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On Planning and Design of High-Piered, Long-Spanned Bridges with Consideration to Seismic Effect

Ponts à grandes portées sur piles élevées et effets séismiques

Brücken grosser Spannweiten mit hohen Pfeilern unter Berücksichtigung der Erdbebenwirkung

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SUMMARY
Seismicity has a great importance in designing large-scale bridges with high piers in mountainous areas. The possible magnitude of earthquake at the site concerned and the frequency characteristics of earthquake waves are studied in detail for the design. Among the seismic analysis performed, results of dynamic analysis are described here. In addition, the plans of the major bridges are outlined.

RESUME
La séismicité est un des éléments très importants pour l'étude de grands ouvrages d'art avec des piles élevées, qui sont construits en région montagneuse. L'intensité possible du séisme ainsi que la fréquence de l'onde séismique sont étudiées en détail. Parmi les analyses séismiques qui ont été effectuées, les résultats de l'analyse dynamique sont décrits dans cet article. En outre, les ponts principaux sont brièvement présentées.

ZUSAMMENFASSUNG
Die Erdbebensicherheit ist ein sehr wichtiger Parameter beim Entwurf von Brücken mit hohen Pfeilern. Die Stärke eines möglichen Bebens sowie die Frequenz der seismischen Wellen werden im Detail untersucht. Zusätzlich zur Untersuchung der seismischen Wirkung werden die Ergebnisse einer dynamischen Betrachtung beschrieben. Ausserdem werden die wichtigsten Brücken vorgestellt.

1. INTRODUCTION

Kan-etsu Expressway is 300km in length, connecting Tokyo with Niigata, the largest city along the north coast of Japan Island. Particularly, this Expressway goes through one of the most severe mountainous areas in Japan. Numata section of 40km in length (Fig.1) is located in the central part of the expressway, with many V-shaped vallays to be passed through. Accordingly huge bridges in terms of length and height are to be constructed along the Expressway. In addition to the severe topography, earthquakes create another hard conditions in planning and design such huge bridges because Japan is a typical earthquake country.

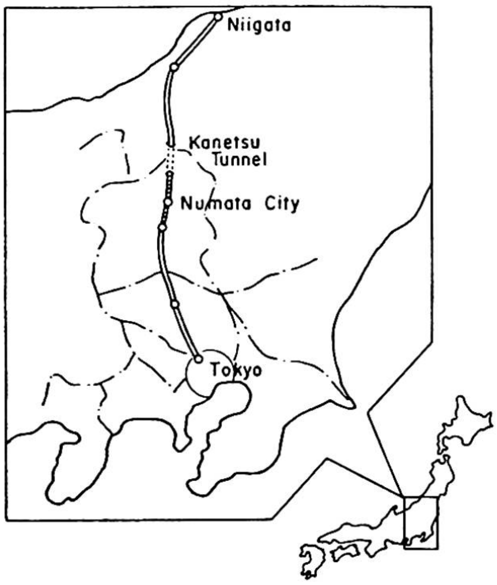

Fig.1 Kan-etsu Expressway

This paper describes the outline of planning and seismic design of the bridges, taking into account conventional seismic design standards together with newly developed seismic design considerations.

2. SEISMIC DESIGN STANDARD IN JAPAN

Usually inertia force which works to super-and sub-structure of the bridge is estimated by static analysis, which replaces the inertia force with the static load. But in case of the important structures, the seismic response analysis considering natural period of the structur is used.

2.1 Seismic Inertia Force in the Static Analysis

Seismic inertia force (F) is calculated as the product of the weight of the structure (W) and the seismic coefficient (k_h), i.e., $F=k_h \times W$
This k_h value is calculated by the following equation in the Seismic Design Standard defined by Japan Road Association.

$$k_h = \nu_1 \cdot \nu_2 \cdot \nu_3 \cdot k_o$$

Where
k_h ; horizontal design seismic coefficient
k_o ; basic seismic coefficient (0.2)
ν_1 ; correction factor by the area difference (0.7,0.85, or 1.0)
ν_2 ; correction factor by the ground difference (0.9,1.0,1.1, or 1.2)
ν_3 ; correction factor by the importance of the structure (0.8, or 1.0)

For this project, $\nu_1=1.0$, $\nu_2=1.0$, $\nu_3=1.0$ are used.
Furthermore, when the calculated natural period of the structure is more than 0.5 sec. , k_h is corrected by multiplying the correction factor by the period (β), which is shown in Fig.2

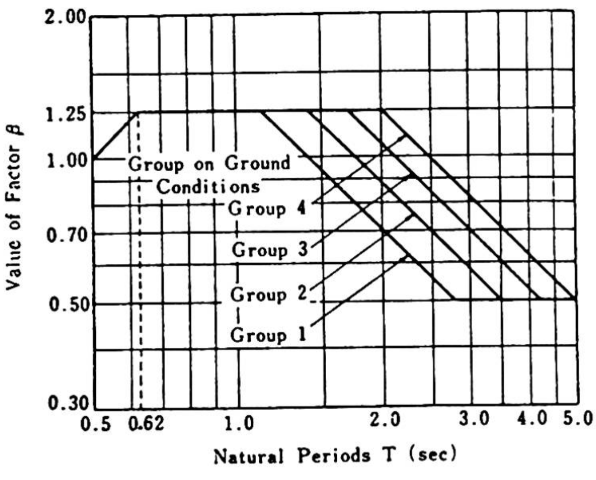

Fig.2 Correction Factor β

2.2 Dynamic Analysis

Dynamic response analysis, which uses average response spectrum and real seismic wave examples, is used for the long span bridges and the flexible structurs with the comparatively long natural period in order to check the seismic stability of these structures.

Objective structures are modelized by multi-lumped mass and spring elements combining each mass. The example of the idealized system is shown in Fig.7. The analysis of deformation and section forces are calculated based on the response given by the seismic impuls to the ground. Modal analysis method using acceleration response spectrum is adopted to caluculate the structural behavior. Assumptions concerning dynamic analyses for bridges in Numata region are as follows.

1) Damping factor (h) is 0.02 for the superstructure and 0.05 for the substructure.
2) Only flexural behavior is analyzed in the condition that the section is rigid enough and it keeps linear between strain and stress.

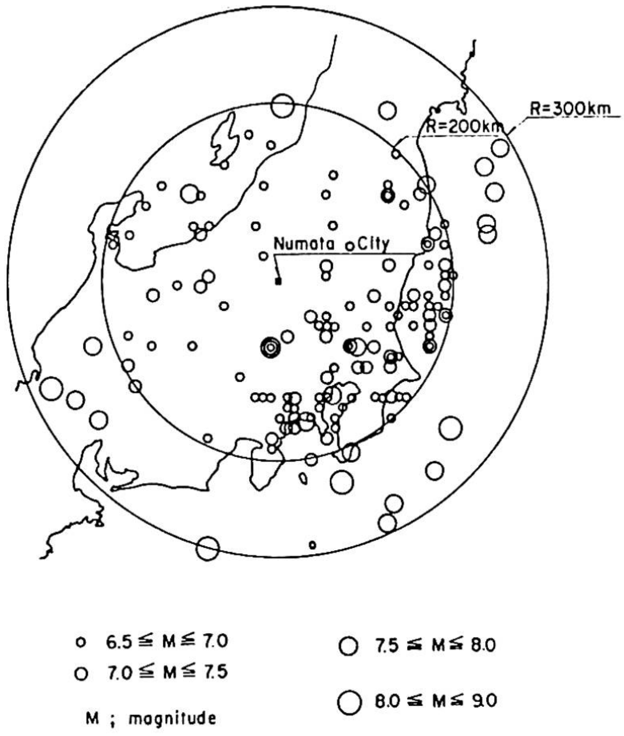

Fig.3 Previous Earthquake Records

3. PREVIOUS EARTHQUAKE RECORDS AROUND NUMATA REGION

Fig.3 shows earthquake records around Numata region greater than Magnitude 6.5 which are estimated to have occured in the past 1500 years. From the figure, it can be judged that major earthquakes greater than Magnitude 8 have taken place in the area along the Pacific Ocean and that the average distance between these focuses and Numata is about 200km.
According to the new Seismic Design Standard (recently proposed), an empirical equation between a magnitude-scale (M) at focus and an acceleration (A gal) at a point concerned is proposed as a function of a distance (Δ) as follows:

$$A_{max} = 24.5 \times 10^{0.333M} \times (\Delta + 10)^{-0.924}$$

By means of the equation above, a relationship between distance (Δ) and an accelaration (A) is plotted in Fig.4 for the previous earthquakes around

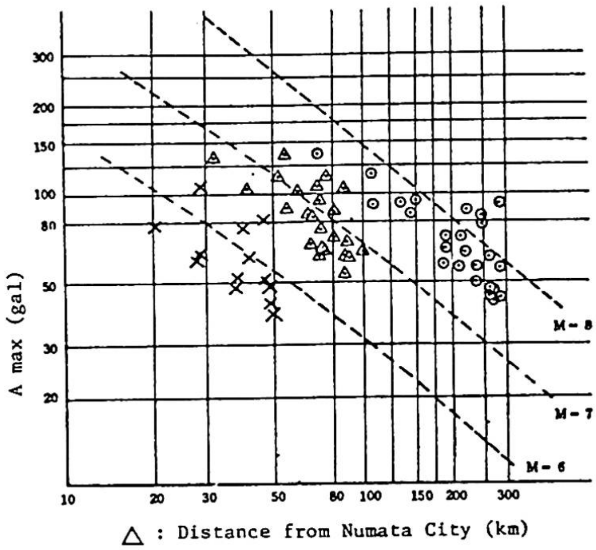

Fig.4 Relation between the Earthquake Focus and Acceleration

Numata. From the figure, an accelaration value (A) for designing bridges in Numata region can be determined as follows:

1) In case of major earthquakes greater than Magnitude 8, a design acceleration value is 80 gal.
2) In case of middle-class earthquakes which can occur around Numata, a design value is 200 gal.

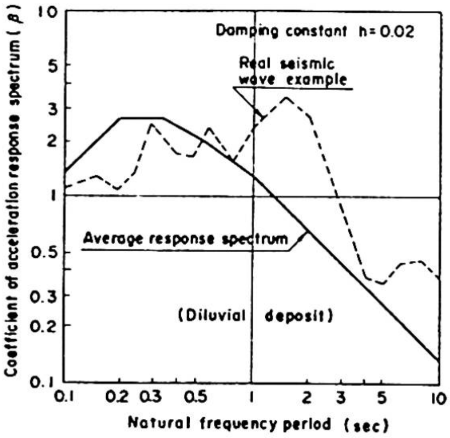

Fig.5 Seismic Response Spectrums

Long span bridges in this project have high piers and are expected to have a fairly long natural period. Generally, frequency characteristics of an earthquake occured at a long distance are known to have long period components dominantly in the spectrum, although an accelaration value for design is relativly small (A=80 gal). Hence, it is requested to check the seismic stability for the spectrum with such long period components, in addition to the middle-class earthquakes (A=200 gal) which will occur near the site. Fig.5 shows two response spectrums.

4. DESIGN EXAMPLE FOR A BRIDGE WITH HIGH PIER -NUMAO RIVER BRIDGE-

Bridge type is 6-span continuous metal box girder with multi-fixed-Piers and bridge length is about 600m.

4.1 Selection of Bridge Type and Result of Dynamic Analysis

The height of piers except P1 is about 65m. There are two reasons why multi-fixed-piers are adopted. One is that inertia force of the superstructure due to the earthquakes is likely divided into each pier evenly because each pier has almost the same height. The other is that the excessive axial force in the superstructure may be caused if the support on the abutment is fixed. The reason why 6-span continuous type is adopted is that it will improve resistance against earthquakes and drivability by increasing the degree of indeterminancy.

Fig.7 shows the model considered in the dynamic analysis in the driving direction. The primary natural period is about two seconds. Therefore the correction factor $\beta=0.9$ is taken based on Fig.2 in the static analysis. The relation between the dynamic analysis and the static analysis is shown on

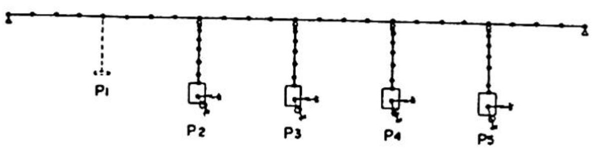

Fig.7 Dynamic Model for Analysis

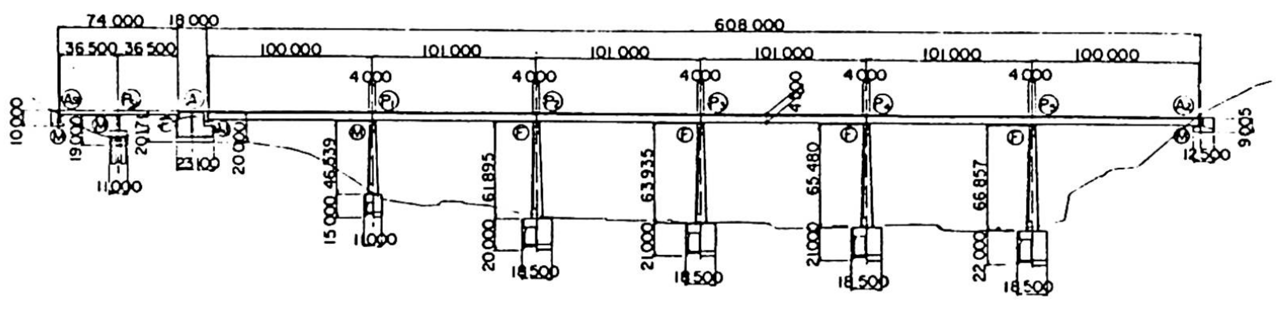

Fig.6 Numao River Bridge

Table-1. It can be seen that the static analysis satisfies the dynamic analysis.

In addition, the installation of the equipments at the girderend to prevent the superstructure from dropping out and the fender to reduce the shock of collision are being investigated considering unexpected excessive deformation.

Table 1 Comparison of Response Results

	Static Analysis	Dynamic Analysis	
	Seismic Coeff. Kh = 0.18	Ave.Response Spectrum 200 gal	Real Wave Example 80 gal
Horizontal Deformation of Superstructure (mm)	175	155	220
Axial Force of Superstructure (ton)	981	812	1,123
Bending Moment at the Foot of Pier #2 (ton m)	86,223	60,713	86,269
Bending Moment at the Foot of Pier #5 (ton m)	82,459	56,735	80,332
Shearing Force at the Foot of Pier #2 (ton)	2,025	1,052	1,497
Shearing Force at the Foot of Pier #5 (ton)	1,947	948	1,332

4.2 Several Practices regarding seismic structure

As for Numao Bridge, several types of structures which are based on completely new design idea were introduced and studied. Conventional idea for designing structures regarding seismic forces is to design structural memberes rigid enough to resist design seismic force in order to obtain the stability of the whole structure. In other words, this design methods lay emphasis on increasing regidity of structural members.

However, entirely new design idea can be introduced regarding seismic forces, which is to allow relatively large horizontal displacements of the structure obtaining larger natural periods and smaller seismic responses. In order to realize the structure based on the above idea, the structural model to be expected to have larger natural period was considered as illustrated in Fig.8. The characteristics of this model is the application of the elastic supports at the girder ends instead of fixing the girder end to the abutment which enables horizontal forces working on the piers lower. Accordingly rigidities of the pieres become smaller, and the natural period of the whole structure become longer. Regarding the actual practices of the elastic supports at the girder ends the rubber gaskets on the recovery free pendulum supports as shown in Fig.9 are being studied.

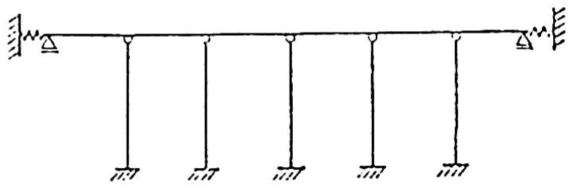

Fig.8 Dynamic Model for Long Natural Period

But there are still several problems to be solved before realizing the system described above. Firstly, the effects caused by the horizontal forces derived from the temperature differences of the structures, should be analyzed in connection with seismic forces. Other miscellaneous problems such as small parts of the system, their maintenances, etc. should also be studied carefully in the future.

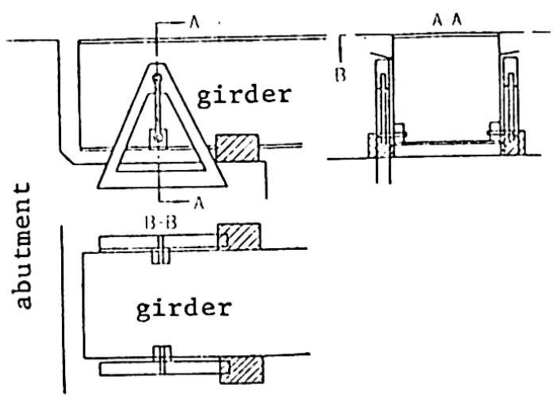

Fig.9 Pendulum Support Example

5. OTHER MAJOR BRIDGES IN THIS SECTION

Nagai Bridge is 500m in length and 98m in height (Fig.-10). The type of superstructure is PC box girder with a maximum span length of 123m.

Katashina Bridge is 1000m in length and 90m in height (Fig.-11). The superstructure is a deck-type truss with 4-lanes.

For both bridges, such a detailed seismic study have been made as one for Numao Bridge mentioned above.

6. EPILOGUE

NIHON DORO KODAN has completed planning and design of the bridges in Numata region, getting advice from the council presided by Dr. Yukitaka Uemae.

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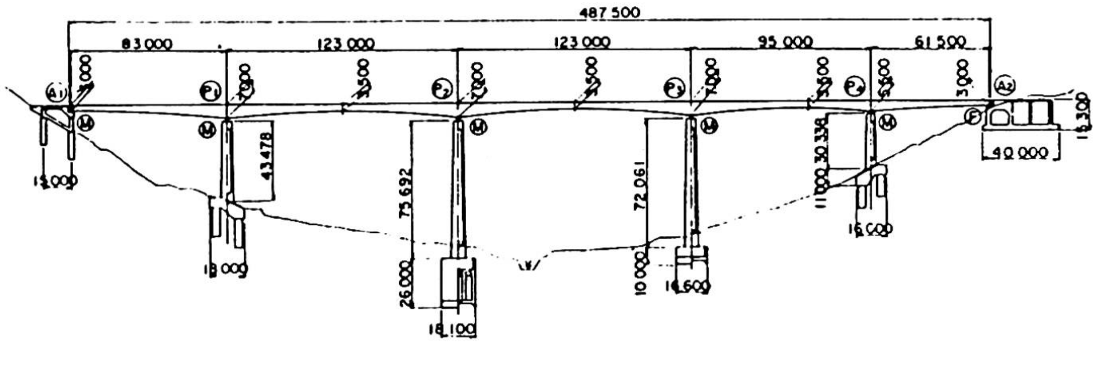

Fig.10 Nagai River Bridge

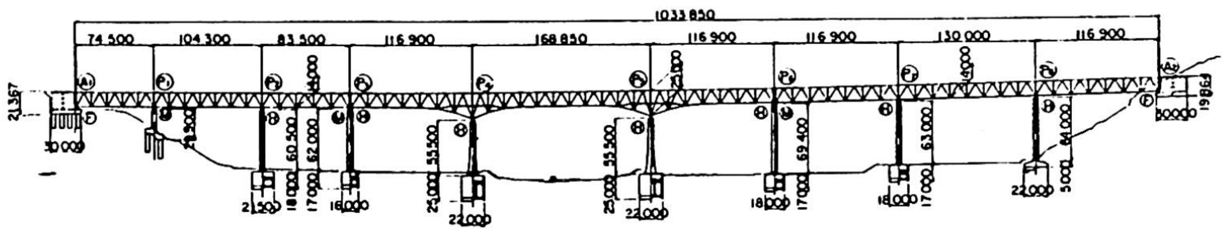

Fig.11 Katashina River Bridge