MEASURES FOR IMPROVING THE LONG-TERM DURABILITY OF A PRESTRESSED CONCRETE BRIDGE USING HIGH-STRENGTH CONCRETE

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ABSTRACT

The Tan-nowa viaduct is a three-span continuous prestressed concrete box girder bridge. For construction of this bridge with small girder height and long span, high-strength concrete of 60 N/mm^2 in design strength was used. High-strength concrete has a dense matrix, inherently excellent in durability. However, as the specific cement content increases, the concrete is more prone to cracking due to shrinkage and larger hydration heat, and workability worsens because of higher viscosity. It was therefore necessary to address many problems to ensure satisfactory durability.

For this bridge project, a committee of technology experts was established to study problems and measures to be taken for making the bridge sufficiently durable, fully developing the inherent performance of high-strength concrete. This paper discusses the overview of the bridge, problems studied, measures taken and outline of the construction.

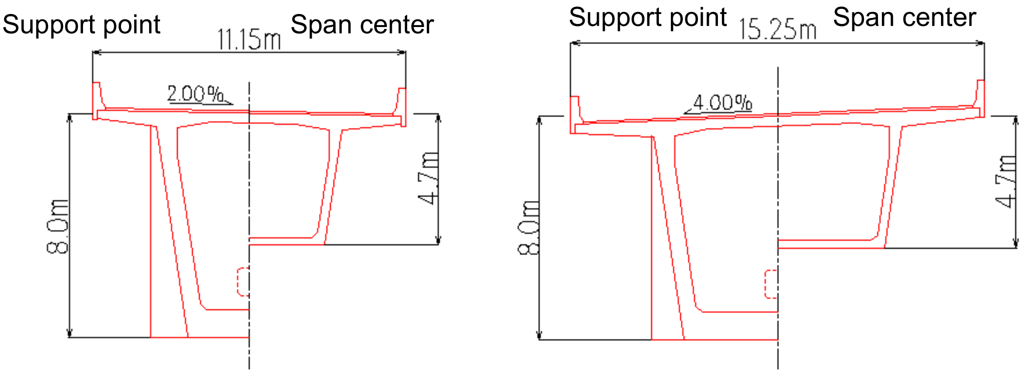
1. OVERVIEW OF THE BRIDGE

National highway route No. 26 is a major road linking Osaka City, the second largest city in Japan, and Wakayama. For alleviating chronic traffic jams on this route, the Daini Hanwa Expressway about 53 km in length is being constructed. In the south district of Osaka prefecture, the Tan-nowa viaduct constructed on the new expressway passes through a residential zone. For minimizing impact on the landscape, a viaduct with a small number of piers and a small girder height was requested. The bridge structure selected is a three-span continuous prestressed concrete box girder bridge, using high-strength concrete.

The main specifications and general view of the bridge are shown in Table 1 and Figure 1 respectively. The main features of this project are: greater length ratio of the side span to the center span compared with standard bridges, width varying from place to place, small girder height, and use of high strength concrete of 60 N/mm^2 in design strength.

Table 1 - Specification of the viaduct

Road specification	Class 3, Category B (Design speed 80 km/h)
Design load	Live load category B (heavy traffic)
Structure type	3 span continuous PC box girder bridge
Bridge length	352.0m
Span length	109.5+126.0+113.5m
Effective width	10.50～14.15m
Longitudinal gradient	2.8%
Transversal gradient	2.0～4.0%
Horizontal alignment	R=∞~A=300～R=700m
Erection method	Cantilever erection



Standard section

Enlarged section

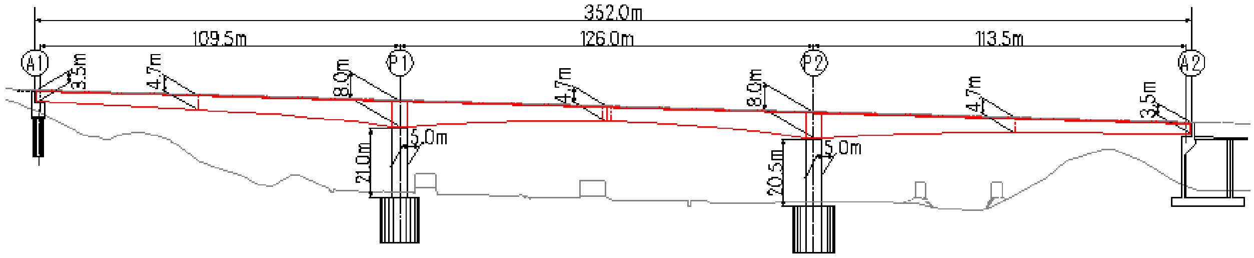


Figure 1 - Overall view

2. CONSIDERATIONS FOR USE OF HIGH-STRENGTH CONCRETE

High-strength concrete exhibits a dense matrix after curing, and is inherently durable. However, as the specific cement content increases, many problems must be addressed, such as decrease of workability and higher probability of cracking adversely affecting durability. The main considerations for this project are summarized in the following.

1) Reduction of shrinkage strain

It is essential to reduce autogenous shrinkage that intensifies as concrete strength increases, and dry shrinkage due to the quality of aggregate.

Cracking in prestressed concrete bridges occurred in this district because of abnormal shrinkage. Considering this damage, it was necessary to select aggregate that would induce smaller dry shrinkage.

2) Measures for mass concrete

High-strength concrete with larger specific cement content generates greater hydration heat. It is therefore imperative to control thermal cracking especially in the mass concrete of the pier head segment.

3) Improvement of concrete surface density and elimination of defects in concrete placement

Since the viscosity of fresh concrete increases as the specific cement content increases, high-fluidity concrete was therefore used to ensure good workability.

There are only a few examples of use of high-fluidity concrete for prestressed concrete bridge projects. It is therefore necessary to determine the form structure, and sequence and method of placement for ensuring dense concrete free of work defects.

Table 2 summarizes the requirements for concrete to be considered in selection of mix proportion.

Table 2 - Performance requirements of concrete

Item	Subitem		Performance requirements
Strength	3 days		29N/mm^2
	28days		60N/mm^2
Fluidity	Slump flow	Just after mixing	650 mm
		On placement	600 mm
Durability	For controlling alkali-aggregate reaction		Use of aggregate proven to be harmless
	Dry shrinkage(εds)		εds ≦ 800μ: No measures taken 800μ < εds≦1000μ: Measures in design 1000μ < εds : Reselection of aggregate

Slump flow: diameter of the specimen after the slump cone is lifted.

3. REDUCTION OF SHRINKAGE STRAIN

3.1. Selection of concrete mix proportion

Suitable mix proportions were selected on the basis of the performance requirements. Tables 3 and 4 summarize the mix proportions and materials selected. Mix proportion I is for the standard section. Mix proportion II with expansive admixture is used for the pier head segment and side spans where external restraint cracking is anticipated as a result of segmented placements.

Table 3 - Mix proportion of concrete

Mixture No.	Cement type	Water to binder ratio W/B (%)	Sand coarse aggregate ratio s/a (%)	Absolute volume of coarse aggregate (m^3/m^3)	Specific content (kg/m^3)						
					W	C(N)	EX	S1	S2	G	SP1
I	N	32.8	51.0	0.31	175	533		573	245	804	10.66
II	N+EX	32.8	51.0	0.31	175	513	20	573	245	804	10.66

Note: The chemical admixture content is C x 2.5%, to be adjusted depending upon weather conditions.

Table 4 - Material list

Material	Symbol	Type	Properties, etc.
Cement	N	Ordinary portland	Density 3.16g/cm^3, specific surface area 3270cm^2/g
Admixture mineral	EX	Expansive agent	Density 3.05g/cm^3
Fine aggregate	S1	Sea sand	Density in saturated surface-dry condition 2.56g/cm^3, Fineness modulus 2.70
	S2	Crushed sand	Density in saturated surface-dry condition 2.56g/cm^3, Fineness modulus 2.90
Coarse aggregate	G	Crushed stone	Density in saturated surface-dry condition 2.62g/cm^3, Solid volume percentage 58.0%
Chemical admixture	SP1	Shrinkage-controlling AE superplasticizer	Polycarboxylate Density 1.09g/cm^3

3.2. Measures for reducing shrinkage strain

Shrinkage strain is composed of dry shrinkage developing over a long span of time and autogenous shrinkage occurring at an early age.

Autogenous shrinkage is significant with high-strength concrete containing a large volume of cement, whereas dry shrinkage mainly depends upon the quality of aggregate.

For reducing autogenous shrinkage, a shrinkage-controlling air entraining superplasticizer was used.

A suitable aggregate causing smaller dry shrinkage was selected. The shrinkage strain was checked by measurement in the trial mix, to evaluate the appropriateness of the materials and mix proportions.

The standard dry shrinkage test was conducted with specimens of 100 x 100 x 40 mm, measuring the change in length due to dry shrinkage. Since the test period may be as long as 26 weeks, two other earlier evaluation procedures were used. One procedure consists in prediction of the final amount of shrinkage using an equation with the interim measurements at 28 days. *1)

The other is the rapid evaluation method*2) using small specimens of 50 mm in diameter x 100 mm. The test period can be shortened to 42 days.

With this rapid evaluation method, it is possible to predict the final amount of shrinkage by an equation with measured values at an early stage, that is, about 2 weeks. Figure 2 shows the comparison of the results of these tests. As demonstrated by this comparison, it is possible to predict the final amount of shrinkage with a precision similar to that of the standard test.

The autogenous shrinkage test uses specimens of the shape similar to that for the dry shrinkage test, to measure change in length in a sealed state for 7 days.

The mixture with shrinkage-controlling air entraining superplasticizer remarkably reduced autogenous shrinkage. Figure 3 shows the measurement results of autogenous shrinkage.

With this mixture, dry shrinkage was 620 μm and autogenous shrinkage was 100 μm, and the total strain was approximately 800 μm including strain that would occur after the test period. These results demonstrate the mixture sufficiently satisfies the performance requirements.

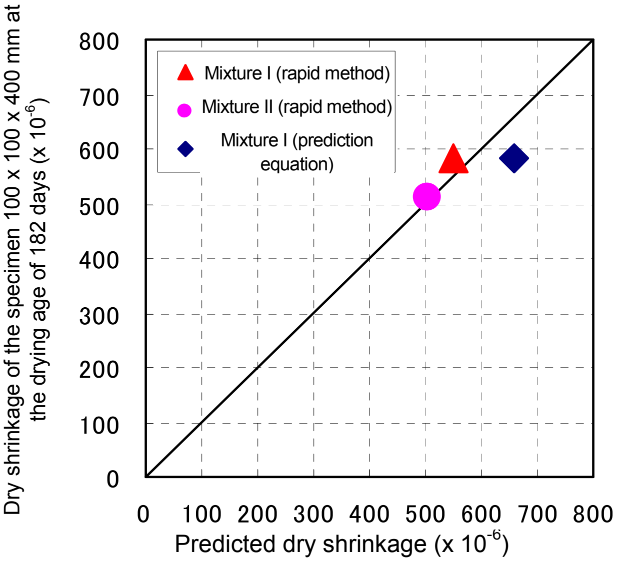


Figure 2 - Measurement results dry shrinkage
(estimated from the data at 14 days)

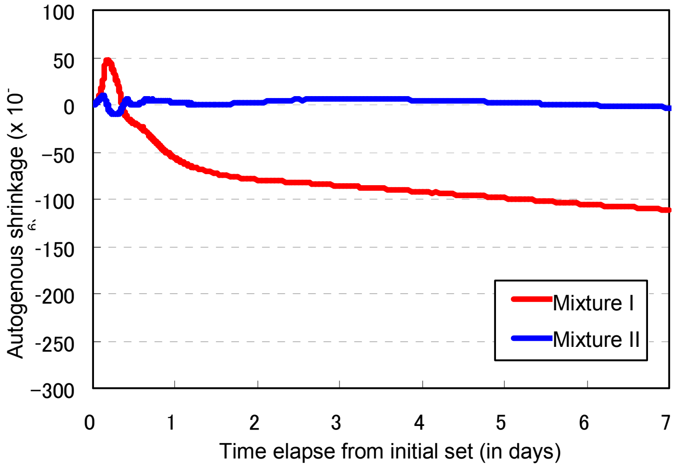


Figure 3 - Measurement results of autogenous shrinkage

4. MEASURES FOR MASS CONCRETE

The cross beam at the pier head is made of mass concrete 5 m thick. Since the high strength concrete liberates much heat as it hydrates, measures were taken against thermal cracking. Referring to the FEM analysis results (Figure 4), cracking was controlled by arrangement of reinforcing bars and by providing cooling air through the sheathes of external cables provided in the cross beam (Figure 5, Photo 1). These measures effectively controlled cracking in the pier head segment.

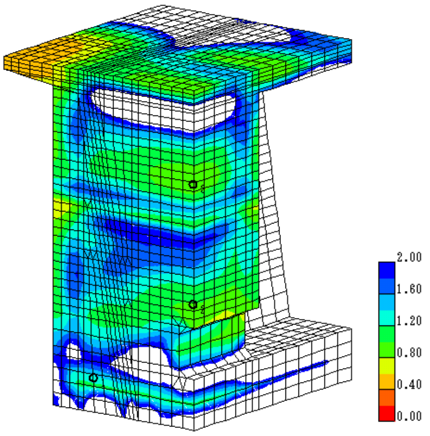


Figure 4 - FEM analysis for the pier head segment

Photo 1 - View of air cooling

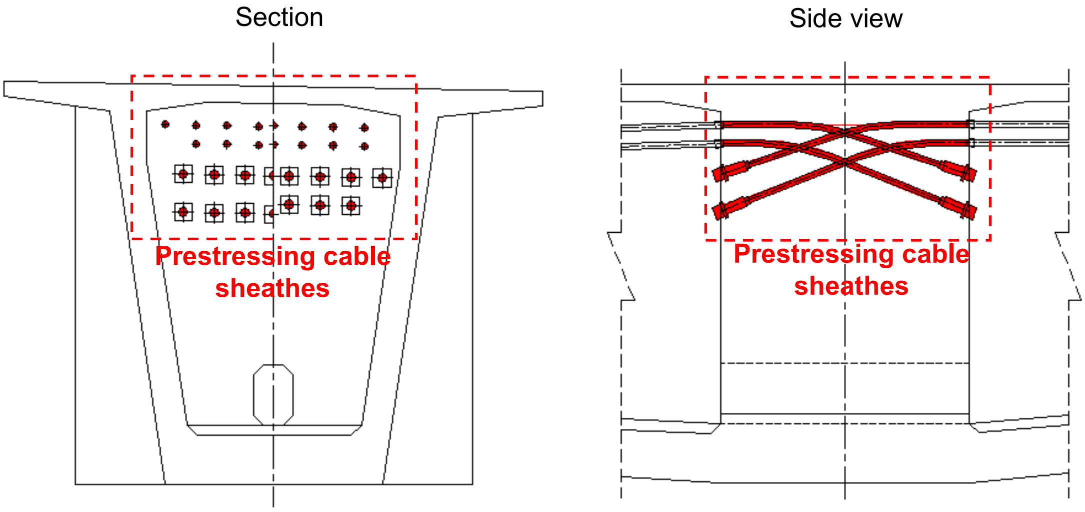


Figure 5 - Cable sheathes used for air cooling

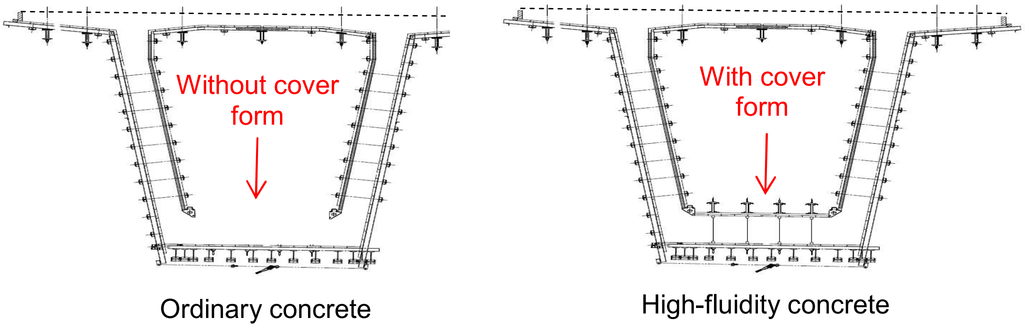
5. IMPROVEMENT OF CONCRETE SURFACE DENSITY AND ELIMINATION OF DEFECTS IN CONCRETE PLACEMENT

5.1. Use of high-fluidity concrete

For achieving a high strength, it is necessary to reduce the water-to-binder ratio. But, with a smaller water-to-binder ratio, viscosity rises, resulting in significant decrease of workability. High-fluidity concrete was therefore used in this project.

Figure 6 illustrates the form structures for ordinary concrete and high-fluidity concrete in the cantilever erection of the bridge. The high-fluidity concrete needs a cover form to prevent concrete from overflowing from the lower slab. The following points are main considerations for the use of high-fluidity concrete.

1) Measures for lateral pressures of concrete
2) Structure of cover form on the upper surface of the slab and prevention of air voids in the upper surface of the cover form
3) Filling method for the lower slab where reinforcing bars and prestressing steel members (prestressing cable sheathes) are arranged in a complex manner
4) Management of concrete placement on site
5) Curing method



Ordinary concrete

High-fluidity concrete

Figure 6 - Difference in form structure

5.2. Validation tests for concrete placement

To find solutions for issues of high-fluidity concrete, various validation tests including full-scale tests were conducted.

Due to the high viscosity of high-fluidity concrete, entrained air remains in the surface of the cover form, producing noticeable air voids.

Considering the occurrence of such defects, tests with small models were repeated and a form structure capable of preventing air voids was determined.

Figure 7 shows the structure of the form selected. A water permeable mat was applied over a sheathing with slits to allow air to easily escape (Photo 2).

Using a full-scale partial model, lateral pressures acting on the form were measured, and filling status was verified. The measured pressures were similar to those supposing the concrete as a liquid. Figure 8 and Photo 3 show the full-scale model.

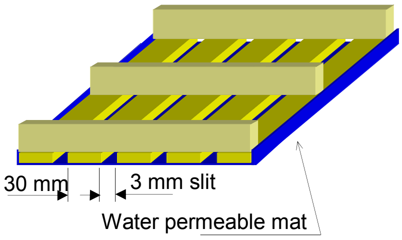


Figure 7 - Structure of the cover form

Photo 2 - Improvement of finished concrete

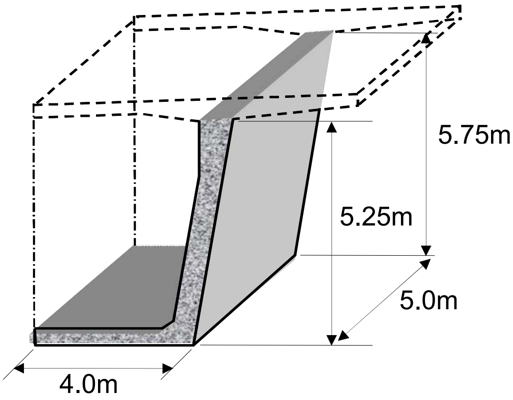


Figure 8 - Full-scale specimen

Photo 3 - Full-scale specimen (slab)

5.3. On-site management of concrete placement

Temperature at the construction site exceeds 30 ºC in summer. The transportation distance from the ready mixed concrete plant to the construction site is great, and it takes a longer time in the morning and evening because of traffic congestion.

The high-fluidity concrete loses its fluidity along with the elapse of time, and especially at high temperatures, decrease in fluidity is more significant. To cope with this problem, the transportation time was meticulously managed for each vehicle, and in close coordination with the ready mixed concrete plant, fluidity of concrete was adequately maintained (Photo 4).

Photo 4 - Management of transportation time

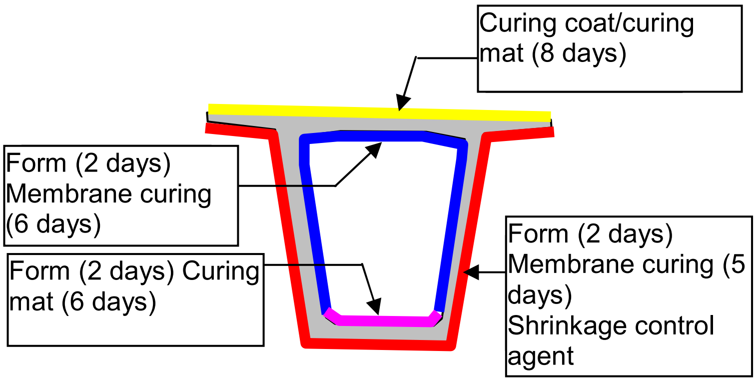


Figure 9 - Curing method and period for each portion

5.4. Curing

The cantilever bridge erection is performed in a cyclic sequence. Prestressing steel members are tensioned about two days after concrete placement, and the work vehicle for concrete placement moves forward. Accordingly the form is removed when the concrete aged about 2 days, and at the same time curing of concrete surface ends. Curing is essential for increasing the density of the concrete surface, thereby enhancing durability of the concrete. In this project, all the concrete surfaces were cured for 8 days after placement of concrete. Membrane curing was performed, that is, the free surface of concrete was covered with a curing mat, and a stretch film was applied on the surface that had contacted the form. After one week, the curing mat and stretch film were removed. On the outer circumferential surfaces that would be more noticeably affected by the atmosphere, a shrinkage control agent was applied to control moisture loss by evaporation. Figure 9 shows the method and period of curing.

6. OUTLINE OF THE BRIDGE CONSTRUCTION

This bridge construction project used the cantilever method. Since the length ratio of the side span to the center span is greater compared with standard bridges, the linking of the central portion was made first, and with counterweights installed on the center span, the remaining cantilever erection of the side span was carried out, thereby reducing the unbalanced moments during the construction. Figure 10 shows the construction sequence.

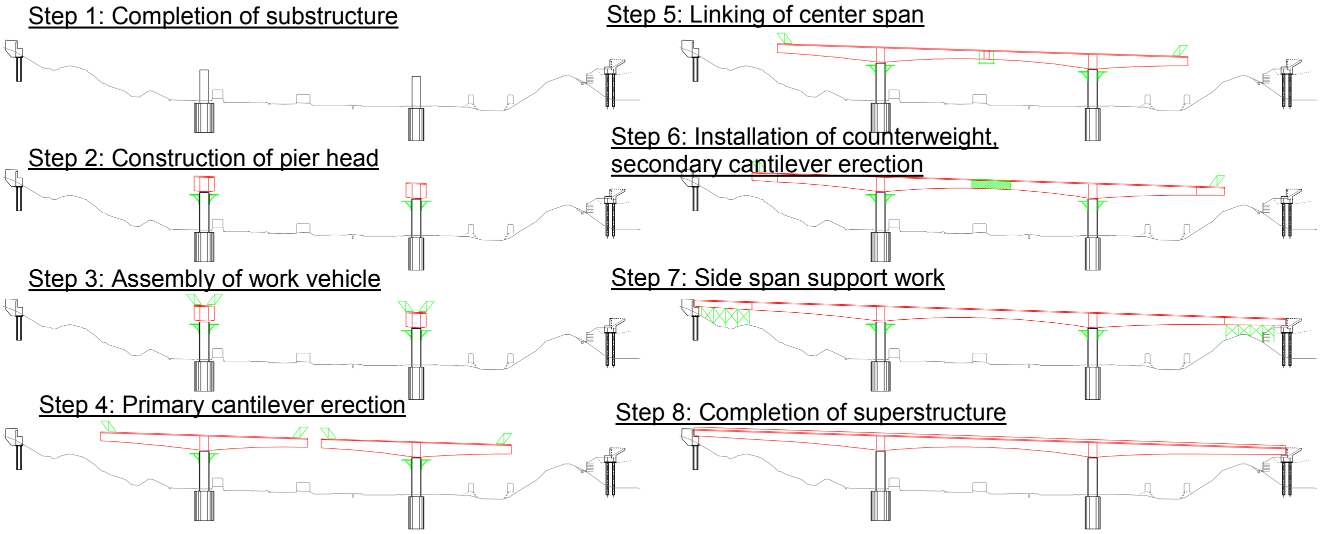


Figure 10 - Construction sequence

CONCLUSIONS

The construction of the superstructure of the viaduct commenced in November 2010, and the main girder was completed in January 2011. The viaduct will be put into service in March 2011.

There are only a few records of use of high-strength high-fluidity concrete, and many problems were studied to find effective solutions. Under the guidance of the committee members including Professor Toyoaki Miyagawa (Kyoto University), Professor Hirotaka Kawano (Kyoto University), Professor Toshiki Ayano (Okayama University) and Doctor Hiroshi Watanabe (PWRI) and others, a highly durable bridge was constructed, fully developing the inherently durable nature of high-strength concrete. The authors would like to extend deepest thanks to the persons concerned.

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