MENSHIN DESIGN OF HIGHWAY BRIDGES IN JAPAN

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ABSTRACT

This paper presents the back ground of seismic isolation of highway bridges in Japan. The Menshin Design which emphasis to reduce deck response by increasing energy dissipating capability and to distribute seismic lateral force of deck to as many substructures as possible is presented. Design guidelines for the Menshin Design and its implementation are described. A new joint research program on Development of New Materials and Passive and Active Control of Long-span Bridges is introduced.

INTRODUCTION

The technology for reducing bridge response has been adopted for long time in Japan (Ref. 1). It has been used from short and medium size bridges to long span bridges. Viscous damper is one of the most typical examples of such technologies (Refs. 2 and 3). It has been successfully adopted to distribute the lateral force to several substructures. The viscous damper provides a resistive force when subjected to a high-velocity motion such as the one encountered during an earthquake, while it does not offer the resistive force to low-velocity motion such as the deck motion caused by temperature change. Hence, by providing the viscous damper the seismic lateral force can be more evenly carried by many columns without constraining deck elongation and shrinkage due to temperature change.

The SU Damper is also an outcome of technical development for reducing bridge response (Ref. 4). It consists of friction bearing and prestressed strand connecting columns and a deck. By adjusting the prestressing of the strand, natural period of the deck is controlled. The strand also prevents the excessive relative displacement of the deck. The friction bearing dissipates the energy so as to increase the damping of the bridge.

Various dampers have also been developed for long span bridges. A special type of vane-damper was adopted to Higashi Kobe Bridge (Ref. 5) and Tsurumi Fairway Bridge (cable stayed bridges). A device to control the natural period and to increase energy dissipation was adopted at Hituishi–Iwaguro bridge (cable stayed bridge) of the Honshu–Shikoku Bridge (Ref. 6).

Base isolation (Refs. 7–10) has been highlighted in Japan as a new technology to reduce seismic response of structures. Special interest was due to the fact the energy dissipation is made by bearings and that compact ruminated rubber bearing such as LRB is available. Various high damping rubber bearings (HDR) have also been developed. Although various dampers have been successfully adopted for long time as describe above, it requires to install dampers in addition to bearings. Maintenance of dampers requires some special attention in addition to the usual maintenance. Some space on the pier crest is also occupied by the dampers. It is good from such maintenance and space point of view to adopt the compact type of bearings with energy dissipating capability such as LRB and HDR. Furthermore, it matches with the trend that rubber bearings should be more used. Existing steel bearings cause problem due to corrosion.

One more important motivation to adopt the seismic isolation is that it becomes possible to construct multi–span continuous bridges. The expansion joints cause vibration and noise pollution, and are not comfortable to drivers. They need to be replaced frequently, and this often causes traffic congestion. Therefore although simply supported girder bridges or two and three span continuos girder bridges have been frequently constructed, such trend needs to be changed. Super multi–span continuous bridges with as long continuos deck as possible are required. For such purpose, LRB and HDR are effective. Because the lateral stiffness of LRB and HDR is small, it absorbs the deck elongation and shrinkage due to temperature change.

Based on those considerations, the seismic isolation is considered promising for highway bridges. However, there are various unique environmental and natural conditions that the occurrence of an earthquake with magnitude over 8 is much frequent and the ground is generally much softer in Japan as compared with in New Zealand, U.S.A. and Italy where many seismic isolated bridges have been constructed, specific researches and technical developments are required in Japan. Based on such technical development, the Menshin Design which is slightly different with the seismic isolation was developed, and is being adopted.

This paper describes the history of the technical development in seismic isolation of highway bridges, and the state of the art of the Menshin Design and its implementation.

PAST TECHNICAL DEVELOPMENT FOR SEISMIC ISOLATION

Guidelines for Seismic Isolation Design of Highway Bridges

For studying the application of seismic isolation to highway bridges, a committee chaired by Professor Tsuneo Katayama, University of Tokyo, was formed through 1986 to 1989 at the Technology Research Center for National Land Development, which was the first major activity to study the seismic isolation of highway bridges in Japan. Three programs were studied in the committee, i.e., 1) survey of seismic isolation devices which can be used for highway bridges, 2) study on the key points of the seismic isolation design of highway bridges, and 3) trial designs of seismic isolated highway bridges. As the final accomplishments of the three year study, "Guidelines for Seismic Isolation Design of Highway Bridges" was published in 1989 (Ref. 11).

Pilot Construction Program of Menshin Bridges

Five highway bridges were constructed as a pilot program under the supervision of the Ministry of Construction to verify the effectiveness and performance of the seismic isolation (Ref. 1). A working group was formulated in the Ministry of Construction to supervise the design and construction. Because the Menshin Design was being developed by the Joint Research which will be described later, it was adopted in the design. Miyagawa Bridge in Shizuoka−ken was completed in March 15, 1991 as the first Menshin highway bridge in Japan (Ref. 12).

Joint Research on Menshin Bridges between PWRI and 28 Companies

A three−year joint research program on the Menshin Design of Highway Bridges was made between Public Works Research Institute and twenty eight companies since July 1989. The goal of the program was to develop the Menshin Design method and the new Menshin devices for highway bridges. **Table 1** shows the research items and the contribution of each organization.

There were four research topics in the joint program:

1)Development of new Menshin devices

The Menshin devices for highway bridges need to be compact and weather−proof since they are installed at narrow pier crests exposed to weathering condition. Ten new devices in total were developed in the program. Among them, 4 high damping rubber bearings (HDR) (Ref. 13), 2 sliding Menshin devices with HDR (Ref. 14), and a roller Menshin device with HDR (Ref. 15) seem promising for application. All Menshin devices developed were tested with use of the dynamic loading system at PWRI under the same loading conditions developed in the program (Ref. 16).

2)Development of expansion joints and restrainers

A knock-off mechanism at an abutment to reduce the impact force induced by the collision between a deck and an abutment (Ref. 17), and a finger expansion joint which is distinguished from the regular finger joints by the transverse movement (Ref. 18), were developed. A special restrainer which absorbs the energy and allows the deck to move in two lateral directions was developed (Ref. 19).

3)Development of Menshin Design method

Taking into account the high seismic activity and the soft soil condition, the Menshin Design method was developed as will be described later.

4)Application of Menshin design

It was found that the Menshin Design can be effectively used to construct super-multi-span continuous bridges with deck length of 1 km (Ref. 20). Connection of existing simple supported girders to reduce the number of expansion joints, and retrofitting of existing bridges to increase the seismic safety by using Menshin Design were studied (Ref. 21).

The final accomplishment of the program was complied in March 1992 as the " Manual of Menshin Design of Highway Bridges" (Refs. 22 and 23).

MENSHIN DESIGN

Although the elongation of natural period and the increase of energy dissipation capability of a structure are key factors in seismic isolation, the elongation of fundamental natural period is not easily achieved for bridges in Japan from various reasons.

First reason is the soft soil condition. Because most of the populated areas are located on alluvial fan deposits, soils are very weak. Second reason is the high seismicity accompanying earthquakes with magnitude over 8 (Ref. 24). Large earthquakes in magnitude produce a ground motion predominant in long period (Ref. 25). Reflecting these environmental and natural conditions, the conservative lateral force coefficients as shown in **Figs.** 1 and 2 have been adopted in seismic design of highway bridges (Ref. 26).

Third reason is difficulty to widen the clearance between decks, and between the deck and abutment. The increase of natural period produces a large relative displacement between the deck and the substructures, and requires special expansion joints which absorb large relative displacement. From the demand of driving comfort, maintenance problems and noise and vibration pollution, every efforts are now directed to reduce the clearance at expansion joints. Because even regular expansion joints currently used cause considerable problem, the increase of gap clearance can not be incorporated.

Fourth reason is the evaluation on collision developed either between abutment and deck or between adjacent decks. When enough clearance is not provided, collision would take place. In fact, collision took place in the past earthquakes (Ref. 27). It is known from these past experiences that collision did not cause critical structural problems although expansion joints were often badly damaged (Ref. 28 and 29). On the contrary, collision dissipates energy. From experiment and analysis, it is effective to constrain the deck response by collision at small deck displacement (Ref. 30). From these reasons, it is superior not to provide a large gap so as to allow the large relative displacement of deck. A little bit larger gap than the normal gap.

Based on these considerations, it seems preferable not to intentionally increase natural period and not to widen the gap clearance at joints. Instead of intentional increase of natural period, combination of increase of energy dissipating capability and distribution of seismic lateral force to as many substructures as possible is preferred in highway bridges. It may be effective to adjust the natural period of bridges so as to avoid the resonance with ground motion. This is an extension of the existing seismic design approach which has been adopted in highway bridge in Japan. The design concept in which bridges are designed taking advantage of the increase of energy dissipating capability and the distribution of seismic lateral force is proposed to be referred as "Menshin Design(免震)" (Refs. 22 and 1).

Followings are the basic principles of Menshin Design for highway bridges with ordinary span length:

1) Seismic lateral force should be distributed to as many substructures as possible. The seismic lateral seismic force should be reduced by increasing the energy dissipating capability with use of Menshin bearings.

2) The natural period of bridges should be not be forcibly elongated, but adjusted so as to avoid the resonance with a ground motion.

3) Gap at expansion joints should not be so widened.

4) The Menshin Design should be adopted only at the site with stable soil behavior. The site vulnerable to soil liquefaction and other type of failure should be avoided.

5) The Menshin Design is encouraged to construct super-multi-span continuous bridges.

MENSHIN DESIGN METHOD

Manual of Menshin Design

The Manual for Menshin Design of Highway Bridges was developed as the final accomplishment of the 3 year joint research program between the Public Works Research Institute and 28 companies (Ref. 22). Although this is not the mandate specifications, it is recommended to consider the basic requirements of the Manual in addition to the Design Specifications of Highway Bridges (Ref. 26). The Manual consists of 9 chapters and 10 appendices. The table of contents is presented in the appendix.

The mandate specification for Menshin Design is being formulated at the Menshin Design Working Group, the Seismic Design Subcommittee of the Bridge Committee, Japan Road Association, based on the Manual of Menshin Design of Highway Bridges. Because seismic performance of Menshin bridges has not yet fully confirmed through seismic experience in the past earthquakes, at the design seismic lateral force is not allowed to reduce from the value specified by the Design Specifications of Highway Bridges. Since various data are being accumulated on the seismic performance of the Menshin bridges, it is expected to reduce the seismic lateral force in the new specifications.

Idealization

In Menshin Design, bridges are designed by following the standard static design method (static frame analysis). Precise evaluation of seismic safety is made by the dynamic response analysis. In such analysis, the Menshin devices are idealized by as a set of equivalent linear springs. Equivalent stiffness and the equivalent damping ratio of the isolator and damper are the major parameters used in the analysis. In the static frame analysis, natural period of the bridge can be computed for each seismic design structural unit as :

$$T = 2.01\sqrt{\delta} \tag{1}$$

$$\delta = \frac{\int w_i \cdot u_i^2}{\int w_i \cdot u_i} \tag{2}$$

where

T : natural period (sec)

w_i : dead weight (tf/m) of the seismic design structural unit (superstructure and substructure above the ground surface assumed in seismic design) at point "i"

u_i : lateral displacement (m) developed in the seismic design structural unit at point "i" when subjected to w_i in the direction considered in design

Damping ratio of the bridge is computed as

$$
\left.
\begin{aligned}
h &= \frac{\sum K_{Bi} \cdot u_{Bi}^2 \cdot c_{hi}}{\sum K_{Bi} \cdot u_{Bi}^2 \cdot c_i} \\
c_{hi} &= h_{Bi} + \frac{h_{Pi}}{K_{Pi}} + \frac{h_{Fui}}{K_{Fui}} + \frac{h_{F\theta i} \cdot H^2}{K_{F\theta i}} \\
c_i &= 1 + \frac{K_{Bi}}{K_{Pi}} + \frac{K_{Bi}}{K_{Fui}} + \frac{K_{Bi} \cdot H^2}{K_{F\theta i}}
\end{aligned}
\right\} \qquad (3)
$$

where

h : modal damping ratio of bridge

h_{Bi} : damping ratio of i-th damper

h_{Pi} : damping ratio of i-th pier/abutment

h_{Fui} : damping ratio of i-th foundation associated with translational movement

$h_{F\theta i}$: damping ratio of i-th foundation associated with rotation

K_{Pi} : equivalent stiffness of i-th pier/abutment

h_{Fui} : translational stiffness of i-th foundation

$K_{F\theta i}$: rotational stiffness of i-th foundation

u_{Bi} : design displacement of i-th menshin device

H : height from the bottom of pier to the gravity center of deck

Eq.(3) gives the approximate estimation of the damping ratio of a bridge. When mode shapes are computed, the modal damping ratio may be computed as

$$
h = \frac{\sum_{j=1}^{n} \phi_{ij}^T \cdot h_j \cdot k_j \cdot \phi_{ij}}{\phi_i^T \cdot K \cdot \phi_i} \qquad (4)
$$

where

ϕ_{ij} : mode vector of j-th structural component for i-th mode

h_j : damping ratio of j-th structural component

k_j : stiffness matrix of j-th structural component

ϕ_{iT} : mode vector of bridge for i-th mode

K : stiffness matrix of bridge.

Table 2 shows the damping ratio recommended for structural component Eqs.(3) and (4).

Design Force

Menshin devices are designed by the seismic coefficient method (SCM) and the bearing capacity method (BCM). The allowable stress approach is adopted in the seismic coefficient method, while the bearing capacity approach is adopted in the bearing capacity method. Bridges are designed by the seismic coefficient method, and then the ductility of reinforced concrete piers is checked by the bearing capacity method.

In the seismic coefficient method, the design lateral force coefficient is given as

$$k_h = c_Z \cdot c_G \cdot c_I \cdot c_T \cdot c_E \cdot k_{h0} \geqq 0.1$$
$$c_T \cdot c_E \geqq 0.8 \tag{5}$$

where

c_Z : modification factor for zone (refer to **Fig. 3**)
c_G : modification factor for ground condition (refer to **Table 3**)
c_I : modification factor for importance (refer to **Table 4**)
c_T : modification factor for structural response (refer to **Table 5**)
c_E : modification factor for energy dissipation capability (refer to **Table 6**)
k_{h0} : standard design horizontal seismic coefficient (=0.2)

The modification factors c_Z, c_G, c_I and c_T are specified in the Design Specifications of Highway Bridges (Ref. 26). The modification factor c_E takes a value shown in **Table 6** depending on the modal damping ratio of the bridge in the fundamental mode. The design lateral force is reduced as large as 20%.

In the bearing capacity method, the lateral force coefficient khc and the equivalent lateral force coefficient khe are given as

$$k_{he} = \frac{k_{hc}}{\sqrt{2\mu - 1}} \tag{6}$$

$$k_{hc} = c_Z \cdot c_I \cdot c_R \cdot c_E \cdot k_{hc0} \geqq 0.3 \tag{7}$$

where

c_Z : modification factor for zone (refer to **Fig. 3**)
c_I : modification factor for importance (refer to **Table 4**)
c_R : modification factor for structural response (refer to Table 7)
c_E : modification factor for energy dissipation capability (refer to **Table 8**)
k_{hc0} : standard lateral force coefficient for bearing capacity method (=1.0)
μ : allowable ductility factor of reinforced concrete piers

The modification factors c_Z, c_I, and c_R are specified in the Seismic Design

Specifications of Highway Bridges. The modification factor c_E depends on the modal damping ratio of the bridge, and takes a value of **Table 8.** The design force is reduced as large as 30%.

Design of Isolators and Energy Dissipators

In design of isolators and energy dissipators, the design displacement of menshin device u_B , the equivalent stiffness K_B and the equivalent damping ratio h_B of the Menshin device are the key factors.

The design displacement of Menshin device u_B is evaluated as

$$u_B = \frac{k_h \cdot W_u}{K_B} \quad \text{(S.C.Method)} \tag{8}$$

$$u_B = \frac{k_{hc} \cdot W_u}{K_B} \quad \text{(B.C.Method)} \tag{9}$$

where

k_h : lateral force coefficient by Eq.(5)
k_{hc} : lateral force coefficient by Eq.(7)
K_B : equivalent stiffness (tf/m) of Menshin device
W_u : weight of the superstructure (tf) supported by the Menshin device

Requirements for Dynamic and Static Load

Various requirements for the devices against static load and dynamic load are described in the Manual. It is unique that precise loading test procedures for both dynamic and static loads are described in the Manual. Some of the important requirements for dynamic load is as:

1) Menshin devices have to be designed and fabricated so that their equivalent stiffness k_B and equivalent damping ratio h_B be within ±20% of the design values.

2) Menshin devices have to be stable against 50 cycles of harmonic loading with design displacement of u_B given by Eq.(9).

3) Deck should return to the rest position even after it was subjected to a large earthquake. The residual displacement u_{BR} developed in menshin devices after it is smoothly released from the deformed displacement of given by Eq.(9) needs to satisfy.

$$u_{BR} \leqq 0.1 \cdot u_B \quad (10)$$

4) The equivalent stiffness and the equivalent damping ratio of menshin devices need to be stable against the change of load condition at normal time, change of natural environment such as the temperature change and earthquake−induced cyclic loading. Stability has to be examined for 1) cyclic loading associated with the elongation and shrinkage of deck due to temperature change and traffic load, 2) effect of loading hysteresis, 3) variation of vertical loading, 4) effect of loading rate, 5) effect of pre−deformation due to creep and shrinkage, 6) direction of excitation, and 7) change of the equivalent stiffness and the equivalent damping ratio depending on the temperature change.

On the other hand, major requirements for static load include :

1) Materials and mechanism of the menshin devices need to give credit to long term use. They need to be stable against the daily and annual cyclic elongation and shrinkage of deck due to the temperature change.

2) The menshin devices need to be stable against local shear strain. Check of the local shear strain needs to be made in accordance with the Design Guidelines of Bearings (Ref. 35).

3) In the rubber−type menshin devices, the creep of rubber which would be developed for the life time of bridges in vertical direction due to the dead weight of superstructure needs not to exceed 5% of the total thickness of rubber.

4) The equivalent stiffness of menshin device at −10℃ need not to exceed 1.5 time the equivalent stiffness at 40℃.

IMPLEMENTATION OF MENSHIN DESIGN

Table 9 shows the directory of Menshin bridges which were completed or are under construction. There are over 30 bridges under design and planning stage. It should be noted that as describe above because the seismic lateral force is not allowed at this stage to reduce from the value specified in the Design Specifications of Highway Bridges, some bridges which merely adopted Menshin bearings are included in **Table 9**. From the same reason, Menshin bearings have been adopted for most of existing bridges as a tool which enables to make simply supported girders continuous. Although the seismic retrofit was not the official reason for adopting the Menshin bearings, the seismic retrofit effect is of course expected in addition to make the deck continuous.

The Road Bureau of the Ministry of Construction compiled in June 1993 a technical development program which is required to challenge toward 21 century (Ref. 34). Seventy four technologies were identified as essential, and the further development of the Menshin Design is included as a technology required to mitigate road environment. Obviously effectiveness of constructing super-multi-span bridges to reduce noise and vibration pollution is highly expected in the Menshin Design. The Ministry of Construction is now intending to effectively use the Menshin Design technology which enables to construct super-multiple-continuous bridges which are advantageous for road environment and enough seismic safety.

Typical implementation of the Menshin Design is as follows. The first Menshin bridge in Japan is Miyagawa Bridge as shown in **Photos 1** and **2**, Shizuoka-ken. It was completed in March 1991. A series of forced excitation tests using an eccentric mass-shaker and quick-release hydraulic jacks were conducted as shown in **Photos 1** and **2** to verify the design. Strong motion observation has been made since the completion, and an analysis of the first data was made (Ref. 31).

Photo 3 shows Yama-age Bridge in Tochigi-ken (Ref.32). This was the first Menshin bridges utilizing high damping rubber bearings. Superstructure is of 6-span post-tensioning prestressed concrete box girder with deck length of 246.3m. Forced excitation tests using an eccentric mass-shaker and quick-release hydraulic jacks were made.

Photo 4 shows On-netoh Bridge on National Highway No.44 in Hokkaido. this bridge experienced a significant shaking during the Kushiro-oki Earthquake in January 1993. The peak acceleration of about 360 cm/sec^2 was induced on the ground surface near the bridge. No damage was developed due to the earthquake. The relative displacement at the bearings in longitudinal direction was only 2 to 2.5 cm. This earthquake provided as important data on the response of a Menshin bridge in cold area. Because temperature dependence of LRB was precisely investigated in laboratory (Ref. 33), a precise analysis is expected.

Photos 5 and **6** show Higashi-ohgi-shima Viaduct with 9-span continuous prestressed concrete girder on Metropolitan Expressway and Matsuno-hama Viaduct with 4-span continuous steel box girder on Hanshin Expressway, respectively. The forced excitation tests were also made for these bridges and the dynamic characteristics of Menshin bridges were investigated.

A unique application of Menshin Design is the O-hito Viaduct which is under construction in Shizuoka-ken as a part of the Izu Crossing Highway. The bridge is of 29-span continuous prestressed concrete girder with deck length of 725m.

Menshin design has been applied for the jointless system and seismic strengthening of existing simply–supported girder bridges. **Photo 7** shows the replacement of existing steel bearings by LRB.

A NEW JOINT RESEARCH PROGRAM ON SEISMIC CONTROL OF LONG–SPAN BRIDGES

A new three–year joint research program on "Development of Seismic Control Systems of Long–Span Bridges" was initiated from October 1993. This research is being made jointly between the Public Works Research Institute, Public Works Research Center and 19 companies. The Public Works Research Center is a foundation belonging to the Public Works Research Institute.

This research is directed to develop a new passive and active control technologies and to use intelligent materials for long–span bridges. As the post Honshu–Shikoku Bridge Project, new bridge construction with center span length over 2 km is being considered. In the technical development program of the Road Bureau of the Ministry of Construction, development of seismic design method for long–span bridge is included as one of the 74 key technologies. Passive and active control technologies for new types of structures are the key issue. The joint research is intended to support this technical development.

The research program includes the following three topics.

1) Development of New Materials and Passive and Active Control
It is intended to effectively use new materials such as super low–yield strength metals, super plastic rubbers, super high damping rubbers and rheological fluid. They may be used to produce energy dissipators for various purpose. Intelligent dampers, a tuned liquid damper and an intelligent knock–off device are to be developed.

2) Development of New Control Design Method
Depending on new materials and passive and active control developed in 1), new controlling methods need to be developed. Accurate evaluation method of damping of structure which use new materials and controlling devices, and optimum control points are to be investigated.

3) Application to Bridges
Various application of the new materials and controlling systems can be considered. Application of the controlling systems to substructures, high piers, suspended slabs,

cable stayed bridges and suspension bridges are studied. Application of active control of bridges during construction stage is promising.

Table 10 shows the research objectives and the contribution of each organization. The 19 companies include material makers, bearing supports fabricators, consulting engineering companies, steel bridge fabricators and general contractors.

CONCLUDING REMARKS

Seismic isolation expanded the freedom of design and construction practice of highway bridges. It has been used as a tool to construct super–multi–span continuous bridges, curved and skewed bridges capable to move in two horizontal directions and seismic strengthening. Data on bridge response through forced excitation tests, shaking table tests, loading tests of energy dissipators and isolators, strong motion observation and seismic excitation are being accumulated. It was very important that On–netoh bridge located close to the fault of Kushiro–oki Earthquake in January 1993 behaved quite well. Through the analysis of those data, the seismic response of Menshin bridges is being verified.

Implementation of the Menshin Design is being made throughout the country. The Menshin Design was applied to 15 new bridges and 8 existing bridges. A number of bridges are being designed and planned.

A new three–year joint research was initiated among PWRI, PWRC and 19 companies to develop new materials and passive and active control systems for long–span bridges. New innovative materials and systems are studied in the program. It is expected to develop new materials, dampers, controlling algorithm and application.

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34) Road Bureau of Ministry of Construction: Five−year Technical Development Program−Challenge to New Possibility toward 21th Century−, June 1993 (in Japanese)
35) Japan Road Association : Guide−Specification of Design of Bearings, July 1991 (in Japanese)

Note

1) 1st U.S.–Japan Workshop : Proc. 1st U.S.–Japan Workshop on Earthquake Protective Systems of Bridges, Buffalo, New York, U.S.A., September 1991, Technical Report NCEER 92–0004, National Center for Earthquake Engineering Research, State University of New York at Buffalo, February 1992

2) 2nd U.S.–Japan Workshop: Proc. 2nd U.S.–Japan Workshop on Earthquake Protective Systems of Bridges, Tsukuba, Japan, Technical Memorandum, No. 3196, Public Works Research Institute, December 1992

APPENDIX

TABLE OF CONTENTS OF MANUAL FOR MENSHIN DESIGN OF HIGHWAY BRIDGES

Table 1 Research Theme and Organizations of Joint Research Program between the Public Works Research Institute and 28 Private Firms for Developing Menshin Design Method of Highway Bridges

Research Theme	P	Ka	Si	Ob	Ku	Tn	H	Ni	Su	M	G	Ok	Ti	I	Nk	Ko	Ns	Ol	Y	To	Bs	Bb	Se	Sh	Pc	J	N	Chief	Sub-Chief
1. Development of Device for Isolation																												Ol	Bs
1.1 High Energy Absorbing Rubber Bearing								○											○	○	○			○					
1.2 Friction Damper													○									○	○						
1.3 Steel Damper								○							○														
1.4 Link Bearing Develop of																	○												
1.5 Viscous Damper																		○											
1.6 Test Method	○							○							○		○	◎	○	○	○	○	○	○					
2 Development of Expansion Joint and Falling-off Prevention Device for Isolated Bridge																												Tc	—
2.1 Expansion Joint				○									○																
2.2 Falling-off Prevention Device	○												○					○											
3. Development of Design Method for Isolated Bridge																												Ka	Pc
3.1 Design Philosophy	○	○	○	○		○						○	◎					○							○	○	○		
3.2 Dynamic Responce Analysis Method	○		○		○	◎		○			○			○															
3.3 Design Method of Device for Isolation	○						○	○				◎	○		○		○	○	○	○	○	○	○	○					
3.4 Simplified Design Method	○	○	◎		○	○					○	○																	
3.5 Design Method of Expansion Joint and Falling-off Prevention Device	○			○			○								○			○							◎				
4. Application of Base Isolation to Bridge																												Ob	J
4.1 Application to Prestressed Concrete Bridge	○	◎							○	○			○														○		
4.2 Application to Steel Bridge	○													○	○	○											◎		
4.3 Application to Multiple Super-long Bridge	○			◎					○							○									○	○	○		
4.4 Application to Seismic Retrofit	○									○				○				○								◎			

P. Public Works Research Institute, Ka: Kajima, Si: Shimizu, Ob: Ohbayashi, Ku. Kumagai, Tn. Takenaka Doboku + Takenaka, H Hazama, Ni: Nishimatsu, Su Sumitomo, M: Mitsui, G: Goyoh, Ok: Okumura, Ti Taisei + Tokyo Fablic + Nippon Chuzo, I: Ishikawajima Harima, Nk NKK + Nippon Chuzo, Ko Kobe Steel, Ns: Nippon Seiko, Oe: Oiles, Y: Yokohama Rubber, To. Toyo Rubber, Bs. Bridgestone, Bb BBM, Se: Seibu Polymer, Sh Showa Densen, Pc Pacific Consultants, J: Japan Engineering Consultant, N: New Structural Engineering Consultants.

Table 2 Damping Ratio Recommended for Structural Components

Structural Components	Steel	Concrete
Super Structures	0.02～0.03	0.03～0.05
Menshin Device	Damping Ratio	
Pier/Columns	0.03～0.05	0.05～0.1
Footing	0.1～0.3	

Table 3 Modification Factor for Ground Condition c_G

Ground Group	I	II	III
c_G	0.8	1.0	1.2

Table 4 Modification Factor for Importance c_I

Group	c_I	Definition
1st class	1.0	Bridges on expressway (limited access highways), general national road and principal prefectural road. Important bridges on general prefectural road and municipal road.
2nd class	0.8	Other than the above

Table 5 Modification Factor for Structural Response c_T

Ground Group	Structural Response Coefficient c_T		
Group I	$T<0.1$ $c_T=2.69T^{1/3}\geqq 1.00$	$0.1\leqq T<1.1$ $c_T=1.25$	$1.1<T$ $c_T=1.33T^{-2/3}$
Group II	$T<0.2$ $c_T=2.15T^{1/3}\geqq 1.00$	$0.2\leqq T<1.5$ $c_T=1.25$	$1.3<T$ $c_T=1.49T^{-2/3}$
Group III	$T<0.34$ $c_T=1.80T^{1/3}\geqq 1.00$	$0.34\leqq T<1.5$ $c_T=1.25$	$1.5<T$ $c_T=1.64T^{-2/3}$

Table 6 Modification Factor for Modal Damping Ratio of Bridge c_E
(Seismic Coefficient Method)

Damping Ratio h	Modification Factor c_E
$h<0.1$	1.0
$h \geqq 0.1$	0.9

Table 7 Modification Factor for Structural Response c_R

Ground Group	Structural Response Coefficient c_R		
Group I	$T \leqq 1.4$ $c_R=0.7$		$1.4<T$ $c_R=0.876T^{-2/3}$
Group II	$T<0.18$ $c_R=1.15T^{1/3} \geqq 0.7$	$0.18 \leqq T \leqq 1.6$ $c_R=0.85$	$1.6<T$ $c_R=1.16T^{-2/3}$
Group III	$T<0.29$ $c_R=1.15T^{1/3} \geqq 0.7$	$0.29 \leqq T \leqq 2.0$ $c_R=1.00$	$2.0<T$ $c_R=1.59T^{-2/3}$

Table 8 Modification Factor for Modal damping Ratio of Bridge c_E
(Bearing Capacity Method)

Damping Ratio h	Modification Factor c_E
$h<0.1$	1.0
$0.1 \leqq h<0.12$	0.9
$0.12 \leqq h<0.15$	0.8
$0.15 \leqq h$	0.7

Table 9 Directory of Menshin Bridges in Japan
(a) New Constructions

Bridge	Location	Deck Length	Administrator	Year Constructed	Super-Structure Type	Bearing Type
Onnetoh Bridge	Hokkaido	102.2m	Hokkaido Development Bureau	1993	4-Span Continuous Steel Plate Girder	LRB
Nagakigawa Bridge	Akita	97m	Noshiro Construction Office, MOC	Under Construction (1993)	3-Span Continuous Steel Plate Girder	LRB
Maruki-bashi Bridge	Iwate	92.5m	Iwate-ken	1992	3-Span Continuous Prestressed Concrete Box Girder	LRB
Yama-age Bridge	Tochigi	250m	Tochigi-ken	1993	6-Span Continuous Prestressed Concrete Box Girder	HDR
Miyagawa Bridge	Shizuoka	110m	Shizuoka-ken	1991	3-Span Continuous Steel Plate Girder	LRB
O-hito Viaduct	Shizuoka	725m	Shizuoka-ken	Under Construction	29-Span Continuous Prestressed Concrete Slab	LRB
Hirao Bridge	Yamaguchi	350m	Yamaguchi-ken	Under Construction (1993)	5-Span Continuous Prestressed Concrete Box Girder	HDR
Uehara Bridge	Nagoya	65m	Nagoya City	1991	2-Span Continuous Steel Plate Girder	LRB
Route #12 Interchange Bridge	Tokyo	136.6m	Metropolitan Expressway Public Corp.	1991	6-Span Continuous Prestressed Concrete Slab	LRB
Bay Shore Route	Tokyo	417.6m	Metropolitan Expressway Public Corp.	Under Construction (1994)	9-Span Continuous Prestressed Concrete Box Girder	LRB
Matsunohama Bridge	Osaka	211.5m	Hanshin Expressway Public Corp.	Under Construction	4-Span Continuous Steel Box Girder	LRB
Izumisano Bridge	Osaka	318m	Hanshin Expressway Public Corp.	Under Construction	6-Span Continuous Steel Box Girder	LRB
Trans Tokyo Bay	Tokyo	910m	Trans Tokyo Bay Highway Corp.	Under Construction (1994)	11-Span Continuous Steel Box Girder	HDR
Trans Tokyo Bay	Tokyo	800m	Trans Tokyo Bay Highway Corp.	Under Construction (1994)	10-Span Continuous Steel Box Girder	LRB
Karasaki Bridge	Fukushima	76.95m	Soma Kyodo Power Company Ltd.	1991	2-Span Continuous Prestressed Concrete Box Girder	HDR

Note) LRB: Load Rubber Bearing, HDR: High Damping Rubber Bearing

(b) Existing Bridges

Bridge	Location	Deck Length	Administrator	Year Constructed	Super-Structure Type	Bearing Type
Komatsukawa Route	Tokyo	120m	Metropolitan Expressway Public Corp.	Under Construction	Interconnection of Simply-Supported Girder (3-Spans)	LRB
Komatsukawa Route	Tokyo	120m	Metropolitan Expressway Public Corp.	Under Construction	Interconnection of Simply-Supported Girder (3-Spans)	LRB
Route #6	Tokyo	80m	Metropolitan Expressway Public Corp.	1992	Interconnection of Simply-Supported Girder (4-Spans)	LRB
Route #6	Tokyo	80m	Metropolitan Expressway Public Corp.	1992	Interconnection of Simply-Supported Girder (4-Spans)	LRB
Route #6	Tokyo	80m	Metropolitan Expressway Public Corp.	1992	Interconnection of Simply-Supported Girder (4-Spans)	LRB
Moriguchi Route	Osaka	90m	Hanshin Expressway Public Corp.	1991	Interconnection of Simply-Supported Girder (2and3-Spans)	LRB
Moriguchi Route	Osaka	90m	Hanshin Expressway Public Corp.	1991	Interconnection of Simply-Supported Girder (2and3-Spans)	LRB
Sakai Route	Osaka	89.5m	Hanshin Expressway Public Corp.	1993	Interconnection of Simply-Supported Girder (4-Spans)	LRB

Table 10 Research Theme and Organizations of New Joint Research Program on Seismic Control of Long−Span Bridge

Research Theme		Research Group																				
				Material Makers				Bridge Fabricaters			General Contractors						Consulting Firms					
		P	PC	OI	BS	YG	NJ	IH	KH	OB	OR	KA	KU	SU	TA	PS	OC	KC	KG	NG	PA	YE
Development of New Materials and Passive and Active Control	Application of Super Low Yield Strength Metals	○	○	○			○															
	Development of Super Plastic Rubber Dampers	○	○		○																	
	Development of Super High Damping Rubber Bearings	○	○			○																
	Development of Electro Rheological Fluid Dampers	○	○	○																		
	Development of Intelligent Knock−off Devioces	○	○							○												
	Development of Intelligent Dampers	○	○	○								○	○									
	Application of Tuned Liquid Dampers	○	○									○										
Development of New Control Design Method	Development of Evaluation Method of Damping Characteristics	○	○					○		○		○					○		○		○	○
	Optimal Control Points by Dampers	○	○					○	○						○			○			○	○
Application to Bridges	Seismic Responce Control during Construction	○	○								○											
	Development installed in Damping Materials Pavement, Curb and Handrails	○	○				○					○		○		○						
	Application to Substructures	○	○														○					
	Application to Bridges with High Pier	○	○					○	○											○		○
	Application to Suspended Slab Bridges	○	○											○		○						
	Application to Cable−Stayed Bridges	○	○							○						○		○				
	Application to Suspension Bridges	○	○																○			

P: Public Works Research Institute, PC: Public Works Research Center, OI: Oiles, BS : Bridgestone, YG: Yokohama Rubber, NJ: Shin−Nippon Steel, IH. Ishikawajima Harima, KH: Kawasaki Heavy Industry, OB: Ohbayashi, OR: Oriental, KA: Kajima, KU: Kumagai, SU. Sumitomo, TA: Takenaka, PS: PS, OC: Oriental Consultant, KC: Kaihatsu Consultant, KG: Kensetsu Gijutsu Consultant, NG: Nihon−Gijutsu Kaihatsu Consultant, PA: Pacific Consultant, YE:Yachiyo Engineering Consultant

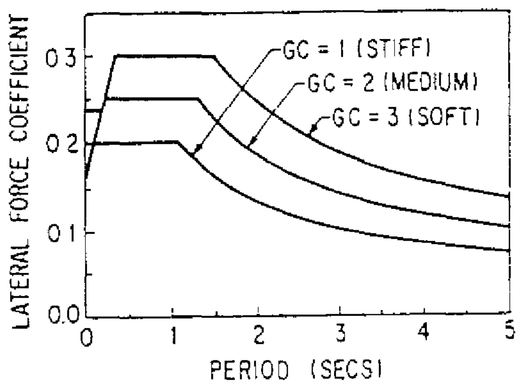

Fig. 1 Lateral Force Coefficient for Seismic Coefficient Method ($c_z = c_t = 1.0$)

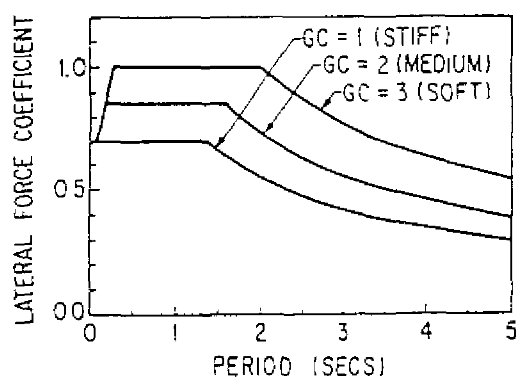

Fig. 2 Lateral Force Coefficient for Bearing Capacity Method ($c_z = c_t = 1.0$)

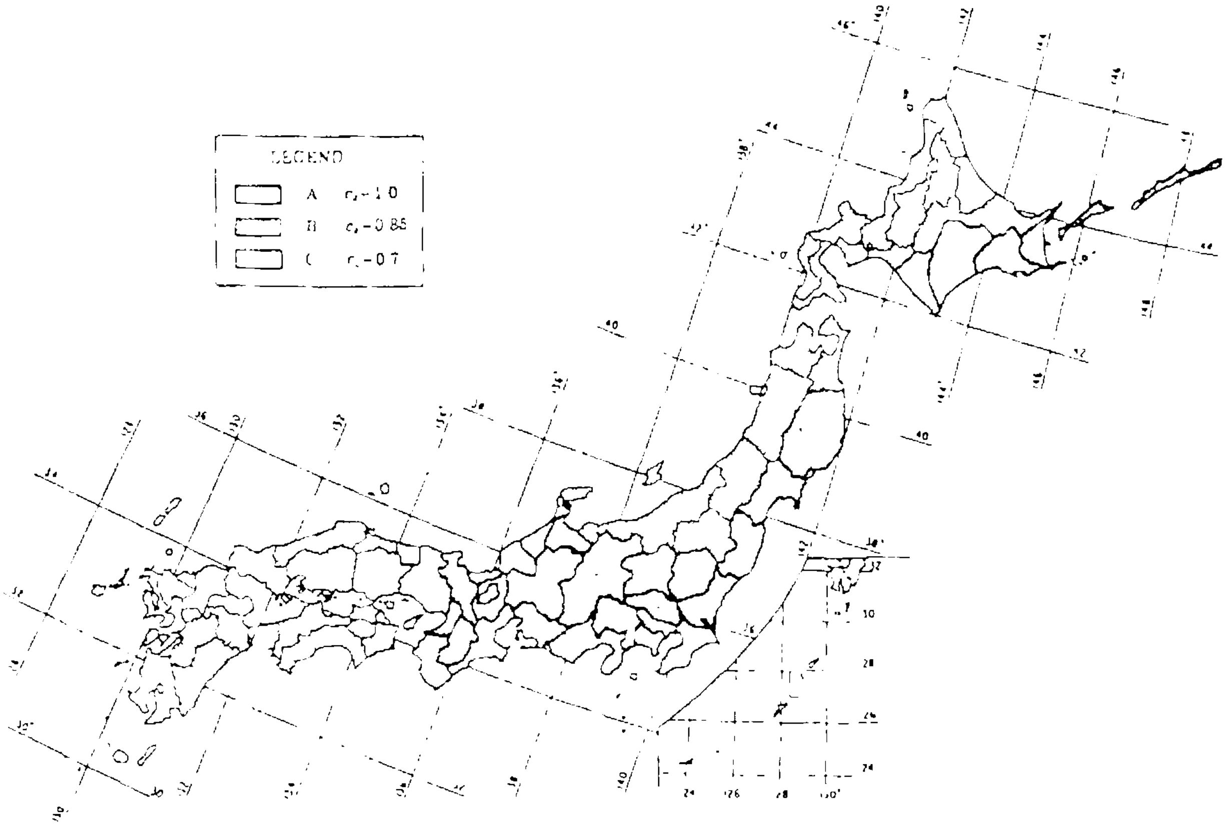

Fig. 3 Modification Factor for Zone c_z