Strain Characteristics of Model Pipe Fixed at One End During Liquefaction

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Strain Characteristics of Model Pipe Fixed at One End During Liquefaction

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This paper deals with vibrating tests using a rubber pipe model in liquefaction process. Pipe strain characteristics during liquefaction are investigated and a procedure for mitigating the damages due to liquefaction is given. In the past earthquakes a number of heavey damages have been caused not only by seismic wave propagation but also by ground failure such as liquefaction, landslide and faults. Liquefaction-induced dynamic behaviour and the failure criteria of the buried pipeline, however, have not been made clear. Therefore, it is important to understand the dynamic response of the buried pipeline and to consider how to prevent those damages.

Experiments were performed using the pipe whose one end was fixed, which was the model of a pipeline connected to a building. They provided fundamental strain characteristics; accumulated residual and vibrating strains concentrated remarkably near the fixed end. In addition, the accumulated residual strains were found to be much larger than the vibrating strains near the fixed end. Furthermore the model ground near the fixed end of the pipe was improved by compaction. Sand compaction reduced the accumulated residual strains, however, it caused the large vibrating strains at the boundary between a loose and a dense sand stratum.

1. Introduction

It is well known that buried pipelines have been frequently damaged by the past earthquakes. These damages were caused not only by seismic wave propagation but also by ground failure such as liquefaction, landslide and faults. Dynamic behaviour and failure criteria of the buried pipeline during liquefaction, however, have not almost been made clear.

The authors already conducted vibrating tests using a rubber pipe model. In those experiments, two ends of model pipe were made free. Experimental results were obtained as follows[1][2];

—The large strains were caused when the excess pore water pressure rose and fell.

—The pipe strains consisted of vibrating strains due to pipe vibrating and accumulated residual strains due to pipe bending. The failure modes induced by them were different from each other.

—The generating factors should contain not only the resonance of the system with exciting force but also traveling of the input waves through the model ground, propagating of the ground strains to the pipe and flexibility of the system.

—On the assumption that the vibrating strains during liquefaction can be obtained as the product of these factors, the vibrating strains generated during liquefaction can be well explained.

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Because the study mentioned above was concerned with the model pipe whose two ends were not fixed, the study did not describe the accumulated residual strains so much. But many damages due to the accumulated residual strains were found in past earthquakes. Therefore, it is necessary to make the accumulated residual strain characteristics clear.

This paper deals with vibrating tests using a model pipe fixed at one end. From these experimental results, the pipe strain characteristics during liquefaction were investigated and how to mitigate the damages induced by liquefaction was discussed.

2. Dynamic Pipe Behaviour in Loose Saturated Sand Stratum

2. 1 Testing procedure

Fig. 1 shows the general view of experimental apparatus. The size of model sand stratum was 500mm in width, 1500mm in length and about 250mm in height. The buried model pipe was a rubber stick with 20mm diameter and 1000mm in length. Its elastic modulus was 810kg/cm^2(79.4MPa) and its weight per unit volume is 1.14g/cm^3(11.2kN/m^3). Fifteen strain gauges were utilized on the model pipe and were waterproofed. They were named gauge number 1, 2, 3, ···, 19, respectively (see Fig. 2). One end of the model pipe was fixed at the rigid arm setting on the sand box. A pore pressure transducer was buried in the depth of the buried pipe to measure excess pore water pressure during liquefaction. This pore pressure transducer was able to measure the

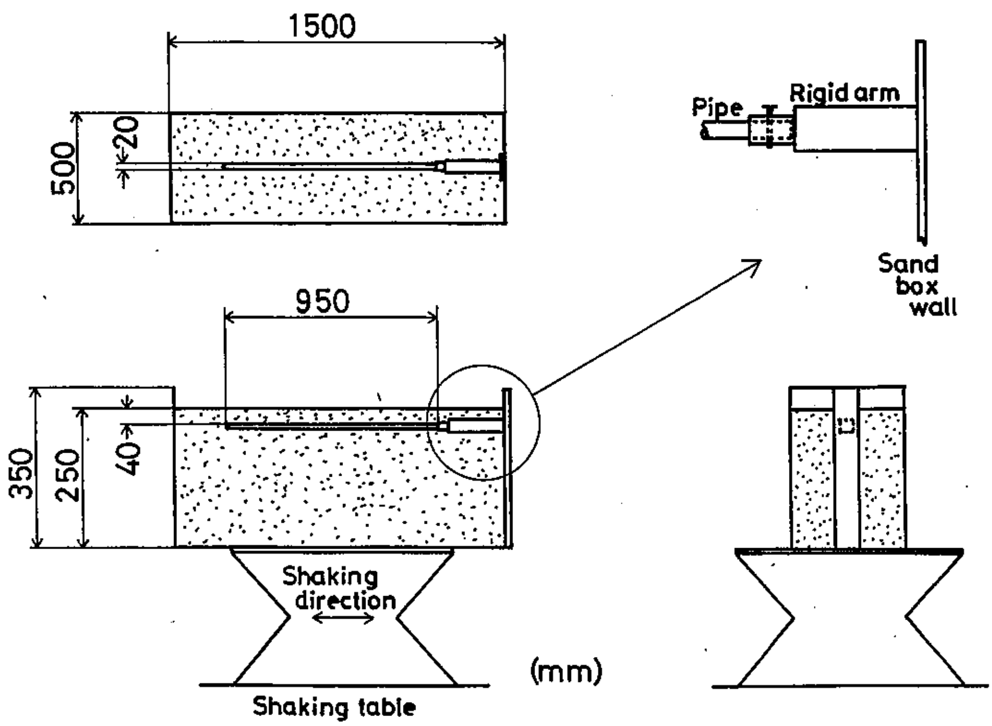

Fig. 1 General view of experimental apparatus.

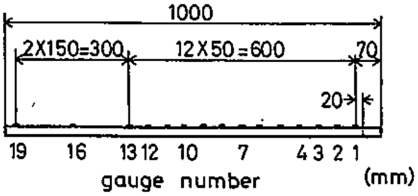

Fig. 2 Model of pipe.

transient pressure with accuracy because this was miniature type pressure transducer using semiconductor and this predominant frequency was very high (8kHz).

The pipe strains and the excess pore water pressure were measured during 30 seconds shaking. Exciting frequency was 5 Hz, exciting acceleration was about 200 gal and depth of the buried pipe was about 40mm.

2. 2 Experimental results and discussions

Fig. 3 shows the pipe strain records at gauge number 1, 4, 7 and 10 and the excess pore water pressure. The pipe strains consisted of accumulated residual and vibrating strains; i. e., an accumulated residual strain is expressed by the transfer distance of the neutral axis in the strain records and a vibrating strain is expressed by the vibrating strain amplitude[1]. Fig. 4 displays the excess pore water pressure, the accumulated residual strains and the vibrating strains. This figure expresses the excess pore water pressure only when the shearing stress is equal to zero in a horizontal plane.

The accumulated residual strains rapidly increased during about 6 seconds shaking and

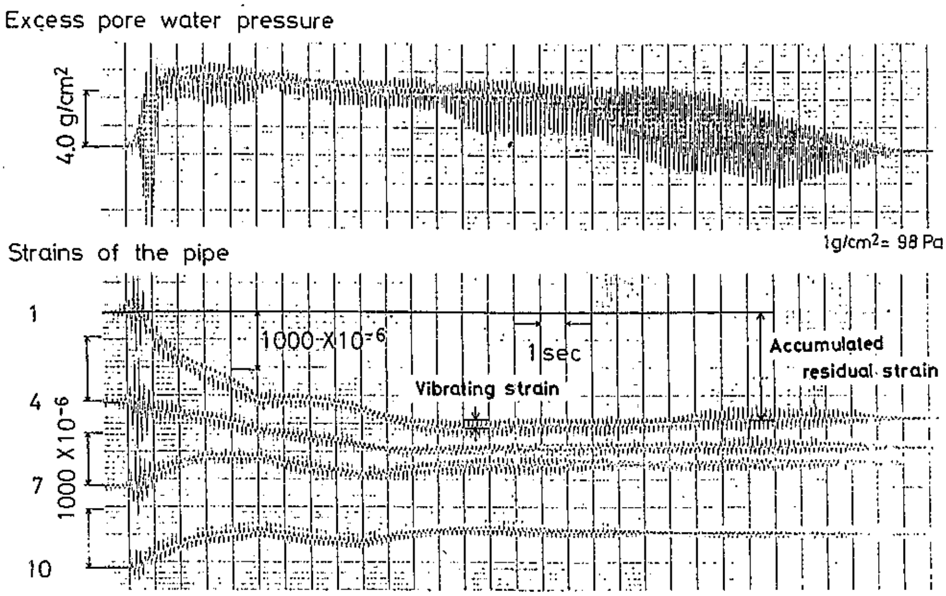

Fig. 3 Records of excess pore water pressure and strains of the pipe.

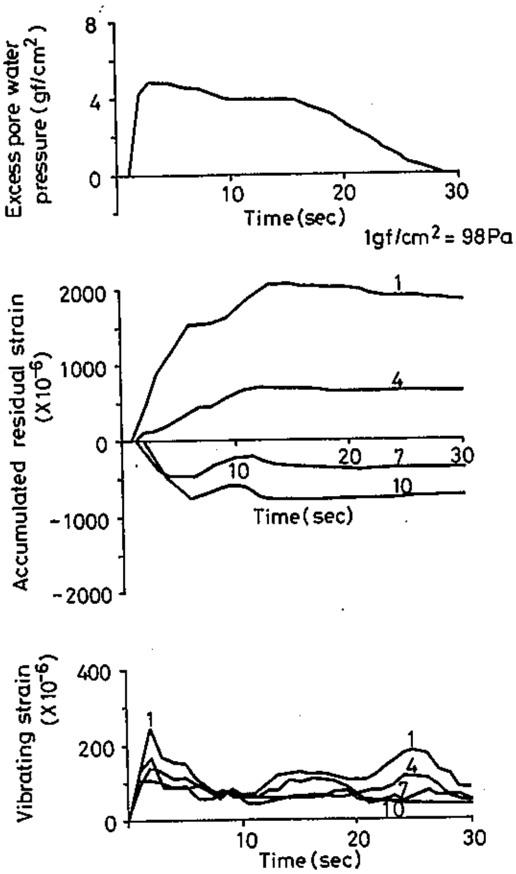

Fig. 4 Time histories of excess pore water pressure, accumulated residual strains and vibrating strains.

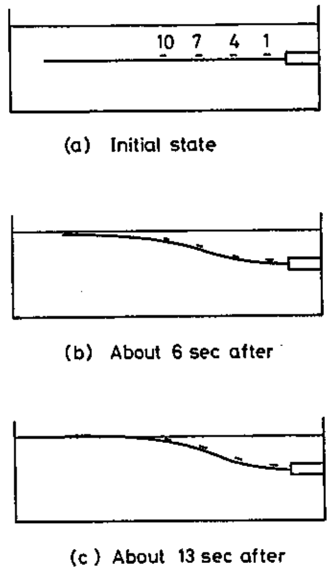

Fig. 5 Deflection of the pipe during liquefaction.

slowly varied during about 7 seconds shaking after then. This strain varying can be explained by Fig. 5. Fig. 5 illustrates the deflection of the pipe during liquefaction. Because vibrating the sand stratum increased the pore water pressure while the effective stress decreased, the model pipe began to bend due to buoyancy. At this time the accumulated residual strains rapidly increased. Free end reached at the ground surface after about 6 seconds shaking (see Fig. 5 (b)) and the pipe strains slowly varied after then. When liquefaction dissipated after about 13 seconds shaking, the pipe deformation retained (see Fig. 5 (c)).

The vibrating strains were large when the model ground was incompletely liquefied and when liquefaction was dissipating. It agreed with the experimental results in Ref. (1). Ref. (1) described the experiments using a model pipe whose two ends were free. And when the model ground was completely liquefied, the vibrating strains were larger than that in Ref. (1), because input wave was transmitted to the pipe from fixed end at this case.

Figs. 6, 7 display the strain distribution. Fig. 6 shows maximum accumulated residual strains. The strain gauges near the fixed end (gauge number 1～5) express compression and others express tension. This agrees with Fig. 5. Gauge number 1 (nearest to the fixed end) shows about

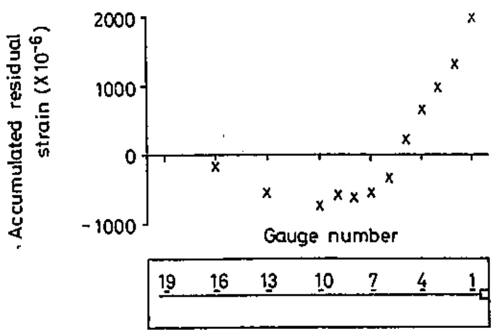

Fig. 6 Distribution of maximum accumulated residual strains.

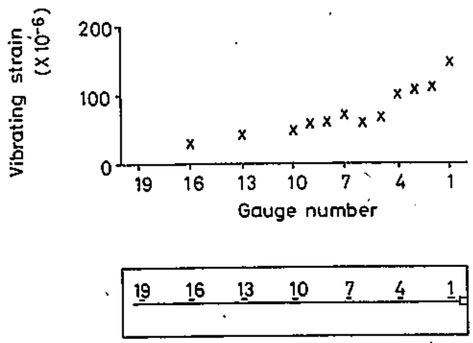

Fig. 7 Distribution of mean vibrating strains.

2000×10^{-6}which is maximum accumulated residual strain. Fig. 7 shows mean vibrating strains. The vibrating strains near the fixed end are large. It is because the input wave does not transmit from model ground but transmits from the fixed end during liquefaction. The maximum vibrating strain in the time records was about 500×10^{-6}at gauge number 1.

As shown above, it is now apparent that the maximum accumulated residual strain is much larger than the maximum vibrating strain. Therefore, the strains caused by pipe bending dominate those due to pipe vibrating near the fixed end.

3. Effects of Ground Compaction on Pipe Strains

3. 1 Testing procedure

One of the ways to mitigate the liquefaction-induced damages is ground improvement by compaction. Therefore, the model ground near the fixed end of the pipe was improved by compaction to mitigate the large accumulated residual strains. Now, strain gauge number 10 coincided with the centre of the ground. Other experimental conditions were the same as the former chapter.

3. 2 Experimental results and discussions

Fig. 8 shows the input acceleration and the strain records at the strain gauges 1, 4, 7 and 10. The strain gauges 1, 4 and 7 were in the densified sand stratum and the strain gauge 10 was at the boundary ground between a densified and a loose sand stratum. Comparing Fig. 8 with Fig. 3 suggested that the ground near the strain gauges 7 and 10 became soft. It was because that in Fig. 3 the large strain was transient but the strains at gauge number 7 and 10 in Fig. 8 was large during some seconds[3].

Fig. 9 is the arrangement of the records. This figure also expresses the excess pore water pressure only when the shearing stress is equal to zero in a horizontal plane. The excess pore water pressure in densified sand stratum increased slightly. And the ground around this pore pressure transducer became soft. It agreed with Fig. 8. The reasons why the excess pore water pressure in densified sand stratum increased are as follows. The reburied sand is not so dense

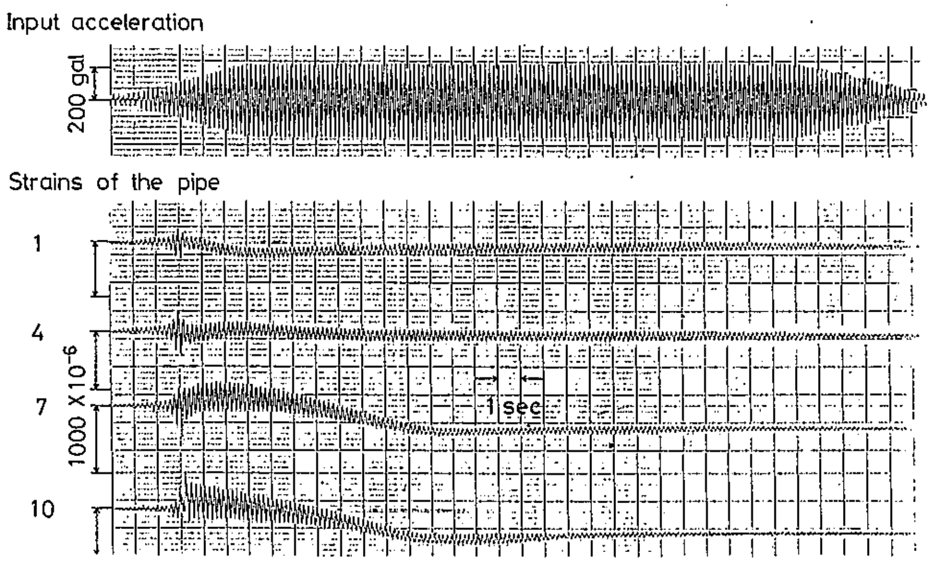

Fig. 8 Records of input acceleration and strains of the pipe.

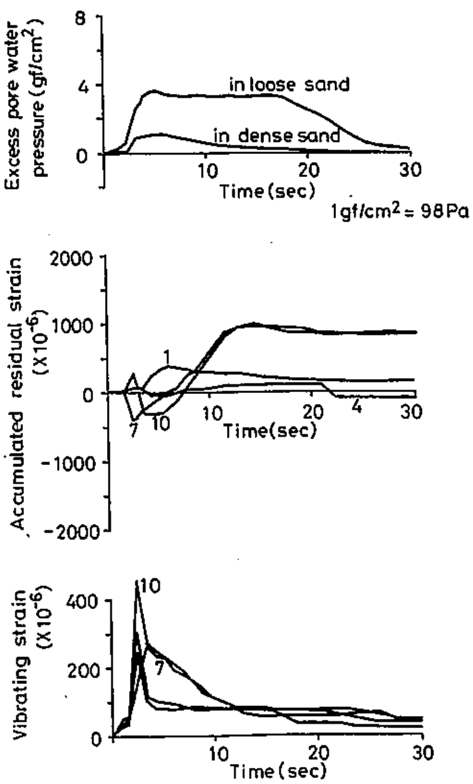

Fig. 9 Time histories of excess pore water pressure, accumurated residual strains and vibrating strains.

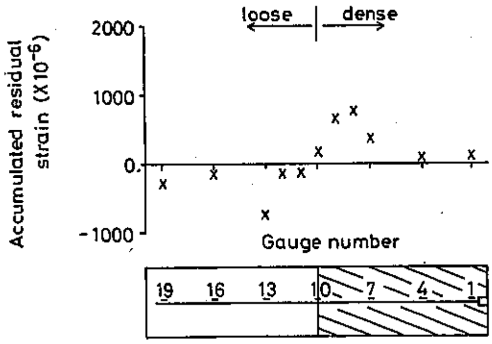

Fig. 10 Distribution of maximum accumulated residual strains.

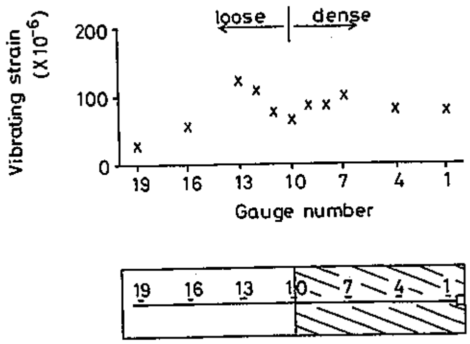

Fig. 11 Distribution of mean vibrating strains.

because model pipe was buried after compacting the ground. The other reason is the water seepage from loose sand stratum during liquefaction. Figs. 10, 11 show the strain distribution. Fig. 10 displays maximum accumulated residual strains. The strain gauge was pasted up at upper part of the pipe, the pipe deformation was shown in Fig. 12. It is considered that the model pipe near the boundary ground bends a little by ground softening around the strain gauges 7~10. Ground softening has an effect on mitigating the accumulated residual strains concentrated at the boundary ground. Maximum strain in Fig. 10 was about 750 $\times 10^{-6}$at the strain gauges 8, 9, or 13. It was much smaller than that in Fig. 6 ; 2000 $\times 10^{-6}$.

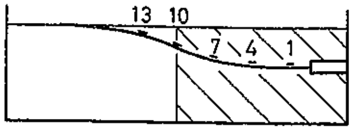

Fig. 12 Deflection of the pipe after liquefaction.

Fig. 11 shows mean vibrating strains. The vibrating strains near the boundary ground were large. The maximum vibrating strain in the time records was about 500 $\times 10^{-6}$at gauge number 7. This was the same value as the former experiments.

As revealed above, compacting the surrounding ground is an effective measure to mitigate the accumulated residual strains concentrated at the fixed end. On the other hand, the dense ground softening causes large vibrating strains during some seconds. Therefore, care should be taken of the dynamic, flexural behaviour of a pipe located between a loose and a densified area.

4. Conclusions

This paper experimentally investigated on strain characteristics of the buried pipe fixed at one end during liquefaction. The summary of the above results will be described below. The pipe strains consisted of the vibrating strains due to vibrating and the accumulated residual strains due to pipe bending. In these experiments the accumulated residual and the vibrating strains concentrated near the fixed end and the accumulated residual strains were much larger than the vibrating strains. Sand compaction of the model ground reduced the accmulated residual strains, however, it caused the large vibrating strains at the boundary ground between a loose and a densified sand stratum. Therefore, care should be taken of the dynamic behaviour of a pipe located between a loose and a densified area.

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