COST OPTIMISATION FOR HIGH-RISE BUILDINGS CONSIDERING NUMBER OF LEVELS OF SHORES AND RESHORES

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The cost of formwork shares a major part in the overall cost of high rise RC construction. Hence, it becomes necessary to optimise the cost of formwork to reduce the overall cost of construction. A MATLAB program has been developed to calculate load transmission between inter-connected slabs and levels of shores/reshores using the simplified method. Cost is optimised using genetic algorithm while ensuring the safety of construction. The study is carried out for 10-storey building for different grades of concrete from M20 to M50, with an increment of 5 N/mm2. The 50-50 combination of shore and reshore levels violate the safety requirement for lower grades of concrete. The study shows that a small difference in the total formwork levels can change the cost of construction to a greater extent. The program is further modified for 20, 40, and 60 storey building. This study is an attempt to explore the impact of shore/reshore levels combination on the cost of construction. Hence, it is suitable for designers and practitioners to decide the levels of shores and reshores for construction based on economy and safety parameters.

Keywords: factor of safety, formwork, genetic algorithm, reshores, shores

INTRODUCTION

Multi-storey building construction is increasing exponentially as the shortage of land becomes a major problem. Hence to cater for the huge demand, the builders want to complete the building at a faster rate with as less investment as possible. In a multi-storey building construction, the time and cost both play important roles. The formwork shares 30-35% of the total cost of reinforced concrete construction (Jha 2011). Hence, it becomes necessary to lower the formwork cost to reduce the total cost of construction.

But while cutting down the cost, the safety of the structure during construction cannot be ignored. Early removal of the forms reduces the cost of the temporary structure, but it may affect the safety of construction. The removal of the formwork increases the load on the lower slabs and form levels. Hence the care should be taken while removing the forms. The transfer of construction loads between slabs and shore/reshore is studied based on a simplified method. The simplified method is proposed by Grundy and Kabaila (1963) for finding the loads on slab and shore/reshore at any time during construction. Since then many researchers worked on the slab-shore/reshore load transfer. Liu *et al*. (1988) discussed construction sequence using the simplified method that calculates the loads accurately. Azkune *et al*., (2010) studied the shore removal pattern to check shore

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overloading. They showed that the overloads occurring due to early removal of shores could cause failure of the structure.

The cost reduction for the formwork becomes necessary to reduce the overall cost of the construction by maintaining certain safety factor. It shows that very little literature is available where the cost of the formwork is a part of the discussion. The researchers considered the total formwork cost as one of the components of the equation to minimize the total cost. But the study related to number of shore-reshore levels for the optimum cost of construction is not reported in the literature.

So this study aims to find the optimum number of levels of shores and reshores that should give the minimum cost of construction ensuring the safety of construction. A genetic algorithm is integrated with the MATLAB program to find the optimised cost for different combinations of levels of shores/reshores. The objective function consists of the concrete grade, number of shores, number of reshores, and overhead charges. These are defined as a function of cycle time to find the lowest cost.

LITERATURE REVIEW

Grundy and Kabaila (1963) proposed simplified method to calculate load distribution among slabs, shores, and reshores. The strength gained by the slabs at any particular time of construction compared with the load applied on the slabs to check the safety of construction. Jha (2011) in his book gives ample illustrations about the use of one-level, two-levels, and three-levels of shores in multi-storey building construction. The analysis is carried out using simplified method to calculate loads on shores and slabs at different stages of construction.

Coello *et al*., (1997) used a genetic algorithm for the design of reinforced concrete beams. The cost of the rectangular beam is minimised considering the cost of concrete, steel and shuttering. The optimisation equation consists of the costs of labour and material for concrete, reinforcement, and formwork. These parameters are examined by many researchers with different optimisation tools to minimise the total cost of construction (Sahab *et al*., 2005). Similarly, the cost of concrete, steel, and formwork are minimised to lower the cost of a concrete beam (Rao 1973).

Senouci and Al-Ansari (1996) presented optimisation method for concrete slab forms. They minimised the cost while ensuring safe slab form design. The cost for sheathing, joist, stringer, shore, and labour are the terms used for the optimisation equation. They observed the cost reduction up to 21%. The same equation is used by other researchers (Kaveh and Shakouri Mahmud Abadi 2010, Kaveh and Behnam 2012; Al-Tabtabai 2000) to optimise the cost of a concrete slab formwork. Tabtabai *et al*., (1999) designed slab formwork considering optimisation of cost. It uses the genetic algorithm as a tool for cost optimisation. The optimisation function is formed considering the cost for sheathing, joists, stringers, shores, and slab volume.

Literature review shows that the work has been carried out to understand the distribution of loads between interconnected slabs through shores/reshores. The cost of the slab is minimised considering the material cost. But the study to minimise the cost of RCC construction considering the levels of shores/reshores is not available. As formwork shares a substantial part of total cost of RCC construction (Jha, 2011), the reduction in the cost is possible if the levels of shores/reshores can reduce. Such a study is not available in the literature where the levels of shore/reshore are targeted for the cost minimisation. Hence this study aims to minimise the cost of RCC construction considering different levels of shores and reshores for a high-rise building using the genetic algorithm.

MATHEMATICAL FORMULATION

A MATLAB program is developed to calculate the distribution of construction loads between slabs, shore, and reshore. This program is based on the construction sequence given by Liu *et al*., (1988) for the calculation of load and strength of slabs at a different time during construction. The strength of the reinforced concrete slab at any time, t is calculated using the formula given by ACI Committee 209R (1992) as shown in Equation 1.

$$(f_c^{'})t = \frac{t}{a+\beta t}(f_c^{'})_{28} \tag{1}$$

Where (f'c)t is the compressive strength of concrete at time t (in day) after casting; (f'c)28 is the 28-day characteristic compressive strength of concrete; a and β are constants depending on the type of cement and curing method used. GA uses this program in MATLAB for optimising the cost using a genetic algorithm. The objective of this study is to reduce the cost of construction with respect to a number of levels of shoring/reshoring ensuring the safety of construction.

Objective Function

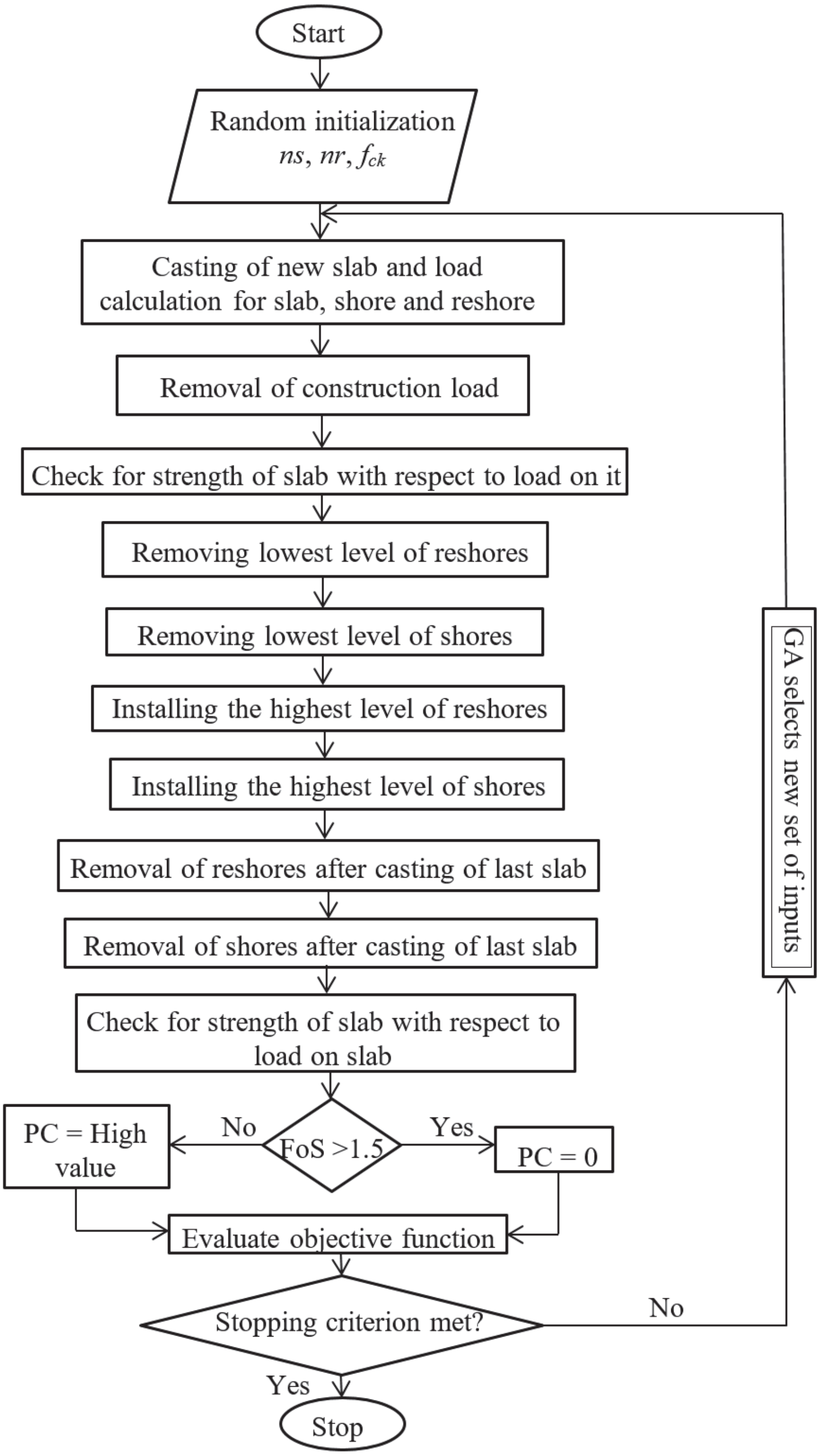
The objective function consists of the number of levels of shores, the number of levels of reshores, grade of concrete, and overhead charges as shown in Equation 2.

$$y = f(ns) + f(nr) + f(f_{ck}) + OC + PC \tag{2}$$

Where y is a fitness function value, ns is a number of levels of shores, nr is a number of levels of reshores, fck is the characteristic strength of concrete, OC is overhead charges during construction, and PC is the penalty cost. The cost of one level of shores is calculated based on the capacity of the shore. The cost of a level of reshores is same as 20% of the cost of one level of shores. The Delhi Schedule of Rates (DSR 2016) gives the cost for different grades of concrete. The cost of concrete includes the cost of material, labour, machinery, plant cost, and profit of contractor.The overhead charges are calculated from the salary of engineer, foreman, and charge hand required to execute the construction of the multi-storeyed building. The penalty cost is added to the total cost when it violates the factor of safety (FoS) condition. The FoS values lesser than 1.3 are unsafe (ACI 347.2R-05 2005). The expected FoS is 1.5 for the present study. The actual FoS obtained at each stage of construction is the ratio of the strength gained by the concrete slab to the load imposed on the slab at any particular time. When the actual FoS is less than 1.5, the total cost increases due to the addition of penalty cost. This equation is formulated for a 10-storey building having each slab of the same dimension. The area of one slab is 200 sq. m. with a thickness of 200 mm. Figure 1 shows the methodology used for optimising the cost of RCC construction. A MATLAB program calculates the load exerted on the slab at each stage of construction.

The strength gained by the slab is also calculated to check the safety of the construction which is part of the previous study conducted by the authors. This program is further modified to find the cost of RCC construction. A genetic algorithm is used to optimise the fitness function. Genetic algorithm does a parallel search of the solution and thus effectively explores many regions simultaneously. In a scenario where the formulation of problem solutions can be envisaged and defined as different possible numbers and a range of parameters, genetic algorithms can be used.

Figure 1: Methodology for cost optimisation



GA generates the solutions to optimisation problems using techniques inspired by natural evolution. Hence, this research problem uses the genetic algorithm as an optimisation tool. The individuals of next generation are selected based on the fitness value of the function with previously selected inputs. The same procedure continues to find the optimum value of the fitness function. The selection process continues till it reaches the stopping criterion.

Constraints
The constraints for the objective function involve the range of variables. The constraints for the n-storey building are as follows:

1. The number of levels of shores (ns) varies from at least one level to one minus as many levels as the number of the storey (1 ≤ ns ≤ n-1).
2. The number of levels of reshores (nr) varies from one level to one minus as many levels as the number of the storey (1 ≤ nr ≤ n-1).
3. The sum of a number of shoring and reshoring levels can attain a maximum equal to the number of the storey. The minimum can be two as at least one level of shoring, and one level of reshoring is allowed (2 ≤ ns + nr ≤ n).
4. The characteristic strength of concrete is taken in the range of 20 N/mm2 to 50 N/mm2 with an increment of 5 N/mm2.

The authors assume the installation time of three days with the considerations of only one shift of workers available for work. The cycle time (T) is the sum of stripping time and installation time. The maximum cycle time can be 30 days.

The program initializes the input parameters i.e. ns, nr, and fck randomly in the beginning through genetic algorithm code based on the n value. The MATLAB program evaluates these sets of values. The FoS is checked simultaneously for each level of construction, and the program decides the PC value at the same level. The objective function evaluates the set of chosen input values. The program repeats these steps until it reaches the stopping criterion.

RESULTS AND DISCUSSION

The MATLAB program evaluates the cost for the 10-storey building. Table 1 shows the results for the given set of inputs. The program gives output for all the considered grades of concrete from M20 to M50. However, Table 1 shows the cost of different combinations of shoring/reshoring levels for M20, M25, and M30 grades of concrete only. Here a sample illustration of the cost for shore/reshore combination of M20 concrete is discussed.

The 1S-1R (one level of shore - one level of reshore) combination is unsafe as the FoS is less than 1.5 during construction. Hence, PC is added to the final value making it as an economically undesirable solution. So 1S-1R combination is economically undesirable condition. The calculation for the cost of 1S-3R combination with a cycle time of 26 days is included for better understanding. The cost of a shore level is a function of T, so the cost increases with the increase in T. The cost of one level of shores comes out to be Rs. 2,600 in this case. The cost of a level of reshores is 20% of the cost of the level of shores. So, here the cost of three levels of reshores is Rs. 1,560. The cost for M20 concrete is Rs. 23, 59,600. The overhead charges for 26 days are Rs. 390,000. The combination of 1S-8R gives the lowest cost as Rs. 25, 57,980 for M20 concrete with13 days cycle time. All the combinations of shore/reshore levels violate the safety condition with the cycle time of six days for M20 concrete. Hence, these combinations give a very high cost.

Similarly, the program shows results for the M25 grade of concrete. The cost is lower when T is six days, as the overhead charge increases with cycle time. At the same time, the lesser number of shore levels gives minimum cost with six days cycle time. The 1S-9R combination gives the minimum cost of Rs. 24, 52,030 for the M25 grade of concrete with six days cycle time.

Table 1: Cost for different combinations of shore and reshore levels for M20, M25, and M30

No. of shore levels (ns)	No. of reshore levels (nr)	M 20		M 25		M 30	
		T (day)	Cost (Rs.)	T (day)	Cost (Rs.)	T (day)	Cost (Rs.)
1	1	-	-	25	27,38,350	12	25,42,540
1	3	26	27,53,760	10	25,11,950	7	24,67,220
1	4	20	26,63,200	9	24,96,970	6	24,52,180
1	5	-	-	8	24,81,950	6	24,52,300
1	6	15	25,87,900	8	24,82,110	6	24,52,420
1	7	14	25,72,960	7	24,67,030	-	-
1	8	13	25,57,980	7	24,67,170	6	24,52,660
1	9	-	-	6	24,52,030	-	-
2	8	-	-	6	24,52,510	6	24,53,260
3	3	-	-	-	-	6	24,53,260
4	5	-	-	-	-	6	24,54,100
6	1	-	-	-	-	6	24,54,820
7	3	-	-	6	24,54,910	6	24,55,660
8	1	-	-	6	24,55,270	6	24,56,020
8	2	-	-	6	24,55,390	6	24,56,140
9	1	-	-	6	24,55,870	6	24,56,620

Table 1 shows that the combination of 1S-1R becomes safe with 12 days cycle time for an M30 grade of concrete. The lowest cost is Rs. 24, 52,180 for the combination of 1S-4R with six days cycle time. The combination of 5S-5R violates the safety condition for M20 to M30 grade of concrete with six days cycle time.

The relation between cycle time and the corresponding cost is shown in Figure 2 for M20 grade of concrete with a different combination of shore/reshore levels. The X-axis is the sum of shore and reshore levels. These are added to show the relationship between total formwork levels, cycle time, and cost so that, it becomes convenient to present four parameters in a single figure. As the cycle time increases, the cost of construction increases. The difference of one level of formwork (between 4 and 5) increases the cost by almost Rs. 1, 00,000 as the cycle time differs by six days. One can visualise the combination of formwork levels and cycle time from the figure for minimizing the cost of RCC construction. The engineers and practitioners can decide on the best combination of shore-reshore based on the priorities of the project.

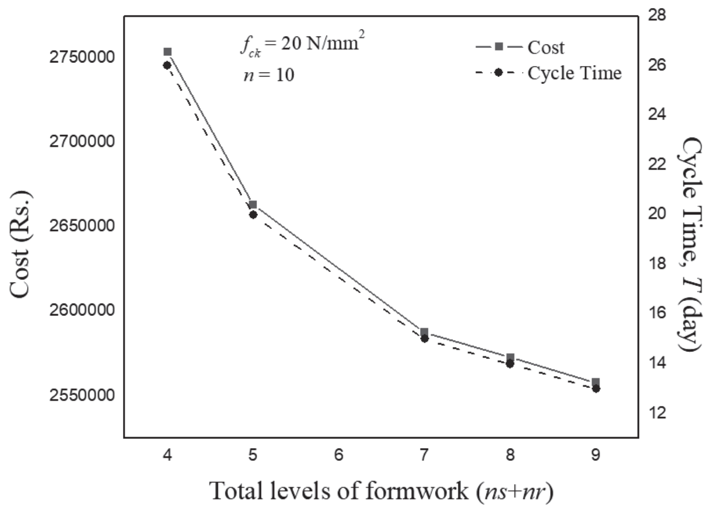


Figure 2: Cost and cycle time variation with total levels of formwork

Figure 3 shows the results for an M25 grade of concrete. The plot shows the combination of one level of shore with different possible combinations of levels of reshores. The figure shows the variation of cost with cycle time for the respective combination of shore/reshore levels. The cost increases by Rs.2, 26,400 when the level of reshore requirement changes from three levels to one level of reshore. The lowest cost is observed for maximum levels of reshores as the cycle time for this combination is the minimum i.e. six days.

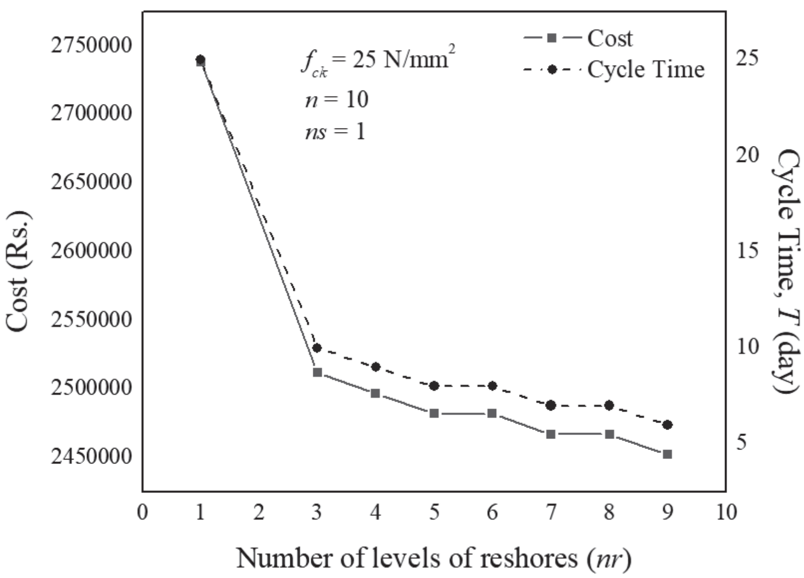


Figure 3: Cost and cycle time variation for one level of shores

Similarly, the program generates results for M35 to M50 grades of concrete in an excel sheet. The minimum cost for an M35 grade of concrete is Rs. 24, 52, 690 with six days cycle time for the 1S-2R combination. Similarly, the minimum cost for M40, M45, and M50 grades are Rs. 24, 53,320, Rs. 24, 54,070, and Rs. 24, 54,820 respectively with a 1S-1R combination and six days of cycle time. 5S-5R gives an economically desirable solution as the factor of safety condition is fulfilled.

Figure 4 shows the variation of cycle time for same shore/reshore combination with different FoS. The program gives the results for a 10-storey building with only one level of shore and different possible levels of reshore for an M20 grade of concrete. The required cycle time increases with increase in FoS to ensure safety throughout the construction. The study considers the FoS values lesser than 1.3 (ACI 347.2R-05, 2005) as unsafe, and the values greater than 2.0 (IS 456:2000) as over safe (uneconomical). Hence the extreme safety conditions are checked for a 10-storey building. It shows that the cycle time is more for higher FoS, as the slab can gain desired strength with more number of level of shore/reshore in place.

The study gives the idea about the cost of construction with respect to shore/reshore levels combination for a 10-storey building.

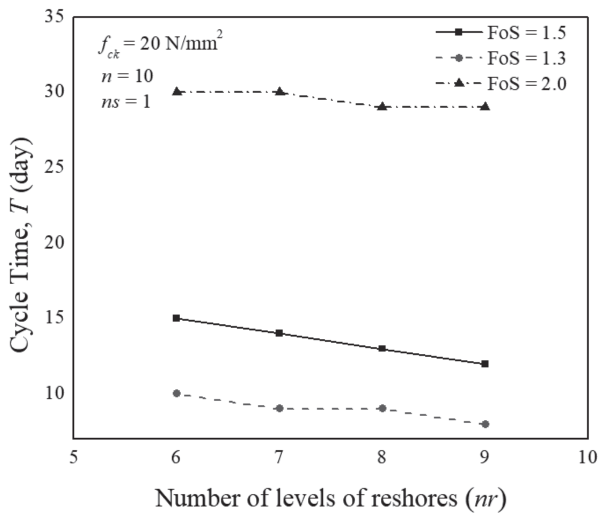


Figure 4: Cycle time variation for different factor of safety

It gives the clear picture of impact of safety consideration on the cost of construction according to cycle time. Hence, this helps the users and practitioners to choose the optimised cost model with respect to cycle time considering the desired safety of the construction.

CONCLUSIONS

The analysis of cost is carried out for a 10-storey building considering the safety during construction. The slabs need to maintain a factor of safety of 1.5 to ensure the safety of the construction. The cycle time plays a major role in the cost calculation. All the combinations of shore/reshore levels violate the safety condition with the cycle time of six days for M20 concrete hence give a very high cost. Whereas, all other grades i.e. M25 to M50, give minimum cost in six days cycle time. The combination of five levels of shores and five levels of reshores violates the safety condition for M20 to M30 grade of concrete with six days cycle time. The cycle time increases with increase in the required factor of safety. A small difference in the total formwork levels can change the cost of construction to a greater extent. The program can be easily modified for any storey with the required FoS to generate the results for cost of construction. This study is an attempt to explore the impact of shore/reshore levels combination on the cost of construction. Hence, it is suitable for the designers and practitioners to decide levels of shores and reshores for economical construction without compromising the safety.

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