Improvement in quality of concrete structures by two-stage mixing method

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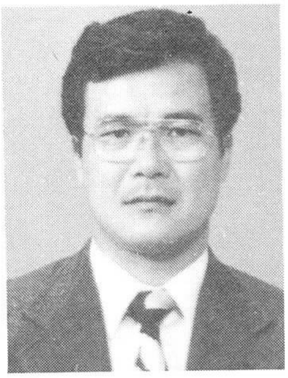
Amélioration de la qualité des structures en béton par la méthode du mélange en deux étapes

Qualitätssteigerung bei Betonbauteilen durch zweistufiges Beton-Mischverfahren

Yukikazu TSUJI
Assoc. Professor
Gunma University
Kiryu, Japan

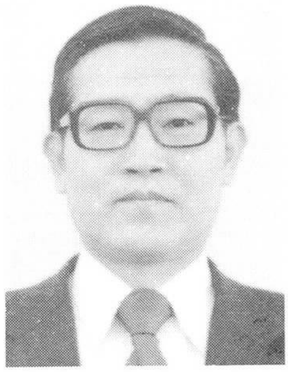


Yukikazu Tsuji, born in 1945, received his M.S. and Dr. Eng. degrees from the University of Tokyo in 1971 and 1974, respectively. After teaching at Ashikaga Institute of Tech. for seven years, he is now at Gunma University.

Yasuro ITO
President
Livecon Eng. Co. , Ltd.
Tokyo, Japan

Yasuro Ito, born in 1926, graduated from Nagano Technical High School, was mainly engaged in manufacturing concrete products for more than 30 years. He received his Dr. Eng. from the University of Tokyo in 1983.

Yasuhiro YAMAMOTO
Manager
Techn. Res. Inst. , Taisei Corp. ,
Yokohama, Japan



Yasuhiro Yamamoto, born in 1935, graduated from the University of Tokyo in 1959, has been mainly involved in research and development of constructional materials. He received his Dr. Eng. from the University of Tokyo in 1973.

SUMMARY
A two-stage mixing method is proposed for manufacturing concrete in which the surface condition of aggregate is first improved by a process of coating with cement paste of a suitable quality, following which the remaining water is added and mixing is done once more. This paper deals with not only the improvement in quality of the concrete itself, but also the results of experiments on quality improvement of structures, cases of practical use, as well as the actual method of manufacturing.

RÉSUMÉ
Une méthode de mélange en deux étapes est proposée pour la fabrication du béton. L'état de surface de l'agrégat est d'abord amélioré par un procédé de revêtement à l'aide d'une pâte de ciment de qualité appropriée, puis le restant d'eau est ajouté et le mélange effectué de nouveau. L'amélioration dans la qualité du béton lui-même, les résultats des expériences sur l'amélioration des structures, des cas d'utilisation pratique et la méthode de fabrication sont expliqués.

ZUSAMMENFASSUNG
Ein zweistufiges Mischverfahren wird für die Betonherstellung vorgeschlagen. In einer ersten Mischphase werden die Zuschlagsstoffe benetzt und durch Hinzufügen des Zementes mit einer Zementpaste überzogen. Anschliessend wird das Restwasser zugefügt und erneut gemischt. Es wird mit diesem Mischverfahren nicht nur eine bessere Betonqualität erhalten. Auch der Bauteil erfährt eine Qualitätssteigerung, wie anhand von Versuchsergebnissen gezeigt wird. Das Mischverfahren sowie praktische Anwendungen werden besprochen.

1. TWO-STAGE MIXING METHOD AND OPTIMUM W_1/C RATIO

In manufacturing concrete, instead of introducing the materials simultaneously and mixing, it is conceivable to use a two-stage mixing method in which the materials are mixed divided into stages as shown in Fig. 1. This is a manufacturing technique in which primary water is first added to set up a suitable surface moisture content of aggregates, and primary mixing is performed together with cement, followed by introduction of the remaining secondary water for secondary mixing. The essential point of this method lies in coating the surface of aggregates, especially of fine aggregate of large total surface area, with cement paste of low water-cement ratio which is in a capillary state[1].

Fig. 2 shows the influence of the ratio by weight W_1/C of primary water and cement on the rate of bleeding of mortar indicated with the fine aggregate-cement ratio by weight S/C as the parameter. The bleeding ratio of mortar mixed in two stages with W_1/C made extremely low becomes higher compared with the conventional simultaneous mixing method. However, the bleeding ratio declines with increase in W_1/C and becomes extremely low compared with the case of conventional simultaneous mixing. And, when a certain value of W_1/C is exceeded, the bleeding ratio increases again. In this way, there exists an optimum W_1/C at which bleeding ratio becomes a minimum. Such a condition in which the bleeding ratio becomes a minimum is prominent with a rich mortar of low S/C. This condition is alleviated with a lean mortar of high S/C, while the optimum W_1/C is in a wide range, and moreover, the value of W_1/C itself becomes large as shown in Fig. 2. In this way, establishment of W_1/C, the ratio by weight of primary water to cement in primary mixing, is important when adopting the two-stage mixing method, and the quality of concrete differs greatly depending on the value set.

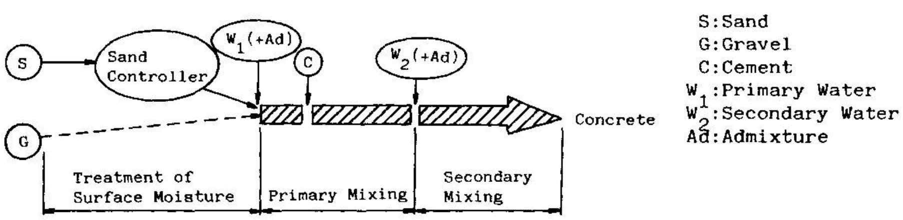


Fig. 1—Example of two-stage mixing method.

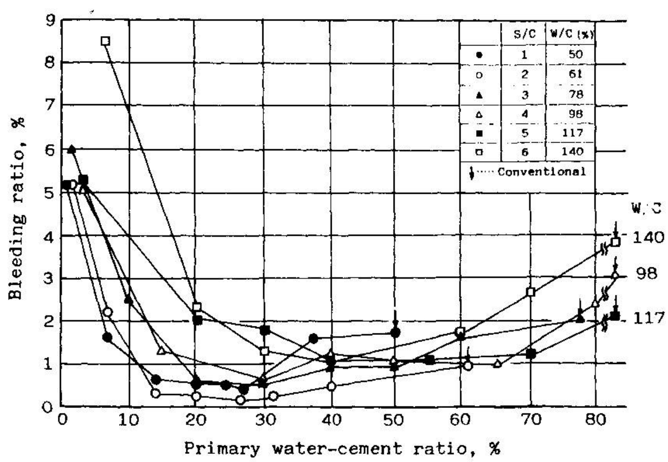


Fig. 2—Primary water-cement ratio and bleeding ratio of mortar.

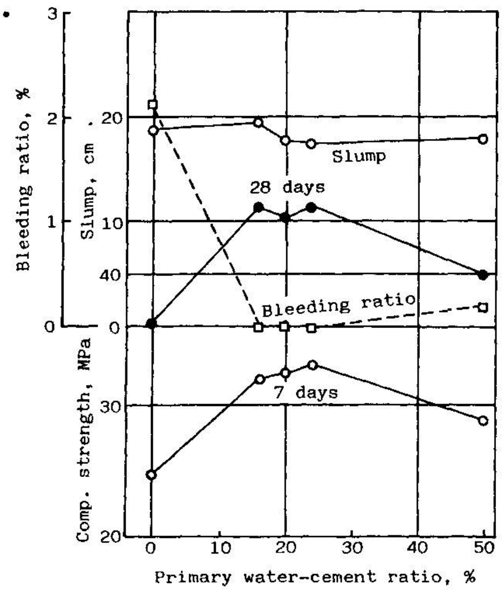


Fig. 3—Primary water-cement ratio and qualities of concrete.

2. QUALITY OF CONCRETE

The results of an experiment on concrete are shown in Fig. 3. This was a case of the final water-cement ratio W/C being 0.50 and slump 18 cm. Two-stage mixing was performed and especially in the range of W_1/C of 0.16 to 0.24, bleeding was reduced drastically to an extent that hardly any bleeding water could be detected. Practically no change was seen in slump even when two-stage mixing was performed.

As a result of testing the amount of dewatering when a pressure of 3.43 MPa was applied to investigate the pumpability of concrete, it was found that concrete made by two-stage mixing was 20 to 60 percent smaller in the amount of dewatering for both the initial and final stages of pressurizing. This trend was more prominent the lower the slump and the lower the water-cement ratio.

It is clear from Fig. 3 that compressive strength of concrete is increased by two-stage mixing. Fig. 4 shows cases of slump maintained constant at approximately 18 cm and with water-cement ratio varied between 0.30 and 0.60. When using the two-stage mixing method compressive strengths and splitting tensile strengths are 10 to 20 percent higher compared with concrete made by the conventional simultaneous introduction method.

3. IMPROVEMENT IN QUALITY OF STRUCTURE

It can hardly be said that concrete structures have always been entirely of uniform quality in the paste, qualities differing between upper and lower positions and parts of the structure, and depending on the conditions when executing work, Particularly, with walls and columns taller than 3 m, wet-consistency concrete of slump higher than 15 cm is often used, and with such members the strength of concrete and bond strength with reinforcing steel are lower at the upper parts and these become weak points of the structure.

Concretes made by the two-stage mixing method and by the conventional simultaneous mixing method were placed in reinforced concrete wall panels of 3-m height, 0.8-m width, and 15-cm thickness, and the compressive strengths of the concretes in the vertical directions of the panels and bond strength distributions of reinforcing bars were compared. The results are given in Fig. 5. The compressive

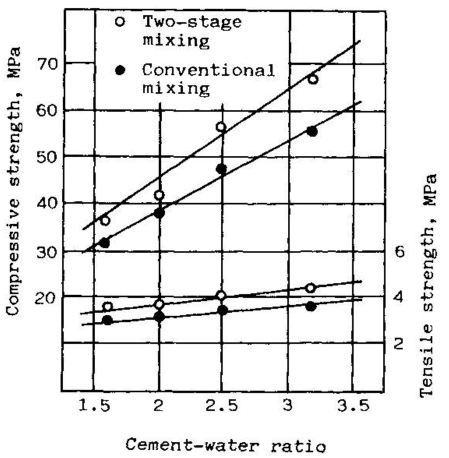


Fig. 4—Compressive and tensile strengths of concrete.

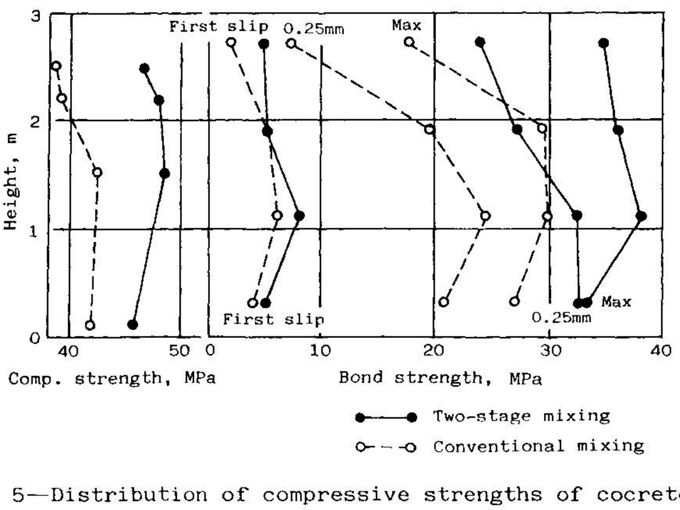


Fig. 5—Distribution of compressive strengths of cocrete and bond strengths of reinforcing steel in wall panels.

strengths and bond strengths according to core samples from various heights are shown. Concrete slump was 18 cm, and water-cement ratio 0.50.

Whereas bond strengths at a height of 2.7 m were 40 to 60 percent lower compared with the bottom parts of the wall panels when using concrete mixed by the conventional method, the decrease in case of the two-stage mixing method was limited to a maximum of 25 percent. Bond strengths per se were higher with the two-stage mixing, and the degree of increase was greater the higher the location in the wall panel. Although not as prominent as with bond strengths, the distributions of compressive strengths showed the effectiveness of two-stage mixing. That is, compressive strengths at various locations in the wall panels were increased 10 to 20 percent over the conventionally-mixed method, and strength reductions did not occur even at a height of 2.5 m.

Such an effect of the two-stage mixing method was confirmed with a reinforced concrete wall panel 8 m in height, 1 m in width, and 40 cm in thickness. In essence, compared with the bottom part of the wall panel, the reductions at a height of 7.5 m were held to 25 percent for bond strength of reinforcing steel and 15 percent for compressive strength, so that the strength reductions were smaller.

That it is possible to reduce variation in quality at various locations in a concrete structure in this way is because with the two-stage mixing method a concrete with extremely little segregation in the forms of bleeding and settling of aggregates is successfully made.

4. CASES OF PRACTICAL USE

Concrete made by the two-stage mixing method was used in large quantities of tunnels such as Seikan Tunnel[2]. Subsequently, it was also used in offshore concrete. Application to buildings[3] and dams[4] lagged behind slightly, but this concrete came to be adopted as the excellent uniformity and stability of quality and the good workability received high regard.

In particular, 1,900 m^3 of concrete by the two-stage mixing method was adopted in 1981 in the administration building annex project of Igata Nuclear Power Station of Shikoku Electric Power Co.. The specified concrete strength was 23.5 MPa, and compared with 610 m^3 of simultaneously-mixed con-

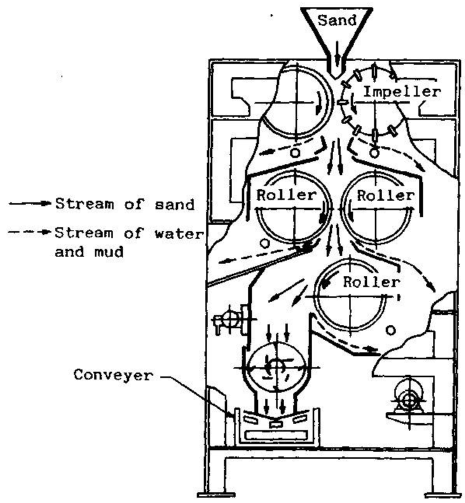


Fig. 6—Sand Controller.

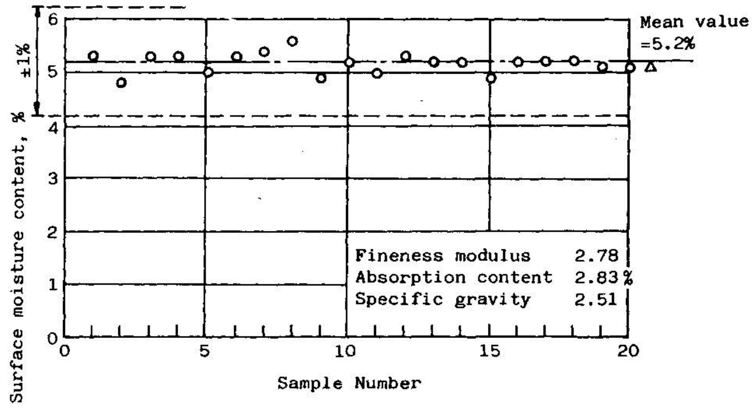


Fig. 7—Control chart of Surface moisture content of sand after adjustment by Sand Controller.

crete used in the same project, compressive strength was 32.2 MPa, 16 percent higher, and bleeding 0.14 cm^3/cm^2, 44 percent less, while the standard deviation in compressive strength of concrete during construction was small at 1.81 MPa, and favorable results were obtained in the aspects of quality and constructability.

The concrete mixer used in this project was a forced-mixing type mixer of capacity 1.5 m^3, while a Sand Controller of fine aggregate-processing capacity 20 m^3/h was newly installed. The Sand Controller, as shown in the diagram of its principles in Fig. 6, is a machine for adjusting fine aggregate to the required surface moisture content. The surface moisture content of pit sand after adjustment, as shown in Fig. 7, was held to a range of roughly 5 ± 0.5 percent.

In 1985, the two-stage mixing method was adopted throughout for concrete work of a total volume of 500,000 m^3 at Tomari Nuclear Power Station of Hokkaido Electric Power Co., and at present, approximately 60 percent of placement of this concrete has been completed. Forced-mixing type mixers, one of 2-m^3 capacity and another of 3-m^3 capacity, and three Sand Controllers, each of 40-m^3/h capacity, are being used for the project. Use of concrete made by the two-stage mixing method is also contemplated for other nuclear power stations to be newly constructed.

5. METHOD OF MANUFACTURING CONCRETE

Concrete by the two-stage mixing method, as shown in Fig. 1, is manufactured by the processes of surface moisture adjustment of aggregates, primary mixing, and secondary mixing. For this purpose, apparatus for adjusting the surface moisture of aggregates, especially fine aggregate which is of large total surface area and a mixer capable of primary mixing of mixes of low water-cement ratio are required. It is amply possible for this primary mixing to be done with an ordinary forced-mixing type mixer.

With only one mixer, however, mixing time will be longer by just the amount of time required for primary mixing, and in an actual concrete plant, efficiency will be lowered to result in poor economy. Hence, two-stage mixers are used for the purpose of shortening mixing time. With the two-stage mixers, as shown in the flow chart of Fig. 8, primary mixing of fine aggregate, cement, and primary mixing water is done using the upper stage mixer to make mortar, while at the

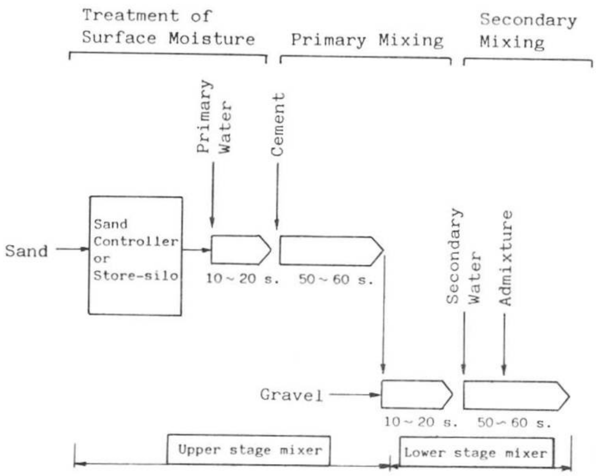


Fig. 8—Flow chart of two-stage mixing method.

Photo. 1—Tomari Nuclear Power Station.

lower stage mixer, the mortar and coarse aggregate are introduced to coat the coarse aggregate surfaces with cement paste of a capillary state, following which secondary mixing water is added to perform secondary mixing. Since primary mixing and secondary mixing are performed simultaneously with this arrangement, mixing time is approximately halved compared with the case of using a single mixer. It is a trend recently for the number of concrete plants equipped with two-stage mixers to increase due to the larger mixing capacity and more stable quality obtained even when the two-stage mixing method is not adopted.

The Sand Controller, as shown in Fig. 6, has been developed for adjusting surface moisture of fine aggregate and is in general use. Recently, in addition, a procedure has begun to be adopted where numerous aggregate hoppers made of concrete are provided and fine aggregate sprinkled with water beforehand is put in these hoppers and adjusted to a thoroughly moist condition for use then in sequence.

ACKNOWLEDGEMENTS

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