# A REPORT ON THE BEHAVIOUR OF STRUCTURES EMPLOYING PRESTRESSED CONCRETE DURING NIIGATA EARTHQUAKE

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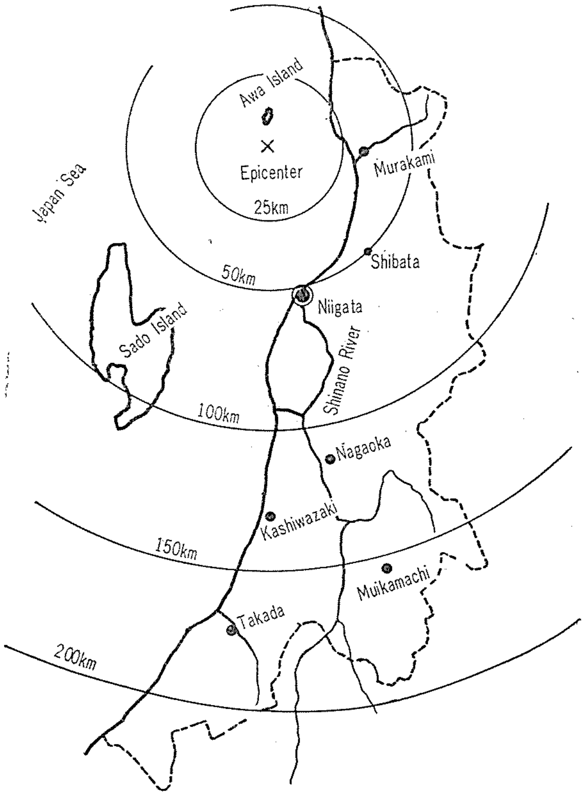
Structures employing prestressed concrete are being designed more and more in Japan. However, until the earthquake in Niigata on 16th June 1964, little actual experience has been recorded about performance of prestressed concrete during a quake. Report has placed the epicenter between 45 and 50 km off the coast of Niigata City and a depth of 20 km. The magnitude was 7.7 on the Richterscale.

The map of Niigata Prefecture and location of the epicenter is shown in **Fig. 1**.

Niigata City is situated on the north-west shore of Japan, the subsoil seems to be sand and silty sand to a depth of 120 m under much of the city. This is a possible explanation for the magnitude of the damage in Niigata City. Groundwater is generally close to the surface. The newer portion of the city is built alogside the Shinano River, and some areas are below sea level and are protected by an embankment. Apart from coastal sand dunes the area is generally very flat. During the earthquake, large volumes of water and fine sand gushed up through fissures which appeared in the ground. This water was not from the many broken pipes, but was of subterranean origin.

**Fig. 1 Niigata prefecture**



In the area near to the Shinano River, there was extensive and irregular subsidence. The maximum subsidence was probably about 1.8 m. Apart from damage caused by a landslip in the coastal dunes, the main damage was in the subsidence area.

Failure of foundation materials did damage many commerial buildings, appartments, houses and some schools. In most cases, such damage occured to structures located near the Shinano River and weak soil deposit, liquidation or consolidation of weak sand or soil deposit, possibly in an old stream channel, apparently caused this slump.

Damage due to the earthquake may be divided into two groupes, that is damages come about as a result of extensive subsidence or landslip and vibration. In Niigata city the damage due to this vibration was observed on the buildings which were built on costal sand dunes, but this type of damage was not serious. Serious damage due to extensive subsidence caused by the earthquake was observed on all the buildings in the city. Many large raft founded or even, pile founded buildings simply tilted over or subsided, but most of these buildings remain structurally sound. This type of tilt and subsidence should occure so gradually that static force should act on these buildings. **Fig. 2** and **Fig. 3** show those types of damage. All the reinforced concrete buildings which have been designed and executed through the provisions of Japanese building code, have not shown any structural damage at all and were not cracked

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seriously even in case of slump or tilt.

One large steel bridge girders fell into the Shinano River due to the extensive subsidence of steel bent founded on steel piles and the girder of adjacent four span pulled off the steel bents and collapsed over the river (**Fig. 4**).

Unfortunately the main fault or subsidence area occurred through the centre of Niigata City, as would be expected no structures could withstand this type of displacemeut (**Fig. 5**).

Aside from Niigata City there were not observed so extensive subsidence as to give serious damage to the structures.

## 1. Structures employing prestressed concrete in Niigata prefecture

More than 68 prestressed concrete structures were built in Niigata prefecture and of the 68 structures employing prestressed concrete, seven of these were in Niigata City and the other structures were distributed all over Niigata prefecture. Of the 68 structures, one of these was canopy of Niigata Railway station and the other 67 structures were bridges. All these bridges were simply supported structures and have suffered no serious damages at all.

Apart from minor spalling of concrete over the abutments or piers at bearing level and deck level, the prestressed portion of the structure was undamaged. The severe damages of this kind were observed only in Niigata City and on the outskirts of the city. The structures which were in Niigata City will be discussed at length later.

Typical distress conditions observed on the prestressed concrete simply supported bridges may be summarized as follows.

1) Instances of hammering of the end of girder agaist each other were observed and spalling of concrete at the end of girder was observed (**Fig. 6, 7, 8**).
2) Vertical and horizontal cracking was frequently visible on the top face concrete of abutment or pier where bearing of prestressed concrete girder was connected to it by shear dowels (**Fig. 9, 10, 11**).
3) Hammering of concrete movable rocker bearing against the wall of the hole where the rocker bearing was placed. Cracking of concrete of abutment or pier was frequently visible. The earthquake emphasized again that the structures should be properly spaced or jointed to prevent hammering of adjacent parts (**Fig. 12**).
4) Rubberpad bearing deformed extensively during the earthquake and did not recover the original position (**Fig. 13**).
5) Abutment and pier shifted or tilted, apparently due to liquidation of weak sandy and silty foundation materials.
6) Cracking and sometimes crushing of concrete was observed on the wingwall of abutment.

Customary practice in Japan is to provid direct mechanical connection between one end of girder and abutment or pier without restraining rotational movement but restraining horizontal movement. The girders are seated on bearings and connected also to the pier caps by shear dowels which are embedded into the concrete of caps. The other end of the girder must be allowed to the horizontal and rotational movements due to temperature, shrinkage effects and to shortening of the components under prestress. At the fixed end of girder, bearing apparatus is usually connected to the support concrete with the embendded bolts. Cross-sectional area of this bolt is commonly calculated so as to be able to resist to the shearing force due to earthquake. Shearing force acting to this bolt during earthquake is assumed to be equal to the total dead weight of girder multiplied by seismic coefficient. The seismic coefficient shall be determined in accordance with regional earthquake activity. Usualy this coefficient is assumed to be equal to 0.2.

Design codes for earthquake-resistant shear dowels have used allowable design stresses 70% greater than normal design stresses. Allowable design shearing stress for mild steel is equal to 600 kg/cm$^2$.

No damages, for example shearing off the bolts, have been observed on all the prestressed concrete bridges and also no falling down of girders has been observed. But in the absence of any suitable cover of concrete to the embedded bolts or appropriate arrangement of mild-steel bars around the pier cap and bolts, the concrete cover has been destroyed due to the horizontal movement of bolt. Sometimes the pull-out of the bolt has been obsereved in the absence of insufficient length of embedded bolt (**Fig. 14**).

It has always been considered that forces of seismic origin should be transmitted by the most direct path. A procedure of using linkage bolts and rubber buffers connected through the adjacent end diaphragms of each span in case of simply supported prestressed concrete constructions will be adequate. This design could reduce the risk of damage due to adjacent spans moving out of phase in earthquake, as well as to transmit the forces to the anchorages in a direct path. Even in this case, special attension should be placed on the design and placing the shear dowels.

Details of shear dowels can handle seismic problems by proper attension to structural investigations and adopting good design practics. In seismic areas it is particularly important that all the requirments of plans and specifications be observed meticulously and that all workmanship be of high quality, because the possibility of earthquake damage is greatly increased by any construction deficiencies.

## 2. Structures employing prestressed concrete in Niigata City

Of the seven structures employing prestressed concrete in Niigata City, four bridges used pre-tensioned standard pre-cast beams employing bonded transverse post-tensioned tendons and two were post-tensioned bridges employing bonded post-tensioned precast girders assembled by transverse prestressing and one was a entire canopy or verandah, over the foyor employing pre-tensioned members on precast colums and beams assembled with mortar joints.

The following report is chiefly concerned to those seven structures located in Niigata City where the main fault or subsidence has occurred.

### (1) Teiseki Bridge

This bridge is 272 m long with 6 m carriageway with 13 spans over the Shinano River. The piers were cast in situ on precast concrete piles. The deck is consisted of pre-cast beams post-tensioned longitudinally and transversaly through the deck and the diaphrams. All tendons are fully grouted and bonded. All beams are adequetly connected to the piers against horizontal forces with shear dowels. Dispite considerable displacement of the foundations and possibly of the river bed, the bridge has suffered no visible damage at all. It is interesting to see that several of the central spans of an adjacent steel pipe bridge have collapsed and are leaning against the undamaged prestressed bridge (**Fig. 15**).

### (2) Higashikosen-Bridge

This bridge has a structural steel centre span with the approch spans consisting of pre-tensioned standard beams with cast-in-situ diaghrams and deck prestressed by transverse tendons. This approch bridge is 203 m long with 8.00 m carriageway, with 15 spans. Beams were supported on reinforced concrete portal frames. There was considerable movement of the piers, some of which moved from 1 cm to 30 cm vertically relative to one another, and horizontally by as much as 40 cm at the top. Because the center steel span was not properly secured, it pulled off the supports and collapsed over the national rail-way line (**Fig. 16**). Apart from minor spalling over the piers at deck level, the prestressed portion of the structure was undamaged (**Fig. 17, 18, 19**)

### (3) Yachiyo Bridge

This bridge has structural steel main spans over the Shinano River with approch two spans consisting of pre-tensioned standard beams with cast-in-situ concrete prestressed by transverse tendons. This approch bridge has two span of 7.5 m long each with 8.5 m carriageway. There was considerable movement of the piers, some of which moved by 30 cm vertically and also extensive subsidence of the approch embankment was obseved (**Fig. 20**). Due to this extensive subsidence and the vibration during the quake, piers simply tilted over as shown in **Fig. 21** and **Fig. 22** and spalling of concrete at the end of beams was observed.

### (4) Ōrai Bridge

The bridge has an overall length of 63.0 m with five equal spans. The bridge provides 5.5 m wide carriageway and is consisted of pre-tensioned standard beams with cast-in-situ concrete prestressed by transverse tendons. Second pier subsided by about 4 cm but no damage was observed in the prestressed portion of the structure. But horizontal and vertical cracking of wing wall of abutment was visible (**Fig. 23**).

### (5) Sasagoshi Bridge

The bridge has an overall length of 56.0 m with five equal spans, providing 9.5 m wide carriageway. The deck is consisted of pre-tensioned standard beams with cast-in-situ concrete prestressed by transverse tendons. Extensive subsidence of approach road surface was observed but the structure was undamged at all (**Fig. 24**).

### (6) Tūsengawa Bridge

This bridge is 15.0 m long with 7.70 m carriageway and the deck is consisted of cast-in-situ concrete slab post-tensioned longitudinally. One abutment slided forward and tipped over backward during earthquake (**Fig. 25**), but the prestressed concrete slab was undamaged.

### (7) Canopy of Niigata Railway Station

The verandah over the foyer is connected to the main reinforced concrete building at one end and the other end is cantilevered. The dimensions of each member and the cable arrangement are shown schematically in **Fig. 26**. Two adjacent beams were powerfully pressed through cantilever beam on the column with tendons. One end of tendon is anchored on the top face of cantilever beam and the bottom end of tendon is anchored in concrete foundation.

Fig. 26 General view of canopy

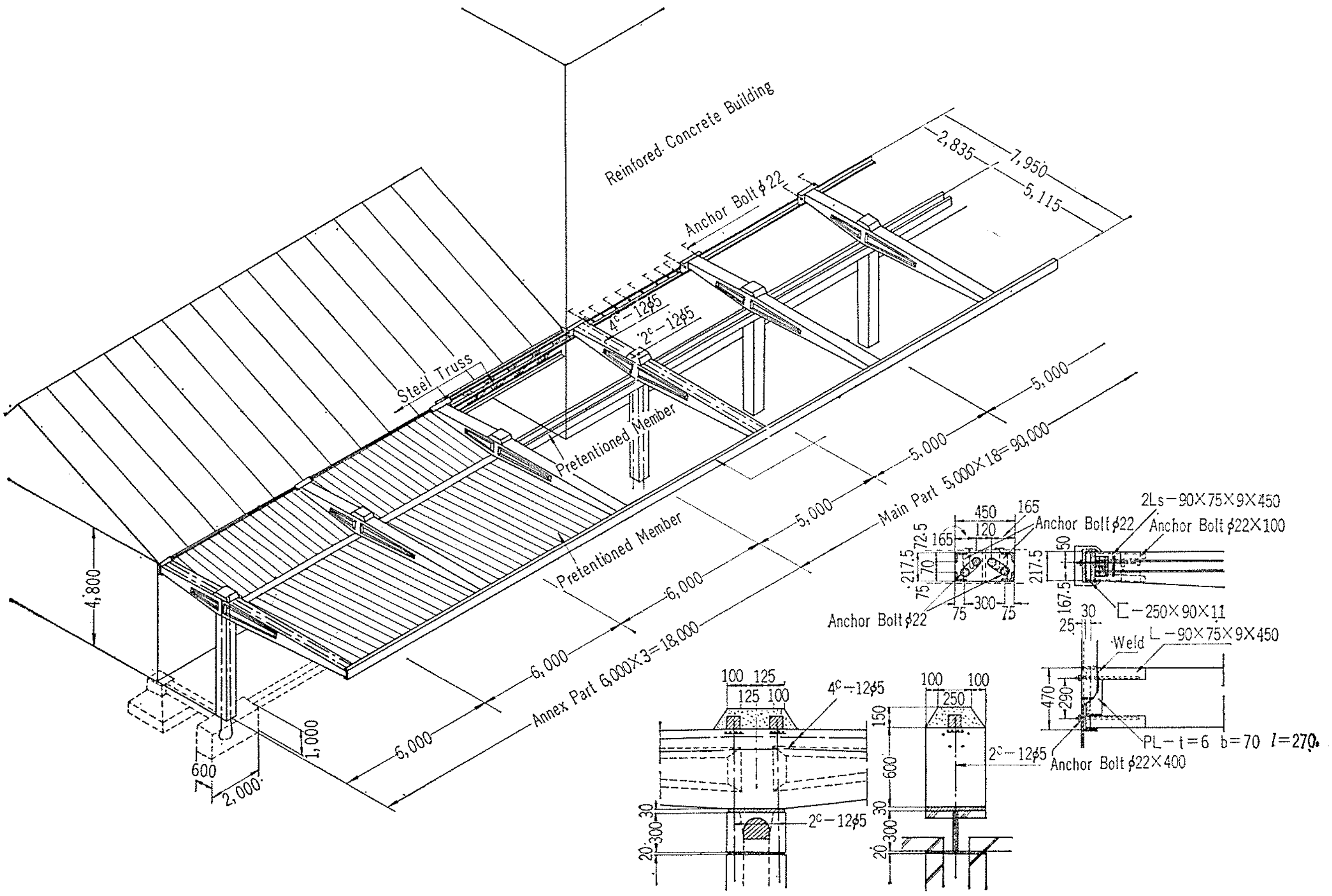
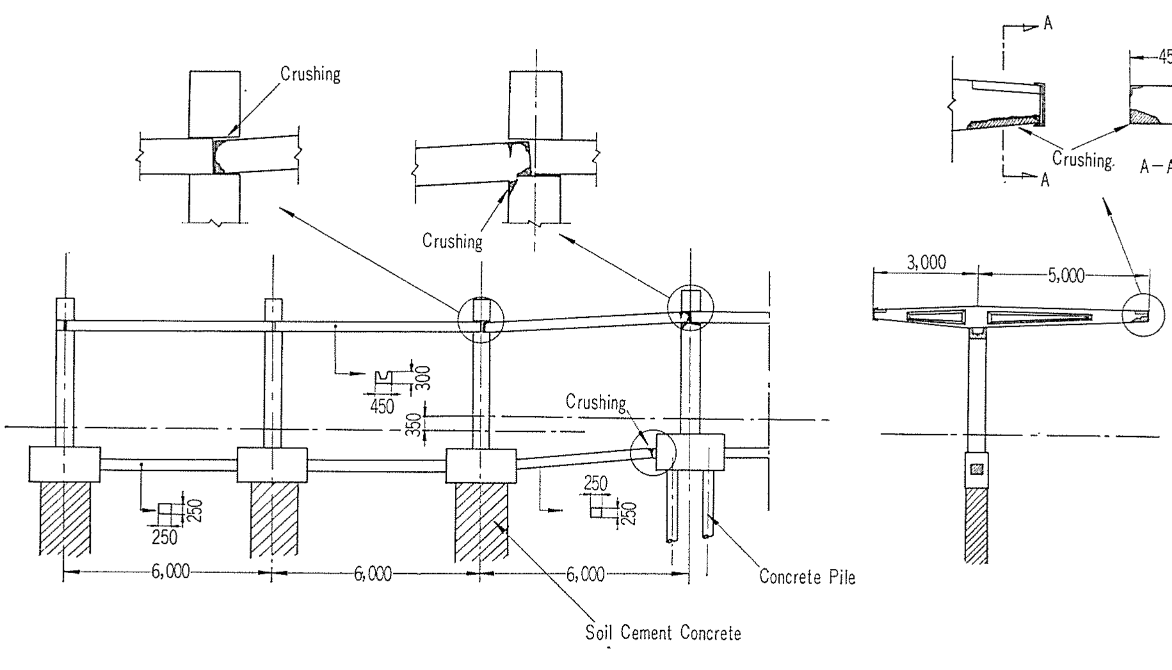


Fig. 30 Damages of members are shown schematically



The main part of this structure (18 spans of 5 m length each) is founded on precast concrete piles but the annex (3 spans of 6 m length each) is founded on soil-cement foundation. The foundation material (very fine sand) is apparently appears to have subsided by about 50 cm during earthquake (**Fig. 27**). The structure founded on concrete piles has withstood the movement extremely well and no damage could observed in the prestressed members. But the structure which was not founded on concrete piles has subsided by about 35 cm relative to the main part of the structure.

Because of this difference of subsidence between two parts, the frame of first one span in the annex was submitted unequal settlement of column and the ends of beam and the cantilever beam were partialy cracked and also crushed (**Fig. 28, 29**). The pretensioned concrete roof member was also damaged on the cracked column. But no damage could observed on the end two spans of the annex.

This damage is apparently caused by difference of extensive and irregular subsidence of the foundations between two parts.

It is belived that Niigata earthquake can solve seismic problems by proper attension to foundation investigations and adopting good structural design practics. Structural damage shows, on the part of designers, a lack of sensitivity to the foundation on sandy or silty subsoil. Designer must pay more attension to the fact that liquidation or consolidation of weak sand or soil deposit could cause extensive subsidence during earthquake.

The anchor bolts holding the bearing plates into the piers or abutments tended to pull out of the thin covered concrete and cracked the concrete. In many cases the anchor bolts pushed the concrete cover and made it cracked. It would appear that this failure of the concrete could have been overcome if adequate mild steel had been provided around the anchor bolts. Furthermore it was evident that the thichness of concrete covering was not sufficient to resist to the horizontal pulling force of the anchor bolts. It is not able to discover the exact design method to which the anchor bolt should be designed but it would appear that the existing shear dowels would not have sufficient strength as a whole.

## Acknowledgments

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Oriental Concrete K.K.; Tajima Kogyo K.K.; P S Concrete K.K.; P C Bridge K.K.; Hotsukaido P S Concrete K.K.; Kowa Concrete K.K.; Sumitomo Kensetsu K.K.

**Fig. 2** Reinforced concrete building tilted over and subsided

**Fig. 3** 4 story reinforced concrete building tipped down

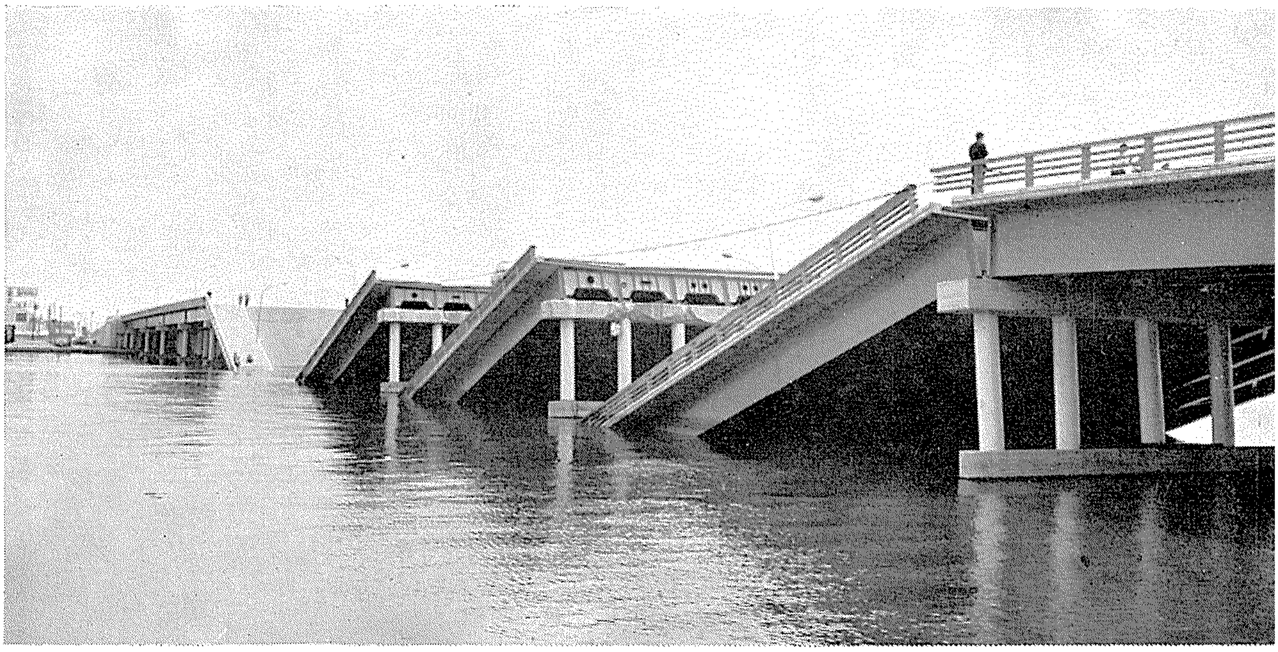


**Fig. 4** Steel bridge fell into the Shinano River (Shin-Showa Bridge)

**Fig. 5** Extensive subsidence of embankment of Shin-Showa Bridge

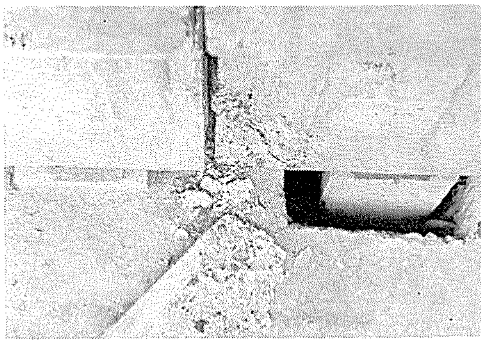


**Fig. 6** Hammering of the end of beam against each other. Spalling of concrete at bottom of beam. (Shiroyama Bridge) Overall length······120 m (4×30 m) (Pcst-tensioned) Width of carriageway······5.5 m

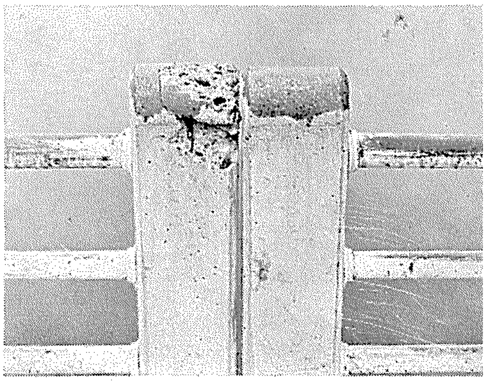


**Fig. 7** Spalling of concrete at top of hand-railpost (Shiroyama Bridge)

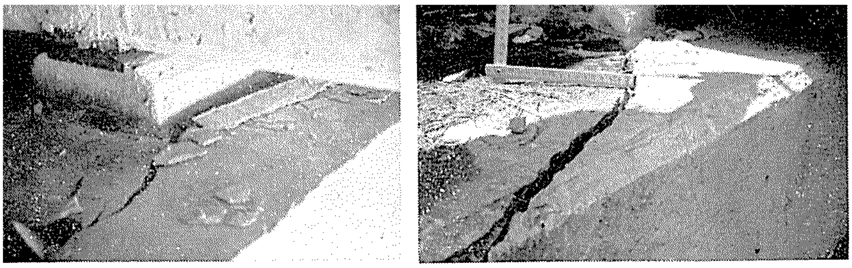


**Fig. 10** Cracking of abutment (Komatagawa Bridge) (Post-tensioned)
All-Over length……50.0 m (2×24.96 m)
Width of Carriageway……5.5 m

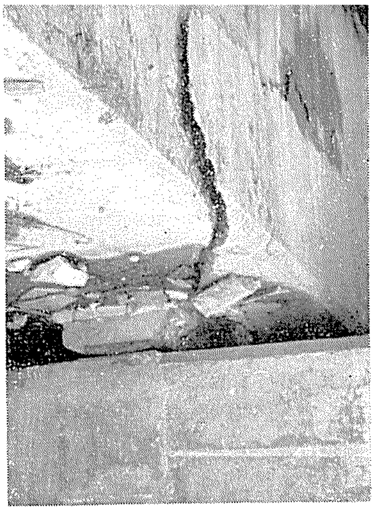


**Fig. 11** Cracking of abutment (Komatagawa Bridge)

← **Fig. 8** Cracking of Concrete at deck level(Yasuda Bridge)(Post-tensfoned)
Over-all length……825 m(23×25.80 m)
Width of carriageway……6.00 m

**Fig. 12** Hammering of concrete movable rocker bearing against wall of hole caused cracking of concrete pier (Yasuda Bridge) →

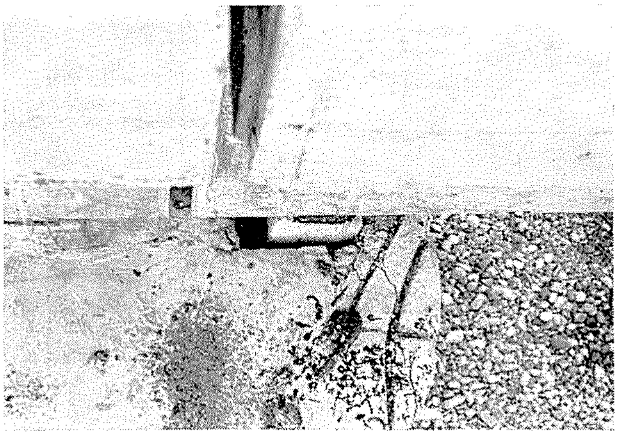
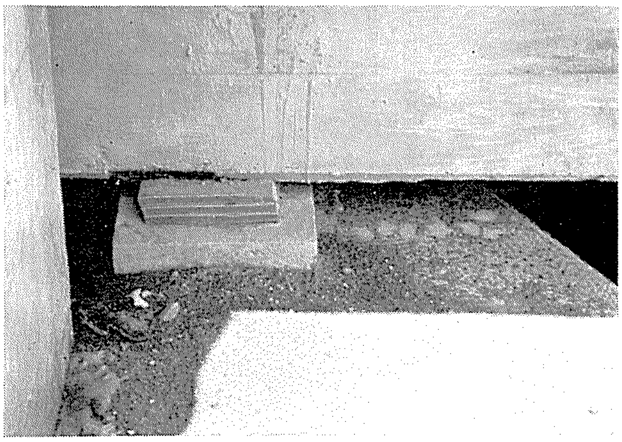
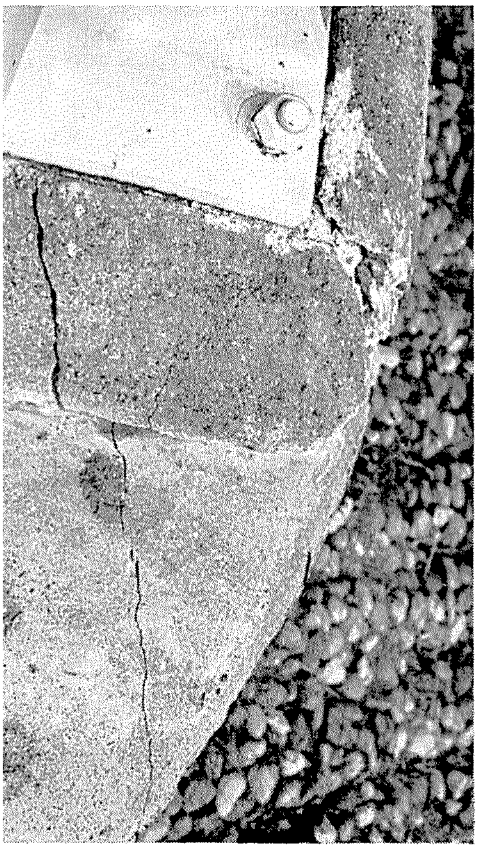


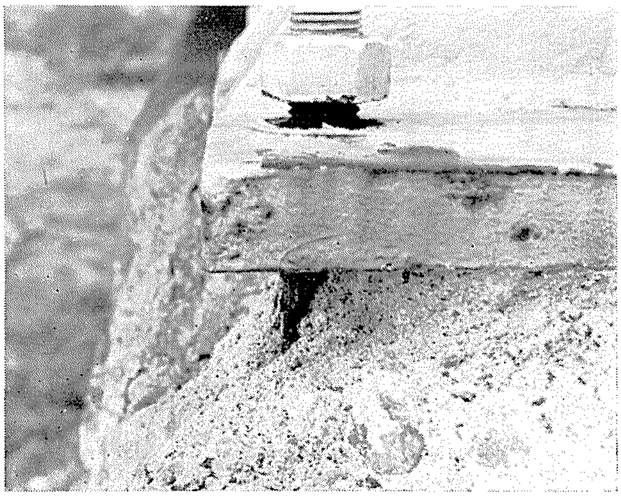
**Fig. 13** Rubber pad bearing tilted over(Kosaka Bridge) (post-tensioned) Over-all length……60.50 m (2×30.20 m) Width of carriageway……6.0 m →





← **Fig. 9** Cracking is visible on the top face concrete of pier (Yasuda Bridge)

**Fig. 14** Pull-out of anchor bolt (Yasuda Bridge) →



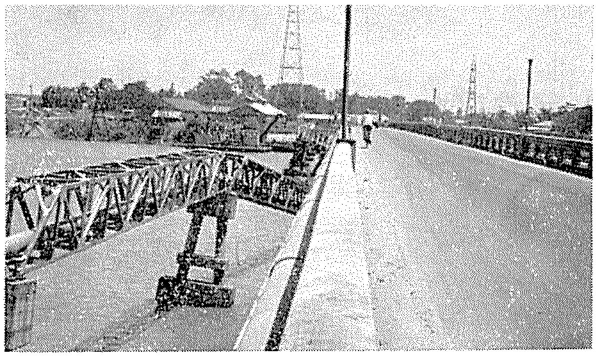


**Fig. 15** Teiseki Bridge

**Fig. 17** Spalling of concrete at deck level

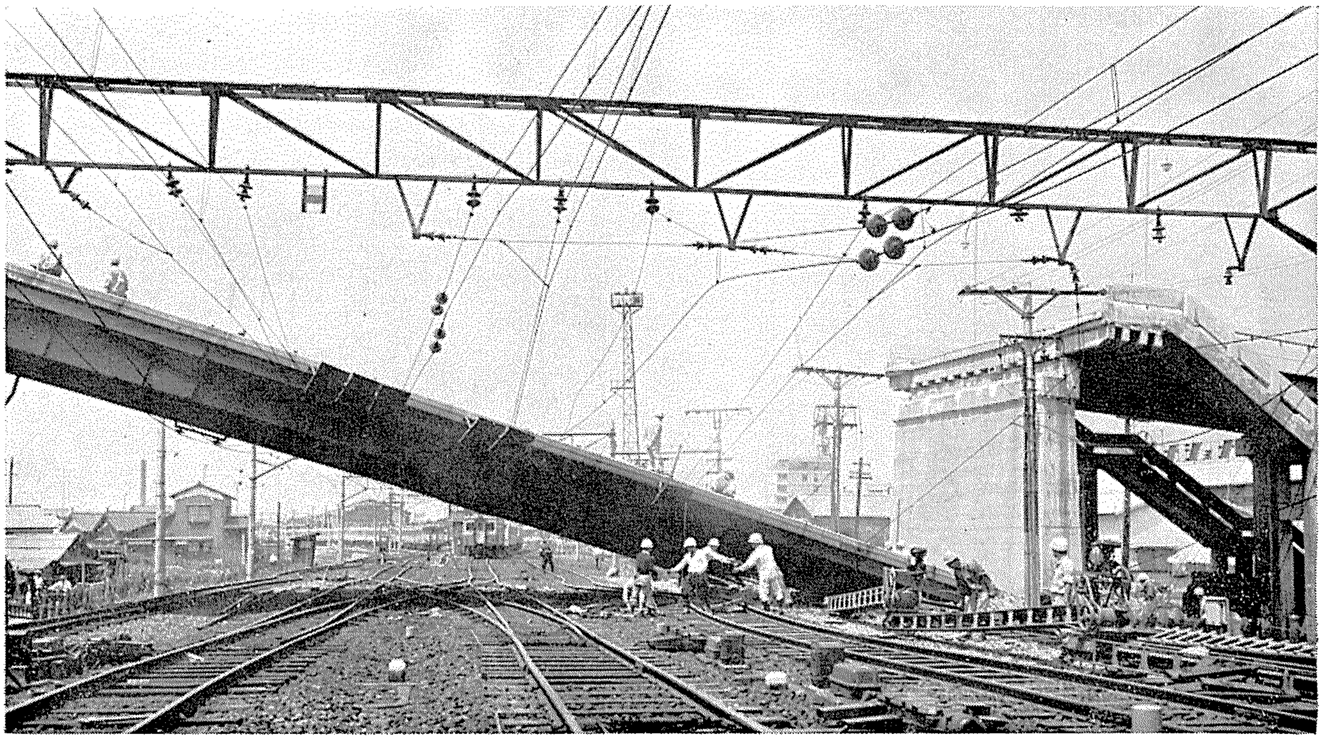


**Fig. 16** Center steel span pulled off the support and collapsed over National Railway Line

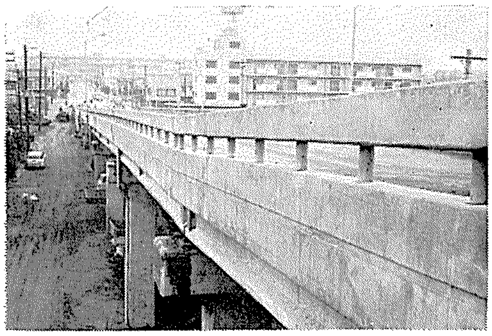


**Fig. 18** Side view of approach span

**Fig. 19** General view of deck surface

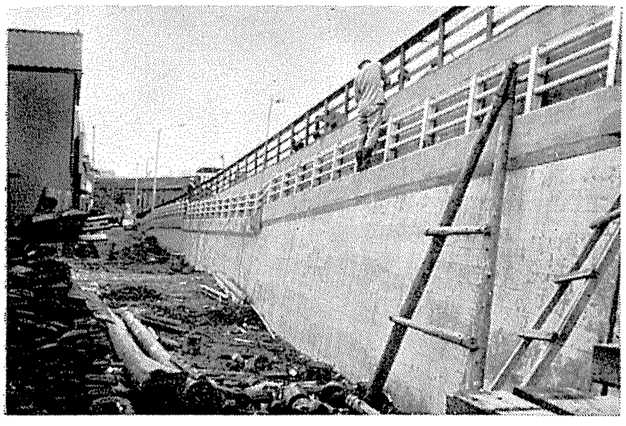


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**Fig. 20** Side view of embankment

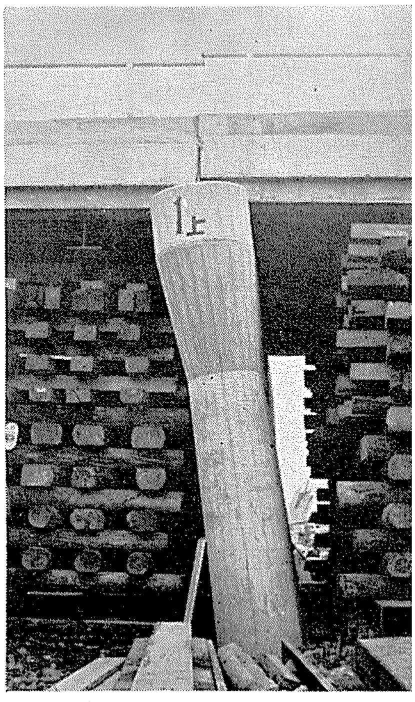

**Fig. 21** Pier tilted over

**Fig. 22** Pier tilted over and spalling of concrete is visible

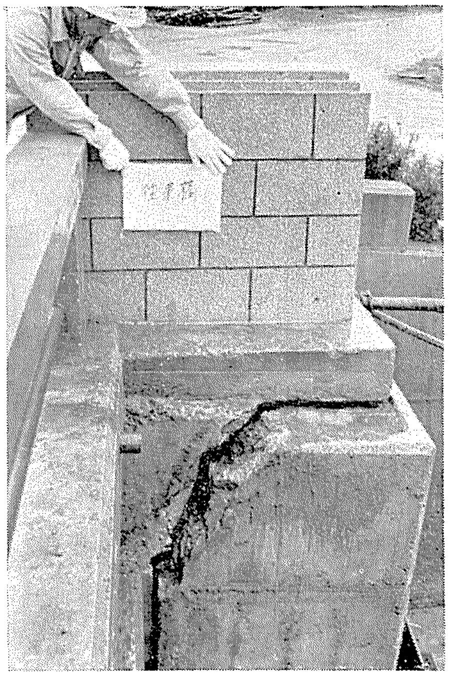

**Fig. 23** Cracking of wing-wall

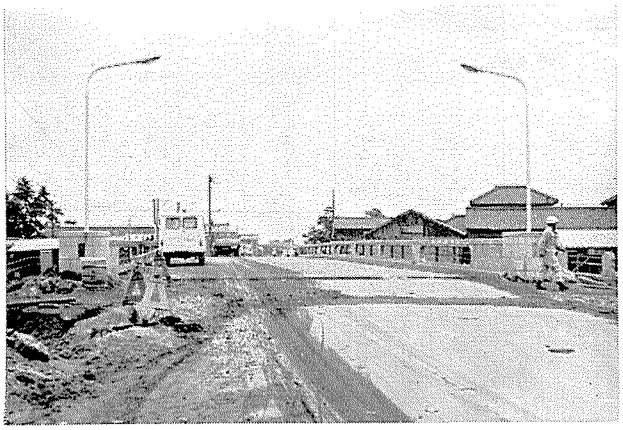

**Fig. 24** Extensive subsidence of approach road is ovserved

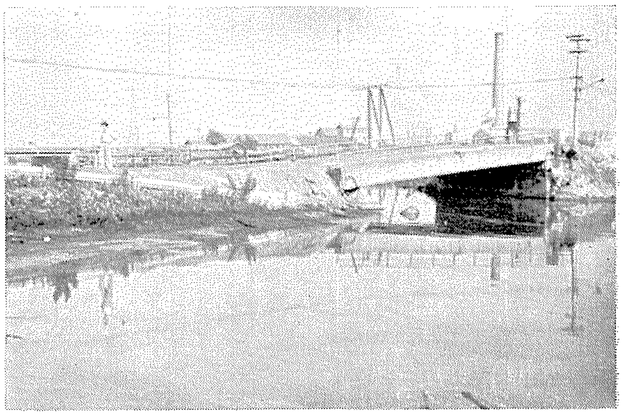

**Fig. 25** One abutment tipped over

**Fig. 27** Subsidence of foundation material

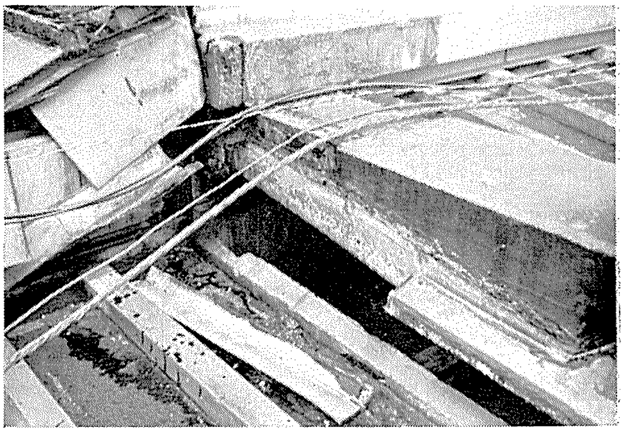

**Fig. 28** Top view of failured members

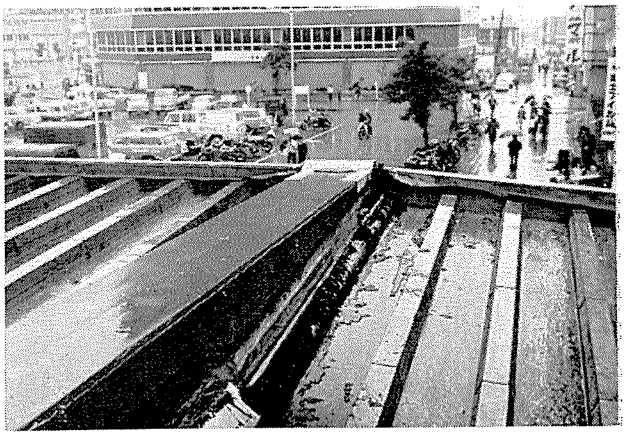

**Fig. 29** Top view of difference of subsidence between main part and annexpart