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Experimental Study of High-Performance Manufactured Sand Self-Compacting Concrete and Application in CFST Deck Arch Bridge

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ABSTRACT

Using the local mechanical sand in Guizhou province, 11 groups of self-compacting concrete ratios were designed. Influences of concrete admixture, mechanical sand powder content, aggregate volume and expansive agent on the mechanical properties and working performance of concrete were studied. The construction mix ratio of self-compacting concrete filled steel tube for the Zongxi River Bridge was determined. Results show that: by using the mechanical sand with a high stone powder content (9%), the slump extension degree of 4h is greater than 450mm, the free expansion rate of 28d concrete is greater than 1.0×10^{-4}, and the strength of 28d is up to 60MPa. A certain amount of stone powder in the mechanical sand can play the role of lubrication, adhesion, filling, so that concrete is not easy to isolate, bleeding, vibration and ramming construction effect is better; expansion agent can make concrete offset dry shrinkage to produce micro expansion, but the content should not exceed 10%. The field 1:1 concrete filled steel tube simulation results show that the prepared sand self-compacting concrete can effectively pass through the steel tube internal studs and internal stiffening plates, and there is no accumulation residue on the pipe wall, which fully meets the design requirements of the self-compacting concrete filled steel tube of the Zongxi River Bridge.

1. INTRODUCTION

Compared with concrete bridges, concrete-filled steel tube (CFST) arch bridges have advances in bearing capacity and span. This attributes to the improvement the local stability of the steel tube because of the filling concrete, and the improvement of the toughness and strength of the concrete due to the external confinement of the steel tube.

During the past two decades, CFST arch bridges are widely applied around the world. According to incomplete statistics, by the end of 2018, more than 400 CFST arch bridges have been constructed in China (Zheng and Wang 2018). Among them, the first Hejiang Yangtze river bridge, completed in 2013 with main span of 530m and rise-span ratio of 1/4.5, keeps the main span record up to now (Zheng and Wang 2018; Xie,

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Wang et al. 2019).

During construction procedure of CFST bridge, concrete pouring of the main arch structure is a key process. Method of concrete-pumping and lifting-up is the most widely used technology in CFST construction. While preparing self-compacting concrete (SCC) is the key to adopting concrete-pumping and lifting-up technology successfully. The combining degree between the core concrete and steel tube affects not only the construction quality but also the safety and stability of the whole bridge(Ma, Wang et al. 2016; Xie, Wang et al. 2019). To ensure the compactness of the filling concrete in the steel tube and good ferrule effect between the steel tube and the confined concrete, micro-expansive SCC has been the optimum selection(Yang, Cai et al. 2015; Ma, Wang et al. 2016).

For SCC, high fluidity, good segregation resistance and gap passing performance are all required to ensure the homogeneity of the mixture in the transportation and pouring process, and to be able to fill mold compaction by self-gravity. Natural sand (NS) is mostly used as fine aggregate for traditional SCC. But due to shortage of natural sand resources and inconvenience of transportation in some special areas, such as mountainous areas in the western part of China, manufactured sand (MS) has become the inevitable alternatives to prepare SCC. Comparing with NS, the particles of MS not only have rough surfaces but also are much more angular. Moreover, high content of stone dust is another important difference between MS and NS (Li, Zhou et al. 2011; Bo 2016).

Lots of experimental researches have been carried out to investigate effect of stone dust on the performance of MS-SCC(Bosiljkov 2003; Gui, Zeng et al. 2011; Li, Zhou et al. 2011; Bo 2016; Xiaofang, Jun et al. 2016). Researches of (Gui, Zeng et al. 2011) indicated that Methylene blue (MB) and stone dust content of MS were important indexes for the workability of MS-SCC. For the situation MB less than 1, stone dust with no more than 15% content will help to improve workability of MS-SCC; for the situation MB greater than or equal to 1, the workability off SCC was sensitive to the change of stone dust content and the content must be less than 5%. To meet the requirements of construction of CFST arches, a C60 grade micro-expansive MS-SCC was prepared in (Li, Zhou et al. 2011). The workability, compressive and splitting strength, modulus of elasticity, restrained expansion and chloride ion permeability as well as freeze-thaw resistance of three MS-SCC mixes with fines content of 3%, 7% and 10% were tested and compared with those of the NS-SCC mix. Results show that the performances of the C60 MS-SCC with fines content of 7% are excellent and compared favorably with those of C60 NS-SCC. In (Xiaofang, Jun et al. 2016),C50 SCC was prepared with MS from limestone in Guizhou Province, China. Similar conclusions were also obtained, such as appropriate stone powder content would improve working performance and increasing compressive strength of SCC. Meanwhile, experimental results also demonstrate that the increase of stone powder content can slightly reduce the concrete's dynamic modulus, chloride penetration resistance, carbonization resistance and sulfate erosion resistance, and has no obvious effect on concrete shrinkage. Experiments in (Benyamina, Menadi et al. 2019) demonstrate that increasing the substitution level of limestone fines in SCC mixtures, contributes to the decrease of the slump flow and the yield stress. Moreover, the inclusion of limestone fines as crushed sand substitution reduces the capillary water absorption, chloride-ion migration and consequently enhances the durability performance. According to the above, the feasibility of preparing high-performance strength MS-SCC with certain stone powder content, including high strength, has been fully demonstrated.

In fact, the performance of MS-SCC depends on the properties of the raw materials a lot. MS-SCC prepared with different kinds of raw material has been investigated to acquire higher strength and application in different projects. Ding (Qingjun, Yi et al. 2017) prepared C100 CFST with high stone powder MS, low air content, ultra-dispersion polycarboxylate superplasticizer and fly ash beads+silica fume. The research results are applied with satisfactory to the construction of concrete filled steel tubular arch rib of Guan Sheng River Bridge in Sichuan, Guang'an. Kumar (Kumar and Radhakrishna 2016) investigated the characteristics of SCC with fly ash and MS through experiments. SCC of M40 grade was designed. The binder in SCC consists of OPC and fly ash in the ratio of 65:35. NS was replaced by MS at replacement levels of 20,40,60,80 and 100%. For each replacement level, constant workability was maintained by varying the dosage of superplasticizer. Zhu (Zhu, Cui et al. 2016) carried out experimental investigation of the effect of MS and lightweight sand (LS) on the properties of fresh and hardened self-compacting lightweight concrete (SCLC). Test results show that increasing the sand ratio (from 0.40–0.50) decreased the filling ability and led to an increased T50 time, the passing ability of MS-SCLCs and LS-SCLCs is still within an acceptable range.

In this paper, aiming to the application of MS-SCC in Zongxi River Bridge, using the local MS in Guizhou province, 11 groups of self-compacting concrete ratios were designed. Influences of concrete admixture, mechanical sand powder content, aggregate volume and expansive agent on the mechanical properties and working performance of concrete were studied. To further demonstrate the practical workability, an in-site concrete filling simulation test with 1:1 ratio was carried out.

2. ENGINEERING BACKGROUND

2.1 Bridge Overview

Zongxi River bridge, an oversize CFST deck truss arch bridge, is the key project of Bijie-Duge expressway in Guizhou Province, China (Xin-hua, Shao-hui et al. 2016). With main span of 360 m, the bridge crosses over a V-shaped valley, shown as in Fig.1. The main arch is catenary shape with arch axis coefficient m = 1.3, vector height h = 69m and vector span ratio f = 1/5.217. To fill concrete into the steel tube compactedly, C55 self-compacted micro-expansion concrete is adopted. However, the distance from the bridge to the nearest provincial highway is 7 km, and there is only one village road on each bank side of the bridge. In such poor transportation conditions, prepare C55 SCC with local MS is the most appropriate choice.

A space truss structure with constant width and variable height is adopted for the main arch, and the section height varies from 6m at the arch top to 12m at the arch foot (middle to middle). The main arch chord is CFST section, including 4 upper chord pipes and 4 lower chord pipes. The upper and lower chords are horizontally parallel with each other, and the transverse center distance is 4m (both sides) and 10m (middle).

According to the stress situation, the upper and lower chords are made of variable-section steel pipes. The size of the upper chord steel tube changes from Φ1200 mm×26mm at the arch foot to Φ1200mm×35 mm at the arch top, while that of the lower chord changes from Φ1200 mm×35mm to Φ1200mm×26mm. According to the need of strength and stability, there are also bracings designed to connect and stiffen the arch tubes, shown as in Fig.2. The butt-joint of steel tube arch rib is bolted with inner flange and welded outside. To solve the stress problems caused by debonding of concrete-filled steel tubular with arch ribs, Φ22mm×100mm headed studs are set on the inner wall of steel tubes at the joints of arch ribs. The studs can not only strengthen the bonding effect between steel tubes and core concrete, but also assist the transferring of shear force on the arch rib cross section. See Fig.3 for the arrangement of headed studs in chord tubes.

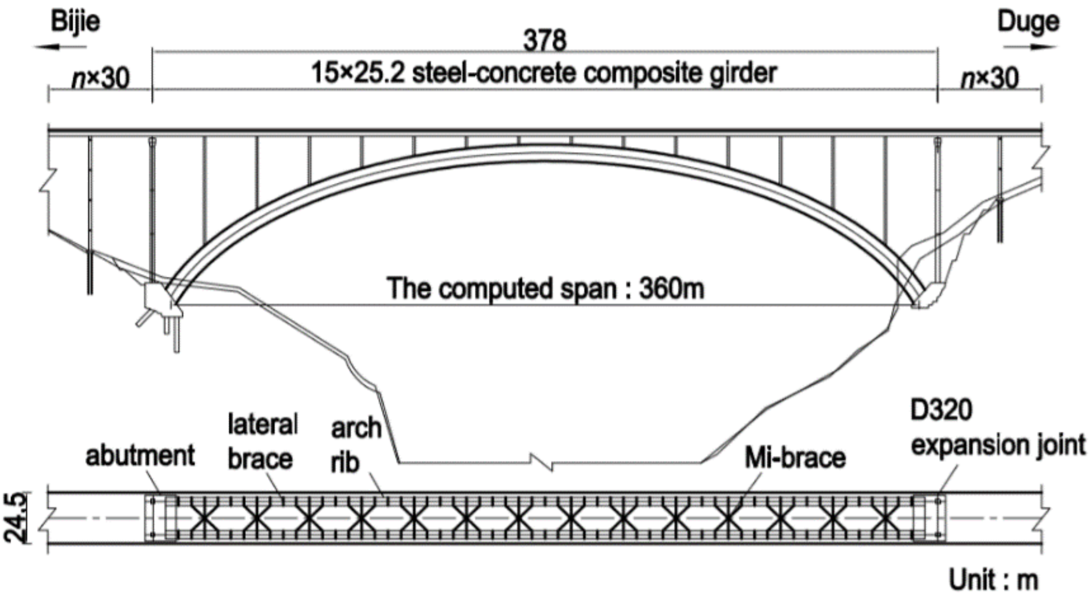
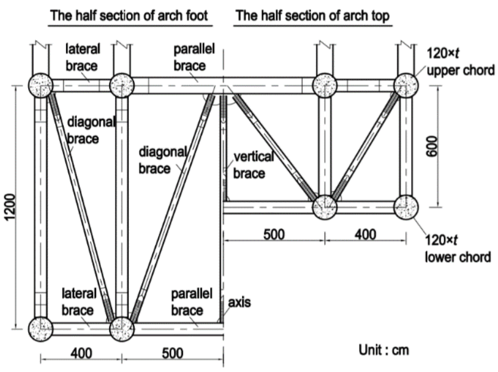


Fig.1 Overall layout of Zongxi River bridge



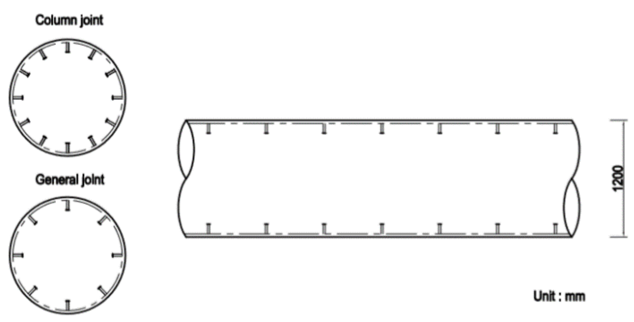


Fig.2 Sections of Main Arch

Fig.3 Studs Arrangement in Chord Tube Joints

2.2 Performance indicator of CFST concrete

According to the above, the main arch structure of Zongxi River bridge is characterized with complicated joint connection. Besides, the concrete volume of single tube of the bridge is estimated to reach 430 m^3. Studs and circular stiffener plates set in the steel tube arch makes it difficult to pump such a big volume of concrete into the steel tube. The conventional one-time push pouring process from the arch foot to the arch roof is bound to damage the inner studs. For Zongxi River bridge, a new concrete filling method named as “filling down and pumping up” is adopted.

Whatever any kind of method adopted, 2 ~ 6 hours are necessary for the whole concrete construction process, including concrete mixing, transportation, pouring and pulp outlet. To ensure the completion of the whole construction process, the concrete is required to be excellent in fluidity, segregation resistance and filling. Meanwhile, it should have good compensating shrinkage after hardening so that good confinement effect would occur between the steel tube and the core concrete. Correspondingly, the bearing capacity and structural stability of the CFST arch bridge could be greatly improved.

Due to the above reasons, for Zongxi River bridge, the prepared C55 MS-SCC should flow unobstructed during the pumping process and completely fill steel tube with micro expansion and self-compacting. Namely, the following performance indexes listed in Table 1 are required to meet.

Table 1 Workability indexes of micro-expansive MS-SCC of Zongxi River Bridge

Workability Indexes	**Requirements**
Slump and slump extension	Initial slump=240±20mm and slump extension＞650mm
Slump retention	Slump≥160mm and slump extension≥450mm after 4 hours
Normal pressure bleeding rate of concrete	≤1.0%
Setting time	Initial setting time≥10h and final setting time≤20h
Air content	＜3.0%
T50	≥3s，≤15s
Compressive strength	3d≥25 MPa，7d≥45 MPa；28d≥60 MPa
Modulus of elasticity of Day 28	≥3.5×10^4 MPa
Concrete free expansion rate of Day 28	＞1.0×10^{-4}

3. CONCRETE RATIO DESIGN

3.1 Materials

According to the local conditions of the bridge, the raw materials produced by local manufacturers were selected. The manufacturers and types of raw materials are shown in Table 2 and the main performance indexes in Table 3 to 6 and Figure 4 to 5.

Table 2 Material selection of manufactured sand self-compacting concrete

Types of material	**Material selection**
Cement	Portland cement (P.O.42.5) produced by Saide Cement Plant in Bijie

Fine aggregate	Manufactured medium sand produced on site
Coarse aggregate	Gravel produced on site, grading between 5~20mm
Admixture	Polycarboxylate high performance water reducer and AEA expansive agent produced by Guizhou Zhongxingnanyou Construction Material Company
Mixing water	Water from the Zongxi River on the site of construction
Silica fume/fly ash	Pulverized fly ash and silica fume produced by Guizhou Tianchensanjiang Construction Material Company

Table 3 Performance index of P.O.42.5 produced in Bijiesaide Cement Plant

Density (g/cm^3)	**Normal consistency (%)**	**Stability**	**Setting time(min)**		**Segregation strength (MPa)**		**Compressive strength (MPa)**	
			Initial set	**Final set**	**3d**	**28d**	**3d**	**28d**
3.1	27.0	Qualified	186	256	5.8	9.0	26.1	51.4
			≥45	≤600	≥3.5	≥6.5	≥17.0	≥42.5
			Qualified	Qualified	Qualified	Qualified	Qualified	Qualified

Table 4 Physical performance index of aggregate

Index	**Apparent density (g/cm^3)**	**Bulk density (g/cm^3)**	**Clay content (%)**	**Clay lump content (%)**	**Voidage (%)**	**Lamellar carpolite content (%)**	**Fineness modulus**	**Crushing index (%)**	**Gradation type**
Manufactured sand	2.678	1.598	/	0.4	40.3	/	3.1	13.9	I Area
Gravel	2.710	1.520	0.2	0.0	43.9	2.9	/	10.3	/

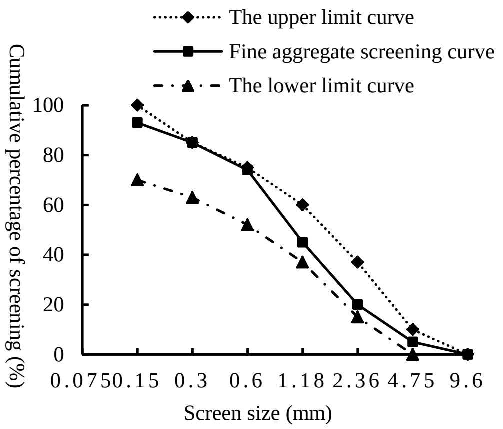


Fig. 4 Gradation curve of manufactured sand

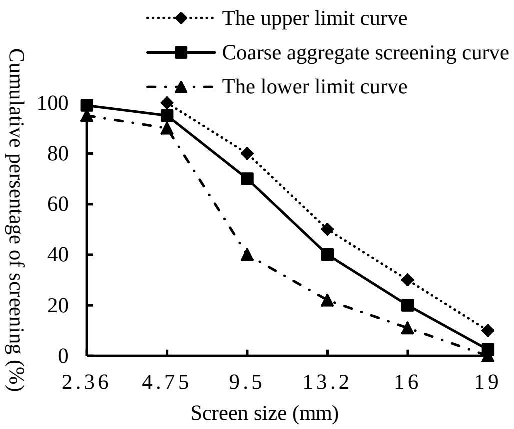


Fig. 5 Gradation curve of gravel

Table 5 Performance index of polycarboxylate water reducer

Water-reducing	**Bleeding rate (%)**	**Air content (%)**	**Ratio of compressive strength (%)**	**Steel rusting**	**Remarks**

rate (%)			**1d**	**3d**	**7d**		
27	53	3.2	175	164	153	Rustless	Proportion is 1.2%

Table 6 Performance index of AEA expansive agent

Setting time (min)		**Compressive strength (MPa)**		**Restrained expansion rate (%)**		**Screen residue of 1.18mm (%)**	**Remarks**
Initial set	**Final set**	**7d**	**28d**	**7d in the water**	**28d in the air**		
225	394	28.6	45.1	0.061	0.005	0.1	Proportion is 8%
≥45	≤600	≥20	≥40	≥0.025	≥0.020	≤0.5	
Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	

3.2 Description of concrete ratio design experiment

In this experiment of concrete ratio design, the influences of concrete admixture, MS stone dust content, aggregate volume and expansive agent on the mechanical properties and working performance of MS-SCC were studied. The content of stone dust in MS used in this experiment was about 9%. It has been shown that the appropriate amount of stone dust (7%~10%) has the effects of lubrication, viscosity increasing, filling and hydration enhancement in MS concrete. During formulating micro-expansive SCC, it is important to study how to add slag, stone dust and admixture could promote mutual action and improve the performance of concrete.

According to the performance of raw materials, construction requirements and relevant specifications, 11 groups of SCC ratios were designed in this paper (shown in Table 7). The ratios are described as follows:

(1) The ratio of P.O is the reference ratio. On the basis of the ratio, different factors are changed to get the other ratio.

(2) Compared with P.O, the content of silica fume in the ratios of P.A1 and P.A2 was reduced, and the increment of slag was different. P.A1 and P.A2 were used to study the effect of slag on the performance of MS-SCC.

(3) The admixture in P.F was changed to fly ash, and the content of MS stone dust in P.F1 and P.F2 was changed on the basis of P.F. It was used to study the effect of stone dust content.

(4) Compared with P.F, the aggregate volume in P.S1 and P.S2 was reduced and increased respectively, and the effect of aggregate volume was studied.

(5) On the basis of P.A1, the dosage of expansive agent in P.E1, P.E2 and P.E2 was increased by degrees. The effect of expansive agent dosage on the expansion and shrinkage performance of MS-SCC was studied.

Table 7 Concrete ratio design of Zongxi River CFTS (unit:kg/m^3)

No.	**Proportion**	**Cement**	**Sand**	**Gravel**	**Water**	**Silica**	**S95 slag powder**	**Expansive**	**Water**

		dosage				fume	or Class I fly ash	agent	reducer
1	P.O	454	879	835	187	52	0	38	7.1
2	P.A1	377.2	879	835	187	16.8	112 slag powder	38	5
3	P.A2	321.2	879	835	187	16.8	168 slag powder	38	5
4	P.F	377.2	879	835	187	16.8	112 fly ash	38	3.9
5	P.F1	455.2	800(0% stone dust)	835	187	16.8	112 fly ash	38	5.2
6	P.F2	346.2	909(12% stone dust)	835	187	16.8	112 fly ash	38	7.5
7	P.S1	377.2	817	794	187	16.8	112 fly ash	38	3.7
8	P.S2	373.2	956	896	187	16.8	112 fly ash	38	4.6
9	P.E1	370.2	879	835	187	16.8	112 slag powder	45	4.5
10	P.E2	363.2	879	835	187	16.8	112 slag powder	52	4.5
11	P.E3	357.2	879	835	187	16.8	112 slag powder	58	4.5

PS: Unmarked content of stone dust of sand is 9%.

4. 4. CONCRETE RATIO TEST RESULTS

4.1 Test approaches and contents

(1) Mechanical performance

The mechanical performance of concrete was studied by measuring the compressive strength, modulus of elasticity and shrinkage of the specimens. According to *Evaluation Standard of Concrete Strength Test* (GB/T 50107-2010), the compressive strength of the specimen with a size of 150mm×150mm×150mm was measured. As per *Standard Test Method for Long-Term Performance and Durability of Ordinary Concrete* (GB/T 50092-2009), the dynamic elastic modulus of the prismatic specimen with a size of 100mm×100mm×400mm was measured by the resonance method, and the prismatic specimen of the shrinkage test had a size of 100mm×100mm×515mm. The concrete strength test is shown in Figure 6, and the concrete contraction test in Figure 7.

Fig. 6 Concrete strength test

Fig. 7 Concrete contraction rate test

(2) Working performance

SCC should have good viscosity, fluidity and filling property, and the slump and slump extension should be used to evaluate whether it meets the requirements of working performance. The test of slump and slump extension was carried out in accordance with *Standard Test Method for Performance of Ordinary Concrete Mixtures* (GB/T 50080-2002). The slump extension test of SCC is shown in Figure 8, and the J-ring test in Figure 9.

Fig. 8 Slump extension test of SCC

Fig. 9 J-ring test of SCC

4.2 Test results

The test results of 11 groups of SCC ratios are shown in Table 8. Comparing the results in Table 8 with the requirements of workability indexes in Table 1, it can be found that the working performance of 11 groups of SCC ratios meets the requirements.

Table 8 Results of concrete ratio design test

Proportion	Characteristic of mix proportion	Elasticity modulus ($\times 10^5$Mpa)		T50 (s)	Slump extension (mm)	Loss rate of slump extension after 4h	J-ring test
		7d	28d				
P.O	9.6% silica fume, without extender	2.92	3.69	4	655	7.6%	2.3
P.A1	20% slag powder	0.38	13.20	7	655	5.3%	3.3
P.A2	30% slag powder	2.24	12.12	7	685	4.4%	3.3
P.F	9% stone dust, 20% fly ash	2.82	11.36	5	685	0.7%	3.0
P.F1	0% stone dust, 20% fly ash	6.59	12.66	4	670	/	3.0
P.F2	12% stone dust, 20% fly ash	2.57	13.03	6	680	/	2.2
P.S1	Reduce aggregate, don't change sand rate	7.30	11.85	3	625	0.0%	2.8
P.S2	Increase aggregate, don't change sand rate	6.38	10.64	5	685	0.7%	2.7
P.E1	20% slag powder, 8% expansive agent	0.45	12.92	7	690	12.3%	2.6
P.E2	20% slag powder, 9% expansive agent	/	/	8	645	11.6%	3.0
P.E3	20% slag powder, 10% expansive agent	/	/	7	650	10.8%	3.5

4.3 Influence factors analysis

4.3.1 Mineral admixture

The curves of 28d compressive strength with age in P.O, P.A1, P.A2 and P.F are shown in Figure 10. Comparing the compressive strength in P.O, P.F, P.A1 and P.A2, the strength in P.O is the largest, and the strength in P.A1 is higher than that in P.F under the same mineral admixture content. It is found that the compressive strength of concrete is reduced after adding the mineral admixture, and the slag powder is more beneficial to the compressive strength of SCC than the fly ash.

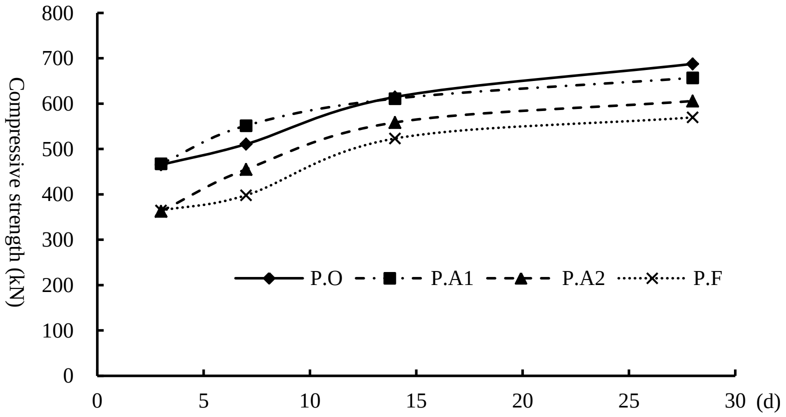


Fig. 10 Effect of mineral admixture on compressive strength of concrete

It can be seen from Table 8 that the 7d elastic modulus in P.O is 2.92×10^5MPa, the 28d is 3.69×10^5MPa, and the growth rate is 26.4%. However, the 7d elastic modulus in P.A2 is only 2.24×10^5MPa and the 28d is 12.12×10^5MPa. The growth rate reaches up to 441.1%. After adding the mineral admixture, the elastic modulus of concrete is small in the early stage, but it increases rapidly in the later stage. And the increase of slump extension and decrease of loss rate indicate that the mineral admixtures are beneficial to increase the fluidity of concrete, and the effect of fly ash is better than that of slag powder.

4.3.2 Stone dust content

The content of stone dust in P.F1, P.F and P.F2 was 0%, 9% and 12%, respectively. Figure 11 shows the change curves of concrete compressive strength in three ratios. It can be seen from Figure 11 that the strength in P.F1 and P.F2 is higher than that of P.F, which means that choosing the appropriate content of stone dust is conducive to the improvement of concrete compressive strength.

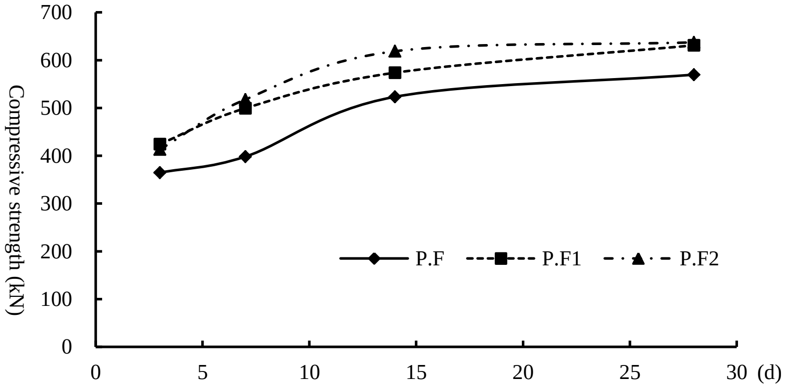


Fig. 11 Effect of stone dust content on compressive strength of concrete

The 7d elastic modulus of concrete in P.F1, P.F and P.F2 is 6.59×10^5MPa, 2.82×10^5MPa and 2.57×10^5MPa respectively, with a large difference. However, the 28d elastic modulus of concrete is 12.66×10^5MPa, 11.36×10^5MPa and 13.03×10^5MPa respectively, with a small difference. It can be found that the increase of stone dust content decreases the elastic modulus of concrete in the early stage, but has little effect on that in the late stage. From the results of P.F1, P.F and P.F2 in Table 8, it can be seen that the workability of the mixture is improved after adding stone dust. However, with the continuous increase of stone dust content, the viscosity of concrete increases and the fluidity decreases. Therefore, the content of stone dust should not be too large, and should be controlled below 12%.

4.3.3 Aggregate volume

Figure 12 shows the effect of aggregate volume on concrete strength. Comparing the 28d compressive strength of concrete in P.F, P.S1 and P.S2, it can be known that with the increase of aggregate volume, the relative dosage of cement decreases, which will slightly reduce the compressive strength of concrete.

It can be seen from Table 8 that the effect of aggregate volume on concrete elastic modulus is not distinct, but more aggregate there is, the more difficult it is for concrete slurry to wrap aggregate and flow.

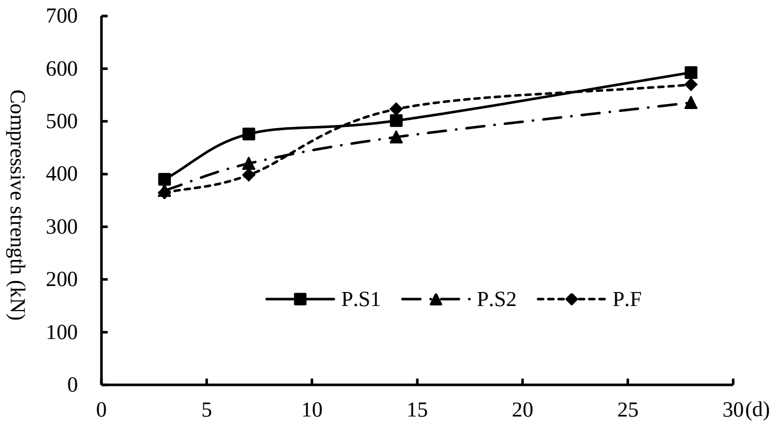


Fig. 12 Effect of aggregate volume on compressive strength of concrete

4.3.4 Expansive agent dosage

By comparing the change of the expansion rate in different concrete ratios with time, the effect of expansive agent content on the micro-expansion performance of concrete is studied. Figure 13 is the expansion rate curve of 9 groups of concrete ratios.

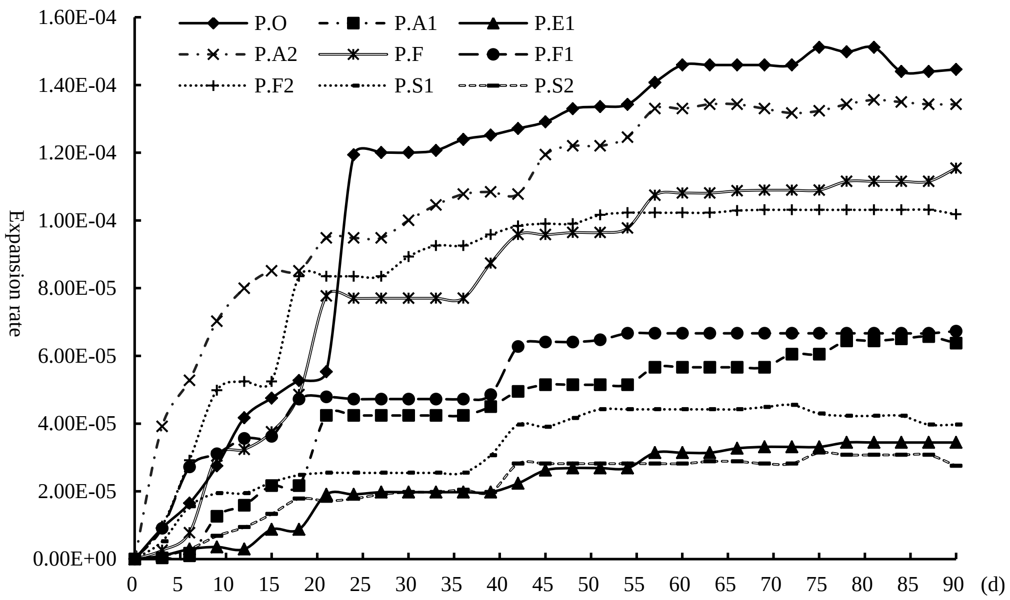


Fig. 13 Expansion rate curve of 9 groups of concrete ratios

It can be seen from Fig. 13 that the expansion rate of the above 9 groups of ratios is basically stable from the 45d, but the 28d expansion rate of other ratios except the reference ratio does not meet the construction performance index requirements of Zongxi River Bridge. So the specimens are actually only in a dry shrinkage state. Continue to adjust the proportion of concrete and increase the content of expansive agent. When the content of expansive agent is increased to about 10%, the concrete dry shrinkage rate turns negative, and the expansion rate reaches 1.2×10^{-4}, meeting the requirements, as shown in Fig. 14. It can be seen that the micro-expansion concrete meeting the construction requirements can be obtained by changing the content of expansive agent.

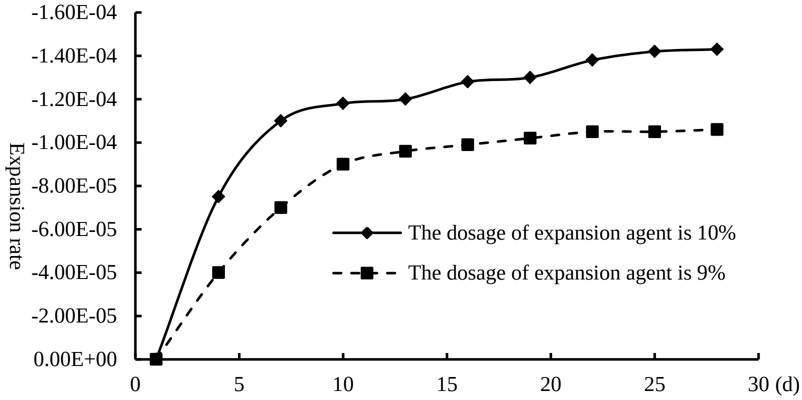


Fig. 14 Concrete expansion rate curve with increasing expansive agent

4.4 Determining the construction mix ratio

On the basis of the above test and construction site conditions, further optimize the water-cement ratio, cement dosage, and content of MS and mineral admixture. The construction mix ratio of C55 micro-expansion MS-SCC for CFST of Zongxi River Bridge is obtained as shown in Table 9. The MS content in Table 9 is 6.4%.

Table 9 Construction mix ratio of MS-SCC in Zongxi River CFST Bridge

Water-cement ratio	Sand rate (%)	Quantity of concrete material per cubic meter (kg)							
		Cement	Extender	Silica fume	Expansive agent	Sand	Gravel	Water	Admixture
0.3	51.0	457	20	52	38	855	835	170	7.938

Fig. 15 Check the compactness of construction mix ratio concrete

The performance of SCC under the construction mix ratio was tested. The measured results showed that the 7d average compressive strength was 55.4MPa, the 28d average compressive strength was 68.8MPa, the slump was 270mm, and the slump extension was 700mm. Concrete has good cohesion and no segregation weeping phenomenon. Fig. 15 shows the crushed concrete specimens after the compressive strength test. It can be seen that the gradation of coarse aggregate and fine aggregate in the specimens has good continuity, the bubbles is less, so the compactness of the specimens is good. The above test results indicate that the working performance of concrete under the construction mix ratio can fully meet the requirements of actual bridge construction.

5. IN-SITE CONCRETE FILLING SIMULATION TEST

5.1 Concrete pumping method of actual bridge

According to the engineering background, it can be known that the CFST construction of Zongxi River Bridge has the following difficulties:

(a) The arch height of steel pipe is high and the structure inside the pipe is complex. If the conventional one-time concrete pumping technique from the arch foot to the arch roof is adopted, it will form a large pumping pressure on the bottom concrete, and will inevitably cause damage to inner studs.

(b) The volume and time of single concrete pouring are large, so it is necessary to improve the pouring speed on the premise of ensuring the pouring quality.

(c) In mountainous areas of Guizhou, it is rainy and the air humidity is high. Besides, the pouring construction period is in winter and the temperature is low, which is not conducive to the setting and hardening of concrete.

To sum up, it was decided to adopt the construction technique of filling down and pumping up for concrete pouring. In other words, one perfusion hole was set at the quarter and three-quarters spans of the main arch ring, and one vent hole was set at the arch foot and the middle of the span. First, the C55 SCC was filled from the perfusion hole at the quarter(three-quarters) span to the arch foot, and then the concrete was pumped upward from the perfusion hole at the quarter(three-quarters) span to the middle of the span.

5.2 Test program of concrete filling simulation

Because the technique of pumping concrete upward is very common, the process of filling concrete downward was only simulated from the quarter span to the arch foot in this test. The size of the steel tube used in the simulation test was exactly the same as that of the actual bridge. And the arrangement of stiffening plates and studs in the tube was also similar to that of the actual bridge.

In order to simulate the concrete flow in the steel pipe of bridge, the curvature and inclination degree (38.68°~20.62°) of the test steel pipe were arranged with the chords on the main arch ring of the Zongxi River Bridge as a reference, and the test steel pipe's bending length is 100m, as shown in Fig. 16. At the end of the steel pipe, an open half pipe was set. During the filling process, the flow and residual condition of concrete in the open half pipe were observed.

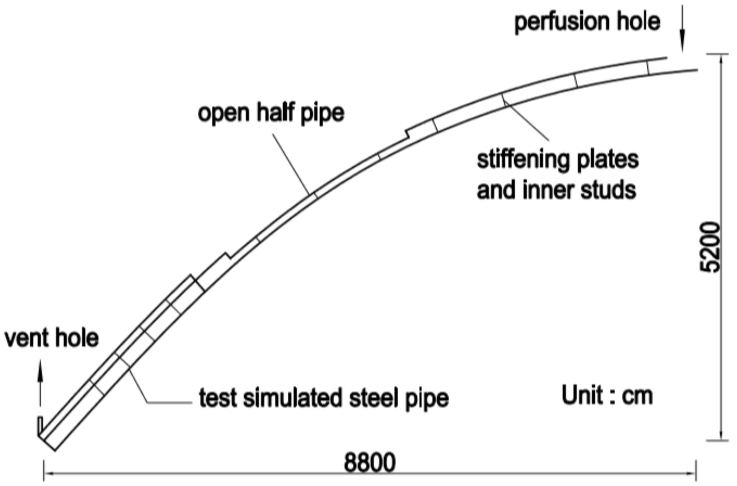


Fig. 16 Steel pipe layout diagram of in-site concrete filling simulation test

5.3 Test results of concrete filling simulation

The test site was selected in the original abandoned soil field of Zongxi River Bridge, and the test temperature was similar to that of formal filling. It can be observed in the open half pipe that the concrete can smoothly pass through the stiffening plates and inner studs, and there is no residue accumulation, indicating that the working performance of SCC is good. Figure 17 shows the concrete flow in the open half pipe in the simulation test.

Fig. 17 Concrete flow in the open half pipe in the simulation test

After filling the test pipe with concrete, check whether there is any cavity in the pipe by tapping. After 7d, the ultrasonic inspection and drilling core were taken to check whether the filling quality can meet the construction requirements of Zongxi River Bridge. The brief statistical results of ultrasonic test are shown in Table 10, and Figure 18 shows concrete core specimens in steel pipes.

Table 10 Results of ultrasonic test

Test position	The mount of measure points	The mount of abnormal points	Compatibility

ZS2-1~ZS21-1	7×20	10	Good
ZS1-2~ZS20-2	7×20	14	Good
ZS3-3~ZS22-3	7×20	16	Good
ZS4-4~ZS23-4	7×20	12	Good
ZX6-1~ZX25-1	7×20	18	Good
ZX7-2~ZX26-2	7×20	13	Good
ZX8-3~ZX27-3	7×20	11	Good
ZX7-4~ZX26-4	7×20	9	Good

Fig. 18 Concrete core specimen in steel pipe of in-site filling simulation test

The results of ultrasonic test and core drilling of CFST show that the concrete filled with CFST in this simulation test is of good quality, and has no cavity, the obvious non-compacted area, silt and debris, etc... The concrete has good uniformity. Therefore, it is feasible for the bridge to adopt the technique of filling down and pumping up.

5. 6. CONCLUSIONS

Aiming to the application of MS-SCC in Zongxi River bridge, through concrete ratio test and in-site concrete filling simulation test, C55 MS-SCC mechanical properties and working performance were studied and the following conclusions could be drawn.

1. It is feasible to prepare C55 high-performance MS-SCC for CFST bridge with local MS in Guizhou, but the stone powder content of mechanical sand should not exceed 12%.

2. The addition of fly ash or mineral powder and other active mineral materials can not only improve the workability of concrete, but also reduce the hydration heat and prevent concrete cracking. Moreover, the lubrication effect of glass beads of active

admixture can also improve the fluidity and slump retention of concrete.

3. The addition of expansion agent should not exceed 10%, so as to produce micro-expansion effect of concrete and offset the dry shrinkage of concrete. Excessive addition of expansion agent will increase the cohesion of concrete slurry to a certain extent, reduce slump, increase the loss of slump, and affect the filling performance of concrete and the ability to pass through obstacles.

4. With local MS with stone dust content of 9%, mix ratio of C55 micro-expansion MS-SCC for CFST of Zongxi River Bridge is obtained. The slump extension degree of 4h is greater than 450mm, the free expansion rate of 28d concrete is greater than 1.0×10^{-4}, and the strength of 28d is up to 60MPa.

5. Results of in-site 1:1 filling simulation test demonstrate that it is feasible to adopt the " filling down and pumping up " pouring technology for CFST deck arch bridge.

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