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Effect of Coarse Aggregate and Slag Type on the Mechanical Behavior of High and Normal Weight Concrete Used at Barrage Structure

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Abstract: Present study is an effort to assess the composite effect of limestone aggregate and blast furnace slag on the mechanical characteristics of normal and high weight concrete at various structural units (barrage girders, main weir and block apron) of New Khanki Barrage Project, Punjab. Mix designs for different concrete classes falling under the domain of high and normal weight concrete were prepared after aggregate quality testing. On attaining satisfactory results of quality testing nine concrete mixes were designed (three for each class: A1, A and B) by absolute volume method (ACI- 211.1). The required compressive strength of normal and high strength was set at 6200, 5200 and 4200 Psi for the concrete types A1, A and B respectively after 28 days (ACI -318). For compressive strength assessment, a total 27 concrete cylinders were casted (9-cylinders for each mix) and were water cured. The achieved average UCS of cylinder concrete specimens at 3, 7 and 28 days are 5170, 6338 and 7320 Psi for A1 – type, 3210, 4187 and 5602 Psi for A-type and 2650, 3360 and 4408 Psi for B- type mix. It has been found that all concrete mixes for suggested classes attained target strength at age of 7-days. The coarse aggregate (Margala Hill limestone) and fine aggregates (from Lawrancepur /Qibla Bandi quarries) used in all concrete mix designs have demonstrated a sound mechanical suitability for high and normal weight concrete.

Keywords: Limestone, aggregate, compressive strength, concrete mix design.

Introduction

Changes in coarse aggregate can affect the strength and physical properties of concrete and to determine the performance of concrete under common loading needs an understanding of the effects of aggregate type and aggregate size (Bush et al., 2006; Ahsan *et al.*, 2000). Normal concrete is mostly comprised of the rock fragments of greater strength (Beshr et al., 2003; Abdullah, 2012).This perceptive can only be gained through extensive testing and surveillance. Concrete strength exhibit variations for mixes made with various water-to-cement ratios and aggregate sizes (Cordon and Merrell, 1963; Alilou and Teshnehlab, 2010).

Khanki Headwork (32º24´09 N and 73º58´14 E) is the oldest headwork on the river Chenab (Fig.1). There are fifty nine small distributaries along with Lower Chenab Canal (LCC), which provide water needs of about 12,000 km² of agricultural lands (Fig. 2). New Khanki Barrage project will replace the longstanding Head works with the new one, which is 900 feet in downstream of the existing structure (IEE Report, 2011).

Generally, a concrete mix design is considered as the combination of concrete ingredients to attain a desired workability and quality but should be well economical. Compressive strength defines the suitability of any concrete class for target strength set (designer specified).The strength of concrete placed in a civil structure is significantly influenced by the quality control processes (batching, curing and placement).

The amount of coarse aggregate to be used in concrete mix design is contingent to a definite fineness modulus (for fine aggregate) and the size of coarse aggregate (ACI 211.1, 2005).The water/cement ratio is analogous to the required strength, durability and workability (at given aggregate size). Aggregate characteristics display a substantial effect on the performance of fresh as well as the hardened concrete (Quiroga and Fowler, 2004; Sanaullah *et al.,* 2017). The preparation of economical concrete mix largely depends on the size and shape of coarse aggregate, while mechanical appearances of rock aggregates are extremely influenced by the mineralogical characteristics of the parent rock (Naeem et al., 2014; Neville, 2000).

Margala Hill limestone is one of the major aggregate sources and an easily available aggregate in Punjab (Ghaffar et al., 2010; Gondal et al., 2009). In present study, the mechanical fitness of Margala Hill limestone is determined as coarse aggregate for designing different concrete mix designs of normal and high weight concrete classes. A suitable concrete mix

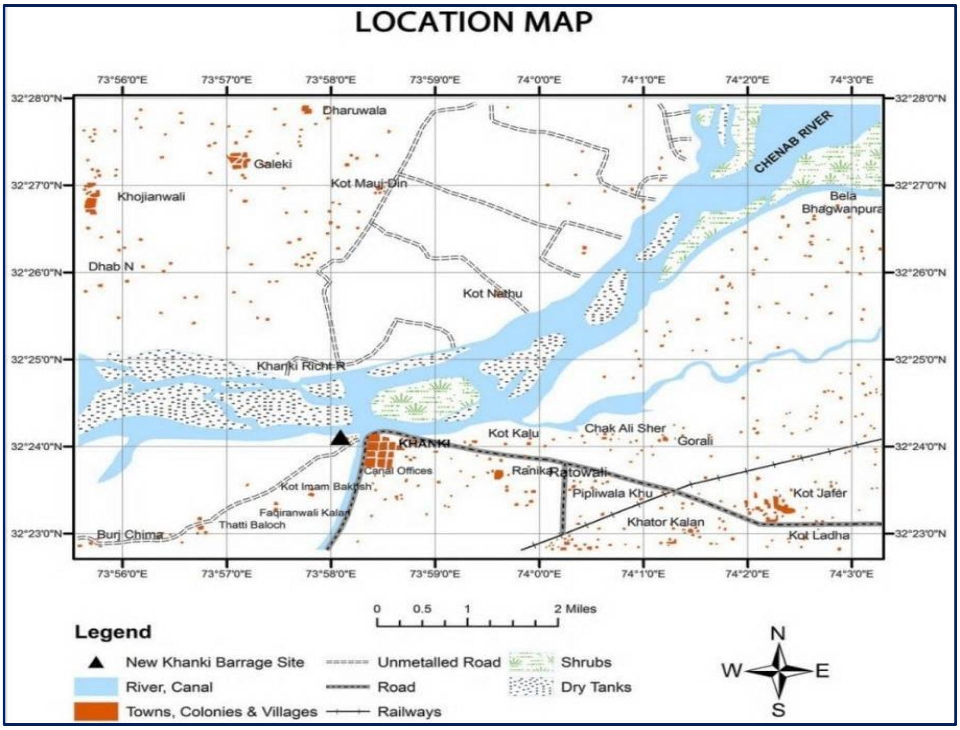


Fig.1 Location map of the study area.

design for mega project like New Khanki Barrage Project significantly influences the cost of the project.

Materials and Methods

Sampling Aggregates

Aggregate sampling can be executed from the flowing stream, stockpiles and from the conveyor belt (ASTM D 75, 1997). At least three equivalent increments are attained and properly sampled from various parts of the conveyor belt and then mixed to find the representative aggregate sample. Stockpiles sampling rarely confirms the reliability of representative samples due to isolation. It is convenient to take 3of samples from different points of the stockpile to combine for representative sample. Sampling of coarse aggregate for New Khanki Barrage Project was done from the conveyor belt.

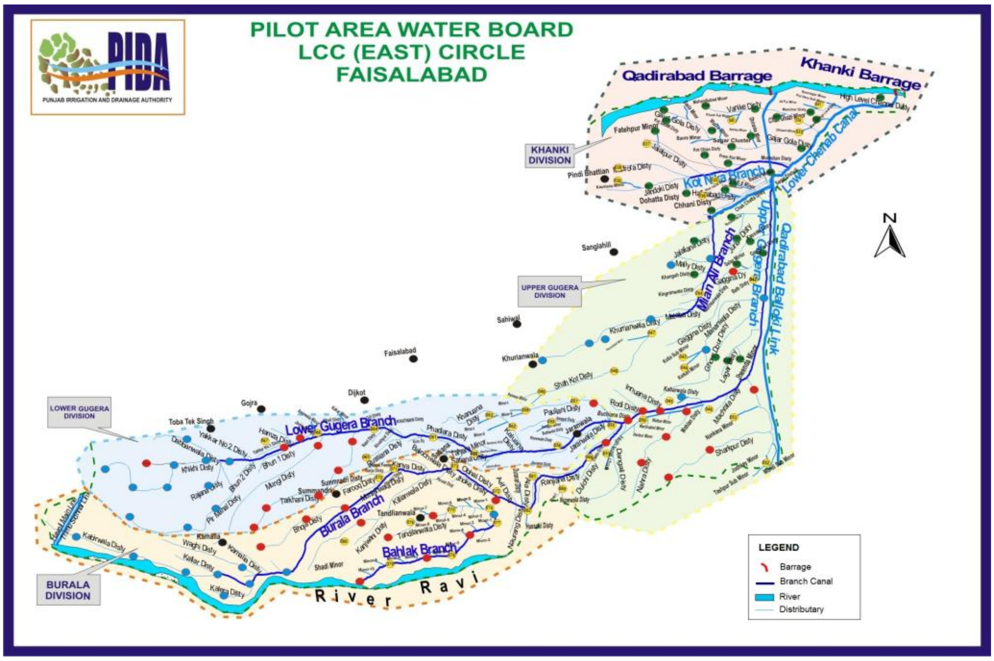
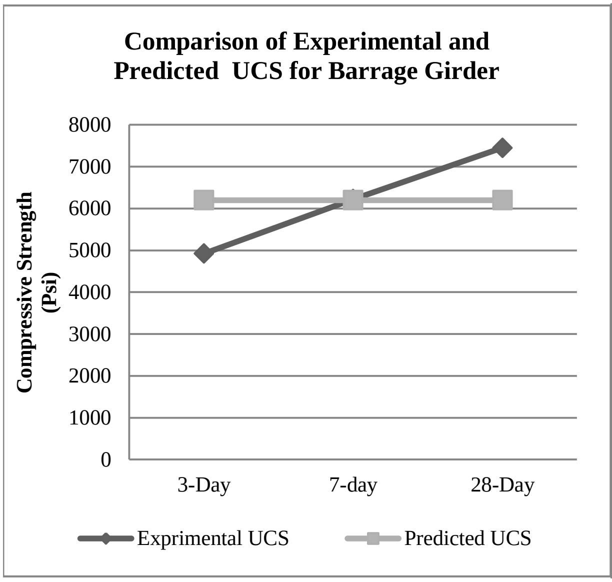


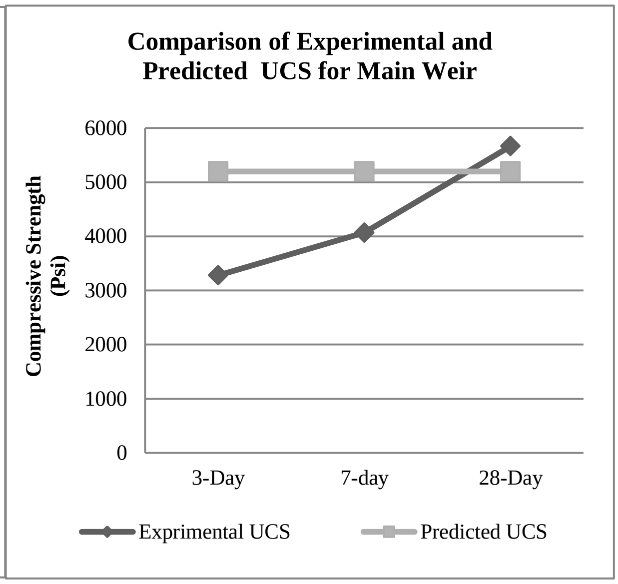
Fig. 2 Lower Chenab Canal and its tributaries (Source: Punjab Irrigation and Development Authority).

Mix Proportions

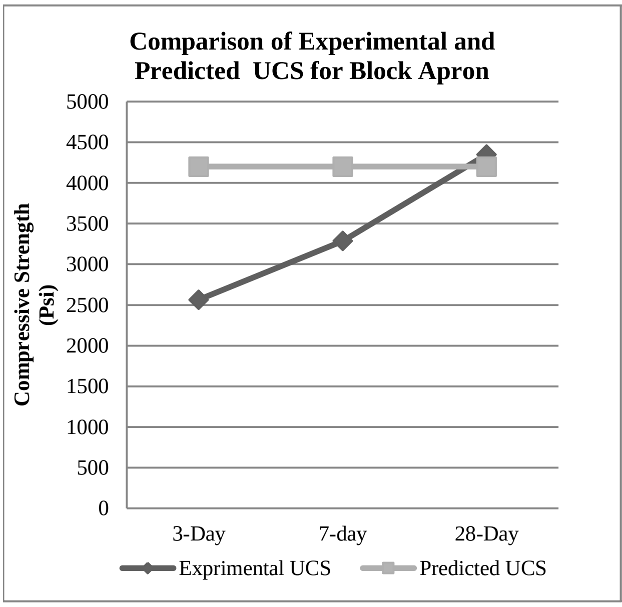
Absolute volume method (ACI 211.1) implemented for concrete mix quantities for this project requires following parameters: the slump, maximum size of coarse aggregate, water-cement ratio, estimation of cement content to be used, proportion of coarse and fine aggregate and the moisture content of the aggregates. Concrete slump is considered as the indicator of concrete uniformity. Values of concrete (cement, coarse aggregate, air and water) and the unit volume of concrete (ACI 211.1, 2005). Aggregate volume is calculated by using unit weights (oven dry) and is batched on the basis of actual aggregate weight (ASTM C 33-03, 2002). A trial concrete mix batch should have a preferred slump with zero segregation (ACI 211.1, 2005). Margala Hill limestone of size 19-4.75 mm was finally selected for concrete mix designs at the project.



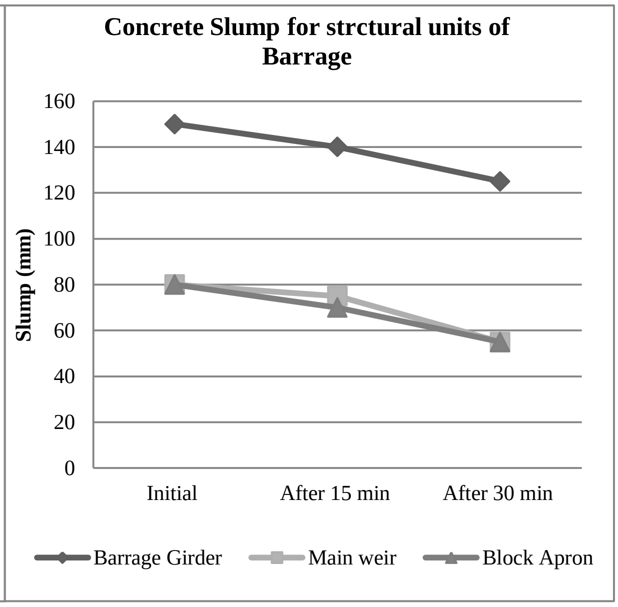
(a) UCS-comparison chart for Barrage Girder.



(b) UCS-comparison chart for Main Weir.



(c) UCS-comparison chart for block apron.



(d) Slump-comparison chart for structural units.

Fig. 3 Comparison charts of UCS (a), (b), (c) and Slump (d).

slump may vary between 25 mm to 100 mm for various construction works (Table 1). The proportion of fine aggregate is defined by the difference of absolute volume of known constituents of concrete

Aggregate Testing

Specific gravity of the oven dry aggregate plays a key role in designing a concrete mix and it is measured by using the specifications of American Society for Testing and Materials (ASTM C 127, 2004; Neville and Brook, 1999). Soundness Test demonstrates the ability of an aggregate to the aggressive action and is measured by dipping it in sodium sulfate solution up to 18 hours in limited evaporation (ASTM C 88, 1999). Los Angeles Abrasion Test is performed for coarse aggregate to assess its physical fitness by estimating percentage abrasion, when rotated with steel balls (ASTM C 131; BSI, 1990).

Fresh and Hardened Concrete Tests

Sampling fresh concrete involves more than two intervals (within fifteen minutes) from the central part of the concrete batch. The container receiving the sample moves through the total width of the discharge (ASTM C 172, 2004) and the temperature of freshly mixed concrete measured by device inserted at the depth of 75 mm of concrete (ASTM C 1064, 2003).

Workability of a freshly mixed concrete is strongly affected by consistency, which may have different variations in concrete workability. Fresh concrete sample is compacted to mold by allowing concrete to recede (ASTM C 143, 2004). Capping of molded cylinders of concrete is completed by using neat cement and the capping apparatus. Moist-cured concrete cylinders and the sulfur mortar are the necessary constituents of concrete capping process (ASTM C 617-98, 1998). The compressive strength of concrete specimens is assessed by placing the molded cylinders (ASTM C 39) under compressive axial load up to the rupture.

Table 1. Appropriate values of slump for concrete used in different works (Source: ACI 211.1, 2005).

Type of construction	Slump (mm)
Reinforced foundation (walls and footings)	25-75
Footings (plain) and walls (substructure)	25-75
Reinforced walls and beams	25-100
Building columns	25-100
Slabs and pavements	25-75
Mass concrete	25-50

Concrete Batching

Concrete preparation involves the continuous volumetric batching of concrete components, mixed and then transported in unhardened state (ASTM C 685, 2001). The cement used should meet the required criteria of ASTM C 150-04 (2001), ASTM C 1157 (2000) or ASTM C 595 (2001). In batching process water, fly ash and the natural pozzolans have certain standard conditions (ASTM C 618, 2001). While selecting a ground granulated blast furnace slag (ASTM C 989-05, 2005) and the air-entraining admixtures (ASTM C 260, 2001), there should be a conforming consideration of the chemical admixtures (ASTM C 494/C 494M-99a, 1999; ASTMC 1017/C 1017M-98, 1998).The auger-type mixer for batching is considered to meet the target requirements of consistency and uniformity (ASTM C 685, 2001). Calibrated proportioning is done by software (Stetter MC 150) and is made sure to yield concrete, as required by the standards (Table 2).

Table 2. Minimum concrete temperature of placement (ASTM C 685, 2001).

Minimum concrete temperature as placed				
Section size	<12	12-36	36-72	>72
In mm	<300	300-900	900-1800	>1800
Temperature	55	50	45	40
In ˚F (˚C)	[13]	[10]	[7]	[5]

Results and Discussion

The concrete strength is evaluated at different structural units of New Khanki Barrage Project for A-1, A and B classes. The absolute volume method (ACI 211.1, 2005) was incorporated for concrete batching according to the required trial mix designs for different classes of normal and high weight concrete. Cylinders of batched concrete in accordance to the designed trial mixes were prepared, put for curing and then tested for the assessment of uniaxial compressive strength (ASTM C 873-04, 2004). A total of 27 concrete cylinders casted (9-cylinders for every class) and their strength was tested at the age of 3, 7 and 28 days (Table 4).Trail mix designs are considered for Barrage Girders, Block Aprons and Main Weir of the barrage project.

Table 3. Weights of components of trial mix concrete according to ACI 211.1.

	Weight per 1m^3 (Kg)		
Components	Barrage G-irder	Main Weir	Block Aprons
Cement	500	238.00	210.00
Water	175	136.00	159.00
Admixture	4.2 Ltrs.	5.28 Ltrs.	4.5 Ltrs.
Blast furnace slag powder	0.00	102.00	90.00
Combined coarse aggregate	973.98	1230.00	1148.00
Combined fine aggregate	748.33	695.00	785.00
Total batch weight	2401.533	2406.28	2396.50

Concrete Mix Design for Barrage Girder

A barrage girder is one of the most basic and vital component of the barrage structure. Steel barrage girders are of two types: I-beam girders and the box-girders. Concrete trial mix for barrage girder was done by absolute volume method (ACI 211.1, 2005) for concrete class A-1.Qiblabandi sand having fineness modulus of 2.7 was used in the water ratio of 0.35 (Table 5). Observed concrete slump was initially of 150 mm and set on 125 mm after 30 min following the target value of 120-150 mm. The attained average compressive strength of the casted cylinders after 3 days was 5171 Psi, after 7 days 6373 Psi and at the age of 28 days, it was 7359 Psi (Fig. 3a). According to the guideline (ASTM C 39), the compressive strength attained at 3 and 7 days should be 30% and 70% of the target strength. All trial mixes for class A-1 satisfy the required values of compressive strength. Observed concrete strength at 7 days has achieved the target strength (6200 Psi).

Table 4. Concrete Mix Trail Observations.

	Slump (mm)			Compressive strength (Psi)								
CMD requirements	120-150			5000-6200								
Barrage girder	Initial (150)	After 15 min(140)	After 30 min(125)	3 days			7 days			28 days		
				5335	5256	4922	6474	6322	6223	7289	7340	7450
CMD requirements	50-75			4000-5200								
Main Weir	Initial (80)	After 15 min (75)	After 30 min (55)	3 days			7 days			28 days		
				3280	3040	3310	4070	4285	4205	5665	5395	5746
CMD requirements	50-75			3000-4200								
Block apron	Initial (80)	After 15 min (70)	After 30 min (55)	3 days			7 days			28 days		
				2565	2775	2610	3285	3370	3425	4348	4490	4385

Concrete Mix Design for Main Weir

Weir is a design for rising up of the water level, its diversion and to manage its flow. Class- A concrete (mass concrete) was suggested to be used in the construction of Main Weir at the barrage. Coarse aggregate of combined sizes (4.75–75mm) was used in the trial mix (ACI 211.1). Ground Granulated Blast Furnace Slag (GGBFS) was added to the concrete as a partial replacement of cement and as an absorber of heat of hydration produced. Considering the quality requirements, three trial batches were made for class-A concrete with Qiblabandi sand (FM 2.7) at the water ratio of 0.40 (Table 5). Initially the concrete slump was observed 80 mm and was 55 mm after 30 min. The archived compressive strength of tested cylinders demonstrated an average strength of 3210 Psi after 3 days 4186 Psi after 7 days and after 28 days, it was 5602 Psi. This trial mix satisfies the target values of strength after 28 days (5200 Psi) and is fit to be used in the main weir (Fig. 3b).

Concrete Mix Design for Block Aprons

Block aprons are a sort of protection provided to the barrage floor on both upstream and the downstream of the river bed. Such concrete blocks are prepared according to standard guidelines (ASTM D 7276). Before using concrete for block aprons, several concrete trial mixes were designed by absolute volume

Table 5. Composition of trial mixes.

Barrage Structure	Cement	Pozzolanic Material	Admixture	W/C	Coarse Aggregate	Fine Aggregate
Barrage Girder	Ordinary Portland cement (Fauji) of Specific Gravity (3.150 kg/m³)	Ground granulated blast furnace slag of Specific gravity: 2.830 kg/m³	A SP-565 of FOSPAK having Specific gravity up to1.185 kg/m³	W/C Ratio: 0.35 and Specific Gravity: 1.000 kg/m³	Margala Hill Limestone of (19-4.75 mm) having Specific Gravity (2.657 kg/m³), Absorption%: (0.883) and Moisture%: 0.84	QiblaBandi Sand having Specific Gravity of 2.71 kg/³, absorption % (1.250), moisture%: (4.00) and Finess Modulus (2.7
Main Weir	Ordinary Portland cement (Fauji) of Specific Gravity (3.150 kg/m³)	Ground granulated blast furnace slag of Specific gravity: 2.830 kg/m³	520 BA of Sika having Specific gravity 1.160 kg/m³	W/C Ratio: 0.40 and Specific Gravity: 1.000 kg/m³	Margala Hill Limestone of (19-4.75 mm) having Specific Gravity (2.657 kg/m³), Absorption %: (0.883)	QiblaBandi Sand having Specific Gravity of 2.71 kg/³ , absorption % (1.250), moisture%: (3.2) and Finess Modulus (2.7)
Block Aprons	Ordinary Portland cement (Askari) of Specific Gravity (3.150 kg/m³)	Ground granulated blast furnace slag of Specific gravity: 2.830 kg/m³	520 BA of Sika having Specific gravity 1.180 kg/m³	W/C Ratio: 0.53 and Specific Gravity: 1.000 kg/m³	Margala Hill Limestone of (19-4.75 mm) having Specific Gravity (2.657 kg/m³), Absorption%: (0.883)	QiblaBandi Sand having Specific Gravity of 2.71 kg/³, absorption % (1.250), moisture%: (3.20) and Finess Modulus (2.7)

method (ACI 211.1, 2005) for class-B concrete (Table 5). Weights of concrete components per $1m^3$ (Table 3) were calculated and trials were executed according to standards (ASTM C33, 2002; ACI 211.1, 2005). Qiblaband sand and slag of specific gravity 2.80 kg/ m^3 in the water ratio of 0.53 was used (Table 5). The observed initial slump for the trial mix was 80 mm, which turned into 55 mm after 30 minutes. The attained average compressive strength was 2650Psi at 3 days, 3360 Psi at 7 days and was 4407 Psi after 28 days. This trial mix satisfies the required values of compressive strength (3000-4200 Psi) and is proved to be successful for B-type concrete to be used for block aprons (Fig. 3c).

Conclusion

The compressive strength of high and normal weight concrete is considerably affected by the quality of coarse aggregate. The Margala Hill limestone aggregate (19-4.75 mm), together with the ground granulated blast furnace slag and the Qiblabandi sand (Fineness Modulus=2.7) appeared very promising for application in the concrete classes A1, A and B, which belong to the normal and high weight concrete classes. Moreover, Margala Hill limestone used as coarse aggregate in different concrete types on various structural components of the barrage has displayed the highest compressive strength value in A1-type concrete, even at the age of 7 days. All of the trail mixes exhibited a workable slump, which indicates their suitability for girders, the main weir and for block aprons of the barrage. Based on these compressive strength values, it is concluded that the amount of cement and slag can be reduced to design an economical concrete mix.

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