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Use of Complex Iterative Method in Structural Design

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Abstract: *In today's world of cut-throat competition, structural optimization is the only way to success. The present study has considered one of the important optimization techniques - Complex Iterative Method - to emphasize its role in structural optimization. Since a structure is a combination of different structural elements, it can be optimized either as a single entity or by partitioning it into sub-structures, wherein different elements are considered separately. In the present case column footing has been considered separately to highlight the effect of optimization technique. The technique has been found easy to understand and implement with encouraging results. The total cost of a RCC footing includes the cost of both concrete as well as steel. In the present case cost of formwork has not been considered as it was found to be contributing very little towards the total cost. Thus three parameters, namely depth of footing, edge thickness of footing and area of rebars were considered for optimization. Footing length and width, which were based on bearing capacity of soil, were left un-altered during the optimization process. Various designs for different input values – load, bearing capacity etc. – were considered to check the robustness of the optimization, and the results were encouraging. The paper illustrates relevance of the method by considering an example.*

Keywords: *Complex iterative method, Optimization, column footing.*

1. Introduction

In structural design, the conventional design procedures guided by various design codes aim at finding out an acceptable design which is not only safe but also satisfies the functional and other requirements of the problem. In the case of footings, more than one acceptable designs of a given problem can be obtained by changing different parameters like length to width ratio, concrete-steel ratio etc. Choice of different design alternatives brings in the concept of 'optimization', which seeks to identify and select the best one, on some established parameter, say cost, weight etc., of all feasible alternatives under given constraints. The concept of minimum cost design of concrete structures is an important and vigorously pursued area of research. Different optimization techniques are available and subsequently used to solve the problem but it is important to check out their ease of applicability in the given scenario so that they can be easily understood and applied by all with custom-built need and modifications.

2. Problem Formulation

The cost of any isolated column footing is given as

$$C = C_{st} V_{st} + C_c V_c \qquad (1)$$

where C = total cost of structural element, i.e. isolated column footing

C_{st} = cost of steel per unit volume of steel

V_{st} = volume of steel in the footing

C_c = cost of concrete per unit volume of concrete

V_c = volume of concrete in the footing

Dividing Eq.(1) by C_c, we get

$$\frac{C}{C_c} = \frac{C_{st} V_{st}}{C_c} + V_c \qquad (2)$$

Putting $V_c = V_G - V_{st}$, where V_G = gross volume of isolated column footing, Eq.(2) becomes

$$\frac{C}{C_c} = \frac{C_{st} V_{st}}{C_c} + (V_G - V_{st})$$

$$\frac{C}{C_c} = \left(\frac{C_{st}}{C_c} - 1 \right) V_{st} + V_G \qquad (3)$$

Taking objective function $Z = \frac{C}{C_c}$ and cost ratio $\alpha = \frac{C_{st}}{C_c}$, (3) becomes

$$Z = (\alpha - 1) V_{st} + V_G \qquad (4)$$

Since C_c is a constant parameter for a given place, the objective function $Z = \frac{C}{C_c}$ represents total cost of isolated column footing which we need to minimize.

Following constraints were considered while formulating the optimization problem:

- Constraint for maximum bending moment due to soil pressure
- Constraint for maximum punching shear
- Constraint for maximum one-way shear
- Constraint for minimum and maximum tensile steel area along X and Y directions

Thus the optimization problem becomes

$$Minimize \quad Z = (\alpha - 1) V_{st} + V_G \qquad (5)$$

subject to the constraints mentioned earlier.

3. Solution by the Use of 'Complex Iterative Method'

The optimization problem was solved using Complex Iterative Method. The method essentially consisted in evaluating the objective function at m (≥ n+1, where n = number of independent design variables) feasible vertices of a complex (closed figure) and iteratively moving towards the optimum point by successive modifications. In each step the vertex X_L which yielded the largest value of objective function and known as worst vertex was replaced by a new vertex X_N along the line joining the worst vertex and centroid of the remaining vertices. It was importantly assured that the new vertex did not violate any of the constraints and gave a smaller objective function value than the worst vertex. The new vertex was obtained as

$$X_N = X_O + \beta (X_O - X_L) \qquad (6)$$

where β > 0

X_O = centroid of all vertices except X_L

X_L = worst vertex

When the reflected point X_N violated any of the constraints, it was moved half way towards the centroid by reducing β-value by half, until it became feasible. In this way, the complex was rolled over and over towards the minimum, remaining within the feasible space. The process was stopped when the deviation of function value at the vertices from the centroid became sufficiently small ($\beta < 0.0005$). In the present case, value of n (number of independent design variables) was taken as two. Depth (d) and edge thickness (t) of footing section were considered as independent design variables. Minimum footing base dimensions (L and B) based on soil bearing capacity remained un-altered during the optimization process. Remaining design variables like area of steel in X-direction (A_{stxx}) and Y-direction (A_{styy}) were derived from these two independent design variables. Algorithm for the solution technique is given in Fig. 1.

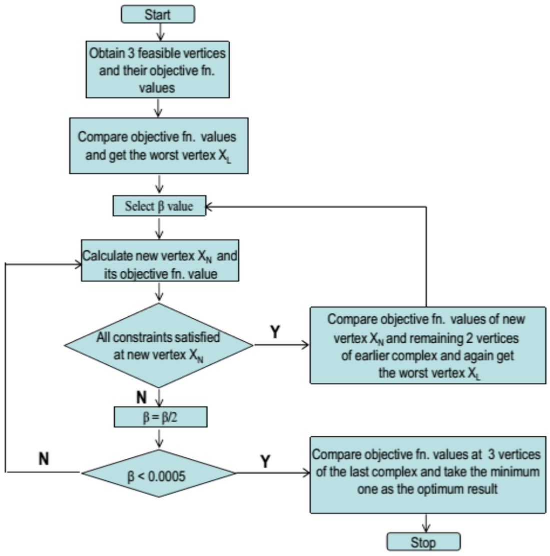

Fig1. *Algorithm for 'Complex Iterative Method'*

4. Selection of Initial Points and Other Parameters

The number of vertices in the complex (m) was taken as 3. Thus 3 feasible starting designs required to initiate the optimization process were selected by considering different set of values for depth and edge thickness. Certain other parameters like cost ratio (α), grades of concrete and steel (f_{ck} and f_y), size of column and footing loads (P and M) were defined at the beginning. Footing base dimensions based on soil bearing capacity, remained unchanged throughout.

5. Example

The given set of loads for the footing is shown in Fig. 2. Grades of concrete and steel were taken as M30 and Fe415 respectively. The cost ratio was taken as 85. Table 1 shows a comparison of conventional and optimum design values.

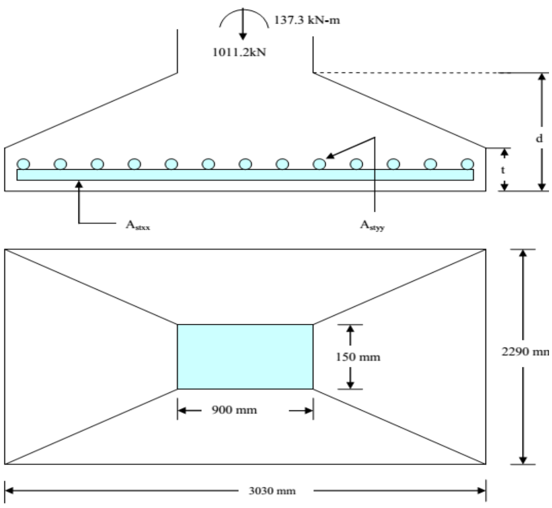

Fig2. *Isolated column footing with load conditions*

Table1. *Comparison of conventional and optimum design values*

Parameter	Conventional design	Optimum design
Length of footing, **L**	3030 mm	3030 mm
Width of footing, **B**	2290 mm	2290 mm
Depth at the face of the column, **d**	590 mm	870 mm
Edge thickness, **t**	490 mm	150 mm
Area of steel along X-direction, $\mathbf{Ast_{xx}}$	1660 mm^2	1365 mm^2
Area of steel along Y-direction, $\mathbf{Ast_{yy}}$	2240 mm^2	2080 mm^2
Objective function, **Z**	4.937945	3.528728
Number of iterative cycles	-	38

6. Conclusions

The given example clearly shows optimization level for the considered footing as 28.54%, which is very encouraging and proves suitability of the Complex Iterative Method for structural optimization. Although both steel and concrete volumes got reduced during the optimization process, the reduction in quantity of steel contributed largely to the overall optimization of the footing. The present technique of optimization was found to be robust one in the sense that it remained largely unaffected by the size of starting complex.

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