BRIDGE CONSTRUCTION STANDARDS IN JAPAN

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OUTLINE OF THE 1996 SEISMIC DESIGN CRITERIA OF HIGHWAY BRIDGES IN JAPAN

by
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Abstract

This paper first describes outline of damage due to the Hyogoken-Nanbu earthquake of January 17, 1995, which caused catastrophic damage to various urban facilities including bridge collapse. Then it presents major points characterized by the revised seismic design criteria briefly compared with the conventional one.

Key Words: Hyogoken-Nanbu earthquake, Seismic design criteria, Highway bridge, Ductility design, Foundation movement, Lateral ground flow.

Introduction

The Kobe or Hyogoken-Nanbu earthquake hit the city of Kobe and surrounding area early morning of January 17, 1995, and caused lots of human sufferings, e.g. fatality of the order of 6400 and catastrophic damages to various urban structures, such as buildings, railways, highways, ports, other lifeline facilities of water supply, gas, electricity and so on. Among them, highway bridges sustained serious damage, including girder fall, collapse of reinforced concrete piers and steel piers, and large deformation of substructures.

A significant amount of vibrational effects was, however, observed on bridge structures in the 1995 Hyogoken-Nanbu earthquake. Nine bridges including 30 spans at Fukae section of Hanshin Expressway fell down due to direct seismic effects. It is estimated that these failures were caused by effects of horizontal ground acceleration over 800 gal.

As for damage to foundations, no details were not cleared immediately after an outbreak of the earthquake because it took time to observe foundations in the underground, but the state of damage to foundations was gradually surveyed in conjunction with restoration work. It was confirmed that a number of foundations were cracked or suffered large horizontal residual displacement mainly due to liquefaction or lateral ground flow induced by liquefaction.

Taking the view of serious and extensive damage to highway bridges, the revised Specifications for highway bridges have been issued by the Japan Road Association and authorized by the ministry of construction in 1996. The new specifications include newly defined or revised earthquake forces, ductility design method, non- linear analysis, design method for liquefaction or lateral ground flow, and so on, based on lessons learned from this destructive earthquake. Table 1 shows the history of seismic bridge criteria in Japan, which were revised repeatedly after major earthquakes occurred.

Effects of the Hyogoken-Nanbu Earthquake

Fig. 1 illustrates focal zone, the epicenter, peak accelerations (in gal) recorded, major transportation networks, and major bridge damage sites. The fault line is visually found only in the northern part of Awaji island, but the other fault line under the ocean and Honshu island is estimated from aftershock epicenters, measured by the Japan Meteorological Agency and other institutions. Large horizontal ground accelerations as mush as 800 gal were observed at several sites in Kobe and nearby. The peak ground velocity and displacement are of the order of 90 cm/m and 50 cm. These ground motions are the highest level ever measured in Japan.

Table 2 shows the summary of damage caused by the 1995 Hyogoken-Nanbu Earthquake. The estimated cost of damages was around 10 trillion yen. These values are the biggest level after the Great Kanto Earthquake.

Bridge damage was observed on National Highway Routes 2, 43, 171, and 176, Hanshin Expressway Routes 3 (Kobe Line) and Route 5 (Bay shore Line), and Meishin Expressway and Chugoku Motorway of the Japan Highway Pubic Corporation.

Large lateral movements of bridge foundations mainly caused by the effects of soil liquefaction and resulting ground flow, were investigated. Fig. 2 shows a relationship between ground flows near bridge foundations and lateral movements of foundations on Hanshin Expressway Route 5. The largest ground flows and foundation movements are of the order of 220 cm and 90 cm, and foundation movements are of the order of half or less of the ground flows.

Many bridge foundations located close to waterfront moved laterally toward the water, up to 90 cm. Movements of rigid foundations were smaller, while those of flexible foundations were larger. Fig. 3 illustrates the mechanism of lateral movement of a pile foundation due to lateral ground flow. From the result the effects of lateral ground flow should be considered in the design of the foundation close to waterfront.

Revision of the Specifications for Highway Bridges

A. Basic Concept:

In the 1996 Specifications for Highway Bridges, Table 3 shows performance criteria to prevent bridges defined as Type A and B classified by those importance from fatal failure against future earthquakes defined as two levels and basic application concepts of seismic coefficient design methods, ductility design method, and dynamic analysis.

B-1. Earthquake Load (level-1):

For the seismic coefficient method, standard horizontal seismic coefficient is defined as:

1990 Spec. (Specifications for Highway Bridges): 0.2g

1996 Spec. (Specifications for Highway Bridges): 0.2g

B-2. Earthquake Load (level- 2):

For the ductility design method, seismic coefficients are defined as:

1990 Spec.: maximum response acceleration = 0.7 ~ 1.0g

1996 Spec.:

Type 1: pacific tectonic earthquake response acceleration (0.7 ~ 1.0g) shown in Fig. 4(a) equal to the level of the Kanto earthquake (1923)

Type 2: near fault earthquake response acceleration (1.5 ~ 2.0g) shown in Fig. 4(b) equal to the level of the Hyogo-ken Nanbu earthquake (1995)

C. Importance:

1990 Spec.: importance of bridges is classified depending on road category, i.e. all bridges on major national road, important major bridges on prefectural or city roads and all bridges except before.

1996 Spec.: Type A: Important Bridges; Type B: Most important bridges, classified by road category, structure type, and function.

D. Earthquake Resistant Design Method:

(a. Seismic Coefficient Method)

1990 Spec.: the seismic coefficient design method is basically recommended.

1996 Spec.: the seismic coefficient design method is employed only for preliminary design.

(b. Ductility Design Method)

1990 Spec.: the ductility design method is recommended only for single RC columns

1996 Spec.: the ductility design method is recommended for RC piers, steel piers, foundations, bearings

(c. Dynamic Analysis)

1990 Spec.: the dynamic analysis is recommended for bridges with complex earthquake behavior, corresponding to seismic coefficient method level.

1996 Spec.: the dynamic analysis is strongly recommended for bridges with complex earthquake behavior, corresponding to the ductility design method level.

E. Liquefaction and Liquefaction-induced Lateral Ground Flow:

1990 Spec.: liquefable soil (D50: 0.02mm-2.0mm) is considered, but liquefaction-induced lateral ground flow is only checked.

1996 Spec.: liquefaction judgement by fine soil ratio, D50, D10; consideration of soil liquefaction and liquefaction-induced lateral ground flow are required.

F. Menshin Design (Partial Seismic Isolation Design):

1990 Spec.: the menshin design is recommended (generally adopted only for special case); design earthquake force is not reduced in spite of resulting larger damping and longer natural period.

1996 Spec.: the menshin design method is strongly recommended.

G. RC Piers:

1990 Spec. requires: transverse reinforcements (30 cm longitudinal spacing generally, 15 cm longitudinal spacing at the termination of longitudinal bars, and no requirement of cross ties)

1996 Spec. requires: transverse reinforcement (15 cm longitudinal spacing and cross ties) to confine core-concrete shown in Fig. 5 ; scale effect on shear strength of concrete; deformation characteristics analysis based on plastic hinge locations shown in Fig. 6 .

H. Steel Piers:

1990 Spec.: the seismic coefficient method is recommended to design steel piers.

1996 Spec.: the ductility design method is recommended for steel piers with and without infilled concrete.

I. Foundation:

1990 Spec.: the seismic coefficient method is recommended.

1996 Spec.: the ductility design method is recommended for pile foundations and caisson foundations

J. Bearings:

1990 Spec.: bearings are designed by the seismic coefficient method

1996 Spec.: bearings should be designed by the ductility method.

K. Unseating prevention systems:

1990 Spec.: unseating prevention measures are required by unseating prevention devices or effective seating length.

1996 Spec.: both of the unseating prevention devices and effective seating length are required.

Conclusion

The Hyogoken-Nanbu earthquake was the first one which caused destructive damage in the urban area, Kobe and nearby since the 1948 Fukui earthquake. It provided a large impact on not only physical matters of earthquake disaster prevention measures but also minds of seismic experts, because it had generally been expected that such destructive damage could be prevented with advanced construction technology.

The Specifications for Highway Bridges were revised by the Japan Road Association and authorized by the Ministry of Construction in 1996, characterized by major revised elements: in the design procedure, the ductility design method and dynamic analysis are adopted more generally, while conventional design methods, i.e. seismic coefficient method become minor; two levels seismic forces of plate boundary earthquake and inland earthquake are explicitly defined; soil liquefaction and lateral ground flow are considered in the foundation design.

As far as data are limited regarding destructive earthquake, It is, therefore, essential that enough redundancy and ductility are endowed in a total bridge system against unknown future destructive earthquake .

Table 1 History of Seismic Bridge Criteria in Japan

Year of Issue	Criteria	Design Procedures	Affecting Earthquakes
1926	Recommendations for Design of Roads. Road Laws (MHA)	Seismic Coefficient Method (Kh=0.15-0.4)	1923 Kanto (M7.9)
1939	Specifications for Design of Steel Hy. Bridges (MHA)	Seismic Coef. Meth. (Kh=0.2, Kv=0.1)	
1956	Revision of Spec. for Design of St. Hw. Br. (JRA)	Seismic Coef. Meth. (Kh=0.15-0.35, Kv=0.1)	1946 Nankai (M8.1) 1948 Fukui (M7.3)
1964	Spec. for Design of Substructures of Hy. Br. (JRA)	Same as above, plus Detailed Calculation Meth.	
1971	Spec. for Earthquake Resistant Design of Hy. Bridges (JRA)	SCM (Kh=0.1-0.24:Rigid), Modified SCM (Kh=0.05-0.3: Flex), Liquef, Restrainer	1964 Niigata (M7.5)
1980	Spec. for Hy. Bridges, Part V. Seismic Design (JRA)	Same as above, plus Deformation Capacity of RC Piers, Dynamic Analysis	1978 Miyagi-ken Oki (M7.4)
1990	Spec. for Hy. Bridges, Part V. Seismic Design (JRA)	SCM (Kh=0.1-0.3), Soil Liquefaction, Restrainers, Ductility of RC Piers, Dy.Analy, Str. Details	1982 Urakawa (M7.1) 1983 Nihonkai Chubu (M7.7)
1996	Spec. for Hy. Bridges, Part V. Seismic Design (JRA)	SCM (Kh=0.1-0.3), Ductility Design Method, Gravelly Soil Liquefaction, Non-linear Dy. Analysis, Menshin Design, Effects of Lateral Ground Flow	1995 Hanshin-Awaji (M7.2)

Table 2 Summary of Damage Caused by The 1995 Hyogoken-Nanbu Earthquake

As of December 27, 1995

Human Suffering	Fatalities	6,308	Cultural & Educational Facilities	1,039 locations
	Missing Persons	2	Roads	9,948 locations
	Seriously Injured	1,883	Bridges	323 locations
	Lightly Injured	26,615	Rivers	430 locations
	Under Investigation	14,679	Landslides	379 locations
	Injured Total	43,177	Block Walls, etc.	1,464 locations
Damage to Dwellings	Totally Destroyed	100,302	Broken Water Lines *)	Approx. 1.29 million households
	Partially Destroyed	108,741	Gas Supply Cut Off *)	Approx. 0.86 million households
	Partially Damage	227,373	Power Failure *)	Approx. 2.6 million households
	Total	436,416	Telephone Service Lost *)	More than 0.3 million lines
Non-residential Buildings	Public Buildings	750	Fires	294
	Others	3,952		

*) Number at peak

Table 3 Performance Criteria and Design Methods

Type of Design Ground Motions		Importance		Design Methods	
		Type-A Bridges (Standard Bridges)	Type-B Bridges (Important Bridges)	Equivalent Static Lateral Force Methods	Dynamic Analysis
Ground Motions with High Probability to Occur		Prevent damage		Seismic Coefficient Method	Step by Step Analysis or Response Spectrum Analysis
Ground Motions with Low Probability to Occur	Type-I (Plate-boundary type Earthquakes)	Prevent Critical Failure	Limited Damage	Ductility Design Method	
	Type-II (Inland Earthquakes)				

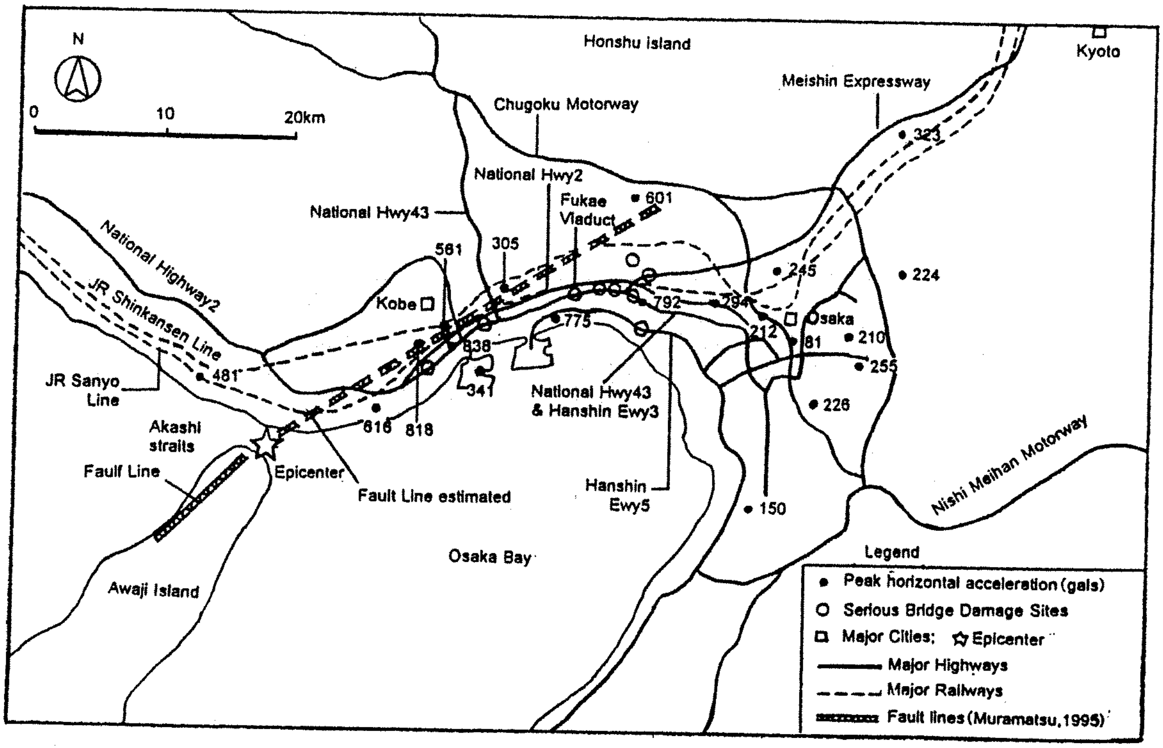


Fig. 1 Focal zone, Epicenter, and Peak Accelerations (gal), Major Transportation Networks, and Major Bridge Damage Sites

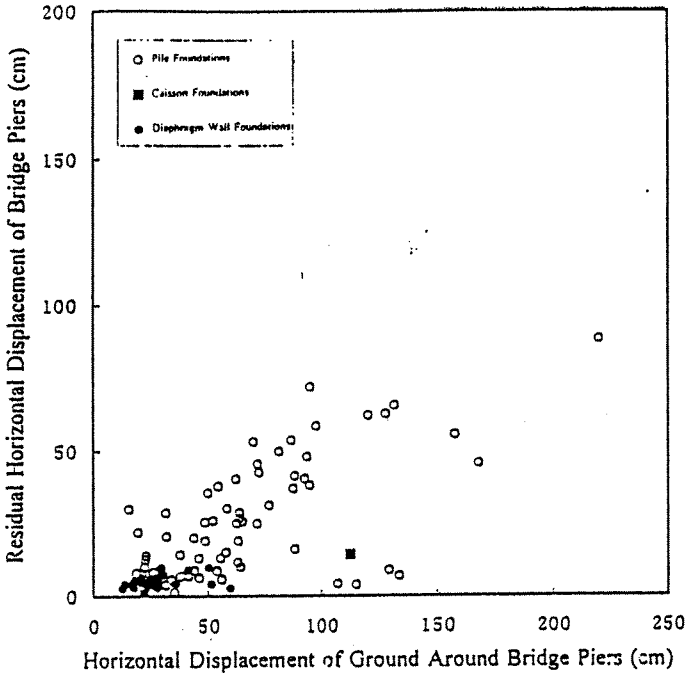


Fig. 2 Relationship between Horizontal Ground Displacement and Residual Horizontal Displacement of Bridge Piers (Hanshin Expressway Route 5)

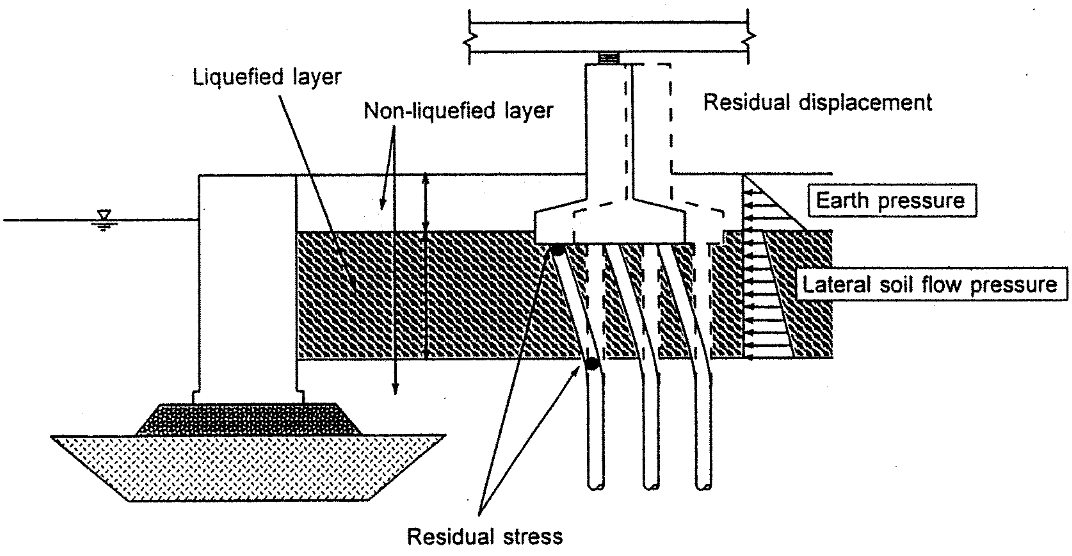
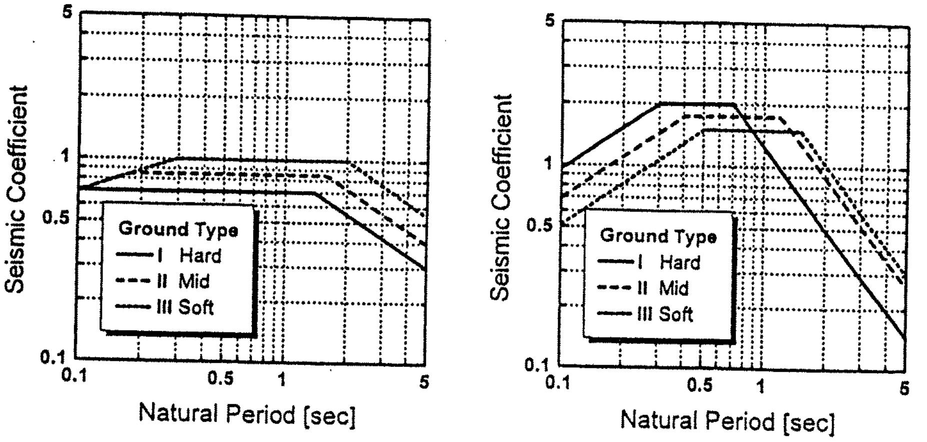
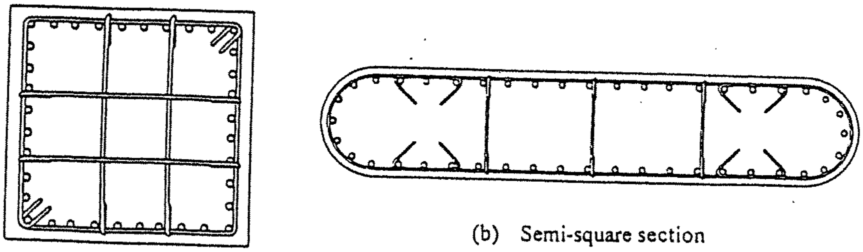


Fig. 3 Damage Mechanism of a Pile Foundation due to Lateral Ground Flow



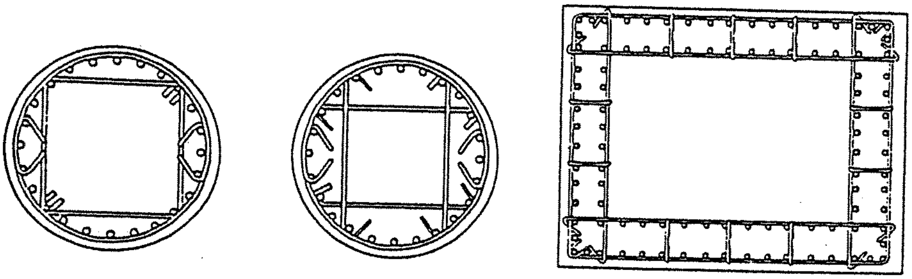
(a) Type-1 Seismic Design Force (b) Type-2 Seismic Design Force

Fig. 4 Seismic Coefficients



(a) Square section

(b) Semi-square section



(c) Circular section

(d) Hollow section

Fig. 5 Confinement of Core-concrete by Tie Reinforcement

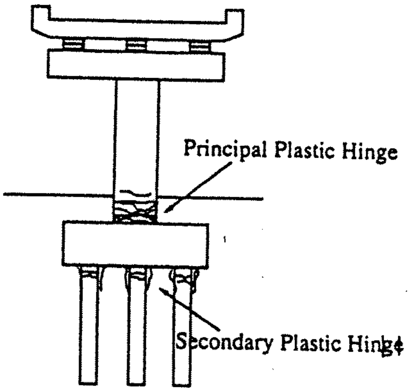


Fig. 6 Location of Primary Plastic Hinge