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# Inspection of Tokyo Elevated Expressway Bridges against Earthquake

Surveillance du réseau routier urbain surélevé de Tokyo en vue de séismes

Untersuchung und Unterhaltung von Hochstrassen in Tokio unter Berücksichtigung von Erdbeben

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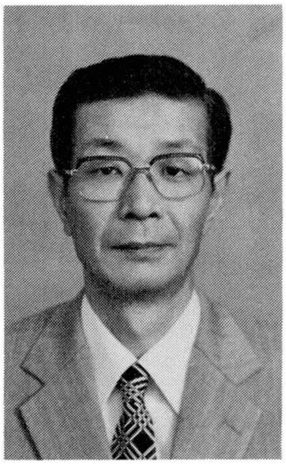


Tsutomu Komura, born in 1935, graduated from the University of Hokkaido at Sapporo, in 1958, and joined the Kanagawa Government from 1958 to 1960. For 22 years he has been contributing at the MEPC to designing, constructing and maintaining the bridges in the Tokyo metropolitan area.

## SUMMARY
The Tokyo metropolitan expressways are toll highways which form a network in Tokyo and are composed mostly of elevated bridges. The Corporation perseveres in an effort to keep them in a favorable condition. Moreover, Tokyo is subject to so frequent earthquakes that the preparedness and measures against them have been provided for in the expressways. The inspection and maintenance work will be discussed in this paper emphasizing the measures against earthquakes.

## RESUME
Le réseau autoroutier urbain à Tokyo est construit principalement sur des viaducs, que la Compagnie publique des autoroutes métropolitaines s'efforce de maintenir en bon état. Pour tenir compte des conditions propres à la région où des tremblements de terre surviennent souvent, des mesures anti-sismiques préventives ont été prises pour les autoroutes. Le rapport fait le point sur la surveillance et les travaux d'entretien entrepris dans le cadre des mesures de prévention des tremblements de terre.

## ZUSAMMENFASSUNG
Die Tokio Metropolitan Expressways sind gebührenpflichtige Stadtautobahnen und bestehen zum grossen Teil aus Hochstrassen. Das Autobahnamt unternimmt viel, um sie gut zu unterhalten. Da sich in Tokio häufig Erdbeben ereignen, sind verschiedene Vorbereitungen und Massnahmen bezüglich der Hochstrassen getroffen worden. Dieser Beitrag behandelt Inspektion und Unterhaltung von Brückenbauwerken unter Berücksichtigung von Erdbebenereignissen.

## 1. OUTLINE OF THE TOKYO METROPOLITAN EXPRESSWAYS

It was the most important for Japan in 1950s to improve the condition of roads and to alleviate traffic congestion. Under such a condition, the "Law on Urgent Measures for Road Improvement" was promulgated in March, 1958. Since the traffic condition in Tokyo was the worst in those days, in line with these government measures, the Metropolitan Expressway Public Corporation (MEPC) was established on June 17, 1959, based on the "Metropolitan Expressway Public Corporation Law" to further the improvement of roads in central Tokyo and its vicinity.

The Tokyo metropolitan expressways are toll highways which form a network in the Tokyo metropolitan area. They are solely express traffic, are separated from business streets and have no level crossings. The main object of them is to smooth traffic for relatively short distance in the Tokyo metropolitan area.

The first expressway was opened on December 20, 1962. Later, the expressways were constructed and scheduled to be extended one after another not only in central Tokyo but also in nearby Kanagawa, Saitama and Chiba prefectures. At present, the expressways total 152.5 kilometers comprising 21 routes. The total number of automobiles using them up to the present has reached about three billion, and the expressways are now used by about 800,000 vehicles daily. In a section, 150,000 vehicles are counted as the highest volume in both directions in a day. Moreover, the expressways under construction are 10 routes with 67 kilometers in length, and new routes under study are over 100 kilometers. This state of the Tokyo metropolitan expressways is shown in Fig 1.

Tremendous sums of money are needed to execute such a big construction work of the expressways and to maintain them. Main financial resources are given through the flotation of the Tokyo metropolitan expressway bonds. These bonds should be redeemed over certain periods (usually thirty years) through collection of tolls after service to the traffic. Now daily receipts from the expressways are over 260 million yen.

The structures of the expressways are designed based on the "Road Structure Ordinance". Most sections of the expressways have two lanes in each direction, and are designed for a design speed of 60 km/h. The Bay-shore route and some of suburban sections are designed for a design speed of 80 km/h, having three lanes or two lanes respectively.

The expressways can be classified by structures as shown in Fig 2. The urban areas in a big city are generally crowded buildings, stores and houses, and land price is very expensive. In acquiring land for the expressways, the Corporation avoids privately owned land as far as possible, using public land instead, such as existing streets, rivers and reclaimed areas. The most part of the expressways are built on the existing streets. That is why the elevated expressway system is adopted, and the expressways may be considered as a series of bridges. A typical section of them is shown in Fig 3.

The Tokyo metropolitan expressways play a very important role in the transportation system of the Tokyo metropolitan area. For this assignments, road structures of the expressways should be always kept in a favorable condition. But their full volume of traffic does not permit partial daytime closure. Maintenance work is therefore done mostly by closing one lane late at night and in the early morning when traffic volume is less. The Corporation has developed a maintenance system which expends as much as seventeen billion yen a year on maintenance, repair, rehabilitation and upgrading of the expressways, mainly bridge structures.

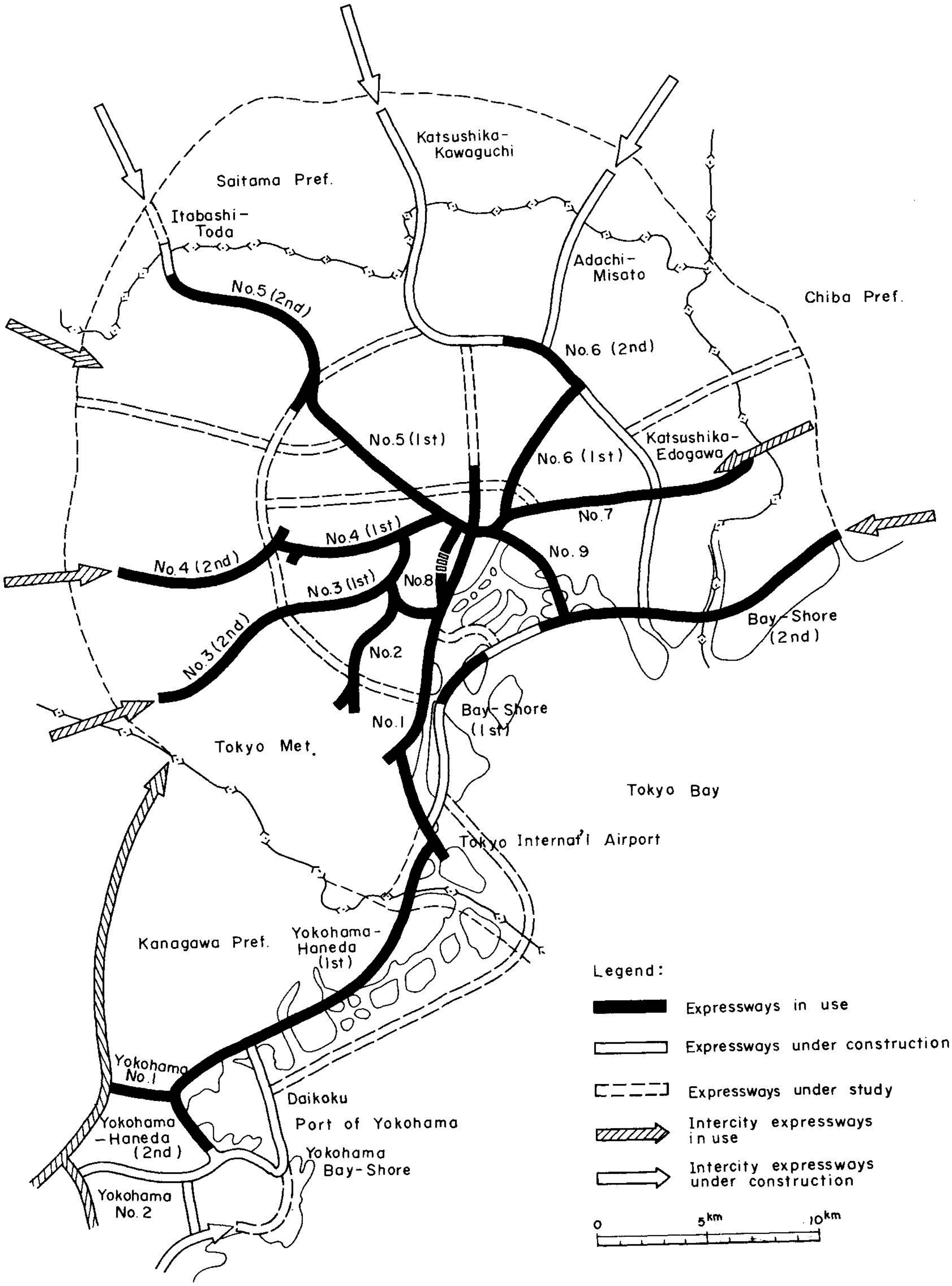



Fig 1 Network of the Tokyo metropolitan expressways

The bridge structures of the expressways are built to withstand earthquakes of considerable magnitude as strong as the Kanto Earthquake of 1923. As a further safe measure, addition to the above maintenance work, the upgrading work of the bridges against earthquake is carried out following various inspections.

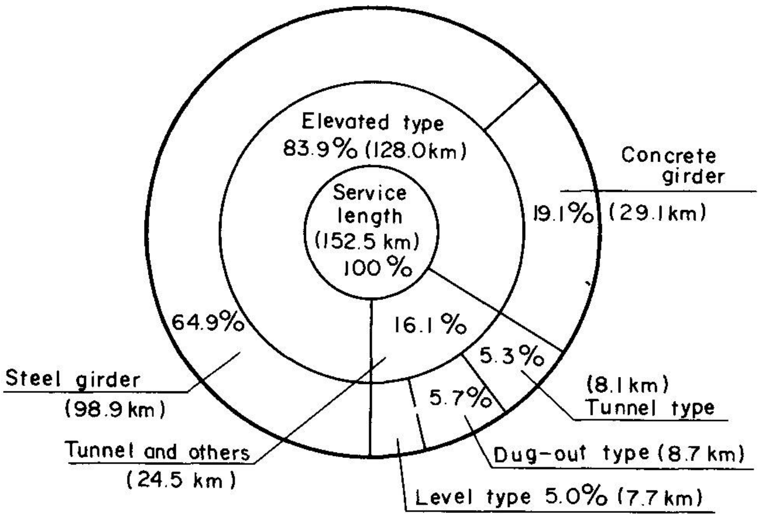



Fig 2 Structural types of the expressways

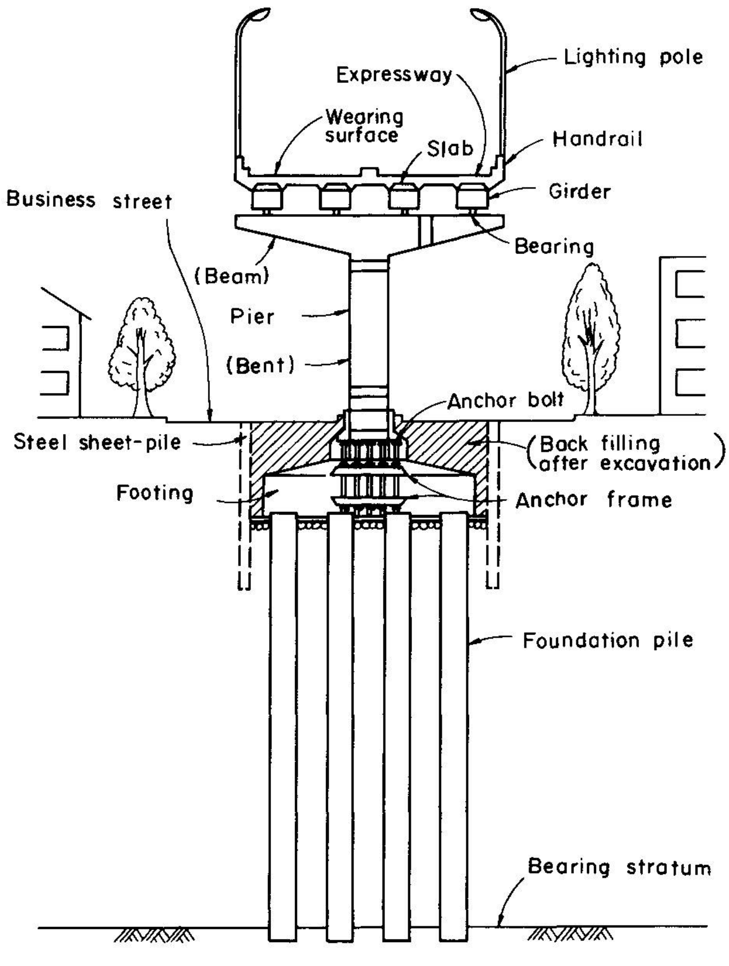



Fig 3 Typical section of the expressways

## 2. INSPECTION AND MAINTENANCE OF THE BRIDGES ON THE EXPRESSWAYS

### 2.1 Routine maintenance work

Main works of the maintenance of the Tokyo metropolitan expressways at earlier stage were to clean the road surface daily, to change bulbs of lighting poles, to upkeep the capacity of the road facilities and to restore the road structures damaged due to collison by motor vehicles.

After some years, primary maintenance works were added to them. They were repainting or coating of steel girders and piers, repair of wearing surface, disposal of water leakages, exchange of expansion joints damaged due to accumlated traffic volume and so on. In addition, due to the superannuation of structures, the increase of traffic volume and the increase of the large sized vehicles, the necessity of repairs of the bridge structures was increasing. Under such a condition, reinforced concrete deck slab has extensively deteriorated. The concrete slabs were strengthened a new stringer between two existing girders or pouring epoxy resin into crack. Its work continues still now. And the concrete girders or piers were also found to crack. They were rehabilitated by various methods.

Availing of the Niigata Earthquake of 1964 and the San Fernando Earthquake of 1971, anti-quake measures for designing were reviewed. It became the important work to provide the devices for preventing superstructures from falling down during earthquake as mentioned in Chapter 5.

Year by year, the increase of traffic volume on the expressways has kept traffic flow worse. To insure an adequate flow of traffic under this condition, the Corporation conducted various measures for traffic control; i.e. to increase emergency parking bays on the expressways and sloping access exit ramps, to widen the width of the expressways, to adjust traffic volume by lane control at merging zones on the expressways, etc.

Recently it becomes necessary to pay an attention to such environmental hazards of motor traffic as noise and vibration. To solve these problems, the Corporation installs appropriate facilities such as noise barriers on the handrails along the residential areas. With regard to vibration, surface pavement and expansion joints are improved. The exchange of deteriorated expansion joints is also effective against noise. As mentioned before, most of repair works are done at night. Noise of the works becomes a problem. The works are desirable to be finished before general bedtime or to be done without noise. The Corporation is developing the execution method or machine with little noise or without noise.

Many underground facilities which maintain the city functions rush in the roads because of less public space in a big city, and the number of them is extraordinarily large in Tokyo. They are subrailways, water and gas mains, telephone cables, high-voltage power transmission lanes and sewerage pipes. As the expressways extend in service length, they often become constructed close to the expressways. To protect the structures of the expressways in these cases is the important work.

It snows rare in Tokyo. But the road surface of the expressways is easy to get freez on snowy weather because they do not have the subterranean heat due to their elevated type of structures. It is difficult to remove snow or to scatter de-icing salts quickly because the expressways extend radially to suburb with no detour, moreover have congestion in entrances. Then an effective method for it is developed.

Fortunately, the serious defects concerning structures such as girders and piers have been rarely observed in the expressways. But the expressways more than 100 kilometers are ten years old in service, and they will have any defects due to the superannuation of structures under severe conditions. The Corporation is developing easier, more advanced and effective maintenance method. The main maintenance works for the structures of the expressways are as follows;

*Maintenance -- Scavengery (road surface, guide sign, pier, etc)
-- Inspection (structure, road surface, road facility, etc)
*Repair -- Repair (wearing surface, expansion joint, paint, downspout, guide sign, etc)
-- Rehabilitation (girder, pier, bearing, foundation, deck slab, handrail, etc)
*Upgrading -- (noise barrier, fall-proof device, emergency exit, emergency parking bay, etc)

## 2.2 Inspection works

The inspection work of the Tokyo metropolitan expressways is an essential part to keep the roads in good condition at all time. Inspection program at present is more systematic and effective than it in early stage.

Inspection is roughly grouped into two kinds. One is inspection by checking design data (data inspection) and the other is in-site inspection. It passed over 20 years since the beginning of construction of the expressways so that the applied standards for design, construction and materials were often revised. There are some structures which are in no conformity with the present standards, and they are certainly to be deteriorated under changing condition. The Corporation has enourmos amounts of drawings and sheets of calculations on design procedure of elevated bridges which are kept on micro-film or fiche, and now are being stored in the computer. Data inspection is to check these data and to pick up the structures under critical condition both analytically and experimentally. Such structures are to be investigated through in-site inspection.

In-site inspection is grouped into three; patrol, periodic and special inspection. Patrol inspection is the most widely used method. It is made by trained inspectors from cars running on the expressways or on the surface streets below the expressways through visual investigation. This inspection is very rough one, but the Corporation perseveres in efforts to detect any defects and to maintain traffic lanes in a serviceable condition.

Periodic inspection is to examine the structural details carefully and closely with eyes, photos and some instruments from on scaffolding or mobile platforms. This inspection is usually undertaken by annual plan based on data inspection. And if any defects are found by patrol inspection, the successive surveillance of the structures is added to it.

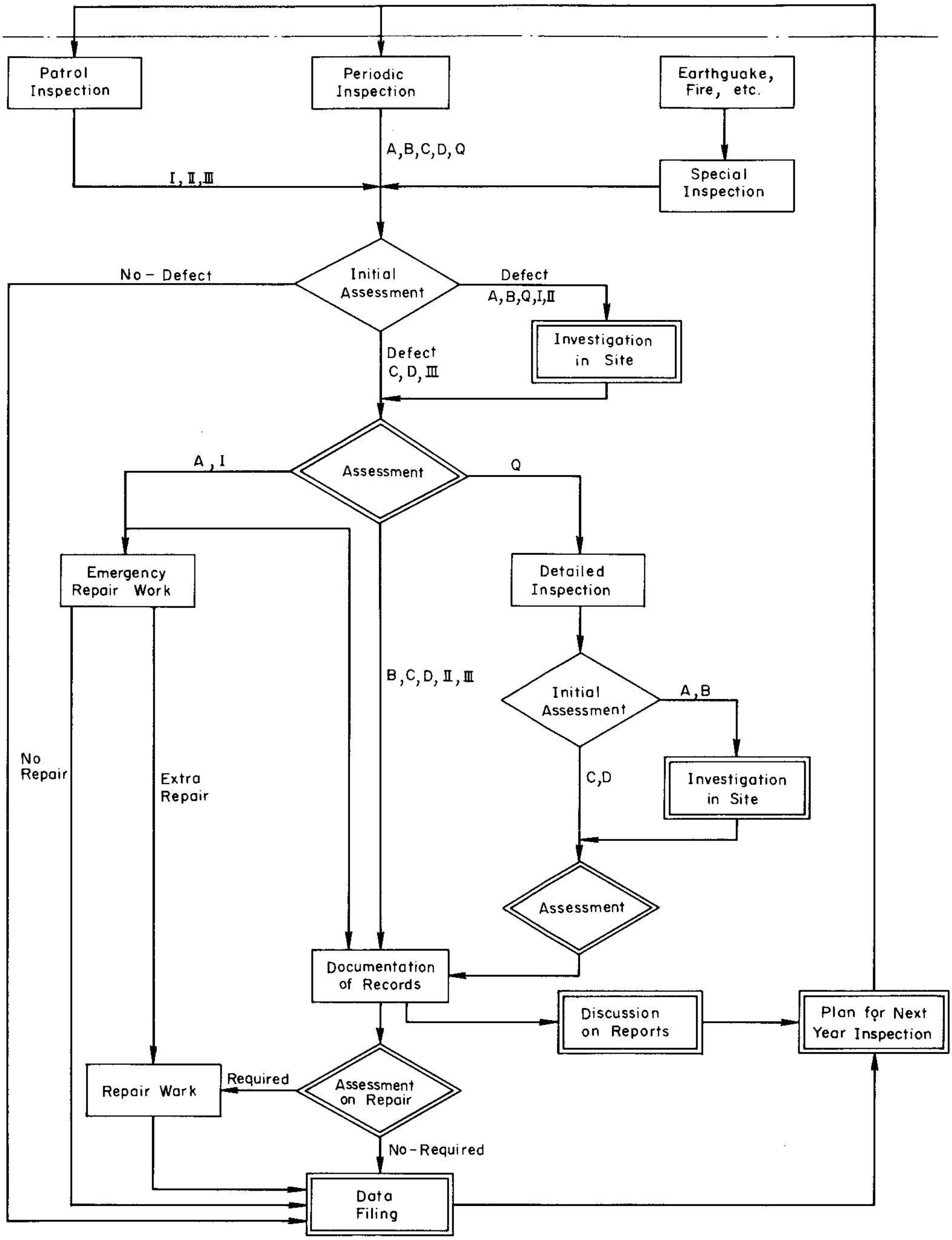
Special inspection is done whenever critical circumstances such as earthquake, fires or vehicles impacts affect the structures of the expressways.

A procedual flow diagram of these inspections is shown in Fig 4. Severity of defects written in Fig 4 is as follows;

Assessment of patrol inspection is classified into I, II and III.

(I) Defects which give serious trouble to traffic or affect people below the elevated bridges
(II) Defects which give some trouble to traffic or affect environmental impacts on the residents along the elevated bridges
(III) Defects which give a little trouble to traffic

Assessment of periodic inspection is classified into A, B, C, D and Q.




Notes: ▭ ◇ = Works by officers of the corporation

A,B,C,D,Q I, II, III } = Severity of defect given in the paper

Fig 4 Procedural flow diagram of inspection

| Kinds of inspection | Structures | Concrete structures | | | Steel structures | | | Wearing surface | Joints | Handrail | Floor slabs | Bearings | Paint | Emer-gency exits | Aseismic devices | Others | Intervals of inspection |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Girder | Pier | Tunnel | Girder | Pier | Bolt | | | | | | | | | Drainage, noise barrier, etc. | |
| Patrol inspection | Frome the traffic lane (Daytime) | Visual inspection from the patrol car running on the expressways ( mainly serviceability for traffic ) | | | | | | | | | | | | | | | Once a day |
| | 〃 (Night) | 〃 ( lighting poles, guide signs, etc. ) | | | | | | | | | | | | | | | Once a week |
| | From the ground (Daytime) | Visual inspection from the patrol car running on the surface streets ( the under surface side of the bridges ) | | | | | | | | | | | | | | | Once a week |
| Periodic inspection | Visual inspection from the ground (mainly on-foot) | ○ | ○ | ○ | ○ | ○ | ○ | | △ | △ | ○ | △ | ○ | △ | △ | △ | Once a year |
| | Photo or visual inspection from the ground | ○ | △ | | △ | △ | △ | | | △ | | ○ | △ | | | | Every five ~ seven years |
| | | | | | | | | | | | ○ | | | | | | Every six years |
| | Photo or visual inspection from the traffic lane | | | | | | | | | ○ | | | | | | | Every five years |
| | | | | | | | | ○ | △ | | | | | | | | Once or twice a year |
| | Inspection from scaffolding or mobile platforms | | | | ○ | ○ | ○ | | △ | △ | ○ | ○ | △* | | ○ | △ | — |
| | | △ | ○ | | △ | ○ | △ | | △ | | △ | ○ | | | | | ( Near pier ) Every ten years for steel Every five years for concrete |
| | Inspection by instrument | | | | | | | | ○ | | | | | | | | Twice a year |
| | | | | | | | ○ | | | | | | | | | | Every ten years |
| | | | | | | | | ○ | △ | | | | | | | | — |
| | Successive surveillance of crack, etc. | ○ | ○ | ○ | | | | | | | ○ | | | | | | Twice a year |
| Special inspection | | Case by case | | | | | | | | | | | | | | | When earthquake, fire, etc. adversely affect the structures |

Note : ○ = Full inspection

△ = Partial inspection

* = Inside of box girder

Fig 5 Combination of inspection

(A) Serious defects needing emergency repair
(B) Defects needing repair in near future or attention in repair
(C) Slight or incipient defects needing to record in the document
(D) Slight defects needing not to record in the document
(Q) Defects needing successive surveillance through further inspection - when the cause of them is ambiguous.

In special inspection, the same assessment rate as aboved is used depending on the circumstances because the cause of defects is clear.

Periodic inspection is so well combined that the structures are effectively inspected through various points as shown in Fig 5. The route and the structure to be inspected are determined by the results of data inspections or in-site inspections in the past, with general intervals as shown in Fig 5. Since there are major similarities in types and caracteristics of elevated structures of the expressways, the condition of such structures can be grasped without full inspection for every structures. When some defect is discovered in a structure, the cause of it is detected. If the causes of the defects are common to structures and the same defects often happen, all similar structures are to be inspected immediately or in near future in degree of defect.

The portion of the structures to be inspected, the item to be observed and the instruments to be used are generally preserved due to the types of the structures. Assessment way and rate are so arranged numerically that there is no difference among various inspectors.

## 3. HISTORICAL VIEW OF ASEISMIC DESIGN PROVISIONS ON HIGHWAY BRIDGES

### 3.1 Provisions before 1980

When the Tokyo Metropolitan Expressway Public Corporation was established, aseismic provisions on highway bridges in Japan was included in the "Specifications for the Design of Steel Highway Bridges (1956)" issued by the Japan Road Association (JRA). In these provisions, the horizontal design seismic coefficient was taken from 0.10 to 0.35 depending on areas and ground conditions. The vertical design seismic coefficient was also specified as 0.10. But the bridges were generally designed using 0.20 as horizontal coefficient and 0.10 as vertical coefficient respectively as same as in the past.

There were no original provisions when the Corporation started his construction work. But each designer of the Corporation had adopted 0.30 as horizontal coefficient ($K_h$) and 0.10 as vertical coefficient ($K_v$) considering that the expressways were only constructed in the Tokyo metropolitan area and on the relatively soft ground, and they would be the most important routes to maintain the capital functions. The expressways designed in this stage were the route Nos 1 and 4.

In 1963, the Corporation had togethered the design criteria which left to the discretion of designers, and established the "Design Standards for the Structures". They contained a chapter for aseismic design, and $K_h$ and $K_v$ were specified to be 0.20 to 0.30 and 0.10 respectively. However, the bridge structures were conventionally designed by 0.30 in $K_h$. Moreover, another idea was introduced in these standards; i.e. fundamental natural period of structural system was compared with predominant period of the subsurface ground which was computed from a period frequency curve based on the measurement results of micro tremor of the subsurface ground, and, if both had no fear of resonance, the lower design seismic coefficients would be adopted. This idea was applied to some bridges with long fundamental natural period of structural system. It was another remarkable point of these standards that a divice to prevent an excessive displacement on a movable support should be provided in steel girders. The elevated bridges on the route Nos 2, 3 and 5 in the west part of Tokyo were designed by these standards.

As the expressways were constructed widely in Tokyo, the data concerning the ground conditions in the various part of Tokyo were brought together. In 1967, the Corporation issued new "Aseismic Design Standards" in which the design seismic coefficients were given depending on ground conditions and structural types as below.

Table 1 Design seismic coefficients

| | | Type of ground* | | | |
|---|---|---|---|---|---|
| Seismic coefficients | | I | II | III | IV |
| Horizontal coef. | For structures above the ground surface | 0.20 | 0.24 | 0.27 | 0.30 |
| | For structures below the ground surface | 0.15 | 0.18 | 0.20 | 0.23 |
| Vertical coefficient | | 0.10 | | | |

* The numbers indicating the types of grounds correspond to the numbers given in Table 2.

Table 2 Classification of grounds

| | Ground conditions of alluvium and Kanto loam layer | | | |
|---|---|---|---|---|
| Thickness of alluvium and Kanto loam layer | Sand & gravel | Sand, clay & Kanto loam layer with $N \geq 5$ | Soft ground | |
| | | | $2 \leq N < 5$ | N** $< 2$ |
| 0 - 3 m | I | Foundations should be constructed after completely removing this thin layers | | |
| 3 - 10 m | III(II)* | III(II) | IV(III) | IV(III) |
| 10 - 25 m | III(II) | IV(III) | IV(III) | IV(IV) |
| Greater than 25 m | IV(III) | IV(III) | IV(IV) | IV(IV) |

* The number in parentheses maybe used as the type of ground if rigid foundations are used.

** An N-value is defined as the number of blows necessary to produce a penetration of 30 cm when a hammer weighing 63.5 kg is dropped onto the standard sampler from a height of 75 cm.

On the other hand, it was stipulated that dynamic earthquake response analyses should be adopted for the bridges which were constructed on the extremely soft soil layer, or for which detailed investigations were required. In those days, the route Nos 6 and 7 in the east area of Tokyo with softer soil layers and the Haneda-Yokohama route were designed.

With viewed from damages to the bridges by the Niigata Earthquake of 1964, the Ministry of Construction made haste for issuing new aseismic code. Referring to the standards of the Corporation, the JRA enacted the comprehensive code against earthquake, i.e. the "Specifications for the Earthquake Resistant Design of Highway Bridges" in 1971. The conventional idea against earthquake was basically revised in these specifications. These specifications provided two methods in determining design seismic coefficients. One was the conventional seismic coefficient method. The horizontal design seismic coefficient $K_h$ was specified as below;

$$K_h = v_1 \cdot v_2 \cdot v_3 \cdot K_o \quad \text{-----------} \quad (1)$$

where $K_h$ : Horizontal design seismic coefficient
$K_o$ : Standard horizontal design coefficient (0.20)
$v_1$ : Seismic zone factor depending on the area divided Japan into three parts due to earthquake-prone degree (0.70 to 1.00)
$v_2$ : Ground condition factor classified in four groups (0.90 to 1.2)
$v_3$ : Important factor, 1.00 for trunk roads and 0.80 for general roads, but maybe increased up to 1.25 for a special case.

The other was modified seismic coefficient method which was applied to the bridges with highraise piers more than 25 m. In this case, the horizontal design seismic coefficient $K_{hm}$ was specified as below;

$$K_{hm} = b \cdot K_h \quad \text{----------------} \quad (2)$$

where $K_{hm}$ : Modified horizontal design seismic coefficient
$K_h$ : Horizontal design seismic coefficient specified in equation (1)
b : Magnification factor depending on the fundamental natural period of the bridge system and also the ground condition classified in four groups (0.50 to 1.25) (refer to Fig 6)

The vertical design seismic coefficient $K_v$ was usually taken as zero except for the design of bearings or the examination of stability against overturnings.

Since there were the bridges damaged in the Niigata Earthquake by liquefaction of sandy soil layers below the real ground surface, new provision for liquefaction was added to the aboves. In the layers which had or might have a potential for liquefaction during earthquake, it was stipulated that those layers should be ignored in design. The estimation method on whether or not the layer would liquefy was shown in the appendix of the specifications. Provisions for aseismic devices to prevent girders from falling down (fall-proof devices) were stipulated in these specifications at first.

The Corporation had applied these specifications to the structures of the expressways for a while. The Tokyo metropolitan area is one of the most earthquake-prone area in Japan, and then seismic zone factor was 1.00 and important factor was 1.25. But the Corporation intended to revise these specifications because these were complicated in getting design seismic coefficient. When rather high piers on the route No 9 were designed, $K_h$ became 0.38 because the route No 9 would be built on the sofest ground in Tokyo, and moreover the ground of it had a high potential for liquefaction. Such high coefficients spent expensive expenditure.

The Corporation therefore issued the "Practical Use" of the above specifications in 1973. The horizontal design seismic coefficients for the bridges with highraise pier more than 25 m and between 15 m and 25 m were fixed numerically in the "Practical Use" without applying modified Seismic coefficient method. Because there were many bridges with highraise pier between 15 m and 25 m on the expressways, and they were often critical against earthquake under applying just above specifications.

Table 3 Design seismic coefficients for superstructures and piers

| | Ground conditions | | | | Remarks |
|---|---|---|---|---|---|
| The height of pier | I | II | III | IV | |
| h ≦ 15 m | 0.20 | 0.22 | 0.24 | 0.26 | $v_3$ = 1.1, b = 1.00 |
| 15 m < h ≦ 25 m | 0.22 | 0.24 | 0.26 | 0.29 | $v_3$ = 1.1, b = 1.10 |
| 25 m < h | 0.25 | 0.28 | 0.31 | 0.33 | $v_3$ = 1.1, b = 1.25 |

Note: The value of $v_3$ may be increased up to 1.25 for special structures, i.e. 1.14 times the value of Table 3.

Table 4 Design seismic coefficients for footings

| | | Ground conditions | | | | Remarks |
|---|---|---|---|---|---|---|
| Level of footings | | I | II | III | IV | |
| I | Below the design ground surface | 0 | | | | |
| II | In the layer which may liquefy | 0.10 | 0.11 | 0.12 | 0.13 | |
| III | In the layer which have a high potential for liquefaction | 0.20 | 0.22 | 0.24 | 0.26 | $v_3$ = 1.1, b = 1.0 |

## 3.2 Current provisions

In 1980, the JRA issued new specifications, i.e. the "Specifications for Highway bridges, Part V, Earthquake resistant Design". These specifications are basically the same as of 1971 except minor changes as follows;

a. To define clearly the soil layers which are judged to be vulnerable for liquefaction using liquefaction resistance factor $F_L$

where $F_L = R / L$ ------------- (3)

R : Resistance of soil elements to dynamic loads
L : Dynamic loads to soil elements induced by earthquake motion
If $F_L$ is smaller than 1.0, the layer shall liquefy.

b. To apply modified seismic coefficient method to the bridges with highraise piers more than 15 m

c. In the above case, to use the value of "b" shown in Fig 6 to avoid a sudden change of "b"-value as a period of 0.5 seconds

d. To start checkin ductilities of reinforced concrete pier

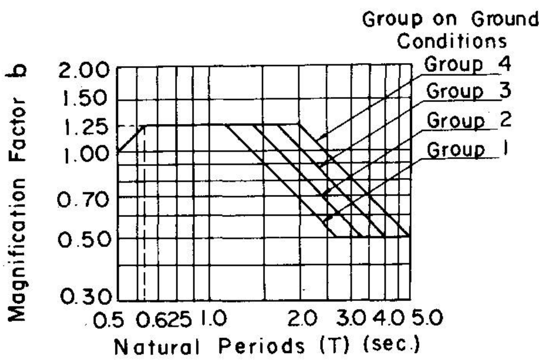



Fig 6 Magnification factor for modified seismic coefficient method

The Corporation basically applies these specifications to the structures of the expressways, and then issues the "Practical Use" again. New "Practical Use" adopts modified seismic coefficient method for the bridges with highraise piers more than 15 m, and shows how to determine the design ground surface by

$F_L$ and pier height.

In the case of liquefaction resistance factor $F_L > 1.0$, the design ground surface is generally laid beneath the bottom surface of the footing, and it may be laid above the top surface of the footing if the real ground surface can be taken as the design ground surface for earthquake-resistance, considering the conditions of grounds at present and in future included back filling after excavation. In the case of liquefaction resistance factor $F_L \leq 1.0$, the design ground surface is taken as shown in Fig 7. For the soil layers with $F_L \leq 1.0$ and within 10 m of depth from the real ground surface, bearing capacities and other soil constants shall be either ignored or reduced as shown in Fig 7, by multiplying the original values by reduction factors $D_E$.

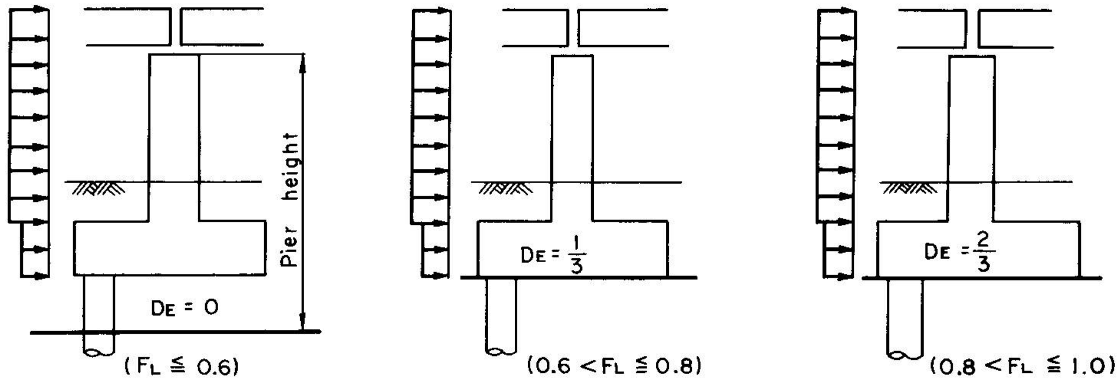



Fig 7 Relationship between $F_L$ and $D_E$

Table 5 Design seismic coefficients

| | Ground conditions | | | | Remarks |
|---|---|---|---|---|---|
| Horizontal coefficients | I | II | III | IV | |
| For superstructures and pier bents | 0.20 | 0.22 | 0.24 | 0.26 | $v_3 = 1.1$, $b = 1.0$ $h \leq 15$ m |
| For footings, abutments, etc. | 0.18 | 0.20 | 0.22 | 0.24 | $v_3 = 1.0$ |

## 4. EMERGENCY PREPAREDNESS FOR THE EXPRESSWAYS BEFORE AND AFTER EARTHQUAKE

### 4.1 After an earthquake warning issues

The council comprising six seismological experts, specially assigned by the Japanese government, is set up in Japan. When data sents to the Meteorological Agency in Tokyo recorded abnormal observations in the earth crust, the experts hasilly assemble at the agency and analyze the data. If their conclusion is that a major earthquake is imminent in some area, especially in the Tokai area (the west direction close to Tokyo) where is the most likely to strike, the prime minister issues a warning against such an earthquake. The warning includes anticipating epicenter, magnitude or intensity and time.

If a big earthquake strikes the Tokai area, the Tokyo metropolitan area is anticipated to have a big damage. Therefore, the central government as well as the local governments concerned immediately takes measures necessary to secure the maximum safety of their residents. The Metropolitan

Expressway Public Corporation is also designated by the prime minister as a designated public organ as provided in the "Law on Prevention for Disaster". When a warning is issued, the Corporation operates a predetermined emergency system in various fields to take emergency measures.

From a technical point of view, an emergency preparedness is provided. It is a kind of special inspection. The following matters are predetermined on the way of special inspection after a warning against earthquake is issued; i.e. subjects to be inspected, types of instruments and cars to be used, numbber of a group to cope with, courses to follow, speed to run, etc. Main subjects to be inspected are as follows;

* Operation test of a wireless communication system
* Operation test of an emergency electrical power supply system
* Operation test of emergency telephones, television cameras for monitoring, variable message boards, warning equipments, fire fighting equipments, etc.
* Check of inspection instruments and materials
* Inspection of scaffolding platforms for ordinary repair works, or removing of them if necessary
* Check or supply of dead batteries, lack of paper and instruments themselves for strong-motion seismograph installed on various points of the expressways
* Enough supply of fuel for patrol cars and vehicles for inspection
* Emergency measures for the structures having serious defects against strong earthquake.

The anti-quake drill for such an earthquake with strong magnitude is held on September 1 of every year, as memory of the Kanto Earthquake Day.

### 4.2 Special inspection immediately after earthquake hits

The way of special inspection is provided in detail, when an earthquake hits the Tokyo metropolitan area unfortunately. The special inspection differs in degrees on intensity of earthquake on the Japanese scale of seven.

No work is done below intensity of two. If intensity of earthquake reaches three (8 to 25 gals), rough inspection is done. Such a degree of earthquake often hits the Tokyo metropolitan area, but there is no damage to the structures of the expressways. However, scaffolding platforms for ordinary repair work are inspected visually from on patrol cars or on-foot. The inspectors follow the predetermined course within an hour.

The earthquake with intensity of four (25 to 80 gals) usually hits Tokyo once or twice a year. In this case, the expressways are inspected visually from patrol cars running on the expressways taking the predetermined courses for about an hour. On the other hand, the under surface of the elevated bridges is checked from patrol cars running on the surface business streets for about three hours. This inspection is done in the same way for intensity of five (weak: 80 to 150 gals, strong: more than 150 gals).

Moreover the structures to be checked through visual inspection on-foot are designated at an earthquake with intensity more than four. These structures include the bridges on each route which are necessary to be paid an attention at earthquake by the inspection mentioned in Chapter 2 or which may have the insufficient strength against earthquake pointed out by the data inspection mentioned in Chapter 5. For example, there are nine bridges on the route No 1, such as the bridges installed an oil damper on each support, rehabilitated cracks of piers and strengthened dapped end of girders in the past. It takes an hour and half at intensity of four, two hours at intensity of five (weak) and three hours at intensity of five (strong) to inspect.

Twenty one strong-motion seismographs were installed in the bridges with higher raise of pier and complicated system, beneath the ground with soft soil layer along the route, etc, and nine of them are out of order. These records have been periodically collected in usual time and gave a great contribution to the earthquake-resistance design of structures up to the present. When an earthquake more than intensity of four strikes the structures, these records are collected at once and analyzed. If any extraordinary motion and accelaration are obtained, a further special inspection is to be undertaken.

When a big earthquake hits Tokyo and it brings the worst situation which paralyzes functions of surface roads, the expressways are to be closed immediately for ordinary vehicles and to be used as exclusive roads for the emergency services such as rescuing, policing and fire fighting activities. To secure these proper use of the expressways, the Corporation always endeavors to let the public know the following matters;

* Drivers should act calmly even against a major tremor, and decelerate their vehicles to stop, taking care of the other cars in front and at rear, in order to avoid accidents.
* To insure the preferential passage of emergency cars, drivers should stop on the left side of each road, with the right lane opened as widely as possible.
* Drivers should escape from the nearest ramps or emergency exits leaving key in the ignition.

## 5. UPGRADING WORKS OF THE BRIDGES AGAINST EARTHQUAKE

### 5.1 Data inspection against earthquake

As mentioned before, the bridge structures of the expressways have been designed to be safe at the time of earthquake such a magnitude as the Kanto Earthquake. However, the aseismic code has been often revised as mentioned in Chapter 3. It is necessary to know in what condition the structures are under the newest aseismic code and to repair or to rehabilitate the structures which may have insufficient strength against earthquake. The following procedure is taken in data inspection against earthquake for provisions of 1980.

At first, applied design seismic coefficients are investigated. It is possible to pick up them because the year of design of each route is recorded and design procedures of the bridges are kept. But their amounts are enormous, and it is impossible to check each bridge. Then a map concerning applied design seismic coefficients for each route is drawn up by adequate sampling.

While a map of ground and soil conditions is made up based on geological data used in design and boring data obtained at construction. Using this map, new design seismic coefficients are computed. Liquefaction resistance factor is also calculated, and assessment for liquefaction is done. Due to the value of $F_L$, the level of the design ground surface is determined. Moreover the height of pier is checked concerning whether modified seismic coefficient method shall be applied or not.

If there is some risk in difference between applied value and computed value in seismic coefficients, in the level of the design ground surface, etc, the bridge is redesigned by both working stress design and ultimate strength design methods and is examined its safety.

Since the bridges on newly constructed routes except the numbered routes (the route Nos 1 to 8) are designed by relatively new provisions, there is no problem. In comparison with only horizontal design seismic coefficients, the bridges on the numbered routes were safe against earthquake because they had been applied $K_h$ = 0.30 or partially $K_h$ = 0.27, because new provisions specify that $K_h$ is 0.22 to 0.26. When the bridges with highraise piers more than 15 m were examined, a couple of bridges on the route Nos 5, 6 and 7 was assessed to be slightly unsafe. But it was proved from the result of redesign that they had enough strength against earthquake.

Provision for liquefaction of sandy soil layer is so relatively new that critical problem is detected. There is no risk against liquefaction concerning the route Nos 2, 3, 4 and 5 in uptown and in the west area of Tokyo. But the bridges on the route Nos 6 and 7 in the east area of Tokyo and the route No 1 along the coastline of the Tokyo bay have a potential for liquefaction during earthquake. Moreover it is necessary for them to let the design ground surface down and the design horizontal forces increase on large scale. Some of them are already upgraded if possible, and the others are under successive surveillance, or are designated as the bridges to be paid an attention at earthquake. Moreover they are being surveyed by dynamic earthquake responce analyses inputting quasi-seismic waves. However the number of them is a little.

## 5.2 Upgrading work concerning aseismic devices

In a series of bridges such as the Tokyo metropolitan expressways, if a part of them falls down during earthquake, it is impossible to serve a function as roads. The Corporation give priority at present to installation of aseismic devices to prevent girders from falling down (fall-proof devices).

These devices had been installed from so early construction stage as mentioned in Chapter 3. But most of them had insufficient strength against earthquake. Year by year, structural details of them were being improved as shown in Fig 8. The basic idea of the present criteria concerning them is as follows;

1) First of all, stoppers should be provided to prevent that upper shoe deviates from lower shoe at movable support.
2) And then it is necessary to satisfy either of the followings.
   a. Both girders between different spans and on the same pier shall be connected to prevent against falling down when either of them deviates from pier top.
   b. Enough length shall be provided, to prevent girders deviating, between the end of support and edge of substructure or between the end of girder and the edge of substructure.
   c. Restriction devices such as projection shall be provided against a large relative movement between girders and substructures.

This upgrading work started from 1971 following new criteria. Compared with constructing the bridges newly, the upgrading work on the existing expressways is done in worse condition; i.e. narrow in working space, no good in workability, undesirable in cutting, holing and welding existing girders, impossible in installing them due to girder arrangement, etc.

Taking an example of steel girder bridges, working procedure is shown in Fig 9. Fig 10 shows various kinds of these devices. The steel bridges on

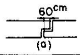
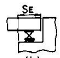
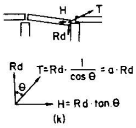
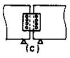
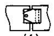
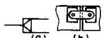
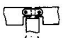
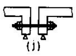
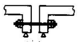
| | | ① | ② | ③ | ④ | ⑤ | ⑥ | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | April 1963 ∿ April 1965 | April 1965 ∿ April 1969 | April 1969 ∿ January 1971 | January 1971 ∿ September 1973 | September 1973∿ April 1980 | April 1980 ∿ | |
| Japan Road Association | | No provisions | No provisions | No provisions | April, 1972<br>(1) To increase the width of the pier top<br>So>20+0.5ℓ, for ℓ≦100m<br>So>30+0.4ℓ, for ℓ≧100m<br>(2) To connect the girders to prevent against the falling down of girders from the pier<br>(3) Overlapped length of the dapped end ≧ 60cm<br><br>(a) | The same as left | April, 1980<br>(1) To provide stoppers to prevent the upper shoe from deviating out of the lower shoe at movable support<br>(2) To satisfy either of ① or ②<br>① To provide the length of $S_E$ in Fig (b) as follows<br><br>(b)<br>$S_E$>70+0.5ℓ, for ℓ≦100m<br>$S_E$>80+0.4ℓ, for ℓ≧100m<br>② To provide an aseismic device to prevent against the falling down of girders<br>1) To connect the girders and substructure<br>2) To provide projections set up at the girders or substructure<br>3) To connect adjacent girders<br>(No provisions in design loads) | Dℓ : Design load<br>Rd : Dead load reaction<br>fay: Allowable stress (Yield point stress)<br>faa: Allowable stress (Allowable stress for service load)<br>$S_E$: Length between the end of the girder and the edge of the substructure<br>So: Specified length, in JRA, between the end of the support and the edge of the substructure<br>S: Length between the end of the support and the edge of the substructure<br>ℓ: Span length of the girder<br>d: Horizontal deflection of the pier top caused by seismic force<br>a: Increased coefficient of load<br>(Generally a = $\sqrt{2}$, by considering θ = 45°)<br><br>(k) |
| Metropolitan Expressway Public Corp (MEPC) | Steel girder | To provide a device to prevent an excessive displacement of a movable support<br>Dℓ : 0.2∿0.3Rd | To provide an aseismic connection device in simply supported girder bridges<br><br>(c)<br>Dℓ: Horizontal force equivalent to the design seismic force | To provide an aseismic device to prevent against the falling down of girders<br><br>(d) (e)<br>Dℓ: 0.6Rd....fay<br>(To apply to continuously supported girder bridge) | (1) Wide pier top<br>Dℓ: 0.6Rd .... fay<br>(2) Narrow pier top (f)<br><br>(f)<br>Dℓ: 1.0Rd .... faa<br>(3) Narrow pier top (g)(h)<br>(When girders are out of position)<br><br>(g) (h)<br>Dℓ: aRd ... faa<br>(a > 1.0) | (1) To increase the width of the pier top<br>S > So + 2d<br>(2)<br>① Narrow pier top(f)<br>Dℓ: 1.0Rd..faa<br>② Narrow pier top(g)(h)<br>Dℓ: aRd...faa<br>③ To provide a restriction device against the movement between the girders and piers<br><br>(i)<br>Dℓ: 0.6Rd..faa | | |
| | Concrete girder | No provisions | 1966<br>For simply supported composite girder bridge only<br><br>(j)<br>Dℓ: 0.3Rd | The same as left | March, 1971<br>(To add the T-shaped girder bridge)<br><br>(j)<br>Dℓ : 0.6Rd ... fay | The same as left | The same as left for MEPC | |

Fig 8 Change of provisions on fall-proof devices

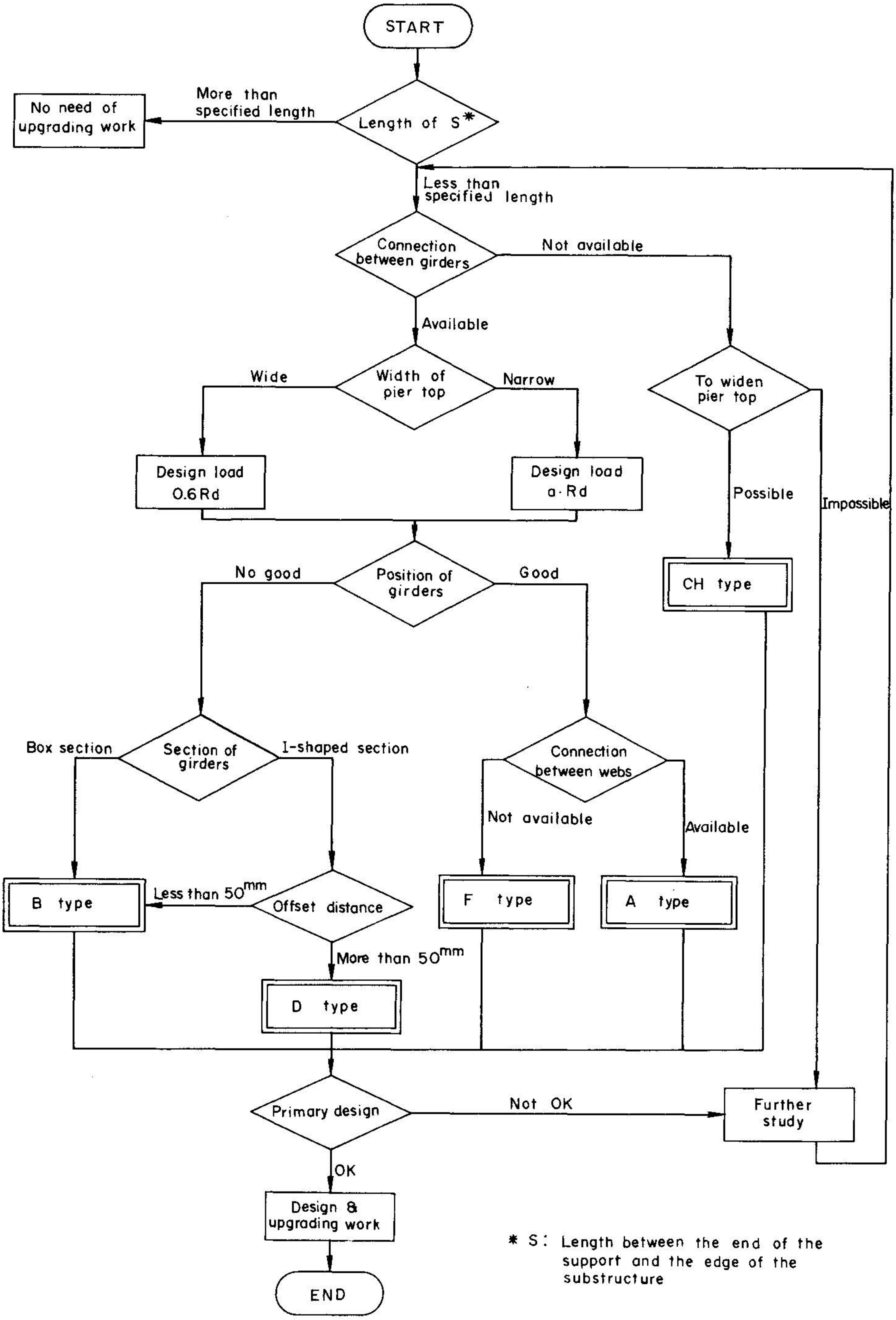



Fig 9 Procedural flow diagram on installation of fall-proof devices

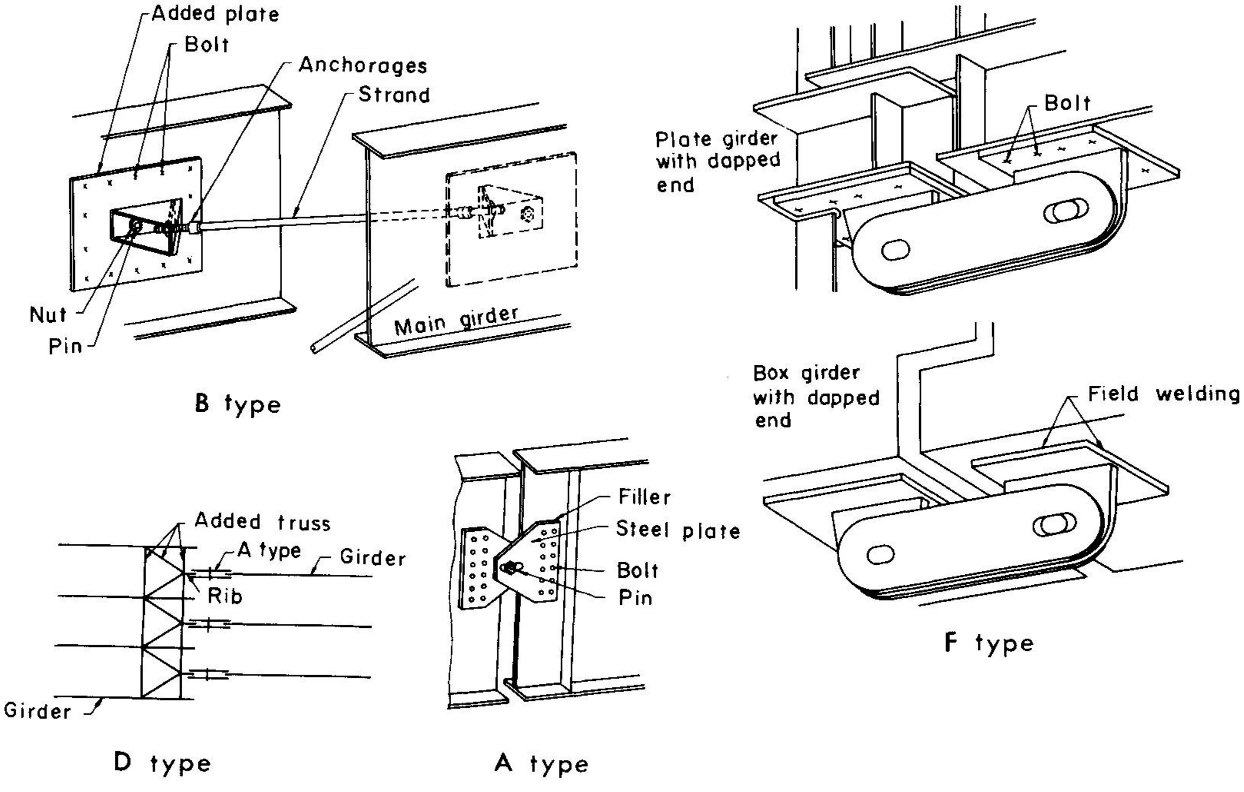



Fig 10 Various types of fall-proof devices for steel girders

1,500 piers were already upgraded, and almost bridges will be upgraded in 1982 except impossible cases.

The installation of connecting devices in concrete bridges is so rather difficult that other retrofits have been devised. For example, they are to widen pier top with concrete placing and prestressing it, and to install restriction devices against the movement of girders as shown in Fig 11. Upgrading work for concrete bridges is done about fifty per cent.

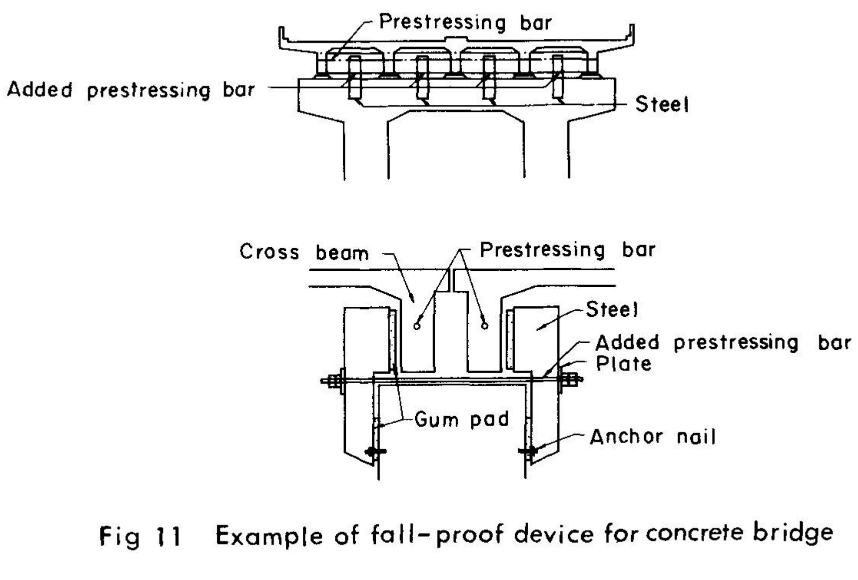



Fig 11 Example of fall-proof device for concrete bridge

### 5.3 Other upgrading works against earthquake

It was reported that bridge damage due to the Miyagi-ken-oki Earthquake of 1978 concentrated on bearing supports and adjoining portions. Various defects concerning bearings are observed through periodic inspection and as of installation of fall-proof devices. Plate bearing shoes are mostly adopted as support system of the expressways, and their defects are failure of side block of shoes, crack of concrete near bearing supports, cut-off or bent of anchor bolts of bearing stiffening plates, lack of concrete or mortar below shoes due to poor workermanship, etc.

Some of them can be covered through the installation of fall-proof devices against earthquake. Of course, serious defects are rehabilitated, by moving the support to the temporary supports and reinstalling new bearings, casting concrete in the portion near bearings and prestressing it, etc. It is too difficult to repair bearings and adjoining portions without closing the traffic on the existing bridges. It seems that breakage of bearing support during earthquake reduces serious failure of the bridge girder and also of the substructure. Therefore, it is not always advised to rehabilitate bearings too strong. Now the Corporation is studying an effective repair program on bearings as well as fall-proof devices.

Emergency exits, which were constructed at early stage, are simple in structural type and are provided at rough intervals. According to the present criteria, they should be provided at intervals of one kilometer and structural details of them are also specified. The number of exits is being increased now, while the simple ladders are being upgraded to the ladders with cages in the rear, or solid spiral staircases and dog-legged staircases as far as possible. Drivers may escape down from the expressways using them safely at earthquake.

## 6. CONCLUSION

The inspection and maintenance works of the Tokyo metropolitan expressways are summerized making a point of measures against earthquake. Since the expressways have been designed, constructed and maintained paying progressive considerations against earthquake, they may be in almost safe at earthquake such a magnitude as the Kanto Earthquake.

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