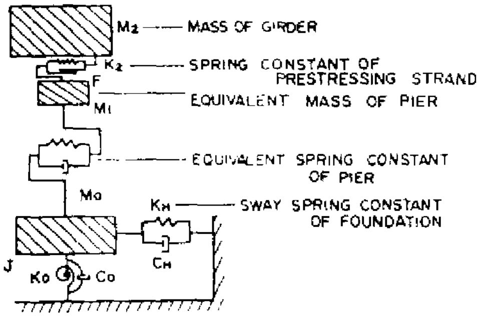
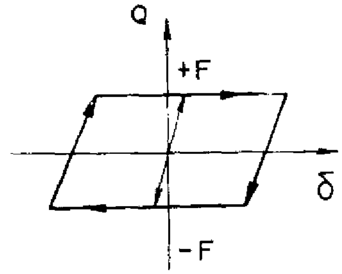


(a) Structural Model



(b) Nonlinear Hysteretic Model Representing Friction at Saddle and Stiffness of Prestressed Strands

Fig. 9 Analytical Idealization of SU Damper

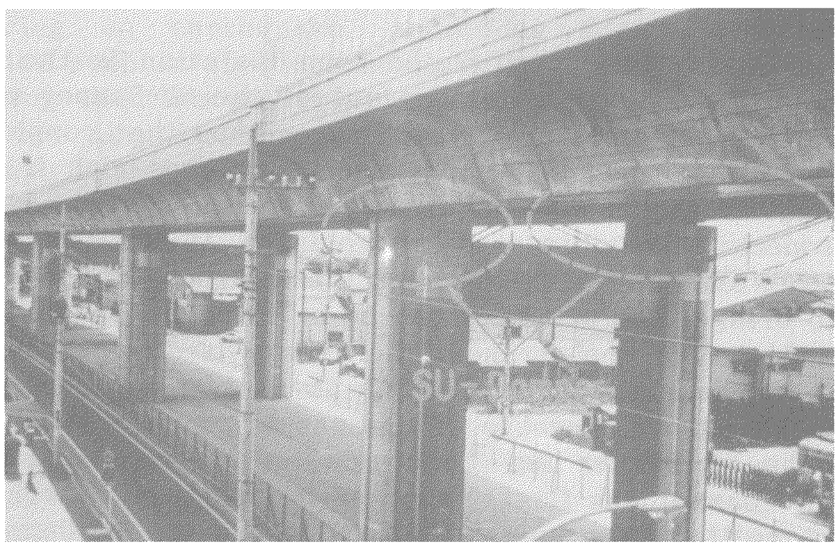
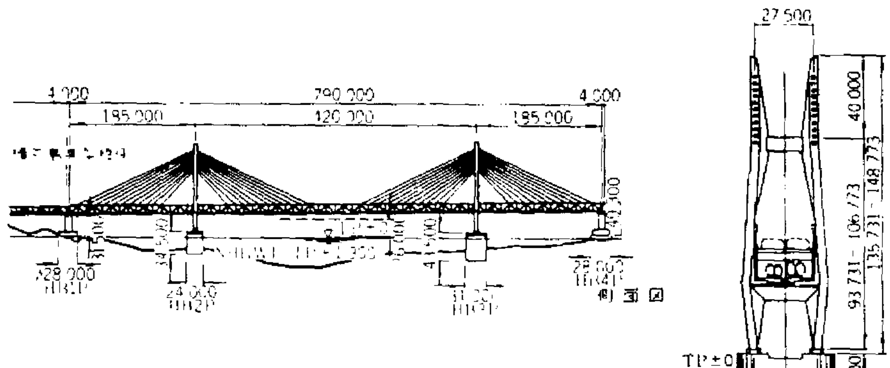
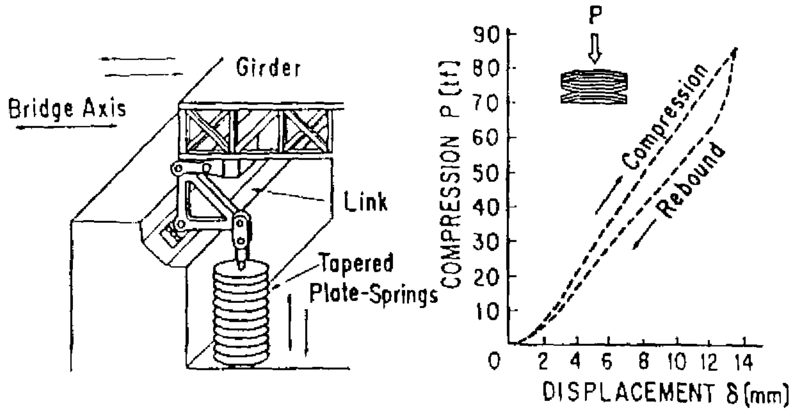


Photo 4 Bridge with SU Damper, Ukizuka Viaduct

Elongation of natural period has been adopted as a measure to reduce seismic lateral force, in particular for cable stayed bridges. Various devices have been developed to elongate natural period of cable stayed bridges. Deck was either isolated from tower (Ref. 19) or supported by links (Ref. 20) for making the deck being free to move in longitudinal direction. For either adjusting the natural period or preventing excessive deck movement, special devices h as springs (Ref. 21) and prestressed strands (Ref. 22) were used. **Fig. 10** shows an example of such attempt in which the deck was supported by plate springs at the end.



(a) General View



(b) Device Consisting of Plate Springs

Fig. 10 Adoption of Elastic Spring to Prevent Excessive Deck Movement Associated with Elongation of Natural Period (Hitsuishi-Iwaguro Bridge)

<u>Distribution of Lateral Force</u> Multi-span continuous highway bridges are likely to be constructed recently with demand of decreasing the number of expansion joints, which make annoying vibration and are vulnerable to traffic load, in order to secure comfortable driving with flat road surface and be released from bothersome maintenance work of the joints. Furthermore, multi-span continuous bridges are known to be more earthquake-resistive from past seismic experiences since they have larger degrees of redundancy than simple supported girder bridges.

However, the seismic lateral force in longitudinal direction for multi-span continuous bridges becomes extremely large as the number of the spans and/or the length of each individual span is extended. Traditionally, the lateral force was concentrated to a single substructure with a fixed bearing and the other substructures support only the vertical dead weight of the girder with movable bearings. However, the size of the single fixed substructure often becomes excessively large from the practical design point of view. To avoid such concentration of lateral force to a single substructure, various devices including rubber bearings have been developed and put into practice.

Distribution of lateral force to substructures can be performed by several methods (Ref. 14). The simplest method is to support the girder by fixed bearings at every piers. Although indeterminate lateral force will be developed due to the elongation and shrinkage of the girder by thermal change, this method may be adopted unless the effect of the force is critical to design substructures. A highway bridge having as many as twelve continuous spans with a total deck length of 507 m has already been constructed (Ref. 23).

The second way is use of rubber bearing. Lateral stiffness of the rubber bearing can be easily adjusted by changing the rubber thickness or rubber material to intentionally modify the distribution ratio to each substructure. Many multi-span continuous bridges have been successfully constructed with use of rubber bearings for distribution of lateral force (Ref. 24). The third way is to adopt a viscous damper as described above.

PERSPECTIVE OF "MENSHIN DESIGN" IN JAPAN

Although elongation of the natural period and increase of energy dissipation capability of a structure are key factors in base-isolation, the elongation of the fundamental natural period for highway bridges leads to large relative displacement between the girder and the substructures, and requires the special expansion joints with large displacement capacity. Because the elongation of natural period has been attempted for cable stayed bridges, further technical development would be made. However for ordinary highway bridges in multi-span continuous type with span length of 10 m to 50 m, it is not appropriate to elongate the natural period so forcibly as in buildings, deeply related with various reasons constrained to highway bridges in Japan.

First reason is softer soil condition. Because most of populated areas are located on alluvial fan deposits, soils are very weak. Second reason is the high seismicity accompanying large earthquakes with magnitude over 8. These large earthquakes caused considerable damage in the past. Reflecting the occurrence of destructive earthquake as well as the worse soil condition, lateral force coefficient as shown in **Figs. 3** and **4** are very high up to long natural period.

Third reason is difficulty to widen the clearance between decks. From the demand of driving comfort, maintenance problems and release from annoying noise and vibration, various efforts have been paid to develop expansion joint with small clearance. Even the regular expansion joints currently used cause considerable problems, 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 be taken place. Actually collision frequently took place during the past earthquakes (Ref. 25). It should be noted from these past experiences that collision did not cause critical structural problems although expansion joints were often badly damaged. Although collision caused failure at contact face (Ref. 25) and/or bearings and stoppers, they were not serious. Although bearings have not been intentionally designed taking account of the fact that they would be damaged during a destructive earthquake, they did behave as a "fuse" to prevent the transmission of larger lateral force than that considered in seismic design. Therefore it may be said that the failure of bearing have been behaved as "isolator" (Ref. 26).

Now turning to the fourth reason, did collision cause serious problem to highway bridges ? The answer is "no" ! As long as enough seat length was provided, it caused no serious structural damage such as falling-off of superstructure. Attention has to be paid only when two adjacent decks with considerable different mass collides. In such case, the heavier deck tends to push the lighter deck, and damage is likely to be developed at the bearings and piers supporting the light deck (Ref. 25). Although the energy dissipating effect is not included in the current seismic design method, it constrains the deck response. It is effective to constrain deck response at early smaller stage of deck movement (Refs. 27, 28, 29). Therefore the superiority for causing collision would become clear if the energy dissipation and constrain of deck movement at small response stage were considered.

Based on these considerations, it seems preferable not to intentionally increase natural period and not to widen the gap clearance at joints in highway bridges in Japan. Therefore instead of intentionally increasing natural period, combination of increase of energy dissipating capability and distribution of seismic lateral force is considered to be preferred to highway bridges in Japan. It may be important to adjust natural period to avoid resonance with ground. This is an extension of the existing seismic design concept of 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" (Ref. 5). Although the original meaning of "menshin" in Japanese is "base isolation", it is a little bit different with "base isolation" in design concept.

The followings are the basic principles considered required to activate menshin design in ordinary size of highway bridges in Japan :

1) Distribution of lateral seismic force should be attempted by adjusting the lateral stiffness of menshin bearings, while the lateral seismic force would be reduced by improving the energy dissipating capability with use of menshin bearings.
2) The fundamental natural period of menshin bridge should be adjusted to avoid the resonance with the ground, being balanced with the distribution effect. Attempt for elongating natural period so forcibly as buildings should not be made.
3) The menshin effect should be used not to make dimension and size of substructures small, but to improve the seismic performance of bridges.
4) Gap at an expansion joint should not be widened in menshin bridges, although a little larger relative displacement is expected to be developed between a girder and substructures during a destructive earthquake.
5) 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.
6) The menshin design should be encouraged to construct super-multi-span continuous bridges with the effect of lateral force distribution.

EXISTING AND CURRENT EFFORTS FOR MENSHIN DESIGN

Guidelines for Base Isolation Design of Highway Bridges For studying the application of base 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 is the first public activity for the base isolation of highway bridges in Japan. Three programs were studied in the committee, i.e., 1) survey of base isolation devices which can be used for highway bridges, 2) study on the key points of the base isolation design of highway bridges, and 3) trial designs of base isolated highway bridges. As the final accomplishments of the three year study, "Guidelines for Base Isolation Design of Highway Bridges (Draft)" was published in 1989 (Ref. 30).

Pilot Construction Program of Menshin Bridges Five pilot menshin highway bridges as shown in **Table 3** are under construction or completed under the supervision of the Ministry of Construction in order to verify the performance of the menshin highway bridges (Refs. 31,32,33). A working group is formulated in the Ministry of Construction for supervising the design and construction. One of them, Miyagawa Bridge in Shizuoka-ken, was completed and opened for the public traffic in March 15, 1991 as the first menshin highway bridge under the program (Ref. 32). Some other bridges following the first five are in design stage.

Table 3 Construction Program of Menshin Bridge

Owner	Name of Bridge	Type of Superstructure	Total Length
Hokkaido developing Bureau	On-netoh Bridge	Steel Girder	456 m
Tohoku Regional Construction Bureau, MOC	Nagakigawa Bridge	Steel Girder	97 m
Iwate-ken	Maruki Bridge	Prestressed Concrete	92 m
Tochigi-ken	Daiichi Karasuyama Bridge	Prestressed Concrete	250 m
Shizuoka-ken	Miyagawa Bridge	Steel Girder	110 m

Joint Research Program on Menshin Bridges The three-year joint research program on the menshin highway bridges is now under way between Public Works Research Institute and twenty eight private firms since July 1989 (Refs. 5, 34). The goal of the program is to develop the menshin design method and the new menshin devices for highway bridges in order to improve the seismic performance of new and existing bridges with less cost. **Table 4** shows the research items and the contribution of each organization. The program will be accomplished in March 1992. "Design Manual of Menshin Design of Highway Bridges" is to be composed as fruits of the research program. There are four research topics in this joint program:

Table 4 Research Items and Organization of Joint Research between Public Works Research Institute and 28 Private Firms for Developing Menshin Systems for Highway Bridges

Research Theme	P	Ka	Si	Ob	Ku	Tn	H	Ni	Su	M	G	Or	Ti	I	Nk	Ko	Ns	Ol	Y	To	Bs	Bb	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, Sh: Showa Densen, Pc: Pacific Consultants, J: Japan Engineering Consultant, N: New Structural Engineering Consultants.

1)Development of new menshin devices

The menshin devices for highway bridges have to be more compact and more weather-proof than the base-isolation devices for buildings since the menshin devices would be installed at narrow and exposed crests of bridge columns. The new menshin devices should be developed exclusively for menshin highway bridges to be effectively constructed. The following ten new devices in the six types are now being developed under the research program.

1) high damping rubber bearing -------------------- 4 devices
2) sliding friction damper -------------------------- 2 devices
3) steel damper -------------------------------------- 1 device
4) roller menshin bearing -------------------------- 1 device
5) link bearing --------------------------------------- 1 device
6) viscous damper ----------------------------------- 1 device

All developed menshin devices but the link bearing were tested with use of the dynamic loading systems of PWRI under the same loading conditions to verify their performance as shown in **Photos 5** and 6.

2)Development of expansion joints and restrainers for menshin bridges

The knock-off mechanism at an abutment to ease the impact force induced by the collision between the superstructure and the abutment, and the finger expansion joints which is distinguished from the regular finger joints by the transverse movement, are being developed. The restrainer which consists of the steel bar installed in the crest of the substructure and the steel casing with rubber inside is also being developed.

3)Development of menshin design method

Taking into account the high seismic activity and the philosophy of seismic design in Japan, the flow chart of the menshin design method illustrated in **Fig. 11** are proposed, in which two levels of design force are considered as limits states. The first level, called as Level 1, is equivalent to the design seismic force considered in the current static lateral force method (refer to **Fig. 3**). This represents the force level developed by moderate earthquakes. The second level, called as Level 2, is equivalent to the design seismic force for the check of the bearing capacity of the reinforced concrete columns for the lateral force (refer to **Fig. 4**), and this corresponds to larger earthquakes such as the 1923 Kanto Earthquake.

4)Application of menshin design

The menshin multi-span continuous bridge with the deck length over 1 km, which is called in the research program as a super multi-span continuous bridge, is examined as a crucial research item. Connecting of existing simple supported girders to lessen the number of troublesome expansion joints, and retrofitting of existing bridges to increase the seismic bearing capacity by using menshin bearings are also studied in the research program.