Observation of Damages of Industrial Firms in Niigata Earthquake

Reporter: Heki Shibata

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Damages of an electric power station, plants of paper manufacturing company and chemical engineering company were investigated from the 20th of June, 1964, to the 23rd, four days after the shock. The second investigation was done on several machinning factories and chemical engineering plants, some of which had been not able to be accessed because of flooding. Our investigation was done mainly concerning as to the following eleven items.

1.	Large-size machine including machine tool	[A]
2.	Irregular shaped machine	[A]
3.	Train-type machine and rails of overhead crane	[A]
4.	Stack and tower	[X],[C]
5.	Large-size column (on chemical engineering plants)	[X]
6.	Column and accumulator (pressure vessel)	[A]
7.	Valves and pumps in piping systems	[A],[E]
8.	Boiler	[A],(C)
9.	Piping systems	[A],[E],(B),(C)
10.	Buried structure and piping	[A],[B]
11.	Tank, liquid storage and gasholder	[A],[C]

The causes of damages of each item are specified the letter following. [A] is assigned to the damage caused by settlement of foundation, [B] to periodic movement of soil, [C] to acceleration of ground motion, [D] to flooding, and [E] is assigned to the damage caused by the failure of supporting structures or by crashing of other structures. [X] stands for the case that no significant or only slight damage was found.

There were two mechanisms which gave significant damages to items on industrial plants. One is, of course, resonating phenomenon to the ground motion. The other is liquifaction of soil. The former was observed on oil storages, a gasholder, a boiler drum and piping systems. The fact that the resonance to a very long periodic wave was also observed besides the acceleration resonance should be mentioned. The free surface of oil, the calculated period of which is more than 8 sec, was resonated. And some of them were burnt very seriously. The liquifaction worked to items in two ways. Buildings and foundations settled in, floated up or turned over just like floating vessels, according to their bulk densities. Buried pipings and suspended structures were waved by periodic movement of liquified soil.

The flooded water and mud worked to machine tools very badly. Most of overhead crane in such factories could not work because of deformations of the rails.

The ways of repairing of several machineries will be also reported.

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The authors report the damages of plants and factories in Niigata Earthquake 1964. They refer to the important design consideration which were obtained through their observation.

1. Introduction

In Japan seral nuclear power plants are under construction. Most of our country belongs to the first class seismic zone. Many chemical engineering plants, which are treating framable or very unstable organic materials, are located around the dense populated areas, Tokyo, Nagoya, Osaka and Kitakyushu City. So we should consider the aseismic design problem not only for minimizing the losses of industries, but also for the safety of the public. The authors have been engaged in establishing the design procedures of earthquake resistent nuclear power plants since 1958. During such period we met three big earthquakes, Hyuganada 1961, Niigata 1964 and Tokachi-oki 1968. By these earthquakes, damages of industrial firms were reported, but no report was presented to the meetings of the World Conferense on Earthquake Engineering, except only one picture of the proceedings of the 3 WCEE.(1)

The authors made their field surveys in Niigata area four days after the shock and three weeks later. Although there were many restrictions, mainly coming from the security problems of industries, the authors obtained fairly good amount of materials. Here they would like to report them, quoting their report in Japanese.(2)

2. Type of Damages

The phenomenon of liquifaction in Niigata has become very famous, and this phenomenon brought two types of damages to the plants. One is a subsidence or a settlement, and another is a dynamic pressure effect of soil. Usually earthquakes bring the damages by acceleration type loading, but there were rather few cases. Dynamic effect of the earthquake was observed on the overflow of the oil at several oil-storages. Water flood caused by tsunami and change of ground level relative to sea level gave enormous losses to machine shops. Some equipments and piping systems were affected by damages of structures, mainly subsidence of buildings and their supports.

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In the liquefied soil all buildings and foundations behaved just like vessels in the water. Some of them settled, but other floated up (upheaved) according to their bulk densities.

It was reported that the surface of the soil on a rice field had waved and the wave had been propagated. The cause of such phenomena has still been discussed, but it is sure that the movement of soil gives the dynamic pressure to under ground structures and pipings.

Flooding of water mixed with heavy oil gave very heavy contamination to every things. And the strong acids, sulphuric acid and nitric acid, which were diluted by flood acted very badly to iron plates.

Resonance phenomena of free surfaces of liquids were reported. The floating roof of oil-storage tank was shown the same phenomenon. Overflow of crude oil caused a big fire around an oil refinary. The amount of damages brought by this fire may be the maximum per a cause.

Except a free surface problem, resonance phenomena were reported only in several cases, but the authors like to mention that the resonance phenomenon still has the strongest effect on damaging the structures and vessels in usual earthquakes. Because the damages of tower type vessels were observed at several places in Tokachi-oki Earthquake 1968 and other earthquakes.

The authors assort the type of damages as follows:

[A] : caused by settlement and upheaval.
[B] : caused by dynamic effect of liquified soil.
[C] : caused by seismic force including resonant effect.
[D] : caused by flooding.
[E] : caused by crashing of buildings and structures.
[X] : no effect of the earthquake was found.

3. Listing of Damaged Items in Industries

items	type of damages
1. Large-size machine including machine	[A]
2. Irregular shape bedding machine tool	[A]
3. Train-type machine (on paper mill) and rails of overhead crane	[A]
4. Tower and stacks	[X], [C]
5. Tower-type vessel (tall type) and column (on chemical engineering plant)	[X], [A]
6. Tower-type vessel (middle size) and accumulator (including pressure vessel)	[A], [E]
7. Large size compressor	[X]
8. Small size conventional equipments and valves	[A], [E]
9. Boiler	[A], (C)
10. Piping systems	[A], [E], (B), (C)
11. Buried pipings and other structure	[A], [B]

12. Tank, liquid storage and fluid-seal gasholder [A], [C]

4. Details of the condition of each item

4.1. Machine tool

Two types of damages were observed. One was caused by an irregular subsidence, and another by water and mud floodings. A jig borer, machine weight 77 t and total weight 270 t, supported by 42 frictional piles, tilted in 1.9° to the river. The reason had been considered as the irregular settlement caused by an irregular distribution of its weight (photo 1). Supporting capabilities of the piles may not be equal at the both ends, because the soil condition of the river side is worse. The tendency of subsidence of the soil was also the same. Planers also tilted like the jig borer.

Many radial drilling machines tilted. Their foundation are not supported by piles and their centres of gravity are rather high. The arms of some of them swang, and hitted their works or tilted by the eccentricities of their centres of gravity. Maximum angle of inclination was 1.75°. The soil structure supporting such machine is estimated as follows: from surface to G.L.-12m it is silt, and there is three meter thick layer of sandy silt, the piles sit on this layer. Under this layer again silt is continue and average bearing capacity might be less than $3\ t/m^2$.

To repair these machine tools there was big trouble, that is, the overhead crane could not move because of distorting of its rail. Most of them were in the sea-water or the mud after the shock. After removing the mud from the finished surfaces of the tool, we should oil them and coat them with anti-ruster immediately. For such treatments, we should lift the sliding table up from the rails, but we could not because of loss of the crane activity.

Liners were inserted under machines, and the gaps were filled with mortar. At first the replacement of the foundation was considered, but there has been no report.

4.2. Crane

There was no severe accident, but most of overhead cranes could not move. Because the rails of cranes or their supporting frames (the portion of a building structure) distorted or sometimes were disconnected. Such situations limited the repairing activities as mentioned above. Tower type cranes were tilted also.

4.3. Train-type machine

A train-type, long frame type machine in this area was a paper machine. The frame of the newest paper machine was inclined in the ratio of 600 mm to 80 m, and was cut partially. The plane gears, which were connected to a guide drum and a dryer, were disengaged each other. The amount of the off-centre of the each planes is 80 mm. This paper machine was installed on the second floor of the reinforced concrete-building. The floor itself was inclined because of the irregular subsidence of its piled foundation. The power unit side was more settled than the other side. The way of repairing was dismembering and re-assembling after strenthening the beams and floor of the building (fig. 2).

4.4. Tower and stacks

Only a few towers of the high voltage transmission line were tilted, but there was no trouble to supply the power. A stack was broken at the midpoint. Its top portion fell into a machine shop, but none was injured. It was made of reinforced concrete, but not new. The concrete of stacks is usually attacked by acidic smoke severely and loses its strength. Inside bricks of steel plate type stacks some times fall off, but this time no report.

4.5. Tower type vessels

In Tokachi-oki Earthquake 1968 and other earthquakes, the damages of tower type vessels or columns at their legs or anchor bolts were reported, but in this earthquake the authors could not find such a damage. The reason is that the dominant frequency of this earthquake was too low to make them resonant. The natural frequency of such vessels is usually higher than 1 c/s.

Their centres of gravity are so high that they were not keeping upright, when the soil at their feets was liquified (photo 2). The heavyer ones are supported by piles usually, so they could escape from the subsidence effect. The lighter ones were sometimes pulled by the other heavier structures through pipings. The way of repairing was to insert liners between its bottom and foundation and to fill mortar in the gap. But some of them are left to be inclined, and others were dismembered. The reactors, some types of which were sensitive to their leveling, were carefully checked.

4.6. Reciprocating type compressor

There was no problem. Because the designer of such a type of compressor had been suffered from the settlement for long time, and had a enough experience.

4.7. Small size conventional equipments and valves

An emergency diesel engine was turned over by the liquifaction of its footing soil. This caused the result that the fire of a crude oil storage could not be suppressed at the first stage. Pumps and other equipments were pulled by pipings or crashed by collapsed structures. Iron casings of valves were cracked by the deformation of pipings at many places (photo 4).

4.8. Boiler and furnace

An boiler drum hung by rods swung and hitted the stopper strongly (photo 3). The gap between its stopper and drum is 90 mm. The natural frequency of this hung drum might be 0.25 c/s, but the authors can not tell exactly, because the down-commers and main steam pipings are connected to the drum.

Fire-bricks of an old type boiler were cracked along joint lines, and some of them were jutting out. A bricked boiler settled down by a fuel hole, the oil burner got out of place and wriggled on the floor with flame. The recovery of such structure seems to be very difficult, but the authors have not known how to be done. A wood-burning device of the ore roaster which uses oil usually was very useful to prevent solidifying of powder ore in a pan.

4.9. Pipings

The resonance type rupture of pipings was observed at only one place (photo 6). An estimated natural frequency of this piping may be 3.6 c/s. The authors can not insist on its cause strongly, but the position of rupture is near the point at which the bending moment becomes maximum when it is supported freely. The authors have been engaged in the dynamic analysis of piping systems, but they could find no good example to prove it.

Most of piping ruptures caused by the forces from structures. Buildings were inclined, the connection of two buildings was disengaged and bridge type office fell down from the supporting structure. Supports stood on a trough tumbled with the upheaval of the trough (photo 6). For such forces the weak points of pipings as follows: casing of valve, welded joints of miter bends, threads portion of screwed joint, some type of bellows (photo 4). A corner of frange and welded joint are also weak, although they are stronger than the items above-mentioned.

To prevent that such extra forces work on pipings, two points should be considered. The first point is that the piping which connects two different structures should be flexible enough. It should provides loop, flexible hose part or at least bends and the length enough to cover its rigidity (photo 7).

The second point is that the use of the piping bridge is recomendable. It is not good design that pipings are supported by individual supporting columns. At least the columns should be connected each other by the members other than pipings themselves. Even in this case, the relative motion of the two structures should be taking into account. And if necessary, pipings should be designed flexibly (photo 8).

Sometimes the part of buildings is designed not so strong as it may completely endure the strong earthquakes. If the designer of piping systems plans to use the building structure as piping supports, he had better to check how the building was designed (photo 9).

The flexible hoses connected to oil strages worked well, when they subsided in several hundred mili-meters. Only three screwed elbows inserted in a upright piping for foaming liquid endured 300 mm of the relative displacement (photo 5). It was observed that the fine thread screws at fittings were pulled off without any damage of them. The outer ring of fittings may be expanded radially by a wedge action of thread surface under the pulling force. The strength of such couplings against the pulling force should be reconsidered.

Pipe of poly-vinyle cloride is often used for low pressure steam and water, sometimes town gas. It is very brittle. They were cut off very sharply (photo 10). There was no report of the fire with town gas, but the use of poly-vinyle cloride, pipes for flamable gas es should be restricted.

4.10. Buried pipings and other structure

The authors did not survey precisely, but they were affected much by liquifying of soil. Upheaved Hume concrete pipes were observed at various places. Flexible couplings of buried pipings behaved rather curiously, at some places metalic bellows were ruptured but rubber hose couplings were not. At another place rubber hose couplings were cut off instead of metalic bellows. The dynamic effects of liquified soil to buried structures should be studied more precisely by the specialists.

4.11. Oil storage and fluid-seal gasholder

The big fire of mammoth oil storages gave the largest amount of damages to the industry and the public around the plant. Three 30,000 kl storages were burnt. It has not be understood yet how it caught fire. Some one reported as follows: the floating roof of an oil-storage had pitched and seemed that the reverse side of the roof had been looked. After several swings crude oil had made fire.

Three types of damages were reported on oil storages. One is the sloshing of oil. It made the floating roof swing or made break the fixed ceiling (fig. 3). The sloshed oil buckled the wall and ceiling, when oil level was lower than middle point (photo 11). This is the second type damage. The third type damage is the subsidence of its bed. The sloshing problems will be discussed later.

Some of them were settled unequally and the wrinkles of their walls were observed. Several ones were subsided by 700 mm. But a new type bed could make the storage escape from such a trouble in Niigata Earthquake (in Tokachi-oki Earthquake 1968 it could not). The new type sand bed is supported by piles made by vibro-floatation method. This type bed is said to endure the bearing pressure of 14~15 t/m^2.

The settlements caused often the main pipe ruptures at the nozzles of their wall. Main valves are usually installed outside of storage walls, so they did not work to stop the oil, when the ruptures were occured. To prevent the flood of the oil through such a opening, some special valve mechanism should be installed at the inside of the wall.

On the recovering procedure during an emergency phase, it was the biggest problem how to transfer the oil. Power supply for pumping was cut,moreover in the case of the floating roof type storage the roof could not follow the level of oil anymore because of the distorsion of its wall. They used LP gas to drive their reciplocating steam driven pumps, and several days later they obtained portable compressors for them. To avoid making space between the surface of crude oil and the ceiling the water was poured to substitute it.

Most of the floating roof type storage including burnt ones were disassembled. But others are being used after the recoveries of their levels within the inclination limit provided by the rule.

An oil fense which separates the blocks of oil storages was cracked at several points for each section, so oil penetrated to other side over the fense. Even if it was not cracked, and if overflows of crude oil occured at both side storages, it did not work for preventing that the fire spreaded anymore. Under the consideration of strong earthquakes, two oil fenses should be arranged for the separation of each block doubly.

A fluid-seal gasholder was damaged. The top bell was tilted and rotated, so guide-arms were offed from guid rails by a meter. This phenomenon was reported in Tokachi-oki Earthquake also. During the earthquake seal water emerged from the gap between its wall and bell was observed. The level of seal water is usually 1~1.5 m lower than wall, so some dynamic effect might be worked on the bell and water.

4.12. Arrester and other equipments of transmission line

Self-standing type arresters, for 140 kV high tension lines, were broken at their feet. These arresters were mounted on the yard of a hydraulic power plant located in 140 km south-west of the epi-center. Fourteen arresters out-of twenty seven became the same condition (fig. 4). The ground of the yard is rather thin soil layer on bed rock, and an estimated seismic force was 50 Gal or so, but several plates of glass of windows on the generator room were broken. Then the authors estimated that a keen shock motion broke such brittle materials because of the wave transmission performance of hard rocks.

Miss-operation of the warning system for the low level of transformer oil was reported. Such a miss-operation might be caused by the sloshing of oil in the transformer.

5. Dynamic evaluation of oil behavior

Professor Yamamoto, University of Tokyo, analyzed the dynamic behavior of oil storages, and evaluated their dynamic behaviors in Niigata Earthquake.(3) The authors quote his paper and add the result of their analysis to it.

The period of the fundamental surface motion of liquid is given by

$$T_i = 1.046\sqrt{d \coth \frac{3.68H}{d}} \qquad (1)$$

(d in meter)

for the cylindrical storage. Here d : diameter, H : height. For the floating roof type storage, the period of the fundamental motion is equal to the eq. (1), if the weight of the roof can be neglected. Periods and sizes of the several oil storages which were damaged as follows:

	capacity (kl)	diameter (m)	oil-level (m)	period (sec)
(A)	5,000	25.2	8.0	5.78
(B)	20,000	44.6	12.1	8.00
(C)	30,000	51.5	13.0	8.79

On the inside wall of the storage (A) , 5,000 kl, the scratched trace by the roof edge was remained. The displacement of the roof can be estimated as 1.5 meter from the trace. On the other-hand, the record of an accelometer (for example, fig. 5) shows that the ground motion became very slow 10 seconds after the first shock. In this phase, the dominant period was approximately 6 seconds and the amplitude of its accelogram was 58.8 Gal. So the displacement X might be 54 cm, if the motion could be assumed as sinusoidal wave.

Displacement x_g of centre of gravity of liquid in a cylindrical storage is given by

$$x_g = \frac{d}{2H} h = \frac{25.2}{8} \times 1.5 = 236^{cm} \qquad (2)$$

here h is the displacement of a floating roof at its edge. So amplification factor A is

$$A = \frac{x_g}{X} = \frac{236}{54} = 4.4 \qquad (3)$$

The authors obtained the response curves for the design of oil storage by using an analog computer. Those curves are summarized to a chart (in fig. 6). This chart shows the relation of transient amplification factors to the critical damping ratio. Parameters on the top group of curves show the number of waves after the first shock. The lower group of curves are the normalized velocity responses to El Centro Earthquake 1940 by Professor Housner (4). For the top group the relation of the period of the system to that of earthquake motion is fixed to be equal each other. In the case of Housner response, the authors choose the periods of the system as 1.0, 2.0 and 3.0 seconds.

The result shows that the amplification caused by a pseudo-resonance with El Centro Earthquake is the level of two or three waves trasient resonance. For damping ratio from 0.5 % to 2 % the amplification factor A is almost flat.

number of waves	amplification factor
1	2.0
2	3.3
3	4.5~4.3

The amplification factor of the above-mentioned case is 4.4, so this value might be said reasonable.

Oil was scattered very widely when it sloshed. In fig. 3 schematic view of heavy oil scattering is shown. Professor Yamamoto showed that shouting oil might reach at the point 31 m from the wall in the case of 20,000 kl storage. He assumed that the oil jet obtained the velocity of 14.5 m/s by the pressure 0.91 kg/cm^2 of sloshing waves.

Most of the oil storages which were damaged in Niigata were located in a silt zone. But there was a storage of concentrated sulphuric acid on a dune (point A in fig. 1), and the jet of acid spouted from the broken point of the ceiling, although other structures on the same yard were not damaged. So the possibility of resonance of the low frequency structure can not be neglected at the other place than a silt zone.

6. Human behavior during the earthquake

The time of the earthquake is several minutes past 1 O'clock. Most of people in the factories had just started their afternoon works. So they seemed to escape rather easily than they were in the midway of their works. Moreover, after several keen shocks, it turned to very slow movements, and the damage by the earthquake was occuring with very slow tempos in this phase. Especially the damage by subsidence or settlement took for several minutes.

In such situations the number of death in the factories was very few. Only one case reported was that a technician had been dead. A tee of liquified ammonium line was broken, so he wanted to closed the stopping valve near the broken point and he breathed the concentrated gas in.

There are the plants which treat the poisonic gases and liquids, ammonium, cyanic acid, chlorine and hypochlorous acid. But there was no report on a fatal accident. During the earthquake operators tried to close the stopping valves in such lines, and they succeeded except the one case above-mentioned. Another group of operators was trying to stop their boiler safely, because they were afraid of the following accidents: instability of water circulation, mixing of water drops with dry steam, emergency shutting down of turbine-side, caused by loss of its load or the vibration of its bearings, leaking of fuel and steam and/or the motion which they felt, No seismic switch was installed in 1964, then the way of operating during the earthquake depended on the operater s judgement.

Which is better to stop all power supply or to continue the supply to the specified points even during earthquakes is the problem which should be considered. If it should be kept, an operator in a power plant is required to make his judgement exactly. It was reported that in such cases operators did their work very exactly, if they had been trained well. But it seemed to be very difficult to make the exact judgement. A manager of such a plant reported that the best way of the plant operation during strong earthquakes was to stop according to the normal emergency operating sequence without any judgement. The daily training is very important to keep the exact, reflectional action of operators. The parttern of this earthquake, the slow novements, seemed to give no hazardious confusion to the people.

On the phase of the recovery, it became also important that the revovery of the employees' home conditions, keeping their families well and supplying their foods enough. If not, it is quite natural for each employee to feel anxious about his family.

7. Problems to be checked and other miscellaneous affairs

To make the quick recovery the industries must consider the following two points. One is that they should have their plan how to recover their factory. And the lay-out of machineries should be done according to the plan. For example, the size of a motor crane decides the width of a pass in a machine shop and the height of its entrance, if the use of a motor crane is planned instead of the dead overhead crane.

Another point is that all drawings which are necessary to recover their factory and to continue their productions should be kept safely from the fire and the flooding. In an office they met the flooding of 300 mm about an hour after the shock, so they moved the drawings on the desks from the lower part of the racks. Several hours later, after the people had gone back to home the water level reached by 2 m, because of the uniform subsidence of the office area. Then most of the drawings were wetted and some of them were scattered.

How to treat the materials on the process is very important. If the price of material is rather high and it can not be kept in midway, for example, photo-film, some kinds of chemicals and foods, the stoppage of the process gives the loss to the industry. If the state of materials is severe to the devices, for example, hot pellet on a rolling machine, melted steel in a continuous casting machine and some-types of boiler and reactor, they can not endure the abnormal condition occured by their stoppage. They need special power supplies for escaping from such abnormal conditions.

How to keep the power supply which is required for the plant security is the problem. Sometimes the capacity of the power supply required is not so low as it can be supplied by conventional emergency power systems. One of the solution is that the utility company and the industry make a contract to keep a power supply for the plant security through a high quality lines even in an emergency case. But there is objections against this opinion. Most of the persons of utility companies think that it is the best way to cut their supply in the case of strong earthquakes to avoid the fires and other accidents.

The overhead lines of power and telephone were stronger than the buried cables, and damaged little. For the quick recovery of their functions, temporal lines were extended overhead. The strength of directly buried cables can not be expected much. It is recommendable that the important cables are put in the large size trough which is constructed under the consideration of various seismic loadings.

The cells of the batteries for emergency power should be fixed. The consideration of the earthquake resistant design for emergency systems are not enough usually, because designers in this field are not the specialists of the earthquake resistant design. So it is important to promote the spread of the knowledge on it to mechanical and electrical engineers.

8. Conclusion

Most of damages in Niigata were caused by a liquifaction phenomenon of soils, however the fact should be remembered that the motive force of damages by strong earthquake is the accelerations, the displacements and their dynamic effects. And that they work upon the structures, pipings and equipments, even if they are installed on the firm and stable foundations.

The authors would like to point out again that spreading the knowledge of the earthquake resistant design to the engineers who do not specialize the civil engineering is the most important job to secure the safety of the plant and the public around it.

The plan of the earthquake resistant plant should be done under the considerations as a complete system including plant safety, damage to the public, total loss by an earthquake, construction cost, insuarance cost and reparing cost.

. Acknowledgement

The authors like to express their enormous thanks to the people who showed them their plants and explained the states of damages of their plants under the extreme confused conditions to them. And they also like to express their great thanks to Professor Yamamoto for lending his files of Niigata Earthquake to them.

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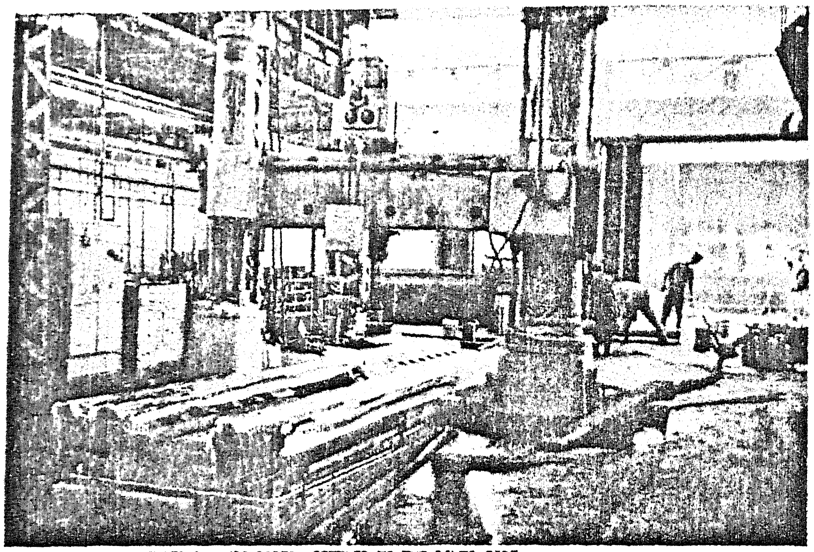


PHOTO 1. JIG BORER, SETTLED TO THE RIVER SIDE.
AN EXAMPLE OF DAMAGES OF LARGE SIZE MACHINE TOOLS.
ITS TABLE WAS REMOVED.

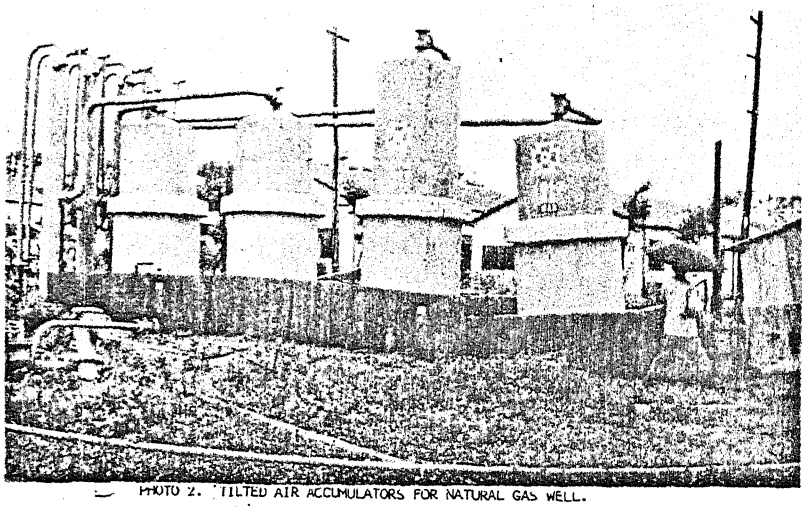


PHOTO 2. TILTED AIR ACCUMULATORS FOR NATURAL GAS WELL.

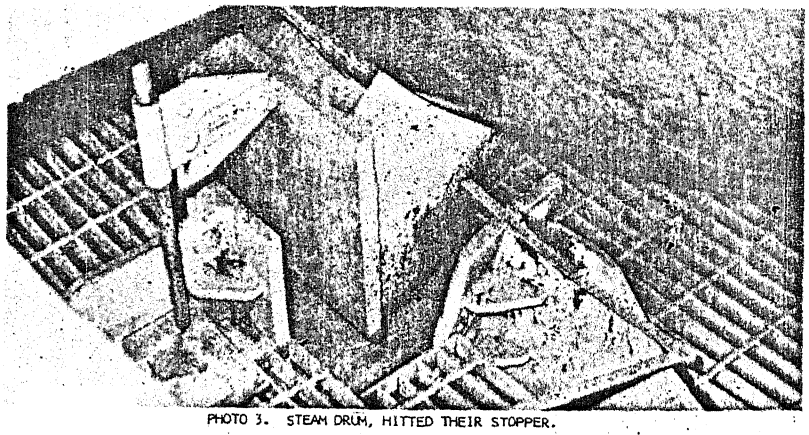


PHOTO 3. STEAM DRUM, HITTED THEIR STOPPER.

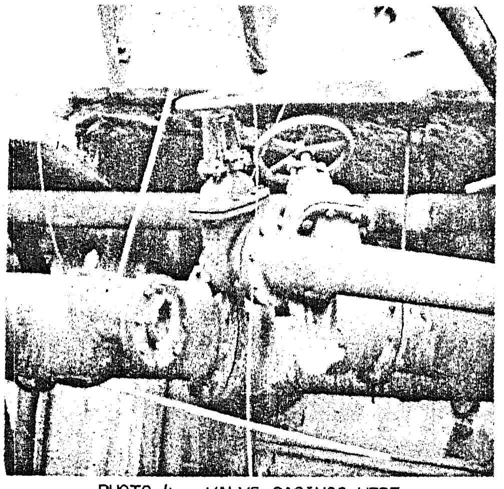


PHOTO 4. VALVE CASINGS WERE CRACKED BY FORCES AND MOMENT TROUGH PIPINGS

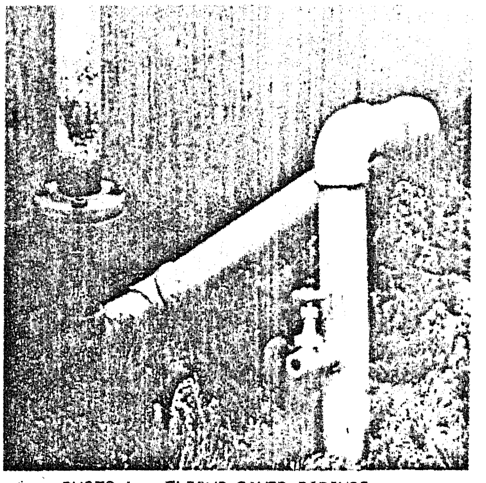
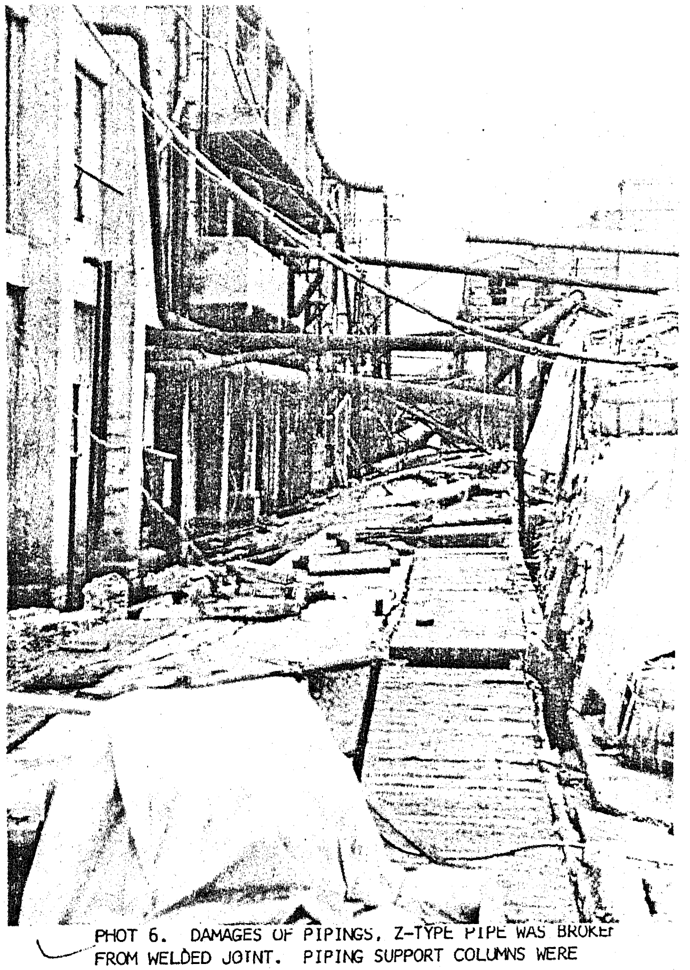
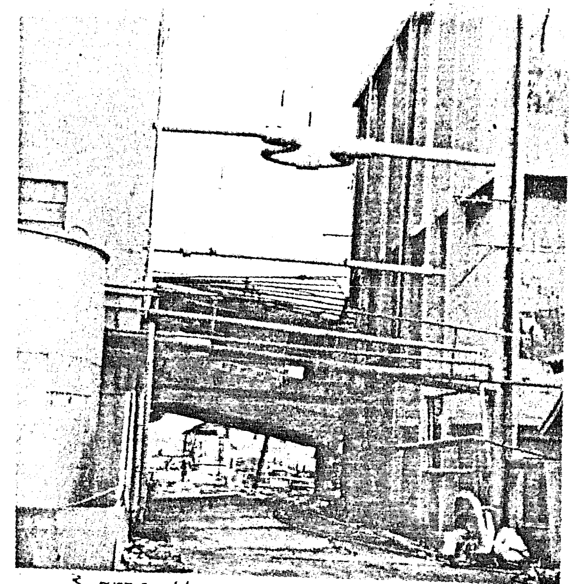


PHOTO 5. ELBOWS SAVED PIPINGS FROM BREAKING.



PHOT 6. DAMAGES OF PIPINGS, Z-TYPE PIPE WAS BROKEN FROM WELDED JOINT. PIPING SUPPORT COLUMNS WERE TURNED OVER

PHOTO 7. FLEXIBLE HOSES COULD ESCAPE FROM THEIR RUPTURES WHEN STORAGES SETTLED.



PHOT 8. ΩL-SHAPE LOOPS OF PIPING LINES HAD ENOUGH FLEXIBILITY TO AVOID THEIR BREAKAGES.

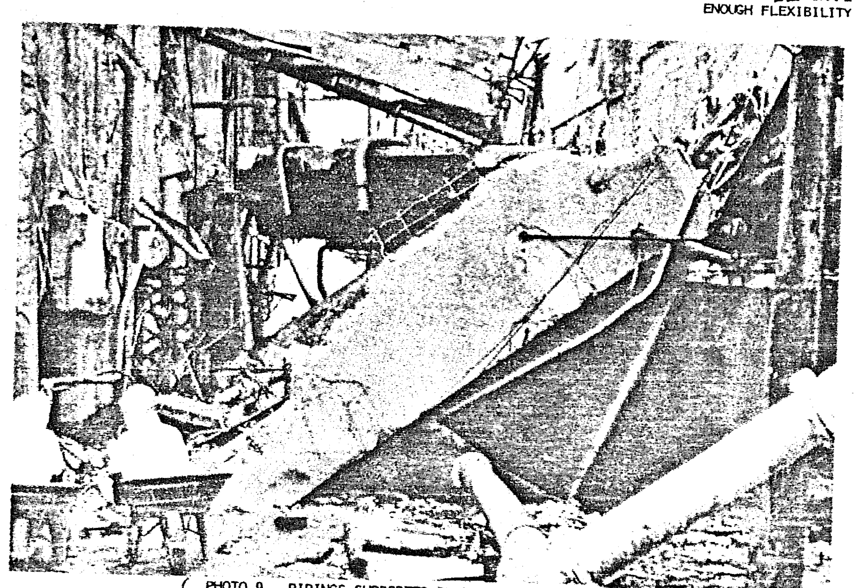


PHOTO 9. PIPINGS SUPPORTED BY THE WEAK PART OF BUILDINGS WERE CRASHED WITH IT.

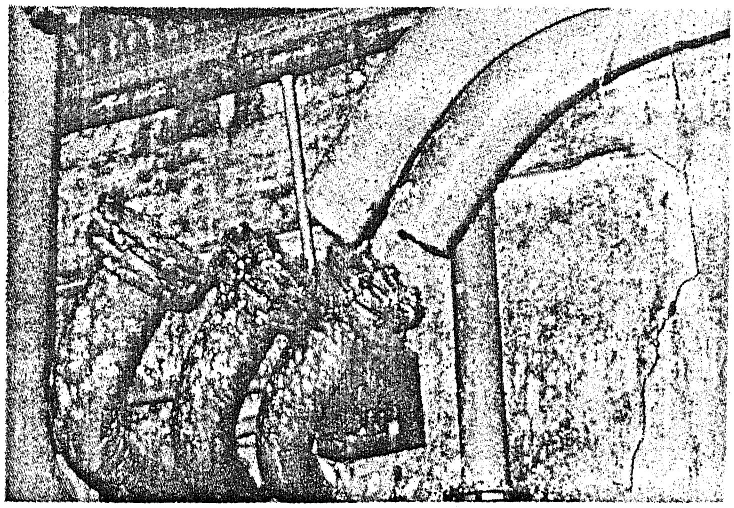


PHOTO 10. PIPINGS OF POLY-VINYLE CLORIDE WERE CUT VERY SHARPLY.

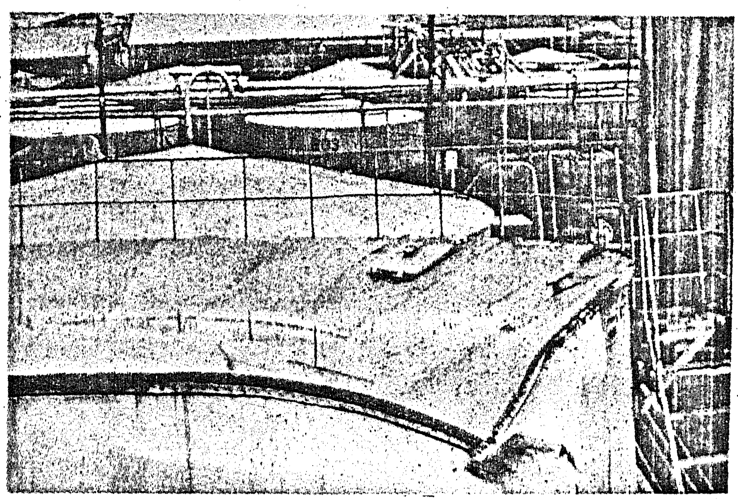


PHOTO 11. SLOSHING OF OIL MADE BUCKLE ITS STORAGE TANK.

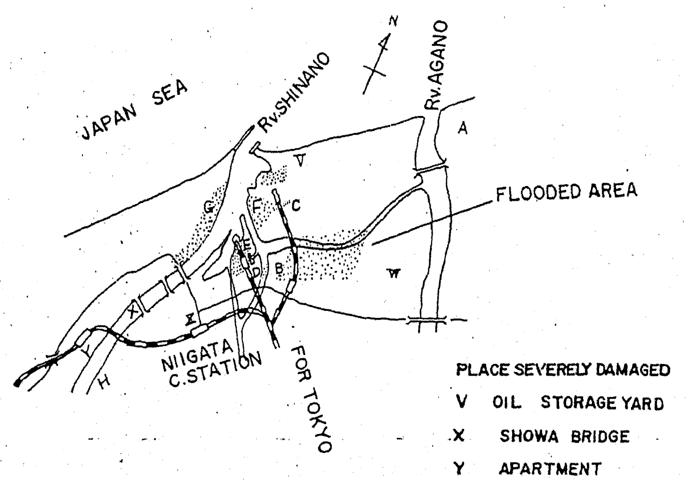


FIG. 1 MAP OF NIIGATA CITY AND ITS VICINITY.

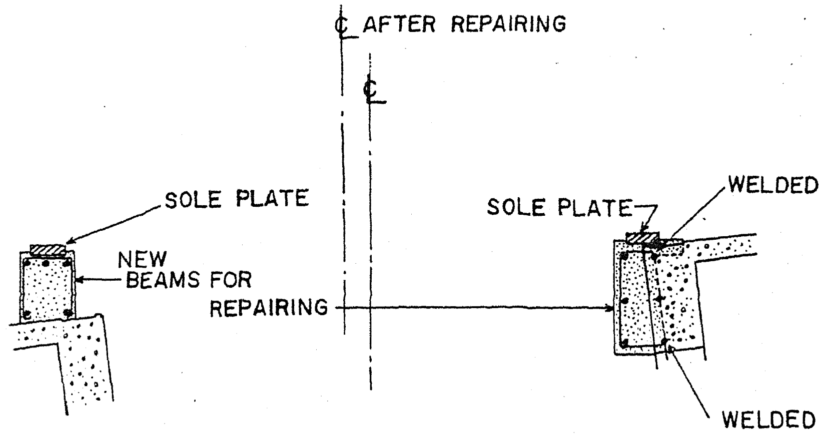


FIG. 2 SCHEMATIC DRAWING FOR REPAIRING OF PAPER MACHINE FOUNDATION (BY COURTESY OF PAPER MANUFACTURING COMPANY).

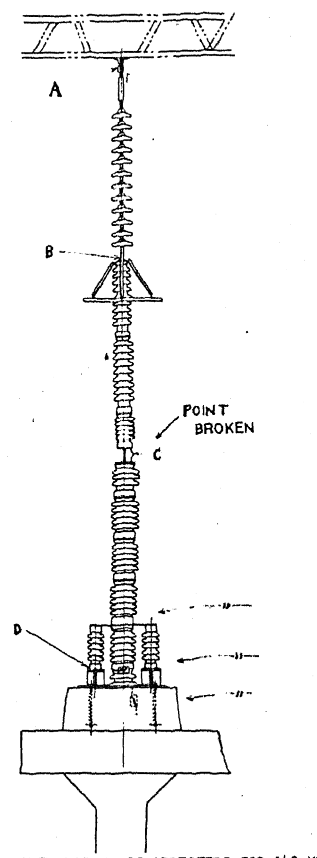


FIG. 4 BROKEN POINTS OF ARRESTERS FOR 140 KV HIGH TENSION LINE. (BY COURTESY OF RAILWAY ELECTRIFICATION ASSOCIATION)

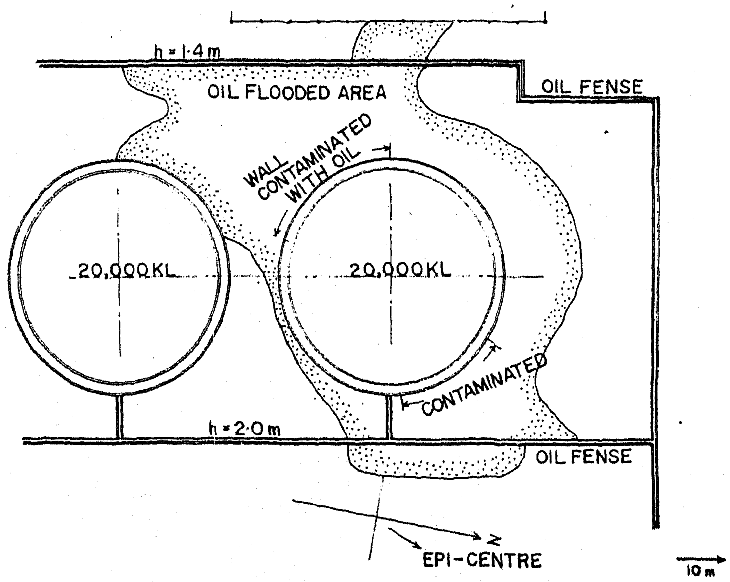


FIG.3 SKETCH OF FLOODED HEAVY OIL AROUND THE FLOATING ROOF TYPE STORAGE (AFTER YAMAMOTO).

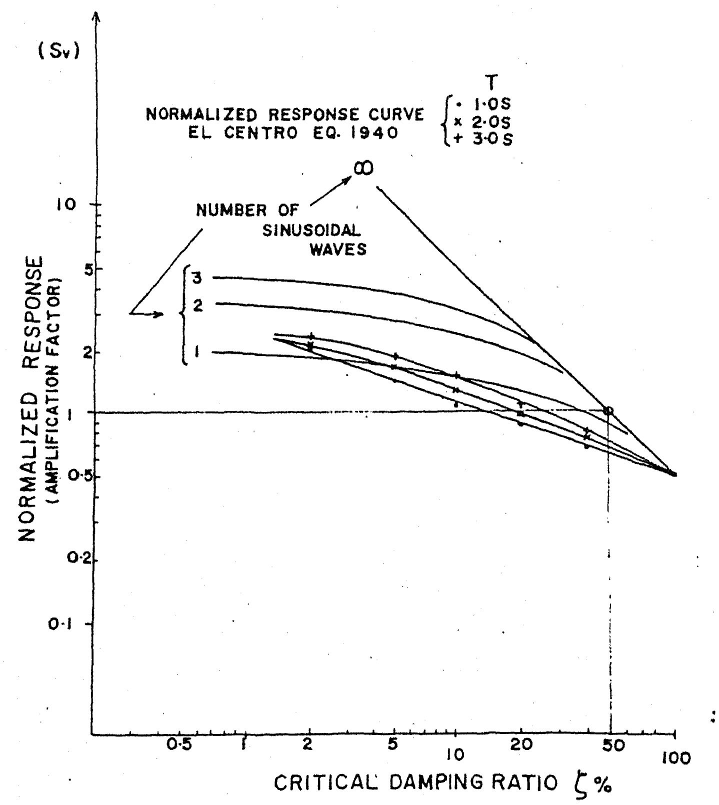


FIG. 6 NORMALIZED TRANSIENT RESPONSE (AMPLIFICATION FACTOR) VS. CRITICAL DAMPING RATIO. FOR ζ_{g} = 50 %, AMPLIFICATION FACTOR IS EQUAL TO UNITY.

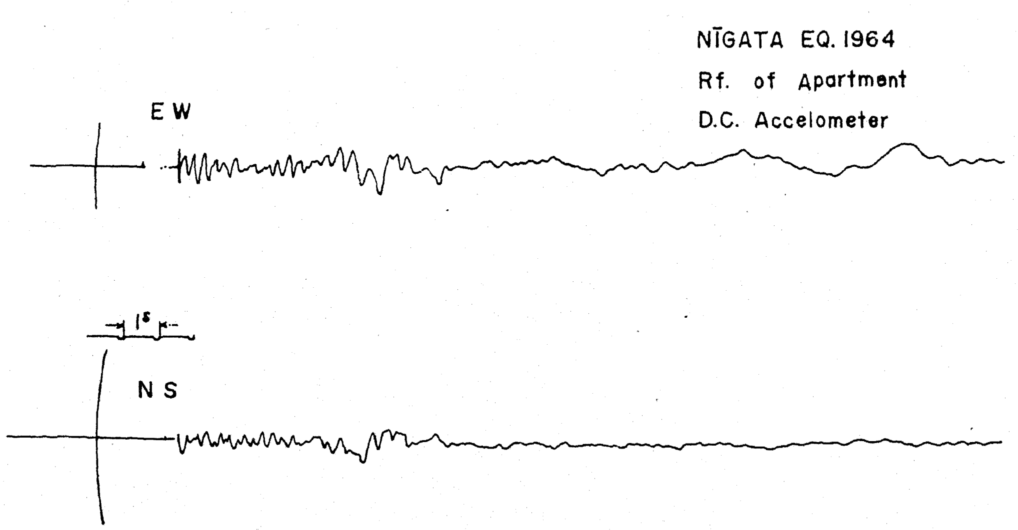


FIG. 5 AN EXAMPLE OF RECORDS OF ACCELERATION WAVES IN NIIGATA EARTHQUAKE.