

Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 73/1/73/2 (1995)

Artikel: Application of super-workable concrete to an arch bridge

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DOI: <https://doi.org/10.5169/seals-55188>

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Application of Super-Workable Concrete to an Arch Bridge

Emploi d'un béton de mise en place très aisée dans un pont à arc

Verwendung eines super-verarbeitbaren Betons bei einer Bogenbrücke

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SUMMARY

An arch bridge was designed to harmonize with the surrounding landscape. Steel bars were positioned with a spacing of 100mm to 250mm in the arch rib portion and concrete with high compactability was considered necessary. Due to the problems involved in placing, and to achieve labor saving, it was decided to place the entire cross section of concrete in one operation. To ease the construction process and speed up completion time, it was necessary to use super-workable concrete for both the arch rib and the crown portions of the bridge. This report describes of the preliminary placing experiments of the super-workable concrete carried out before the construction, and the results of quality control at the construction work.

RÉSUMÉ

Dans le cas d'un pont en arc, devant bien s'intégrer dans son environnement, il a été prévu d'espacer les armatures de 10 à 25 cm et d'utiliser un béton à haute densité dans l'arc. Étant donné les problèmes techniques de mise en place et afin d'économiser des coûts de main-d'oeuvre, le bétonnage a été effectué en une seule étape. Pour accélérer la réalisation, il a été également décidé d'employer un béton de mise en place très aisée dans les nervures et à la clé de voûte du pont. L'article présente les essais préliminaires avec ce béton de mise en place facile et donne les résultats du contrôle de la qualité sur le chantier.

ZUSAMMENFASSUNG

Für eine Bogenbrücke, die mit der umgebenden Landschaft harmonieren sollte, wurden im Bogen Bewehrungseisen im Abstand von 10 bis 25 cm und ein Beton mit hoher Verdichtbarkeit vorgesehen. Wegen der Probleme beim Einbringen- und um Arbeitskosten zu sparen - wurde entschieden, den gesamten Betonquerschnitt in einem Arbeitsgang einzubringen. Dazu wurde für die Bogenrippen und den Scheitel besonders leicht verarbeitbarer Beton benötigt. Der Beitrag beschreibt die Vorversuche mit diesem "super-verarbeitbaren" Beton und die Ergebnisse der Qualitätssicherung auf der Baustelle.



1. INTRODUCTION

For super workable concrete, while having high fluidity it must have moderate stability at the same time, in addition it has self-compactability. So, it can flow the spaces between the reinforcing bars and forms without vibration.

The concrete used in this construction was super workable concrete with binary components containing blast furnace slag and it was placed around 1500m^3 . The two structural parts for which the super workable concrete were applied are the arch rib and crown portions shown in Figure 1. The arch rib is a triple box section of radius 63.406m, thickness 2m and width 9.4m, and due to different heights at the river banks the bridge is asymmetrical. The upper and lower slabs of the hollow arch rib are 300mm thick, and reinforcement of maximum diameter 35mm spaced at 125mm to 250mm across the width and at 100mm spacing vertically was used. From aesthetic and construction considerations it was decided to place the concrete in one operation, using the super workable concrete. The bar arrangement drawing can be seen in Figure 2.

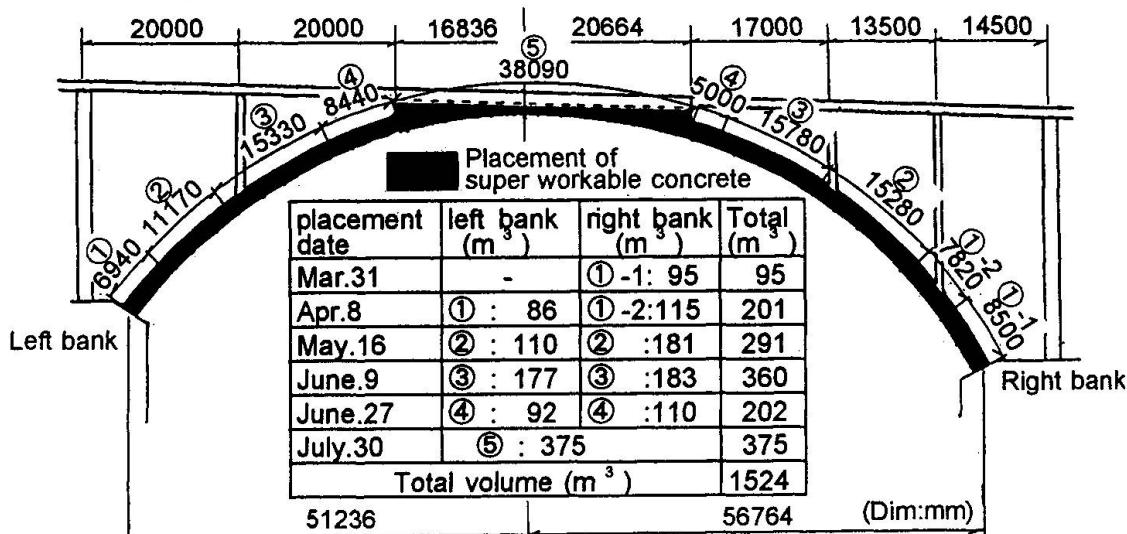


Fig.1 Side view of the arch-bridge and placement block

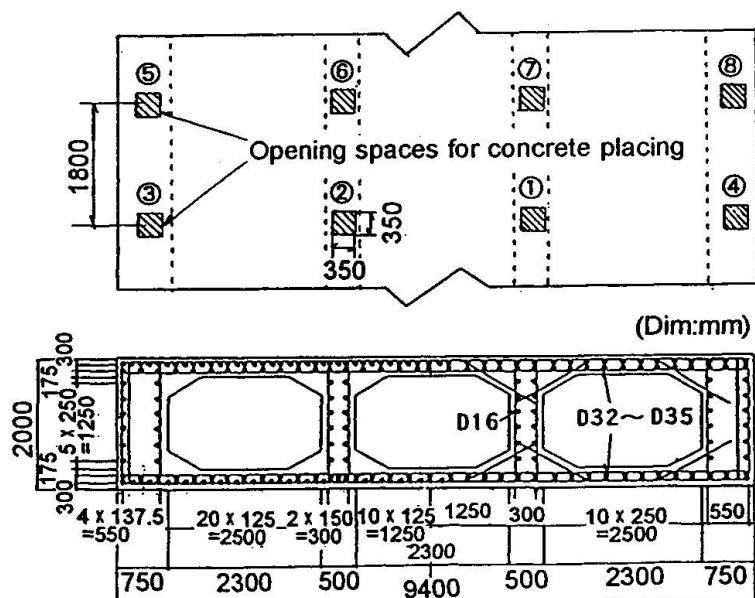


Fig.2 Bar arrangement of arch-rib and order of placement

Cement (C)	Blast furnace cement B type (Blain value of blast furnace slag: 6000cm ² /g, Replacement ratio :60%, Specific gravity:3.01)		
Fine aggregate (S)	Sea sand (Specific gravity:2.55, F.M:2.63)		
Coarse aggregate(G)	Crushed stone (Gmax:20mm, Percentage of solid volume:58.5%)		
Admixture	Superplasticizer(SP) and AE agent(AE)		

Table 1 Materials

*Time when slump flow reached 50cm

W/C (%)	s/a (%)	kg/m ³			SP (C x %)	AE (C x %)	slump flow (cm)	* 50cm flow time (sec.)	Air (%)	V-funnel falling time (sec.)	
		W	C	S							
37	50	170	461	806	825	2.0-2.4	0-0.012	60 ± 5	6.0 ± 3	4.5 ± 1.5	7.5 ± 2.5

Table 2 Mix proportionTable 3 Items and value of quality control

2. CONSTRUCTION OF SUPER WORKABLE CONCRETE

2.1 Outline of the work

The materials are shown in Table 1. To improve the stability, blast furnace slag with a Blaine value of 6000cm²/g was used as an additional binder to cement, the replacement ratio was set to 60%, the highest value for type B blast furnace cement.

The mixing proportions for the super workable concrete are shown in Table 2. For the construction work, the water content per unit volume of concrete was reduced to 5kg/m³ less than the preliminary placing experiments to prevent the loss of stability caused by variations in surface moisture of fine aggregate. The concrete placed by pump and the outlet was positioned at each opening in turn, as shown in Figure 2, and the concrete placed in the order shown without the use of a vibrator for compaction. When the concrete level reached 40cm below the outlet the lid was placed to close the opening.

The rate of placing during the construction was about 1.5m/hr, and based on the results of lateral pressure measurements made during the preliminary placing experiments, and allowing for a margin of safety, a load of 70kPa was taken as the form design lateral pressure loading.

2.2 Quality control of super workable concrete

2.2.1 Quality control method

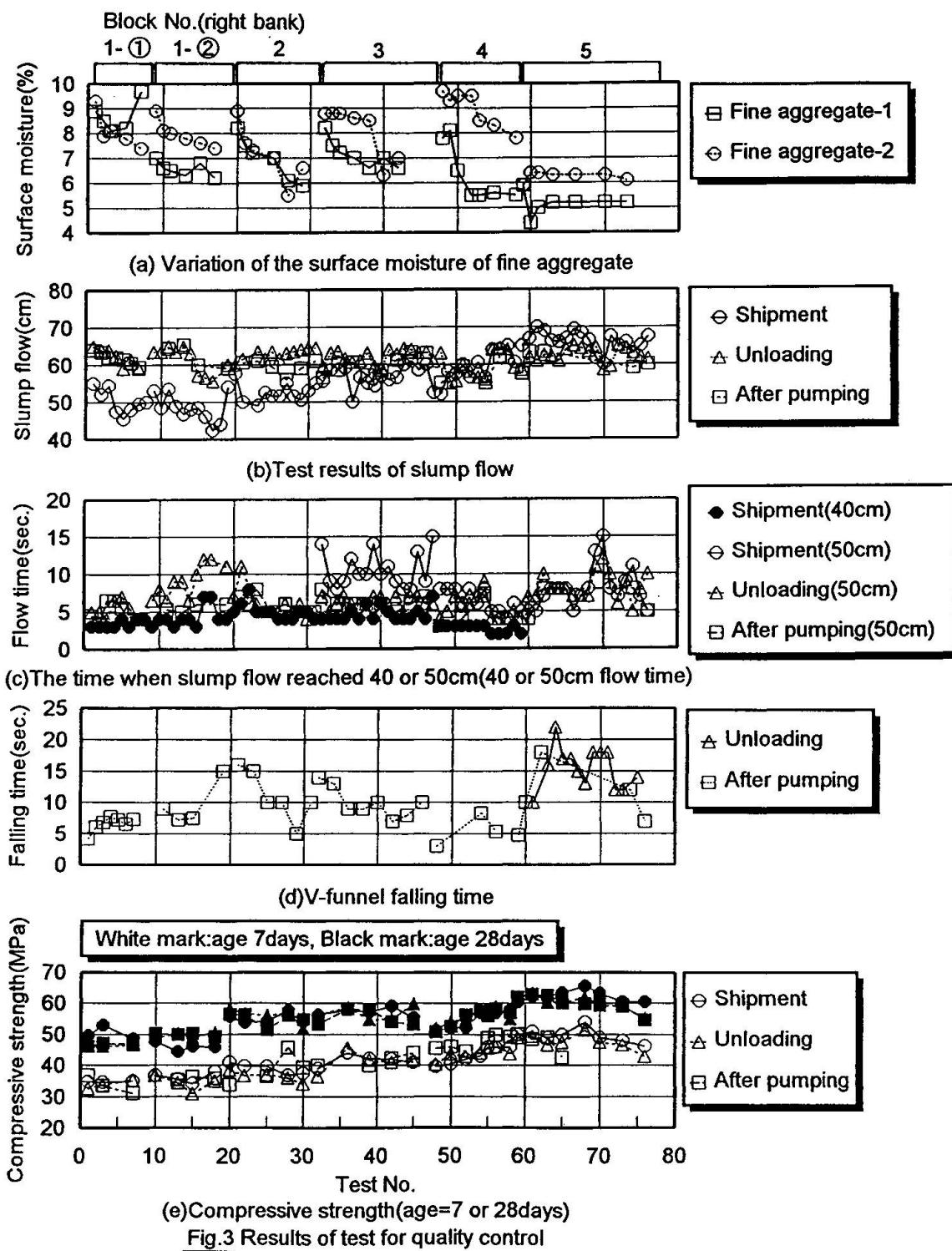
The values for concrete quality at the point of unloading and after pumping are given in Table 3. It was decided that in cases where the time from mixing to completion of placing exceeded 2 hours, (1.5 hours in hot weather concrete), the concrete would be disposed of, regardless of the conditions of fresh concrete. Therefore it was necessary to transport the concrete from the mixing plant to the site in 40min to 50min which meant the supply base had to be changed to suit the placing conditions. Concerning the frequency of quality testing, firstly the quality of concrete of 3 agitator trucks was confirmed immediately after shipment, then at a ratio of one in 3 to 5 trucks. If there was a considerable fluctuation in quality, then every truck would be checked until consistency of quality was restored.

2.2.2 Results of test for quality control

In Figures 3(a) to 3(e), are shown the results of quality tests carried out at shipment, unloading and after pumping.



As can be seen from Figure 3(a), the fine aggregate is a combination of two systems, one of which is used in the making of regular concrete, and the surface moisture is affected considerably by the amount and rate of shipment and results in considerable fluctuations. However, in the case of number 5 placement block (crown portion), the concrete was placed at night as countermeasure of hot weather concrete, and as a result the amount of surface moisture was relatively stable.



(e) Compressive strength(age=7 or 28days)

Fig.3 Results of test for quality control

The results of slump flow tests are shown in Figure 3(b). At the time of commencement of the concrete placement in March it was found that there was a tendency for the slump flow to increase by 10cm from the time of shipment to the time of unloading, which was the same as in the case of the preliminary placing experiment carried out in February. From this result, to achieve a slump flow of 60 ± 5 cm at unloading or after pumping, it was decided to make the slump flow value at shipment 50 ± 5 cm. However, due to the rise in environment temperatures (temperature when the concrete is mixed up) the increase in slump flow and the time taken to reach a peak value of slump flow became short, so to increase the value of slump flow, the amount of superplasticizer was increased. At the time of final placing (crown portion : July 30), there was virtually no difference between the slump flow value at shipment and the slump flow value at unloading or after pumping.

The time when the slump flow reached 40 or 50cm (abbreviate to "40 or 50cm flow time") is shown in Figure 3(c). For the case of a slump flow of around 55cm at shipment, 40cm flow time was measured, and during the latter half of the construction work, when the slump flow had increased to around 60cm, the 50cm flow time was measured. There was a large variation in 40 or 50cm flow time measured at the commencement of placing, at block 1, and during hot weather from the latter half of block 4 and during block 5, but was stable during the intermediary phase of the work, at shipment in 4 to 5sec. (40cm flow time), at unloading or after pumping in 5 to 7sec. (50cm flow time).

The V-funnel falling time measured at after pumping fluctuates considerably even when there is little variation in slump flow, this is seen as the effect of different viscosities of the placed concrete (see Figure 3(d)). Also, the V-funnel falling time value showed the same relative trend as the 50cm flow time after pumping, but the V-funnel falling time showed the differences most clearly. The main reason for the variations in V-funnel falling time, even though the super workable concrete is of fixed mix proportion and same slump flow, is believed to lie in the surface moisture content of fine aggregate. In such a case, it is necessary to measure the surface moisture and make fine adjustments to the set value.

In Figure 3(e), the results of compressive strength tests at 7 days and 28 days for shipment, unloading and after pumping are shown. The increase in environment temperature gave rise to difficulties in maintaining the ease of slump flow at after pumping, necessitating an increase in superplasticizer causing a corresponding gradual increase in the compressive strength.

2.3 Measurement of lateral pressures

In Figures 4 are shown the results of measurements of the lateral pressures made during the preliminary experiments, while in Figure 5 is shown the results of the measurements made during the actual construction work.

The test specimen was in the form of an unreinforced structural column 7.5m high, the concrete was placed in 5 layers allowing different interval of placement. The rate of placing in all cases was about 2.6m/hr.

In Figure 4 is shown the relationship between the time elapsed since shipment and the ratio of lateral pressure and liquid pressure on the preliminary placing experiments. It was found that the measured values showed a good correlation with the straight line of the regression equation. By setting the rate of placing in the regression equation, the maximum lateral pressure on the formwork can be obtained. Substitution of the respective values in equation (1) yields the quadratic equation (2).

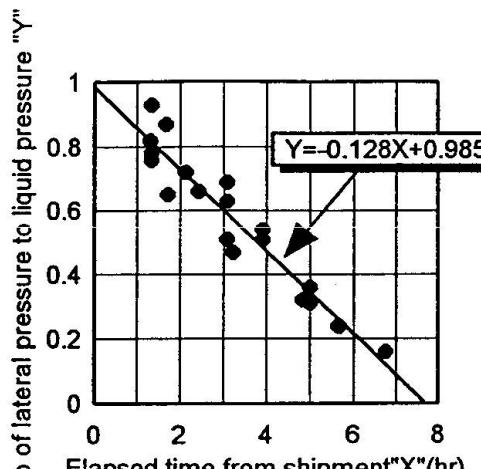
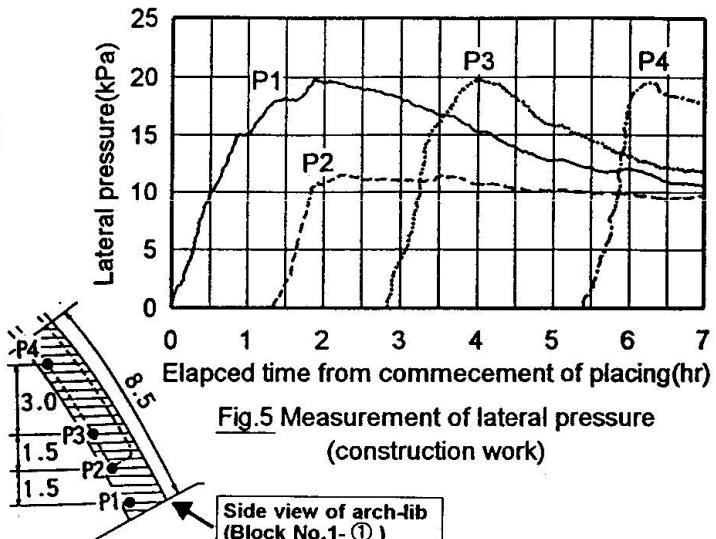


Fig.4 Ratio of lateral pressure to liquid pressure with elapsed time



$$Y = P_c/P_w = -0.128X + 0.985 \quad \dots \dots \dots (1)$$

$$P_c = -7.4X^2 + 63.8X - 57.0 \quad \dots \dots \dots (2)$$

where: P_c : Concrete lateral pressure (kPa)

P_w : $R \times W_c$ liquid pressure

R : Rate of placing $2.6(\text{m}/\text{hr}) \times t$

W_c : Weight per Unit Volume of Concrete $2272 \times 9.8 (\text{N}/\text{m}^3)$

t : Elapsed time from commencement of placing concrete = $X - 1$ (hr)

The lateral pressure occurring during the No.1 block placement in construction work can be seen in Figure 5. From the figure it can be seen that the pressure reaches a maximum of about 20kPa and then falls with time. The placing speed was around 1.0m/hr to 1.5m/hr, taking the average, about 1.1m/hr. Lateral pressures were measured at the placing of other blocks too, and in all cases the maximum pressure was found to be around 20kPa. In the design of the forms and falsework, considering the results of preliminary experiments and allowing for safety, a design load of 70kPa was adopted, however as the actual measured maximum was 20kPa, this was abandoned on the way and a value of 44kPa was adopted for design.

3. CONCLUSION

It was found possible to efficiently place approximately 1500m^3 of suitably prepared super workable concrete for the arch rib and crown portion of the concrete arch bridge within the agreed completion time. By carrying out various preliminary experiments, and in particular by continuous measuring of the lateral pressures on formwork, it was possible to perform the placing successfully.

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