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Experimental Study on Mechanical Properties of Concrete in the Complex Environment of China-Laos (Moding-Vientiane) Railway

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Abstract. In order to make different strength grades of concrete which meet the requirements of the complex engineering environment of China-Laos (Moding-Vientiane) Railway, the raw materials such as cement fabricated in Laos and water reducing agent made in China were chosen, the effect rules of size and the effect rules of different fly ash contents on the mechanical properties of C55 concrete were studied through the concrete mix proportion design and the mechanical property tests of different strength index. And the concrete mix proportion of C20~C60 was determined. The results showed that the concrete which meet the requirements of China railway standards (TB10424-2010) can be configured according to the mix proportion in this paper. In the case of the additive is fly ash only, the appropriate content of fly ash in C55 concrete for China-Laos (Moding-Vientiane) Railway bridges was determined to be 15%. The test results in this paper had been successfully applied to the concrete construction of real bridges.

Keywords. China-Laos (Moding-Vientiane) Railway, complex engineering environment, concrete, mechanical property, fly ash

1. Introduction

With “The Belt and Road Initiative” being put forward and comprehensively promoted, while meeting the domestic infrastructure construction needs, China has also turned its attention in engineering construction industry to foreign countries. So far, more than 150 countries or international organizations have signed nearly 200 cooperation agreements with China [1]. Under the framework of “The Belt and Road Initiative”, the China-Laos (Moding-Vientiane) Railway (hereinafter referred to as the “China-Laos Railway”) has become an important part of the bilateral cooperation between Laos and China. As the first overseas railway designed and constructed using Chinese standards, the engineering features of the China-Laos Railway include: engineering hydrogeology is complex and the risk of construction safety is high, the terrain and landform are complex and changeable, and the construction environment is poor, the environment

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along the road is more sensitive and the pressure of environmental protection is great, the construction resources guarantee is difficult and so on[2]. Affected by the economic and industrial development in Laos, there are few floor materials, cement and admixtures for the durable concrete used for bridges and sleepers, and the quality of concrete is difficult to be guaranteed. Therefore, how to reasonably select the source of raw materials and prepare concrete in accordance with the engineering standards has become one of the key problems to be solved in the construction of China-Laos Railway.

In the China-Laos Railway bridge project, the Bannahan Mekong River Bridge is the key node. The Bannahan Mekong River Bridge is a continuous rigid frame bridge. It is 1652m long, with the main bridge being (80+144+80) m and the piers being 63.5m high. Although the China-Laos Railway is connected with the Yuxi-Mohan railway in China, and China can supply the raw materials for this bridge, the transportation costs are too high, and the tedious customs formalities between the two countries will have a serious impact on the progress of the bridge project. The research results in Laos show that only considering the bridge concrete project, the supply capacity of the cement and sand manufacturers in Laos can be basically satisfied, but the material performance is still unknown. In addition, Laos has no suitable water-reducing agent production enterprises, and the water-reducing agent still needs to be provided by domestic transportation.

Based on the above situation, to ensure the quality of concrete for the Bannahan Bridge of China-Laos Railway, C20, C30, C35, C40, C55 and C60 concrete meeting the requirements of China railway standards were investigated and prepared in line with the principle of local materials. As the concrete raw materials to be concerned that cement, fly ash, river sand and gravel are fabricated in Laos and water reducing agent is made in China. On this basis, through a large number of concrete specimen strength tests, the applicability of China's current standards for such projects were studied, and the research results can provide technical reserves for subsequent similar overseas projects.

2. Mix Proportion Design of Concrete

2.1. Raw Materials

According to China's standards of TB10424-2010[3], the performance of raw materials was tested and evaluated, water is local tap water, and all the indicators meet the requirements of the TB10424-2010 specification.

- Cement. C20~C40 concrete were made of P·O 42.5 cement. Specific surface area is 346m^2/kg, initial/final setting time is 117/172min, compressive strength of 3 days is 23.6MPa, compressive strength of 28 days is 47.5MPa. C55~C60 concrete were made of P·I 52.5 cement. Specific surface area is 346m^2/kg, initial/final setting time is 130/169min, compressive strength of 3 days is 36.4MPa, compressive strength of 28 days is 61.1MPa.
- Fly ash. The fly ash is Grade I class F fly ash, activity index is 98%, water demand ratio is 95%, ignition loss is 1.3%, water content is 0.4%.
- Fine aggregate. The fine aggregate is river sand. The fine aggregate is region II medium sand, fineness modulus is 2.8, grain distribution is well-graded, silt content is 1.7%, chloride ion content is 0.01%.
- Coarse aggregate. The coarse aggregate is crushed stone. For C20~C40 con-

crete, gradation composition is 5~25mm, maximum engineering particle size is 26.5mm, apparent density is 2730 kg/m^3. For C55~C60 concrete, gradation composition is 5~20mm, maximum engineering particle size is 26.5mm, apparent density is 2780 kg/m^3.

- Admixture. Water reducing rate is 29%, compressive strength ratio of 28 days is 140, air content is 2.8%, change of slump at 1h longitude is 20mm.

2.2. Mix Proportion Design of Concrete

The relative humidity of the environment where the line is located is relatively high, with an annual average of between 75 and 85%. According to the design requirements of the bridges, the mix proportion of concrete should be applicable to prestressed concrete of railway concrete bridge engineering structure in the T2 environment grade or the same strength grade. Firstly, the theoretical mix proportion of the benchmark concrete of each strength grade concrete was calculated according to the standards of JTG55-2011[4]. Then they were optimized and adjusted according to the requirements for good working performance of general bridge structure. Finally, three mix proportions of each strength grade concrete were determined preliminarily, and the most suitable one was chosen from the above three mix proportions of each strength grade concrete, which meet the requirements of design and construction.

According to the standards of GB/T 50080-2016[5], the workability of concrete was tested. See Table 1 for the final concrete mix proportion of different strength grades and the test results of their working and mechanical properties. It can be seen from the Table 1 that the concrete properties with different strength grades.

Table 1. Mix proportion of concrete with different strength and corresponding test results

Raw materials and performance	C20	C30	C35	C40	C55	C60
Cement (kg/m^3)	224	259	280	295	418	432
Fly ash (kg/m^3)	96	111	120	126	74	76
Sand (kg/m^3)	865	805	773	746	710	685
Gravel (kg/m^3)	1058	1066	1067	1073	1088	1117
Water (kg/m^3)	157	159	160	160	150	150
Water-binder ratio	0.490	0.430	0.400	0.380	0.305	0.295
Fly ash content (%)	30	30	30	30	15	15
Water reducing agent dosage (%)	1.0	1.0	1.0	1.0	1.2	1.2
Initial slump (mm)	190	200	200	200	200	200
Initial air content (%)	2.7	2.8	2.8	2.7	2.7	2.8
Compressive strength of 28days (MPa)	28.5	39.0	43.8	49.6	67.0	73.6

3. Tests on Mechanical Properties of Concrete with Different Strength Grades

3.1. Casting and Testing of Concrete Specimens

According to the concrete mix proportion of different strength grades mentioned above, different sizes of specimens were prepared for each strength grade, including six (150×150×150) mm standard cube specimens, three (100×100×100) mm non-standard cube specimens, and three (150×150×300) mm prism specimens. To ensure the accuracy of the test results, concrete specimens of three sizes of each strength grade were poured in groups. Then they were cured under the standards of TB10424-2010[6]. After the curing period had reached 28 days, compressive strength (f_{cu}) test, split tensile strength (f_{ts}) test and axial compressive strength (f_{cp}) test were carried out, shown as Figure 1. The test results are listed in Table 2. In the Table 2, $f_{cu,150}$ is the compressive strength of the standard cube specimens, $f_{cu,100}$ is the compressive strength of the non-standard cube specimens, $f_{cp,150}$ is the axial compressive strength of the prism specimens, $f_{ts,150}$ is the splitting tensile strength of the standard cube specimens.

According to regulation 6.0.5 of GB/T 50081-2002, “The recommended compressive strength ratio of concrete (150×150×150) mm standard cube specimens to (100×100×100) mm non-standard cube specimens under C60 is 0.95”. According to the test results in Table 2, the average ratio of standard cube strength to non-standard cube strength of each sample is 0.9577 (C55) at most, 0.9251 (C60) at least, and 0.9418 at average, which basically meet the recommended value of the specification. This shows that the raw materials selected in this paper can be used to prepare concrete of various strength grades that meet Chinese concrete construction specifications.

Figure 1. Specimens under curing and destroyed specimens after strength tests

Table 2. Tests results on mechanical properties of different concrete specimens

Strength grade	$f_{cu,150}$ (MPa)	$f_{cu,100}$ (MPa)	$f_{cu,150}/f_{cu,100}$	$f_{cp,150}$ (MPa)	$f_{ts,150}$ (MPa)
C20	28.95	30.36	0.9536	27.34	3.59
C30	43.22	45.81	0.9435	42.73	4.55
C35	48.47	51.72	0.9372	46.80	4.88
C40	53.86	57.66	0.9341	50.74	5.07
C55	67.00	69.96	0.9577	62.79	5.61
C60	73.60	79.56	0.9251	71.01	6.19

3.2. Dimension Effect Analysis of Concrete Strength

The curve of the compressive strength ratio $f_{cu,150}/f_{cu,100}$ of C20 to C40 changing with concrete strength was drawn, shown as Figure 2. It can be seen from the Figure 2 that $f_{cu,150}/f_{cu,100}$ will decrease linearly as the strength grade of concrete increase. According to the measured data, the relationship between $f_{cu,150}/f_{cu,100}$(y) and concrete strength grade (x) was obtained as $y = -0.001x + 0.9734$ using the least square fitting. For C55 and C60 concrete, although there are little test data, it can still be seen from Table 2 that $f_{cu,150}/f_{cu,100}$ decreases with the increase of concrete strength grade. Shown as Figure

3-Figure 5 that the relationship curves between $f_{cu,100}$, $f_{cp,150}$, $f_{ts,150}$ and $f_{cu,150}$ respectively. As can be seen from the Figures, with the increase of $f_{cu,150}$, $f_{cu,100}$ and $f_{cp,150}$ show a linear increase, while $f_{ts,1050}$ increases in the form of power function. Eq. (1) - (3) are mathematical relations obtained by curve fitting. For the convenience of comparison with the existing specifications and related research results, the fitting formula is no intercept formula.

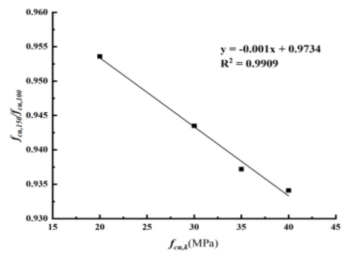

Figure 2. The trend of $f_{cu,150}/f_{cu,100}$ changing with strength

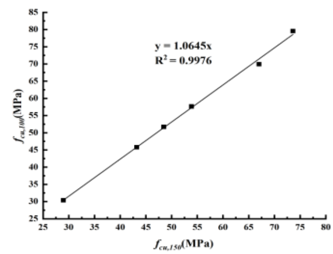

Figure 3. The relationship between $f_{cu,100}$ and $f_{cu,150}$

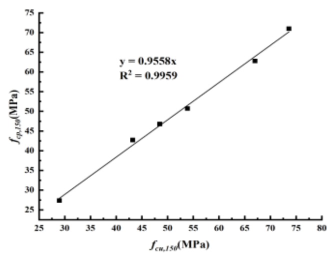

Figure 4. The relationship between $f_{cp,150}$ and $f_{cu,150}$

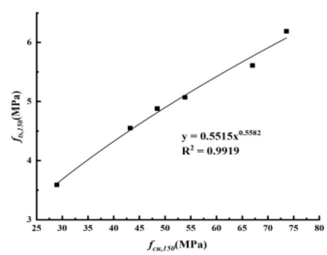

Figure 5. The relationship between $f_{ts,150}$ and $f_{cu,150}$

$$f_{cu,100} = 1.0645 f_{cu,150} \tag{1}$$

$$f_{cp,150} = 0.9558 f_{cu,150} \tag{2}$$

$$f_{ts,150} = 0.5515 f_{cu,150}{}^{0.5582} \tag{3}$$

4. Effect of Fly Ash Content on Mechanical Properties of C55 Concrete

4.1. Test Objective

The main body of Bannahan Mekong River Bridge is largely made of C55 concrete, fly ash is only used as mineral admixture for C55 concrete. Existing studies [7] showed that fly ash can improve the creep performance of concrete. The reasons are mainly fly ash morphology effect, activity effect and micro-aggregate effect. The comprehensive action of these effects improves the internal microstructure of concrete, greatly improves the compactness of concrete and enhances its resistance to deformation. Zhao Qingxin et al. [8]found that under the same fly ash content, the difference in water-binder ratio would also directly affect the durability of concrete. Existing studies [9] had confirmed that fly ash can better play the role of dense filling when water-binder ratio is relatively low. However, when the fly ash content is too high, the cement will be reduced, which will directly lead to the reduction of hydration products, it's unfavorable to the development of concrete elasticity modulus. Therefore, as for the C55 concrete used for Bannahan Mekong River Bridge, to determine the appropriate content of fly ash, it is necessary to study the influence of different fly ash content on the mechanical properties of C55 concrete.

4.2. Test Design and Test Results

In this test, 4 groups of mix proportion were designed with different fly ash content of 0%, 10%, 15% and 20%, as shown in Table 3. After they had been standard cured, cube specimen compressive strength test, axial compressive strength test and concrete elasticity modulus test were completed in accordance with the national specification GB/T 50081-2002. See Table 4 for test results. It can be seen from the test results that when the fly ash content is 0%, 10%, 15% and 20%, compared with that of compressive strength of 7d concrete, the compressive strength of 28d concrete increases by 13.5%, 22.1%, 29.3% and 28.9% respectively.

Table 3. Concrete mix proportion with different content of fly ash

Fly ash content (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water reducing agent(kg/m^3)	Water (kg/m^3)
0	492.0	0.0	710	1088	5.904	150
10	442.8	49.2	710	1088	5.904	150
15	418.0	74.0	710	1088	5.904	150
20	393.6	98.4	710	1088	5.904	150

Table 4. Mechanical property of concrete with different content of fly ash

Fly ash content (%)	$f_{cu,150}$ of 7 days(MPa)	$f_{cu,150}$ of 28 days(MPa)	$f_{cp,150}$(MPa)	Elasticity modulus (×10^{4}MPa)
0	54.63	62.00	59.91	3.99
10	52.45	64.04	60.76	4.05
15	51.25	66.26	61.29	4.06
20	50.84	65.53	62.43	4.08

4.3. Influence of Fly Ash Content on Compressive Strength

The curve of concrete compressive strength with different fly ash content at 7d and 28d was drawn, shown as Figure 6. It can be seen from the Figure 6 that fly ash content has different effects on concrete strength at different ages. At the age of 7 days, the compressive strength of concrete decreases with the increase of fly ash content. However, at the age of 28 days, the compressive strength of concrete increases with the increase of fly ash content, but when the fly ash content increases to more than 15%, the compressive strength of concrete tends to be stable. When the fly ash content increases from 0% to 15%, the compressive strength of concrete on 28 days increases from

62MPa to 66.26MPa, increasing by 6.9%. However, when the fly ash content increases to 20%, the compressive strength of concrete decreases slightly.

4.4. Influence of Fly Ash Content on Elasticity Modulus

The curve of elastic modulus of concrete with different fly ash content was drawn, shown as Figure 7. It can be seen from the Figure 7 that at the age of 28 days, the elasticity modulus of concrete increases with the increase of fly ash content, but the change is not obvious. When the fly ash content increases from 0% to 10%, 15% and 20% respectively, the elasticity modulus increases from 3.99×10^4MPa to 4.05×10^4MPa, 4.06×10^4MPa and 4.08×10^4MPa, with increases of 1.5%, 1.8% and 2.3% respectively.

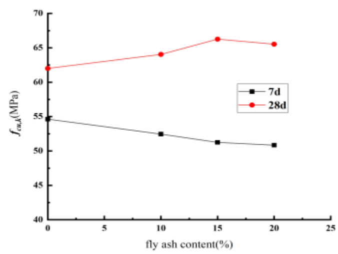

Figure 6. Influence of fly ash content on $f_{cu,150}$

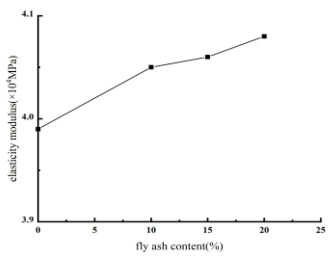

Figure 7. Influence of fly ash content on elasticity modulus

5. Application of Practical Construction

Based on the experimental study in this paper, the mix proportion of C55 concrete used for China-Laos Railway bridges was determined, and the fly ash content was determined to be 15%. The actual construction mix proportion and test results of the C55 concrete of Bannahan Mekong River Bridge are listed in Table 5. It can be seen from the Table 5 that the C55 concrete mix proportion meets the requirements of TB10424-2010 in terms of various working and mechanical properties. The mix proportion has been successfully applied to the concrete construction of the main beams of Bannahan Mekong River Bridge of China-Laos Railway.

Table 5. Construction mix proportion of C55 concrete and corresponding test results

Raw materials and performance	C55
Cement (kg/m^3)	418
Fly ash (kg/m^3)	74
Sand (kg/m^3)	710
Gravel (kg/m^3)	1088
Water (kg/m^3)	150
Water-binder ratio	0.305
Water reducing agent dosage (%)	1.2
Initial slump (mm)	200
Initial air content (%)	2.7
Compressive strength of 7 days (MPa)	52.6
Compressive strength of 28 days (MPa)	66.8

6. Conclusion

- Aiming to the complex engineering environment of China-Laos Railway, in line with the principle of local materials, choosing the concrete raw materials fabricated in Laos and water reducing agent made in China, C20~C60 concrete which meet the requirements of China railway standards (TB10424-2010) can be investigated and prepared.
- Dimension effect analysis of concrete strength showed that, as the strength of concrete increased, the compressive strength ratio of standard cube specimens $f_{cu,150}$ to non-standard cube specimens $f_{cu,100}$ decreased linearly. The strength relationship of the three specimens of different sizes was as follows, with the compressive strength of the standard cube $f_{cu,150}$ increased, the compressive strength of the non-standard cube $f_{cu,100}$ and prism axial compressive strength $f_{cp,150}$ increased linearly, while the splitting tensile strength of the standard cube $f_{ts,150}$ increased in the form of power function.
- Taking fly ash content as the only variable, test results showed that fly ash content had different effects on concrete strength at different ages. At the age of 7 days, the influence of fly ash content on compressive strength of concrete was not significant, or even slightly decreases. However, at the age of 28 days, the compressive strength of concrete increased significantly with the increase of fly ash content, but when the fly ash content increases to more than 15%, the compressive strength of concrete tended to be stable.
- At the age of 28 days, the increase of fly ash content had little influence on the improvement of elasticity modulus of concrete. When fly ash content increased from 0% to 20%, the elasticity modulus only increased from 3.99×10^4MPa to 4.08×10^4MPa, with an increase of 2.3%.
- The experimental results of this paper had been successfully applied to the concrete construction of the main girder of Bannahan Mekong River Bridge of China-Laos Railway, which can provide reference for similar projects.

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