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Cost Optimization of Column

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Abstract: The ratio of longitudinal steel area to gross concrete section is in the range from 0.01 to 0.08, according to BNBC/ACI Code. The common practice is to choose an arbitrary section and check that for bending and axial load with a reinforcement ratio around 2-3% but we don't know whether it is economical or not. However, for a particular moment and load there is only one section which is economical, it means only for a certain percentage of reinforcement the section will be optimized. Since the cost of concrete and reinforcement are different which may increase or decrease independently, the percentage of reinforcement in the optimized section varies with the price ratio of steel to concrete. Analysing for the present cost ratio of steel and concrete, it is seen that a column section is optimized at 1 percent of reinforcement for low-rise to medium rise building. This is true for any column that after a certain price ratio it is optimized at reinforcement of the order of 1 percent on that loading and moment condition. Use of high strength concrete in the column has an effect of minimizing the cost. Using 5000 psi concrete instead of 3000 psi concrete saves 20-50 percent of total cost in general. For same axial load and moment resisting capacity, a circular column is found to be more costly than a square column. Also, the cost differences between circular and square column increase with the increase in gross area of concrete.

Keywords:

1 Introduction:

According to BNBC 1993, the ratio of longitudinal steel area (A_{st}) to gross concrete area (A_g) in column is in the range from 0.01 to 0.08. But, in practice, designers do not usually provide more steel than 4% of the gross concrete area (A_g) because of the difficulty owing to congestion of the reinforcement. The common practice in designing a column is to choose arbitrary sections and check them for bending and axial load with a reinforcement about 1% to 4% of the gross concrete area. However, for a particular loading condition, there is only one section which can be found economical, which means for a certain percentage of reinforcement the section is optimized. The percentage of reinforcement in the optimized section is found to vary with the price ratio of steel to concrete.

Use of high strength concrete in the column is another way to minimize the total cost of the column. High strength concrete reduces the requirement of high percentage of steel reinforcement in the column. Cost of steel being the governing factor in the optimization of the column section, the section gets optimized with the increase in strength of concrete. Therefore, the effect of percentage of reinforcement and the strength of concrete both in the optimum design of column section is dealt with in this paper. Also, the cost comparison between circular and rectangular column sections having same axial load and moment resisting capacity is analyzed in this paper to select an economical section.

2 Methodology

Cost optimization analysis is carried out in this paper for three cases:

1. To find a optimized percentage of reinforcement considering existing price of concrete and reinforcement
2. To compare the cost of column for various strength of concrete
3. To compare the cost of circular and square column for similar loading condition.

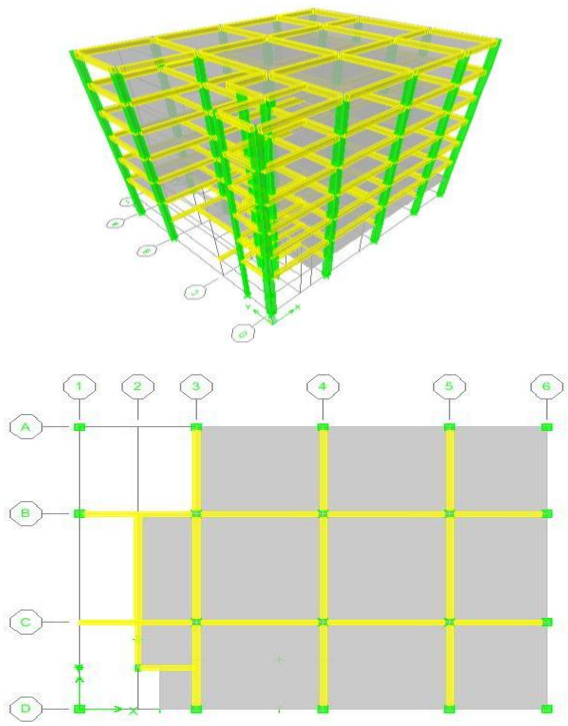

***Figure 1**: 3D view and plan of a six storied building*

Figure 1 shows the three dimensional and plan view of a typical six storied building which is analyzed for designing the columns. For a specific loading condition, the required percentage of reinforcement for a column will decrease with the increase in gross concrete area. This will decrease up to a certain section and after that the required amount of reinforcement will increase. To find the optimized section, columns of a particular building are chosen and designed for various section and percentage of reinforcement for a specific loading condition. Finally, total cost versus percentage of reinforcement graph is plotted for different price ratios to find out the optimized percentage of reinforcement. ETABS 9.7 is used to design the column.

Again, in comparing the cost of column for different strength of concrete, column of a particular building is chosen and designed for different strength of concrete by ETABS 9.7. Finally, a graph of total cost versus strength of concrete is plotted to show the result. For similar loading condition, both square and circular column are designed firstly by changing the concrete gross area and secondly by changing the percentage of reinforcement. The cost of ties in both cases is neglected as difference of cost of ties is very little. Finally, two graphs are plotted for either of the cases showing the variation of cost. PCA COL software is used here to design the column.

3 Selection of Structure:

The cost optimization analysis is performed for various types of buildings. The conclusions and remarks are given on the basis of the structures which have been dealt with. In this paper, the analysis results (tables and figures) are shown only for a six storied irregular type of building as shown in figure 1. The column B4 of the building is analyzed here for optimum cost calculation.

4 Cost Analysis:

A ground floor column with a story height of 10ft is considered. 60 grade reinforcement and 4000 psi concrete is chosen for the analysis. The present cost of 60 grade steel and 4000 psi concrete are given below.

Cost of 60 grade Reinforcement

= 60000 BDT/ton

Cost of 4000 psi concrete

= 210 BDT/ cft

5 A Optimized Percentage of Reinforcement Considering Existing Price:

The applied axial load and moment in the square column is resisted both by concrete and steel simultaneously. As the cost of concrete and reinforcement may increase or decrease independently, the economic section is found to depend on a factor called price ratio X where,

X= Price of 1cft reinforcement (490 lb)/Price of 1 cft concrete

= (Price of reinforcement (ton)/Price of concrete (cft)) × 223 × 10^{-3}

The following table shows the cost analysis of B4 column at ground floor of the selected building for different price ratios. Two graphs are plotted from the above table to represent the result. Figure 2 implies for the comparison of cost for various price ratios and figure 3 shows the variation of optimizing percentage of reinforcement with the price ratios.

***Table 1**: Cost analysis of B4 column (Square) for different price ratios*

BxL (Column Size)	A_g (Column area)	A_{st} (Steel area)	Percentage of Steel	Total Cost (BDT) for X=5	Total Cost (BDT) for X=10	Total Cost (BDT) for X=15	Total Cost (BDT) for X=20	Total Cost (BDT) for X=25	Total Cost (BDT) for X=30	Total Cost (BDT) for X=50	Total Cost (BDT) for X=65
16x18	288	17.864	6.203	5503	6805	8108	9410	10713	12016	17226	21134
18x18	324	14.925	4.606	5813	6902	7990	9078	10166	11255	15608	18873
18x20	360	13.532	3.759	6237	7223	8210	9197	10184	11170	15117	18077
18x22	396	11.922	3.011	6644	7514	8383	9252	10122	10991	14468	17076
18x24	432	10.672	2.470	7078	7856	8635	9413	10191	10969	14082	16416
20x22	440	9.348	2.125	7098	7780	8462	9143	9825	10506	13233	15278
20x24	480	8.04	1.675	7586	8173	8759	9345	9931	10518	12863	14621
22x22	484	6.598	1.363	7539	8021	8502	8983	9464	9945	11869	13313
22x23	506	5.802	1.147	7802	8225	8648	9071	9494	9918	11610	12879
22x24	528	5.280	1.000	8085	8470	8855	9240	9625	10010	11550	12705

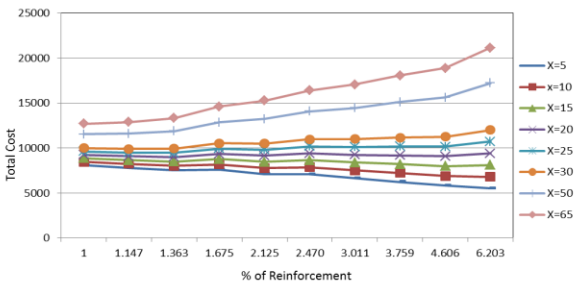

Figure 2: *Graphical analysis of cost for various price ratios*

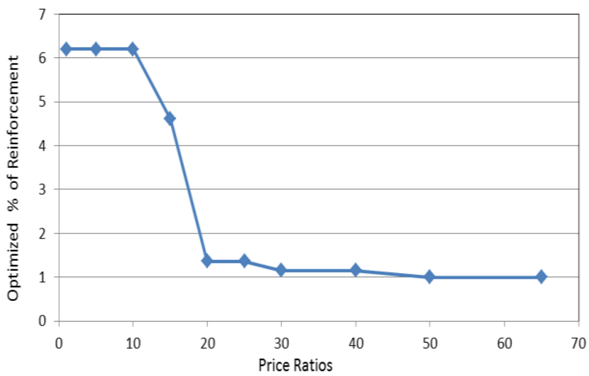

Figure 3: *Variation of Optimized percentage of reinforcement with price ratios.*

For current price of reinforcement and concrete, the estimated price ratio is 65. It can be seen from the figure 2 that use of 1 percent of reinforcement at the existing price ratio gives the most cost effective design of column and the estimated cost is found 12705 BDT. The corresponding cost for 2.47 percent of reinforcement is estimated 16416 BDT. The difference in cost is 3711 BDT may seem very small. But considering the overall structure, this amount will not be so small. For the B4 column of this particular building, use of 2.47 percent of reinforcement instead of 1 percent of reinforcement increases the column cost by 29.21percent. Again, column designed using 4.6 percent of reinforcement is about 1.5 times more costly than column designed using 1 percent of reinforcement.

Figure 3 shows how the optimized percentage of reinforcement changes with the changes of price ratios. When the price of concrete and reinforcement are same, i.e X=1, the column section needs about 6.2 percent of reinforcement to get optimized. With the increase in price ratio, the optimized percentage of reinforcement decreases and after a certain price ratio the economical percentage of reinforcement becomes of the order of 1 percent. This is true for any column that after a certain price ratio (X=30) the column design is optimized at reinforcement of the order of 1 percent on that loading and moment condition..

6 Cost Comparison Of Column For Various Strength Of Concrete

The same structure is now analyzed for a given section of column (20"x20") at the ground floor level but for different strength of concrete. The price of concrete increases with increased concrete strength. The cost analysis result for B4 column is summarized below in the table 2.

Table 2: *Cost analysis of B4 column for different strength of concrete*

Concrete Strength (psi)	Price of Concrete Per Cft (BDT)	Column Size (inxin)	Reqd. Reinforcement (in^2)	Cost of Reinforcement (BDT)	Cost of Concrete (BDT)	Total Cost (BDT)
2000	195	20X20	22.397	20785	5417	26202
2500	198	20X20	19.177	17797	5500	23297
3000	201	20X20	15.876	14733	5583	20317
3500	205	20X20	13.101	12158	5694	17853
4000	210	20X20	10.547	9788	5833	15621
4500	215	20X20	8.059	7479	5972	13451
5000	220	20X20	5.849	5428	6111	11539
5500	223	20X20	4.000	3712	6194	9907

Price Source: Various Construction Firms, Bangladesh, August 2011

The analysis shows the required amount of reinforcement decreases with the increasing strength of concrete for a specific loading condition. The moment and axial load on a column is resisted by concrete and reinforcement simultaneously. As the selected column section is fixed and the loading condition is similar, so the required reinforcement decreases with the increasing strength of concrete. Form the graph, it is also seen that when the concrete strength is increased, the increase in cost of concrete is very small compared to the decrease in cost of steel.

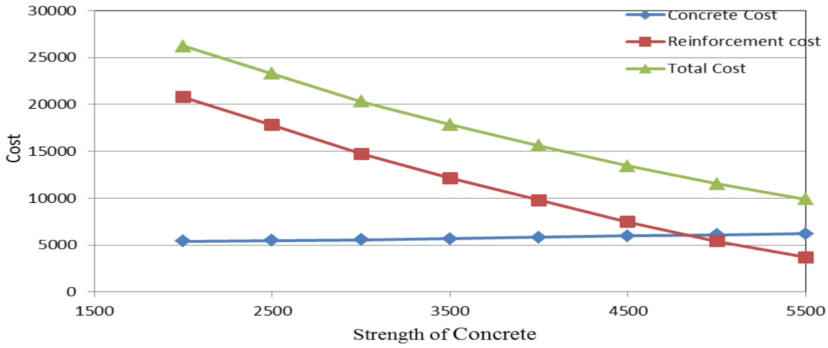

***Figure 4**: Variation of cost with increase in the strength of concrete.*

Also, the total cost reduces 2 times for this particular column when 5000 psi concrete is used instead of 3000 psi concrete. After performing the similar analysis for some high rise buildings, it is found that using 5000 psi concrete instead of 3000 psi concrete saves 20-50 percent of total column construction cost.

7 Comparison of the cost between circular and square column for similar loading conditions:

For architectural purposes, engineers frequently use circular columns. Therefore, it is of prime importance to know the cost effectiveness of circular column with respect to square or rectangular column. For comparison purposes, 8 (A~H) column samples are taken and are designed as both circular and square columns in two ways:

- Keeping the gross concrete area same but changing the required reinforcement
- Keeping the reinforcement same but changing the required gross area.

The result is shown in the table 3 and table 4.

***Table 3**: Cost comparison between square and circular columns changing the gross concrete area*

Sample	L	B	A_g	No. of Bar	A_{st}	Percentage of Steel	Axial Load Capacity	Moment Capacity M_x	Moment Capacity M_y	Cost of Concrete (BDT)	Cost of Reinforcement (BDT)	Total cost
A	12	12	144	8#6	3.52	2.44	128	73	73	2100	3267	5367
	Dia	16.75	220.5	8#6	3.52	1.60	128	74	74	3216	3267	6482
B	15	15	225	8#8	6.32	2.81	220	164	164	3281	5865	9146
	Dia	21.25	355	8#8	6.32	1.78	220	166	166	5177	5865	11042
C	16	16	256	8#8	6.32	2.47	252	190	190	3733	5865	9598
	Dia	22.75	406.5	8#8	6.32	1.55	252	194	194	5928	5865	11793
D	19	19	361	8#9	8	2.22	369	312	312	5265	7424	12689
	Dia	27	572.5	8#9	8	1.4	366	316	316	8349	7424	15773
E	20	20	400	8#9	8	2.00	413	350	350	5833	7424	13258
	Dia	28.35	638	8#9	8	2.01	413	359	359	9304	7424	16728
F	22	22	484	8#10	10.16	2.10	505	481	481	7058	9429	16487
	Dia	31.25	767	8#10	10.16	2.07	488	488	488	11185	9429	20614
G	24	24	576	8#10	10.16	1.76	611	585	585	8400	9429	17829
	Dia	34	908	8#10	10.16	1.77	602	595	595	13242	9429	22670
H	25	25	625	8#10	10.16	1.63	657	643	643	9115	9429	18543
	Dia	35.5	990	8#10	10.16	1.65	648	657	657	14438	9429	23866

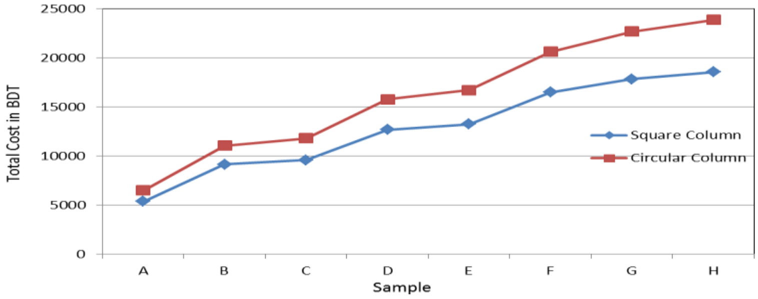

***Figure 5**: Difference in cost for various samples (Same reinforcement)*

***Table 4**: Cost comparison between square and circular columns changing the reinforcement*

Sample	L	B	A_g	No. of Bar	A_{st}	Percentage Of Steel	Axial Load Capacity	Moment Capacity M_x	Moment Capacity M_y	Cost of Concrete (BDT)	Cost of Reinforcement (BDT)	Total cost
A	12	12	144	8#6	3.52	2.44	128	73	73	2100	3267	5367
	Dia	13.5	143.14	8#10	10.16	7.10	132	74	74	2087	9429	11516
B	15	15	225	8#8	6.32	2.81	220	164	164	3281	5865	9146
	Dia	17	226.98	8#14	18	7.93	231	170	170	3310	16705	20015
C	16	16	256	8#8	6.32	2.47	252	190	190	3733	5865	9598
	Dia	18	254.47	11#11	17.16	6.74	258	193	193	3711	15925	19636
D	19	19	361	8#9	8	2.22	369	312	312	5265	7424	12689
	Dia	21.5	363.05	15#10	19.05	5.25	372	310	310	5295	17679	22974
E	20	20	400	8#9	8	2.00	413	350	350	5833	7424	13258
	Dia	22.5	397.61	16#10	20.32	5.11	420	352	352	5798	18858	24656
F	22	22	484	8#10	10.16	2.1	505	481	481	7058	9429	16487
	Dia	25	490.87	11#14	24.75	5.04	504	481	481	7159	22969	30127
G	24	24	576	8#10	10.16	1.76	611	585	585	8400	9429	17829
	Dia	27	572.56	12#14	27	4.72	613	587	587	8350	25057	33407
H	25	25	625	8#10	10.16	1.63	657	643	643	9115	9429	18543
	Dia	28	615.75	13#14	29.25	4.75	671	664	664	8980	27145	36125

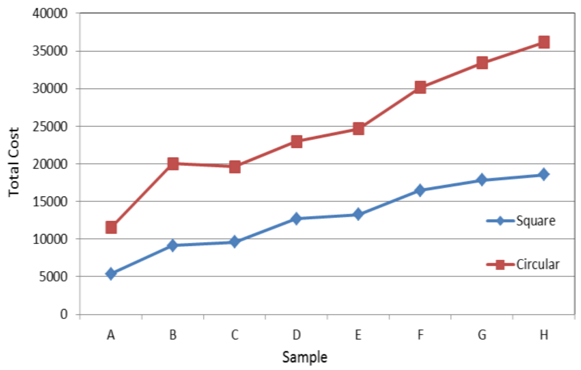

***Figure 6**: Difference in cost for various samples (Same concrete gross area)*

Considering the same reinforcement (Table 3), it can be seen that a circular column requires more concrete area than a square column for same loading conditions. Therefore, circular column costs about 20-30 percent more than square column in this case. Considering the similar gross concrete area (Table 4), it can be seen that a circular column requires more reinforcement than a square column. Therefore, circular column costs about 80-130 percent more than square column in this case. So when column is designed as circular it should be designed keeping the reinforcement same as square or rectangular column.

8 Conclusion:

When the price ratio is more than 30, column section gets optimized at reinforcement of the order of 1 percent. For present market price of concrete and reinforcement (X=65) in Bangladesh, a column section is optimized at 1 percent of reinforcement. This implies a column of larger section with reinforcement around 1.0 percent is more economical than a column of smaller section with 3-4 percent of reinforcement. Therefore, engineers should go for larger concrete section instead of larger percentage of reinforcement for optimum design for low rise buildings.

If proper high strength of concrete can be obtained in field condition, it can result in minimizing the total cost of column. Using 5000 psi concrete instead of 3000 psi concrete saves 20-50 percent of total cost. Use of 1.0 percent of reinforcement sometimes increases the column dimension more than the acceptable limit. High strength concrete may be used in this case to reduce the section and at the same time it is economical too.

The circular column is more costly than a square column having same axial load and moment resisting capacity. However, sometimes engineers prefer circular column for architectural beauty or other practical purposes. But when cost is a vital factor, circular columns should be avoided as much as possible.

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