NIIGATA EARTHQUAKE OF 1964

Japan National Committee on Earthquake Engineering

I. SEISMOLOGICAL ASPECTS OF THE NIIGATA EARTHQUAKE

An earthquake which occurred about 1:01 p.m., June 16, 1964 (Japan Local Time), caused extensive damage in Niigata City, a major city on the Japan Sea coast of the island of Honshu, Japan, and in Yamagata and Akita Prefectures.

From the point of view of geotectonics the earthquake originated in an area where Tertiary geosyncline is underlain by the old geological structure of the Honshu Arc of Japan. The focus of the earthquake is considered to lie within an old structure rather than a shallow and young structure. Other major earthquake which originated in the same Inner Arc of the Hoshu Island include the Tango earthquake of 1927 and the Fukui earthquake of 1948.

According to Japan Meteorological Agency the seismological data for the Niigata earthquake are as follows:

(1) Origin time....$13^h\ 01^m\ 40^{sec}$, 16^d, VI, 1964 (local time);
(2) Epicenter..... 38.4°N, 139.2°E;
(3) Focal depth....about 40 km;
(4) Magnitude..... M = 7.5 by Gutenberg-Richter scale.

Figure 1-1 shows the distribution of the seismic intensity (JMA scale) of the Niigata earthquake according to investigations by JMA. The figure gives a conversion chart between the JMA scale and the Modified Mercalli scale.

As will be described later in this report though some buildings in Niigata City showed marked tilting an intensity of V (JMA scale) was estimated for the city because the tilting of buildings was attributed to the extremely unusual ground conditions. The horizontal accelerations estimated from observation of overturned rectangular tombstones are 400 gals at Atsumi, in the visinity of the epicenter, 300 gals at Senami, and 250 gals at Tsuruoka.

Strong Motion Seismograph Records: The Building Research Institute, the Ministry of Construction, had installed a SMAC type strong motion seismograph in the basement and a DC type strong motion seismograph on the fourth floor of an apartment building at Kawagishi-cho, Niigata City (the next apartment building overturned during the earthquake). These instruments recorded a maximum acceleration of 190 gals in the basement location. At Niigata Meteorological Observatory, Niigata City, earthquake motions were also recorded by a displacement type seismograph of 1:1 magnification. See Fig. 1-2.

Topographic Movements: Marked crustal movements were observed in connection with the Niigata earthquake. On the island of Awashima near the epicenter, a rise of about 80 cm was observed on the west coast, and a rise of 150 cm on the east coast. On the other hand, along the Japan Sea coast of Honshu there was a subsidence of about 45 cm at Hayakawa which is just across from Awashima, and a coastal stretch of about 50 km south and north of Hayakawa showed subsidence. It was then inferred that an earthquake fault or faults had been created in the bottom of the sea between Awashima and Honshu. The appearance of at least two new sea-bottom faults as a result of the Niigata earthquake has been confirmed by subsurface explorations after the earthquake: by echo sounding survey, sperker survey and by bathyscaphe the Yomiuri, and by comparing the sea- bottom cotours before and after the quake. The above-mentioned values of upheaval and subsidence were obtained from careful measurement of the variation in the coastline.

Precise levelling and triangulation are now underway by the Geographical Survey Institute in order to determine more accurate ground movements. Fortunately in this area levelling had been conducted very frequently before the earthquake in connection with the subsidence problem in Niigata City. In the levelling data shown in Fig. 1-3 it is pointed out that peculiar ground movements were observed for two to three years prior to the earthquake along the coast of Honshu across from Awashima. This phenomenon is particularly noteworthy in connection with the problem of earthquake forecasting.

In addition, a peculiar ground movement was observed in Niigata City just before the earthquake. The area in and around Niigata City had been noted for severe ground subsidence due to pumping water for producing natural gas, and number of deep wells had been equipped with automatic subsidence recorders. Beginning nine hours before the earthquake at fourteen of these wells, minute but clear ground movements were recorded. Whether or not the ground movements were related to the forewarning phenomena of earthquake should be determind by future studies. Nevertheless, the observation is extremely interesting in connection with the question of earthquake forecasting.

Tsunami: Japan Meteorological Agency issued a tsunami warning immediately following the earthquake. The heights and arrival times of the tsunami are shown in Fig. 1-4. The tsunami was 2 to 4 meters high on the coast opposite Awashima. The tsunami reached 6 meters above the sand beach at Fuya. The tsunami affected almost the entire Japan Sea coast from Hokkaido to Yamaguchi Prefecture. The height of the tsunami was 60 cm at Iwanai, Hokkaido, and only 20 cm at Hamada, Yamaguchi Pref., and the damage was limited to the vicinity of the epicenter.

Aftershocks: Immediately following the earthquake the Earthquake Research Institute, the University of Tokyo, and other research organizations installed temporary stations to observe aftershocks by means of high magnification seismographs. As shown in Fig.1-5 the epicenters of these aftershocks are mainly distributed in an area around the waters between Awashima and Honshu. The focal depths of most aftershocks range from 10 km to 40 km. It is noted that the Niigata earthquake had considerably fewer felt aftershocks than the Fukui earthquake of 1948.

II. GROUND CONDITIONS (PARTICULARLY IN NIIGATA CITY)

A peculiar phenomenon during the earthquake was the settlement and tilting of many reinforced concrete buildings. As it can be attributed to the unusual ground conditions, some available data concerning the subsurface conditions are presented. Prior to the Niigata earthquake the problem of ground subsidence in and around Niigata City had attracted public attention for some time. Within the city limits there had been a considerable accumulation of soil exploration and test data in connection with the ground subsidence problem and for routine foundation design. The locations where such boring logs were available (150 locations and 220 holes) are indicated in open circles in Fig. 2-1.

The coastal portion of Niigata Plain is alluvial and consists of marine sediments due to the current along the Japan Sea coast and of river or lake deposits along the Shinano River. Although there is no general agreement the alluviums may be considered to extend approximately 30 m below the ground surface and is underlain by the diluvium.

Topographically the city of Niigata may be divided into aeolian sand dunes running approximately parallel with the coastline, and strips of lowlands between the dunes. To show the subsurface conditions in the lowlands the profile of Fig. 2-2 was constructed along the chain-dashed line in Fig. 2-1 on the basis of the boring data obtained before the earthquake. The profile shows that the soils are primarily sandy down to depths of 20 to 30 m. Lines of equal N-values of the standard penetration resistance test are shown in the figure to indicate relative density of the sand. Very loose sand for which the N-value is less than 5 extends down to several meters in most parts. At greater depths the N-values tend to increase to 30 at depths from 10 m to 20 m.

Within the predominantly sandy strata there are isolated thin lenses of sandy silt, silty sand, or these with organic matter having high compressibility and low permeability.

In Niigata City in general the ground water table is quite shallow partly due to the ground subsidence in the area. The ground water table in the lowlands is about 1 m below the ground surface.

The coastal dune area (Zone A in Fig. 2-3) suffered practically no damage during the earthquake. Of the lowlands marked B and C, most cases of severe damage were concentrated in Zone C, and only light to moderate damage was observed in Zone B, the two zones being separated by remarkably clear demarcation. Within Zone C the sandy ground underwent very extensive liquefaction, which caused many buildings to settle and/or tilt. In an extreme case a four-story reinforced concrete apartment building overturned completely.

To explain why Zones B and C both of which lie in the lowlands showed such remarkably different behaviors, one must investigate the soil properties in more detail. When frequency distributions of N-values for Zones B and C are compared for a given depth the most significant difference in the mean values is observed for the range of depths between 5 m and 10 m, the mean

N-value for Zone B being greater than that for Zone C. A difference of a lesser degree is recognized for the depths 10 to 15 m, but no significant difference exists for the depths less than 5 m or greater than 15 m.

It is inferred, therefore, that the contributing causes for different degrees of damage in Zones B and C should lie primarily in the depths between 5 m and 10 m, but not in the depths greater than 15 m or smaller than 5 m.

About 40 borings were performed immediately after the earthquake at the locations marked in dark circles in Fig. 2-1 in order to provide data for comparing N-values before and after the earthquake. For example a boring log shown in Fig. 2-4 indicates that the N-values either increased or decreased after the earthquake depending on depths. These data were processed statistically to determine for a given depth an N-value which remained unchanged after the earthquake. The result is shown by Curve ABC in Fig. 2-5.

When the borings whose N-values for the depths from 0 to 10 m were smaller than the values given by Curve ABC of Fig. 2-5 were plotted on the map, they all lie within Zone C of Fig. 2-3. The N-values given by Curve ABC of Fig. 2-5 may be considered to correspond to the critical void ratios for the sand for given depths. Where the void ratios of the sand were greater than the critical void ratio, it is conceivable that the earthquake motion caused a volume reduction of the sand and an increase in the pore water pressure, which in turn caused liquefaction and extensive damage to buildings located in Zone C.

In those areas in Niigata City where structural damage was appreciable there were numerous sand craters as shown in Plate 2-1, indicating the presence of excess pore water pressure within the sand. According to comprehensive analyses of specific gravity, grain size distribution, grain shape, and mineralogical composition of the ejected sand, it can be concluded that the ejected sand originated from depths not greater than 10 m.

III. DAMAGE TO CIVIL ENGINEERING STRUCTURES

The structures which were damaged by the Niigata earthquake include port and harbor facilities, bridges, water supply system, railroads, roads, levees, power facilities, airport, and agricultural facilities. The earthquake damage was characterized by its close relationship with the ground conditions and with the fact that the ground level of the Niigata area had been below the sea level as a result of ground subsidence. These two factors tended to magnify the extent of damage.

Port and Harbor Facilities: The earthquake and subsequent tsunami caused 22×10^9 yen damage to Niigata Harbor, Sakata Harbor and nine other harbors. In particular, Niigata Harbor received devastating damage totaling to 21.8×10^9 yen. The damage facilities include quaywalls, piers, bulkheads, coastal levees, breakwaters, training dikes, spur dikes, beacon lights, channels, sheds, warehouses, loading machinery, roads, and railroads. Plates 3-1 to 3-5.

The bulkheads along the Shinano River, the quaywalls, and a part of the coastal levees collapsed due to the earthquake and allowed the tsunami to reach large inhabited areas inland.

Quaywalls and bulkheads, mostly of sheet-pile construction, suffered the worst damage of all the port and harbor facilities. Typical failure modes were the settlement of the wall and forward movement of the wall line. Forward tilting was more frequent than failures due to inadequate depth of penetration. Many cases of damage were caused by inadequate counterfort. Only light damage was noted in new quaywalls which had been designed according to the current specifications which called for adequate counterfort resistance. Broken tie-rods were noticed at some low quaywalls and bulkheads.

Landing piers built on well foundation showed marked forward tilting and settlement owing to inadequate bearing capacity during the earthquake. The pile-supported portion of the pier between the well foundations also showed some forward tilting and settlement, which, however, seemed to be caused indirectly by the failure of the well foundations rather than of the piles. The apparent superiority of the piles may be attributed to their greater depth of penetration which was an important factor in the stability of this type of soil. This argument is supported by the fact that, of the quaywalls of the same type, the ones with shallower water suffered heavier damage. This is being incorporated into the basic policy for rehabilitation of Niigata Harbor.

It was clearly demonstrated that the type of structure which did not involve lateral earth pressure suffered little damage: landing piers and dolphins showed less damage than gravity walls.

Subsidence of reclaimed land was probably responsible for most damage to the sheds and warehouses. Failures involving circular slides which had been noticed in other earthquakes were not evident this time except for very isolated cases, indicating the peculiar nature of the ground in Niigata.

As a general trend concerning the relationship between soil properties and damage pattern, it was noticed that the damage increased with a decrease in the N-value of the sand, and that inclusion of locally weak strata within relatively dense soils made the ground susceptible to damage due to subsidence.

The damage to some of the port facilities may be attributed to the fact that the factor of safety of the structures had been reduced by several additions of earch fills to cope with ground subsidence, and that the shear strength of the soil near the ground surface decreased during the earthquake. Although the earthquake did not reveal any basically new types of failure, it was characterized by an extensive display of certain phenomena associated with sandy soils which had been recognized only in the laboratory or had occurred in a limited scope in previous earthquakes.

Bridges: Although bridges were damaged throughout Niigata, Yamagata, and Akita Prefectures, heavy damage such as collapse of superstructures, excessive settlement and tilting of abutments and piers, cracks, and breakage, were confined to the estuaries of the Shinano and Agano Rivers. In other areas permanent bridges suffered relatively light damage such as cracks in abutment wing walls, settlement of approach roadways, and cracks around expansion joints. Collapse of wooden bridges was primarily due to loss of strength from aging. Table 3-1 lists bridges where traffic was partially or completely stopped as a result of the earthquake.

Bridge superstructures fell off piers at Showa Bridge in Niigata City (Figs. 3-1, 3-2, and Plate 3-6), at an overbridge east of Niigata Railroad Station (with a 26.6 m main span of built-up steel girders and timber pile foundation), and at Shin-Matsuhama Bridge on the estuary of the Agano River (under construction). The following two bridges suffered extensive damage due to lateral movement of the river banks towards the center of the river: Yachiyo Bridge located downstream from Showa Bridge (Fig. 3-3, Plates 3-7 and 3-8) and Bandai Bridge (with six 40 m main spans of concrete arches and 14.88 m side spans of two-hinged arches). The damage to the side spans is shown in Plate 3-9.

The modes of bridge failures may be classified as follows: (1) settlement, tilting, or lateral movement of foundations under abutments and piers; (2) distortion or breakage of girder supports and of expansion joints in decks; and (3) fall of girders. Except for the fall, the superstructures proper suffered only minor damage. At Bandai Bridge, however, where the superstructure was rigidly connected with the abutments and piers, the end arches nearly collapsed, and the first main arch from the right bank had a large crack of a maximum opening of 5 mm which caused a noticable change in the arch form.

Probable causes of the damage to the bridges are summarized as follows: (1) The ground conditions: In and around Niigata City where damage was heavy the soils consist of recently reclaimed land and young sedimentary deposits having low density and shallow ground water table. The foundation failures were probably caused by loss of bearing capacity due to liquefaction of sand, or by ground movement where structures were supported by different soil strata (abutments along the Shinano River, for example). (2) Defective design and construction: Factors which contributed to aggravating damage to bridges are inadequate flexural rigidity of the superstructures, insufficient lateral resistance of soil, discontinuity in the dynamic characteristics of neiboring substructures, and defective or inadequate bearings.

Railroads, Water Lines, etc.: The subgrade of Niigata port railroad was severely distorted and submerged due to the collapse of tide embankments and ground subsidence. The railroad embankments on loose sand in Niigata City showed marked settlement. Hair cracks appeared in several tunnels. The entrance to a tunnel located in a landslide area showed severe cracks and had to be reinforced with steel frames. No trains overturned due to the earthquake. A survey has been conducted to determine how the train personnels who happened to be on duty felt the earthquake and handled the situation (425 questionaires have been returned).

The three water filtration plants within the city limits of Niigata suffered only minor damage because they were founded on firm ground. No serious difficulties were encountered for restoring their operation. The water pipes were embedded under streets. There were about 400 km of pipes of diameters from 100 mm to 700 mm, most of which were of cast iron with lead joints, and mechanical cast iron pipes were used in more recent installations. The earthquake caused the joints to loosen, fall off, break, or crack. The damage was attributed to cracks in the ground, uneven subsidence, wavy ground movements, and random motion of the ground due to liquefaction of sand. The worst damage to the water lines occurred in the lowlands along the Shinano River where most lines required full replacement.

Of the two runways at Niigata Airport one was paved with asphaltic concrete and the other with Portland cement concrete. The latter runway consisting of rectangular concrete slabs of 6 m x 8 m x 0.25 m became inoperative when the earthquake produced severe distortion. On the other hand the asphaltic concrete runway suffered little damage and was restored after emergency repairs.

Earthwork: Damage to earthwork such as roads, railroad embankments and levees, was closely related to the ground conditions. Longitudinal cracks along the top of the slope, general subsidence, and shear failures occurred where embankments were placed on loose sand deposits along old river-bed and buried marshes, or on repaired portions of old levees. Where longitudinal cracks and lateral movement of slopes occurred, the failure mode seemed to resemble a circular slide, and riprap and mattress placed at the toe appeared to be effective in restraining slides. Transverse cracks appeared in embankments stradling two different subsoils, e.g., an embankment placed on a repaired part of an old levee. Plates 3-10 to 3-12.

As far as embankment materials were concerned, cohesive soils showed greater resistance to cracks and slides than cohesionless soils.

At boundaries between embankments and rigid structures such as bridges, sluice gates, and culverts, the embankments were likely to settle or crack due to discontinuity in vibration characteristics.

Many of the failures of cut slopes occurred where the slopes had been composed of loose deposit of previous landslides. Natural slopes in diluvial or older strata developed few landslides.

It is interesting to note that some oil tanks founded on loose sand experienced different degrees of damage depending on whether or not the sand had been mechanically stabilized. For example, sandy ground whose natural N-values ranged from 1 to 15 over a depth of 8 m was densified by vibrofloatation using 17 % filler so that the N-values increased to a range between 5 and 25. An oil tank weighing 15 t/m^2 built on this stabilized ground settled only 2 to 3 cm due to the earthquake, whereas another tank of a smaller load built on untreated soil nearby suffered marked differential settlement. In this case the vibrofloatation process probably contributed to improving the uniformity of soil properties as well as increasing the average soil density. Plate 3-13.

IV. DAMAGE TO BUILDINGS (SUPERSTRUCTURES)

Damage to buildings may be divided into three groups: (1) damage associated with vibration, (2) damage due to movements of sandy ground, and (3) damage due to fires and tsunami. See Plates 4-1 to 4-23.

(1) Vibrational Damage.

Damage due to vibration appeared similar to usual damage observed in previous earthquakes. The damage which occurred within 50 to 60 km radii from the epicenter (between Murakami and Tsuruoka) were primarily due to vibration of superstructures and to landslides caused by strong shocks. In these mostly hilly areas, however, the ground is generally firm and relatively few cases of damage were reported.

Reinforced Concrete Buildings: Although few in number, reinforced concrete buildings in these areas, particularly those in the hills, suffered heavy damage. In particular, school buildings suffered mainly diagonal cracks, which was primarily associated with distortional vibration of the structures.

Wooden Buildings: Wooden buildings in the hills received very light damage thanks to the firm ground. On weak ground (not necessarily sandy soils), however, wooden buildings were damaged showing usual failure modes (Ohyama, Tsuruoka; and Yokkaichi, Murakami).

Damage due to landslides: A village was crushed by a landslide due to the earthquake at Fuya, Sanpoku.

(2) Damage due to Movements of Sandy Ground.

The earthquake caused numerous cases of sand eruption, subsidence, and landslides in the sandy soils along the Japan Sea coast. Heavy structures, particularly reinforced concrete buildings, showed unusual settlement. Damage to light buildings was associated with large deflection in their foundations caused by ground movements. Severe cases of the damage were concentrated in Niigata City.

Reinforced Concrete Buildings and Concrete Block Buildings: Among about 1500 reinforced concrete buildings located in Niigata City, approximately 310 suffered damage. Two thirds of the damaged buildings settled or tilted en masse without appreciable damage to the superstructure proper. The remaining third developed cracks in columns, beams, and walls due to differential settlements. Damage due to differential settlements was concentrated at adrupt changes in plan or elevation, or near inadequate expansion joints.

The damaged buildings were located within Zones B and C (Fig. 2-3). Buildings on piles bearing on firm strata at a depth of 20 m suffered no damage. Buildings on shallow foundation or on friction piles in loose soil were damaged.

Concrete block buildings suffered the same type of damage as the reinforced concrete buildings, i.e., settlement and tilting en masse, or cracked walls due to differential settlements.

Steel and Timber Construction: Steel and timber buildings were often damaged by severe deformation in foundation, differential settlements, or by settlement of neiboring heavy buildings. In some occasions sand eruption caused partial lifting of buildings. This type of damage was widespread throughout Akita and Niigata Prefectures wherever recent fills on old river-bed and swamps were encountered.

(3) Damage due to Fires and Tsunami.

In Niigata City fires broke out from oil tanks as a result of the earthquake and caused extensive damage to oil refining facilities. However, relatively small portion of the inhabited areas was affected by the fires.

Many buildings were affected by the tsunami. Particularly, the estuary regions in Niigata City were inundated for a considerable period.

V. DAMAGE TO BUILDING FOUNDATIONS

The nature and extent of damage to building foundations are not clearly assessed because few foundations have been excavated for direct inspection. There are, however, some isolated evidences of damage: where a building was founded on reinforced concrete piles, the piles tilted in the same direction as, and to a somewhat greater degree than, the superstructure; a building slid laterally 2 m off timber piles; and in several occasions reinforced concrete piles were damaged at the top.

Let us examine the relationship between the type of foundation and damage to the superstructure. Among buildings with shallow foundations located within Zone C (Fig. 2-3), those on mat foundations suffered the least damage, and buildings on strip footings seemed to have performed slightly better than those on isolated footings.

Buildings on shallow foundations placed on soils having N-values less than 15 suffered considerable damage in their superstructures, whereas few buildings founded on soils having N-values greater than 15 were damaged.

For buildings on pile foundations the degree of damage to the superstructure seemed to depend a great deal on the depth of pile penetration and on the strength of the soil at the pile tip. Within Zone C, all the buildings on relatively short piles whose tips were located in soils of small N-values suffered severe settlement and/or tilting —— probably because the soil around the pile tip underwent almost complete loss of bearing capacity due to liquefaction of soil during the earthquake, even if the static bearing capacity had been adequate.

Let us plot for each building the relationship between the N-value at the pile tip and the depth at the pile tip. Then the points for damaged buildings are located below Curve DBE in Fig. 2-5, and those for undamaged buildings are above the curve. Thus, in Fig. 2-5 Curve ABC gives critical N-values for liquefaction of soil, and Curve DBE represents critical N-values for damage to buildings on piles. The zone below Curve AB may be considered to represent a complete loss of pile resistance due to liquefaction. The shaded zone ABD may correspond to a case in which the soil above the pile tip was liquefied but the soil at the pile tip was unaffected, i.e., loss of frictional resistance along the pile caused an overload at the pile tip which in turn caused a bearing capacity failure and damage to the superstructure. In case of Zone CBE the superstructure was not damaged probably because liquefaction of the ground caused only partial loss of pile resistance.

ACKNOWLEDGMENT

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TABLE 3-1

	Type of Superstructure	No. of Damaged Bridges	Type of Foundation
Highway Bridges	Timber	10	Timber piles
	Simply supported girders	3	Timber piles, reinforced concrete piles, or steel pipe piles
	Simply supported trusses	1	Open caissons
	Reinforced concrete arches	1	Timber piles and pneumatic caissons
Railroad Bridge	Simply supported girders	1	Open caissons

Fig. 1-1 Isoseismal map of Niigata Earthquake

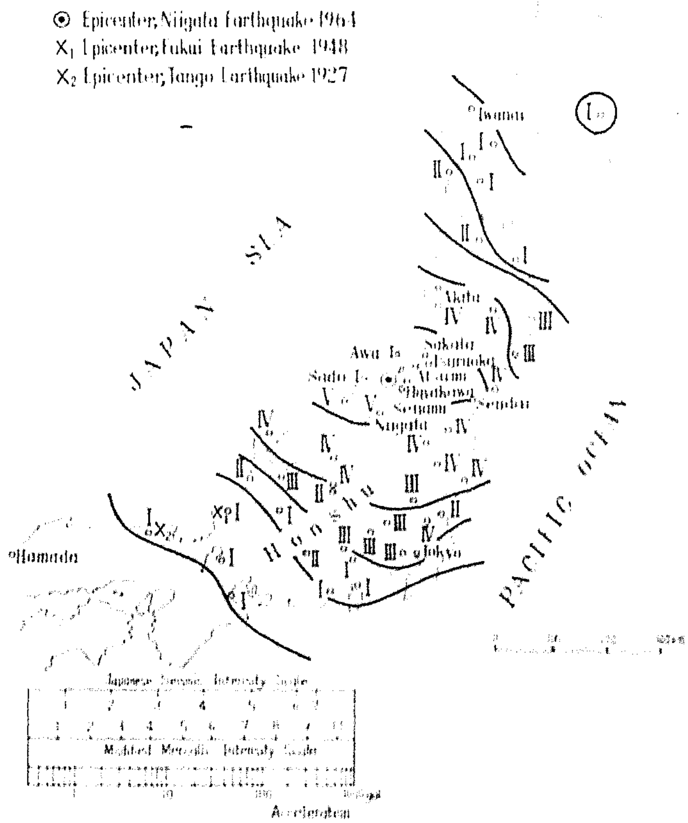


Fig. 1-2-a Record of the strong motion Niigata earthquake accelerogram.

Fig. 1-2-b Record of the strong motion seismograph observed at Niigata Station of JMA (1/5 the actual) (To = 5 sec. Magnification of the seismograph is 1:1)

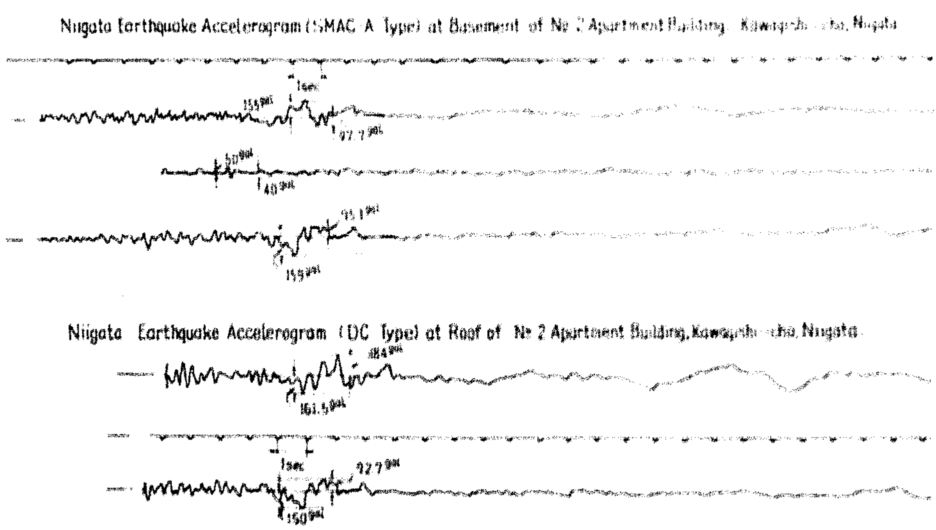


Fig. 1-2-a

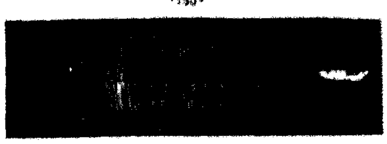


Fig. 1-2-b

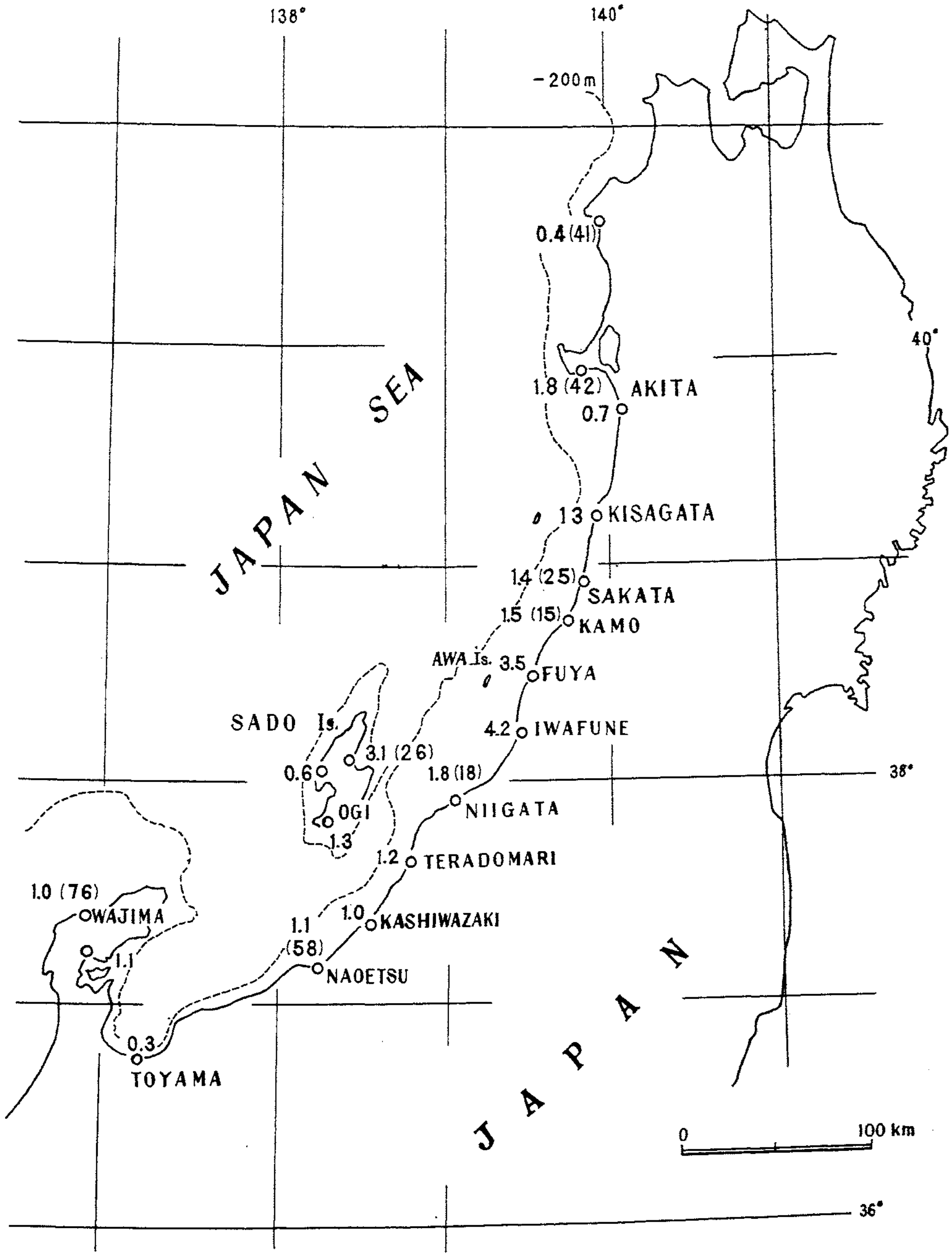


Fig. 1-4

Height of tsunami waves in meters above mean sea level. Figures in brackets represent the arrival time of tsunami in minutes after the outbreak of the Niigata earthquake. (After T. Hatori of Earthquake Research Institute)

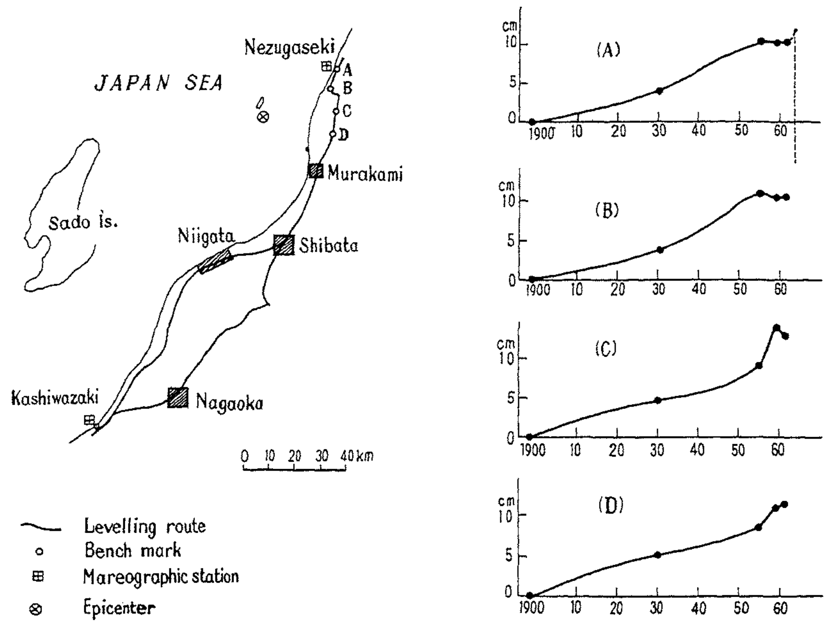


Fig. 1-3 Level change of primary bench mark (after I. Tsubokawa of Geographical Survey Institute)

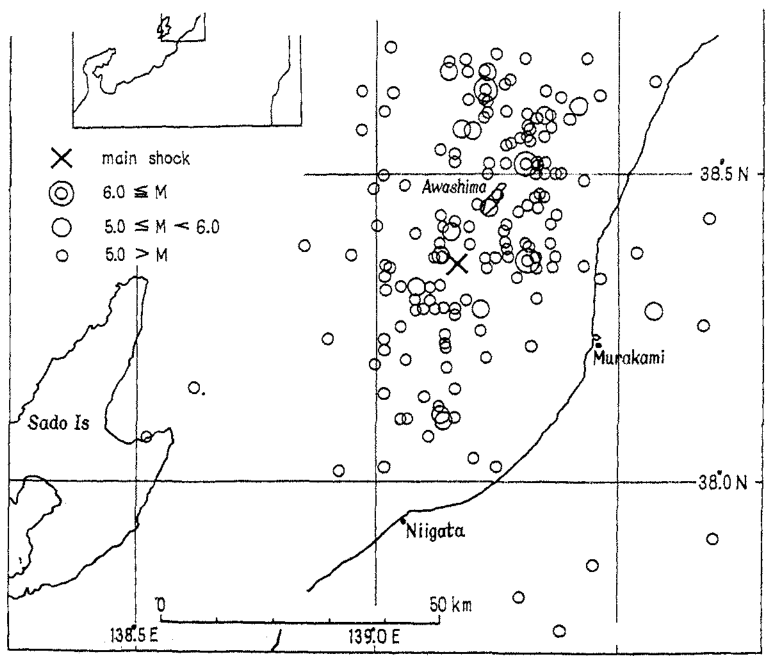


Fig. 1-5 Epicenter of aftershocks (After JMA)

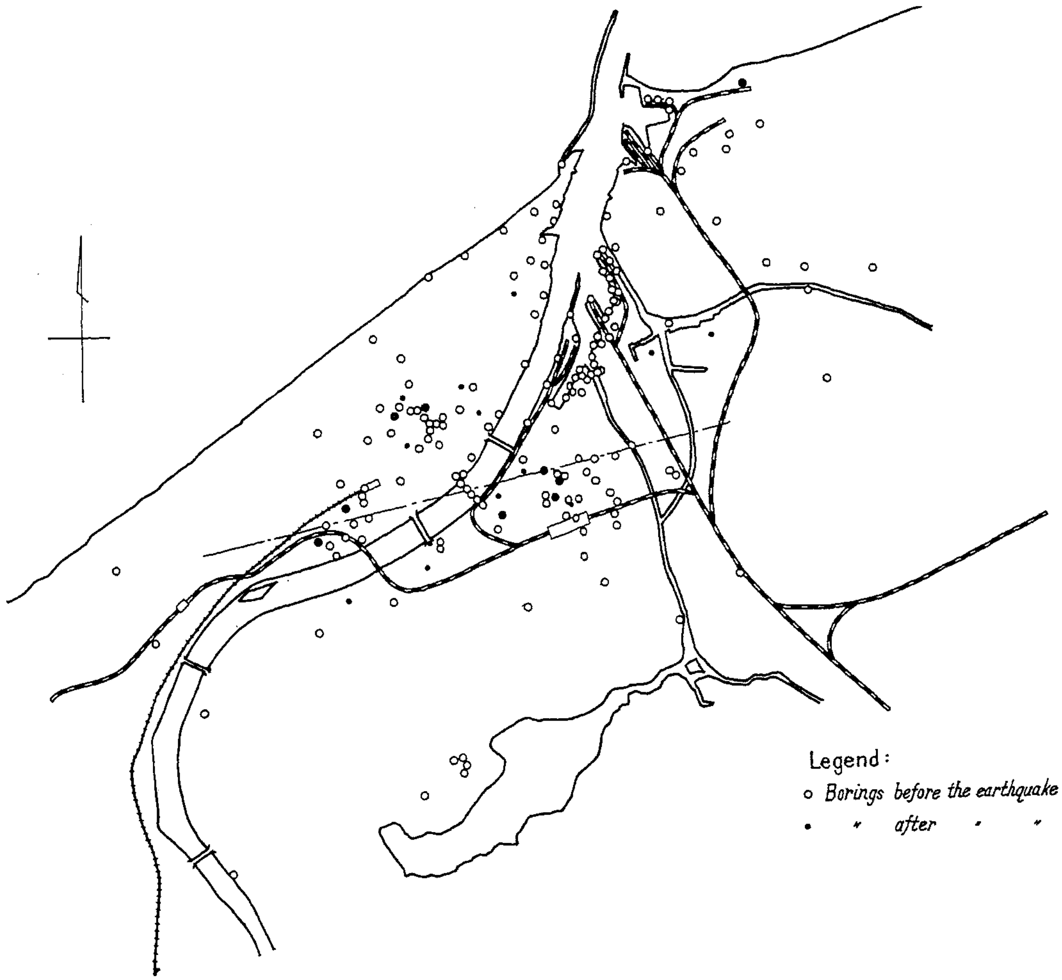


Fig. 2-1 Location of borings in Niigata City

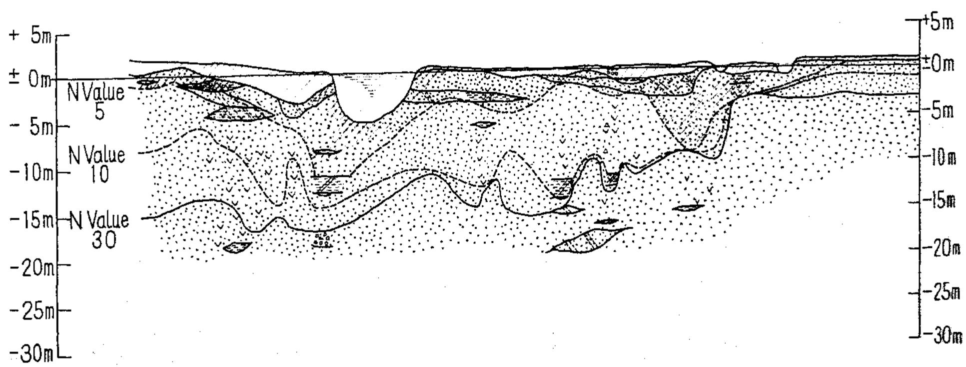


Fig. 2-2 A soil profile in Niigata City

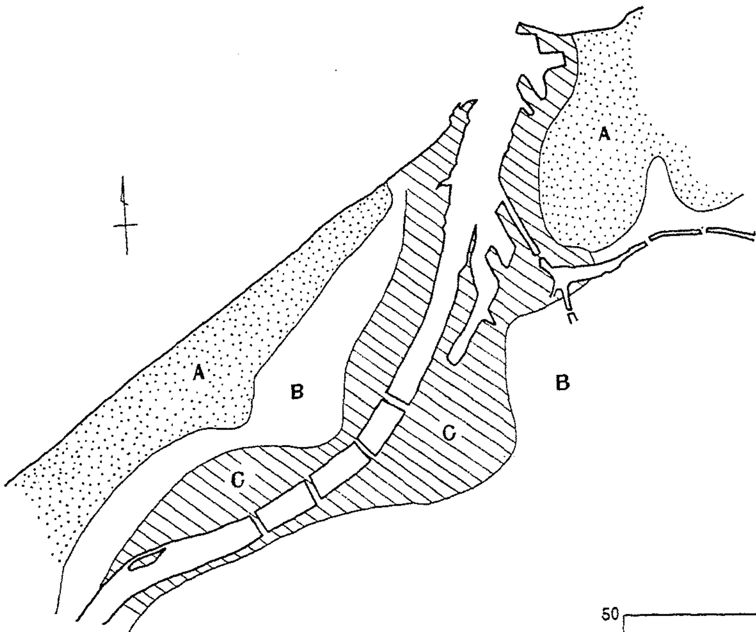


Fig. 2-3 Zones in Niigata City according to degrees of damage.

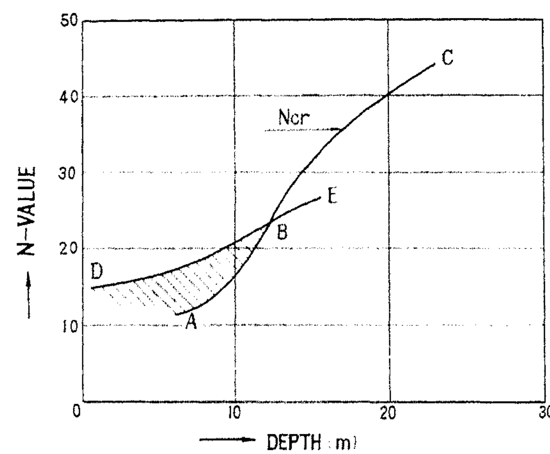


Fig. 2-5

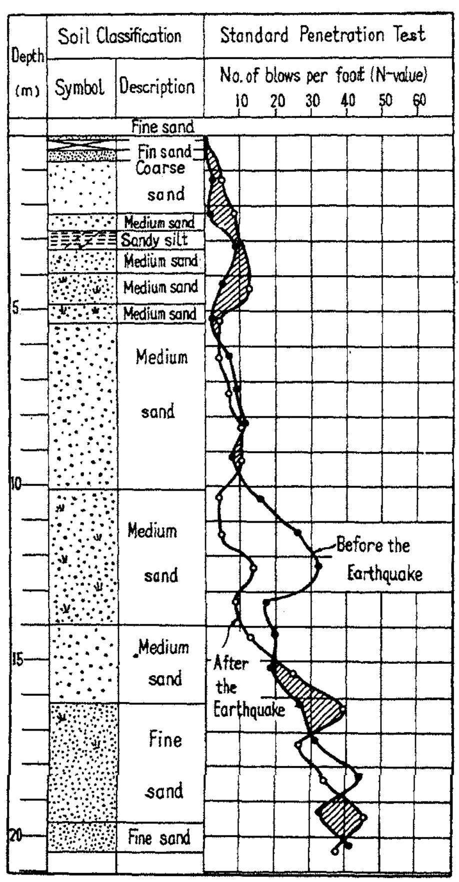


Fig. 2-4 N-values *before* and after the earthquake

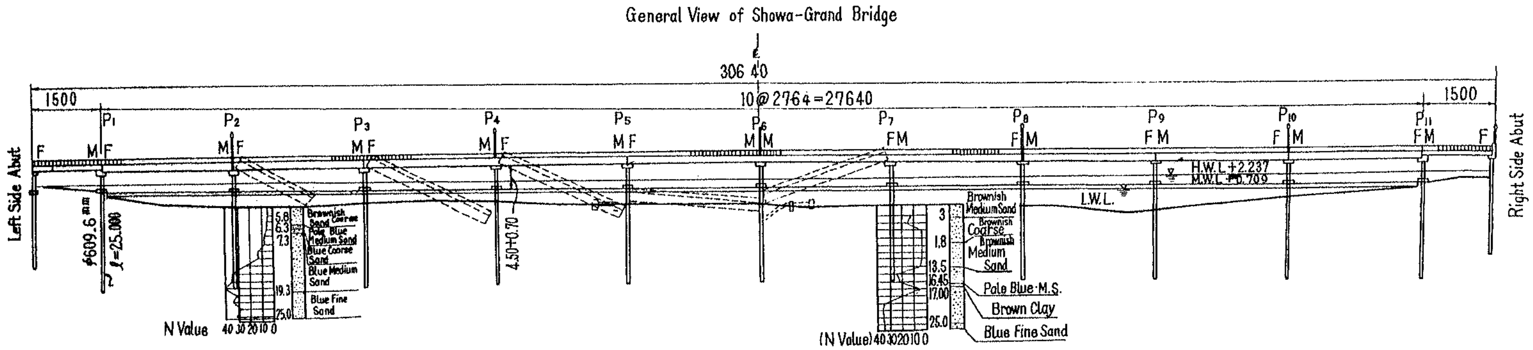


Fig. 3-1 Showa Bridge

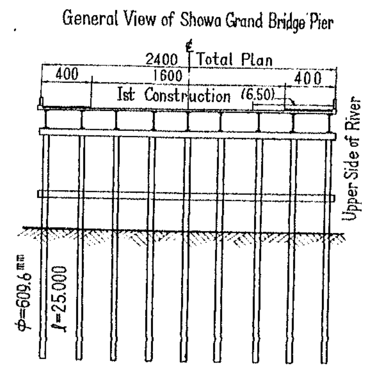


Fig. 3-2 A transverse crosssection of Showa Bridge

Fig. 3-3 Yachiyo Bridge

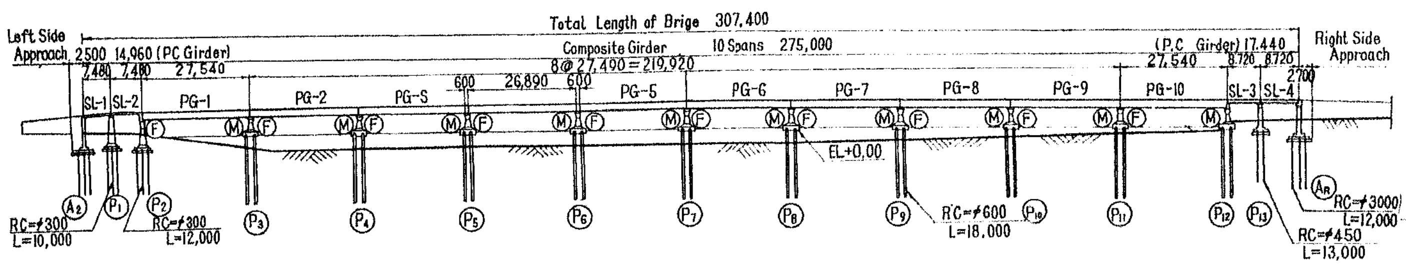


Plate 2-1.

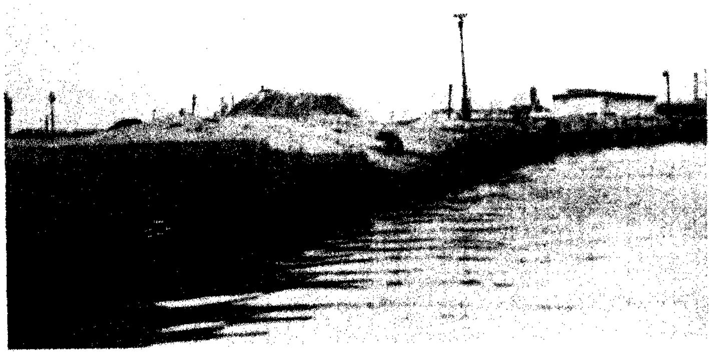


Plate 3-1. Damage to Pier D at Niigata Harbor. Severe tilting occurred at well foundations.

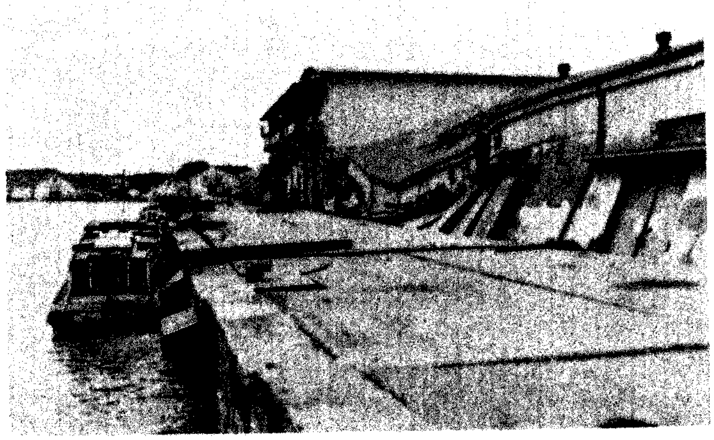


Plate 3-2. Damage to quaywalls and sheds at East Pier. The sheet pile quaywall settled 20cm (max.) at the top and moved 3.00m (max.) towards the water.

Plate 3-3. Damage to sheetpile quaywall at South Pier. Maximum settlement: 35cm; maximum translation: 2m.

Plate 3-4. Damage at corner of South Landing Pier (concrete blocks) and South Pier (sheetpile).

Plate 3-5. Damage to sheetpile quaywall reaching a depth of 4.0m.

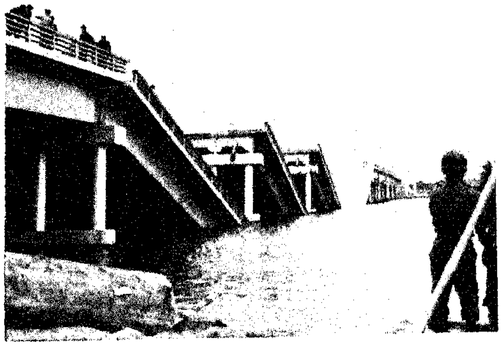


Plate 3-6. Showa Bridge viewed from the left bank upstream.

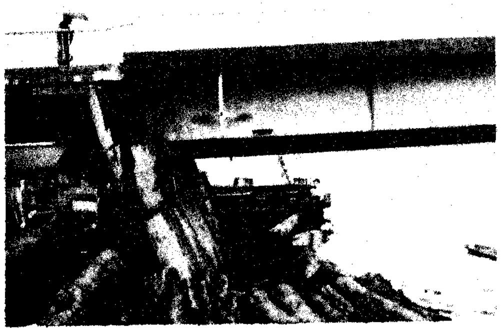


Plate 3-7. The left bank abutment of Yachiyo Bridge viewed from the downstream side.

Plate 3-8. Damage to a support at Yachiyo Bridge. (A roller support on the left side)

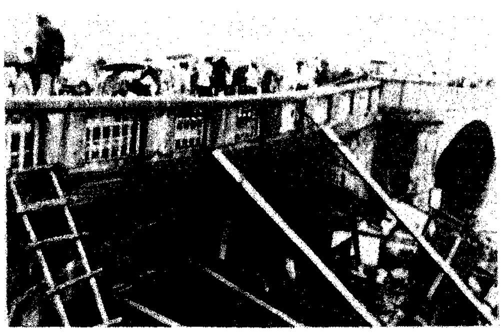


Plate 3-9. Deformed arch span at Bandai Bridge, viewed from the upstream side.

Plate 3-10. Longitudinal cracks in a levee.

Plate 3-11. General subsidence of railroad embankment on old river-bed.

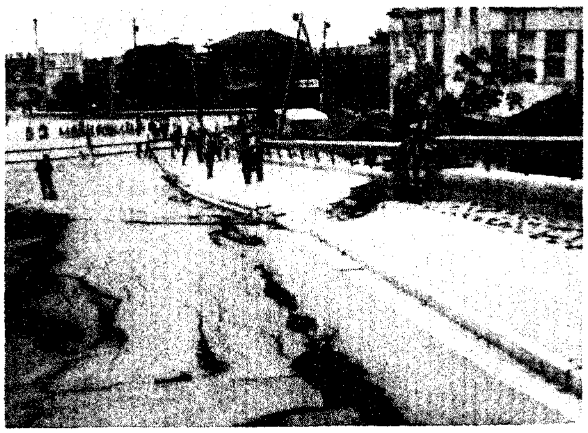


Plate 3-12. Subsidence of embankment at a bridge approach.

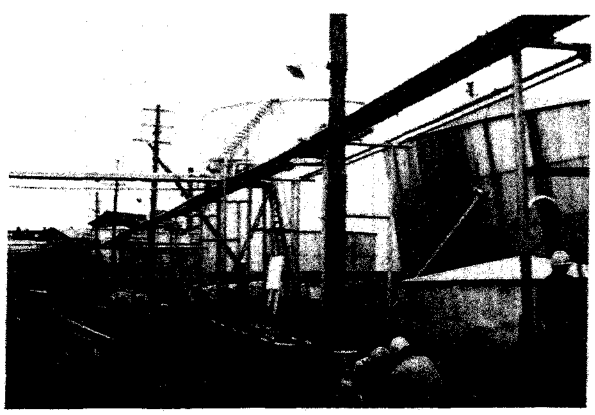


Plate 3-13. The far tank was built on soil stabilized by vibrofloatation. The tank in the foreground was built on untreated soil.

Plate 4-1. Apartment buildings at Kawagishi-cho, Niigata.

Plate 4-2. Near Yachiyo Bridge, Niigata. Note cracks and craters in the ground.

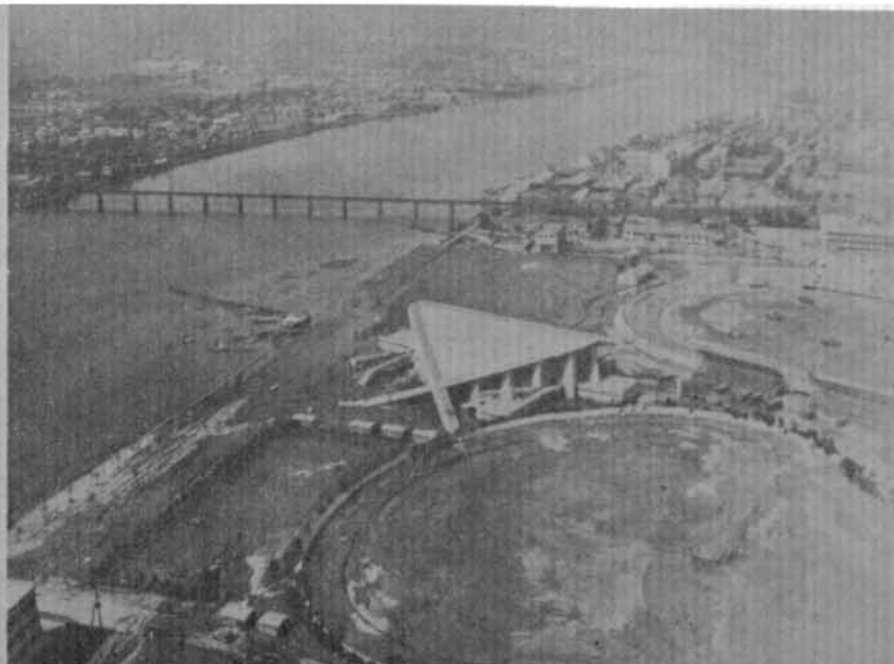


Plate 4-3. Gymnasium and athletic fields, Niigata.

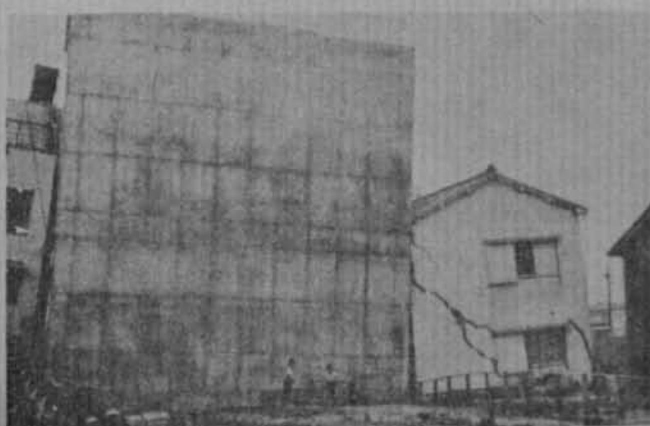


Plate 4-4. At Higashi-machi, Niigata. Cracks in the right building were caused by settlement of the reinforced concrete building on the left.

Plate 4-5. A wooden school building. The stairs in the center settled.

Plate 4-6. A warehouse. Columns were broken at braces.

Plate 4-7. Side view of the warehouse of Plate 4-6.

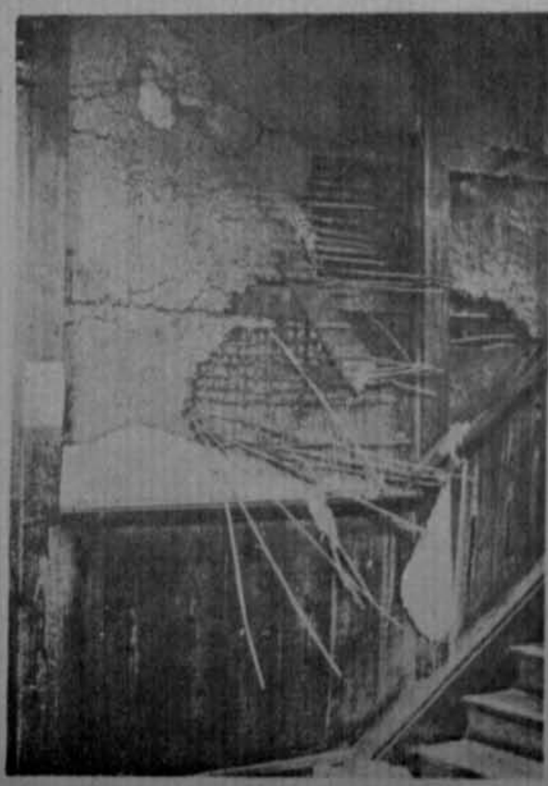


Plate 4-8. Damage to earth wall.

4-9

Plate 4-9. A steel-framed garage.

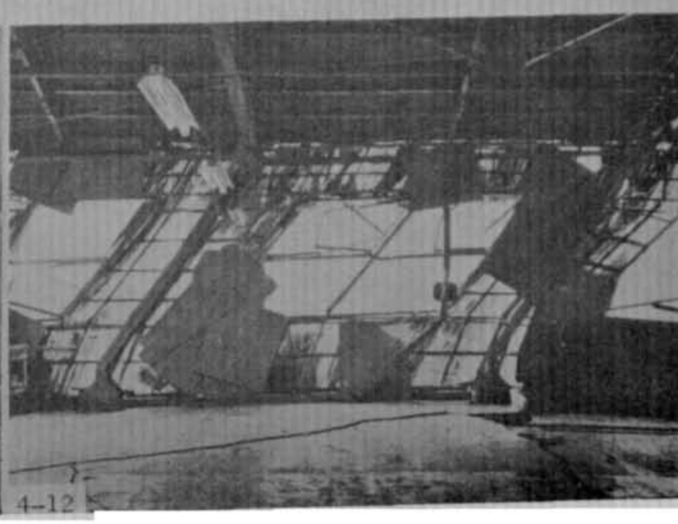
4-10

Plate 4-10. A steel-framed plant building

Plate 4-11. Flexural failure of a column of the building of Plate 4-10.

Plate 4-12. An inside view of the building of Plate 4-10.

4-11



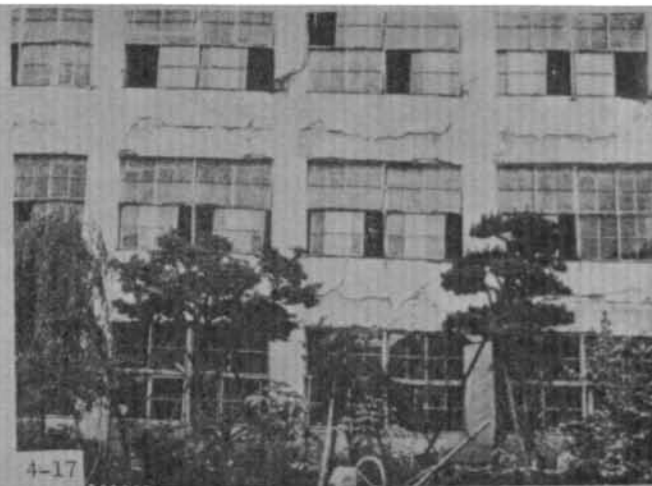
4-12

Plate 4-13. An overturned apartment building (See Plate 4-1).

Plate 4-14. Large settlement (max. 2 m) and tilting (140/1000) of a building on 6-m timber piles designed to carry 6 t per pile.

Plate 4-15. A large amount of tilting toward the heavier side of the building.

4-16



4-17

Plate 4-16. A school gymnasium of reinforced concrete one story structure with partial second floor. A ground crack nearby caused this shear failure of the column.

Plate 4-17. A 3-story reinforced concrete school building on 6-m timber piles. A ground crack ran across this 45-m long building causing the third point to settle 40 to 60 cm.

Plate 4-18. A crack in a column caused by a ground crack which ran below the building.

Plate 4-19. A distant view of the building of Plate 4-18.

4-18

4-19

Plate 4-20. Failure near the junction between a two-story reinforced concrete building (on the left) and a three-story reinforced concrete addition.

Plate 4-21. A school building at Sanpoku-mura, Iwagune-gun.

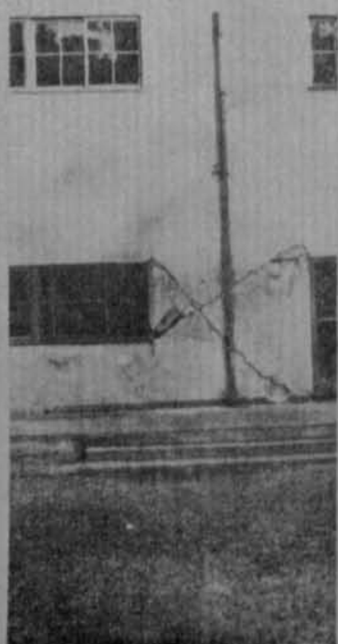


Plate 4-22. A distant view of the building of Plate 4-21.

Plate 4-23. Cracks in this concrete block building were caused by differential settlement.

Buildings Damaged by the Niigata Earthquake

	Number of persons dead	Residential buildings			Damage to non-residenti buildings
		Complete collapse	Partial collapse	Flooding	
Niigata City	11	2104	16468	11101	1882
Niigata Pref. except Niigata City	3	914	32303	954	20931
Yamagata Pref.	9	486	43263	39	28676
Akita Pref.	5	19	7668	137	4887
Fukushima Pref.	0	11	9	0	13
Total	28	3534	99711	12231	56389

NIIGATA EARTHQUAKE OF 1964

By Japan National Committee on Earthquake Engineering

QUESTION BY: F. KRATKY - NEW ZEALAND

In the survey about damage of buildings in Niigata Earthquake, has a comparison of behaviour of structures with concrete and steel frames been made and has any conclusion been reached?

QUESTION BY: Y. OTSUKI - JAPAN

Although Earthquake Engineering has progressed recently most of the efforts are devoted to the vibrational responses in a single dimension, i.e., up and down direction. Some of the damage experiences indicate to us that some of the damage patterns cannot be fully explained by the current vibrational concepts. It will be worthwhile to recognise that the vibrational approach to the problem is essentially a problem of wave propagation through a medium called "Soil". In other words, when the horizontal dimension of the building is comparable or not less than $\frac{1}{4}$ of the wave length, a comparable phase difference will be observed which can no longer be assumed equivalent to a simple one dimensional model as has been done. This field must be explored. I think that the most important aspect in an earthquake resistant structural design is "to think" and make sure that any local damage will not develop into total collapse.

QUESTION BY: P.W. TAYLOR - NEW ZEALAND

Surely, if there is any lesson to be learnt from this disaster, it is this: that it does not matter whether the structural frame is of steel or of concrete; it does not matter whether it is designed to the California Code or to no code at all; if the foundation fails, the building fails!

To summarise the conclusions of the panel, with regard to foundation failure, (as I understand them):

1. Liquefaction of loose saturated sand is the cause of much of the damage.
2. This was avoided where deep compaction (e.g. by Vibroflotation) had been used.
3. Piles 6 metres long in these uncompacted sands did not prevent subsidence (of up to $1\frac{1}{2}$ metres).
4. Raft foundations behaved better than inter-connected spread footings.

REPLY BY H. UMEMURA

The Niigata Earthquake caused significant damage to numbers of reinforced concrete or steel buildings. For most of these buildings, the damages were the direct consequence of liquefaction in the sandy soil (saturated, grain size 0.2 to 0.8mm) which extended down to a depth of about 10 m below the ground surface. This was particularly so in Niigata City, where many reinforced concrete or steel buildings were close together.

The nature of the damage to these two types of buildings was, however, somewhat different. Heavier buildings, mostly of reinforced concrete construction, suffered settlement or tilting as a whole without significant damage to the superstructure. On the other hand lighter buildings, mostly of steel or wooden frame construction with relatively light foundations, suffered unequal settlement or sliding of columns in accordance with the deformation of ground surface. Heavier buildings supported by strong soil layers with N-value (standard penetration resistance test value) over 25 had practically no settlement or tilting. Lighter buildings had little damage if they were provided with a raft or similar strong foundation system, as I have explained in the panel discussion. This means that both reinforced concrete and steel frame buildings can be made earthquake resistant by selecting a proper foundation and structural system. From an economical point of view, however, it appears that lighter construction is more preferable for such a soil condition as would be encountered in Niigata City.

It should be mentioned that the conclusion of the comparison of reinforced concrete and steel frame structures, based on the damage survey in Niigata area where subsoil condition is rather singular, should not be taken for granted in general. The comparison should be made carefully and according to the particular subsoil conditions in question.

The ductility factors for damaged buildings are of much concern for us. For the time being, however, we have been collecting information of damage as a matter of fact, and very few attempts have been made at the dynamic or structural analysis of damaged buildings.

Very little damage was reported of elevators or stairways, much less human casualities as the direct result of their failure. In general, the relatively small toll of lives was a characteristic and fortunate consequence of this earthquake. Reportedly, residents in an overturned building could evacuate to the roof before the building fell down, and they got out of the building safely after the complete overturning. It is believed that the ground moved during the earthquake with a large amplitude and a long period of vibration, as indicated by the strong motion seismograph records.

It is possible, however, that people in the buildings would crowd at the stairway or elsewhere on the occasion of earthquake, and this might cause a fatal panic, although fortunately it was not the case in Niigata. This possibility should be taken into account in the architectural and engineering design of buildings in seismic zones.

QUESTION BY: J.A. FISCHER - U.S.A.

In the comparison of the Showa and Yachiyo bridges it can be seen that rather large diameter piles were used (60 cm diam?). The piles were only loaded to about 4½ tons and 25 tons - rather light loads for such a size of pile. Can you describe the reason for the light loads - soils and structural - and the effect that soil conditions, loading and pile type may have had upon the differences in damage.

REPLY BY K. KUBO: As you said, the vertical load applied to the piles is not so heavy, but the result experienced through the earthquake is that the Yachiyo Bridge of light load has had lighter damage than the Showa Bridge of heavy load, and some piles of the Showa Bridge were bent by horizontal seismic force and failed. That is why I said that the piles of the Showa Bridge were not strong enough to resist the seismic force, and this experience will be a certain guide in the future design of pile-bent piers in sandy soil.

NIIGATA EARTHQUAKE OF 1964

DISCUSSION

BY PROF. AUREL A. BELES

The very interesting slides and explanation given about the effects of earthquakes on buildings in Skopje, Anchorage and Niigata, showed again the great importance of design and construction of buildings for their resistance to earthquake forces. The description and interpretation of the damage are of great importance as buildings in Skopje were of quite modern types and many of those in Anchorage and Niigata were designed according to codes for seismic regions.

I want to point out again the importance of the publication and the spreading of such examples in seismic countries.

At the same time I would show that in such a publication one could give also some examples of strengthening that could be easily applied in seismic regions to existing buildings and structures in order to prevent damages produced by future earthquakes. As an example I want to mention that historical monuments in Bucarest that have been strengthened by very simple and cheap methods previous to the 1940 earthquake, especially old churches, behaved very well during this earthquake, whilst other similar churches which had not been strengthened suffered heavy damage.