

COMPARATIVE EVALUATION OF ACI AND NOMINAL MIX DESIGN METHODS FOR STRENGTH AND COST EFFICIENCY OF CONCRETE

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ABSTRACT

Concrete mix design plays a crucial role in achieving the desired balance between strength, durability, and cost-effectiveness in construction. This study presents a comparative evaluation of the American Concrete Institute (ACI) mix design method and the conventional Nominal Mix approach, which is still widely used in routine construction practices. The objective was to assess the compressive strength development and cost implications of both methods for M25 and M30 grade concretes. Concrete cylinders were cast, cured under controlled laboratory conditions, and tested for compressive strength at 7, 14, and 28 days. The results indicated that both methods successfully achieved the target strengths for M25 and M30 grades. However, the ACI method consistently optimized material usage, resulting in significant cost savings. Cost analysis revealed that the Nominal Mix required approximately 16.4% and 18.6% higher costs than the ACI mix for producing one cubic foot of M25 and M30 grade concrete, respectively. The findings highlight the limitations of empirical mix design and emphasize the advantages of adopting systematic approaches such as the ACI method. While slightly more complex, the ACI method provides superior long-term value by ensuring consistent strength performance, efficient material utilization, and reduced overall construction costs. These results suggest that large-scale projects can benefit substantially from adopting the ACI mix design over conventional Nominal Mix practices. This study also provides engineers and practitioners with direction as the construction industry looks for ideal mix designs that balance performance, strength, and sustainability. This study adds to the conversation on concrete mix design, enhancing decision making for strength based and economical construction methods at a time when resource efficiency is of paramount importance.

Keywords: Concrete mix design, ACI method, Nominal mix, Compressive strength, Cost efficiency

1. INTRODUCTION

Concrete is a versatile construction material that is used in a wide range of constructions (Amin *et al.*, 2022). It is made up of cement, water, admixture, crushed rock for coarse aggregate, and sand for fine aggregate. A well-made concrete mix will ensure the strength of the finished structure. Additionally, it increases material efficiency by eliminating wastage of materials. If the proportioning of materials has not been done correctly, good quality materials, thorough mixing, appropriate transportation and placement, suitable compaction, and much more caution may not still result in good concrete quality (Aginam *et al.*, 2013). Determining the ideal ratio of the ingredients is crucial to producing concrete of acceptable quality at a reasonable price (Demissew, 2022). The process of selecting suitable concrete ingredients and calculating their relative amounts to produce concrete with the required strength, and workability at the most affordable price is known as concrete mix design (Amin *et al.*, 2022). Numerous factors, including material specific gravity, cement type and strength, minimum and maximum cement content, water-to-cement ratio, mixing water requirements, aggregate-to-cement ratio, types, shapes, and maximum sizes of aggregates, grading of aggregates, ratio of fine to total aggregate, entrapped air content, concrete exposure conditions, and properties of concrete in green and hardened concrete, have been found to influence the proportions of ingredients in concrete (Ahmed *et al.*, 2016).

The purpose of mix design is to obtain the most economic and practical combination of readily available materials, which satisfies the performance of concrete. There are two types of concrete mixtures: nominal mix and design mix. Nominal mix is used for minor buildings, whereas design mix concrete is used for major or extensive projects. (Chhachhia, 2021). The choice of concrete mix design can affect a construction project's energy efficiency, environmental effect, and overall sustainability. The majority of countries use their own concrete mix design techniques, which are founded on empirical relationships, tables, charts, and graphs created as a result of in-depth research and testing of locally accessible materials and adhere to the same fundamental trial-and-error guidelines (Mindess, 2019). The three most widely used techniques for calculating the proportions of concrete elements are the American (ACI), Indian (IS), and British (DOE) standards (Dixon *et al.*, 1997). The three different proportioning methods differ from each other in terms of the quantities of materials required to produce the concrete. In order to proportion concrete mixtures efficiently the right mix design method must be deployed. In general the method to be adopted is aimed at utilizing the least amount of concrete paste to obtain the desired qualities of concrete. According to (Shetty, 2005) some of the various proportioning methods include; American Concrete Institute 211-91 (ACI Method), British DOE method (DOE method), Fineness Modulus Method, Maximum Density Method, Surface Area Method, India Standard-10262-82 method (IS method). Among the various methods in use, the method proposed by the American Concrete Institute Standard (ACI, 1996) is probably the most popular one. Because the ACI Standard proposes a mixed design technique that considers the most cost-effective use of available ingredients to produce concrete with optimum workability, and strength.

Despite the widespread use of ACI mix design, many developing countries (including Bangladesh) rely on nominal mixes, particularly in small and medium sized projects. Nominal mix design is a conventional method of concrete proportioning in which fixed ratios of cement, fine aggregate, and coarse aggregate are adopted without detailed mix design calculations. Very little study has evaluated the performance of nominal and ACI mix design methods employing locally available materials in underdeveloped nations, despite the fact that both are well documented.

Considering all these factors, this research project aims to investigate a comparative result of compressive strength, material efficiency and cost analysis of concrete using locally available materials based on ACI and Nominal mix design, addressing a critical gap in current construction practice.

2. METHODOLOGY

2.1 Materials

In the concrete mix design, standard grades of concrete M25 and M30 were designed by ACI and Nominal mix design and compared. Materials used for this investigation include; Ordinary Portland Cement (OPC), coarse aggregates, fine aggregates and water. Ordinary Portland Cement (OPC) with a cement mix of 95–100% clinker and 0–5% gypsum was used in this study. The freshness of the cement was ensured by verifying its production date before purchase. The physical properties of used cement in this study are shown in table 1.

Table 1: Physical properties of OPC utilized in the study

| Property | OPC |
|----------------------|------------------------|
| Grade | 42.5 |
| Specific gravity | 3.15 |
| Initial setting time | 70 minutes |
| Final setting time | 260 minutes |
| Unit Weight | 1420 kg/m ³ |
| Fineness | 225 m ² /kg |

Locally available clean Sylhet sand which was passed through the 4.75 mm sieve was used in this study. Figure 1 represents the particle size analysis of the fine aggregate (sand).

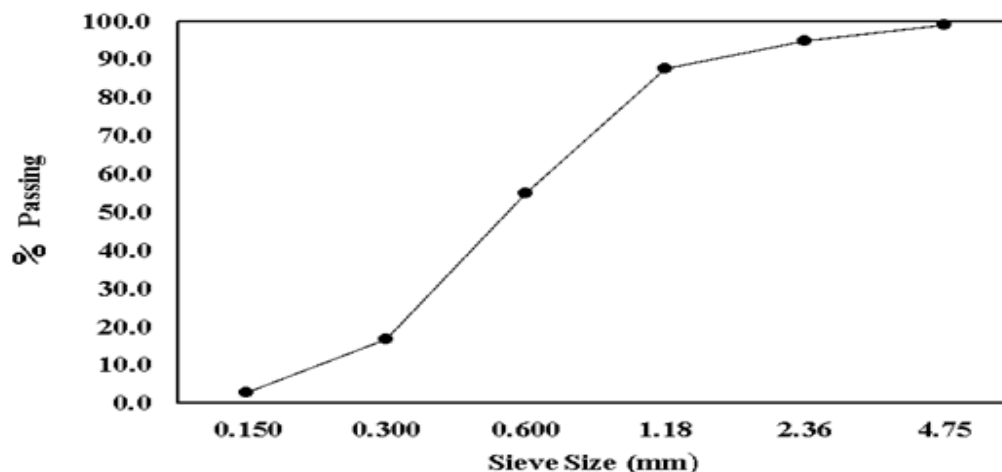


Figure 1: Particle size distribution curve of fine aggregate (Fineness Modulus, F.M = 2.4)

Figure 1 shows that 100% aggregate was passed through 4.75 mm sieve and about 5 % aggregate was passed through 0.15 sieve which indicates fine to medium sand according to particle size distribution curve. Also, it was seen that the aggregate sample was relatively well graded containing a variety of particle size, as indicated by the curves continuous rise. For dense packing and enhanced strength of concrete, this type of gradation is advantageous.

Stone chips of 20 mm was used as coarse aggregates which was clean and free from impurities. The particle size analysis of the coarse aggregate was shown in figure 2.

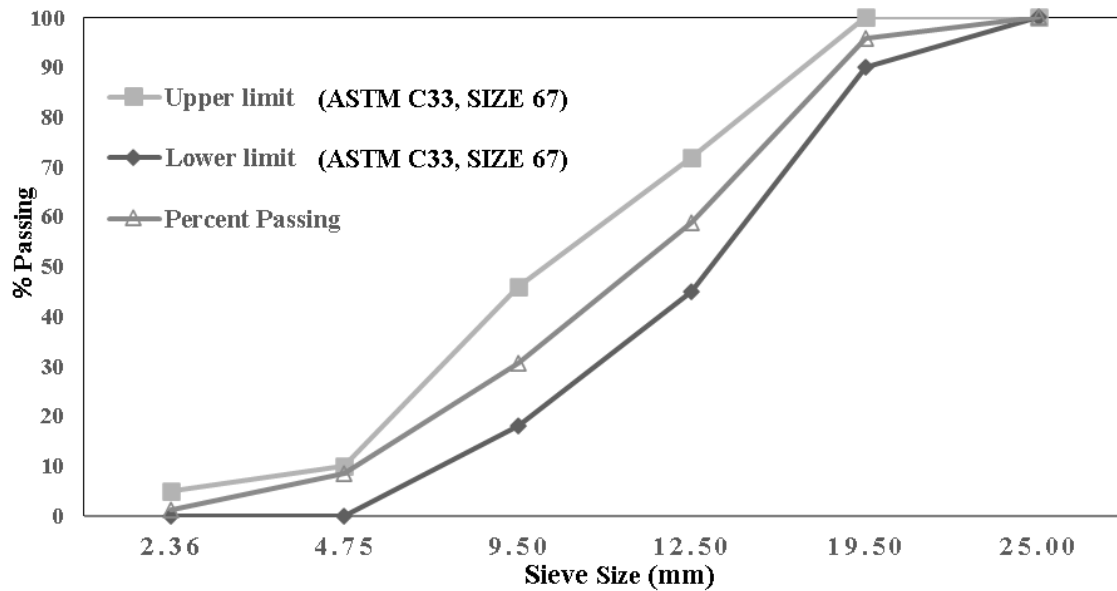


Figure 2: Particle size distribution curve curve of Coarse aggregate

Figure 2 represents the particle size distribution of coarse aggregate where the experimental gradation curve was plotted against the standard upper and lower limits. The aggregate had well graded profile which ensured proper particle interlocking and desired mechanical performance of the mix.

Table 2: Summary of aggregate physical properties used in this study

| No | Parameter | Result | |
|----|--|---------------------------------|---------------------------|
| 1 | Nominal maximum size of coarse aggregate | 20mm | |
| 2 | Coarse aggregate | Natural crushed stone aggregate | |
| 3 | Fine aggregate | Sylhet sand | |
| 4 | Silt content of sand | 2.8% | |
| 5 | Water absorption | Coarse aggregates | 0.6% |
| | | Fine aggregates | 1.68% |
| 6 | Loose bulk density | Coarse aggregates | 1545.33 kg/m ³ |
| | | Fine aggregates | 1467.00 kg/m ³ |
| 7 | Compacted bulk density | Coarse aggregates | 1674.67 kg/m ³ |
| | | Fine aggregates | 1572.00 kg/m ³ |
| 8 | Specific gravity | Coarse aggregates | 2.69 |
| | | Fine aggregates | 2.65 |
| 9 | LOS ANGELES ABRASION value | Coarse aggregates | 22.80% |
| 10 | Aggregate Crushing Value | Coarse aggregates | 21.01% |
| 11 | Fineness modulus (FM) sand | | 2.40 |
| 12 | Uniformity Coefficient (C _u) of Coarse aggregate | | 2.65 |
| 13 | Coefficient of Curvature (C _c) of Coarse aggregate | | 1.51 |

2.2 Concrete Mixing

2.2.1 Nominal Mix Method

In the Nominal Mix method, the concrete mix was determined using fixed volumetric ratios, without accounting for the specific properties or quality of individual materials. This method was based on experience and approximations rather than precise calculations. The nominal mix proportions of 1:1:2 for M25 and 1:0.75:1.5 for M30 were used in this study in accordance with IS 456:2000 (Standard, I. 2000), which allows nominal mixes for grades up to M30 under controlled material and workmanship circumstances. The water-cement ratio was taken to be 0.4 in this study. These proportions ensures an adequate binder to aggregate ratio to achieve the target strength. Table 3 represents the amount of materials for 1 m³ of concrete by nominal mix.

Table 3: Proportions of ingredients for 1m³ concrete determined by Nominal mix method

| Materials | M25 (1:1:2) (kg/m ³) | M30 (1:0.75:1.5) (kg/m ³) |
|------------------|--|---|
| Cement | 530 | 655 |
| Coarse aggregate | 1210 | 1115 |
| Fine aggregate | 570 | 526 |
| Water | 212 | 262 |

2.2.2 ACI Mix Design Method

The ACI method is an improvement over the early methods of concrete mix design. According to ACI (American Concrete Institute) 211.1-91 guidelines, the quality and properties of each material used in the concrete mix such as specific gravity, moisture content, and gradation were precisely determined. ACI (211.1-91) recommended Concrete Mix Design procedure which was taken into account for calculating the amount of materials are as follows –

- Step 1: Selection of slump
- Step 2: Selection of maximum size of coarse aggregate
- Step 3: Estimation of mixing water content and air content
- Step 4: Selection of Water-Cement Ratio
- Step 5: Estimation of Cement Content
- Step 6: Estimation of Coarse Aggregate (CA)
- Step 7: Estimation of Fine Aggregate (FA)
- Step 8: Adjustments for aggregate moisture and Calculate Batch Volume

Considering the above-mentioned steps, the total dry volume of materials was calculated which is shown in table 4.

Table 4: Adjustment For 25 MPa and 30 MPa Concrete ACI Mix Design based on Trial Mix Volume

| Materials | Dry volume (kg/m ³) M25 | Dry volume (kg/m ³) M30 |
|------------------|---|---|
| Cement | 412 | 460 |
| Coarse aggregate | 1065 | 1065 |
| Fine aggregate | 675 | 630 |
| Water | 205 | 205 |

2.3 Concrete casting and curing

A 4 inch x 8 inch cylinder was selected for concrete casting in this study. The number of specimens tested for M25 and M30 grade nominal mix based concrete was 18 and ACI mix based concrete was 18. Thus, numbering to total of 36 cylinders were cast for testing compressive strength based on Nominal and ACI mix design method. After casting, all the test specimens were stored for 24 hours. They were put into a curing tank for 7, 14 and 28 days. The compressive strength of concrete was determined by compressive strength testing machine.

3. RESULT AND DISCUSSIONS

3.1 Compressive strength

The table 5 presents the outcomes of compressive strength assessments conducted at curing intervals of 7, 14 and 28 days. These assessments were performed on cylinder by compressive strength test machine according to ASTM C39/C39M.

Table 5: Average Compressive Strength of 25 MPa and 30 MPa Concrete
(Based on ACI Method and Nominal Mix Method)

| Method | Average compressive strength (MPa) | Average compressive strength (MPa) | Average compressive strength (MPa) |
|-------------------------|--|--|--|
| | 7 days | 14 days | 28 days |
| ACI (25 MPa) | 23.35 | 29.35 | 33.62 |
| Nominal Mix (25 Mpa) | 25.04 | 32.34 | 37.51 |
| ACI (30 MPa) | 31.38 | 35.47 | 43.19 |
| Nominal mix (30 MPa) | 35.07 | 41.34 | 46.8 |

Table 5 shows a clear and consistent increase in compressive strength with different curing ages for all type of concrete mixes. For a given target strength, the nominal mix method consistently produced higher average compressive strength than the ACI mix methods. This trend is evident in both 25 MPa and 30 MPa concrete. At 7 days, all mixes achieved a substantial portion of their target strength indicating good early strength development. Also at 14 days, a pronounced increase in compressive strength is observed for all mixes, reflecting continued hydration and densification of the concrete matrix. The results achieved in 14 days, indicate that the concrete is on a significant gain of strength trajectory toward its 28-day design strength.

3.1.1 Cost Analysis

The cost-effectiveness analysis of concrete mix design has been carried out by calculating the unit cost of concrete per cubic feet for each mix design method using the cost of concrete ingredients in Dhaka City, Bangladesh. Table 6 represents the approximate cost analysis of ACI and Nominal Mix Method for M25 and M30 concrete.

Table 6: Approximate Cost Analysis of ACI and Nominal Mix Method for M25 and M30 Concrete

| Material (Approximate) | Rate | 25 MPa (ACI) | 25 MPa (Nominal mix) | 30 MPa (ACI) | 30 MPa (Nominal mix) |
|-------------------------------|-------------|---------------------|-----------------------------|---------------------|-----------------------------|
| Cement | 10 tk/kg | 412 | 530 | 460 | 655 |
| 20 mm DG Stone Chips | 5 tk/kg | 1065 | 1210 | 1065 | 1115 |
| Sand | 1.63 tk/kg | 675 | 570 | 630 | 526 |
| Water | 0.25 tk/kg | 205 | 212 | 526 | 262 |
| Per cft Cost (BDT) | | 300 | 349.2 | 311.5 | 369.4 |

The table 6 represents that the concrete designed with ACI method came out as the cheapest due to the smallest amount of cement content, and nominal mix was the most expensive method because of the high amount of cement consummation per cubic feet of both grades of concrete. This economic analysis introduces a pragmatic aspect to the concrete mix selection process, where the financial implications of various material compositions can significantly impact project feasibility and budgetary considerations.

4. CONCLUSION

The paper presents experimental findings and comparisons related to the utilization of Nominal mix and ACI mix based concrete. The following conclusion can be drawn based on the results obtained in the experiments.

- The Nominal Mix Method achieved a higher 28-days compressive strength which is 15.54 % greater than ACI Method for 25 MPa concrete. But both exceeded the target strength of 25 MPa.
- The Nominal Mix Method achieved a higher 28-days compressive strength which is 12.02 % greater than ACI Method for 30 MPa concrete. But both exceeded the target strength of 30 MPa.
- The ACI Method is significantly more cost-effective because for making 1 cft 25 MPa concrete the Nominal Mix required approximately 16.4% higher cost than ACI mix.
- The ACI Method incurred a total material cost for making 1 cft 30 MPa Concrete is 311.58 Taka per cubic feet, while the Nominal Mix Method cost was 369.42 Taka per cubic feet an increase of approximately 18.6%.
- ACI Mix Design Method presents a better balance between performance, cost, and quality in large scale construction scenarios compared to Nominal mix methods. It can be a little more complex but provides better long-term value, especially in terms of material savings and performance. In contrast, the Nominal Mix is simpler but less efficient and more costly.

DECLARATION OF AI USE

The authors utilized chatGPT (open AI) to refine the language, correct grammatical errors and improve the clarity and readability of the text during this preparation of this manuscript. The authors took full responsibility for the final content and confirm that all decisions regarding the manuscript remain their own.

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