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Preparation and Optimization of Mix ratio for C50T Girder Manufactured Sand and Concrete

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ABSTRACT

Considering actual construction conditions of Binchuan-Heqing Highway, this paper provides the C50 mix ratio conforming to engineering requirements by strictly controlling the quality of raw materials, optimizing the design of mix ratio scientifically, preparing superior C50 concrete 0 with manufactured sand, and optimizing the concrete mix ratio based on the adjustment of fly ash replacement, water-cement ratio, polycarboxylate-type water reducer mixing amount, sand ratio, etc. The result indicates that, the water-cement ratio has a great influence on the concrete strength, and if the ratio of coal ash is high in the binding material, the early compressive strength of the concrete will increase slowly.

1. Introduction

As an inseparable part of interconnectivity in Yunnan Province, the mainline of Binchuan-Heqing Highway is 66.513 km in the full length, in which it is 18.27 km within Binchuan County, and 48.24 km within Heqing County, and bridge tunnels account for 49.7% of the total length. The specific requirements and quality demand for concrete is high in the whole line. However, due to the insufficiency of natural river sand along Binchuan-Heqing Highway, it's difficult to prepare high-performance concrete, and the river sand required for building the highway must be purchased from other places, and the price of river sand transported to the construction site is very high, up to RMB 250/m^3. As construction enters the peak period, the construction mixing station can be short of sand.

As specified in the *Technical Specification for Construction of Highway Bridge and Culverts* (JTG/T 3650-2020), if river sands are difficult to obtain, fine aggregates can be prepared by limestone, basalt and other hard stones, and then processed into manufactured sand [1]. However, except for hydropower industry and high-grade cement of housing construction industry, manufactured sands haven't been extensively applied in other industries, especially in highway C50 and above mix ratio. Meanwhile, there are obvious differences in the manufactured sand process of highway and hydropower industry. Water conservancy industry is featured with intensive construction points, advanced sand-generating equipment, stable physical properties of the sand generated and excellent quality. However, highway engineering is featured with multiple construction points, wide areas and huge differ-

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ence in the quality of manufactured sands, and unstable physical properties, which are mainly caused by the different lithology of the parent rock, the huge difference in rock strength as well as the small sand-making equipment, different models and huge difference in quality [2], seriously restricting the application of manufactured sands in highway construction. In addition, Binchuan-Heqing Highway is set with multiple bridges, demanding on concrete quality control, so C50T girder manufactured sand concrete is analyzed and studied, in terms of the special construction conditions of Binchuan-Heqing Highway.

2. Raw Materials and Test Method

2.1 Raw Materials

(1) Cement

The cement is the P.O 42.5 cement supplied by Yunan Yongbao Cement Co., Ltd., and the physical properties are as shown in Table 1.

Table 1. Physical Properties of Cement

Standard Consistency/ (%)	Setting Time/ min		Stability	Specific Area (m2/kg)	Strength/ (MPa)	
	Initial Set	Final Set			R3	R28
28%	205	256	Qualified	345	27.3	46.7

(2) Fine aggregate

The manufactured sand is the coarse sand produced along Binchuan-Heqing Highway in Xiangshupo, and the fineness modulus, powder content, total mud content of fine particles, crush index, and MBV are 3.1, 6.2%, 0.2%, 22% and 0.8% respectively, meeting the provisions and design requirements.

(3) Coarse aggregate

The macadam is 5-25 mm continuously graded limestone grains, with excellent appearance, 5.6% of faller content, 19.0% of splinter value, 0.6% of sludge content, and can conform to the provisions and design requirements.

(4) Additive

The additive is the polycarboxylate-type superplasticizer produced by YCIH High-performance Concrete Co., Ltd., with 30% of water reduction amount, 23% of bleeding rate, and qualified 28 d compressive strength rate.

2.2 Test Method

Properties of mixture: The relevant performance test should be implemented in strict accordance with the *Standard for Test Method of Properties on Ordinary Concrete* (GB/T 50080-2016).

Test method of basic mechanical properties: Test the relevant properties in accordance with the *Test Methods of Cement and Concrete for Highway Engineering* (JTG 3420-2020). The standard size of concrete cube is 150 mm, and the 3 d, 7 d and 28 d strength should be respectively measured after maintenance.

3. Design of C50T Girder Concrete Mix Ratio

According to JGJ 55-2011 *Specification for Mix ratio Design of Ordinary Concrete*, the actual strength of concrete is about 58.23 MPa, and since the T-shaped girder is featured with small section area, and small bar spacing, concrete pouring can be quite difficult, so it's necessary to ensure excellent concrete performance [3].

3.1 Influence of Water-cement Ratio on the Strength of Manufactured Sand Concrete and the Workability of the Mixture

As shown in Table 2, as the water cement ratio increases, the workability of the manufactured sand concrete improves to a certain extent, but when the water cement ratio reaches to 0.32, the manufactured sand concrete mixtures are subject to bleeding phenomenon. As the water cement ratio increases, the compressive strength of the manufactured sand concrete decreases along with the small lowering degree of 28 d, and notable decreasing amplitude of 7 d. Based on the compressive strength and relevant performance demand for the actually manufactured sand concrete, the water cement ratio selected is 0.31.

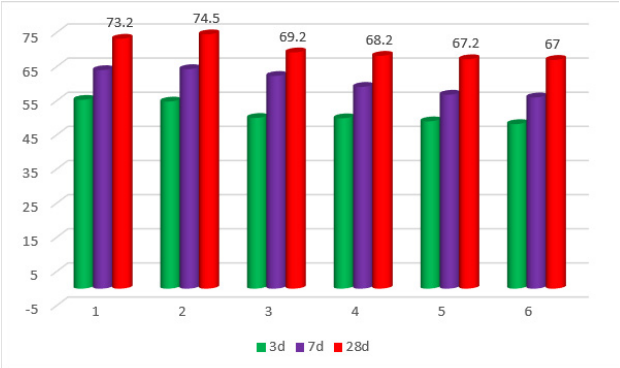

Figure 1. Water-cement Ratio and Strength Result

3.2 Optimized Design of Concrete Strength

Considering the slow development of early compressive strength of concrete after replacing cement with coal ash, the mixing amount of coal ash and cement is tenta-

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tively set as 30 kg - 50 kg and 440 - 460 kg respectively. As can be seen from the reference and construction experience, the early compressive strength lowers with the blending strength of the coal ash. In order to ensure early strength and construction progress, the water-cement ratio of the concrete should be changed to 0.31 and 0.30 respectively, and the test result is as shown in Table 4.

As shown in the result, when the water-cement ratio is 0.30, the concrete can meet the requirements for early durability, but when the sand ratio increases to a certain extent, the workability of the concrete mixture lowers with the increase of the sand ratio, resulting in concrete bottom scrabbling and sinking [4,5] due to excessive thickness. To lower the risk of concrete cracks, the sand ratio in the mix ratio should be adjusted accordingly.

To figure out the influence of sand ratio on concrete cracks, we carried out plate crack test as per the mix ratio listed in Table 5. As for the specific test procedures, please refer to the *Standard for Test Method of Long-term Performance and Durability of Ordinary Concrete* GB/T 50082-2009.

The test result should be calculated and confirmed as per the following requirements:

(1) The average fracture surface of each crack should be calculated as per the following formula:

$$a = \frac{1}{2N}\sum_{i=1}^{N}(W_i \times L_i)$$

(2) The crack number per unit area should be calculated as per the following formula:

$$b = \frac{N}{A}$$

(3) The total crack area per unit area should be calculated as follows:

$$c = a \bullet b$$

In the formula:

W_i --- Accurate the maximum crack width i (mm) to 0.0l m;

L_i--- Accurate the geometric length of No. i crack to 1 mm;

N---Total crack number (pcs);

A--- Accurate the plate area (m^2) to two decimal places;

a--- Accurate the average crack area of each crack (mm^2/pcs) to 1 mm^2/pcs;

b--- Accurate the crack number per unit area (pcs/m^2) to 0.1 m^2 pcs/;

c---Accurate the total crack area per unit area (mm^2/m^2) to 1 mm^2/m^2

As shown in the test result, when the sand ratio increases, the workability of the concrete improves, but as the sand ratio increases, the concrete crack number and crack area also increases accordingly. Considering the mutual influence of the workability and durability, the sand ratio and the quantity of additives are set as 42% and 1.0% respectively.

After repeated test and maximum optimization of the mix ratio, the final mix ratio of C50T girder is set as: C:F:W:S:G:A=460:30:148:776:1072:4.9.

3.3 Engineering Application

According to engineering practices, the slumps of concrete mixtures from the mixing station to T girder prefabrication site can be kept at 180-220 mm, conforming to the construction pumping requirements as well as the requirements for the engineering strength and 3 d tension stress.

4. Summary

By designing and optimizing the mix ratio of C50T girder, we have a deep understanding of the optimization technologies of concrete mix ratio, which can be summarized as follows:

(1) If coal ash is added in the concrete, the early compressive strength of the concrete develops slowly, because coal ash is not involved in the early hydration. In that case, when making concrete with anti-crack and high early strength requirements, the mixing amount of coal ash should be lowered, especially for concrete with low water-cement ratio. In case of preparing high-strength and high-performance concrete, rather than concrete demanding for early compressive strength, the mixing amount of coal ash may increase correspondingly.

(2) Water-cement ratio is a main factor influencing concrete strength, and the concrete strength can be increased significantly by lowering the water-cement ratio, but if the water-cement ratio is low, and the workability for the concrete mix ratio is weak, it's hard to meet the design requirements. In that case, when preparing high-performance concrete demanding for low water-cement ratio and low dissociation rate, it's applicable to adjust the dosage of additives as per the mix ratio, and improve the sand ratio of proper efficiency for concrete mix ratio, to meet the technical requirements.

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Table 2. Workability and Strength Result of the Concrete

No.	W/B	Sand Ratio/%	Mix ratio/(kg/m3)					Slumps/Divergence (mm)	Strength (MPa)			Workability
			C	W	S	G	A		R3	R7	R28	
1	0.30	45	494	148	832	1016	5.0	215/550	55.3	64.0	73.2	Poor workability
2	0.30	44	494	148	813	1035	5.2	220/540	54.8	63.3	74.5	Slightly heavy
3	0.31	45	494	153	832	1016	5.1	220/530	50.0	62.3	69.2	Slightly sticky
4	0.31	44	494	153	813	1035	5.0	220/540	49.9	59.1	68.2	Excellent workability
5	0.32	45	494	158	832	1016	5.1	220/550	49.0	56.8	67.2	Slight bleeding
6	0.32	44	494	158	813	1035	5.2	220/540	48.2	56.0	67.0	Bleeding

Table 3. Workability and Strength Result of Concrete Mixed with Coal Ash

No.	W/B	Sand Ratio/%	Mix ratio/(kg/m3)						Slumps/Divergence (mm)	Strength (MPa)			Workability
			C	F	W	S	G	A		R3	R7	R28	
7	0.30	45	460	30	148	832	1016	5.0	215/540	52.1	58.0	67.8	Thick
8	0.30	44	440	50	148	813	1035	5.2	220/580	48.2	55.8	66.5	Excellent workability
9	0.31	45	460	30	153	832	1016	5.1	220/550	47.6	54.3	64.3	Slightly thick
10	0.31	44	440	50	153	813	1035	5.0	220/600	46.8	52.3	62.0	Slightly thick

Table 4. Concrete Strength and Workability Result of Different Sand Ratios

No.	W/B	Sand Ratio/%	Mix ratio/(kg/m3)						Slumps/Divergence (mm)	Strength (MPa)			Workability
			C	F	W	S	G	A		R3	R7	R28	
11	0.30	42	460	30	148	776	1072	4.9	215/540	48.8	57.0	68.8	Excellent workability
12	0.30	43	440	50	148	794	1054	5.0	220/580	46.2	54.9	67.6	Excellent workability
13	0.30	44	460	30	153	813	1035	5.2	220/550	46.0	53.9	66.5	Excellent workability
14	0.30	45	440	50	153	832	1016	5.3	220/600	45.5	52.6	62.8	Slightly thick

Table 5. Influence of Different Sand Ratios on the Early Crack of the Concrete

No.	Average Crack Area of Each Crack [a] mm^2/pcs	Crack Number per Unit Area [b] pcs/m^2	Total Crack Area per Unit Area [c] mm^2/m^2
11	11.24	8.3	93.27
12	45.15	16.7	753.92
13	46.86	16.7	782.59
14	48.62	18.7	885.23

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