

The impact of materials cost on the weight of concrete buildings

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Abstract

Today, concrete structures are the most commonly used structures in construction industry and are considered as an important industry of Iran with respect to the increasing trend of construction. In concrete structures, a considerable part of total weight of the structure is allocated to the concrete members' weight leading to the increase of dead load of the structure. To decrease the dead load of the structure, lightweight concrete is often used. This type of concretes is more expensive than normal concretes but due to decreasing the members' size, economic use of concrete and steel as well as decreasing transportation cost, they are preferred to be used in the structures. Lightweight concretes are also fire-resistance inherently. On the other hand, to obtain higher strength in various buildings, the cost of concrete production is increased. Highly resistant concrete will have more weight leading to more dead load. With respect to the mentioned features, using lightweight concrete is not recommended for high strengths. Considering above, it seems that the cost and price of concrete and other materials used in concrete buildings affect the weight of concrete buildings. In this regards, the present study attempted to investigate the importance of materials' cost and their role in concrete buildings' weight.

Index terms- Cost, Concrete buildings, Materials, Strength

1 INTRODUCTION

After water, concrete is a widely used material by human in industry and is considered as an important industry with respect to the increasing trend of construction. In spite of numerous advantages of concrete, concrete members compared to steel members have greater size due to the less strength of concrete relative to steel. Therefore, the members in concrete structures include a considerable weight of the structure due to the dead load. Using lightweight concrete in concrete structures, these dead loads can be decreased to a great extent. For this advantage, lightweight concretes have been widely used in concrete structures recently. Lightweight concrete is not considered a new innovation in concrete technology and its application dates back to a long period time. There are some evidences that its usage dates back to the third millennium BC.

Decreasing the density of concrete causes to decrease of the structure's weight leading to the decrease of foundation weight, decrease of pressure on frames, increase of construction speed, saving transportation costs, the possibility of using precast pieces, increase of thermal insulation and soundproof effectiveness. Notably, lightweight concrete shows more strength against fire (Clark, 1993).

In reinforced concrete structures, decreasing the weight of buildings is a critical issue which has been highly considered in Iran during the recent years. Decreasing the weight of structures leads not only to the decrease of earthquake forces applied on building and increases of seismic security level but is a factor to maintain environment and change construction industry to a sustainable industry due to the decrease of structural materials such as cement and rod (Chandra and Bronson, 2002).

While on the other hand, decreasing the weight of structure may cause to increase cost, decrease compressive strength and increase concrete porosity; and it seems that Pozzolans can solve above defects to some extent with respect to the useful characteristics created by them in concrete.

In this regards, the present study attempts to investigate the effect of materials' cost in concrete structures' weight. The present study also is the first work done on the considered subject but a short review of the related works can be presented as follows:

Rmezaniapour (2011) studied the applications of lightweight concrete and its effect in the strength and cost of buildings. Based on the study, he concluded that various types of structural and non-structural lightweight concretes due to their weight, thermal insulation, less production and transportation costs, as well as enough strength against seismic forces are highly considered in industry.

Naghi Pour et al (2003) also investigated decreasing the weight of structure and its effect in affordability of the design against quakes. They examined the effect of decreasing walls' weight in building using new roof systems and standard confirmed wall in steel structure in order to achieve an economic and effective design.

Another study done by Lemay (2011) revealed that evaluating concrete buildings' life cycle is a valuable tool to evaluate environmental effects of buildings and their economic effects. Further, comparing concrete and steel structures indicated that concrete structures save more energy, have higher thermal insulation and are more affordable in application.

Gajda et al (2006) based on their work on concrete structures' weight concluded that concrete structures are the most used materials in environment. They referred to one of concrete structures application is in bridge building in which the amount of cement are increased to make them more economic and strong.

1-1 Lightweight concrete and its application

Now days, engineers and architectures have been able to progress economically in construction through using lightweight concrete directly (in terms of its special light weight) and indirectly (in terms of being insulation and decreasing fuel consumption).

Lightweight concrete are produced through various ways. Three main distinguishable groups include lightweight aggregate concrete, aerated concrete and no-fines concrete. The first group is the concrete with integrated structure in which lightweight aggregate is used instead of aggregate. They can be found in the forms of structural, non-structural and thermal insulation. In the second group, concrete is made based on putting a large amount of empty spaces into the concrete. The third type is made by omitting lightweight aggregate leading to a high porosity in concrete. In this type of concrete, normal coarse aggregate while using lightweight aggregate can decrease the weight of concrete to a large extent and improve its thermal insulation characteristics (Ochsendorf et al., 2011).

As one of the applications of lightweight concrete, bridge building can be referred. In bridges, decreasing the weight make the desk wider without needing to make a lot of change in its structure. Since lightweight concrete is applied in one side of the pier and normal concrete is applied in another pier to balance the weight during embedding a longer span on the lighter pier, this feature allows piers to close to the earth leading to a significant decrease in cost.

The thickness of the bridge desk can be increased by changing desk or surfacing it to provide more covering on reinforcement to better drainage without adding additional dead load to the structure; also lightweight concrete is used to create longer span to avoid the need of expensive piers.

1-2-Economic analysis of lightweight concrete

It is wrong to say that lightweight aggregate concrete is not appropriate to use in construction since it is more expensive to produce compared to normal concrete. High cost of lightweight aggregate concrete due to the advantages of dead load decrease and ease of transportation,

especially in case of precast elements, can be compensated somehow (Chandra and Bronson, 2002).

As an economic advantage, it can be referred to lightweight concrete in reinforcement concrete frames leading to saving costs in foundation. Floor slabs consists a major part of structure frame's weight (consist 60% of dead load on the foundation). Moreover, the amount of soundproofing and thermal insulating is so that it is no need to additional layers for general or minimal insulating. Also, it can be said that using lightweight concrete in arches are less valuable since saving in weight is followed by saving costs. In a normal and equal condition, total saving value of cost can be 5% to 7% of concrete skeleton price which is often less than 2% of total building price (Family, 1987).

The concrete made of normal sand and gravel is the best criterion to compare lightweight construction concrete. To minimize the effect of price changes in time and place of presented results, the computed price of 1m^3 lightweight concrete is divided on the computed price of 1m^3 normal concrete with defined characteristics. The quotient of this division is called design cost factor. By price, materials price is not only intended but other parameters such as work force cost are considered. Considering the fact that achieving to require fluency need to add super lubricant and it leads to significant cost increase, the cost of providing materials should also be taken into consideration (Chandra and Bronson, 2002).

2-Discussion and results

2-1-Comparing various Regulations of the world regarding the decrease of building weight

According to Regulation 2800 of Iran, confidence coefficient against overturning equals with overturning moment which should be greater than 1/75. To satisfy confidence coefficient, the structure weight will be deterministic. Now, if numerical value of confidence coefficient is decreased, the weight of structure will be decreased. Therefore, confidence coefficients against overturning were

investigated in other Regulations and are as follows:

- Regulation of Canada:

Overturning moment in structure base level is multiplied by reduction coefficient of J.

$$T < 0.5 \text{ (Sec)} \Rightarrow J = 1.0$$

0.5

$$\text{(Sec)} < T < \text{(Sec)} \Rightarrow J = (1.10 - 0.2T)$$

As it is observed, in the Regulation of Canada, overturning moment is multiplied by reduction coefficient of 0/8; that is, confidence coefficient against overturning is 1/25.

- Regulation of America, Egypt and Ethiopia: in this Regulation, the reduction coefficient is considered 1/0.
- Regulation of El Salvador: in this Regulation, overturning moment in structure base level is multiplied by the reduction coefficient of K.

The maximum stories number of 10 $\Rightarrow K = 1/0$

The maximum stories number of 20 $\Rightarrow K = 0/8$

The stories numbers between 10 to 20 are being interpolation:

The structure pendulum is inverse $\Rightarrow K = 0/75$

Where the maximum confidence coefficient against overturning of the above Regulation is the same value of the Regulation of Canada, that is:

$1/25 \leq$ confidence coefficient

Therefore, it can be concluded that the Regulation of Iran has considered the greatest confidence coefficient against overturning while by decreasing this coefficient, the weight of structure can be decreased. Hence, the issue of decreasing the weight of buildings, especially concrete buildings is of high importance with respect to Iran's seismicity.

2-2-Optimization for mix design

The act of optimizing mix design is to provide various concrete designs with different aggregates amounts and then, select the best mix option through comparing characteristics such as the mechanical strength, economic costs and good flexibility of concrete. In this regards, the first stage is to provide informational bank for existing aggregates. The information bank includes name and price, granulating parameters (softness module, granulation number granulating coefficient, density changes, water absorption, compressive strength, and frost resistance).

Optimum mix design encompasses the following cases:

- Computing size and amount of aggregates according to the above mentioned numerical method
- Computing the ration of water to cement using applicable formulae (depending on concrete strength, cement strength, and aggregates' quality)
- Computing the amount of water consumed as well as aggregating parameters such as classification, shape, levels characteristics

Aggregation number of an aggregate can be computed as follow (Birsh, 1984):

$$\lambda_j = \sum_{i=1}^M Q_i \lambda_i$$

Where:

Q_i : The residual ration in the sieve

λ_i : Aggregation number in the given aggregate ratio

Aggregate mix can be computed by simulating aggregation number:

$$\lambda = \sum_{j=i}^N K_j \lambda_j$$

The mount of consumed water is also computed using the following formula:

The coefficient depended on concrete mixture = K

However, it should be noted that standard method refers to general characteristics of aggregates (maximum size, softness module) and does not state their characteristics in details. Aggregating method allow to investigate the characteristics of concrete more exactly.

To optimize concrete mix, the following recommendations can be presented which can affect the process positively:

- A) Inserting optimization information
- Concrete and consumed materials characteristics, slump cone, compressive strength, aggregate type, the amount of existing air, maximum size of aggregate
 - Various ways of mixing existing aggregates: aggregate numbers from information bank (N1 = sand, N2 = gravel)

The final number of combinations with various sizes of aggregate, in case of having one type of sand and gravel:

$$n_c = N1 \times N2$$

- B) Mix design for all combinations of aggregates size and computing characteristics for optimization
- Aggregates mix design using numerical method with computations of the quality criterion of specific aggregates
 - Standard deviation mean between rhetorical classification and real curve of S
 - Concrete mix design and computing combinations in $1m^3$ which have the following characteristics:

- (CEM): The amount of cement consumed in each m^3 of concrete
- (W): The amount of water consumed in each m^3 of concrete
- (D): Computational density of concrete

In case of using mix design for both lightweight and heavy concrete, the characteristics related to each of them should be considered in computations.

To compute the economic criteria of the design, the followings should be taken into consideration:

- The cost of materials consumed in $1m^3$ of concrete
- Computing individual purpose function for the given characteristics to determine their optimization degree through the ratios from 1 to 5

Computing individual purpose function for all combinations of aggregates size:

$$n_c = N1 \times N2$$

Where:

N_y : The specific number which should be optimized

η_i : Default coefficient for the importance of given characteristics for optimization

Φ_i : Individual purpose function for the importance of given characteristics for optimization

To compare purpose function for combinations of various aggregates, the best concrete can be obtained. The best concrete will have the greatest Φ .

2-3-The structural efficiency of lightweight concrete structures

To achieve the optimum efficiency in structures, it is necessary to improve the ratio of strength to the weight. The main cause of using lightweight concrete in buildings is to decrease weight leading to improve the performance of architectural expression and constructability of a structure. In buildings, it can be achieved through fire resistance narrow slabs, longer ceiling spans, increasing the height of building and addition to the number of structure stories. Decreasing the weight causes that the ground is used more optimally and more space is provided in the building. Additionally, decreasing the weight leads to the decrease of materials, the decrease of foundation causing to minimizing surface foundations, less piles, smaller pile caps, and less reinforcement; the decrease of dead loads minimizing the pieces of beams supports, floor, and piers; and the decrease of dead loads which reduce static seismic forces (Ashtari, 2004).

2-4-Lightweight concrete design in Iran

Since Iran is an earthquake-prone country, it has suffered from financial and non financial damages many times. On the other hand, high population growth rate has caused many problems in housing sector in large cities, especially during the recent years. As a result, construction with the use of appropriate methods, economic design (making use of optimal construction material) and mass buildings can significantly help to decrease the housing problem, especially for low income class of the society.

In earthquake-prone areas, earthquake force is increased proportional to the building weight leading to designing more resistant buildings in larger dimensions with spending less cost. Accordingly, decreasing the weight of building is an effective way of decreasing construction cost and decreasing applied forces (lateral and gravity) on buildings (Marceau, 2007).

Moreover, the advantages of using lightweight concrete have been identified as an important structural material and it is used increasingly. By decreasing the weight of super structures, the

weight of foundation and its construction cost as well as the transportation and installation costs are decreased. Since the objective of economic and optimal design is to achieve a design creating the least cost in construction in addition to supplying the design requirement, minimum use of materials with the most efficiency of the structure is one of the necessary conditions of obtaining low cost to implement the structure.

3-Conclusion

As the studies reported, using lightweight aggregate and cheap materials in concrete structures cause to saving materials, decreasing transportation costs, performance improvement, increasing shelf life of concrete, and decreasing the weight of building.

Moreover, the obtained results revealed the relation of using lightweight aggregate materials with the increase of shelf life of structure to decrease energy resources consumption. These benefits are consistent with green buildings objectives. Using lightweight aggregate materials decreases main construction costs and importantly, it decreases the cost of the structure's shelf life and generally, put construction in the way of sustainable development. The benefits of lightweight concrete materials can compensate the high price of them.

In this regards, it is necessary to change the existing attitudes. In concrete buildings constructed currently, it is observed that they suffer from a structural weakness while an optimal design can be implemented by spending fewer costs and the decrease of buildings weight.

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