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Construction of the Usagawa Long-Spanned Concrete Arch Bridge

Construction d'un pont en arc, de grande portée, en béton

Herstellung einer weitgespannten Bogenbrücke aus Beton

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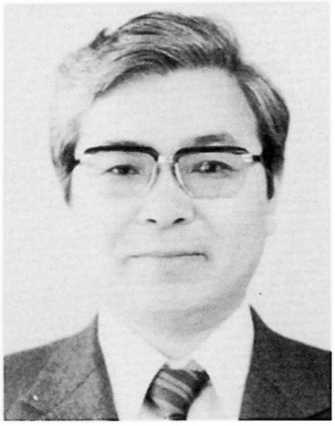

Born in 1937, graduate from Kumamoto Univ., Faculty of Civil Engineering. Civil Engineer for planning, design and supervision of Highway Projects at Nihon Doro Kodan for 25 years.

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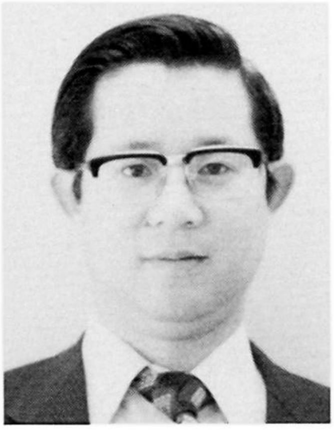

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SUMMARY
Usagawa Bridge, built by Nihon Doro Kodan (the Japan Highway Public Corporation) in 1981, is a reinforced concrete arch bridge with a span of 204 m. The result of application of flowing concrete to the arch ring of the Usagawa Bridge is discussed. This concrete, to which is added a water-reducing agent with high performance, was used for the purpose of enhancing the concrete workability and quality.

RESUME
Le Pont Usagawa construit par Nihon Doro Kodan (Corporation Publique Japonaise des Routes), en 1981, est un pont en arc d'une portée de 204 m. La mise en place du béton dans l'arche a été réalisé avec un plastifiant de haute efficacité, maintenant l'ouvrabilité du béton et améliorant sa qualité.

ZUSAMMENFASSUNG
Die Usagawa-Brücke, die von Nihon Doro Kodan (öffentliche Gesellschaft für Autobahnen in Japan) im Jahre 1981 gebaut worden ist, ist eine Betonbogenbrücke mit einer Spannweite von 204 m. Der Beitrag behandelt den Bau des Bogens, der — um eine bessere Verarbeitbarkeit und Qualität des Betons zu erreichen — unter Verwendung von Beton-Verflüssiger erstellt worden ist.

1. Introduction

Usagawa Bridge was constructed in 1981 as a part of the Chugoku Expressway. This bridge is a reinforced concrete arch bridge with 204m of an arch span. Since its arch ring has a large cross-section carring four lanes (two lanes for each derection), various techniques have been incorporated in the designing, the quality control of materials and others to reduce the dead load. The arch ring was constructed with prestressed concrete using a cantilever method with temporary stays used prestressing bar together with a temporary steel girder arch. Having an experience in the construction of the same type of bridge with 145m of the arch span, Taishaku Bridge in 1978, the Japan Highway Public Corporation has realized the necessity of highly-workable concrete. Thus the flowing concrete was used with a view of enhacing the concrete workability and quality for the construction of Usagawa Bridge.

A water-reducing agent with high performance has been fairly utilized in the fields of concrete products and building construction as well, but it had not yet then brought results in the civil engineering field in Japan. Usagawa Bridge was the first case that a water-reducing agent with high performance was used on a full scale for a bridge with a long span.

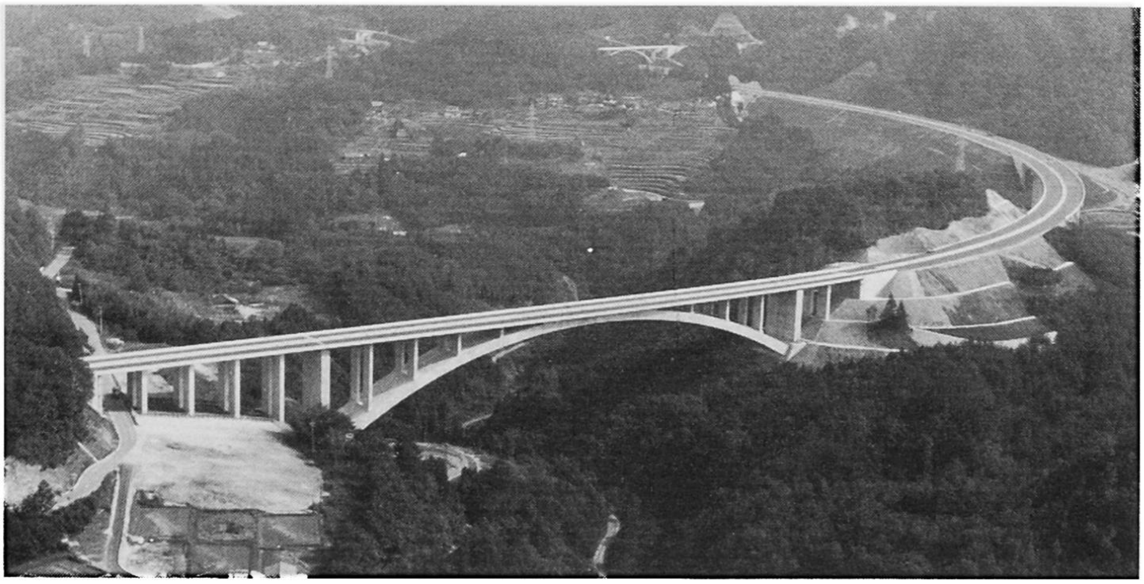

Photo 1, Appearance of Usagawa Bridge

2. Structure Outline

The structure of Usagawa Bridge is shown in Fig. 1. The following are characteristics of the bridge:

1) A hyper bolic curve is used for the arch axis. The shape of the bridge is asymmetric and flat, (The span-rise ratio is 1/6 at the right bank and 1/9 at the left bank respectively.)
2) The arch ring carries four lanes and has 17.8m wide box section (3 cells) in order to imprive the earthquake resistance in a transversal direction to the bridge axis. The girder depth varies from 3.6m at the crown to 4.4m at the springing.
3) At the crown, the arch ring and the upper slab are monolithicized to reduce the dead load as well as to make the arch rise as large as possible.
4) The upper deck is designed as prestressed concrete hollow slabs with 18m spans. Each of the two prestressed slabs carries two lanes.

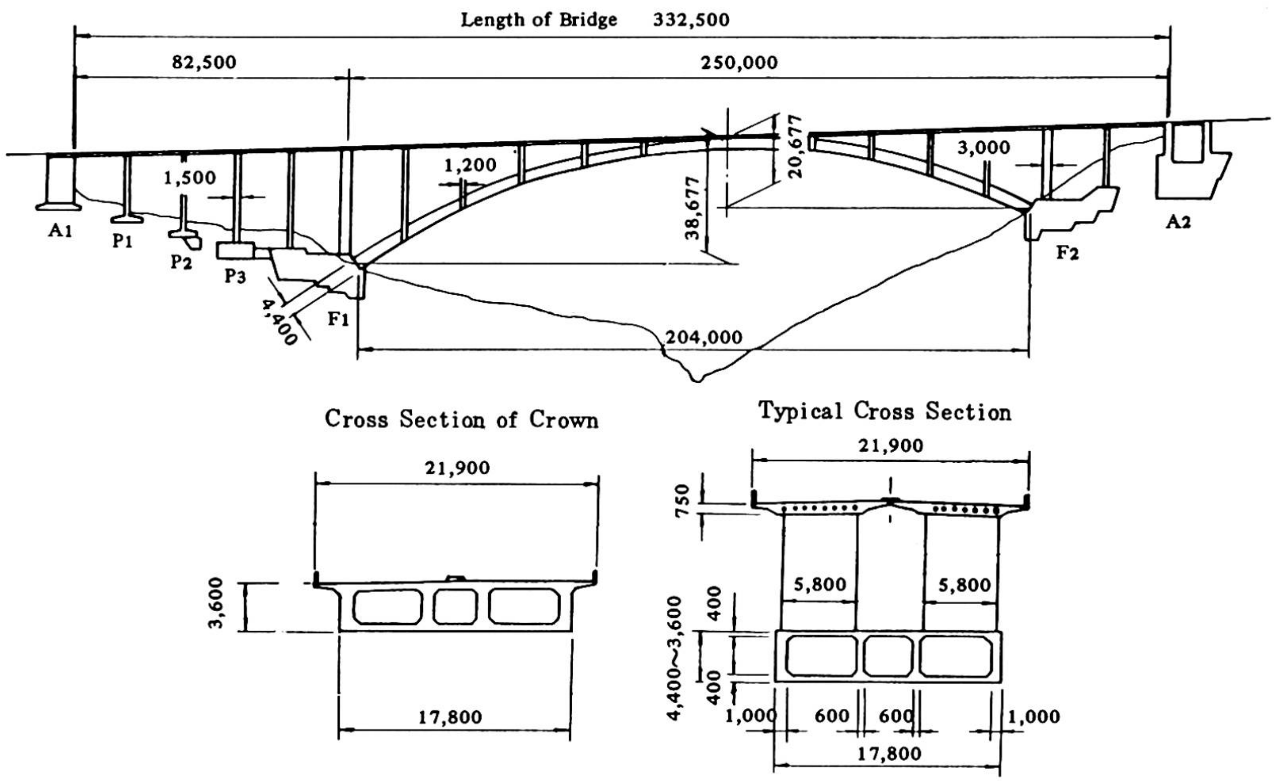

Fig. 1 General Arrangement

The following are principal materials used for Usagawa Bridge construction (includes principal temporary materials):

Concrete	41,300 m^3	
Reinforcing bar (SD30)	2,150 t	
Prestressing bar	690 t	(for Temporary Works)
Steel girder arch	1,090 t	(for Temporary Works)
Pylon column (steel)	121 t	(for Temporary Works)
Rock anchor (SEEE F160)	4,089 m	(for Temporary Works)

3. Construction Procedures

A cantilever method with temporary stays used prestressing bar and temporary steel girders were jiontly used to build the arch ring (See Fig. 2).

Step 1 First, arch abutment, abutment column and steel pylon on both side are built. Then, rock anchors are installed to secure the arch abutment against any movements during the arch ring construction. Next, the first section of 8m of the arch ring from the base is constructed on falseworks and a travelling form is assembled on the section.

Step 2 For the next 50m sections from both the bases, every 4m block is built by the cantilever method with temporary stays used prestressing bar from abutment column. The travelling form is also used. Prestressing bars are arranged for the arch ring to relieve tensile stresses in the concrete during the construction.

Step 3 For approximately 100m section in the center of the arch ring, first, steel arch members are installed by a cable erection method utilizing the steel pylons to finish the arch shape.

Step 4 After removing temporary cable stays and pylons used for the construction of steel arch members, the steel arch members are covered with concrete by every 6m block using the travelling from to complete the concrete arch.
Step 5 After building the vertical members on the arch ring, starting from both banks, each span of the upper slab is constructed one by one using steel girders as a falsework.

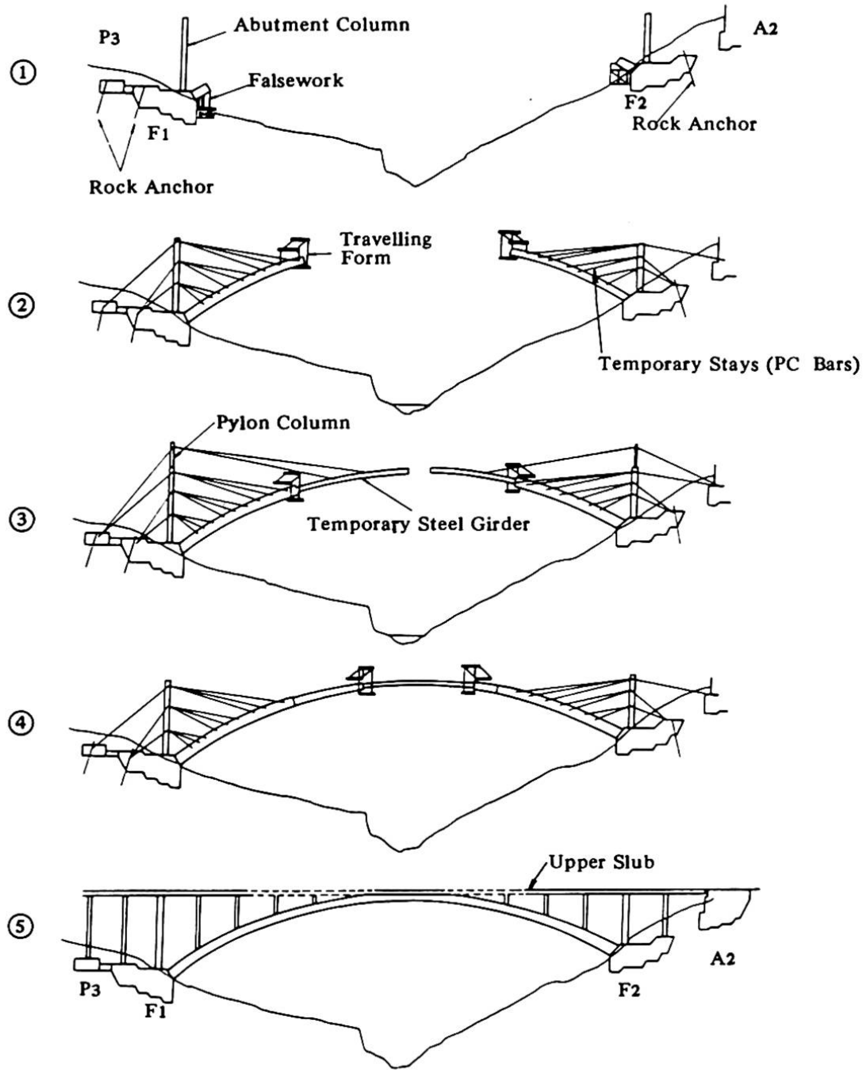

Fig. 2, Construction Process

4. Construction of Flowing Concrete

The 100m-long center section the arch ring is made up of blocks of 6m in length which was built using two large travelling forms. The following problems were observed at the time of concrete casting in the blocks:

1) As shown in Fig. 3, plate girder structures were placed inside the arch ring, and around them reinforcing bars and prestressing bars were intricately arranged making concrete casting dificult.
2) Because the arch ring was inclined and it required top covering forms at its top and bottom slabs of the box section, the positions for applying vibrators were limited. It was also dificult to visually confirm the condition of cast concrete.

3) The concrete volume of one block was 170m^3 and it was supposed to be too large for a usual construction by a travelling form. It was therefore necessary to enhance the concreting efficiency.

To solve the problems, application of high-workability concrete was needed. However, concrete with the design strength of 40 N/mm^2 with high-early-strength cement was used for this bridge. The cement content of the concrete was considerably large, which reaching 440-460kg/m^3 if the slump value at the time of sending off from the plant were set at 9cm.
For the above reasons, to avoid adverse effects resulting from drying shrinkage, heat of hydration and etc., to control water and cement contents, and to obtain high-workability concrete, flowing concrete has been employed.
In applying flowing concrete, the mix proportions, the types and dosages of the superplasticizer and the slump increase were determined on the results of both laboratory and on-site tests, then concrete workability was confirmed and quality control items were selected.

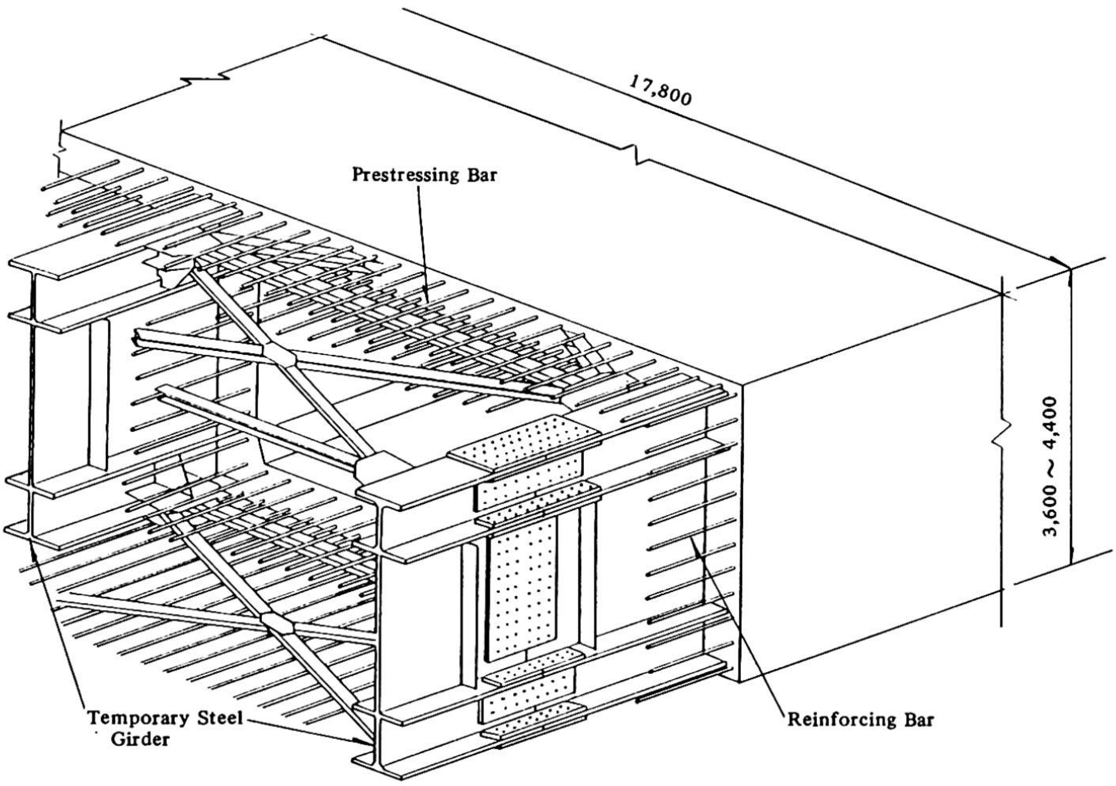

Fig. 3, Detail of Arch Ring

5. Mix Proportions and Production of Flowing Concrete

The proportions of the flowing concrete is shown in Table 1. Basic rules employed to determine the target slump value are as follows:

1) A slump value for the base concrete is set as small as possible: less unit water and cement contents are used. The slump value required for casting is obtained by adding superplasticizer. The slump increase is minimized but not to affect the concreting efficiency.
2) According to the on-site test results, good workability and dense concrete can be obtained when the slump value at the end of the delivery hose is a little more than 11cm. So, taking into consideration possible 2cm slump loss while pumpcreting, the slump value immediately after superplasticization should be 13cm or more.

3) To avoid segregation of the materials due to pumpcreting or excessive application of vibrators while casting, less than 16cm slump at its maximum after superplasticization is recommended, considering the fluctuation of the slump value.

Table 1, Arch Ring Concrete Proportion

Where to use	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Slump (cm)	Air content (%)	Admixture (kind)
Cantilever	440	180	619	1,086	9±1.0(at a plant) 7±1.5(at casting)	4±0.5(at a plant) 4±1.0(at casting)	Water-reducing admixture
Steel girder arch	430	176	624	1,099	7±1.0(at a plant) 13±2.5(flowing concrete) 11±2.5(at casting)	4±0.5(at a plant) 4±1.0(flowing concrete) 4±1.0(at casting)	Water-reducing admixture + Superplasticizer

Note: "Flowing concrete" shows the values immediately after admixing the superplasticizer into the ready mixed concrete delivered to the site.

Based on the above rules, 7cm slump for the base concrete and additional 6.5cm target slump value for the flowing concrete have been determined. (See Fig. 4)

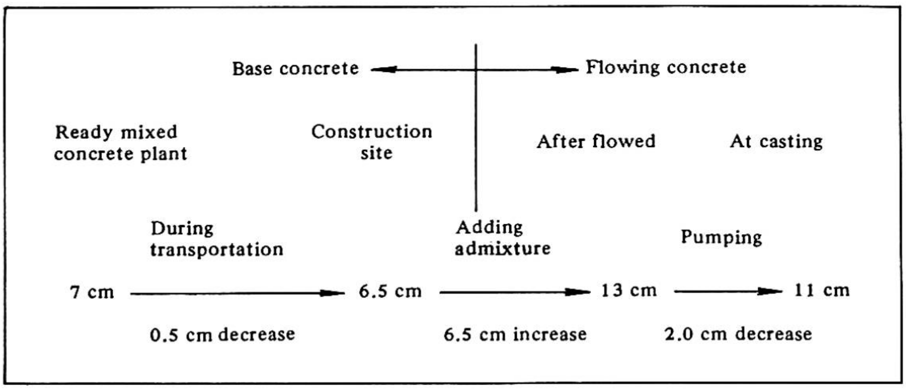

Fig. 4, Slump Change of Concrete

6. Concrete Casting

Superplasticizer was added on site right before casting of concrete to prevent a slump loss as could occur in a transportation time lapse.
The dosage of superplasticizer was fixed during the whole construction period to prevent errors resulting from complicated control regardless of atmospheric temperature or the slump change of the base concrete. The dosage of superplasticizer per truck mixer was measured by an automatic gauge and printed out on a recording machine each time, so as to prevent possible errors at the time of adding. After adding, concrete was agitated at a medium speed (18-20rpm) based on the test results.
It was known from the test results that a slump loss after superplasticization due to the time lapse can be recovered to the required slump value by re-adding superplasticizer. This method, however, requires prompt judgement on dosage and timely application. Moreover, it might confuse field control. Accordingly the concrete with an inadequate slump as a result of the time lapse or for other reasons was rejected.

The concrete for each block of the arch ring was cast first onto lower slabs, then web members and upper slabs. In particular, for the blocks of the steel girder arch section, smallersized vibrators were applied at closer intervals with shorter vibration time in order to overcome the narrowness of the concrete-casting space and avoid material segregation due to excessive vibrations. In addition, since the arch ring was inclined, the top covering up one by one as the concreting proceeded.

Concreteing was smoothly done by two concrete pumps, although the pumpcreting distance was as long as 300m in horizontal equivalent. Furthremore, the concreting efficiency was improved and casting time was considerably shortened and thus the concrete casting was easily done.

A volume of approximately 3,500m^3 flowing concrete was cast for the period from the summer to winter. During the summer, coarse aggregates were kept cooled by underground water to lower the temperature of the mixed concrete. During the winter, on the contrary, by warming up mixing water within 30-35°C, the temperature of the mixed concrete was maintained a above 10°C, and travelling forms were covered entirely with canvas and kept warm using jet heaters and others to cure concrete.

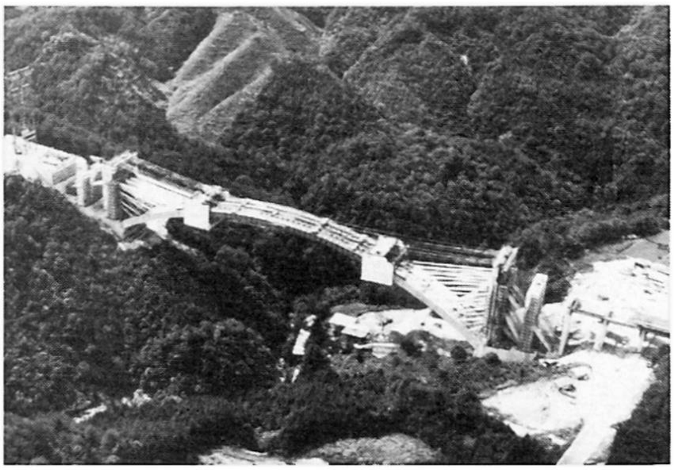

Photo 2, Construction of Arch Ring

7. Results of the Quality Control of Flowing Concrete

Quality control items for the concrete and frequency of testings or measurements of those items are shown in Table 2. Target strength at 28-day of the concrete was set at 46.4 N/mm^2. The slump value and the air content were based on the preliminary test results.

Table 2, Quality Control of Flowing Concrete

Stage	Test Items	Number of Testing Times			
		At Plant	Before superplastisized	After superplastisized	At casting
Stage 1 (Beginning of construction)	Workability	——	Observed visually every agitator truck		——
	Slump	Once a agitator truck (1st~5th) Once every 5 agitator truck (6th~)	Once a agitator truck (1st~5th) Once every 2 agitator truck (6th ~10th) Once every 5 agitator truck (11th~)		Once every 5 agitator truck (for all agitator truck)
	Air content and temperature	Once a agitator truck (1st) Once per 50 m^3 (2nd~)			Once per 150 m^3
	Compressive strength	——	9 pieces per the first 50 m^3 After that: 9 pieces per 150 m^3	12 pieces per first 50 m^3 After that: 12 pieces per 150 m^3	
State 2 (Quality was settled)	Workability	——	Observed visually every agitator truck		——
	Slump	Once a agitator truck (1st~5th) Once per 50 m^3 (6th ~)	Once a agitator truck (1st~5th) Once every 5 agitator truck (6th~)		Once every 5 agitator truck (for all agitator truck)
	Air content and temperature	Once a agitator truck (1st) Once per 50 m^3 (2nd~)			Once per 150 m^3
	Compressive strength	——	9 pieces per 150 m^3	12 pieces per 150 m^3	——
Stage 3 (Usual control)	Workability	——	Observed visually every agitator truck		——
	Slump	Once a agitator truck (1st ~5th) and once every 10 agitator truck (6th ~)			Once every 10 agitator truck
	Air content and temperature	Once a agitator truck (1st agitator truck only)	Once a agitator truck (1st) and once 10 agitator truck (2nd~)		Once per 150 m^3
	Compressive strength	——	6 pieces per 1 block	12 pieces per 150 m^3	——

X Note: Figures in parenthes are ordinal number of agitator truck which arrived at site.

The results of the quality control tests are as follows:
The average value actually measured of the additional slumps by the superplasticizer was 6cm, while the target value had been set at 6.5cm. It proved that the concrete was superplasticized to the prescribed level. Furthermore the fluctuation of the slump value after superplasticization was 0.57cm in standard deviation. This preliminary test results. The air content was 0.5% higher than that of the base concrete and not much fluctuation was observed. The strength of the flowing concrete was a little lower than that of the base concrete. Most of the flowing concrete, however, was above the target strength.

Table 3, Results of Measurement at the Time of Construction

	Slump (cm)			Air content (%)			Increase of slump (cm)	Compressive strength (N/mm²)	
	Before transporting	Before adding	After adding	Before transporting	Before adding	After adding		Before adding	After adding
Number of samples	159	162	162	72	81	86	162	23	33
Average	7.9	7.5	13.5	3.8	3.7	4.0	6.0	50.1	49.1
Standard deviation	0.336	0.500	0.571	0.263	0.313	0.248	0.686	3.06	2.94
Fluctuation coefficient	4.3	6.7	4.2	6.9	8.5	6.2	11.4	6.1	6.0
Maximum value	8.5	8.5	15.0	4.2	4.6	4.6	8.0	57.2	54.2
Minimum value	6.5	6.0	12.5	3.3	3.2	3.1	4.5	45	43.1

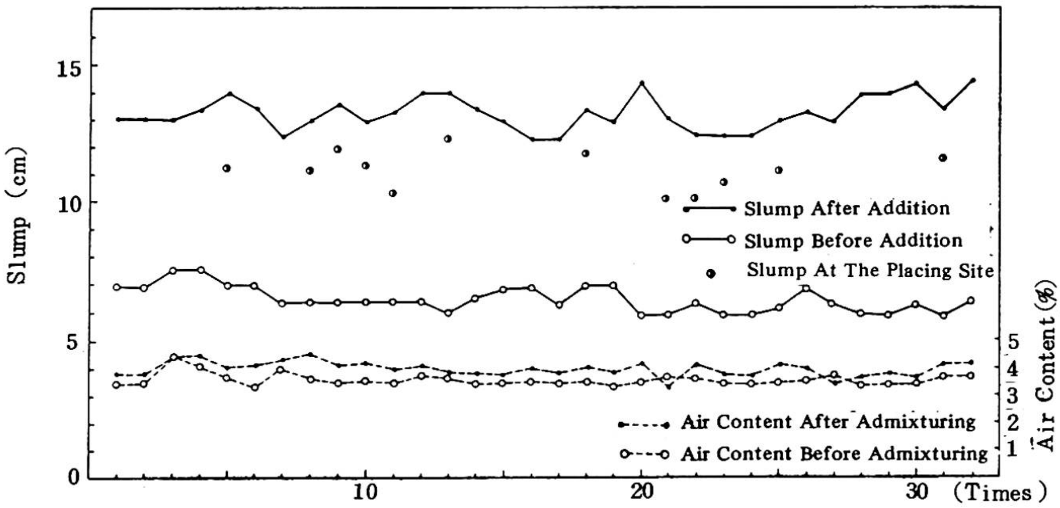

Fig. 5, Slump and Entraining Air Content

8. Conclusion

Having examined the execution results of the flowing concrete used for Usagawa Bridge, we are confident that the flowing concrete has not caused any troubles with the quality and workability of the concrete nor affected the concreting efficiency, but has brought excellent results beyond our expectation.

As to the concrete casting methods, there has been a trend on the increase in a quantity of concrete at a time using a pump, which calls for the improvement of pumpcreting efficiency.
Moreover, it has become more difficult to fill the structure with a low slump concrete, for reinforcing and prestressing bars are more densely placed in the structure as the bridges have become larger and longer.
Therefore, a high-workable concrete with high quality are increasingly needed. Consecuently, we need more experiences in using such flowing concrete as used for Usagawa Bridge, to present standards for this type of concrete. We hope that a flowing concrete will be used extensively in the future.