Application of Chemical Prestress to Precast Concrete Box Culverts

Application de la précontrainte chimique aux éléments en béton fabriqué de conduites souterraines

Anwendung chemischer Vorspannung bei vorgefertigten Kanälen mit kastenförmigem Querschnitt

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1. Introduction

In Japan, with the extremely great increase in sewer line works and construction of underground utilities ducts, the use of precast concrete box culverts has increased rapidly, and 600,000 tons of products were manufactured in 1975. Since permissible crack widths in box culverts are severely restricted to insure the durability, the application of chemical prestress was considered. Chemical prestress is introduced in a reinforced concrete member by expansive concrete overcoming the restraint by steel. The amount of chemical prestress differs greatly if steel quantities and arrangements vary. In general, as the quantity of restraining steel increases, the amount of chemical prestress increases as shown in Fig.2, although the elongation of restraining steel decreases.

Almost as soon as an expansive admixture began to be on the market, chemical prestress was applied in precast products of pipe form[1]. Regarding the products of box form, chemical prestress was not applied until the end of 1973. From the test results of small sized frames, conducted in 1972 and described in this paper, it was confirmed that the application of chemical prestress to box culverts would be promising. Then, chemical prestress was first applied to the actual products of box form in Tsurumi Concrete Company where about 100,000 tons culverts being manufactured annually, after carrying out the quality control tests of expansive concrete and the loading tests of actual products. In 1975, chemically prestressed concrete products reached 50 % of the total products in the company, and it is expected to reach 75 % in 1976.

Concerning the application of chemical prestress, a question

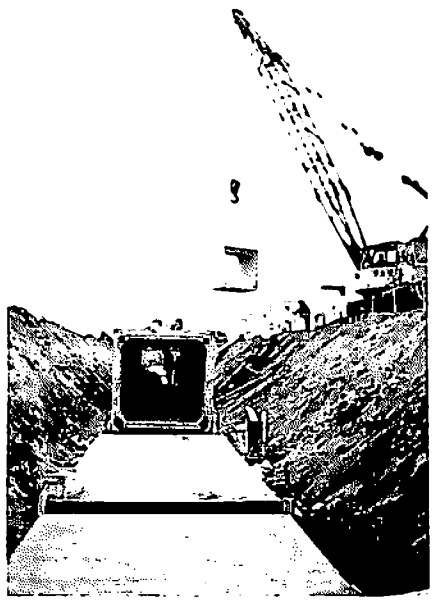

Fig.1 Precast concrete box culvert

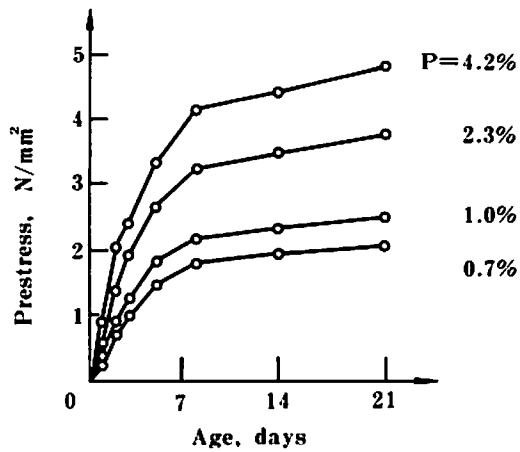

Fig.2 Increase in chemical prestress (p is percentage of steel in concrete)

was raised whether the effect of prestress might be decreased due to creep and shrinkage of concrete, eventually becoming almost completely lost, since the extent of prestress, which would be effectively utilized, would be about 3 N/mm^2 at most. The authors[2] have insisted that the effect of chemical prestress introduced in a member buried underground might last for a long period of time, because

(1) amount of chemical prestress in a member exposed to be weathered but not loaded did not change so much for a year,

(2) amount of chemical prestress in the tension side of a member, which is important for cracking resistance, did not decrease due to the external moment, and

(3) shrinkage of concrete might be small enough to be neglected for a member buried underground.

At this time, in order to confirm our insistence, experiments on actual products were carried out.

2. Behavior of Chemically Prestressed Concrete Box Culverts

2.1 Behavior of Beams

The increase in strain of a tensile reinforcing bar in a chemically prestressed concrete beam when external moment acts is extremely small compared with that in an ordinary reinforced concrete beam[3]. An example is shown in Fig.3. This reduction of strain is because of the chemical prestress, and the degree of the reduction is corresponding to the expansive strain produced in the bar during expansion of concrete. The expansive strain or chemical prestress can be predicted with sufficient accuracy for practical purpose from the result of the standard expansion test, using hypothesis that the work done on the restraining steel bars by unit volume of expansive concrete is to be constant irrespective of concrete mix and curing[4]. Measured expansive strains with various steel percentages (p) were compared with the estimated values from the measured strains of standard specimens which had about 1 % of steel. The differences between the measured values and the estimated ones were within about 20 % as shown in Fig.4. The amount of expansive strain of reinforcing bars can easily become about 5×10^{-4} although it changes according to mix proportion of concrete, curing method, steel percentage and arrangement of bars. Therefore, crack widths of chemically prestressed concrete members could be greatly reduced compared with those in ordinary reinforced concrete members, because crack widths are proportional to the strain of tensile reinforcing bars.

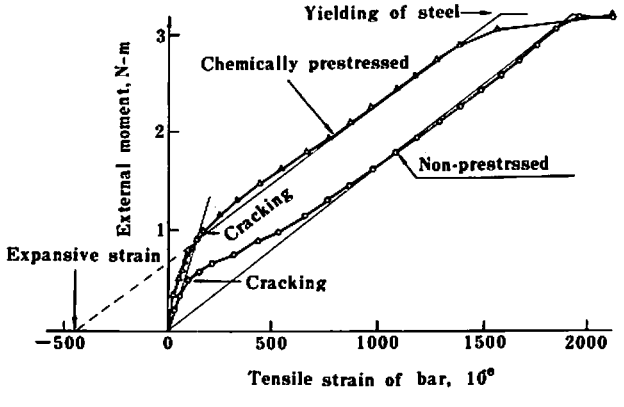

Fig.3 Increase in tensile strain of a bar in beam due to external moment

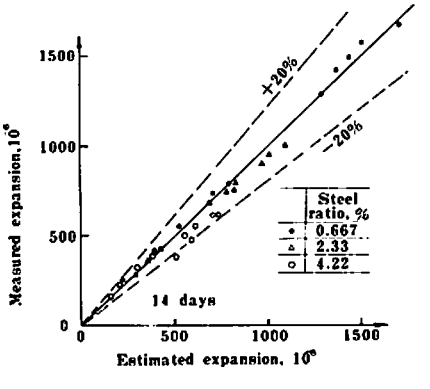

Fig.4 Measured and estimated expansions

2.2 Behavior of Frames

In order to ascertain the behavior of chemically prestressed concrete box culverts, experiments on frame specimens were conducted. The chemical prestress of beams of a frame specimen was about 3.0 N/mm^2, which coinsided with value in case of a different column rigidity and of the beam specimen with identical cross-sectional dimensions. For columns, when cross-sectional dimension was identical, roughly equal value was indicated, but when the cross sectional area of concrete was double leaving steel area equal, expansive strains of bars were increased by approximately 1.4 times while the chemical prestress was about 0.7 times. This suggests that the concept of "work done by expansive concrete" proposed by Tsuji[4] is also applicable to the case of frame.

Similarly to a beam specimen, flexural cracking resistance is improved due to chemical prestress, added to which increase in tensile strain of bars after cracking is smaller as shown in Fig.5. External moments in this figure were calculated from the applied loads on the upper beam of a specimen based on the elastic frame analysis assuming the flexural rigidities of the beams and columns to be constant. As the flexural rigidity of a beam is lowered after bending cracks are produced in it, the moments actually working will be smaller at beams and larger at columns.

After carrying out the tests on actual products, it was decided that the sections of slabs and walls in chemically prestressed concrete box culverts were reduced to 80 % of those in ordinary reinforced concrete box culverts. Besides reduction in quantity of materials, due to reduction of costs in transportation and installation accompanying lightening of product weights, concrete box culverts prestressed chemically are more economical than those without prestress.

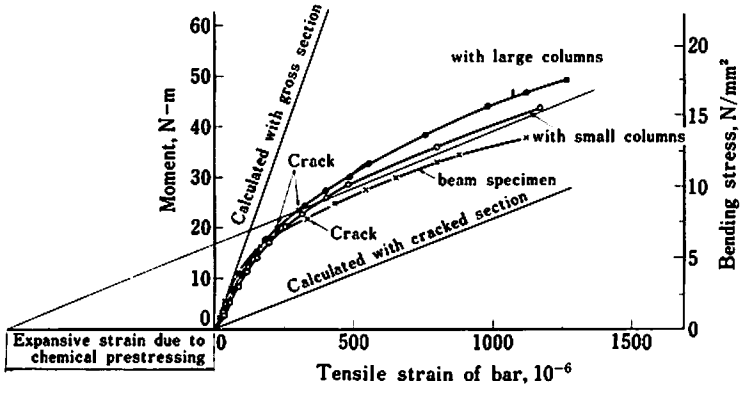

Fig.5 Increase in tensile strain of a bar in box culvert

3. Variation with Time in Effect of Chemical Prestress

For the purpose of confirming the existing of the effect of chemical prestress over a long period of time, experiments on the actual products were carried out. Specimens were selected from products representative of box culverts being sold on the market. Inner widths are 2,500 mm, inner heights 1,500 mm and specimen-lengths 900 mm. The cross sections of slabs and walls of specimens with chemical prestress were approximately 80 % of those without prestress. Two methods of storing specimens were adopted. One was a method reproducing actual conditions in which specimens were buried underground at the age of 2 months and excavated before testing. The other was a method of storing in air in a condition that specimens would not be exposed to rain assuming a state which would be the most adverse for effect of chemical prestress to continue to exist. Up to the present, loading tests have been completed for the ages of 14 days, 2 months and 9 months for storage in air, while testing at the age of 9 months has been completed for the case of underground storage. Further, there are six specimens still in storage and it is scheduled for final testing to be performed at the age of 5 years.

From the results of loading tests at each age, cracking moments were obtained as indicated in Fig.6. A cracking moment was calculated from the load when the first crack appeared in the upper slab, and the flexural cracking stresses in the figure were obtained from the cracking moments assuming concrete is an elastic material. The effect of chemical prestress at the age of 14 days was to increase the flexural cracking stress about 2.0 N/mm^2. When specimens were stored in air, there was recognized a slight reduction in cracking moment, but even at the age of 9 months the effect of chemical prestress was distinct. The cracking moment of chemically prestressed specimens buried underground from 2 months to 9 months were approximately 30 percent larger than the value at the age of 14 days. This result confirms the previous finding[2] that even if dried once the effect of chemical prestress is improved if members are placed in an atmosphere of high moisture.

4. Conclusions

(1) It is clarified that the behavior of box culverts subjected to bending moment can be greatly improved if chemical prestress is utilized.

(2) The effect of chemical prestress in precast concrete box culverts buried underground lasts for a long period of time. Even in case of products placed in air there still remained ample effect of chemical prestress.

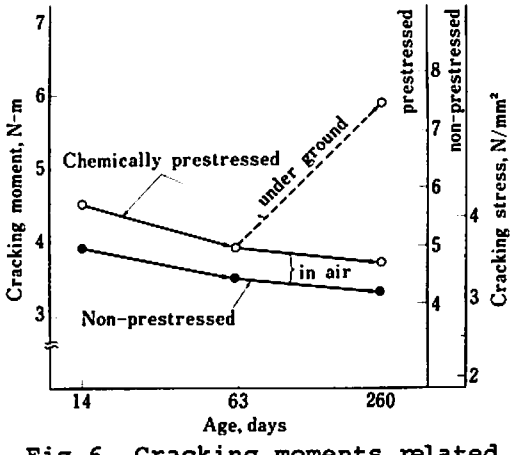

Fig.6 Cracking moments related to age of concrete

In essence, the application of chemical prestress to precast concrete box culverts is useful for cracking resistance and controlling crack widths over a long period of time. Besides reduction in quantity of materials, due to reduction of costs in transportation and installation accompanying lightening of product weights, concrete box culverts prestressed chemically can be more economical than those without prestress.

References

(1) Kokubu,M., "Use of Expansive Components for Concrete in Japan", ACI, SP38, 1973.
(2) Okamura,H., Tsuji,Y. and Maruyama,K., "Effect of Creep on the Behavior of Chemically Prestressed Concrete Members", Abstracts of 30th Congress, Japan Society of Civil Engineers, Vol.5, 1975 (in Japanese).
(3) Okamura,H. and Tsuji,Y., "Behavior of Chemically Prestressed Concrete Members", Transactions, Japan Society of Civil Engineers, No.225, May 1974.
(4) Tsuji,Y., "Fundamental Study on the Use of Chemical Prestress in Concrete", Transactions, Japan Society of Civil Engineers, No.235, March 1975 (in Japanese).

SUMMARY

Flexural cracking resistance in a precast concrete box culvert is improved due to the effect of chemical prestress, added to which increase in tensile strain of reinforcing bars after cracking becomes smaller. The effect of chemical prestress lasts for a long period of time. Therefore, the sections of slabs and walls can be reduced to 80 % of those in usual culverts.

RESUME

La précontrainte chimique augmente la résistance des fissures à la flexion dans les éléments en béton préfabriqué de conduites souterraines; en outre elle diminue la contrainte de traction de l'armature après l'apparition des fissures. L'effet durable de cette précontrainte a pu être constaté, et l'on peut ainsi réduire la section des produits jusqu'à 80 % de la section normale.

ZUSAMMENFASSUNG

Chemische Vorspannung von vorgefertigten Kanälen mit kastenförmigem Querschnitt führt zu einer Erhöhung der Rissesicherheit und zu einer Beschränkung der Rissweite. Die Wirkung der chemischen Vorspannung bleibt lange erhalten. Aus diesem Grunde konnte die Dicke von Platten und Wänden auf 80 % des Ueblichen reduziert werden.