S1-3-5

APPLICATION OF HIGH STRENGTH FIBER REINFORCED MORTAR TO PRESTRESSED CONCRETE STRUCTURES

Michihiro SAKURADA
Senior Research Engineer, Technical Research Institute, P.S. Mitsubishi Construction Co., Ltd., Japan.

Hiroaki OHYAMA
Section Manager, Design Proposal Dept., Branch Office of East Japan, P.S. Mitsubishi Construction Co., Ltd., Japan.

Takuya MORI
General manager of Nagoya Branch, P.S. Mitsubishi Construction Co., Ltd., Japan.

ABSTRACT:
High strength fiber reinforced mortar was developed and its applicability for towers and low height girder bridges were studied. Various material experiments and the loading experiments of tower and girder specimens were conducted. As a result, it showed that it is possible to construct towers and low height girder bridges by application of high strength fiber reinforced mortar. High strength fiber reinforced mortar was already applied to actual low height girder bridges and towers. In addition, it can be economically applied to the prestressed concrete structures whereas ordinary concrete cannot be adopted.
Keywords: high strength fiber reinforced mortar, creep, drying shrinkage, diffusion coefficient of chloride ions

1. INTRODUCTION

Recently in Japan, high strength concrete whose strength is over 150N/mm^2 has developed and been used for various structures such as buildings and bridges [1]. But, as for high strength concrete, coarse aggregates sometimes reduce fluidity of fresh concrete, increase fluctuation of strength and limit compressive strength. Therefore, coarse aggregate used for high strength concrete should be selected carefully. Consequently, the authors developed a high strength mortar hereinafter called high strength fiber reinforced mortar that was reinforced steel fibers and had no coarse aggregate [2]. Photo 1 and Photo 2 show the high strength fiber reinforced mortar and the steel fiber respectively. Since coarse aggregate is not mixed, the high strength fiber reinforced mortar has high fluidity and high design strength of 120N/mm^2. And because of steel fibers, it is possible to prevent cracks caused by autogenous shrinkage and prevent brittle failure caused by high strength [2], [3].

When the high strength fiber reinforced mortar was developed, various material tests were conducted and compressive strength, Young’s modulus, creep coefficient, drying shrinkage, diffusion coefficient of chloride ions were confirmed. The authors invented applications of the mortar to prestressed concrete bridges with low height girders and prestressed concrete towers. And also, loading experiments of girder and tower specimens were conducted. By application of the mortar, prestressed concrete bridges with low height girders and a prestressed concrete tower were actually realized and it was verified that there were many advantages such as reduction of the girder height, increment of the durability and cost reduction by using the mortar. In addition, it was also shown that these advantages can not be obtained by using ordinary strength concrete.

In this report, it is introduced that material properties of the high strength fiber reinforced mortar and applications of the mortar to actual prestressed concrete structures.

Photo 1 High strength fiber reinforced mortar

Photo 2 Steel fiber

2. PROPERTIES OF HIGH STRENGTH FIBER REINFORCED MORTAR

2.1 Materials and Specified Mix

Table 1 and Table 2 show the materials and the specified mix of high strength fiber reinforced mortar respectively. High strength fiber reinforced mortar is consist of silica fume premixed cement, crushed sand, steel fiber and water with super plasticizer. These materials are weighted and mixed by actual equipments such as batching units and forced action mixers for ordinary strength concrete. As for high strength fiber reinforced mortar, special materials and equipments are not used in consideration of the economy.

Steel fiber is mixed in order to prevent cracks caused by autogeneous shrinkage and prevent brittle failure which is characteristic of high strength concrete. In high strength fiber reinforced mortar, steel fiber
If mix rate of steel fiber is 0.5 vol.%, it is confirmed that no shrinkage cracks and no brittle failure occur by results of various experiments and construction of actual structures [3], [4].

Curing method of high strength fiber reinforced mortar is steam curing as shown in Figure 1 in order to gain high strength early and prevent cracks caused by autogenous shrinkage.

2.2 Strength

Table 3 shows the strength properties of high strength fiber reinforced mortar after steam curing. Design strength, tensile strength, flexural strength and Young's modulus are 120N/mm^2, 8.0N/mm^2, 15.0N/mm^2 and 40kN/mm^2 respectively. These strength are 3 times as high as ordinary strength concrete used prestressed concrete structures but Young's modulus is not so high compared with ordinary concrete. It is confirmed that only flexural strength increases along with mix rate of steel fiber but compressive strength, tensile strength and Young's modulus are not influenced.

2.3 Durability

Results of accelerating carbonation tests, freeze-thaw tests and diffusion coefficient tests of chloride ions are shown in Figure 2, Figure 3 and Table 4 respectively. These durability tests were conducted under the condition of without steel fiber, the rest was mix proportion shown in Table 2.

High strength fiber reinforced mortar has high durability in terms of carbonation, freeze-thaw and chloride attack because of low water cement ratio of 17%. Especially, diffusion coefficient of chloride ions is 0.0217cm^2/year which is approximately 1/20 times as small as ordinary strength concrete whose water cement ratio is 36% for general prestressed concrete structures [5].

Figure 4 shows the concentration of chloride ion at surface of the reinforcement. The concentration was calculated according to standard specifications for

Table 1 Materials

Material	Mark	Spec
Cement	C	Silica fume premixed cement, Density: 3.08g/cm^3
Steel fiber	SF	Tensile strength: 2340N/mm^2, Density: 7.85g/cm^3, Length:13mm, Diameter: 0.16mm
Sand	S	Crushed sand, Density: 2.57g/cm^3, Absorption: 1.03%, Maximum diameter: 5mm
Super-plasticizer	SP	Polycarboxylic acid family

Table 2 Specified mix

f'_{ck} (N/mm^2)	W/C (%)	Air (%)	Unit weight(kg/m^3)				SP/C (%)
			W	C	S	SF*	
120	17	2.0	210	1235	948	40	3.0

*Mix rate of steel fiber: 0.5vol.%

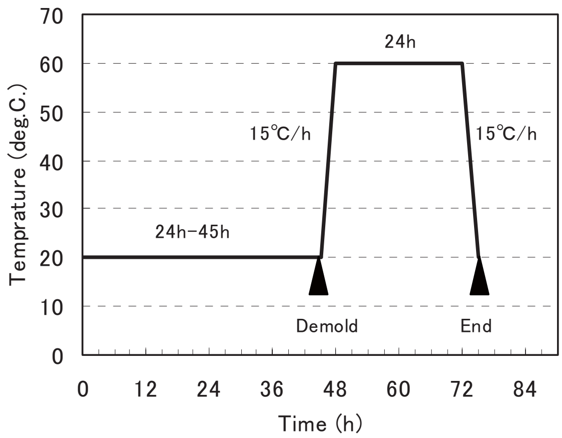

Figure 1 Method of curing

Table 3 Strength properties

	Unit	High strength fiber reinforced mortar	Ordinary strength concrete	ratio
Design strength	N/mm^2	120	40	3.0
Tensile strength	N/mm^2	8.0	2.7	3.0
Flexural strength	N/mm^2	15.0	5.3	2.8
Young's Modulus	kN/mm^2	40	33	1.2

Table 4 Diffusion coefficient of chloride ions (cm^2/y)

High strength fiber reinforced mortar	Ordinary strength concrete*
0.0217**	0.463***

* Water cement ratio is 36%
** Result of test according to JSCE-G572-2003
*** Calculated by "$\log D_p = -3.9(W/C)^2 + 7.2(W/C) - 2.5$" [6]

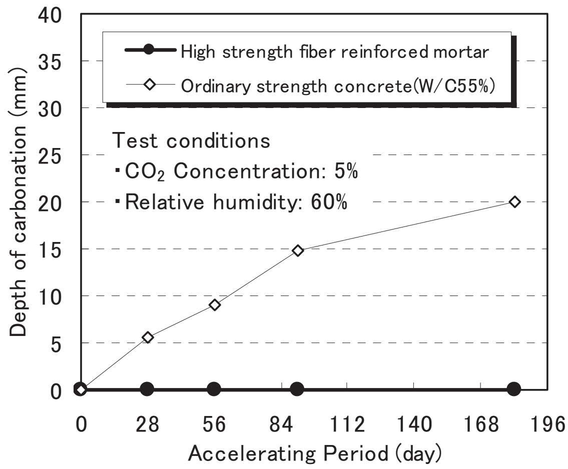

Figure 2 Result of accelerating carbonation tests

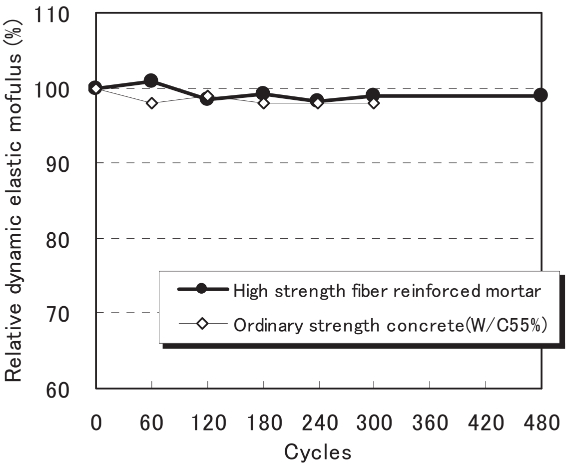

Figure 3 Result of freeze-thaw tests

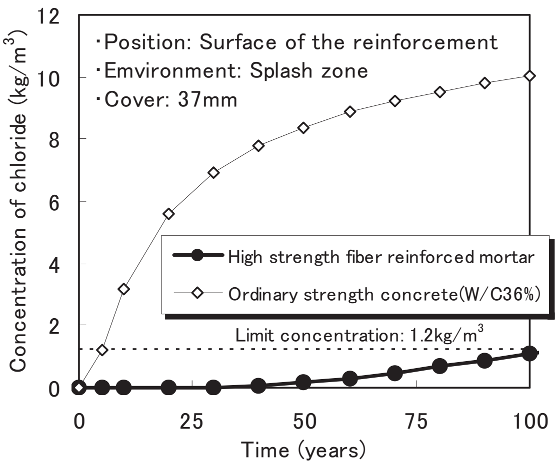

Figure 4 Concentration of chloride ions

concrete under the environmental conditions which were splash zone, cover of 37mm and elapsed time of 100 years [6].

The concentration of the chloride ions is less than 1.2kg/m^3 which is limit of rust development at the surface of the reinforcement after 100 years. Therefore, it is verified that high strength fiber reinforced mortar has durable period of 100 years under the splash zone if its cover is over 37mm.

2.4 Creep And Drying Shrinkage

Figure 5 and Figure 6 show the result of creep tests and result of dry shrinkage tests respectively. For comparison, results of the ordinary strength concrete that of unit quantity of water is 150kg/m^3 and that of water cement ratio is 35% are also shown. In addition, results of high strength fiber reinforced mortar were measured after steam curing of 3 days and those of ordinary strength concrete were measured after underwater curing of 28 day.

From these results, it is confirmed that creep coefficient of the high strength fiber reinforced mortar is 0.75 which is 75% of the ordinary strength concrete. Meanwhile, it is also confirmed that dry shrinkage of the mortar is from 300μ to 400μ which is the same level of the ordinary strength concrete.

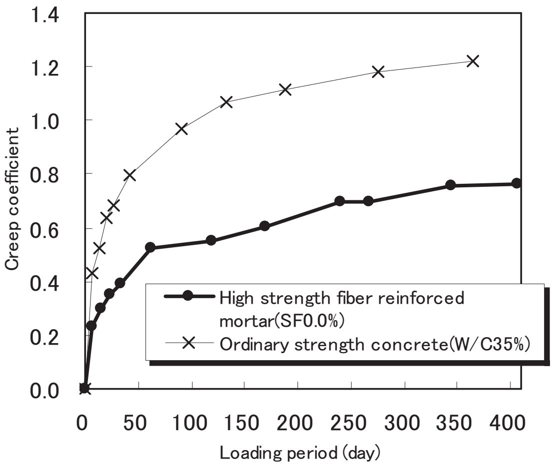

Figure 5 Result of creep tests

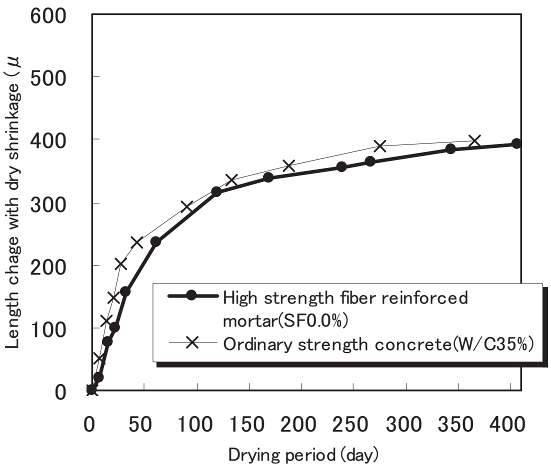

Figure 6 Result of dry shrinkage tests

3. APPLICATIONS

3.1 Low Height Girder Bridges

Generally, the ratio between the girder height and the span length, hereinafter called height span ratio, is approximately 1/20 in terms of the ordinary prestressed concrete girder bridges. However, as for prestressed concrete girder bridges, the lower girder height causes the larger flexural stress in the girder as shown in Figure 7. If the height of the girder is extremely low (the height span ratio is under 1/30), it is necessary to introduce the large prestress to the girder in order to increase the compressive strength of the girder in order to introduce the large prestress to the girder. Therefore, the low height girder bridges whose height span ratio is up to approximately 1/50 can become possible by application of the high strength fiber reinforced mortar to the girders. In addition, it is also possible to reduce the cost of the low height girder bridge because the high strength fiber reinforced mortar can reduce the number of girders.

When the low girder bridge with the high strength fiber reinforced mortar, flexural load experiments, shear

Table 5 Actual application results of the prestressed concrete bridges with low height girders

	MAMEKAI Bridge	KAIKI Bridge	TSUNEISHI Landing Bridge
Kind of bridge	Road bridge	Road bridge	Landing bridge
Structural system	Simple girder bridge (post-tensioned)	Simple girder bridge (pre-tensioned)	Simple girder bridge (Post-tensioned)
Design strength	120N/mm^2	120N/mm^2	120N/mm^2
Mix rate of steel fiber	0.5vol.%	1.0vol.%	0.5vol.%
Bridge length	26.0m	17.7m	26.4m
Span length	25.2m	8.3m	25.6m
Girder height	1.05m (Center), 0.85m (End)	0.3m	0.55m
Height span ratio	1/24～1/30	1/28	1/47
Owner	Hitachi-Ohta city	Bizen city	KAMTECS Co., Ltd.
Construction Period	2005.12.7～2006.3.30	2006.2.15～2006.5.31	2006.7.10～2006.12.20

load experiments and fatigue experiments were conducted and it was verified that the prestressed concrete beams with the mortar had enough strength and high durability against fatigue [3], [7].

After these experiments, the low height girder bridges with the high strength fiber reinforced mortar were applied to three actual prestressed concrete bridges. The actual application results of the low height girder bridges are shown in Table 5.

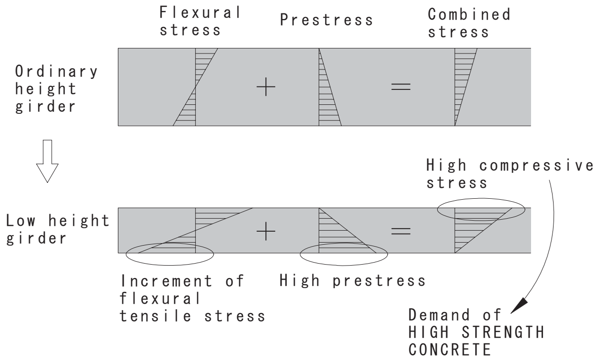

Figure 7 Stresses in prestressed concrete girders

(1) MAMEKAI Bridge [8]

MAMEKAI Bridge is the first low height girder bridge with the high strength fiber reinforced mortar. This bridge is a simple supported girder bridge with one span, 26.0m long, 6.0m wide and its span length is 25.2m. The section of this bridge is T-shaped. The completed MAMEKAI Bridge is shown in photo 3. Though the original plan was a usual prestressed concrete bridge whose design strength was 40N/mm^2 with T-section, it became possible to make the height of the girder end to be low by using the high strength fiber reinforced mortar. As a result, the earthwork volume of the approach part was reduced.

Photo 3 MAMEKAI Bridge

Photo 4 and Photo 5 show the situation of the placing of the mortar and the situation of the erection of girders respectively. This bridge was constructed with the pre-cast segment method. The precast segments were manufactured in a factory and carried to the site. These segments were combined by prestressing on the erection girders and erected by the truck crane.

Photo 4 Situation of placing of the mortar

Photo 6 shows the aspect of MAMEKAI bridge after one year from the completion. Problems such as cracks and the rust by corrosion of the steel fiber were not observed at MAMEKAI Bridge where one year passed from the completion.

Photo 5 Situation of erection of the girder

(2) KAIKI bridge[9]

The completed KAIKI bridge is shown in Photo 7. KAIKI Bridge is a simple supported girder bridge with 2 spans, 17.7m long, 5.8m wide and its span length is 8.3m. The section of this bridge is hollow-shaped. This bridge is located on the sea that is severe environment against the salt damage.

The construction of this bridge was conducted in order to replace old bridge that was the reinforced concrete damaged by salt. In the plan of this bridge, the effective width was going to be spread from 4.3m to 5.0m and the substructure was going to be used continuously without replacing. Therefore, it was necessary to make the superstructure as light as possible. However, if the ordinary strength concrete was used for this bridge, the cover should be 70mm according to specification for highway bridges in Japan because this bridge was located on the splash zone. Therefore, it was difficult to make the superstructure of this bridge light. Consequently, the low height girder bridge with high strength fiber reinforced mortar was applied to this bridge since the mortar made it possible to lighten the superstructure due to decrease the girder height and the durable period against the salt damage could be 100 years if the cover was approximately 40mm.

The girders of this bridge were manufactured in a factory. Prestressing of the girders was introduced by pre-tension method. The girders were carried to the site by trucks and erected by the truck crane.

(3) TSUNEISHI Landing Bridge[10]

Completed TSUNEISHI Landing Bridge is shown in Photo 8. This landing bridge is a simple supported girder bridge with one span, 26.4m long, 2.0m wide and its span length is 25.6m. The section of this bridge is hollow-shaped. The location of this landing bridge is on the sea and the environment is classified into the splash zone. The old bridge made of steel was decided to be replaced because of the severe corrosion by the salt. The low girder bridge with high strength fiber reinforced mortar was applied because the mortar had durable period of 100 years against the salt damage without maintenance and made it possible to decrease the height of the girders as low as the old bridge.

The girder height of this bridge is 0.55m against the span length of 25.6m and the height span ratio of 1/47 is achieved though it is not the road bridge. In order to achieve the low height girders, 4 prestressing strands of 19S15.2 were arranged to the girder. The designed compressive stress of the girders in the prestressing was 35N/mm^2, therefore it was impossible to realize such low height by the ordinary strength concrete.

4.2 Prestressed Concrete Tower

The high strength fiber reinforced mortar was applied not only to the bridges but also to a prestressed concrete tower. Figure 8 and Photo 9 show the profile and the completed tower respectively. The height of this tower is 40m and the purpose of this tower is to install the equipments for mobile phones.

Though the towers for the mobile phones are generally made of steel, the tower made from the high strength fiber reinforced mortar was used because the mortar made it possible to improve the durability of the tower.

Photo 10, Photo 11 and Photo 12 show the situations of the construction. This tower was constructed with the pre-cast segmental method. The pre-cast segments which were 5.0m long and octagon shaped were manufactured in a factory and carried to the site. In the site, the pre-cast segments were combined by prestressing which were introduced by the vertical prestressing steel bars anchored in the footing.

The diameter of this tower is 1167mm at the base and 500mm at the top. The high strength fiber reinforced mortar could make the shape slender as well as the steel towers. And, though the mean thickness of the member

Photo 6 MAMEKAI Bridge after one year

Photo 7 KAIKI Bridge

Photo 8 TSUNEISHI Landing bridge

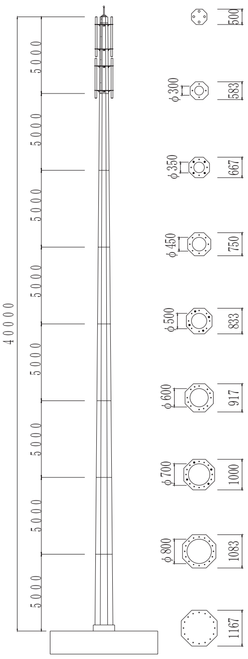

Figure 8 Profile

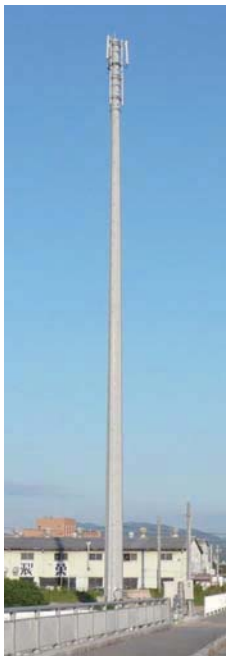

Photo 9 Tower

was more than 250mm if the ordinary strength concrete was used, the mean thickness could become 150mm by the utilization of the high strength fiber reinforced mortar. The reduction of the member thickness could realize the reduction of the inertia force by earthquake and the simplification of the erection.
It is thought that such prestressed concrete towers without bolted connections are effective to make the aspect of the tower improve since the scenery is often demanded in the city area.

5. CONCLUSION

In this paper, the properties of high strength fiber reinforced mortar and its application results to the prestressed concrete structures were introduced. From the results of the material tests, loading experiments and actual executions, the following were verified.
(1) High strength fiber reinforced mortar has high fluidity and high design strength of 120N/mm^2.
(2) Owing to steel fibers, it is possible to prevent cracks caused by autogenous shrinkage and prevent brittle failure.
(3) High strength fiber reinforced mortar make it possible to realize prestressed concrete structures such as low height girder bridges whose height span ratio is 1/47, high durable bridges, slender towers and so on. And it was difficult for the ordinary strength concrete to realize these prestressed concrete structures that had high added value in terms of structural performance, durability and cost.
(4) For the reasons stated above, it is thought that the number of the adoptions of the high strength fiber reinforced mortar increases from now on.


Photo 10 Completed pre-cast segments


Photo 11 Situation of the erection


Photo 12 Situation of prestressing

REFERNCES

1. JCI, "Report of The Study Committee for Structural Performance of High Strength concrete," Jul., 2006.
2. Sakurada, M., Amemiya, Y., Ohyama, H., Mori, T., "Material Properties of High Strength Fiber Reinforced Mortar," Proceedings of the JCI, Vol.29, June, 2007, pp.133-138.
3. Amemiya, Y., Sakurada, M., Mori, T., Niwa, J., "Characteristics of PC Beams Used Ultra High Strength Fiber Rainforced Mortar," Proceedings of the JCI, Vol.25, July, 2005, pp.1657-1662.
4. Sakurada, M., Ohyama, H., Mori, T., Niwa, J., "Experimental Study on Prestressed Concrete Pole made with Ultra High Strength Fiber Reinforced Mortar," Proceedings of the 15th symposium on developments in prestressed concrete, JPCEA, Oct., 2006, pp.449-454.
5. Japan Road Association, "Specifications for Highway Bridges, Part III, Concrete Bridges." Mar., 2002, pp.171-175.
6. JSCE, "Standard Specifications for Concrete Structures -2002, Materials and Construction," Mar., 2002.
7. Sakurada, M., Ohyama, H., Ishida, K., Hamada, S., "Fatigue Experiments of Prestressed Concrete Beam made from High Strength Fiber Reinforced Mortar," Proceedings of the 16th symposium on developments in prestressed concrete, JPCEA, Oct., 2007, pp.363-366.
8. Miyamae, T., Kikuchi, T., Kimura, K., Konishi, T., "Design of MAMEKAI Bridge," Proceedings of the 15th symposium on developments in prestressed concrete, JPCEA, Oct., 2006, pp.29-32.
9. Iwai, T., Kamezawa, N., Fujioka, Y., Ishida, K., "Construction of Pre-tensioning Girder made from Ultra High Strength Fiber Reinforced Mortar -KAIKI Bridge-," Proceedings of the 15th symposium on developments in prestressed concrete, JPCEA, Oct., 2006, pp.33-36.
10. Tanaka, H., Uchida, K., Ishida, K., "Construction of Post-tensioning Girder made from Ultra High Strength Fiber Reinforced Mortar," Proceedings of the 16th symposium on developments in prestressed concrete, JPCEA, Oct., 2007, pp.367-370.