NIIGATA EARTHQUAKES, 1964

BUILDING DAMAGE AND SOIL CONDITION

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GENERAL ASPECTS OF DAMAGE

The statistics of damage by Niigata Earthquake of 1964 to persons and buildings are shown in Table 1. As damage to persons, twenty-six died and four hundreds forty-seven were wounded. As damage to buildings, the number of collapsed buildings was 2,130; 6,240 were partially damaged and the total number of slightly damaged buildings amounted to 31,240. Three hundreds buildings were burnt down by fire and 15,300 were inundated by the tidal wave.

When compared with the damage due to Fukui Earthquake in 1948, it is astonishing to see how small the damage of Niigata Earthquake is, whereas the magnitude of Fukui Earthquake is smaller than Niigata Earthquake. At the time of Fukui Earthquake, 3,870 persons died and 35,400 buildings collapsed. Such difference in the extent of damage may be attributed to the particular aspects of damage due to Niigata Earthquake, which will be discussed later.

Fig. 1 shows a bird's-eye-view of Niigata, the city most heavily damaged by the earthquake of 1964. The population of the city of Niigata is about 300,000. Fig. 2 is a picture of a group of apartment buildings at Kawagishi-cho in Niigata city taken from an aeroplane. It will be seen that a building at the center of the site is completely overturned and all other buildings are tilted toward different directions. This event of overturning made Niigata Earthquake very famous.

One characteristic aspect of Niigata Earthquake was the appearance of numberless cracks of fissures on the ground surface. The width of the largest crack, as shown in Fig. 3, was about 2 and half meters.

Fig. 4 shows an example of collapsed wooden building. However, by Niigata Earthquake, there were few wooden buildings which fell down and this example rather belongs to exceptional case. Fig. 5 is another example of damage to wooden building. Since the ground was cracked around the middle of the building, only such a part of the buildings that were located just above the crack was damaged, the other part of

Table 1. Damage due to Niigata Earthquake

Persons		Buildings				
Death	Wound	Collapse	Damage	Slight Damage	Burnt	Inundate
26	447	2,130	6,240	31,240	300	15,300

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Fig. 1. **Fig. 2.** **Fig. 3**

the building remaining intact. Fig. 6 shows one more example of damaged wooden building. The part of the building around the entrance was partially made of reinforced concrete and, as the weight of that part was heavy, it made a considerably large settlement. As a result, the adjacent wooden part was pulled down by the reinforced concrete part and large cracks appeared at the connection.

Fig. 4

Fig. 5

Fig. 6

In every case of earthquakes in the past, wooden buildings used to suffer heavy damage and reinforced concrete structures remained safe. However, at the earthquake of Niigata of 1964, the situation was completely reversed, the fact which may be regarded as the most characteristic feature of the Niigata Earthquake. Corresponding to this situation it seems suitable to focus attention mainly upon the damage to reinforced concrete buildings.

Fig. 7 shows the number of reinforced concrete buildings in Niigata city constructed annually. In 1955 there was a big fire in Niigata city, and the central part of Niigata was almost burnt down. After this big fire, the construction of fire-proof concrete buildings was recommended by the city authority and, therefore, the number of reinforced concrete buildings increased year by year as shown in the diagram. From this statistics it was found the total number of reinforced concrete buildings was about 1530 at the date of the Earthquake. Out of these 1530 concrete buildings, about 340 were more or less damaged by the earthquake, and therefore the rate of damage is about 22%.

Out of these 340 damaged buildings, about 1/3 suffered damage to a certain extent in their superstructures. The damage to superstructure may be classified into three types as will be shown in the following.

Fig. 8 shows one type of damage to superstructure which may be called "tension

Fig. 7

Fig. 8

Fig. 9

type". The building is a gymnasium of the Niigata High School, and the ground beneath the columns moved to outward directions at the both sides of the building. Therefore, the frame of this structure was acted upon by tension force and, as a result, the columns were sheared as shown in Fig. 9. The foundation beam which connects the feet of columns in the both sides was torn off as shown in Fig. 10 over its full depth, and even reinforcing bars also failed by tension. Fig. 11 also shows the damage of tension type caused by crack of the ground surface which appeared just below the building, resulting tension failure of the ceiling slab as shown in Fig. 12.

Fig. 13 is another type of damage to superstructure which may be called "simple beam type". The ground at the middle of the building lost its bearing capacity and, therefore, the middle part of the building structure made large settlement or downward deflection. While the ground at the both ends of this building remained intact, the superstructure behaved just like a simply supported beam.

Fig. 14 shows damage of "cantilever type". The main part of the building remained almost safe and the annex part made large settlement. Therefore, the fixed-end of the cantilever was separated by about 2 feet.

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

FAILURE OF FOUNDATION

Thus, 1/3 of damaged reinforced concrete buildings suffered damage in superstructure; however, as to remaining 2/3 of damaged buildings, they just settled, tilted or overturned as a whole without any damage in their superstructures. Fig. 15 again shows overturned apartment buildings at Kawagishi-cho. It was completely overturned but any crack, even a hair crack, could not be detected in its superstructure. Doors and windows worked quite well just as usual even in this state of complete overturning.

Fig. 16 is an example of warehouse completely overturned. This warehouse is of

Fig. 15 **Fig. 16**

Japanese style in appearance but made of reinforced concrete. There was no damage to the structure in this case, too. Fig. 17 is one of apartment buildings at Kawagishi-cho which tilted about 30-degrees without any damage to superstructure. Fig. 18 is a building of 4 stories located near the Niigata railway station. This building tilted about 20 degrees without any damage. Fig. 19 shows a building of 3 stories which tilted about 10 degrees. At the same time this building settled by 2 or 3 meters, and its first story looks like a basement.

It was of considerable interest to know in which direction the buildings were tilted by the earthquake motion. Fig. 20 shows the distribution of tilted direction, arrows

Fig. 17 **Fig. 18** **Fig. 19**

Fig. 20

showing the direction of tilting and the length of the arrow being drawn in proportion to the angle of tilting. From this figure, however, no general tendency can be seen with respect to the directions of tilting. They are dependent neither to the direction toward the epicenter of the earthquake nor to the direction of the river flow. Fig. 21 is a statistical expression of direction in which buildings were tilted. It may be seen that inclinations toward north and south directions slightly prevail. In one building there are usually heavy side and light side, and it can be imagined that a building would be tilted towards its heavier side. Nevertheless, in reality, statistics has indicated the building which tilted to heavy side is 54% and the building which tilted to light side is 46%, being almost fifty-fifty.

Fig. 22 shows a relation between the angle of tilt and the magnitude of settlement in which, however, correlation is not so definite. The angles of tilt were measured by means of clinometer and the accuracy of measurement was satisfactory. On the other hand, difficulty was encountered in measuring the settlements of buildings since the

Fig. 21

Fig. 22

ground surface around almost all buildings became up and down as a result of the earthquake and no definite reference datum could be established. Therefore, the accuracy for settlement measurement was not so reliable which, in turn, may be a reason for scattering of points in Fig. 22.

DISTRIBUTION OF DAMAGE AND SOIL CONDITION

In usual case, the extent of damage used to be expressed by means of damage to superstructure. However, as far as the Niigata Earthquake concerns, there was little damage to superstructure and, therefore, it may be more adequate to use the angle of tilt as a measure of the extent of damage.

Fig. 23 is the distribution of damaged buildings in Niigata city expressed in this way. Small circle represents the angle of tilt less than 1° , large white circle represents the angle of tilt between 1° and 2.5° , and large black circle shows the angle of tilt more than 2.5° , that is, heavy damage. If one looks at all circles including small circle, it can be said that damaged buildings are distributed all over the Niigata city. If, how-

Fig. 23

ever, attention is paid to the black circles only, it can be seen they are concentrated in several limited areas. Such areas are, for instance, in front of the Niigata Railway Station, around Kawagishi-cho where overturned apartment building is located and a narrow belt along the Shinano river. In other words, very clear boundaries can be found between damaged and undamaged zones at a large number of spots within the Niigata city. Fig. 24 is a zoning map of damage, in drawing which it was quite easy to trace boundary lines. "A" represents the zone of little or no damage, "B" represents the zone of small damage and "C" is the zone of heavy damage.

Now, the problem is to find out what difference is there between soil conditions in A, B and C zones; particularly, difference between B zone of small damage and C zone of heavy damage. If there might be any condition, which exists in C zone and which does not in B zone, that must be critical to the occurrence of heavy earthquake damage.

Immediately after the earthquake we tried to collect as many boring data as possible which had been made in the city of Niigata before the earthquake, and succeeded to gather about 200 boring records at about 100 locations. Fig. 25 shows the distribution of such boring locations. In Fig. 25 a certain number of black points are marked, which show the locations of new borings being made after the earthquake. At the locations of doubled circles boring data both before and after the earthquake are

Fig. 24

available, the latter having been made to know the change of ground condition due to the earthquake. Discussions will be made later as to information obtained by these new borings.

The fact that was revealed by the collection of these data is the ground of Niigata consists almost solely of sand layers as shown in Fig. 26, and only lens-like layers of silty sand are scatteredly inserted. In Fig. 26, three lines corresponding to N -values of standard penetration test equal to 5, 10 and 30 are indicated.

Together with boring data we gathered as many soil mechanics test results as possible, and the most striking feature of Niigata sand being found from those data is that its grain-size distribution is extremely uniform. In Fig. 27, the hatched area shows the range in which almost all grain-size distribution curves of Niigata sand fall, and it will be seen how steeply those curves stand up. Their coefficients of uniformity are smaller than 5.

In order to find difference, if any, between soil conditions in B zone of small damage and those in C zone of heavy damage, frequency-distribution diagrams of N -values of standard penetration test are drawn in Fig. 28 for A, B and C zones. Fig. 28 (a) is a histogram of N -values which are within the range of depth between 2 and 5 meters,

Fig. 25

Fig. 26

Fig. 27

Fig. 28

Fig. 28

Fig. 28

Fig. 28

and little difference can be recognized between B and C zones. Fig. 28 (b) is a histogram of N-values measured at the depths from 5 to 10 meters, in which there is marked difference between B and C zones. Fig. 28 (c) is for the range of depth between 10 to 15 meters; again the curves are becoming similar. Fig. 28 (d) represents the range from the depth of 15 to 20 meters, wherein the curves for B and C zones coincide quite well with each other.

In Table 2 N-values of B zone and C zone are compared from a statistical viewpoint by means of test method of significant difference. A conclusion from this analysis is that the difference of N-values in B and C zones in the range of 5 to 10

Table 2. Test of Difference in N-Values

Depth (m)	2-5		5-10		10-15		15-20	
Zone	B	C	B	C	B	C	B	C
Number of Samples	226	302	390	525	358	501	239	423
Mean of N-Values	5	5	21	8	31	20	36	33
Standard Deviation of N-Values	11	3	14	4	14	11	11	11
t^*	0.5		21.6		13.2		1.6	
Significance	×		○		△		×	

* Tolerance limit $P = 0.001$

meters depth is quite significant, the difference in the range of 10 to 15 meters is doubtful, and there are no differences in N-values within the depth from 2 to 5 meters and in the range deeper than 15 meters. Consequently, it may be concluded from the analysis shown in Table 2 that the smallness of N-values in the range of depth from 5 to 10 meters, or with less probability, from 5 to 15 meters had probably something to do with the heavy damage in C zone. Similar analysis has been made with respect to the difference of N-values in A and B zones; however, no clear difference has been resulted. Consequently, extremely small damage in A zone as compared with B zone may be attributed to a fact that A is the zone of sand dune with considerable height and the ground water table is located at a deep level, while in B zone the ground surface is flat and low, and the ground water table is at the level less than about 0.5 meters.

MECHANISM OF FAILURE

Several examples of the overturning of large-scale structure were experienced in the past, and it was reported in every case the soil beneath the structure was soft, sensitive clay and the sliding, as shown in Fig. 29 (a), took place under the structure and, at the same time, the upheaval of the ground surface appeared at the opposite side of the overturning. In the case of Niigata earthquake, however, the soil is not clay but sand, and the building sank down without any sign of sliding and without any trace of upheaval at the opposite side as shown in Fig. 29 (b).

Fig. 30 is the bottom face of the overturned apartment building at Kawagishi-cho, and any trace of sliding can not be found around the ground surface. Fig. 31 is again the overturned warehouse, in which neither trace of sliding nor upheaval of the ground surface can be discovered.

On the contrary to the behavior of heavy buildings, light structures buried in the ground floated up as shown in Fig. 32, which is a box of reinforced concrete for sewerage purifier. Thus, heavy thing just sank down and light thing floated up; this fact means the ground or the soil behaved just like water or liquid. Then, we have come to an idea that the ground liquefied under earthquake vibration or the idea of so-called liquefaction.

Fig. 29

Fig. 30

At the time of Niigata earthquake, there appeared numberless sand craters, from which a mixture of sand and water was ejected high into the air. Fig. 33 shows an example of such sand volcanos.

These sand craters are the unmistakable evidence of the rise of pore water pressure in the ground and it was believed that this rise of pore water pressure, in other words,

Fig. 31

Fig. 32

Fig. 33

Fig. 34

the decrease of effective grain-to-grain pressure, was the cause of liquefaction.

About 40 borings were made, as mentioned before, to get information on how the ground condition was changed by the earthquake motion. Fig. 34 is an example showing the change of N-values before and after the earthquake. From this figure it can be seen that sand which was loose before was compacted and sand which was dense before was loosened. Then, it may be possible to assume that there is a certain intermediate N-value between loose and dense states which was not changed during the earthquake.

Basing on comparisons of boring data before and after the earthquake, Dr. Y. Koizumi* established a curve shown in Fig. 35 which represented such N-value at each depth that hadn't changed during the earthquake. Dr. Koizumi defined this curve as the curve of critical N-value, and we consider this curve corresponds to so-called critical void ratio at each depth. If a sand whose N-value is below this curve of critical N-value is subjected to shear deformation by earthquake vibration, it contracts its volume and, due to this volume contraction, the pore water pressure within it will

Fig. 35

Fig. 36

* Y. Koizumi: Changes in Density of Sand Subsoil Caused by the Niigata Earthquake, Paper Submitted to Conference on Soil Dynamics under the Japan-United States Cooperative Science Program, Tokyo, July 1965.

be increased. Hence, the effective stress is decreased or reduced to zero and, as a result, the sand may be liquefied.

Next problem is how to connect this concept of critical N-value with the actual damage to buildings, and for this purpose both curves of critical N-values and actually measured N-values are drawn together in Fig. 36 for comparison. Between the intersection of two curves, d and a, the actually measured N-values are below the critical N-values, and it is conceivable that the hatched part in Fig. 36 may liquefy under the earthquake vibration. Hence, this range is defined as the zone of liquefaction, or the zone of potential liquefaction, and the points d and a will be referred to as the upper and lower limit of the zone of liquefaction, respectively.

As a use of the critical N-curve shown in Fig. 35, we first fixed our eyes upon the depth of 8 meters, since the depths of foundation, i.e. the depth of footing base for spread foundation and the depth of pile tip for pile foundation, of more than 3/4 of buildings in the city of Niigata are equal to or less than 8 meters. The critical N-value at the depth of 8 meters is 12. If N-value at the depth of 8 meters actually measured at a boring location is smaller than 12, a cross mark is plotted at the location and, if it is larger than 12, we plot a circle meaning safe. Thus, Fig. 37 has been obtained. It will be seen in this figure that the area in which cross marks are distributed resembles quite well with the shape of C zone already shown in Fig. 24.

In next trial attention was paid to the depth corresponding to the lower limit of the

Fig. 37

zone of liquefaction. In Fig. 38, contour lines are drawn which show the depths of the lower limits of the zone of liquefaction, and it is observed in Fig. 38 that the shape of the contour lines showing the depth of 10 meters or 15 meters looks like the shape of C zone of heavy damage.

As another application of the curve of critical N-values, both the depths of the upper and lower limits of the zone of liquefaction were considered simultaneously in Fig. 39, in which the abscissa is the depth of upper limit, H_u , and the ordinate indicates the depth of lower limit, H_l , of the zone of liquefaction. From these plotted points it will clearly be seen that the points which represent the borings in C zone fall within a limited range. The boundary between cross marks and circle marks is so distinct that this diagram may be used effectively as a definite criterion to the occurrence of failure due to the liquefaction of sandy ground.

In Fig. 40 which is a re-representation of Fig. 39, the vertical distance from a plotted point to the 45-degrees line represents the difference between the depths of the upper and lower limits of the zone of liquefaction, that is, the thickness of the zone. Now let us consider the two points P_1 and P_2 in Fig. 40. At these two points, the depths to the upper limit of the zone of liquefaction are same but, since the thickness of the zone of liquefaction at P_2 is smaller than P_1 , the former point is outside the critical range. It will be known, therefore, that even if the ground has been partially liquefied there occurs little damage unless the thickness of the liquefied zone is larger than a certain limit. Similarly, the points P_1 and P_3 indicate same thickness of the zone of

Fig. 38

Fig. 39

liquefaction. Nevertheless, since the depth of the upper limit of the zone of liquefaction is larger at the latter point than the former, the latter remains in the undamaged zone. It indicates us that damage does not occur provided that, above the liquefied zone, there remains an intact zone having the thickness more than a certain limit and it acts as effective surcharge upon the underlying liquefied zone.

According to the measurement and analysis of microtremors in the city of Niigata,

Fig. 40

Fig. 41

their period-distribution curves can be classified into three typical types, namely A, B, and C, as shown in Fig. 41, in accordance with the predominant period and the characteristic shape of the curves, and it can be pointed out that these three types, A, B and C correspond with few exceptions to the zones A, B and C of little, slight and heavy damage shown in Fig. 24, respectively.