Effect of material strength on the cost of RCC building frames

H. M. A. Mahzuz¹ · Mohammed Ridwan Choudhury¹ · Anindya Rakib Ahmed¹ · Sourav Ray¹

Received: 17 August 2019 / Accepted: 30 November 2019 / Published online: 7 December 2019
© Springer Nature Switzerland AG 2019

Abstract

In this study, the influence of twelve concrete mix ratios and two rebar grades on the cost of 3, 7, 12 and 20 story RC building frames was investigated. Cylindrical concrete specimens having different mix ratios (by mass) were prepared with Ordinary Portland Cement and locally available fine and coarse aggregates. The compressive strength of concrete was tested on the 28th day of curing. A linear equation is proposed to predict the compressive strength of concrete keeping it as the function of the percentage of cement and the ratio of coarse and fine aggregate. Based on the compressive strengths obtained from different mix ratios, buildings of the same model were designed using the ETABS, as per the provision in Bangladesh National Building Code-2006 (which has a great similarity with the latest ACI code). Also, each building was evaluated individually for the two most conventionally used rebar grades. Therefore, in total 96 buildings were evaluated to obtain the total materials cost for each of the mix ratios and rebar grades. It was seen that (1) for low rise building the cost becomes lower when the lower strength concrete is used, (2) for medium to high rise building high strength concrete can be considered cost-efficient, (3) the mix ratios having a higher coarse aggregate/fine aggregate ratio tends to increase the cost, and (4) 500 MPa rebar was found cost-effective compared to 400 MPa rebar.

Keywords Building · Concrete · Cost · Compressive strength · Mix ratio · Rebar · Steel

1 Introduction

Minimization of the cost of construction can help a lot to get affordable buildings for housing, healthcare, business, and educational purpose. In this study, 12 different concrete mix ratios having different compressive strengths and 2 conventionally used rebar grades were evaluated in minimizing the cost of construction for 3, 7, 12 and 20 story RCC building frames. The building models were designed in ETABS 2015 by following Bangladesh National Building Code (BNBC) considering the buildings were situated in Dhaka, the capital of Bangladesh. The prices of the construction materials were taken into consideration as of the FY-2018. Many researchers are seen to do identical works in this area of knowledge. The results in short of a few of them are presented below.

For example, in a study, a mathematical method based on a modified regression theory was formulated for the prediction of concrete strength. The model can prescribe all possible mixes that will produce the desired strength of concrete. It can also predict the strength of concrete under a specified mix ratio [1]. Another study reviewed and summarized the cost optimization of concrete structures. The study suggested to design concrete structures based on cost minimization rather than weight minimization. It was concluded that there is a real demand to perform research on cost optimization, especially for large structures with many members where optimization can result in significant savings [2]. Similar research was done on the cost optimization of reinforced concrete flat slab buildings following the provisions of the British Code. Here, the optimization process was handled on three different levels. In the

✉ H. M. A. Mahzuz, mahzuz_211@yahoo.com; ✉ Sourav Ray, sourav.ceesust@gmail.com; Mohammed Ridwan Choudhury, ridwan.cee@gmail.com; Anindya Rakib Ahmed, arahmed11912@gmail.com | ¹Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet 3114, Bangladesh.

primary step, the optimum positioning of the column was achieved by an in-depth investigation. In the next step, for each column layout, the most favorable dimensions of structural members were found adopting a “hybrid optimization algorithm”. Finally, another thorough inspection was done to determine the optimum number and size of reinforcing bars of reinforced concrete members [3].

Other researchers studied mix proportioning of high-performance concrete. They have suggested special performance requirements using conventional concrete materials can be achieved only by selecting a low ratio of water to cement. It demands the use of high cement content. For heavy structures, higher strength of concrete is preferable because it reduces the use of steel which is the most expensive among the conventional construction materials. The use of chemical and mineral admixtures can cut down the cement content and this results in cost-effective HPC [4]. Another attempt was made to determine the most economical span length for framed RCC building. For that, code enforced guidelines supported by mathematical investigation were followed. The cost appropriateness is justified in terms of the required concrete volume and reinforcement. Comparing all the facts for a given live load it is seen that shorter spans in the range of 5–6 m are more economical [5].

Ahmad [6] conducted a study on optimum concrete mixture design using locally available materials. In his study he found that, $\frac{\text{water}}{\text{cement}}$, $\frac{\text{coarse aggregate}}{\text{total aggregate}}$ and $\frac{\text{total aggregate}}{\text{cement}}$ are the crucial criteria affecting the design of a concrete mixture as well as cost. For specific strength and durability, single $\frac{\text{water}}{\text{cement}}$ must be selected and should be maintained constant. However, to lessen the amount of cement within constraints resulting in optimum design of a concrete mix, $\frac{\text{coarse aggregate}}{\text{total aggregate}}$ and $\frac{\text{total aggregate}}{\text{cement}}$ may be varied. If the amount of cement can be reduced maintaining the same concrete strength it will be cost-effective. On the other, in a study, it was found that as the height of RCC buildings increases it becomes less profitable. The main causes of such happening are increased dead load. Other supporting factors are lesser stiffness, higher foundation size, and excessive time consumption. In this situation, the “steel–concrete composite” frame system can offer a better, effective and economical solution to most of the problems in medium to high-rise buildings [7].

Moreover, modern-day innovative construction practices and techniques are able to save effectively both the energy and money. Therefore, effective financing in these sectors allows the beneficiaries to save the cost of structures that are more effective, demand-driven, productive and profitable. Even such approaches can build buildings that use less energy and can be more cost-effective [8]. Interval of columns in building to a large extent shapes

the gross cost of the materials. Because higher span length needs a higher dimension of column, beam, and slab. Subsequently, it can increase the dead load of the structure, which can lead to a heavier size of footing as well. The minimum overall dimensions of heavily loaded floors columns can safely be suggested “one-fifteenth” of the usual span. On the other hand for roof columns having a comparatively lighter load the minimum size can be “one-eighteenth” of the usual column spacing [9].

Similar to the column, the beam is another major structural element of a building. Many structural engineers like to use the thumb rule to select the beam depth: 19 mm per 300 mm span, considering the depth of the beam twice the width. Experience proves that such consideration is cost-effective as well [10]. In general, industrial and warehouse multistory RCC buildings are massively loaded. For such cases, a flat slab with column panel and capitals is proven to be very effective. Only shorter to moderate column spacing are economically feasible for heavily loaded buildings. The use of one or two waffle slab is also considered as an alternative and economically feasible slab system that can offer a larger span without the obstruction of column [11].

In general, the cost of the RCC becomes cheaper if the grade of steel is improved. That’s why, in terms of total steel use, it is seen that steel of 400 MPa and 500 MPa is cheaper than 275 MPa. Also because of higher spacing allowance, tied reinforcement is generally cost-effective than spiral reinforcement in columns [12]. Even reuse of so-called waste materials (e.g. stone powder, arsenic-contaminated sludge, etc.) can also give similar or sometimes better strength than the conventional materials [13–15]. Also, carbon-based wastes are considered resources in construction industries since they can secure both the economy and environment [16–18].

2 Materials and methods

During concrete casting, Ordinary Portland Cement (OPC) of CEM I, 52.5 N (ASTM C-150, Type-1) was used as binder materials. Constant water to cement ratio (0.45 ± 0.02) was also maintained to have good workability (slump: 65–75 mm). As coarse aggregate, well graded crushed stone chips (19 mm downgraded) were collected and as fine aggregate, Sylhet Sand having a Fineness Modulus of 2.67 ± 0.01 was used. They were chosen maintaining the provisions of ASTM C150 for cement and according to ASTM C33 for fine and coarse aggregates [19, 20]. The market prices of these materials are presented in Table 1. 12 mix ratios were chosen including the standard mix ratios used in practice. For each of the mix ratios compressive strength test was conducted on three samples. The three

Table 1 The market price (FY-2018) of cement, fine aggregate and coarse aggregate

Cement	Fine aggregate	Coarse aggregate
\$5.6 per bag (50 kg)	Local name: Sari Balu Price: \$10/m ³	19 mm crushed stone Price: \$43/m ³

Table 2 Mix ratios and the corresponding 28 day compressive strength

Mix ratio (by mass)				Compressive strength (MPa)
Number	Cement	Sand	Stone	
1	1	1	0.5	33.5
2	1	1	1	25.2
3	1	1	2	21.4
4	1	1.25	2.5	20.0
5	1	1.5	1	22.5
6	1	1.5	2	20.5
7	1	1.5	3	18.6
8	1	2	1	21.8
9	1	2	2	19.5
10	1	2	3	17.5
11	1	2	4	15.3
12	1	3	3	15.1

results were averaged and the compressive strength of the corresponding mix ratio was found. The mass based mix ratios and the corresponding 28 day compressive strength are listed in the Table 2. Samples were molded and cured in accordance with ASTM C31/C31 M-15 [21]. Compressive strength test of the samples were done as per the guidance of ASTM C39/C39M-15a [22].

The deformed bars were chosen according to ASTM A615 [23]. The price of 400 MPa and 500 MPa steel was same: \$600 per ton. Models were designed for 3, 7, 12 and 20 story buildings. Each model had the plan shown in Fig. 1, (floor area per story = 24 m × 24 m = 576 m²). In total, 96 (= 4 different heights of buildings × 12 concrete mix ratios × 2 grades of steel) building models were created in ETABS-2015 (a well-known and popular software used in structural engineering for integrated analysis, design and drafting of buildings). The design of the building models were such that the columns and beams were near to failure under the applied loading condition. The column dimensions were selected in a manner to keep the ground floor column's PMM Ratio or rebar percentage close to 4.0%. It is to be noted that, in the study, only the material cost (of cement, sand, stone and steel) was calculated for beam, column and slab.

The loads and load assigns in ETABS are shown in the Table 3. Few other factors which are considered constant

Fig. 1 Building model (plan view)**Table 3** The loads and load assigns in ETABS

Load assigns	Load values (kN/m ²)	Acting on
Live load	2	Slab
Partition wall (PW)	1	Slab
Floor finish (FF)	1.5	Slab
Wall load	25	Beam

Table 4 Factors considered for analysis as per BNBC-2006 [24]

Subject	Value
Wind speed in Dhaka	210 km/hr
Zone coefficients, Z	0.15
Structure importance coefficients (I)	1.00
Response modification coefficient for structural systems, R	8.00
Site coefficient, S (i.e. Stiff or dense soil condition where the soil depth is less than 61 meters)	1.00

for each case as per BNBC-2006 [24] are shown in Table 4. After design and analysis the models in ETABS, following data were obtained to proceed to the next phase of the study: (1) the total volume of steel (of slabs, columns and beams) used in the design for each of the models and (2) the total volume of concrete (of slabs, columns and beams) used in the design for each of the models. Later, these values were inputted to obtain the cost of each materials as well as the total cost for each models. Note that, the design

Table 5 Mix ratios and compressive strength of concrete grouped into two sets according to $\frac{CA}{FA}$ ratio

Mix ratio no.	Cement	Sand (FA)	Stone (CA)	$\frac{CA}{FA}$	Cement % (C)	Compressive strength (MPa)
Set-1, $\frac{CA}{FA} \leq 1.5$						
12	1	3	3	1.00	14.30	15.1
10	1	2	3	1.50	16.67	17.5
9	1	2	2	1.00	20.0	19.5
6	1	1.5	2	1.33	22.22	20.5
8	1	2	1	0.50	25.00	21.8
5	1	1.5	1	0.67	28.57	22.5
2	1	1	1	1.00	33.33	25.2
1	1	1	0.5	0.50	40.00	33.5
Set-2, $\frac{CA}{FA} = 2$						
11	1	2	4	2.00	14.29	15.3
7	1	1.5	3	2.00	18.18	18.6
4	1	1.25	2.5	2.00	21.05	20.0
3	1	1	2	2.00	25.00	21.4

of foundation as well as its cost estimation was not done in the present study.

3 Results

Since the cost of coarse aggregate is much huger than that of sand, therefore it can be said that in a mix ratio, the higher the $\frac{CA}{FA}$ the more costly the construction will be. Therefore the 12 mix ratios are divided into two sets as presented in Table 5.

Using the software, SPSS-Version 2017, a linear equation (Equation-1) is proposed (having $R^2 = 0.95$) to predict the compressive strength of concrete (σ in MPa) keeping it as the function of percentage of cement (C) and $\frac{CA}{FA}$. The lower and upper limit of cement percentage is 14–40%, and of $\frac{CA}{FA}$ is 0.5–2.0. The input values for Eq. 1 are also shown in Table 4. The corresponding comparison of the compressive strength of concrete found from experiment and calculated using Eq. 1, are presented in Fig. 2, which have a variation ranging from +6.7 to –7.8% with the experimental result.

$$\sigma = 6.27 + 0.62C + 0.14 \frac{CA}{FA} \quad (1)$$

3.1 For 3 story building

For 3 story building with 400 MPa steel, the cost versus compressive strength of concrete is presented in Fig. 3. The shape of the curve does not represent any regular shape. But if the concept of the two sets of $\frac{CA}{FA}$ is introduced than better representation can be achieved (Fig. 4). Also, the total dead load of the building frame is shown behind the

Fig. 2 Comparison of the compressive strength of concrete found from experiment and calculated using Eq. 1

Fig. 3 Total cost versus compressive strength for 3 story building with 400 MPa steel

curves as area. Same approach is taken in Fig. 5, for 3 story building with 72.5 Grade steel. From the Figs. 4 and 5 it is evident that, the 500 MPa steel is cost effective than 400 MPa steel. By using 500 MPa steel for a 3 story building (576 m² per story) on an average \$2170 can be saved which

Fig. 4 Total cost versus compressive strength by grouping mix ratios for 3 story building with 400 MPa steel

Fig. 7 Total cost versus compressive strength by grouping mix ratios for 7 story building with 400 MPa steel

Fig. 5 Total cost versus compressive strength by grouping mix ratios for 3 story building with 500 MPa steel

Fig. 8 Total cost versus compressive strength by grouping mix ratios for 7 story building with 500 MPa steel

Fig. 6 Cost comparison of materials for 3 story building with 500 MPa steel

Fig. 9 Cost comparison of materials for 7 story building with 500 MPa steel

is 7.20% of the total material cost. Comparison of various materials cost just for 500 MPa steel is shown in Fig. 6, here classification based on $\frac{C_A}{F_A}$ is not maintained.

3.2 For 7 story building

For 7 story building the cost versus compressive strength of concrete with 400 MPa and 500 MPa steel, are presented in Figs. 7 and 8 respectively. From the Figures, it is also evident that the 500 MPa steel is more cost effective than 400 MPa steel. By using 500 MPa steel for a 7 story building (576 m² per story) on an average \$5495 can be saved which is 6.30% of the total materials cost. Comparison of

various materials cost just for 500 MPa steel is shown in Fig. 9.

3.3 For 12 story building

Identical scenario is also seen for 12 story building. The cost versus compressive strength of concrete with 400 MPa and 500 MPa steel, are presented in Figs. 10 and 11 respectively. It is evident that the 500 MPa steel is more cost effective than 400 MPa steel. By using 500 MPa steel for a 12 story building (576 m² per story) on an average \$9354 can be saved which is 4.83% of the total materials

Fig. 10 Total cost versus compressive strength by grouping mix ratios for 12 story building with 400 MPa steel

Fig. 11 Total cost versus compressive strength by grouping mix ratios for 12 story building with 500 MPa steel

Fig. 12 Cost comparison of materials for 12 story building with 500 MPa steel

cost. Comparison of various materials cost just for 500 MPa steel is shown in Fig. 12.

3.4 For 20 story building

For 20 story building the cost versus compressive strength of concrete with 400 MPa and 500 MPa steel, are presented in Figs. 13 and 14 respectively. From the figures it is evident that the 72.5 Grade steel is more cost effective than 400 MPa steel. By using 500 MPa steel for a 20

Fig. 13 Total cost versus compressive strength by grouping mix ratios for 20 story building with 400 MPa steel

Fig. 14 Total cost versus compressive strength by grouping mix ratios for 20 story building with 500 MPa steel

Fig. 15 Cost comparison of materials for 20 story building with 500 MPa steel

story building (576 m² per story) on an average \$23789 can be saved which is 3.65% of the total materials cost. Comparison of various materials cost just for 500 MPa steel is shown in Fig. 15.

4 Discussion

The present study tried to find the influence of concrete mix ratios and rebar grades on the cost of RC building of different stories. From the existing literature review, no such attempt was found on a large scale. On a smaller scale, the output of this research partially matched with few researchers. For example, as found by Ahmad [6],

Fig. 16 Cost variation per increment of concrete strength of different construction materials

the ratio of different aggregate was an important factor for cost optimization, is also found true in the present investigation. Span length- 6 m was also maintained as per suggestion [5]. The general opinion of proving cost-effective options by high strength steel also proved to be the same from the current outcomes [12]. Yet, the need for a wider study is felt [2] considering story number, concrete strength, and steel strength. It is hoped that the result of the present study can fulfill this demand, maybe in a small range. Though this study was carried out as per BNBC-2006 (which has significant similarity with the latest version of American Concrete Institute (ACI)), yet it can also be done as per other codes as well.

In this study, all calculation is done focusing on a single building model (Fig. 1). It is expected that the cost will be changed as per the building plan and market price of construction materials. Yet identical result is supposed to have, as got in the present study. The gist of the research discussed as follows:

1. The total material cost of RCC building varies significantly with the compressive strength of concrete.
2. As found from Figs. 6, 9, 12 and 15, the cost of sand was not significantly changed with the concrete strength. The cost of stone and steel are seen to be decreased as the concrete strength was increased. Also, the cost of cement was significantly seen to be increased with the concrete strength. The qualitative presentation of cost variation per increment of concrete strength of different construction materials is shown in Fig. 16.
3. For 3 story RCC building frames higher strength of concrete does not help in reducing the total cost. The total cost becomes lowest when the lowest strength of concrete is in use.
4. For 7, 12 and 20 story RCC building frames the total cost gradually increases with increasing compressive strength of concrete. But when concrete strength crosses 25.5 MPa the total cost starts to decrease.

Therefore, high strength concrete can be considered as cost-efficient for mid to high rise buildings.

5. Concrete mix ratios having a greater portion of coarse aggregates ($\frac{CA}{FA} \geq 2$) increases the cost.
6. The total dead load of the building frame decreases (more than 10%) with increasing compressive strength of concrete (in the range between 15.1 and 33.5, as shown in Table 2).
7. In every case, 500 MPa steel rebar is significantly cost-efficient (even up to 7.20%) compared to 400 MPa steel rebar.

5 Conclusion and recommendation

The entire study was conducted using the local market price over a simple building plan. Both of the above can indeed be changed as per place. Therefore, the above study is only applicable to the mentioned constraints. Yet, such an initiation can play a documentary baseline for bigger and more generalized studies. Also, the costs for foundation, formwork, labor and labor cost, etc. have not been taken into consideration. Therefore, more studies can be conducted keeping all of them in the count.

Acknowledgements The authors of the paper are grateful to the Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh, for all the necessary support for the research.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest to the publication of this article. There are no copyrights relevant to this work. There are no relationships or activities to disclose that could be perceived to influence on the submitted work.

References

1. Onwuka D et al (2011) Prediction of concrete mix ratios using modified regression theory. *Comput Methods Civ Eng* 2(1):91–103
2. Sarma K, Adeli H (1998) Cost optimization of concrete structures. *J Struct Eng* 124(5):570–578
3. Sahab M, Ashour A, Toropov V (2005) Cost optimisation of reinforced concrete flat slab buildings. *Eng Struct* 27(3):313–322
4. Bharatkumar B et al (2001) Mix proportioning of high performance concrete. *Cem Concr Compos* 23(1):71–80
5. Mahzuz HMA, Ahmed M (2010) Selection of economical span in RCC building. *SUST Stud* 12(1):93–98
6. Ahmad S (2006) Optimum concrete mixture design using locally available ingredients. *Arab J Sci Eng* 32(1B):27–33
7. Begum M et al (2013) Cost analysis of steel concrete composite structures in Bangladesh. *Asian J Civ Eng* 14(6):935–944
8. Elattar SMS (2009) Towards a global vision for building technology future. *Eur J Sci Res* 30(3):495–504

9. Witer G, Urquhart LC, O'Rourke CE, Nilson AH (2001) Design of concrete structures, 7th edn. Mc-Graw Hill, New York, p 447
10. Nilson AH, Darwin D, Dolan CW (2003) Design of concrete structures, 13th edn. Mc-Graw Hill, New York, p 388
11. Fintel M (1986) Multistory structures. Handbook of concrete engineering, 2nd edn. CBS Publishers & Distributors, Delhi, p 352
12. Ferguson PM, Breen JE, Jiras JO (1987) Reinforced concrete fundamentals, 5th edn. Wiley, New York, p 253
13. Haque M, Ray S, Mahzuz HMA (2012) Use of stone powder with sand in concrete and mortar: a waste utilization approach. *ARPJ Sci Technol* 7(2):613–618
14. Mahzuz HMA, Ahmed AAM, Yusuf MA (2011) Use of stone powder in concrete and mortar as an alternative of sand. *Afr J Environ Sci Technol* 5(5):381–388
15. Mahzuz HMA, Alam R, Alam NM, Basak R, Islam SM (2009) Use of arsenic contaminated sludge in making ornamental bricks. *Int J Environ Sci Technol* 6(2):291–298
16. Ghernouti Y, Rabehi B, Safi B, Chahid R (2014) Use of recycled plastic bag waste in the concrete. *J Int Sci Publ Mater Methods Technol* 8, ISSN 1314-7269
17. Hasan A, Islam MN, Karim MR, Habib MZ, Wahid MF (2015) Properties of concrete containing recycled plastic as coarse aggregate
18. Kamble SA, Karad DM (2017) Plastic bricks. *Int J Adv Res Sci Eng* 6(4):134–138
19. ASTM C150/C150M-15 (2015) Standard specification for Portland cement. ASTM International, West Conshohocken, PA. www.astm.org
20. ASTM C33/C33M-13 (2013) Standard specification for concrete aggregates. ASTM International, West Conshohocken, PA. www.astm.org
21. ASTM C31/C31M-15 (2015) Standard practice for making and curing concrete test specimens in the field. ASTM International, West Conshohocken, PA. www.astm.org
22. ASTM C39/C39M-15a (2015) Standard test method for compressive strength of cylindrical concrete specimens. ASTM International, West Conshohocken, PA. www.astm.org
23. ASTM A615/A615M-15ae1 (2015) Standard specification for deformed and plain carbon-steel bars for concrete reinforcement. ASTM International, West Conshohocken, PA. www.astm.org
24. BNBC (2006) Bangladesh National Building Code, Dhaka, Bangladesh

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.