ISBN: 978-984-34-8313-3
www.iabse-bd.org

# Use of high strength concrete (C-60) in Paira bridge (Lebukhali bridge), Bangladesh

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*Paira Bridge (Lebukhali Bridge) Construction Project, Barishal, Bangladesh*

ABSTRACT: High strength concrete (HSC) has been widely applied worldwide in recent years due to its favorable strength and dense microstructure. High-strength concrete shows some characteristics and engineering properties different from those of normal-strength concrete even though utilize similar raw materials. Use of high-strength concrete for pretension concrete bridge girders has become accepted practice by many countries highway authorities because of its technical and economic benefits. High-strength concrete permits longer span girders and increased girder spacing, thus reducing total bridge cost**.** Paira Bridge (Lebukhali Bridge) is an Extra-dosed Cable Stayed Bridge which is being constructed over the River Paira to connect Dhaka-Mawa-Bhanga-Barisal-Patuakhali Road (N8). Type of the superstructure of this bridge is Pre-stressed concrete Extra dosed Box-Girder. For construction of superstructure, concrete needs to have minimum 28 days ultimate cylinder crushing strength of 60 MPa (83.25 MPa cube equivalent) according to the technical specification of this bridge. To achieve this strength, cube concrete specimens of length 150mm, width 150mm and height 150mm were made with different mix proportions using different types of available construction materials. When making these specimens, minimum cementitious content was 415 Kg/m$^3$, maximum size of aggregate was 20mm nominal size, maximum water cement ratio was 0.4 and slump was bound to stay between 180mm to 250mm. Two Mix-designs of concrete class-60 was finalized to use in construction. Concrete ingredient proportion for mix-design-01 was cement: fine aggregate: coarse aggregate = 1:1.17:1.82 (By weight) where cement was 348 kg/m$^3$ and for mix design-02 1:1.18:1.82 (By weight) where cement was 359.6 kg/m$^3$ and cement to water = 1:0.24 (By weight) for both mix-design. For mix-design-01 cylinder equivalent compressive strength was 59.84 MPa for 7 days, 64.15 MPa for 14 days and 70.31MPa for 18 days and for mix-design-02 cylinder equivalent compressive strength was 65.21 MPa for 7 days, 64.20 MPa for 14 days, and 78.08 MPa for 17 days.

## 1 INTRODUCTION

The Barishal-Patuakhali link is part of one of the most important National Highways of Bangladesh i.e. Dhaka-Mawa-Bhanga-Barishal-Patuakhali-Kuakata road (N8). Kuakata, one of the major tourist spots of Bangladesh is located about 287km away from capital city Dhaka and is connected with the capital through the National Highway (N8). Currently massive development work is taking place in this region under different ministry of Bangladesh focusing the national development plan. At Lebukhali Ferry Ghat, 189$^{th}$ km of this National Highway (N8) i.e. 26$^{th}$ km of Barishal-Patuakhali road, a ferry service is being maintained by Roads and Highways Department (RHD) on the river Paira. The construction of Paira Bridge over the river Paira at Lebukhali section will ensure a smooth transportation link to the other parts of Southern region of Bangladesh and to Paira Thermal Power Plant, Paira Sea Port as well as Kuakata. This will aid and promote the connectivity for entire southern region of Bangladesh. Government of Bangladesh proposed construction of an all-weather bridge over river Paira which was later named by Paira Bridge. It is also known as Lebukhali Bridge. Roads and Highways Department (RHD), Bangladesh signed a contract with a Chinese contractor named "Longjian Road and Bridge CO. Ltd" on 12$^{th}$ April 2016 for the construction of this bridge. Finally Construction works started on 24$^{th}$ July 2016.

Design of Paira Bridge was finalized for main bridge to be an Extra-dosed Cable-stayed Bridge with PSC 4 lane Box Girder superstructure of length 630 meters configuring of two central main spans- 2x200 m and two transition spans- 2x115 m on either end connected of viaduct bridges on North and South side. Viaduct bridge was designed to have 12x30m span PSC I-Girder on the North Bank (Barishal end) and 16x30m span PSC I-Girder on South bank (Patuakhali end), in total length 840m. Therefore total length of Paira Bridge stands for 1470m.

The bridge superstructures was designed according to requirements of AASHTO for modeling, load combinations and stress limits and analyzed using finite element models. Analysis for dead load, superimposed dead load and live load was carried out using STADD-Pro software for structural analysis. For pre-stressing effects on superstructure during construction and service stages, ADAPT-ABI software was used with inputs generated through calculations using spreadsheets. Design of superstructure was carried out using limit state design approach for ULS and SLS case.

The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute defines high-strength concrete as concrete with a compressive strength greater than 6,000 psi.

For many years, high-strength concrete has been used in the columns of high-rise buildings. However, there has been increased use of high-strength concrete in bridges where both strength and durability are important factors to be considered. The primary reasons for selecting high-strength are to produce more economical product, provide a feasible technical solution, or a combination of both. High-strength concrete is required in engineering projects that have concrete components that must resist high compressive loads. If high strength concrete is used for bridge beams, there are number of advantages such as,

- Size reduction – It will make erection easier.
- Increase in span range – It will reduce the cost of construction.
- Reduction in pre-stressing force – It will reduce the cost of tendons.
- Increase in the effectiveness of pre-stressing due to reduction of pre-stress losses.

Manufacture of high-strength concrete involves making optimal use of the basic ingredients that constitute normal-strength concrete. Producers of high-strength concrete know what factors affect compressive strength and know how to manipulate those factors to achieve the required strength. In addition to selecting a high-quality portland cement, producers optimize aggregates, then optimize the combination of materials by varying the proportions of cement, water, aggregates, and admixtures. When selecting aggregates for high-strength concrete, producers consider the strength of the aggregate, the optimum size of the aggregate, the bond between the cement paste and the aggregate, and the surface characteristics of the aggregate. Any of these properties could limit the ultimate strength of high-strength concrete.

Considering high degree of precision and feasibility, cast in place box segments have been chosen for extra-dosed main bridge superstructure. Cast in place single cell box segments with inclined webs has been connected with struts to bottom of each segment. Overall depths of segments near support are varying from 6.75m to 4.00m and that of uniform depth after that are 4.00 meters. After experimenting with normal strength concrete on the cast in place box segments, it was found that concrete having less than crushing strength of 60MPa would not meet the requirement. Hence concrete grade 60 (C-60) was selected for the construction of cast in place box segments.

All materials used by the contractor in concrete grade 60 (C-60) works are tested at the site materials laboratory. Crushed stone, coarse sand, cement, reinforcement steel, admixtures etc. that are procured to site are tested separately and in concrete trial mixes. As procurement of materials is an ongoing process, taking samples and testing is performed on a regular basis. Some verification tests or other tests that cannot be carried out in the site laboratory are performed in the research laboratories of KUET, Khulna and BUET, Dhaka. Concrete trial mixes for grade C-60 has been carried out as well as other routine tests with the progress of the construction works on Viaducts and Main Bridge. During every C-60 concreting, 9 concrete cube is collected from site. Cubes are used to determine compressive strength for 7days, 14days and 28days.

28 days cylinder compressive strength for concrete grade 60 (C-60) is 60MPa. So cube equivalent target strength is (fck + 1.65 times standard deviation + 5MPa) 83.25MPa (Reference: RHD, STD Volume 2 of 5, Technical Specification).For trial mixes for concrete grade 60 (C-60), cube concrete specimens of length 150mm, width 150mm and height 150mm were made with different mix proportions using different types of available construction materials. For every trial mixes, minimum cement and cementitious content was 415Kg/$m^3$, slump was bound to stay between 180mm- 250mm nominal, maximum size of coarse aggregate was 20mm nominal, maximum water to cement ratio was 0.41. Assumed data for air void was 2.0%, Specific gravity of cement was 3.15, blending proportion of coarse aggregate and fine aggregate was 60:40 for every trial mixes.

## 2 MATERIALS AND EXPERIMENTS

### 2.1 *Cement*

Ordinary Portland Cement (OPC) and Rapid Hardening Cement (RHC) specifying BS 12 and ASTM C150 (Specification for Portland cement) can be used for producing High Strength Concrete. As a binding material, Type I Portland cement, Bashundhara OPC 52.5N cement conforming to ASTM C150 specification was used in this study. Manufacturer of the cement used in this bridge is Bashundhara and source of this cement is Mongla, Khulna. Chemical composition tests for cement were performed following ASTMC114 and results are shown in Table 1. Physical properties were tested according to ASTM C191 for initial and final setting time, and ASTM C595 for compressive strengths. The specific gravity was recorded as3.15. Physical properties of the cement are presented in Table 2.

Table 1. Chemical composition analysis of cement.

| Parameters | Weight (%) | Parameters | Weight (%) |
|---|---|---|---|
| $SiO_2$ | 19.93 | MgO | 2.10 |
| $Al_2O_3$ | 5.05 | $SO_3$ | 3.23 |
| $Fe_2O_3$ | 3.43 | Cl | 0.008 |
| CaO | 62.64 | $Na_2O$ | 0.13 |
| $K_2O$ | 0.65 | | |

Table 2. Physical properties of cement.

| Name of Test | Result Obtained |
|---|---|
| Initial Setting Time | 107.0 min |
| Final Setting Time | 270.0 min |
| Normal Consistency | 25.5% |
| Strength (7days) | 40.9 MPa |
| Strength (28days) | 54.8 MPa |

### 2.2 *Fly-Ash*

Fly ash is a supplementary cementitious material used in concrete. Fly ash forms when the impurities (clay, feldspar, quartz, shale and others.) in the coal fuse together during combustion. The result is a very fine, glasslike particles that are so small they resemble Portland cement. Because of its small, glasslike nature, fly ash increases the workability of concrete, typically used in pumping concrete and for forms in which the concrete must fill many crevices and small openings. Paira Bridge is using fly ash type 1 which is coming from China and it is gray colored powder. Chemical composition and physical properties tests of fly ash were performed following ASTM C618 and results are shown in Table 3.

Table 3. Chemical and physical tests of fly-ash.

| Name of Test | Result Obtained |
|---|---|
| Silicon dioxide ($SiO_2$) | 63.12 |
| Aluminium Oxide ($Al_2O_3$) | 14.98 |
| Iron Oxide ($Fe_2O_3$) | 4.02 |
| Sulfur trioxide ($SO_3$) | 0.29 |
| Moisture Content | 0.8 |
| Loss on ignition | 2.18 |

### 2.3 *Slag*

Slag is a byproduct of iron blast-furnaces. It is made from iron ore, coke (carbon-rich “fuel” resulting from the burning of coal) and flux (limestone or dolomite). White color powdered slag was used in Paira Bridge is S105 type and comes from China. Chemical composition tests of slag were performed following ASTM C0989-93 and results are shown in Table 4.

Table 4. Chemical composition of slag.

| Parameters | Result Obtained |
|---|---|
| Sulfide Sulfur (S) | 0.59 |
| Sulfide Sulfur (as $SO_3$) | 0.31 |
| Aluminium Oxide ($Al_2O_3$) | 12.11 |

## 2.4 *Silica Fume*

Silica fume is highly reactive material that is used in relatively small amount to enhance the properties of concrete. Because of its chemical and physical properties, it is very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable. Silica using in Paira Bridge is coming from China and it is powdered and of deep gray color. Tests of silica were performed following ASTM C1240 and results are shown in Table 5.

Table 5. Test results of silica.

| Name of Test | Result Obtained |
|---|---|
| Silica (SiO2) | 92.21% |
| Moisture | 3.02% |
| Loss on ignition | 4.37% |

## 2.5 *Coarse Aggregates*

Selection of good quality, strong aggregates is essential for high strength concrete as aggregate strength and aggregate bond are critical factors governing the concrete strength. Crushed aggregate with angular cubical particles are the most suitable for high strength concrete. Maximum aggregate sizes of 20mm have been using in this bridge to produce C-60 concrete. Crushed stone coming from Dubai are being used here as coarse aggregate. Tests of coarse aggregate were performed following AASHTO M-80and results are shown in the Table 6.

Table 6. Test results of coarse aggregate.

| Name of Test | Result Obtained |
|---|---|
| Specific Gravity (SSD) | 2.779 |
| Water Absorption | 0.6 |
| L.A.A | 9.5 |
| Unit Weight | 1591 $Kg/m^3$ |
| Flakiness Index | 13.8 |

## 2.6 *Fine Aggregates*

Fine aggregates with rounder particle shape and smooth surface texture have been found to reduce water demand and therefore preferred in high strength concrete. Natural coarse sand type fine aggregate from Sylhet, Bangladesh is being used in production of C-60 in this bridge. Tests of fine aggregates were performed following AASHTO M-6 and results are shown in Table 7.

Table 7. Test results of fine aggregates.

| Name of Test | Result Obtained |
|---|---|
| FM | 2.75 |
| Specific Gravity | 2.697 |
| Unit weight | 1517 $Kg/m^3$ |
| Absorption | 0.942 |

## 2.7 *Water*

Potable/drinking water from Deep Tube Well have been using in production of C-60 in Paira Bridge. Different properties of water were tested following AASHTO T-26 and results are shown in Table 8.

Table 8. Test result of water.

| Parameters | Result Obtained | Parameters | Result Obtained |
|---|---|---|---|
| pH | 8.24 | Arsenic (As) | 0.006 mg/l |
| Turbidity | 2.75 NTU | Total Suspended Solids (TSS) | 8 mg/l |
| Chloride | 405 mg/l | Carbon-di-oxide ($CO_2$) | 8 mg/l |
| Total Hardness (as $CaCO_3$) | 62 mg/l | Total Alkalinity (as $CaCO_3$) | 355 mg/l |
| Iron (Fb) | 0.2 mg/l | Sulphate ($SO_4$) | <1 |
| Total Dissolved Solids (TDS) | 844 mg/l | Acidity (as $CaCO_3$) | 9.09 mg/l |

## 2.8 *Admixture*

For producing C-60 concrete in Paira Bridge, PCA-1 concrete super plasticizer admixture is being used. The purpose of using super plasticizer is to give concrete the ability to flow; that is, it greatly increases the slump while maintaining cohesion. With regard to workability, super plasticizers often increase flow for only about ½ hour to an hour. Different tests of admixture were performed and results are shown in Table 9.

Table 9. Test result of admixture.

| Parameters | Result obtained |
|---|---|
| Solid Content | 19.63% |
| Density | 1.068 |
| Chlorine ion content | 0.0016 |
| Ash content | 0.538% |
| Specific gravity @ 15$^o$C | 1.05 |
| Residue by oven drying | 3.98% |

# 3 CONCRETE PRODUCTION AND TESTS

## 3.1 *Concrete Production*

Concrete mixes were made for C-60 production using different W/C ratio, different sand-to-aggregate volume ratio and different cement content. Air content was assumed to 2% as no air entraining admixtures was used. Finally two mix-designs were finalized for C-60. Mix design-01 is used for producing concrete most of the time. Batch weight per m$^3$ of mix design-01 is shown in Table 10 and batch weight per m$^3$ of mix design-02 is shown in Table 11.

Table 10. Mix design-01 of C-60 concrete.

| Ingredient | Absolute Volume (m$^3$) | Sp. Gr. X 1000 | SSD Condition Batch Wt. (kg/m$^3$) |
|---|---|---|---|
| Cement | 0.1105 | 3150 | 348 |
| Fly-Ash | 0.02784 | 2500 | 69.6 |
| Silica | 0.0172 | 2700 | 46.4 |
| Slag | 0.0414 | 2800 | 116 |
| Fine Aggregate | 0.2536 | 2672 | 678 |
| Coarse Aggregate | 0.3804 | 2762 | 1056 |
| Water | 0.1392 | 1000 | 139.2 |
| Admixture SBT PCA-1 | 0.0099 | 1000 | 9.86 |

Table 11. Mix design-02 of C-60 concrete.

| Ingredient | Absolute Volume (m$^3$) | Sp. Gr. X 1000 | SSD Condition Batch Wt. (kg/m$^3$) |
|---|---|---|---|
| Cement | 0.1142 | 3150 | 359.6 |
| Fly-Ash | 0.0348 | 2500 | 87 |
| Silica | 0.0172 | 2700 | 46.4 |
| Slag | 0.0311 | 2800 | 87 |
| Fine Aggregate | 0.2542 | 2687 | 683 |
| Coarse Aggregate | 0.3813 | 2769 | 1056 |
| Water | 0.1392 | 1000 | 139.2 |
| Admixture BASF (Master Glenium Ace 30 IT) | 0.0081 | 1000 | 8.12 |

Concrete Ingredient Proportion for Mix design-01:
Cement: Fine Aggregate: Coarse Aggregate = 1: 1.17: 1.82 (By weight)
Cement: Fine Aggregate: Coarse Aggregate = 1. 1.29: 1.93 (By volume)
Cement: Water = 1: 0.24 (By weight)

Concrete Ingredient Proportion for Mix design-02:
Cement: Fine Aggregate: Coarse Aggregate = 1: 1.18: 1.82 (By weight)
Cement: Fine Aggregate: Coarse Aggregate = 1. 1.29: 1.94 (By volume)
Cement: Water = 1: 0.24 (By weight)

### 3.2 *Tests of Concrete*

Compressive strength test of 7 days, 14 days and 18 days for mix design-01 and 7 days,14days and 17 days for mix design-01 &02 were performed in Paira Bridge site laboratory. Results of both mixes were satisfactory to accept them as final designs. Test reports for mix design-01 and mix design-02 are shown in Table 12 and Table 13 accordingly.

Table 12. Compressive strength tests for mix design-01.

| Age (Days) | Slump (mm) | Compressive strength, Cube (MPa) | Equivalent cylinder strength, MPa (Cube strength * 0.8) |
|---|---|---|---|
| 07 | | 74.80 | 59.84 |
| 14 | 250 | 80.19 | 64.15 |
| 18 | | 87.89 | 70.31 |

Table 13. Compressive strength tests for mix design-02.

| Age (Days) | Slump (mm) | Compressive strength, Cube (MPa) | Equivalent cylinder strength, MPa (Cube strength * 0.8) |
|---|---|---|---|
| 07 | | 81.51 | 65.21 |
| 14 | 250 | 80.25 | 64.20 |
| 17 | | 97.60 | 78.08 |

## 4 CONCLUSIONS

High Strength concrete is very useful for building long-span bridge like Paira bridge and to ensure durability of structures. Appropriate proportioning of the mix ingredients is essential to produce High Strength Concrete like C-60. This can be obtained after doing many trial mixes. Additional ingredients like admixtures, Slag, Fly ash, silica fume etc is essential for manufacturing High strength concrete. It is observed that high cement content, low water cement ratio, high quality materials, chemical admixtures and mineral admixtures such as silica fume, fly ash and slag with appropriate proportion will result in a high strength concrete. Proper Curing of Concrete is also necessary in this regard. Selection of mix proportion for concrete grade-60 was finalized in Paira Bridge after doing many trial mixes with low water cement ratio and higher cementitious material since these two are the key way to obtain high strength concrete. High strength concrete like C-60 can be used in large infrastructure for its added advantages.

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