

The optimum cost design of Flat slab with drop panel formulated in is nonlinear programming problem (NLPP) in which the objective function as well as constraint equation is nonlinear function of design variables. In SUMT the constraint minimization problem is converted into unconstrained one by introducing penalty function. In the present work is of the form.

$f(x, r)$ is the penalty function $f(x)$ is the objective function r is the non-negative penalty parameter, and m is the total number of constraints. The penalty function (x, r) is minimized as an unconstrained function of x and r , for a fixed value of r . The value of r is reduced sequent rained and the

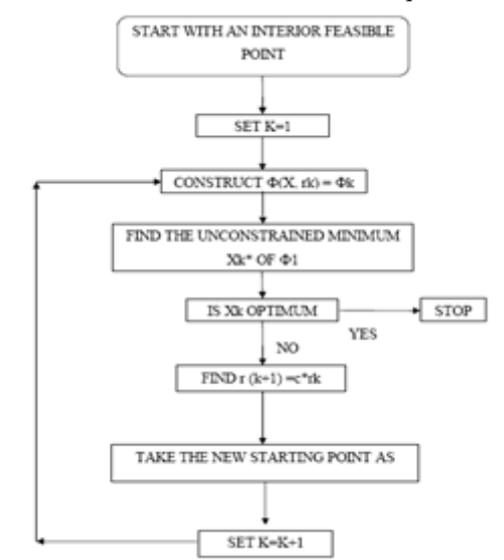


Fig.4 flow chart for the interior penalty function method

sequence of minima obtained converges to the constrained minimum of problems as $r \rightarrow 0$. The present optimization problem is solved by the interior and exterior penalty function method. The method is used for solving successive unconstrained minimization problems coupled with cubic interpolation methods of on dimensional search. The program developed S. S. RAO for SUMT is used for the solution of the problem. The program is written in MATLAB language.

V. DIFFERENT CONDITIONS AND PARAMETERS FOR ANALYSIS AND DESIGN

For comparative study consideration following parameter are consider for different results.

- F_{ck} =Characteristic strength of concrete = M20, M25, M30.
- F_y =Characteristic strength of steel = F_y415, F_y500 .
- C_{cost} =Cost of concrete. (Including formwork and labour charges)(As per District Schedule Rate (Maharashtra-Raigad Region 2013))
M20=7302 Rs./m³
M25=8580 Rs./m³
M30=8647 Rs./m³
- S_{cost} =Cost of steel (Including labour charges) (As per District Schedule Rate (Maharashtra-Raigad Region 2013))
 $F_y415=64$ Rs. /Kg
 $F_y500=65.8$ Rs. /Kg
- Total span= 20m X 20m, 25m X 25m, 30m X 30m, 35m X 35m, 40m X 40m.

VI. ILLUSTRATIVE EXAMPLES

For different conditions and start from starting point and end with optimized point the result shown in graphical form as below.

(Typical format of graph shown here for Span=20mX20m, Grade of concrete=20, Grade of steel=415)

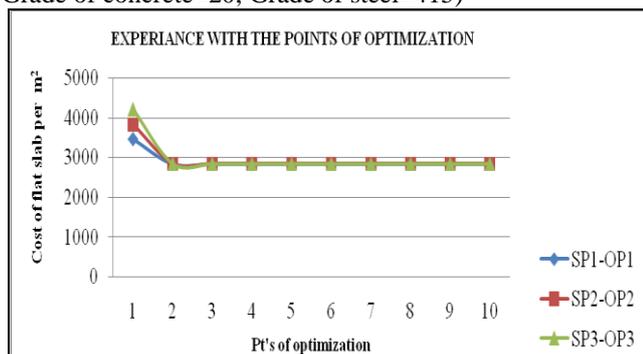


Fig.5 Typical graph for the points of optimization

The problem of cost optimization of flat slab with drop panel has been formulated as mathematical programming problems. The resulting optimum design problems are constrained non-linear programming problems and have been solved by SUMT. Parametric study with respect to different type of spans and grade of concrete combinations of flat slab sections has been carried out. The result of optimum design for flat slabs have been compared and conclusions drawn.

- It is possible to formulate and obtain solution for the minimum cost design for flat slab with drop panel.

- Interior penalty function method can be used for solving resulting non-linear optimization problems. For flat slab thickness and thickness if drop panel, the chosen values of initial penalty parameter " r_0 " and reduction factor " C " worked satisfactorily.
- Exterior penalty function method can be used for solving resulting non-linear optimization problems. For flat slab the number of span in x and y direction the chosen values of initial penalty parameter " r_0 " and additive factor " C " worked satisfactorily.
- It is possible to obtain the global minimum for the optimization problem by starting from different starting points with the interior penalty function method.
- The minimum cost design of flat slab is fully constrained design which is defined as the design bounded by at least as many constraints as there are the design variables in the problems.
- Actual percentage of the saving obtained for optimum design for flat slab depends upon the number of span of slab, grade of steel and grade of concrete.
- Maximum cost savings of 33.91% over the normal design is achieved in case of flat slab with drop panel.
- The optimum cost for a flat slab is achieved in M20 grade of concrete and fe415 grade of steel.
- The cost of flat slab unit increased rapidly with respect grade of concrete increases and grade of steel increases whereas cost of flat slab decreases as the number of span increases by keeping total length of slab constant.
- The percent reduction in optimum cost for a flat slab is directly proportion to number of span increases.

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