고층 아파트 파일 기초의 최적화 설계

Optimization of the RC pile cap for high-rise apartment buildings

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Abstract

Optimization of the RC pile cap for high rise apartment buildings has been performed with the aim of the cost minimization. The principle of divided parameters has been used. As a result the cost has been reduced by 25 percentage.

Pile cap design

The pile cap is a flat reinforced concrete plate supported by piles (Fig.1). The pile diameter is 1.5 m. Its bearing capacity is 1000 *tons*. The pile cap is designed in accordance with ACI 318-89 [1] as a simple beam with span 7.0 m and two cantilevers 3.0 m each. Pile step is 4.5 m.

The pile cap should satisfy the following requirements of the ACI 318-89:

1. Punching shear strength,
2. Flexural strength,
3. Beam shear strength.

Initially the pile cap was designed so as to provide the shear strength by concrete only. The strength of concrete was 210 kg/cm^2. The depth of the cap appeared to be 1.6 m. The requirements for shear strength were also satisfied. Then the pile cap was designed as a deep beam and cross sectional areas of longitudinal reinforcement were determined. The total length of the beam is 13.0 m. The applied load is uniformly distributed over the length 12.0 m. Its intensity is 50.74 t/m^2.

Method of optimization

The optimization has been carried out on the basis of the principle of divided parameters [2]. In accordance with this principle all variable parameters are divided into two groups - external and internal parameters. Internal parameters are

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usually associated with reinforcement, external - with geometrical dimensions and strengths of the materials (concrete and reinforcement). All constraints are also divided into two groups - external constraints, containing only the external parameters, and internal constraints, containing external as well as internal parameters.

Then the problem of reinforced concrete structures optimum design is divided into two subproblems - internal and external ones. The internal optimization problem is to determine the optimum values of internal parameters satisfying internal constraints; the external parameters are fixed. The external optimization problem is to find such fixed set of external parameters which selects the best solution to the internal optimization problem.

The process of optimization consists of a number of tests. In each test the values of external variable parameters are fixed; external constraints are checked up (if they are not satisfied the test is stopped); internal optimization problem is solved; the value of the objective function is computed. The values of the external variable parameters are changed from test to test in accordance with methods of unconstrained optimization or optimum experimental design.

Optimization of RC structures based on the principle of divided parameters is carried out in the following order:

1. Specify variable parameters and an objective function.

2. Specify constraints.

3. Divide variable parameters into external and internal ones.

4. Divide constraints into external and internal ones.

5. Divide the general optimization problem into external and internal problems.

6. Select algorithms to solve the problems.

7. Fix an initial trial in the best possible way.

8. Solve the problem.

The procedure for pile cap optimization

The pile cap optimization was carried out in accordance with above listed order.

1. Variable parameters were strength of concrete, span of the beam (the distance between piles could be changed), depth of the plate, parameters of the reinforcement (cross sectional areas of longitudinal and shear reinforcement, number of bars, spacing between bars). The objective function was the cost of the pile cap strip 4.5m wide.

2. Constraints were the above requirements of ACI 318-89. In addition the requirements for concrete strength should have been satisfied: only three strengths of concrete 210, 240, 270 kg/cm^2 could be used for the pile cap.

3. The variable parameters were divided in the following way. Strength of concrete and the span of the beam were external parameters, depth of the plate and parameters of the reinforcement were internal variable parameters.

4. External constraints were the requirements for concrete strength and obvious requirements for the beam span. The rest of the constraints were internal ones.

5. Internal optimization problem was to find the values of the plate depth as well as of the reinforcement parameters so as to minimize the objective function and to satisfy the above mentioned internal constraints. The external parameters were fixed. The external optimization problem was to find a fixed set of external parameters so as to satisfy the external constraints and to select the best solution to the internal optimization problem among all possible solutions. The best solution is the solution with the minimum value of the objective function.

6. One of the methods of unconstraint optimization, namely the method of coordinate descent was used to solve the external optimization problem. The internal optimization problem was solved on the basis of the algorithms presented by ACI 318-89.

7. The initial trial was described above. In addition it should be mentioned that the span of the beam was fixed so as to obtain equal cross sectional areas of longitudinal reinforcement in the mid-span and support section of the beam.

8. To solve the problem the tests were carried out.

A test consists of the following operations:

1) Fix the values of the beam span and concrete strength.

2) Solve the internal optimization problem. Determine the depth of the pile cap so as to provide the shear strength by concrete only. In this case the requirements for punching shear strength are satisfied as well. Calculate minimum longitudinal reinforcement so as to satisfy the requirements for flexural strength.

3) Knowing the unit costs of the materials (concrete and reinforcement) calculate the total cost of the pile cap strip 4.5m wide.

The unit cost(per m^3) of concrete with different strength is presented in Table 1. The unit cost(per *ton*) of reinforcing bars is 405,000 *won*.

First in accordance with the method of coordinate descent only one external parameter, namely the span of the beam was changed (increased and decreased). The value of the second external parameter (strength of concrete) remained the same as in the initial trial. From the results of the performed calculations it became clear that the span length had been was fixed in the initial trial optimally: the total amount of reinforcement increased when the span length changed. Therefore in further optimization only one external parameter (strength of concrete) was changed.

The results of the optimization are presented in Table 2. The value of the objective function in the initial trial is 6,189,000 *won*. In tests No. 1 and No. 2 the values of concrete strength were increased. Concrete strength (the external variable parameter) has only three possible values. In this case the method of coordinate descent coincides with the exhaustive search with respect to external parameters: all three possible values of concrete strengths were considered. From Table 2 one can see that the decrease of pile cap depth leads to the cost decrease.

Therefore it was decided to change the procedure adopted to solve the internal optimization problem with the aim of obtaining the minimum pile cap depth:

1. Find the minimum pile cap depth so as to satisfy the requirements of punching shear.
2. Calculate minimum cross sectional area of longitudinal reinforcement so as to satisfy the requirements of flexural strength.
3. Calculate shear strength provided by concrete.
4. Calculate minimum cross sectional area of shear reinforcement so as to satisfy the requirements of shear strength.

This procedure permitted to obtain the optimum solution for which the pile cap depth was 1.1m and the cost was 4,678,000 *won*, i.e. in comparison with the initial trial the cost was reduced by about 25 percentage.

Conclusion

The above example has shown that the optimum design based on the principle of divided parameters can considerably reduce the cost of even relatively simple RC structures. For complex structures the method effects more savings.

Reference

1. American Concrete Institute(1989). *Building code requirements for reinforced concrete.* ACI committee 318, Detroit, Mich.

2. Krakovski, M.B.(1981), *Recommendations on optimum design of RC structures.* Moscow(in Russian).

Table 1 Unit costs of concrete

Concrete strength (kg/cm^2)	Cost of concrete (won/m^3)
210	58,860
240	60,400
270	61,500

Table 2 Results of optimization

Test No	Strength of Concrete kg/cm^2	Plate depth m	Cost of concrete $1,000won$	Cost of reinforcement $1,000won$	Total cost (objective function) $1,000won$
0	210	1.60	5,681	508	6,189
1	240	1.45	5,477	559	6,036
2	270	1.35	5,217	590	5,807
3	270	1.10	3,887	791	4,678

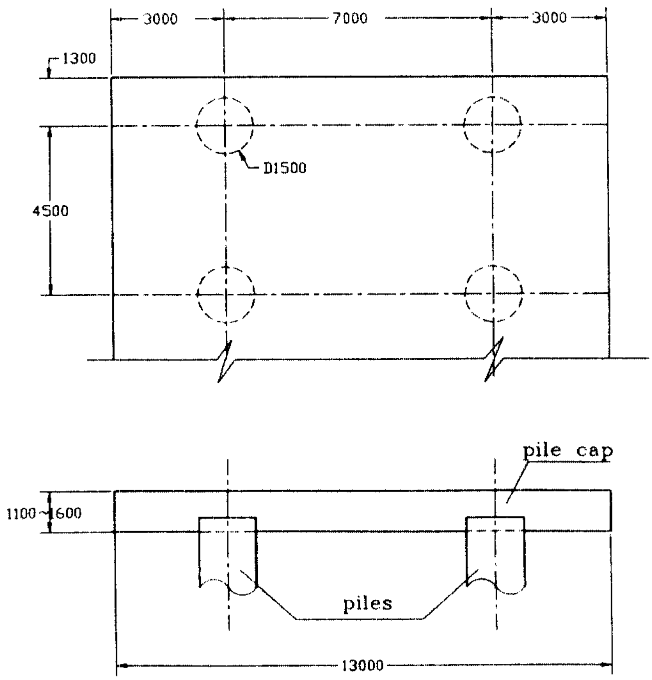

Fig. 1