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# Thermal Behaviour of Multi-Span Viaduct in Frame

Comportement thermique d'un viaduc en portique

Thermisches Verhalten eines statisch unbestimmten Rahmentragwerkes

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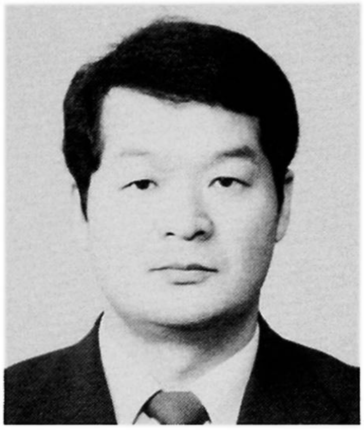

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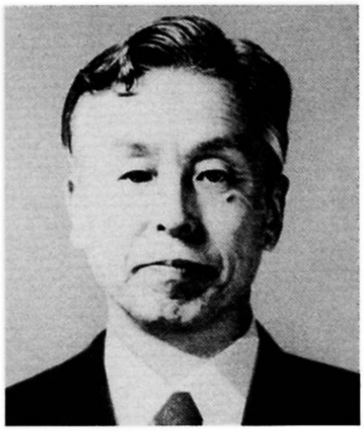

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## SUMMARY
The authors designed an economical viaduct using a statically highly indeterminate frame with better moment distribution. The results of the in situ measurements on the structure over a period of one year show that the temperature expansion was successfully restrained and more material could be saved.

## RESUME
Les auteurs ont réalisé, de façon économique, un viaduc en portique avec une haute hyperstaticité et une meilleure distribution du moment de flexion. Les résultats de mesures faites montrent que la dilatation causée par les changements de température est restée minime que de la matière aurait encore pu être économisée.

## ZUSAMMENFASSUNG
Die Verfasser haben einen kostengünstigen Viadukt als statisch hochgradig unbestimmtes Rahmentragwerk mit einer günstigen Momentenverteilung entworfen. Die Messungen über ein Jahr haben ergeben, dass die Verformungen infolge der Temperaturschwankungen erfolgreich beschränkt werden konnten und noch mehr Materialersparnis hätte erreicht werden können.

## 1. INTRODUCTION

In Japan, reinforced concrete viaducts of frame are widely used for railway structures. The typical example is the viaduct for Shinkansen, the world famous bullet train line. Many concrete frame structures have been constructed because of their favorable moment distribution and lower cost.

The structures have normally expansion joints every 30-40m. To construct such structures economically, the authors designed a 400m-long viaduct based on the idea of a long continuous viaduct. See Fig. 1. and Photo 1.

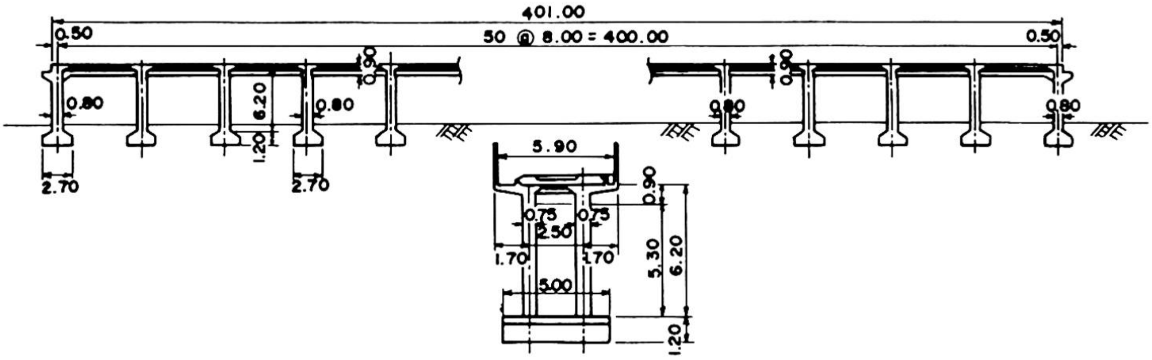


Fig. 1 General View

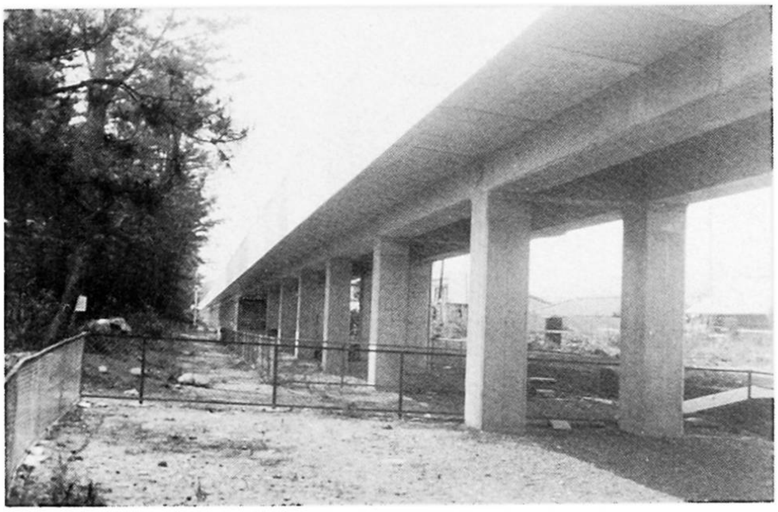

Photo 1. 50-span Concrete Viaduct

The basic concept of the long continous viaduct comes from the following idea. It is well known that a long welded rail fixed on the track bed expands due to temperature change only in the end portions. Most of the expansion in the middle portion is restrained by the bed. See Fig. 2.

The application of the concept to the viaduct shows that an infinitely long viaduct could be constructed. The increased number of piers enhances the rigidity of the infrastructure, which results in the restraint of the superstructure expansion. The expansion of a viaduct longer than a certain length could be restrained to a constant value.

This paper reports on the long-term measurements of displacements and stresses of a reinforced concrete viaduct designed on the present concept and shows that the concept is applicable to the design of viaducts with possibly more economy.

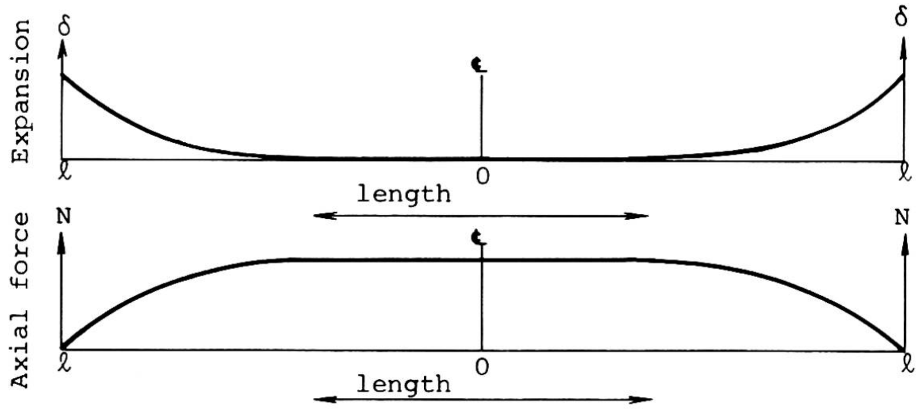


Fig. 2 Expansion, axial force and length of a long welded rail

## 2. DESIGN AND CONSTRUCTION

### 2.1 Fundamental tests

The tests of measurements necessary for the establishment of the design conditions were conducted on the following four items:

(1) Temperature and displacement of the viaduct,
(2) Model experiment and analysis of the designed viaduct,
(3) Model experiment and analysis of the expansion transverse slit intervals for the expansion,
(4) Horizontal load test applied to the foundation of an existing viaduct.

### 2.2 Design

The horizontal member of the viaduct is designed as a steel-reinforced concrete structure because of large horizontal forces.
The concrete strength of the columns in the end portions was made stronger by 20% to resist larger bending moment at the column ends.
The structure was analyzed elastically as a fifty-span frame the taking axial deformation into account. The stress analysis was based on the allowable stress design method.

### 2.3 Construction

During the construction, the drying shrinkage of the concrete had to be reduced as less as possible. Using KOSAKA and MORITA'S theory , the authors estimated the amount of the shrinkage and determined that the concrete had to be placed sectionally over 3-4 spans and nine months later over the rest of the spans.

## 3. MEASUREMENT

### 3.1 Outline of measurement

The greatest difficulty in the design of the viaduct was how to deal with the large axial beam stress and column bending moment to restrain slab and beam expansion due to temperature change.

Since the main purpose of the measurement was to observe thermal behavior of the structure and identify factors preventing construction of a longer structure, the measurement was continued for one year after the construction completion and the results were studied in three periods. At the same time the crack measurement was also conducted. Table 1 shows the measured items.

Table 1 Measured Items

| Surveyed items | Detail | Equipment |
|---|---|---|
| Weather observation | Atmospheric temperature | Thermocouple |
| Structural temp. | Concrete member temp. | Thermocouple |
| Structural displacement | Horizontal member displacement | Wire displacement meter |
| | Horizontal foundation displacement | Wire displacement meter |
| | Column displacement | Transit, plumb and cord |
| | Column rotation angle | Inclination meter |
| Stress | Reinforcement bar | Bar stress gauge |
| | Shape steel | Surface strain meter |
| | Concrete | Concrete non-stress meter |
| Structural soundness | Crack measurement | Crack scale |
| Concrete property | Compressive strength, Young's modulus | Dial gauge |

## 3.2 Results of measurement

### 3.2.1 Atmospheric and member temperatures

Table 2 shows the atmospheric and structural member temperatures measured for one year. The measurement was conducted at 6:00 and 14:00. The member temperature means the average value of 12 measurements on the slabs and beams.

Some member temperatures exceeded the design limits of $\pm$10°C from the average, but the measured values of stresses and expansions did not exceed the design limits, showing complicated relations between sresses, expansions and temperature change.

Table 2 Atmospheric and Member Temperature (Unit: °C)

| Measured time / Item | Atmospheric tem. | | Member tem. | |
|---|---|---|---|---|
| | 6:00 | 14:00 | 6:00 | 14:00 |
| Max. temperature | — | 30.00 | — | 30.00 |
| Min. temperature | -1.0 | — | 2.0 | — |
| Temperature difference between max. and min. | 31.0 | | 28.0 | |
| Annual average tem. | 13.3 | 18.9 | 16.3 | 18.0 |
| | 16.1 | | 17.2 | |
| Difference between ave. and max. | 13.6 | | 12.8 | |
| Difference between ave. and min. | 17.1 | | 15.2 | |

3.2.2 Relation between member temperature and expansion

Fig. 3 shows the relation between beam expansion and temperature expressed in terms of deviation from the annual average values, where the beam expansion is determined by the difference of displacements at the tops of two adjacent columns. Fig. 3a shows the relation in one of the end spans and Fig. 3b in the center span.

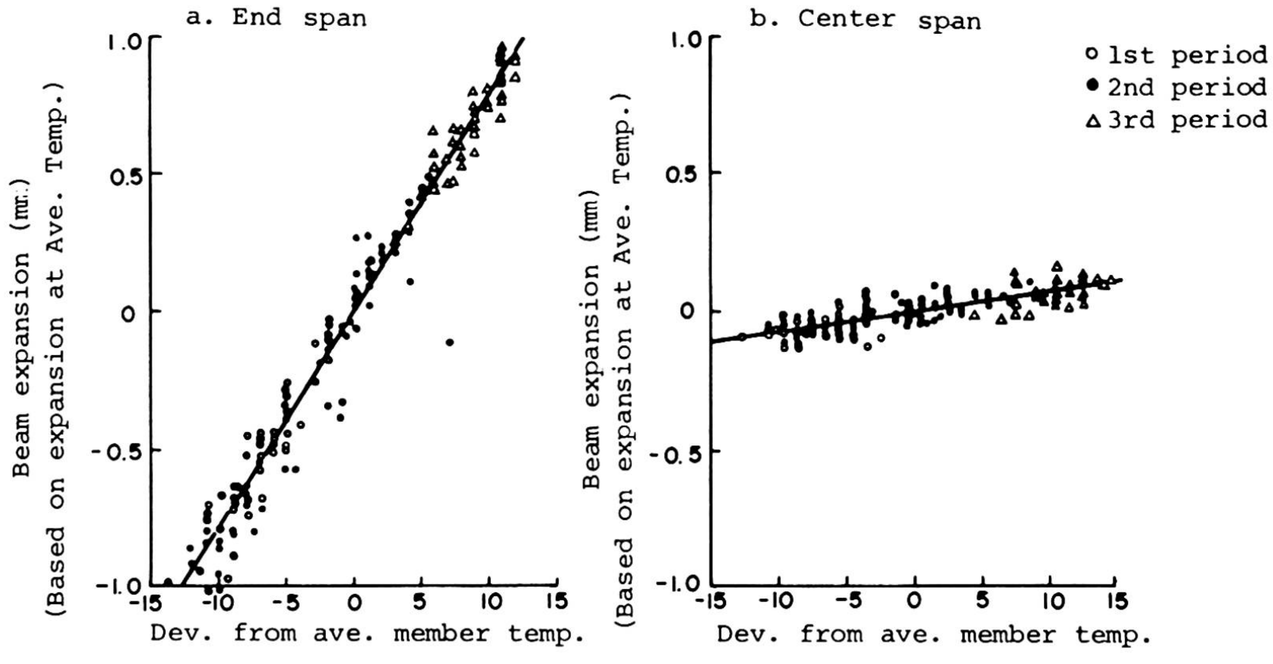


Fig. 3 Relation between beam expansion and member temperature

Fig. 3a and 3b clearly indicate the difference of expansion per unit temperature in the end span and center span, showing that the expansion in the center portion is very well restrained.

Fig. 4 illustrates the relation between the beam expansion at a temperature change of 10°C and the column position. The theoretical value based on the elastic theory is shown in the figure. The figure demonstrates accelerated restrain of the expansion towards the center of the structure. The measured values fall within the theoretical values. From the result it could be assumed that the columns in the end spans are supported elastically.

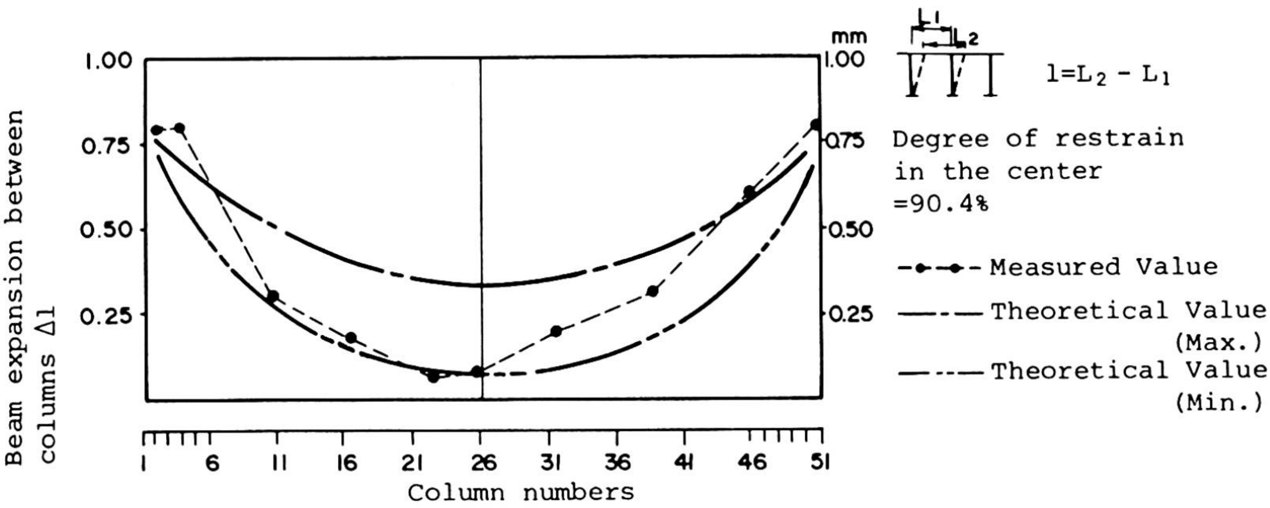


Fig. 4 Relation between beam displacement and column position (t=10°C)

### 3.2.3. Force and moment

The axial force and the bending moment are calculated using the measured value. Fig. 5 and 6 show the measured values and the theoretical values(2) of the axial force and the column bending moment, falling within the theoretical limits.

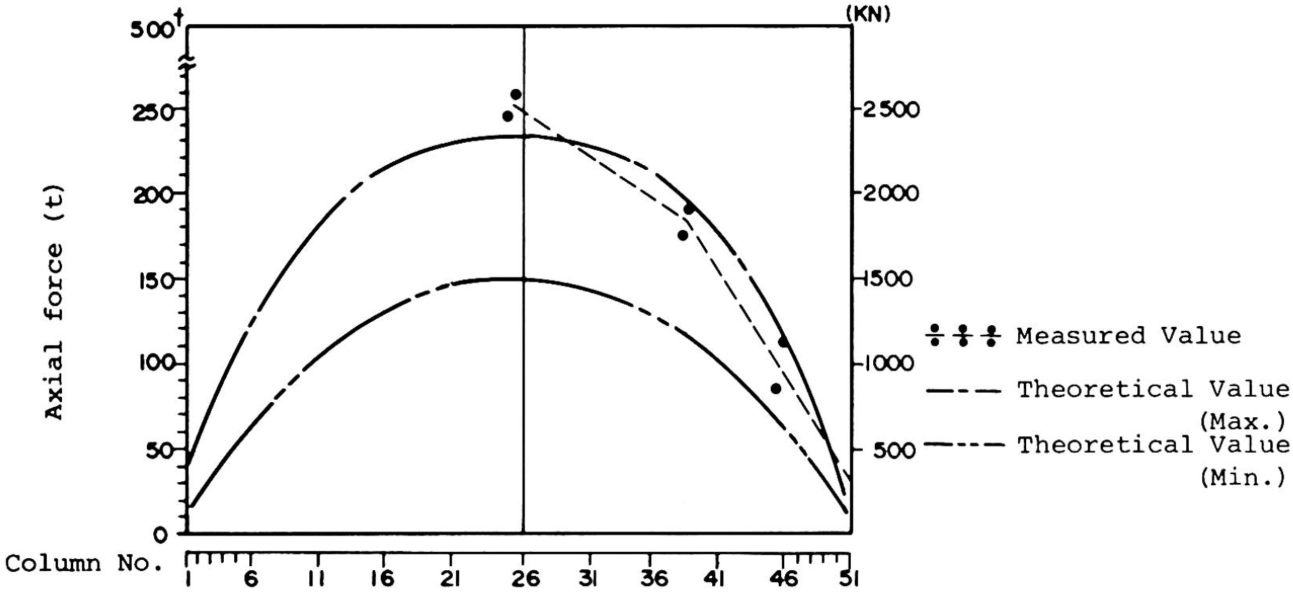


Fig. 5 Beam axial force (due to temp. difference 10°C)

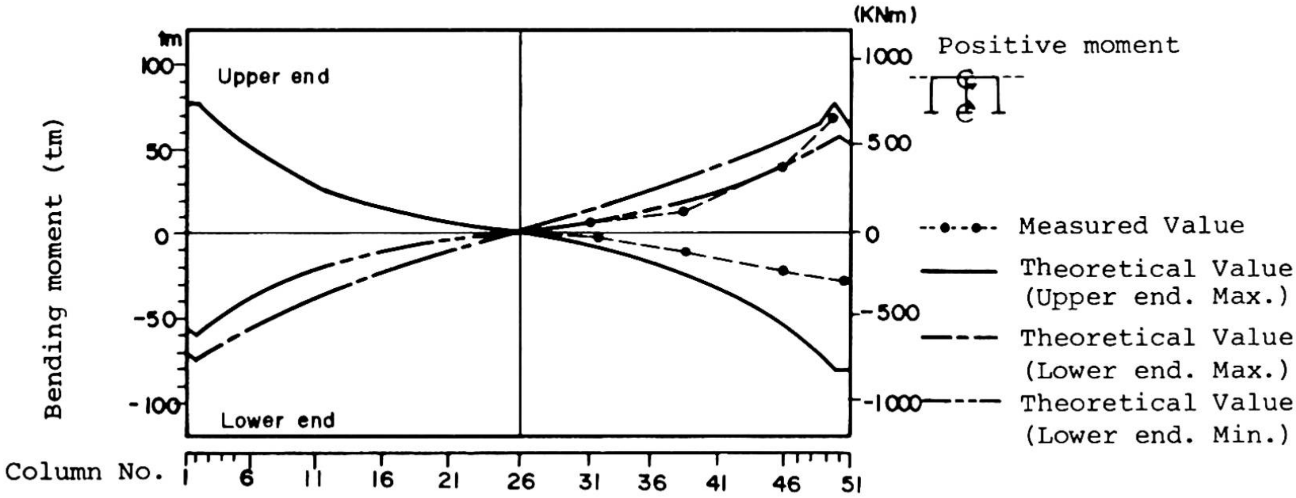


Fig. 6 Column bending moment (due to temp. difference 10°C)

### 3.2.4. Drying shrinkage

As explained in 2.3, concrete was partially placed nine months later. In the design, the shrinkage is assumed to finish 70% of the final value according to KOSAKA and MORITA'S theory(1) at the later concrete placement.

This assumption was verified by the stress measurement of steel bars conducted at the middle of the column height where the stress was not influenced by other factors.

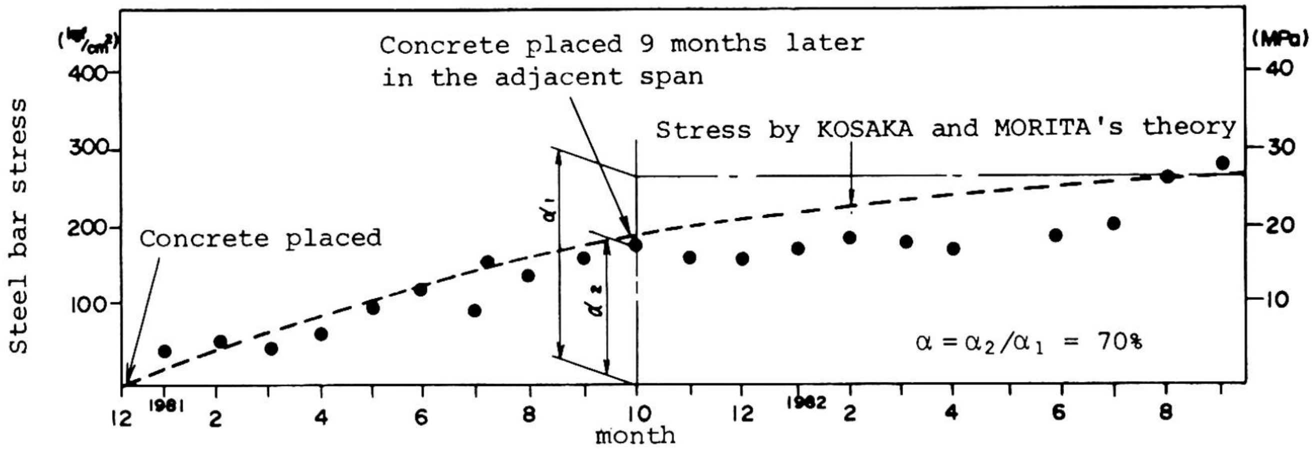


Fig. 7 Time variation of bar stress

3.2.5. Cracks

Fig. 8 shows crack development in the slabs and columns. These cracks developed mainly in winter because of the temperature shrinkage of the long and restrained structure. One year later, no further crack development was observed. More cracks developed in the center span which was restrained more strongly. The widths of the cracks were narrower than the 0.2mm cracks which were observed in the ordinary concrete viaduct and showed better durability of the structure.

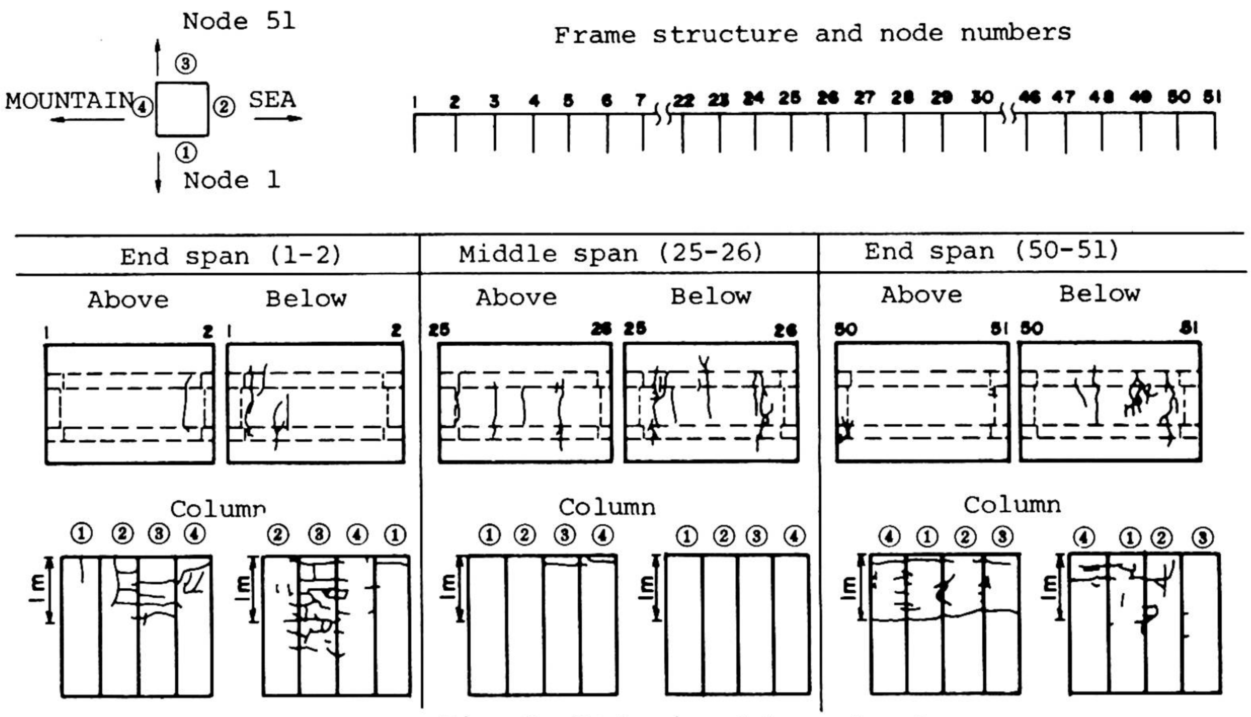


Fig. 8 Craks in slabs and columns

## 4. SUMMARY OF THE MEASUREMENT

The results can be summarized as follows.

(1) An application of the long welded rail concept

The temperature expansion of the 400m-long viaduct was restrained as much as 90.4% in the center span. This result shows that the concept of the long welded rail can be applied effectively to the design of a long multi-span viaduct in frame.

(2) Concrete placement for the reduction of drying shrinkage

Concrete placement executed nine months later in every fourth or fifth span was successful for the reduction of the drying shrinkage. For the estimation of the drying shrinkage, KOSAKA and MORITA'S theory[1] is useful.

(3) Column support condition

The measurement shows that the columns are virtually supported by horizontal and rotational springs at the lower ends. The coefficients of the rotational and horizontal reactions estimated from the measurement agree with the results of a load test at the construction site.

(4) Material saving

The calculation based on the measurement shows that the reinforcement in some sections could be saved as much as 20%.

## 5. ACKNOWLEDGEMENT

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