



Original Article

Effect of Layout and Size Optimization Conditions in Architectural Design of Reinforced Concrete Flat Slab Buildings

¹ Yousef Zandi, ² Roza Naziri, and ³ R Hamedani

¹ Assist. Prof. Dr, Civil Engineering Department, Islamic Azad University, Tabriz Branch, Iran

² Student . Architectural Engineering Department, Islamic Azad University, Tabriz Branch, Iran

³ Project Manager and Technical Adviser of Hormozgan Cement

ABSTRACT

Reinforced concrete was chosen as the structural system by the design team for several important reasons on this residential building. The floor to floor heights were minimized with the use of thin, post-tensioned concrete slabs, which allowed the Owner to cost effectively maximize the number of floors in the building. In addition, concrete provided the necessary stiffness for the Outrigger-Braced lateral system while providing the speed of construction necessary to meet the project schedule demands. Cost optimization of RC flat slab buildings using a multi-level optimization procedure was presented. The procedure includes finding the optimum column layout, cross-sectional dimensions and reinforcement of concrete elements. The design optimization of two RC flat slab buildings with different plan and number of storeys was illustrated. Genetic algorithm as a global search technique in conjunction with a local search technique can successfully be used in design optimization of RC structures. Cost of floor slabs is the major structural cost which can result in a significant cost saving in optimization of RC flat slab buildings. It was shown that column layout optimization of flat slab buildings can produce substantial savings in the total structural cost of the building.

Keywords: Reinforced concrete, column layout optimization, genetic algorithm, hybrid optimization algorithm, flat slab building.

Received 12.03.2013 Accepted 21.04.2013

©2013 AELS, INDIA

INTRODUCTION

In flat slab buildings floors are directly supported by columns without the use of intermediary beams (Figure 1a). To increase punching shear resistance of flat slabs, columns may be flared to form a column head (column capital) or the slab may be thickened around columns as a drop panel or both (Figure 1b). Flat slab systems are popular for use in office and residential buildings, hospitals, schools and hotels. They are quick and easy to formwork and build. The architectural finish can be directly applied to the underside of the slab. Absence of beams allows lower story heights and as a result, cost saving in vertical cladding, partition walls, mechanical systems, plumbing (a) Flat slab without drop b) Flat slab with drop panels)



Figure 1: Flat slab systems in building construction

and a large number of other items of construction especially for medium and high-rise buildings. They provide flexibility for partition location and allow passing and fixing services easily. Windows can be extended up to the underside of ceiling. The absence of sharp corners gives greater fire

resistance and less danger of concrete spalling and exposing the reinforcement. Moreover, where the total height of a building is restricted, the use of a flat slab will result in more stories accommodated within the set height [13].

Design optimization of isolated reinforced or prestressed concrete slabs has been widely studied [4-6]. This paper presents cost optimization of RC flat slab buildings according to the British code of practice for design and construction of reinforced concrete structures, BS 8110, [7].

Structural analysis of flat slab buildings

Equivalent frame method (EFM), recommended by BS 8110 [7] and several codes of practice (e.g. the American, Canadian and Australian codes), is used for the analysis of a flat slab building. In this method, the flat slab building having a rectangular plan is modeled as a sequence of longitudinal and transversal plane frames. Each frame consists of a row of equivalent columns and beams which represent the columns and the strips of slabs bounded laterally by centerlines of the panels adjacent to the centerline of the row of columns. In this study, it is assumed that equivalent frames are loaded by uniform gravity dead and live loads and lateral loads are resisted by other structural systems such as shear walls. Since the bending moment over the width of slab strips (equivalent beams) in equivalent frames is variable, the width of equivalent beam is divided into two strips, namely, column and middle strips. The actual moments are averaged over the width of these strips. The average bending moment over each strip is obtained as a percentage of the total bending moment at each section of the equivalent beam according to the recommended values by the code of practice. Required reinforcement at each section of the slab is calculated according to the obtained design bending moment in each section of column and middle strips as shown in Figure 2.

Statement of the problem

Design variables

Consider a flat slab building having n_f storey's of arbitrary heights and n_x and n_y spans of equal lengths l_x and l_y in x and y directions, respectively (Figure 2). The number of spans in the longitudinal and transversal directions of the building is used as design variable. Also cross-sectional dimensions, and the number and size of steel bars in a given section of RC elements are considered as design variables. The number of spans in each direction describes column layout of the structure. Figure 2 illustrates design variables in a typical floor of a flat slab building. The thickness of the floor slab, t_i , and the number and size of reinforcement in different positions over the floor slab are the design variables.

Figure 3 shows design variables for a column. To simplify the problem, it is assumed that all columns have rectangular cross-section, all steel bars have the same diameter and they are symmetrically concentrated in four corners of the section. Since it has been assumed that lateral loads are resisted by shear walls or another systems capable of withstanding lateral forces, there is no considerable shear force in the column section. Therefore, the size and spacing of column links are calculated according to the code recommendations to prevent outward buckling of the longitudinal bars and provide ductility of columns. Four different typical columns are considered in each storey, which are corner column, two edge columns in the longitudinal and transversal sides of the building and one intermediate column.

Figure 4 shows a typical layout of shear reinforcement around a column-slab connection. The size of bars, ϕ , and the number of reinforcement in each layer, N_1 , N_2 etc. are considered as design variables in a typical connection. The number of required layers of shear reinforcement for each column-slab connection depends on the magnitude of punching shear stresses around column. The use of column head can also be considered as an optional feature for increasing punching strength of slabs (Figure 5). The cross-sectional dimensions of a column head in contact with the floor slab are the design variables for the column head. A typical reinforcement detailing is considered for column heads. Therefore, the number and size of column head steel reinforcement are not considered as design variables. Four types of column-slab connections have been considered in each floor. These are a corner connection, two edge connections for columns located in longitudinal and transversal sides of the building and an intermediate connection.

Objective functions and design constraints

The objective function is the cost of labor and material for concrete, reinforcement and formwork for, n_f , floors, n_c typical columns and foundations and the cost of the foundation excavation for a quarter of the building.

$$n_f n_c C = \sum_i C_i(\mathbf{x}_i) + \sum_j C_j(\mathbf{x}_c) + C_f(\mathbf{x}) \quad (1)$$

$$i=1 \ j=1$$

subject to:

$$G_i(\mathbf{x}_f, \mathbf{x}_c) \leq 1 \quad i = 1, 2, \dots, n_g, \quad (2)$$

$$x_j^l \leq x_j \leq x_j^u \quad j = 1, 2, \dots, n_s, \quad (3)$$

$$\mathbf{x} = (x_1, x_2, \dots, x_n) = (\mathbf{x}_f, \mathbf{x}_c). \quad (4)$$

The first term in equation (1) represents the sum of the cost of floors, the second term is the sum of the cost of all typical columns and C_f is the total cost of the foundation including excavation for a quarter of the building. The foundation cost is approximately calculated by assuming all foundations are identical pad footings. The cost of shear reinforcement around columns and column heads has been also included in the cost of floors. In expression (2), G_i is the i -th behavioral constraint function which is resulted from a design provision. Expression (3) gives side constraint on j th design variable.

In these expressions, x_j^l and x_j^u are the lower and upper limits for j th design variable and n_g and n_s are the total number of behavioral and side constraints, respectively. Design constraints are introduced according to BS 8110 [7] code requirements. These design constraints includes strength, serviceability, stability and ductility requirements Also architectural and practical considerations are applied to the problem. For example a

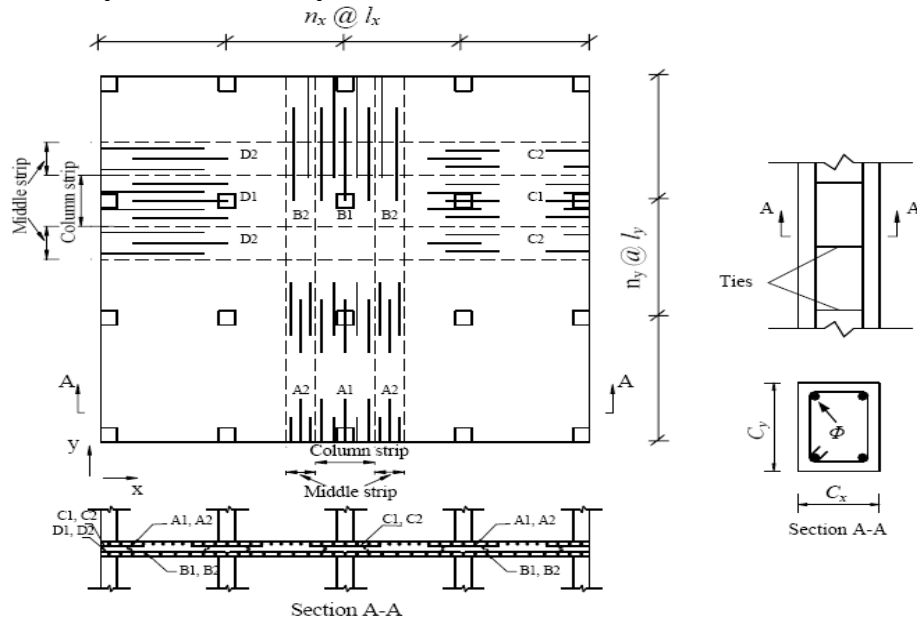


Figure 2: Typical layout of bending reinforcement in a flat slab.

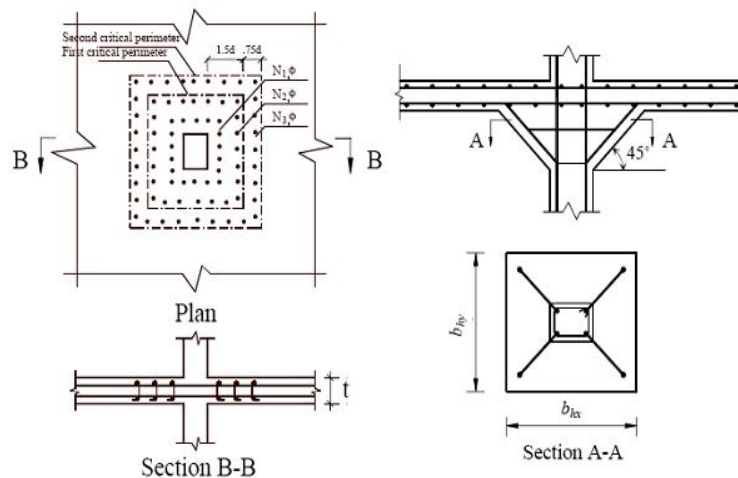


Figure 3: Layout of shear reinforcement.

Design optimization procedure

The design optimization procedure is handled in three levels. In the first level different column layouts for a building of a given number of storey's, length and width of rectangular plan are compared to find the optimum number of spans in longitudinal and transversal directions. For each column layout, a model is constructed for structural analysis. Design optimization of the structure is then carried out as explained below and the total cost of the optimum structure for the defined column layout is calculated. The minimum total cost among all the results obtained for different column layouts identifies the optimum column layout.

In the second level the section dimensions of columns and the thickness of slabs for each assumed layout are found. In this level a hybrid optimization algorithm based on a genetic algorithm (GA) [8] is employed. The algorithm includes two stages. In the first stage a modified GA is initially used for a global search to find the optimum or a near-optimum solution for the cross-sectional dimensions of the elements. In the second stage this solution is considered as a base point for a local search using a discredited form of Hooke and Jives method [9].

In the third level, using an exhaustive search method [10], the optimum amount of reinforcement (the number and diameter of bars) for each group of members with given dimensions and the column capital dimensions are determined.

EXAMPLES AND DISCUSSION

Two design examples will be presented. Table 1 gives information used in these design examples. It is assumed that there are no straps between pad foundations.

Example 1

To determine the unit prices, Spon's Architects' and Builders' Price Book 2001 [11] and Harris [12] have been used. Table 2 shows the floor thickness and columns cross-section dimensions for the optimum and conventional designs. For the conventional design, cross-sectional dimensions of RC elements were fixed at the values shown in Table 2 and the design optimization program, developed in this study, was used for structural analysis and calculation of the size and number of reinforcement bars of RC elements. Table 3 compares the results of cost components for different elements of the optimum design with those of a conventional design. It is important to mention that with the optimum thickness of 220 mm, the required area of reinforcement at the middle of the two spans is governed by the deflection constraint. It means that the area of reinforcement in these spans has been increased as compared with that obtained from strength requirements. In other words, the increase of the amount of reinforcement at the middle of few spans has been more economical than increasing the thickness of the slab to satisfy deflection requirements. As Table 2 shows, the slab thickness for the optimum design is 30 mm smaller than that for the conventional design. Therefore, to prevent punching shear failure in the optimum design the cross-sectional dimensions of the edge columns on the edge parallel to x direction have been increased as compared with those of the conventional design. For this reason, as Table 3 shows, the total cost of columns for the optimum design is 3.3% larger than that for the conventional design, however optimum design produced 2.8% cost saving in the total cost of the building as compared with the conventional design.

Table 1. Specifications of design examples

Specification	Ex. 1	Ex. 2
Number of spans in x direction	4	5
Number of spans in y direction	3	5
Length of spans in x direction (m)	5	7.5
Length of spans in y direction (m)	6	7.5
Number of storeys	1	3
Storey height (m)	4	3.95
Live load (N/m ²)	5000	5000
Dead load (N/m ²)	2500	1500
Characteristic strength of concrete (N/mm ²)	35	35
Characteristic strength of main steel bars (N/mm ²)	460	460

Characteristic strength of shear steel bars (N/mm ²)	250	250
Allowable bearing pressure of soil (kN/m ²)	200	200
Top cover of steel bars in floor slab (mm)	20	25
Bottom cover of steel bars in floor slab (mm)	25	25
Cover of steel bars in columns	40	40
Maximum bar diameter of main reinforcement of slabs (mm)	25	25
Minimum bar diameter of main reinforcement of slabs (mm)	10	10
Maximum bar diameter of main reinforcement of columns (mm)	25	32
Minimum bar diameter of main reinforcement of columns (mm)	10	10
Maximum bar diameter of shear reinforcement (mm)	12	12
Minimum bar diameter of shear reinforcement (mm)	6	6
Unit cost of concrete (£/m ³)	55	53.5
Unit cost of reinforcement (£/kg)	0.5	0.4
Unit cost of formwork (£/m ²)	20	18.5
Excavation, disposal and backfill cost of soil (£/m ³)	20	20

Table 2. Comparison of cost components of the optimum and conventional designs

Design	Thickness of floor (mm)	Column dimensions (Cx × Cy) (mm)			
		Corner	Edge (x)	Edge (y)	Inter.
Optimum	220	250 × 250	250 × 300	250 × 250	250 × 250
Conventional	250	250 × 250	250 × 250	250 × 250	250 × 250

Table 3. Comparison of cost components of the optimum and conventional designs

Design	Total cost of floors (£/m ²)	Total cost of columns (£/m ²)	Total approximate cost of foundation (£/m ²)	Total cost of building (£/m ²)
Optimum	38.411	5.944	5.2	49.556
Conventional	39.811	5.756	5.411	50.978
Cost saving %	3.5	-3.3	3.9	2.8

5.2- Example 2

This design example has been chosen from a report on the comparative costs of concrete and steel framed office buildings [13]. In this study, the average of the unit prices for each material, presented in the aforementioned report, is used in the design optimization of the building.

First it is assumed that the span lengths are fixed in both directions as l_x and l_y are

7.5 m, i.e. n_x and n_y are 5. Figure 6 shows the comparison of the total cost components of concrete, reinforcement and formwork of the superstructure of the building obtained from the conventional and optimum designs. The breakdown of costs of the floors and columns is also shown in this figure.

The total cost of the superstructure according to the conventional design is 55.46 £/m², and according to the optimum design is

42.57 £/m². As a result, design optimization of the structure has led to 23.3% saving. According to this figure the cost of floors and columns is about 89% and 11% of the total cost for the conventional design and 91% and 9% of the total cost for the optimum design, respectively. Those results show that the cost of floors is the major part of the structural cost and emphasize the importance of the optimization of floors in the flat slab buildings, as concluded by other researchers [13, 14]. It can be observed that the largest component of the overall cost is the cost of formwork (39% and 51% for

the conventional and optimum designs, respectively). The cost of concrete contributes 33% and 36% of the structural cost for the conventional and optimum designs, respectively. The smallest component is the cost of reinforcement being 28% and 13% for the conventional and optimum designs, respectively. The largest cost saving is achieved by reducing the cost of reinforcement (63% cost saving). Since the main part of the formwork cost relates to soffit of the floors, which is identical for both of the conventional and optimum designs, the smallest cost saving is achieved for formwork (0.5% cost saving).

In addition to the optimum sizes of structural elements, the optimum number of spans is also determined in this example. As already discussed the optimum column layout is specified by comparison of the minimum structural cost of different column layouts of the building. Figure 7 shows the variation of the minimum structural cost of the building with respect to the span lengths. The most economical span lengths are $l_x = l_y = 5.357$ m (i.e. $n_x = n_y = 7$). The total cost of the optimum superstructure per unit area of the building for the optimum column layout, the optimum and conventional designs of the previously assumed column layout, mentioned above, are 40.62 £/m^2 ,

46.89 £/m^2 and 63.56 £/m^2 , respectively. Therefore, the optimum column layout can

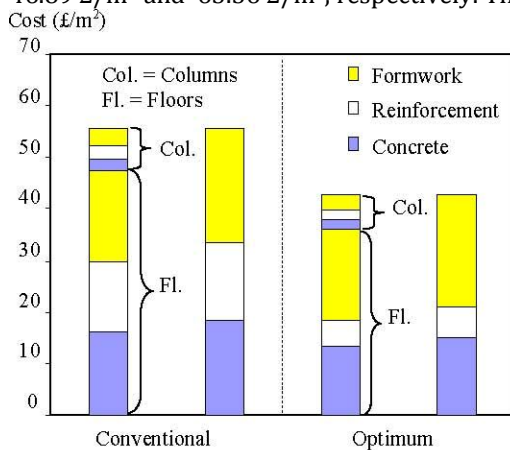


Figure 4. Comparisons of cost items

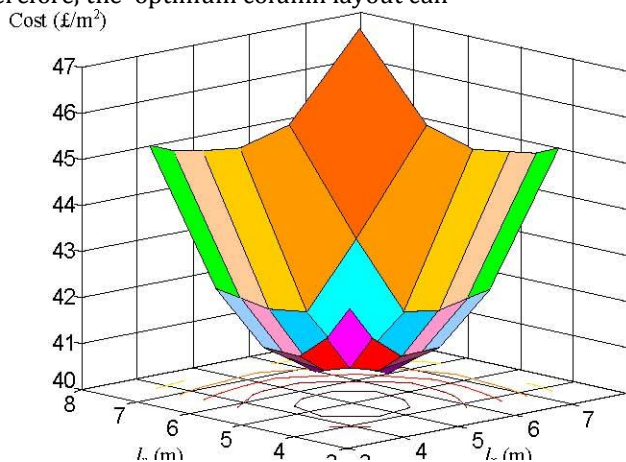


Figure 5. Comparisons of cost items

produce 36% and 13% cost saving as compared with the conventional and optimum designs with fixed spans equal to $l_x = l_y = 7.5$ m, respectively.

CONCLUSIONS

This paper presents column layout and size optimization of Reinforced concrete (RC) flat slab buildings to BS 8110 code of practice. The objective function is the total cost of the building including the cost of floors, columns and foundations. The total cost of the building includes the cost of material and labour for reinforcement, concrete and formwork of structural elements. Excavation cost is also considered for foundations. The optimization process is handled in three levels. In the first level the optimum layout of building is determined through an exhaustive search. In the second level the optimum cross-sectional dimensions of RC elements are found using a hybrid algorithm based on genetic algorithm (GA). In the third level an exhaustive search is applied to seek the optimum size and number of steel bars for each individual type of structural elements. Two practical examples are given to demonstrate the achieved cost savings.

REFERENCES

1. Goodchild, C.H. (1997), "Economic concrete frame elements", Reinforced Concrete Council, Crowthorne, UK.
2. Mosley, W.H., Bungey, J.H. and Hulse, R., (1999). "Reinforced concrete design" MacMillan Press Ltd., London.
3. Fanella, D.A., (2000). "Concrete Floor Systems, Guide to Estimating and Economizing", 2nd ed., Portland cement Association (Pca), Illinois, USA.
4. Rozvany, G.I.N., (1967). "The behavior of optimized reinforced concrete slabs", Institute of Engineers, Australia, CE9 (2), pp. 283-294.
5. Dutta, T.K., Ratnalikar, N.V. (1973). "Optimal design of reinforced concrete slabs". Journal of Institute of Engineers, India, 54(C12): 47-52.
6. Sahab, M.G., Ashour, A.F., Toropov, V.V., (2000). "Cost optimization of reinforced concrete flat plates". In nd

- proceedings of the 2nd ASMO UK/ISSMO Engineering Design Optimization Conference, July 2000, Swansea, UK, pp.197-203.
7. BS 8110, (1997). Structural use of concrete, Part 1, Code of practice for design and construction, British Standards Institution, London.
 8. Goldberg, D.E., (1989). Genetic Algorithms in Search, Optimization and Machine Learning", Addison-Wesley Reading, Massachusetts, USA.
 9. Hooke, R., Jeeves, T.A., (1961). Direct search solution of numerical and statistical problems, J. of Assoc. Computer Mach., 8: 212-229.
 10. Rao, S.S., (1984). Optimization theory and application, 2nd edition, Wiley Eastern Limited, New Delhi, India.
 11. Spon's Architects'and Builders' Price Book,(2001), 126th edition, Spon Press, London.
 12. Harris, E.C., "CESMM3 price data base 1999/2000", Thomas Telford Ltd., 1999, London.
 13. Goodchild, C.H., (1993). Cost model study", Reinforced Concrete Council, Crowthorne, UK.
 14. Matthew, P.W. and Bennett, D.F.H., (1990). Economic long-span concrete floors", Reinforced Concrete Council, Crowthorne, UK.

How to Cite this Article

Yousef Z., Naziri R. and Hamedani R.(2013). Effect of Layout and Size Optimization Conditions in Architectural Design of Reinforced Concrete Flat Slab Buildings. *Bull. Env. Pharmacol. Life Sci*, Vol 2 (5): 62-68