Provisional Report on the Oct. 6, 2000, Western Tottori Prefecture Earthquake*

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1. INTRODUCTION

On October 6 at 1:30 in the afternoon, an intense earthquake hit the western part of Tottori prefecture, Japan. It was the largest earthquake to hit Japan since the devastating Kobe earthquake in 1995. It had JMA and moment magnitudes of 7.3 and 6.6, respectively; the latter was about 40% of the Kobe earthquake. The epicenter was located some 30 km south of Yonago, a port city on the Japan Sea-coast. The focal depth was about 11 km. More than 2600 people were evacuated. As of Oct. 8, 95 people were reported injured in Tottori prefecture; 20 among them suffered severe injuries such as bone fractures, however, the quake did not cause any fatalities.

This report briefly describes preliminary results from the authors' investigation (Oct. 7-9), focusing on landslides, liquefactions, toppling and slipping of gravestones etc. The map below (**Fig. 1**), shows the investigated sites numbered in chronological order.

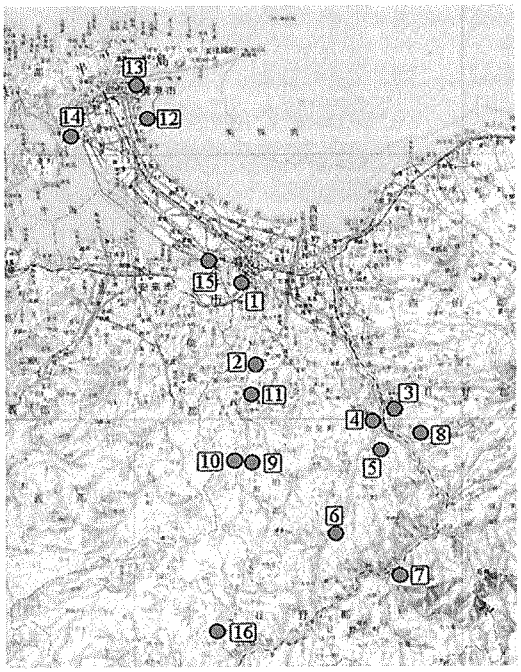

Fig. 1 Investigated sites

* The greater part of this paper is taken from the authors' latest publication in the Monthly Journal of the Institute of Industrial Science, University of Tokyo, "SEISAN-KENKYU", 2000.

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2. DETAILED DESCRIPTION OF DAMAGE

Location 1, 133°19.9'E, 35°25.1'N.

Visit to the cemeteries at the Keijuji- and Sousenji-temple (**Fig. 2**): A few gravestones were toppled. The gravestones slipped on the average about 1 cm and some 70 % of them rotated clockwise.
As first estimate one can assume that to topple the gravestones an acceleration of 0.33g is necessary since the height to width ratio is 1:3. For the rotation to occur one can assume that the gravestone where slightly tilted in a vertical plane at the same time as accelerated horizontally in a direction perpendicular to the vertical plane. From the slippage observations, assuming a friction ratio of 0.5 (μ), and using the formula: $(1/2)mv^2=mg\mu\Delta$ it is possible to estimate a velocity of 30 cm/s corresponding to the average slippage, Δ of 1 cm.

Fig. 2 Cemetery of Keijuji temple

Location 2, 133°20.4'E, 35°22.1'N Cemetery at the Kashiwao, Seihaku town

This graveyard spreads over a thin terrace-like ridge sticking out towards the narrow valley of Houshouji river. The graveyard is covered up with soft sand of weathered granite. Cracks, about 2cm-wide, were found in the soil along the rim of the "terrace". Almost all graves were completely destroyed. Because of the severe destruction it is difficult to estimate acceleration and velocity with help of the simple formulas and assumptions as done for the cemeteries visited on the 1st day

Location 3, 133°26.4'E, 35°20.6'N Mizoguchi city hall

The building is closed of because of the severely damaged columns of the 1st story and large cracks in the stair between the 1st and 2nd story. Longitudinal rebars were of plain type and stirrups were widely spaced about 30 cm. A concrete block wall next to the building was also damaged probably due to too few and corroded reinforcement bars. Many of the buildings in the city had damaged roof tiles.

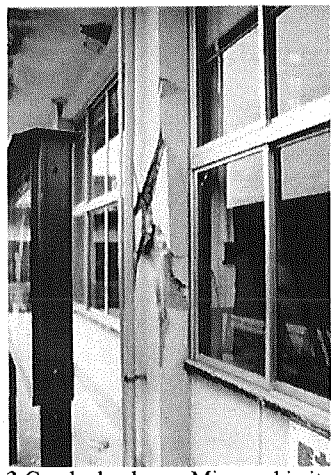


Fig. 3 Cracked column, Mizoguchi city hall

Location 4, 133°26.2'E, 35°19.9'N Rock fall at Nakaso area.

A volcanic (igneous) rock wall of Pliocene Epoch (5 - 2 million years old) was cracked up along its joints into a number of large (about 1-2 m sized) pieces. The intact part of the stone is gray with tiny fragments-inclusions of separate substances (most probably Mica). Originally exposed parts are rather brownish with small clusters of moss sticking to the surfaces. The broken rock pieces rolled down the steep slope (40 degrees). One piece bounced on the pavement of Prefecture Route rolled into a ditch breaking the concrete wall of the ditch. The front part of a car was squashed, but fortunately the driver survived.

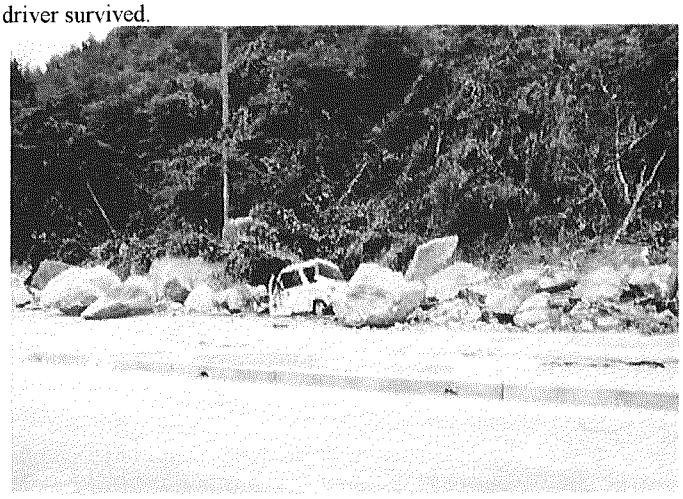


Fig. 4 Rock fall at Nakaso area

Location 5, 133°26.2'E, 35°19.1'N Slope failures at Furuichi.

There is a multi-stepwise configuration in Furuichi. The slope failure took place at the northern slope of the highest (second major) terrace. The terrace consists of weekly-cemented sediments of volcanic soils and rocks. Cedar trees growing on the slope face have a shallow root system and causing the soil mass, being reinforced by the roots, to slip as a large mat.

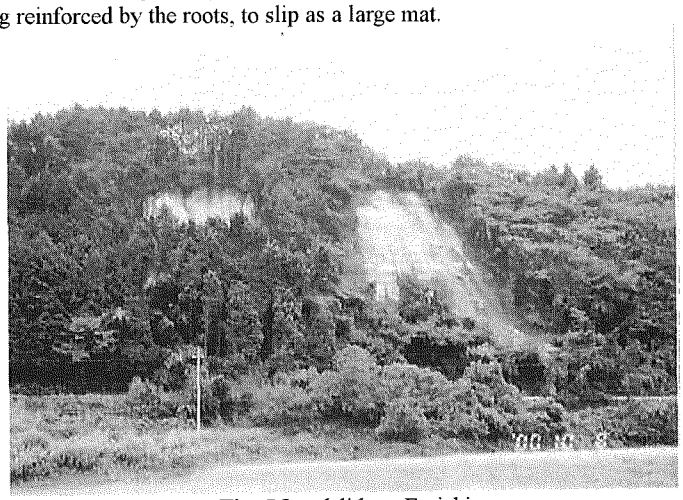


Fig. 5 Landslide at Fruichi

Location 6, 133°23.8'E, 35°15.3'N Ground cracks at Fukuoka in Nibu region.

Surface cracks found across a narrow valley situated above a cluster of after shocks. Road pavement was also cracked. A possible fault surface rupture, but the cracks in the soil are most probably due to small slope failures. A reconnaissance team from Kyoto University could neither find any evidence of fault surface rupture in this area.

Location 7, 133°26.8'E, 35°14.3'N Neu, Hino town.

Damaged roofs were covered with plastic sheets to prevent leaks in the case of rainfall. The traffic on the Japan Railway Hakubi line was suspended due to rock falls and slope failures

Location 8, 133°28.1'E, 35°19.2'N Rock falls along Otaki-Shiramizu prefectural route.

Taking a detour through Neubara, we came up to Osaka, a small village along the valley formed by river erosion through a thick sediment of volcanic ash, pumices and other suspended matters carried by pyroclastic flows from Mt. Daisen. The weekly-cemented soil appearing on upright cliffs is totally white, and once soaked up with water, it looses bond among grains. A big piece of rock was found broken in pieces on a asphalt pavement. White radial lines remaining on the pavement tells that the rock flew in pieces in all directions.

Location 9, 133°19.9'E, 35°18.0'N: Kashoo dam

The concrete gravity dam withstood exceptionally high accelerations, 530 gal at the base in the North-South direction and 2200 gal at the crest in the North-South direction. Only some minor damage was observed. The machine room of the outlet sub-gate in the center of the picture (photo taken from east abutment) had some diagonal cracks in the concrete and the windows were broken. The west abutment parking lot settled about 10 cm causing cracks in the asphalt pavement. An engineer in the control room located at the west abutment told that he could not remain standing during the shake.

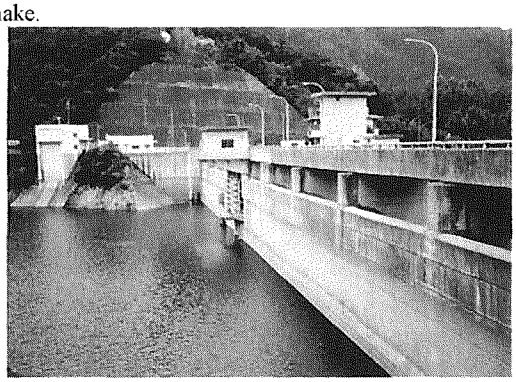


Fig. 6 Kashoo dam

Location 10, 133°19.6'E, 35°17.9'N: Hakusan bridge.

A two-span simply supported steel girder bridge located on the west side of the Kashoo dam reservoir. Two abutments and one wall-type reinforced concrete pier in the middle support the bridge. The heights of girders differ reflecting the difference in length of the two spans. The top of the pier thus has a stepwise shape. The road, and the bridge, is slightly inclined upward to the upstream side of the Kashoo dam. The backfill of the southern end abutment subsided by about 18 cm causing the girders for the upstream span of 18m to be pushed downstream towards the middle pier. This seems to have caused the bearings of the girders at the pier to be pushed outward in such a way that the parapet between lower and upper decks of the pier cracked and large pieces of concreted spalded off, which were found remaining on the lower deck of the pier. This damage caused the bridge girders to settle a few centimeters as can be seen from the nut on the bearing bolts. The expansion joints of the bridge deck were almost closed.

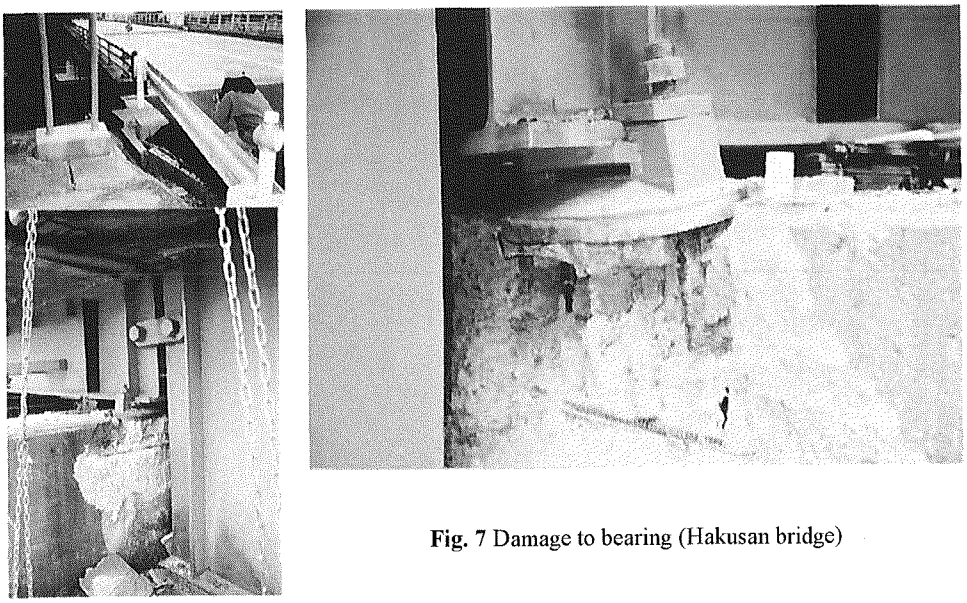


Fig. 7 Damage to bearing (Hakusan bridge)

Location 11, 133°20.1'E, 35°21.1'N: Collapsed house and Cemetery at Aga, Saihaku town.

One of the few collapsed buildings. At the nearby cemetery almost all graves were destroyed. One gravestone rotated more than 135 degrees without toppling. Ground acceleration was estimated to more than 500 gal and velocity to some 90 cm/s.

Fig. 8 Flattened house at Saihaku town:

It is common in this area that a household has both main and detached houses. Detached houses often have garages for cultivators and/or store-rooms.

Location 12, 133°15.3'E, 35°31.4'N: Sakai Minato dream port park.

Widespread liquefaction causing lateral spreading and sand boils. Quay walls moved slightly outward causing joints between concrete pavement slabs to open up. Some cracks could be seen in the pavement. Numerous large sand boils in parking lot as seen below in the photo. Retaining walls along channel moved towards channel due to heaving failure. The soil was gray very fine silty sand.

Fig. 9 Sand boils at Sakai Minato dream port park

Location 13, 133°15.1'E, 35°32.6'N: Sakai Minato fisherman's wharf.

The wharf has a roof along its sides, each side being supported by a two row of concrete columns. The concrete pavement slabs settled up to 1 meter due to liquefaction, while the pile supported columns did not settle. Lateral spreading pushed quay walls towards the water and causing one of the columns to tilt. The area is closed off from use. A large amount of liquefied sand could be seen in drainage channels along the wharf. The two lower photos show the large opening of the joints between the concrete slabs caused by the lateral spreading.

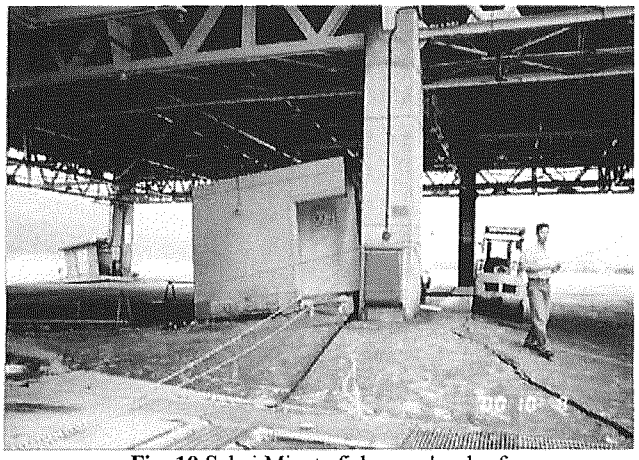


Fig. 10 Sakai Minato fisherman's wharf
Settlement of subsoil caused the concrete pavement to be bulged by the pile foundation

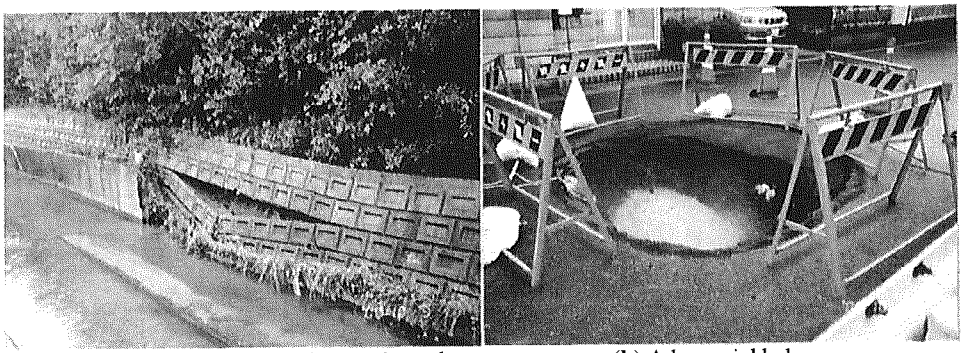
Location 14, 133°12.2'E, 35°30.8'N: Nakaura water gate.

Quay wall failure at the Nakaura water gate. A possible scenario could be: The liquefied backfill soil squeezed through openings between quay wall blocks causing settlement behind the quay wall and subsequent failure of the quay wall because the backfill was "eroded" away. Another scenario could be: Lateral spreading caused the quay walls to fail allowing the liquefied soil run out into the water, with subsequent settlement/slope failure behind the quay wall.

Fig. 11 Lateral flow at Nakaura water gate

Location 15, 133°18.2'E, 35°26.2'N: Abe-Hikona residential area.

Extensive liquefaction. Pile supported apartment buildings suffered no structural damage, but post liquefaction settlement of about 25 cm of surrounding soils caused sewage pipes to break and entrance staircases to be offset. Many one or two story houses were tilted and had cracked walls. Almost all houses were assigned yellow "cards", meaning people can still remain in the house but should be careful. A green card means that the building suffered no or little damage, while a red card building has to be evacuated. The photos show how the retaining walls along a channel suffered damage due to liquefaction. A Large sinkhole caused by the main shock on Friday the 6th had been repaired but the large aftershock on Sunday evening caused the same sinkhole again. The doors in the gate were offset some 20 cm. An electric pole settled almost 3 meters.



(**a**) Toppled retaining wall along a channel (**b**) A large sinkhole

Fig. 12 Abe-Hikona residential area

Location 16, 133°19.1E, 35°12.1'N: Sugesawa dam.

The accelerations were much lower than at the Kashoo dam, thus also here no damage was observed. The transverse acceleration at the base was 106 gals and the longitudinal was 153 gals.

3. SUMMARY

Tottori prefecture suffered a lot of damage to civil engineering structures, which, as of Oct. 8, 2000, was estimated to have reached 9.8 billion yens loss; about half of that amount was from liquefaction-inflicted damage. But luckily, the epicentral area was rather sparsely populated, and the intense shake reaching 530 gal at the base of Kashoo dam (above a cluster of aftershocks) did not cause any death in that area.

More detailed descriptions and updated pieces of information are available at the following URL: http://norway.iis.u-tokyo.ac.jp/tottori/index.html

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