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EARTHQUAKE DAMAGE BY LIQUEFACTION-INDUCED PERMANENT GROUND DISPLACEMENT

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SUMMARY

The damage to bridges, foundation piles and buried pipes caused by the 1964 Niigata earthquake was re-investigated from the viewpoint of liquefaction-induced permanent ground displacement, which were measured by using aerial photographs taken before and after the earthquake. A close casual relationship between the damage and permanent ground displacement was found, and it was concluded that most of the damages by the earthquake were caused by permanent ground deformation rather than inertia force of structures.

INTRODUCTION

We, the authors, measured liquefaction-induced permanent ground displacement caused in Noshiro City, Akita, Japan during the 1983 Nihonkai-Chubu earthquake, and in the vicinity of the Shinano River, Niigata, Japan during the 1964 Niigata earthquake by aerial surveys using photographs of each area taken before and after respective earthquake.

As for the measurement results and relations between permanent ground displacements and topographical and geological conditions, details have already been reported(Ref. 1, 2).

It is significant to note, however, that especially along the Shinano River, horizontal displacement of more than 20m had been observed, which was verified by the drastic decrease of the width of the River occurred by the earthquake.

Similar cases have been reported in the U.S. concerning permanent ground displacements induced by liquefaction after several earthquakes. According to O'Rourke et al., it is reported that reclaimed ground area in San Francisco City had slid by 2 - 3m after the 1906 San Francisco earthquake, which damaged buried pipes in that area (Ref. 3). Also, Youd et al., reported a case from the 1971 San Fernando earthquake; a maximum of 3m of permanent ground displacement in horizontal direction had been caused near the Upper Van Norman Lake vicinity, and that this displacement brought damage to buried pipes, bridges and power sub-station facilities in the area(Ref. 4).

The objective of this report is to study the damages to structures caused by liquefaction-induced permanent ground displacment and is also to look into casual relationships between the ground displacement and damage to structures.

DAMAGE TO BRIDGES

As have already been pointed out in the Introduction, a large magnitude of permanent ground displacement occurred along the Shinano River area toward the River. Photo 1. shows the damage to the pier of Yachiyo Bridge on the left bank. As indicated in Fig. 1, it is completely broken at the middle of the pier. According to the investigation conducted immediately after the earthquake, ground displacement had been caused toward the River displacing the foundation of the pier. It was then estimated that the steel girder restrained the pier from the deforming at the top of the pier and caused a large bending moment at the middle of the pier. Fig. 2 shows horizontal displacements measured near the left bank side of Yachiyo Bridge. It should be noted that the ground on the left bank side moved by 4 - 5m toward the River. It can, threfore, be concluded that these ground displacements were the direct cause of the damage done to the pier of the Bridge.

In case of the Niigata earthquake, two bridges fell down during earthquake. One of them was the East Over-RAilway Bridge as seen in Photo 2. This Bridge was constructed with a simply supported steel girder with a span of 10m. The girder on the side of movable shoe slid off the pier and fell down, crushing a train running right beneath it. The foundations fo the Bridge pier consisted of reinforced concrete piles of 30cm in diameter. Fig. 3 shows one of the damaged piles extracted from the ground after the earthquake. Following special features were found about the damage to the piles: firstly, a large number of cracks were seen only on the one side of the pile, and secondly, the cracks were caused in the lower portion of the pile as well as in the upper portion. These features indicate a fact that the pile s were not damaged by repeated inertia force, but rather by some static external force.

Liquefaction-induced permanent ground displacements are considered to increase gradually and to continue even after earthquake motions are over. Fig. 4 shows displacement on ground surface around the Bridge. In the area lying in the north of the Bridge, ground displacement was toward the north direction, and in the area lying in the south of the Bridge, ground displacement occurred toward the south direction. In other words, ground displacement expanded the distance between the two piers of the Bridge.

The above-mentioned damage inspection and ground displacements lead to the conclusion that the cause of the fall-off of the bridges was the liquefaction-induced permanent ground displacement.

DAMAGE TO FOUNDATION PILES

In the neighborhood of Niigata Railroad Station, damage to foundation piles are reported to have been found in two buildings. Photo 3. shows damage of piles of a three-story RC building (N Building). This damage was found by Kawamura and others twenty years after the earthquake had occurred(Ref. 5). All the piles were completely broken at two elevations: one in the upper portion and the other in the lower portion. Deformation of the piles are illustrated in Fig. 5. The horizontal deformation of the piles were estimated as 1.0 - 1.2m as shown in the Figure. Fig. 6 indicates displacement vectors in the area nearby N Building. Horizontal displacement of ground surface was about 1.5m, which agrees mostly with the horizontal deformation of the piles. In addition, the direction of deformation of the piles were heading southeast, which are almost the same as the illustrated vectors of horizontal displacement.

Photo 4. shows another example of damage occurred to reinforced concrete

pile, which was found during the reconstruction of a hotel building of five stories as shown in Fig. 6 (H Building). The foundation piles were totally broken and permanent displacement in the neighborhood of this Building reached over 5m.

DAMAGE TO UNDERGROUND PIPELINE

Photo 5. indicates a cast-iron gas pipeline pushed out to ground surface. This was found near Niigata Railroad Station, and horizontal permanent ground displacement in this area is shown in Fig. 7. The Figure shows strain of the ground on horizontal plane, which was calculated from the measured permanent ground displacement within the area indicated by the dotted line. A compressive strain with a magnitude of 0.3×10^{-2} was caused in the direction of the pipe axis. It is presumed that the pipe was forced out to ground surface by the compressive ground strain which triggered the buckling of the pipe, coupled with the decresed resistance of the ground in lateral direction, which was induced by liquefaction.

CONCLUSION

What have already been recognized as damage to structures induced by liquefaction are floating of light-weight structures as manholes, subsidence or inclination of buildings, or sliding of soil structures such as embankments. This research disclosed a fact that liquefaction-induced permanent ground displacement is one of the governing factors of damages done to structures. Effect of permanent ground displacement induced by liquefaction is yet to be considered or acknowledged as a guideline for earthquake resistant design. It is, therefore, essential to verify the mechanism of occurrence of permanent ground displacement, and to examinebehaviors of structures against ground displacement for the purpose of establishing newer earthquake-resistant design method, which will count permanent ground displacement into full consideration.

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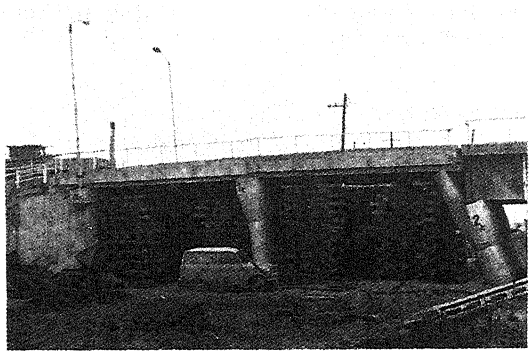

Photo 1.
Damage to Pier of Yachiyo Bridge

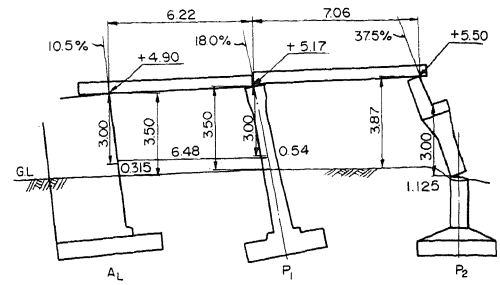

Fig. 1
Damaged Pier of Yachiyo Bidge

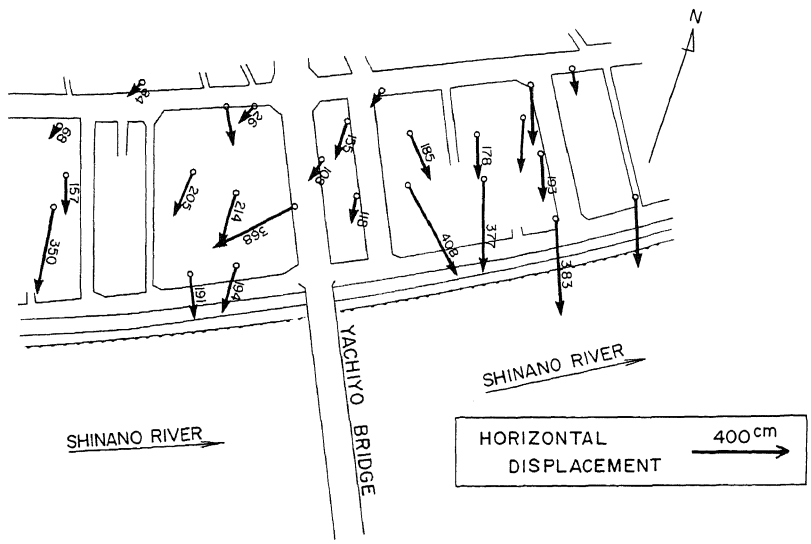

Fig. 2
Permanent Ground Displacement in the Neighborhood of the Damaged Pier

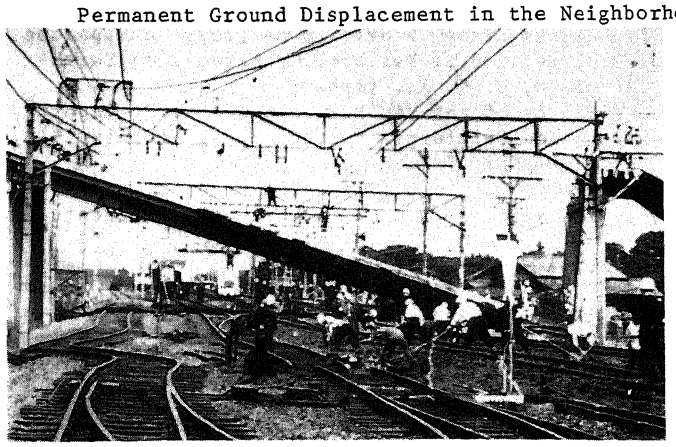

Photo 2.
Collapse of East Over-Railway Bridge

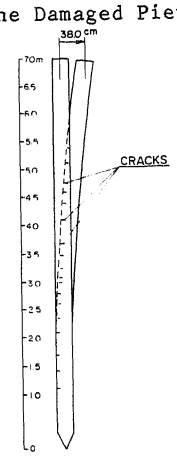

Fig. 3
Deformation of RC Piles

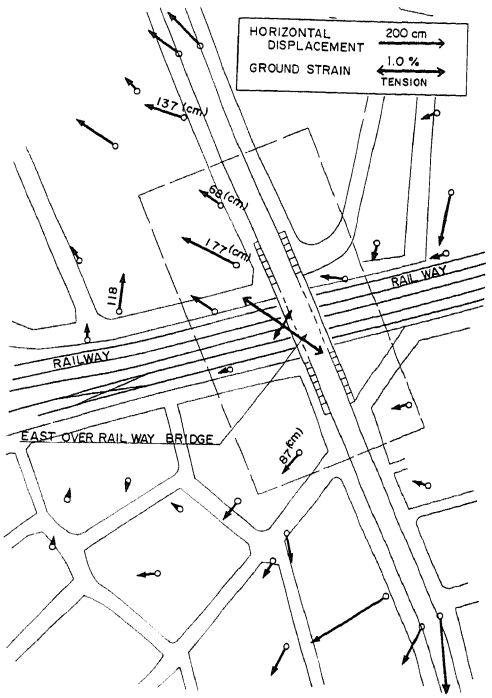

Fig. 4

Permanent Ground Displacement in the Neighborhood of the Collapsed Bridge

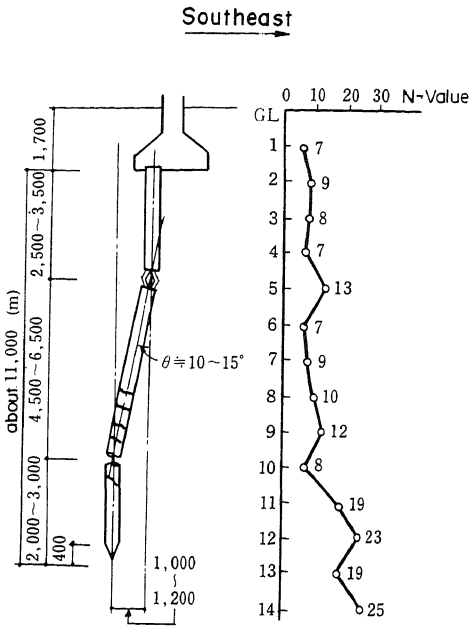

Fig. 5

Deofrmation of Broken Piles (Ref. 5, Kawamura, S.)

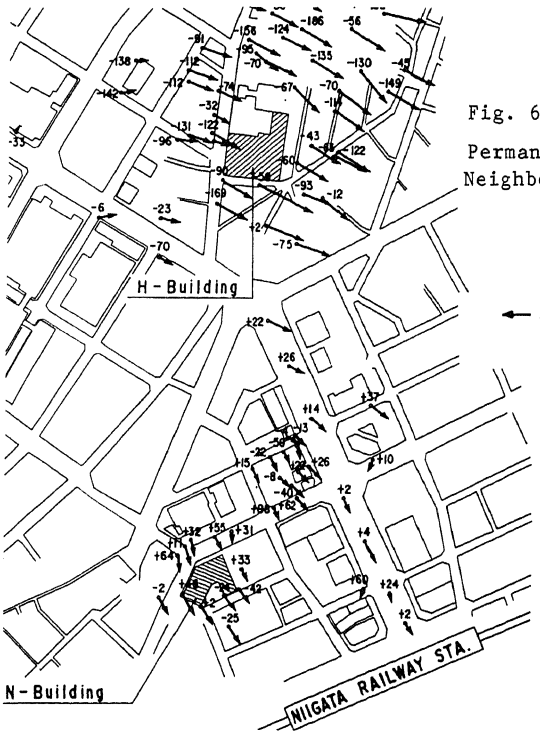

Fig. 6

Permanent Ground Displacement in the Neighborhood of the Building

← 2m Horizontal Displacement
± Vertical Displacement (cm)

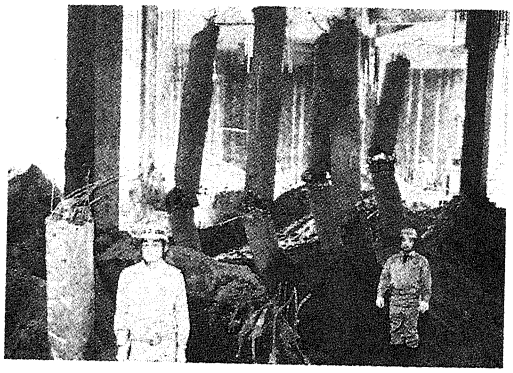

Photo 3.

Broken RC Piles
(ref. 5, Kawamura, S.)

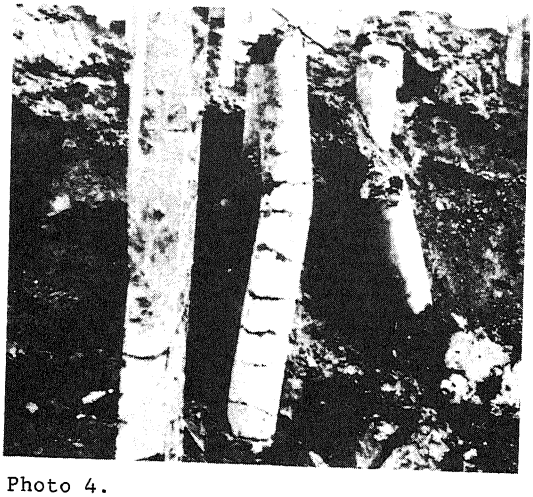

Photo 4.

Broken RC Piles (H Bldg.)

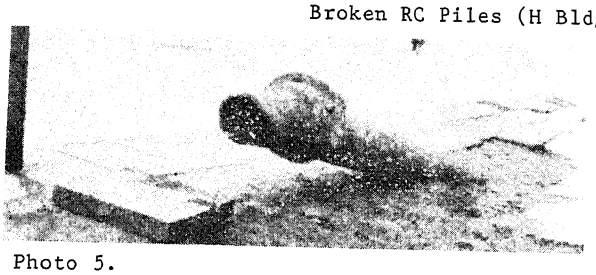

Photo 5.

Pushed-out Buried Gas Pipe

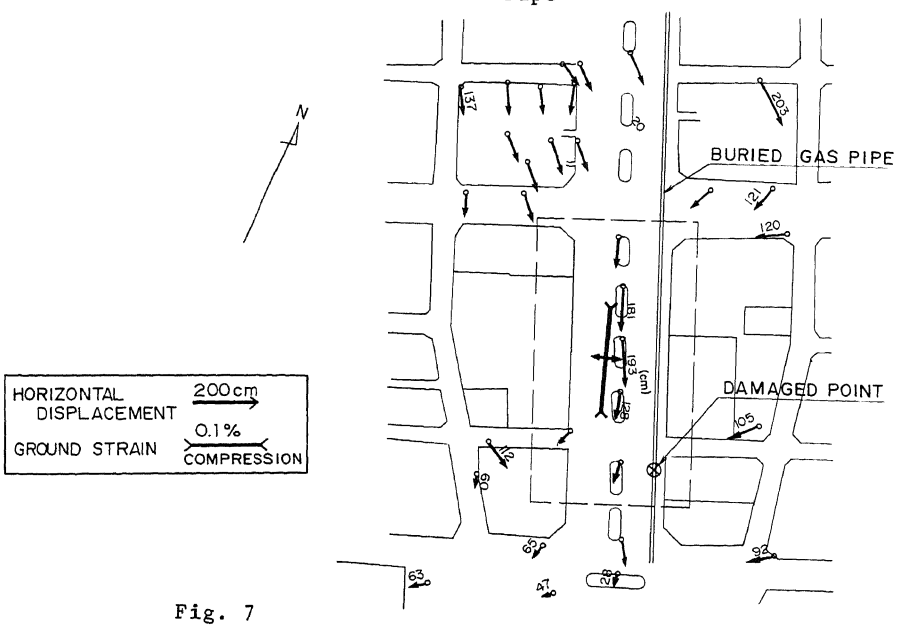

Fig. 7

Permanent Ground Displacement and Strain
in the Neighborhood of Damaged Gas Pipe