

INSPECTION AND RETROFITTING FOR EARTHQUAKE RESISTANCE
VULNERABILITY OF HIGHWAY BRIDGES IN JAPAN

by
Tadayuki TAZAKI¹

SUMMARY

All highway bridges in Japan are supervised technologically through the authorized specifications by the Ministry of Construction. The ministry has conducted the inspection of highway bridges three times (i.e. 1971, 1976 and 1979). The first one in 1971 was to point out the deteriorated bridges liable to be damaged in earthquakes. The second in 1976 was to check the items being closely related with the possibility of damage. The third inspection in 1979 was to classify bridges according to their earthquake resistances. This paper introduces the procedure of the latest inspection and its retrofitting in 1979.

INTRODUCTION

It is necessary in earthquake disaster mitigation planning to extract structures liable to be damaged in earthquakes. Two methods exist for the extraction. The one is to point out the structures liable to be damaged when they have the vulnerably structural factors according to the experiences of past earthquakes. The other is to analyse structures and to judge their safety.

The inspection of highway bridges conducted by the Ministry of Construction, Japan, in 1979 sequentially applied both of the methods. Possibly vulnerable bridges were extracted by the former method. The vulnerable factors considered were;

- (1) the design based on the old specifications,
- (2) deteriorated materials, and
- (3) vulnerable types of structures according to the damage in past earthquakes.

The extracted bridges were inspected by the latter method.

The priority of retrofitting was determined by the importance of bridges.

PROCEDURE OF THE INSPECTION

The inspection of highway bridges conducted in 1979 consists of four steps. The first step is to select the routes to be inspected, which are indispensable in emergency.

The second step is to extract the possibly vulnerable bridges. Referring the reports of past earthquakes, damage of bridges is more affected by the vulnerable subgrounds and substructures than superstructures, so that the formers are emphatically inspected.

The bridges extracted by the second step are to proceed to the third step. It is to inspect the stability of subgrounds and foundations, and

1) Senior Research Engineer, Earthquake Engineering Division, Public Works Research Institute, Ministry of Construction, Tsukuba Science City 305, JAPAN

the section moduli of piers.

The fourth step is to analyse structures dynamically if required.

The retrofitting method for each type of vulnerability identified is lastly proposed. The priority of retrofitting is to be determined by the availability of substitutive routes and the easiness of traffic resumption in emergency.

The procedure of the inspection is shown in Fig. - 1. This paper mainly describes the second and third steps.

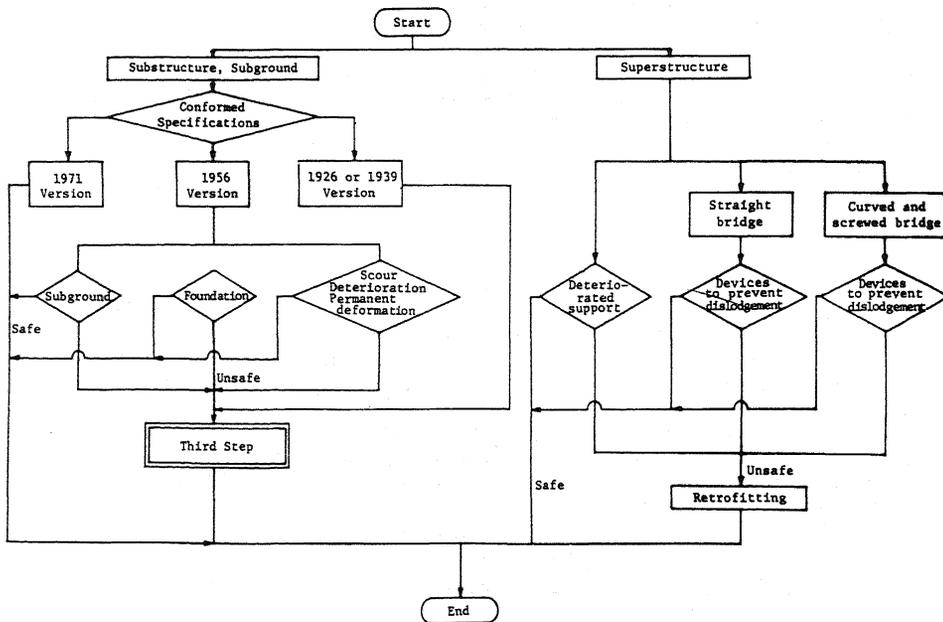


Fig. 1 Flow Chart of Inspection in the Second Step

Possibly Vulnerable Bridges (Second Step)

The second step is to extract the possibly vulnerable bridges which should proceed to the more detailed inspection in the third step. The vulnerable factors considered are as follows:

(1) Specifications Conformed

Owing to the progress of earthquake engineering, specifications have been revised several times.

At least the structures conformed with the latest specifications of 1971 were considered to have enough safety. The structures before the 1956 specifications were considered to be possibly unsafe. Those between 1956 and 1971 were judged depending on the subground, foundation and deterioration of the substructure.

For instance of the improvement of the specifications no attention had been paid to liquefaction before the specifications of 1971 were issued.

(2) Subground

a. Loose and Saturated Sand

Loose and saturated sand is liable to liquefy in earthquakes. Sandy layers which were less than 10 m deep and whose N-values were less than or equal 10, or the sites where historical liquefaction was reported were extracted.

b. Poor Subsoil

Peat layers or the sites where adjacent dikes and embankments settled were extracted.

(3) Substructure

a. Lack of Enough Rigidity

The substructure as shown in Fig. 2 suffered damage in Miyagiken-oki earthquake of 1978. The damage would have been attributable to the independent two caissons and insufficient rigidity of the tying members.

The pile bent substructure as shown in Fig. 3 experienced damage in Niigata earthquake of 1964.

Both types of the foregoing substructures have insufficient rigidity. Therefore the substructures without enough rigidity were extracted.

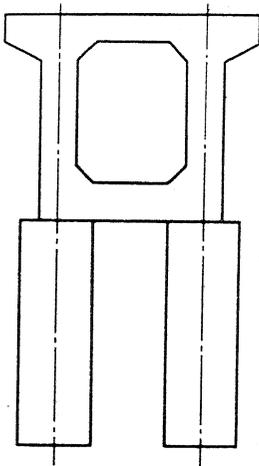


Fig. 2 Independent Caisson Foundation

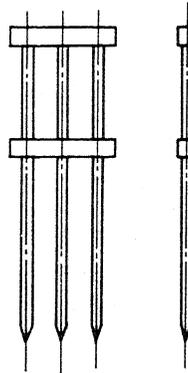


Fig. 3 Pile-bent Foundation

b. Brittle Materials

Substructures made of plain concrete, brick and masonry were extracted.

c. Settlement and Inclination

The substructures which settled or inclined were extracted.

(4) Superstructure

a. Curved Bridge

A curved bridge acts rather different in an earthquake from what is expected in conventional design. In conventional design a bridge was designed in longitudinal and transverse directions.

However a curved bridge bears not only the forgoing loadings but also torsional loading. The curved bridges without considerations of torsional loading and whose radius were less than 100 m were extracted.

b. Skew Bridge

By the similar reason as curved bridges, skew bridges of less than 60° of angles were extracted.

c. Deteriorated Supports

The supports of deteriorated anchor bolts, deteriorated bearings and over-dislodged supports were extracted.

d. Lack of Devices to Prevent Dislodgement

The supports without devices to prevent dislodgements which were specified by the specifications of 1971 were extracted.

Classifying Bridges by their Resistance (Third Step)

The bridges extracted by the second step were to be inspected in the third step. Here only subgrounds and substructures were inspected, because superstructures do not affect the damage according to the experiences of past earthquakes as far as they passed the second step inspection.

(1) Subground

a. Liquefaction Resistance Factor

Liquefaction resistance factor, F_L is defined as the ratio of the resistance index of soil elements to dynamic loads R , and the shearing stress loads index to soil elements induced by earthquake motions L . The procedures to calculate R and L are shown in Reference [2]. Subground having the total thickness of the layers of greater than 10 m whose F_L were less than 0.6 was judged to be liquefied in earthquakes.

b. Bearing Capacities

In the relationship between the overturning moment and the bearing capacity of foundation three zones were defined as safe (A), slightly unsafe (B) and unsafe (C) in Fig. 4.

(2) Substructure

a. Section Modulus of Pier

Aged piers possibly have the insufficient section moduli compared to the current specifications. The section moduli of inspected piers were compared with those of the Standard Design issued by the Ministry of Construction and other institutions, which were designed based on the current specifications. The checking charts are shown in Figs. 5 - 7. Fig. 5, Fig. 6 and Fig. 7 correspond to wall pier, column pier and rigid frame pier

respectively. The line dividing zones A and B was drawn by enveloping the dimensions designed by the Standard Design. The line dividing B and C was drawn by multiplying by 1.1 (reserve strength of reinforcement) of the line between A and B. Zone C was determined to be preferentially retrofitted.

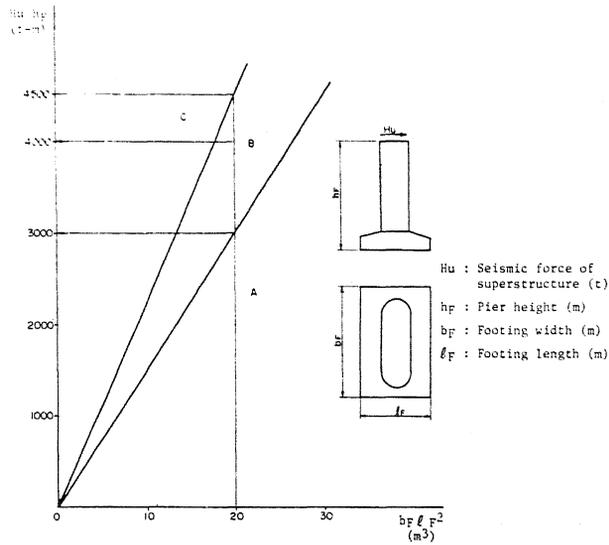


Fig. 4 Checking Chart for Bearing Capacity

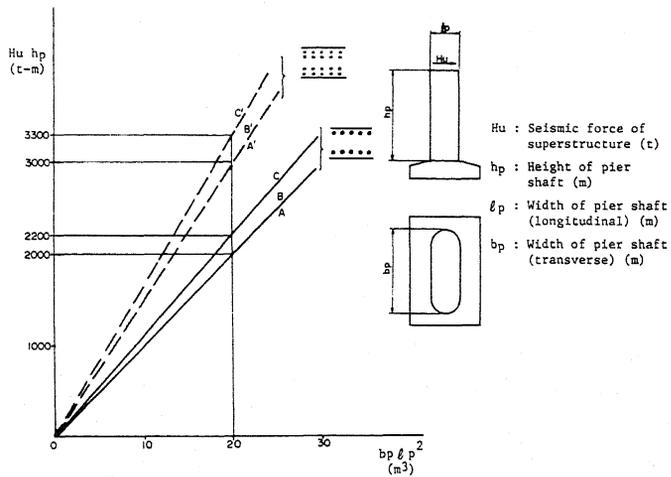


Fig. 5 Checking Chart for Wall Pier

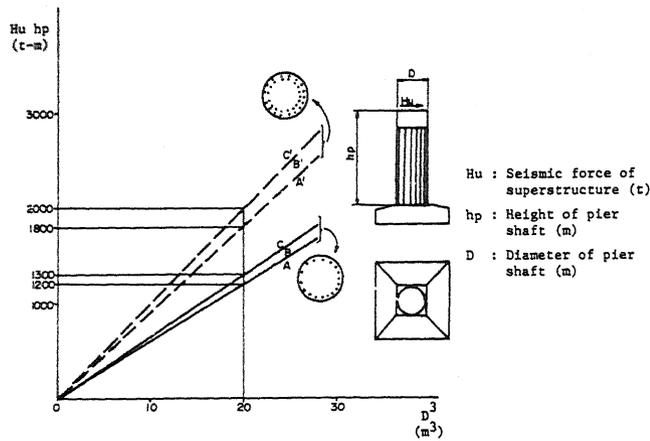


Fig. 6 Checking Chart for Column Pier

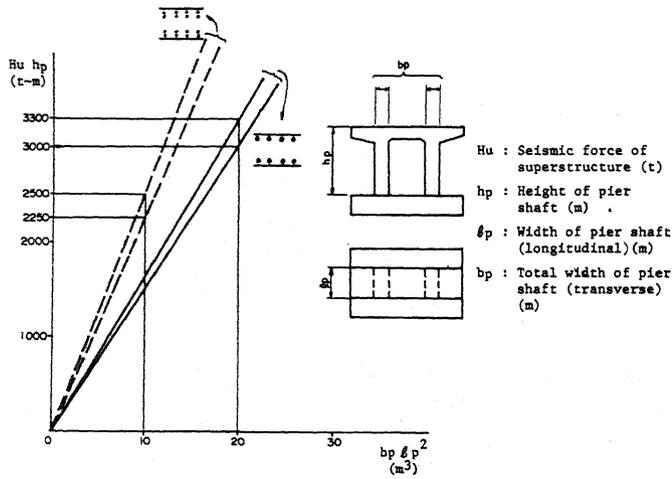


Fig. 7 Checking Chart for Rigid Frame Pier

b. Safety Factor of Pile Foundation

Aged pile foundations are liable to be damaged than other types of foundations according to the experiences of past earthquakes. The reason for this would be that there did not exist capable pile drivers in old days. Additionally most piles before 1950 were made of timber. Therefore pile foundation was exceptionally inspected by calculating the safety factor SF as follows.

$$SF = \frac{R_u}{V_i}$$

R_u : Ultimate bearing capacity of a pile (t)

$$V_i : \text{Vertical reaction of pile } i \text{ (t)} = \frac{V}{n} + \frac{Ve}{X_i^2} X_i$$

V : Vertical load (t)

n : Number of piles

e : Eccentricity (m)

X_i : X coordinate of i-th pile (m)

Dynamic Analysis

The bridges extracted by the above step were inspected by applying the dynamic analysis, if required.

Determining the Method of Retrofitting

The retrofitting method for each type of vulnerability identified is shown in Table 1.

Table 1. Proposed Method of Retrofitting

Classification	Vulnerable Factor	Method of Retrofitting
Subground		Surrounding by sheet piles Pile driving behind abutments Driving additional piles Sand compaction piles
Substructure	Scour Lack of enough rigidity Section modulus of pier Section modulus of footing Safety factor of pile foundation	Consolidation of foundation Additional rigidity Additional section Expansion of footing Additional piles
Superstructure	Curved bridge } Screw bridge } Deteriorated support Lack of devices to prevent dislodgement	Devices to prevent dislodgement Enlargement of bridge seat Connecting devices of adjoining girders Exchange of support Installing devices

DISCUSSIONS

About 37000 bridges were inspected in which 42% were judged to be retrofitted.

It is necessary to get a reasonable level of retrofitting from an economic point of view. Because of the low recurrence of damaging earthquakes, the retrofitting investment is obliged to be at a lower level, when the direct effects of retrofitting are only considered. However the retrofitting also has the indirect effects, such as the traffic and transportation, regional economy and opportunity loss for repair and reconstruction. When such indirect effects are considered, more retrofittings are rationalized.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude for the suggestions and supports of Messrs. Tatsuya Fujii and Yoshihiko Enami of Ministry of Construction, Japan.

REFERENCES

- 1) Specifications for Earthquake Resistant Design of Highway Bridges, Japan Road Association, 1971
- 2) T. Iwasaki, et al : A Practical Method for Assessing Soil Liquefaction Potential Based on Case Studies at Various Sites in Japan, Second International Conference on Microzonation, San Francisco, 1978
- 3) A. Longinow, et al : Bridge Retrofitting Selection of Critical Bridges in a Road Network, Technical Council on Lifeline Earthquake Engineering Specialty Conference, Los Angeles, August 1977