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Autor: Mise, Jun / Uchida, Micho

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Soil-Structure Interaction on Multispan Continuous Bridge

Influence réciproque du sol et de viaducs autoroutiers

Wechselwirkung von Baugrund und Tragstruktur bei mehrfeldrigen Autobahnbrücken

JUN MISE MICHO UCHIDA
Nihon Doro Kodan
Osaka, Japan

SUMMARY
The highway construction office of Nihon Doro Kodan is trying to adopt multispan continuous viaducts with 10 to 20 spans. This type of bridge has a problem of soil-structure interaction. The problem was solved by analyzing many trial cases; it confirmed the propriety of the design method by a long term observation on actual behavior of a 10 span continuous bridge constructed 4 years ago.

RESUME
Le bureau des autoroutes Nihon Doro Kodan a un programme des construction de viaducs autoroutiers par tranches continues de 10 à 20 travées; ce programme est en cours d'exécution. Ce type de viaduc présente un problème d'interaction sol-structure. Le problème a été résolu par l'analyse de nombreux cas et la méthode d'étude justifiée par des mesures à long terme effectuées sur un viaduc de 10 travées continues qui avait été construit 4 ans auparavant.

ZUSAMMENFASSUNG
Das Autobahnbüro Nihon Doro Kodan begann mit der Praxis, Autobahnbrücken mehrfeldrig, nämlich 10- oder 20-feldrig durchlaufend zu bauen. Bei diesen Brücken stellt sich das Problem des Zusammenwirkens von Baugrund und Tragstruktur. Mit dem Problem wurden die Autoren durch systematische Untersuchungen fertig und bestätigten die Richtigkeit der Entwurfsmethode durch langjährige Messungen an einer vor 4 Jahren ausgeführten, 10-feldrigen durchlaufenden Stahlbetonbrücke.

INTRODUCTION

Standard types of viaducts adopted for expressways in Japan are reinforced concrete slab bridge with hollows as shown in Fig.1. This standard bridge is consisted of 5 continuous spans and the span length is varied from 15 to 20 meters, in general.

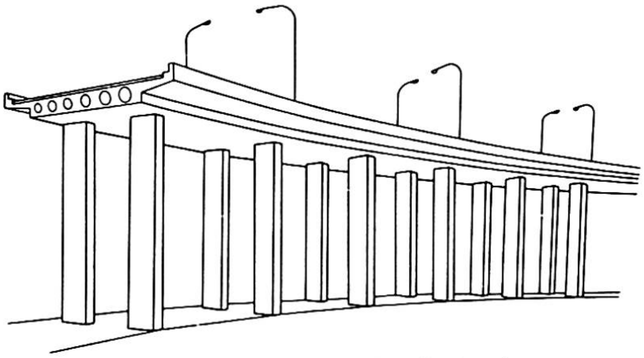

Fig. 1 Standard Viaduct

Nihon Doro Kodan (Japan Highway Public Corporation) is trying to adopt a bridge with many more continuous spans such as 10 to 20 (Fig.2) for the purpose of lessening expansion joints on the surface of viaducts. These joints are the weakest point in bridges and cause a problem of frequent maintenance. By lessening them, the maintenance of bridge becomes easier and also car driving becomes more comfortable. One of distinctive problem of the multispan continuous bridge in Japan is a problem of soil-structure interaction. However, the design of this type of bridge becomes possible if an advantage of soil behavior is taken into account.

This paper describes a basic concept in designing this type of structure and introduces the actual behavior obtained from a long term field measurement for a 10 span continuous bridge constructed 4 years ago.

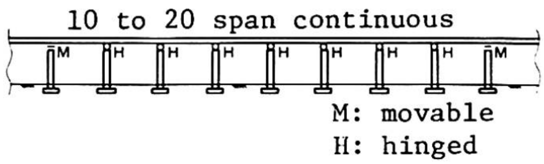

Fig.2 Multispan Continuous Bridge

OUTLINE OF STRUCTURE

Since inertia force of superstructure due to earthquake increases in a continuous bridge as the number of spans increases, the design of the substructure in a multispan continuous bridge becomes almost impossible due to too much concentration of horizontal force if bearings of only one or two piers are hinged. Therefore, dispersion of the horizontal seismic force is required by increasing the number of hinged piers in designing a multispan continuous bridge. However, the increase in the number of hinged piers results in the increase in the horizontal forces to the piers caused by deformation of the superstructure due to temperature variation or shrinkage of concrete. The amount of these horizontal forces is also a function of stiffness of the substructures including the soil foundation. The less the stiffness of the substructures, the smaller the horizontal force to be induced. Therefore, continuation of bridges can be done if the flexibility of soil foundation is taken into account in the design. In conventional bridges, their superstructures and substructures have been designed individually. However, in designing a structure such as multispan continuous bridge, analytical solutions obtained through a model together with the superstructure, substructure and soil foundation should be employed, referring to their interaction effects.

INFLUENCE OF SOIL FOUNDATION

A structural model employed for a design considering the interaction effects of the structure and the soil foundation should, of course, include a factor representing a mechanical behavior of the soil. It is usually represented by a spring. Since the properties of soil used in this type of design should represent the behavior of the soil foundation properly, more precise survey of the soil is required prior to the design for this type of bridge, comparing with a conventional one. Steel and concrete used for the superstructure and substructure are considered to be homogeneous and the mechanical properties can be found easily and accurately by testing their specimens. Moreover, their moduli of elasticity remain almost constant under the ordinal loading condition. On the contrary, the values obtained for the mechanical behaviors of soil do not always have a good accuracy for design although they are estimated by testing or surveying. Moreover, test results of soils sampled from different sites usually differ each other even if they belong to a similar tyep of soil. In addition, the load-deformation relation of soil is usually non-linear even if under the ordinal loading condition. Therefore, in actuality, performance of non-linear calculation is required to evaluate the soil behavior. However, it could be practical to design such a structure with selected upper and lower boundary values of soil properties, considering that the reliability of data for soil is uncertain.

FEATURE OF A STATICALLY INDETERMINATE STRUCTURE

In case of a highly indeterminate structure such as multispan continuous bridge with many hinged piers, the entire bridge still remains stable due to stress redistribution even if the loading capacity of some part of piers or foundations exceeds their limiting values. This feature is quite unique comparing to the case of conventional bridges with only one or two piers hinged. Therefore, it is not always appropriate to adopt design values used in conventional bridges, such as displacement or uplift of pile foundation, as the limiting values in this type of structure.

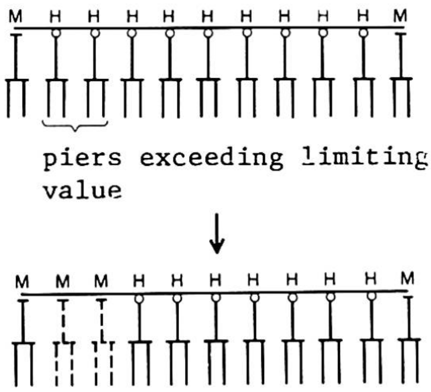

Fig. 3 Structure Model

If the deformation of the pier near the end of the bridge exceeds its limiting value due to temperature variation or earthquake, the soil of the foundation may be considered to be yielded in design. However, it is difficult to find the real yield point of the soil and the real behavior of the yielded soil, so that one of the realistic design of the bridge in the case above mentioned may be done by considering two types of structure models (Fig.3). In the first model, the pier is considered still to resist the horizontal force assuming the soil foundation to behave elastically in spite of its yielding. In the second model, the pier is assumed not to resist any horizontal force in the longitudinal direction. The safety of the structure is considered to be guaranteed if the safety of the two distinct models is obtained.

OBSERVED BEHAVIORS OF AN ACTUAL BRIDGE

A multispan continuous reinforced cocrete slab bridge with 10 spans was

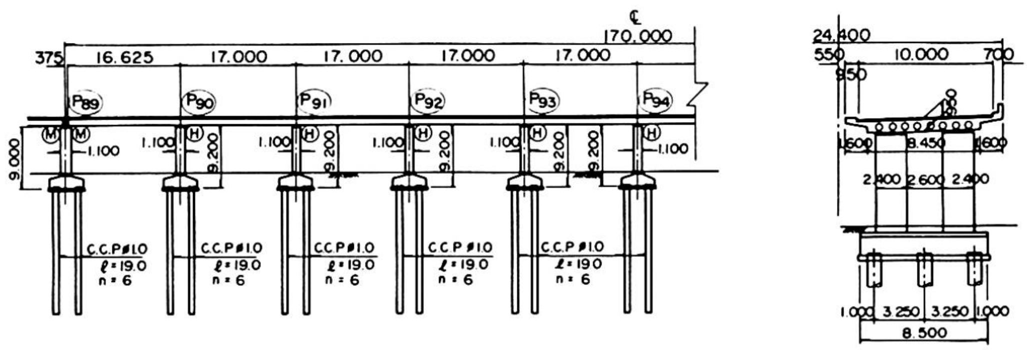

Fig. 4 General View of 10 Span Continuous Bridge

constructed in 1976 at Kanazawa in Japan (Fig. 4). Hinged bearings are installed on top of all piers but both ends of the bridge where movable bearings are installed. Concrete piles cast in site with 1.0 meters in diameter are used for the foundation of piers.

As above mentioned, influences of temperature variation and shrinkage of slab concrete become an important factor for design of multispan continuous bridges. A long term field measurement of actual behavior of the bridge has been carried out for the purpose of finding the influences mentioned above and also confirming the effects of soil behavior. The measurements were done successfully. Fig. 5. to Fig. 10 are the part of the results.

Fig. 5 shows temperature variation of the slab concrete two years after placing.

Fig. 6 shows movements of both ends of the bridge in two years.

Fig. 7 shows the amount of shrinkage of the slab concrete estimated from elongation of the slab.

Fig. 8 shows the relation between elongation of the slab and strain of the second pier from the bridge end.

Fig. 9 shows the relation between elongation of the slab and strain of the pile of the second pier from the bridge end.

Fig. 10 shows temperature variation of the slab concrete a day.

Concluding results obtained from the long term field measurements of the structure are as follows:

1. The temperature variation of the slab concrete depends nearly on that of the atmosphere. The minimum temperature of the slab concrete was 0 °C and the maximum was 35 °C (Fig. 5).
   Although the range of temperature variation taken in the design was 10 °C up and down from the average temperature, it would have been more rational to take the range as 15 °C.
2. The coefficient of thermal expansion of the slab concrete calculated from the measured relation between the temperature variation and the elongation at the end of the slab was $0.9\text{x}10^{-5}$1/°C, while it was assumed to be $1.0\text{x}10^{-5}$1/°C in the design.
3. Temperature difference between the top and bottom of the slab reached up to 10 °C during summer due mainly to direct sunshine (Fig. 5).
   Stress caused in the slab by this temperature difference is quite large and is not always negligible.
4. Shrinkage of the slab concrete calculated from the measured value of elongation or strain of the slab was found to be approximately $8\text{x}10^{-5}$ within the age of one year and it remained almost undeveloped since then (Fig. 7).
   This value corresponds to temperature variation of -8 °C, although it was assumed to be -15 °C in the design.
5. Behavior of the piers and foundations caused by the elongation of the slab due to temperature variation or shrinkage was almost linear elastic (Fig. 8, Fig. 9). This result seems to give a guarantee the assumption that the soil foundation may be represented as a linear elastic spring. In addition, over all stiffness of the substructure including the soil foundation obtained from the measurement was found to agree reasonably with that used in the design.

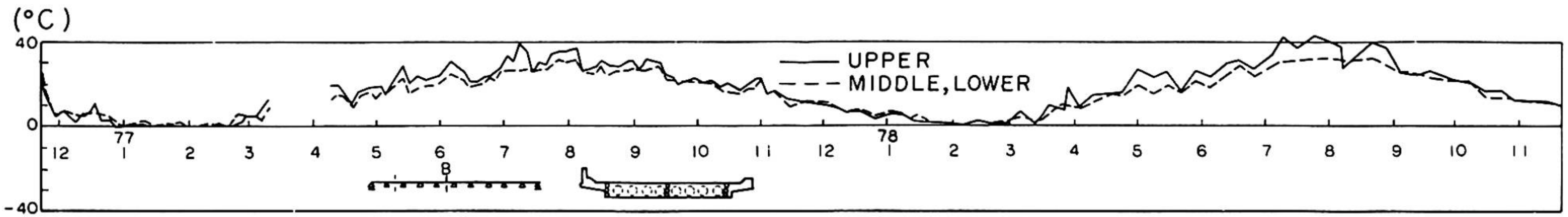

Fig. 5 Temperature Variation of Slab Concrete

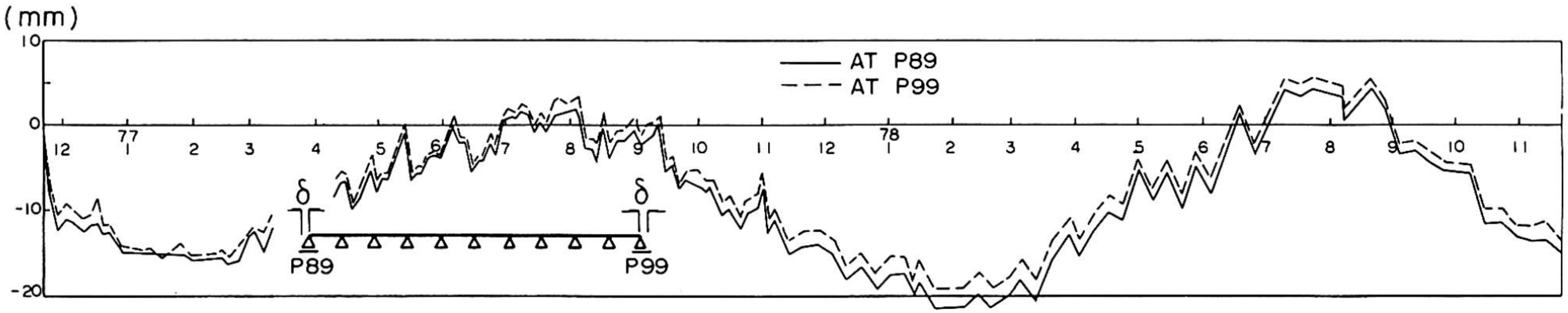

Fig. 6 Elongation of Slab

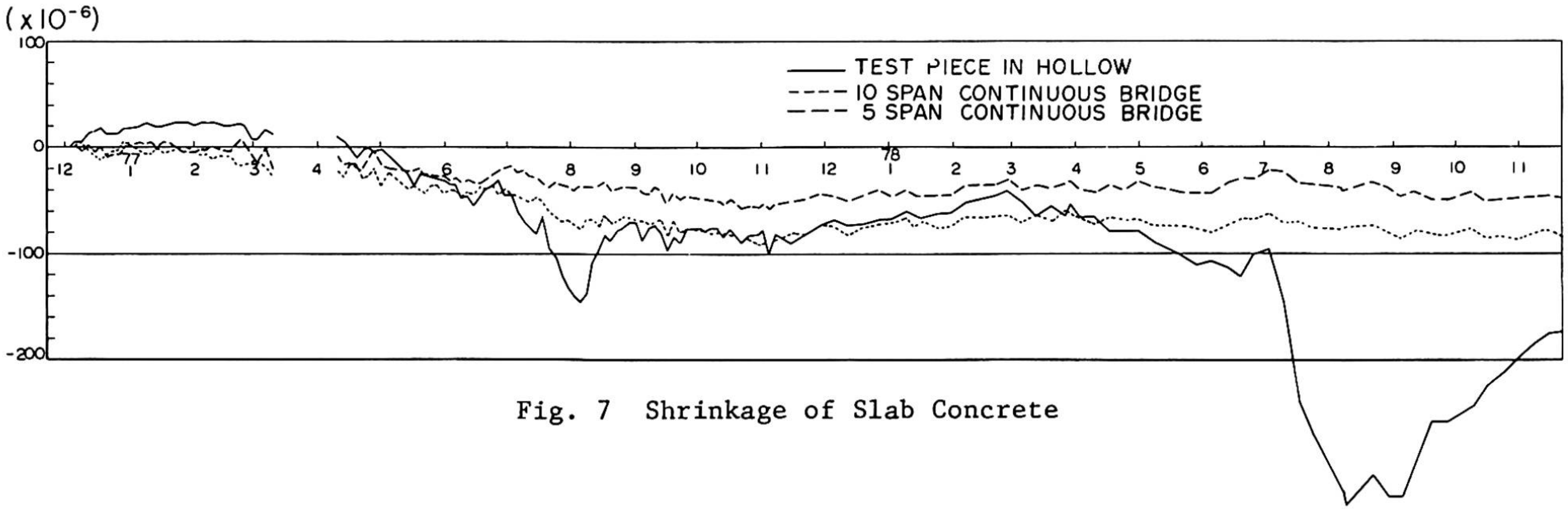

Fig. 7 Shrinkage of Slab Concrete

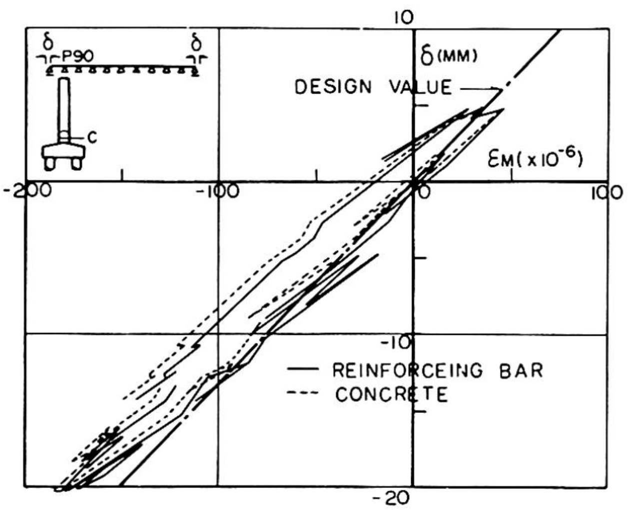

Fig. 8 Relation between Elongation of Slab (δ) and Strain of Pier (εM)

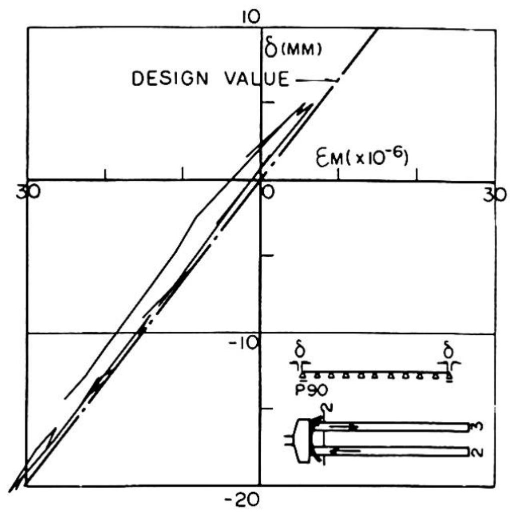

Fig. 9 Relation between Elongation of Slab (δ) and Strain of Pile (εM)

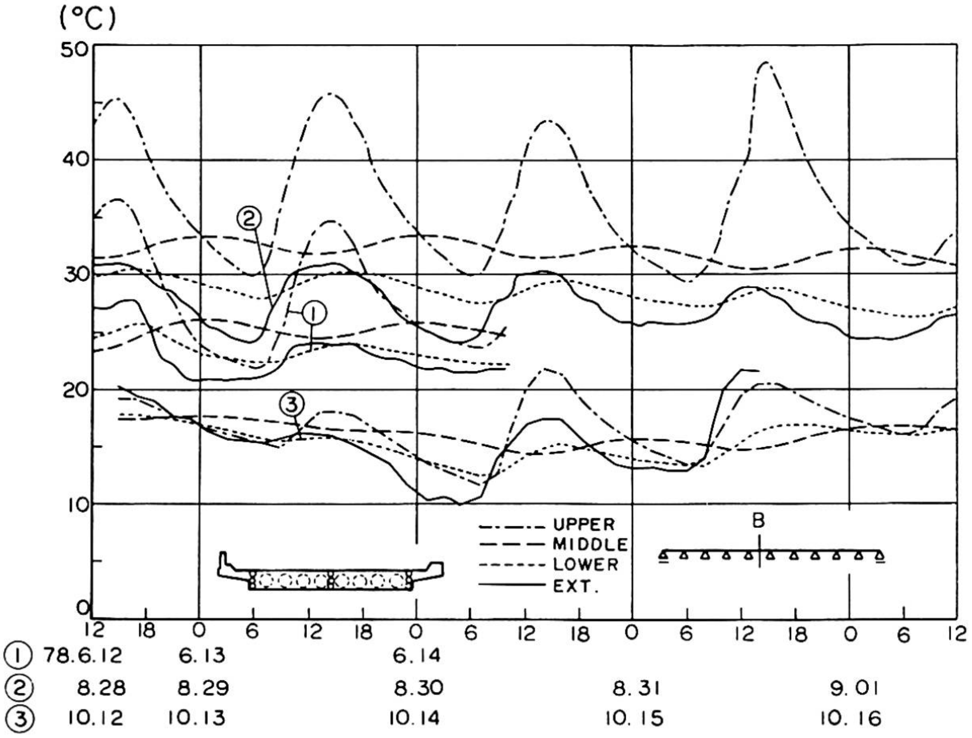

Fig. 10 Temperature Variation of Slab Concrete a Day

CONCLUDING REMARKS

Multispan continuous bridges can be designed in Japan by taking the preferable behavior of soil foundation into account. Adoption of this type of bridges enabled expansion joints to lessen and also proved to be economical as a whole. In addition, installation of many hinged piers could increase the load bearing capacity against earthquake.

Multispan continuous bridge would be very suitable structure as an expressway bridge in Japan which is often forced to be constructed on the very soft ground and yet must be taken the effect of earthquake into account.

Nihon Doro Kodan has established a design manual for multispan continuous bridge using various theoretical approaches and results obtained from a long term field measurement. We would like to apply this type of bridge more to future highway construction.