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Damage Inflicated on Concrete Structures during Tokachioki Earthquake and Concept on Aseismatic Design

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1. Preface

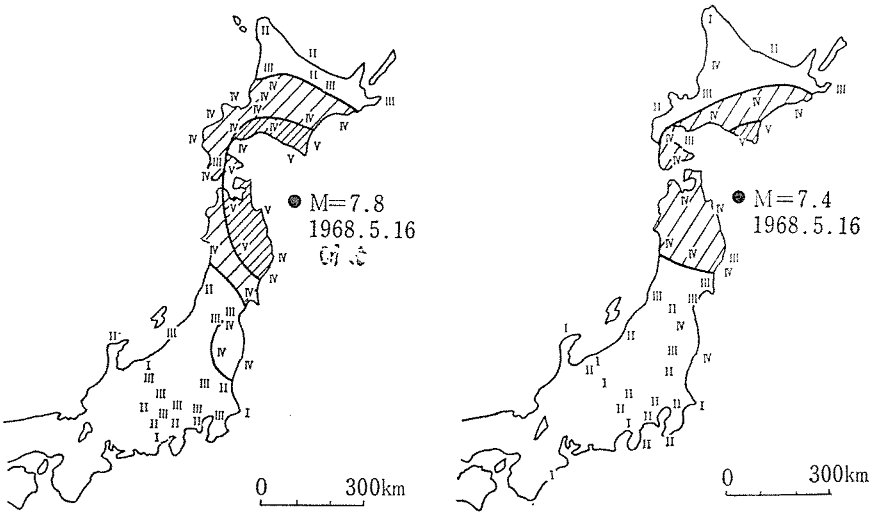
At 9 : 49, May 16, 1968, the Hokkaido and Tohoku regions were hit by a great earthquake, which was strongly felt in the Kanto and other areas as well. The epicenter is traced to a point, 40.7 degrees, N. latitude, 143.7, E longitude, and its depth 20 km. This earthquake, named Tokachioki Earthquake, was of 7.8 magnitude, in which the maximum acceleation was observed to be 230 gal, horizontal, near Hachinohe city.

On hearing the news of the Earthquake, the writer left for the Tohoku Region and enaged there in investigating the damage done to the railway structures of concrete there, mapping out plans at the same time to rehabilitate such damaged structures. A few days later, the writer was requested by Dr. Inomata of the Prestressed Concrete Technology Association to investigate of damage inflicted on the prestressed concrete highway bridges in the Hokkaido and Tohoku Regions. On investigation, the damage on the prestressed concrete bridges, both for highways and railways, was found to be extremely slight. As a matter of fact, they were all found usable again at once.

Damage, however, on the reinforced concrete structures, plain concrete structures and brick structures was found considerable. As the feature of damage done seems to suggest a rational way of designing aseismatic concrete structure, including prestressed concrete structures, the writer wishes to report on the outcome of the investigation and express his idea on the aseismatic design.

In reporting, the writer wishes to acknowledge first cooperation accorded to him by the Morioka Construction Division, JNR, Morioka Railway Operating Division JNR, and the Prestressed Concrete Engineering Association, as well as to the JNR, the Ministry of Construction, Hokkaido University, Tohoku University, etc. for allowing him to use reference materials needed in conducting the investigation.

Fig. 1 Isoseismal Map of Tokachioki Earthquake 1968.



(a) Isoseismal Map of Tokachi-oki Earthquake.

(b) Isoseismal Map of an Aftershock of Tokachi-oki Earthquake.

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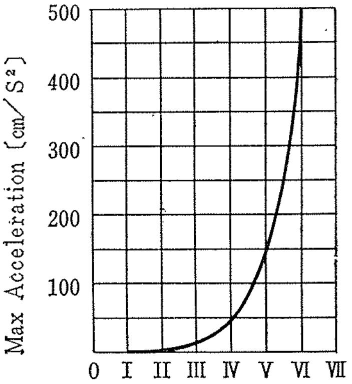
2. Tokachioki Earthquake : Damage in brief

The seismic center and the seismic intensity registered at various places, as announced by the Meteorological Agency, are as shown in **Fig. 1.** The levels of magnitude as decided upon by the Central Meteorological Observatory, are as Shown in **Table 1,** and the relation between the seismic intensity scale and the maximum acceleration rate is as roughly illustrated in **Fig. 2.** In **Fig. 3,** the main features of geological condition. The number of railway sections where train service was suspended on account of the Earthquake and the damage sustained here are given in **Table 2.** As seen in this table, major parts of the damage done to the railway was roadbed disturbance. The damages done to the bridges and other structures were rather slight and comparatively small in number. At the time of the Earthquake occurrence, there were a great number of trains in operation in the afflicted areas ; but the cases of derailment were extremely small in number. Besides, there was no case of wounded or killed reported among the passengers, though those killed or missing otherwise in the afflicted areas totaled 52, the wounded 329 and the houses collapsed numbered 689. The damage sustained by public civil engineering facilities alone reached 8,000 million yen. The total direct damage was estimated at 53,100 million yen.

Table 1 JMA Seismic Intensity Scale

Scale of Seismic Intensity (Central Meteorological Observatory)	
0	Felt on a seismograph but not by human beings.
I	Felt by person standing still or by person extremely sensitive to earthquake.
II	Generally felt by everyone. Slight shaking of window and door.
III	Building shakes, window and door rattle, hanging objects such as electric light sway, and ripple on surface of water in a vessel is noticed.
IV	Strong movement of building. Unstable objects fall and water spills from a vessel 4/5 filled.
V	Wall crack, grave stone and rock lantern topple. Damage to brick chimney and mud-plastered store houses.
VI	Approximately 30% of the wooden buildings are destroyed. Mountain and cliff slides are numerous. Cracks appear on level ground.
VII	Over 30% of wooden buildings are destroyed.

Fig. 2 Max Acceleration and seismic intensity scale



(Central Meteorological Observatory)

The peculiarity of damage done by the Earthquake, as far as the railways were concerned, was that it was alomost confined to the roadbed, which was distorted, or collapsed, or its slope destroyed. As far as the roads and high ways were concerned, the damage mostly consisted in the subgrade deformation and slope destruction. For the waterways and waterworks, it can be said that the damage done was mainly caused by displacement in the foundation. Accountable for the fact that the damage was done mostly to the foundations and earthworks is the heavy rainfall that had hit the Tohoku and other regions three days before the Earthquake (it exceeded 160 mm in and around Hachinohe).

Among the earthworks, however, those secions where cutting had been done sustained only small damage in general. On the Tohoku Main Line sections where JNR is laying additional tracks, almost no damage like slope face collapse was found done to even those cutting slopes where no sodding had been done or where the sodding had not well settled down.

A considerable damage was seen done to the railway and highway sections set up by banking. As shown in **Fig. 4** (a), (b), there were many places where the banking foundation collapsed and sank. Many banking slopes saturated with the rain water were completed of destruction by the Earthquake. Some cases of banking flowage were found, too.

Some damage was done to the railway-ferry junction facilities, mainly to the No. 2 Wharf of

Fig. 3 Main features of geological conditions

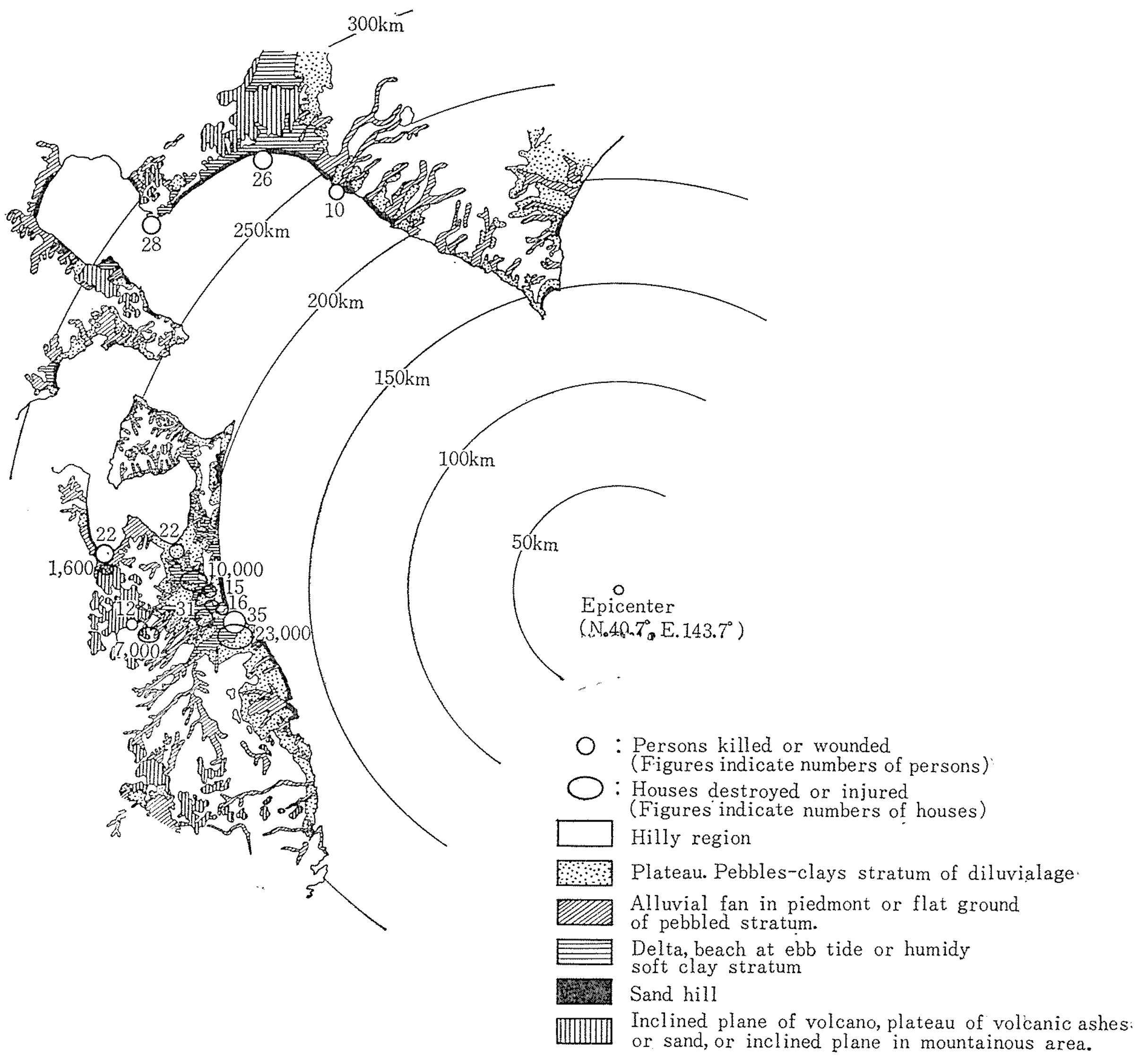


Table 2 Damage Sustained in Railways

Region	Number of sections where train service was suspended	Features of Damages					
		Subgrade disturbance	Inclined pier and abutment	Flowage of bridge girder	Remarkable Cracks of Tunnal lining	Others	Total
Hokkaido	38	88	16	3	1	14	121
Tohoku	66	119	17	3	0	23	162
Total	104	207	33	5	1	37	283

Aomori harbor and various equipments near by the wharf. The cross section of the wharf is shown in **Fig. 5.** There is a soft clay layer of about 40 m under the sea bottom near the wharf, and the shipping facilities are set up floating over this soft clay layer. Built in 1924, the foundation of these facilities had been sinking down, reaching about 2.7 m down the original level before the Earthquake hit. The damage to the facilities, generally speaking, were heavier where the sinking were greater. Near the No. 2 Wharf, the Earthquake caused the sinking to reach about 60 cm, and at the same time it seems to have caused the quay walls to incline toward the seaside to some extent.

Fig. 4 (a)

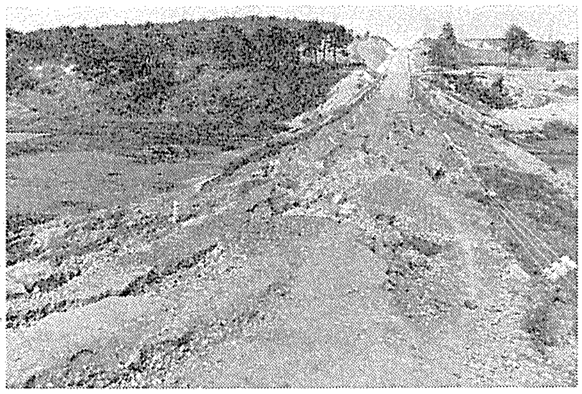


Fig. 4 (b)

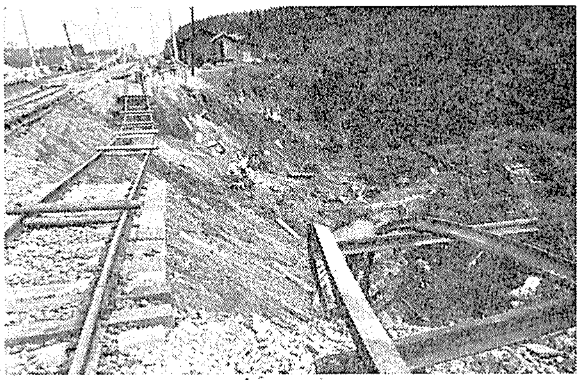
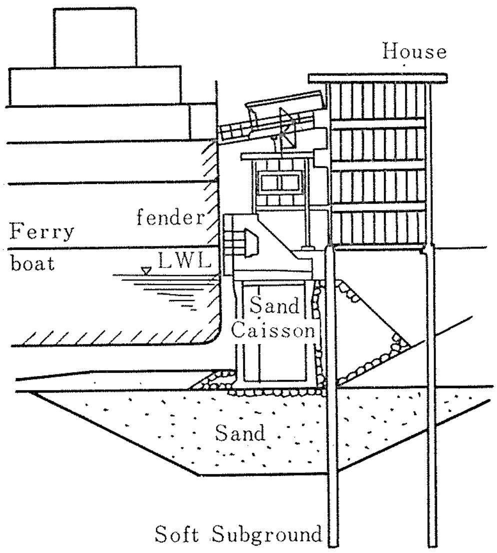


Fig. 5



On the Pacific coast of Hokkaido and the Tohoku Region, there are various harbor facilities and equipments set up in such cities as Kamaishi, Miyako, Hachinohe, Muroran, Tomakomai and Kushiro. The damage here was rather slight, though sinking or sliding of some quay walls, partial roofing deformation, and the like were noted. During the period of about 20 to 60 minutes after the Earthquake, various regions along the Pacific coast had seen tidal waves but the damage was confined only to destruction and drifting of some fishing boats. Laver and oyster cultivation was damaged to some extent.

Buildings were found damaged in places in the afflicted areas. Wooden buildings were seen collapsed or broken down due to landslide, irregular foundation sinking, etc. Generally speaking, most of the wooden structures were seen to

Fig. 6 Wooden hauses

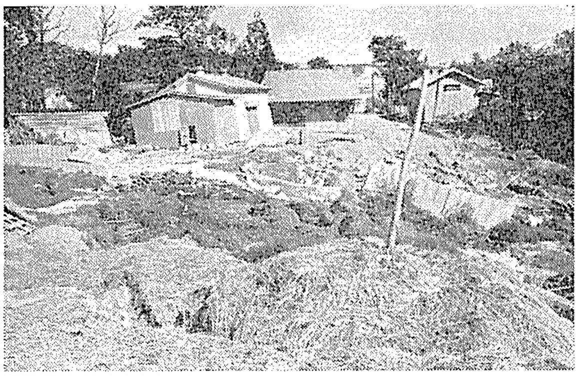


Fig. 7 Diagonal cracks of reinforced concrete beams

have simple foundation, being small in scale and light in weight, and it seems natural that many had sustained damage due to irregular foundation displacement. **Fig. 7**, **8** and **9** show some examples of reinforced concrete buildings that sustained serious damage during the Earthquake. Notable of the damage done are : large diagonal cracks in the columns, crumbling of concrete of column, buckling of longitudinal bars, breaking up of bar anchorage, tie disabling, tie bar breaking, diagonal cracks on the walls and the beams, and collapsing of columns and entire walls. In the case of some reinforced concrete buildings, considerable damage was found done even when there was no notable irregular foundation sinking or landslide.

Examples of damage done to reinforced concrete bridges are shown in **Fig. 10**. The Shiriuchi Bridge is a 22.5 m span reinforced concrete bridge of cantilever type. Its pier foundation near the centeral part which had been noted sunken to some extent sank further during the Earthquake, causing the bridge pier at the same time to dip and break the cantilever part of the girder. In the case of the reinforced concrete aqueducts in **Fig. 11**, displacement was noted near the abutment, and some shear crack occurred in the shear key on the upper end of the pier, though no water was found leaking.

The Komoto Bridge has a 40 cm high cross beam at its supporting part, and on this cross beam some large diagnal crack was seen (**Fig. 12**).

The Anenuma Elevated Bridge is of ordinary type of structure seen commonly among elevated railway bridges in this country. The columns are rigidly connected by horizontal beams near the ground surface, and four precast reinforced concrete piles are driven in as foundation piles under each column. A 20 m deep layer of extremely soft soil lies near by over the supporting layer, with several meters high banking running parallel to the bridge some 20 to 30 m apart. With the underground water level coming so close to the grand surface, it had been thought that execution

Fig. 8 Breaking up of tie bars and buckling of longitudinal bars, Concrete crumbled.

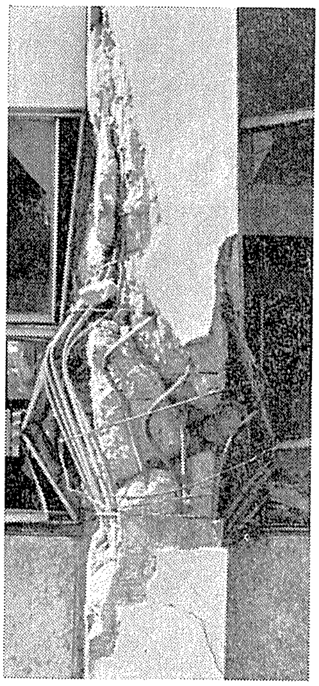


Fig. 10 Shiriuchi Bridge
(Reinforced Concrete)

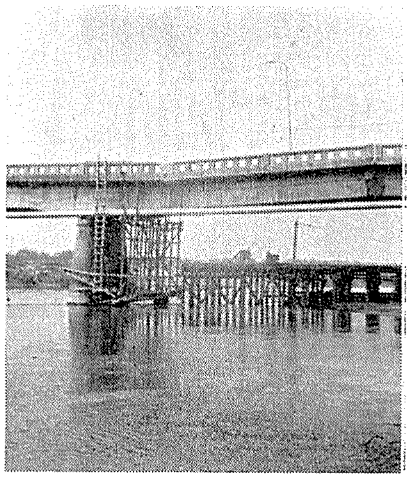


Fig. 11 Reinforced Concrete aqueducts

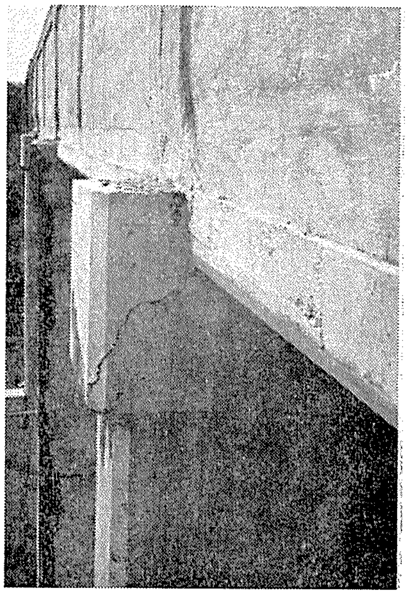


Fig. 9 Diagonal cracks of wall

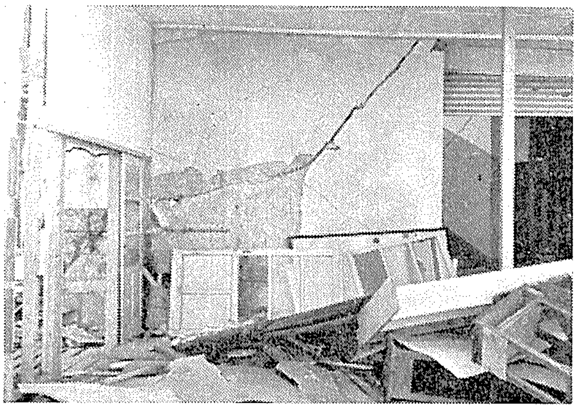


Fig. 12 Komoto bridge (Reinforced Concrete)

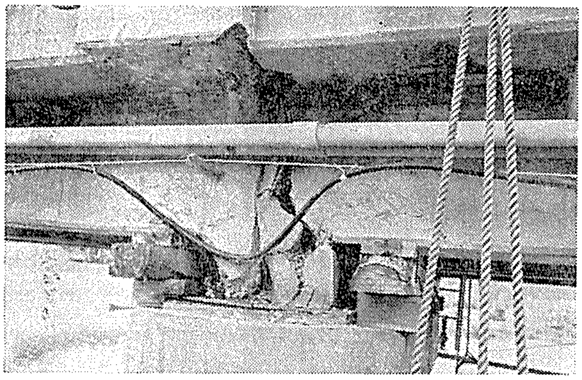


Fig. 13 Anenuma railway viaducts (Reinforced concete 3-span continuous rigid frame)

of work would not be easy if the beam to be connected to the columns were to be located below the ground surface, as the underground water would then spout out. So, the beam ws set up above the ground surface, and fine sand was used for the banking to bury the beam. At the time of the Earthquake, a dynamic displacement of about 70 cm in the direction right angle to the track is presumed to have taken place, judging from some ground surface cracks near the elevated bridge and to the disturbance in the track alignment. A dynamic displacement of about 10 cm at least is also presumed to have occurred in the direction of track, judging from some deformation of the joints between the bridge blocks and to that of construction joints of the railing. After the Earthquake, the position of the elevate bridge is seen partially moved about 10 to 30 cm away from the original position. The surface of the rice paddy near the elevated bridge in opposite side of the banking is seen to have partly risen about 5 to 10 cm.

The structure of Ogawara Elevated Bridge is about the same as that of the Anenuma Elevated Bridge, except that it has reverse-circulation piles driven in as foundation piles. Compared with the Anenuma Elevated Bridge, damage sustained by the Ogawara Elevated Bridge was small. One pile under certain column was found to have sunk about several cm during the Earthquake, and great bending cracks were seen on the horizontal beams rigidly connected to the column.

No special rehabilitation work was needed to be done about the damaged spots for both the Anenuma and Ogawara Elevated Bridges before letting the repairing train pass through on to other afflicted areas.

Fig. 14 shows a brick abutment, about 16 m high, with some bending shear crack on. In the cracks bricks and joints are seen broken.

Fig. 14 (a)

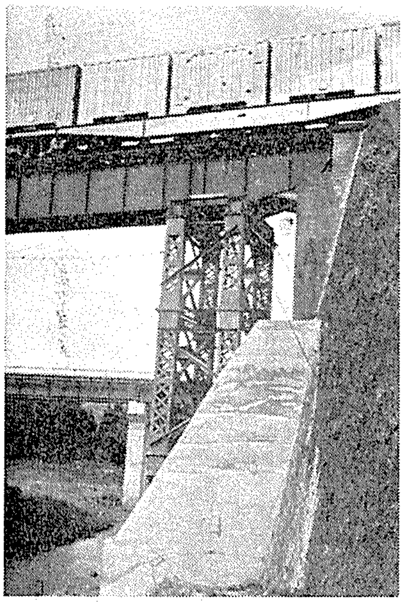
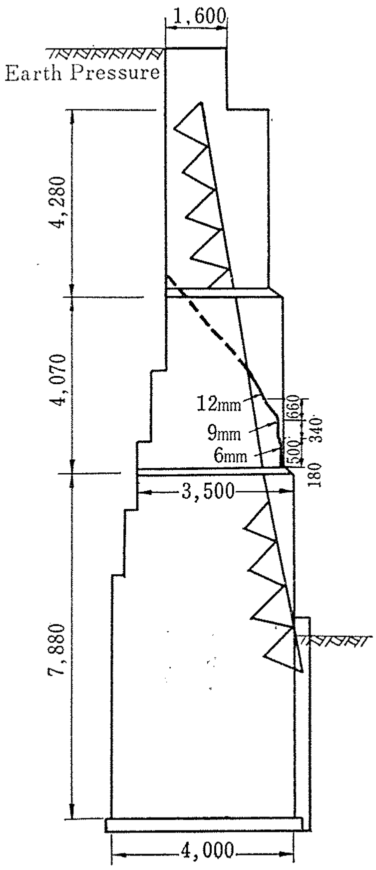


Fig. 14 (b)



3. Damage on prestressed concrete structures

Almost all the prestressed concrete structures in the Hokkaido and Tohoku regions are bridges of the simple beam or continuous beam type. Distribution of these bridges is as given in **Fig. 15**. There is quite a number of these bridges in the areas, and some damage was anticipated before the investigation begun.

However, on investigation almost no damage was found inflicted on the superstructures of prestressed concrete bridges themselves. Only in a very small number of them, the main beam was found to have moved about 1 to 3 cm at the right angle to the bridge span, some cracks and breakage on the mortar near the shoes, some shoes broken. The extent of only such a slight deformation of the supporting part was about the same as that experienced in an earthquake that hit the Kyushu areas on Feb. 21, 1968.

In **Fig. 16** to **19**, the damages done to prestressed concrete bridges are shown. In some bridges, of which precast prestressed concrete T-beams of the post-tension type had been brought in one after another for assembling in the transverse direction with a prestressing tendon, and the shoes used are made of cast iron, the mortar under the shoe was partly broken and some shoes were found cracked during the earthquake. The dimension of the beam seat of the abutment having been too small, the horizontal shearing force working on the anchor bolt of the shoe was seen to have brought about some crack on the upper part of the abutment.

In some elevated bridges and others, the adjacent main beams had transversely gone from

Fig. 15 Sites of the investigated prestressed concrete bridges

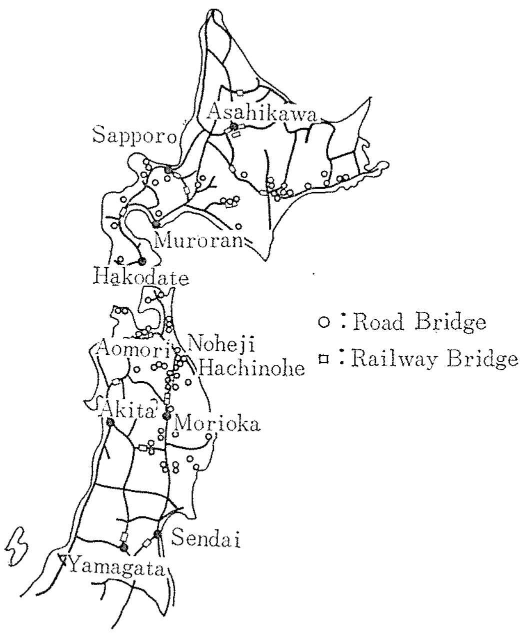


Fig. 16 Cracks on the bearing surface and front surface of the pier : too narrow bearing area and not reinforced enough

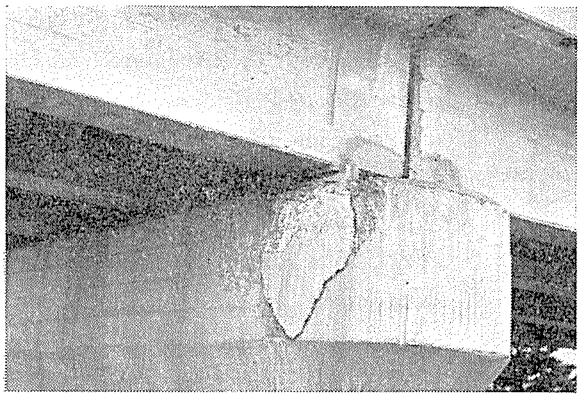


Fig. 17 (a) Break-off of bearing plate-shear key of shoes

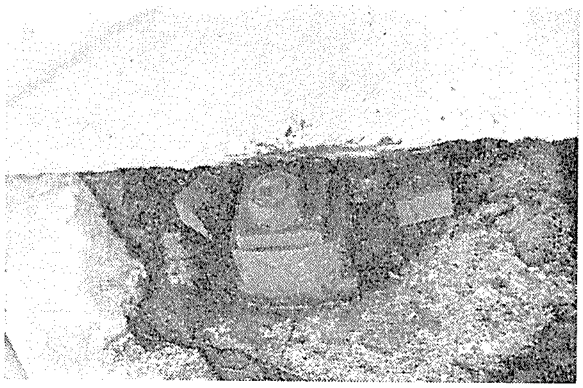


Fig. 17 (b) Tear-off of concrete
(Ebino-Earthquake)

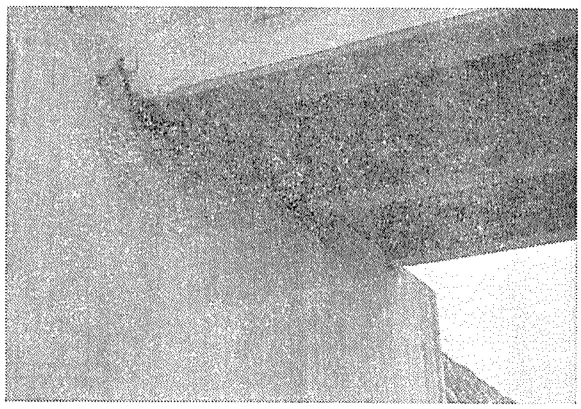


Fig. 18

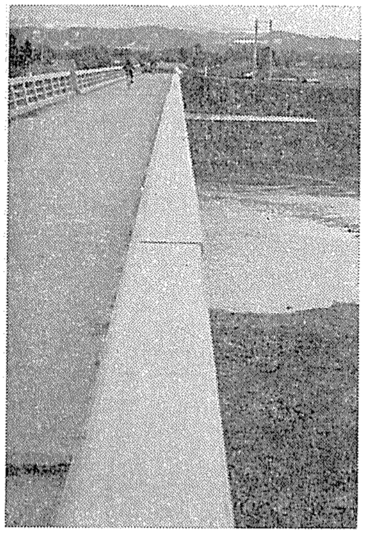
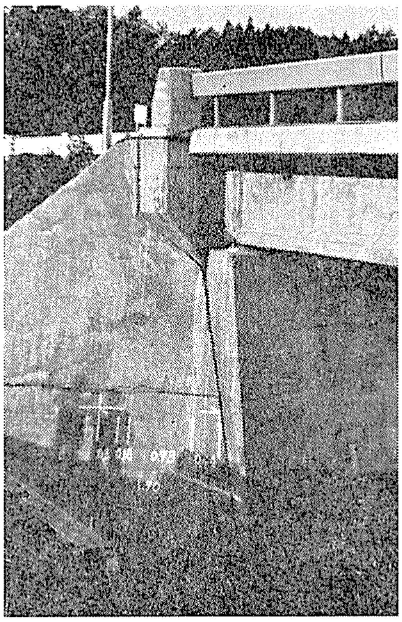


Fig. 19 Cracks at wing wall of abutment.



each other and the bridge alignment has become irregular. The cases where cracks occurred on the wing wall near the abutment as shown in **Fig. 19** were frequently seen. Cases of foundation sinking and slope face collapsing were also frequently seen.

4. Aseismatic (Earthquake-proof) designing for prestressed concrete structures.

In the present-day earthquake engineering, no definite method of designing earthquake-proof structures is clearly made known. Judging from the investigation of damage conducted on the spot in the areas hit by the Tokachioki Earthquake and others, damage to the structures was done generally at places where the soil formation is soft and weak, where the ground sinking is ordinarily considerable, where the soil formation is soft and the topography has changed drastically due to banking artificially done on the ground surface. Damage to the structures seems to have been heavy at a place that foundation displacement and landslide due to an earthquake are heavy. Thus, it seems obvious that the damage to a structure depends largely on the the working of foundation, though almost nothing has been made known as yet on the dynamic behavior of the foundation during an earthquake as well as on the working of the foundation underground. The dynamic properties and characteristics of structures will have to be made clear before any rational way of designing earthquake-proof structures is to be developed. It is paradoxical, therefore, to say that in designing a concrete structure one must ensure safety against the hazards of earthquake phenomena remaining so ambiguous as yet.

Be that as it may, it may well be said that, compared with the arch and rigid frame structures, the prestressed concrete bridges of simple beam and continuous beam are less susceptible to the effect of the dynamic behavior of foundation underground. Almost all the damage sustained by the prestressed concrete bridges during the Tokachioki Earthquake was found to be that on the shoes or the related parts thereto. These parts, designed in traditional method, can be easily damaged in great earthquake.

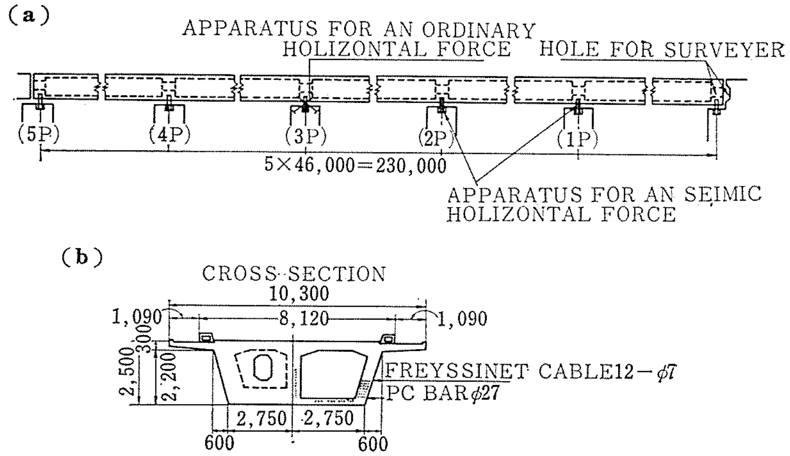
In the design of the recent concrete bridge, especially in the prestressed concrete bridge, how to design an economical bridge against earthquake is a problematical point. In this connetcion, certain contrivances in the design of structure and the weight reduction of structure will be described with certain examples.

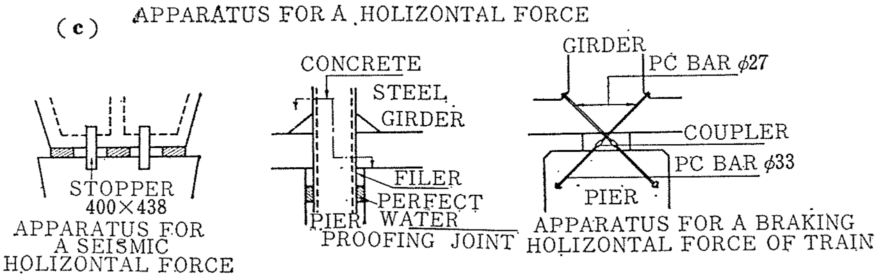
In **Figs. 20, 21, 22** and **23**, some prestressed concrete bridges designed to be earthquake-proof by the writer and his associates are shown.

In case the continuous girders are adopted, the problematical point in the design is how the horizontal force due to earthquake acts on them. In the conventional design, girder is fixed to one of the supports and movable on the rests and the fixed support receives almost all the horizontal earthquake forces. With such construction of continuous girders, if the span becomes longer and the number of continuous spans increasses, enormous horizontal force has to be supported by one support only. In case the faundation rests on a soft ground bed such as the diluvian formation, the foundation that supports the horizontal earthquake force has to be remarkably great and will have a big margin against the vertical service load. On the other hand, the other piers with movable shoes cannot be made small. As a whole, the foundation structure cannot be effectively used. In order to eliminate such defect as this in the continuous girders, the structure in which the horizontal force is distributed to be supported by all the piers comes to practice. **Fig. 20** shows one of the examples designed in this method, the Setagawa bridge on Tokaido main line.

As to the braking load, it is supported not only by the frictional force on the shoes, but also by the steel rods as shown in **Fig. 20** (c). The steel rod for braking force of train is so made as it is readily cut off, when the great horizontal force due to earthquake acts. After the rod is cut off, the stopper columns that are projected from the girder hit the pier one after another, and all the piers finally support the horizontal force due to earthquake.

Fig. 20 Setagawa Railway-Bridge





The design concept that the horizontal earthquake force of girder is to be distributed to all piers is based on the analysis of dynamic behavior of continuous prestressed concrete bridge. **Fig. 21** shows one of the examples of dynamic analysis which the writer and his associates have executed in their actual prestressed concrete railway bridges.

In Washinosugawa bridge shown in **Fig. 22** the flexible intermediate piers are used, and the big abutment is constructed at each side of the gorge. In this bridge, the continuous girder, simple girders and the fixed abutments are respectively connected by horizontal connecting rods so that the horizontal force caused by earthquake may be transmitted to the fixed abutments.

In the simple girder, there are many cases where the horizontal force at earthquake time as well as normal time is transmitted to the substructure, generally by the anchor bolt of steel shoes. For the double track through-prestressed concrete girder erected on the Arakawa bridge on Tohoku main line, rubber shoes are used, taking into consideration the angular deformation of girder at the support in the directions of bridge span and perpendicular to it. The ground in this vicinity is very bad, there exists sand layer as the surface layer of several meters deep, below which is covered with alluvium (of N value mostly zero) down to as deep as 30 m below the ground surface level, and the ground sinks at a rate of about 10 cm per year.

In case of rubber support, the stopper column of reinforced concrete as shown in **Fig. 23** is used against the horizontal force at the time of earthquake.

From the standpoint of importance of railway bridge, simple girders are mutually connected by horizontal connecting steel rods to prevent the girders from falling down at the time of earthquake. The connected part is so constructed that it does not resist to contraction due to creep and shrinkage of concrete, but resists to the abrupt deviation at the time of earthquake only.

Fig. 21 Example of Dynamic Analysis of Continuous Bridge

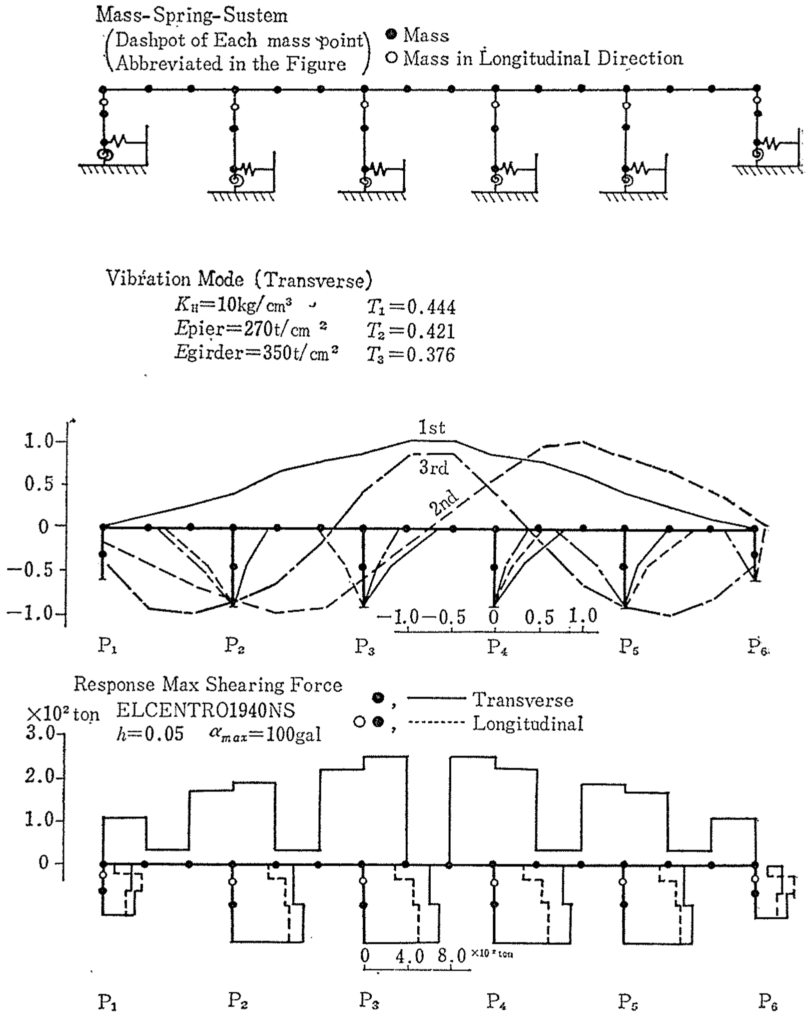


Fig. 22 Washinosu Railway-Bridge

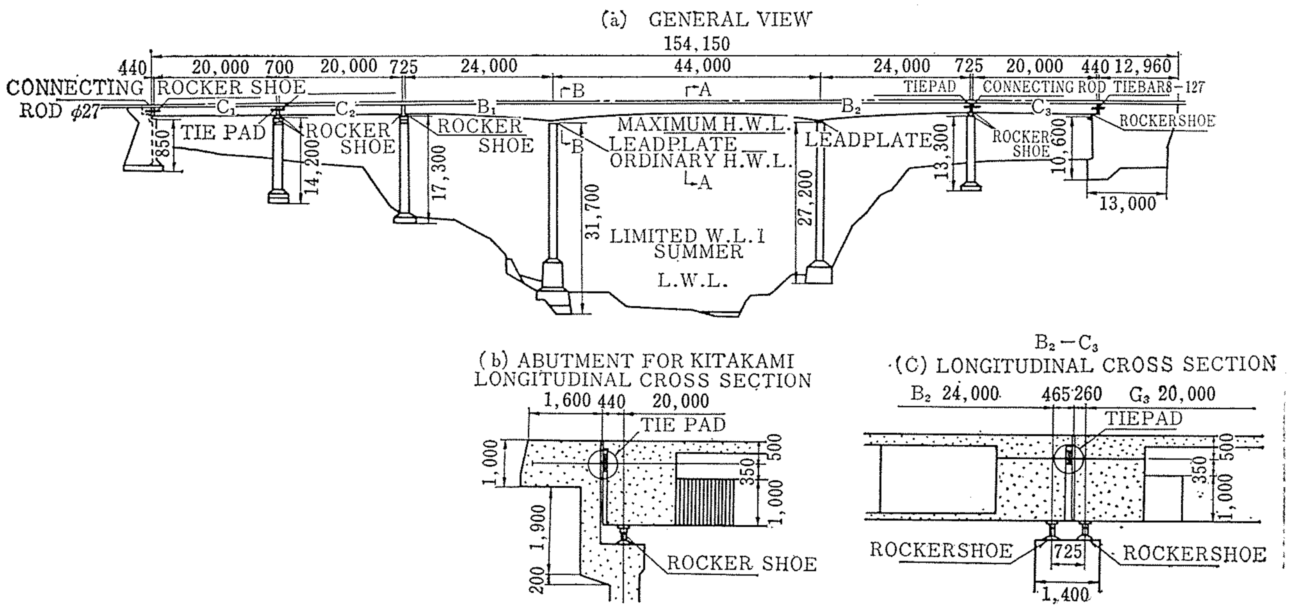


Fig. 23 Arakawa Bridge

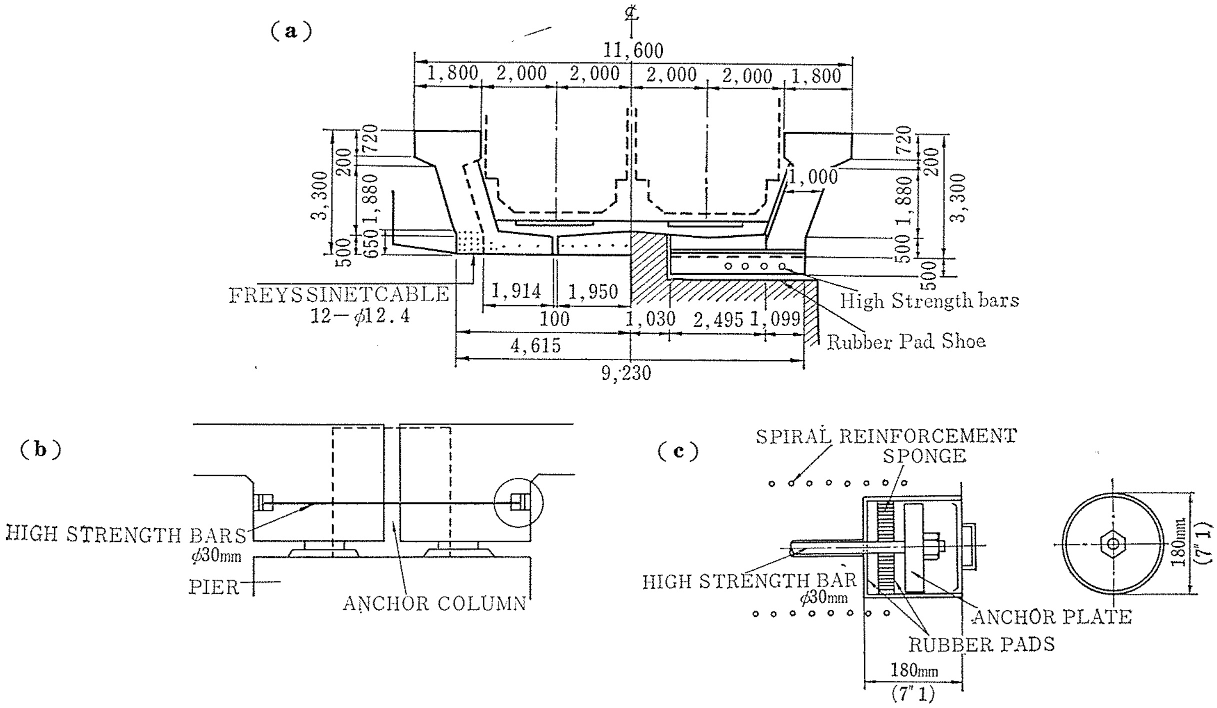
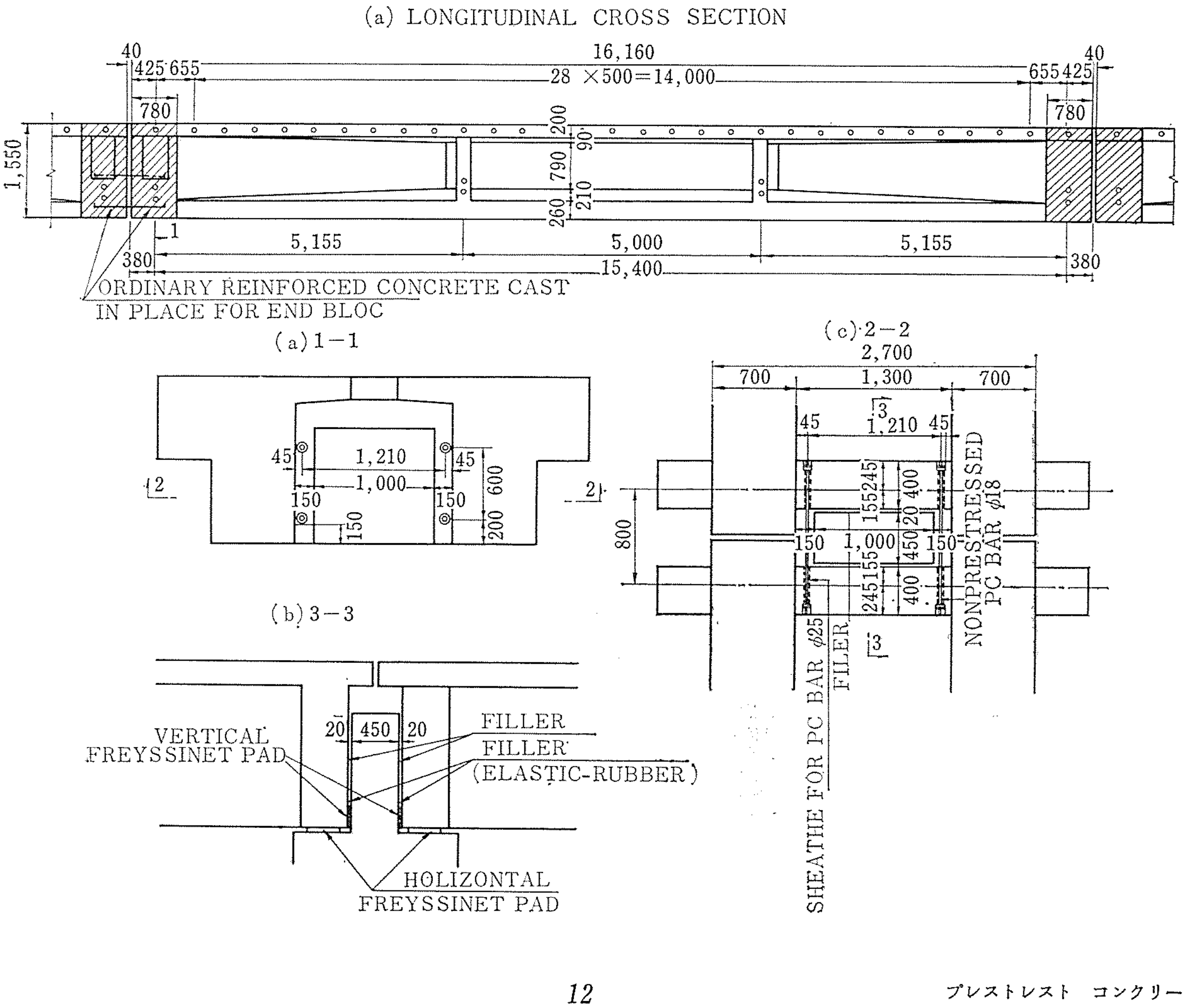


Fig. 24 Arakawa-nishi Railway Viaduct (Light weight Aggregate Concrete)



In the Arakawa west elevated bridge made of light weight aggregate concrete, the aseismatic structure in which the similar shear key and horizontal connecting steel rods are used, is adopted (**Fig. 24**).

Reference

1) Fusayoshi Kawakami, Chuzo Itakura : "Report on the damage during Tokachioki Earthquake" Journal of the Japan Society of Civil Engineers, Vol. 53, No. 7, July 1968, pp. 109~122 (in Japanese).
2) Kobayashi, Osawa, Shiga, Ono, Ichikawa, Kitago, Morii, Azuma : "Reportt on the damage durig Tokachioki Earthquake" Journal of Architecture and Building Science 1968, July, Vol. 83-No. 998 (in Japanese).
3) Kurosaka, Hisada, Honma, Kikuchi : "Report on the damage in the civil engineering facilities during Tokachioki Earthquake" The Dobokuseko, Vol. 9, No. 8, 1968 Aug., pp. 47~58 (inJapanese).
4) Takeichiro Ikehara : "Report on the damage of railway structures during Earthquake of Tokachioki" Dobokugizitsu (in Japanese).

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