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Shaking table tests on liquefaction mitigation of embedded lifelines by backfilling with recycled materials

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Abstract

The 2011 off the Pacific Coast of Tohoku Earthquake caused significant damage to embedded lifelines in the Tokyo Metropolitan area. In particular, the floating of embedded sewage pipes and manholes was widely observed on recently constructed artificial islands, where liquefaction took place both in loose backfill soils and the surrounding subsoil. This problem should be addressed in earthquake-prone regions where future earthquake risks are a concern. Thus, the aim of the present study is to develop new backfilling methods using recycled or economical materials to mitigate the liquefaction-induced floating of sewage pipes. The examined recycled materials were crushed glass, crushed concrete, a mixture of tire chips and sand, and cement-treated liquefaction ejecta. Several series of shaking model tests were conducted to investigate the performance of the recycled backfill materials. The proposed methods are to be used when old or damaged pipes are replaced by new ones where the excavation of backfill soils is required. The influence of liquefaction in the surrounding subsoil on the performance of improved backfills constructed of recycled materials was also taken into account. The model test results showed that the examined materials are useful for mitigating the liquefaction-induced floating of buried pipes irrespective of the liquefaction potential in the surrounding subsoil. The importance of balancing the unit weight of the backfilling materials and the surrounding subsoil was highlighted for enhanced safety when the surrounding subsoil was liquefiable. In particular, crushed glass showed the most promising performance for preventing pipeline damage caused by liquefaction.

Keywords: Earthquake; Liquefaction; Lifelines; Recycled materials; Model test; Mitigation

1. Introduction

The destruction of lifeline facilities, caused by the 2011 off the Pacific Coast of Tohoku Earthquake, was fatal to the post-earthquake operation of modern cities near Tokyo Bay. In particular, liquefaction-induced damage to sewage pipes was profound and more than one month was required until its temporary service was resumed (Yasuda et al., 2012; Urayasu City, 2012). As dredging was used for reclamation in the concerned region, a vast area of subsoil is prone to seismic liquefaction disasters. The floating of manholes and sewage pipes was widely observed (Fig. 1), which resulted in a change in the inclination of the pipes. Consequently, the flow of sewage water by gravity became difficult. The problem with underground lifelines was recognized to be very important among many geotechnical problems (Towhata et al., 2012).

This paper addresses an improvement in backfilling technology by which liquefaction-induced problems with underground

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Fig. 1. Examples of liquefaction-induced damage in sewage facilities: (left) floating of manhole and (right) clogging of sewage pipes.

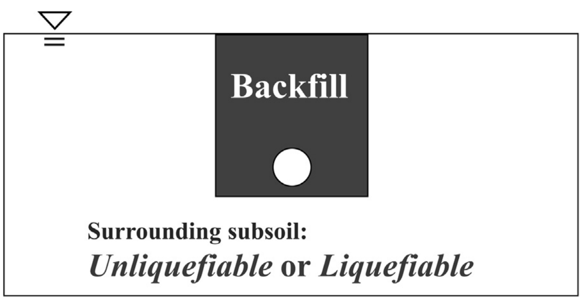

Fig. 2. Situation of surrounding subsoil with and without liquefaction.

sewage pipes can be mitigated. In the model tests, two different situations in the surrounding subsoil were considered: unliquefiable and liquefiable (Fig. 2). The latter situation has not previously been fully studied, but is now recognized as being important after the experiences of the 2011 earthquake. Note that the present paper does not consider the floating of manholes, as their mechanism and mitigation have been studied elsewhere (e.g. Tobita et al., 2012; Technical Committee on Earthquake Resistant Design of Sewage Lifelines, 2008). This paper emphasizes the experimental findings rather than a theoretical or analytical approach to mitigating the liquefaction-induced floating of embedded pipes using recycled waste as backfill materials.

2. Background of conventional methods

The mechanism of the floating of embedded pipes due to liquefaction has been studied (Yasuda et al., 1995; Koseki et al., 1997, 1998). To restore damaged sewage pipes after the 2004 Niigata Chuetsu Earthquake, three mitigation measures were proposed: backfilling with compacted sand, coarse aggregates, and cement-mixed sand (Technical Committee on Earthquake Resistant Design of Sewage Lifelines, 2004). The following sections briefly discuss these measures providing several case histories (Technical Committee on Earthquake Resistant Design of Sewage Lifelines, 2008).

2.1. Backfilling by compacted sand

The potential for liquefaction in a sandy backfill can be reduced by sufficient compaction, as has widely been practiced since the 1970s. It has been recommended that a degree of compaction (Dc) of more than 90% be achieved for sandy backfills. In past earthquakes, such as the 2007 Noto Peninsula Earthquake and the 2007 Niigata Chuetsu-oki Earthquake, liquefaction occurred in sandy backfills that had $Dc < 90\%$; thus, sewage pipes deformed and floated. On the other hand, well-compacted sandy backfills with $Dc \geq 90\%$ demonstrated satisfactory performances during the earthquakes. It should be noted that compaction work is not always easy to perform in the limited space of a backfill trench as it may cause damage to buried pipes.

2.2. Backfilling by coarse and highly permeable aggregates

As excess pore water pressure is dissipated rapidly in highly permeable backfills, it has been recommended that aggregates which have a mean grain size (D_{50}) larger than 10 mm and a 10% – passing grain size (D_{10}) larger than 1 mm be used. In past earthquakes, good performances were reported with aggregates. Note that $Dc \geq 90\%$ is recommended so that a large settlement of the backfill due to traffic loading and earthquakes can be minimized. To prevent the breakage of buried pipes during compaction, reinforced pipes are often used in practice. However, this leads to additional construction costs. Moreover, the purchase of quality-controlled aggregates is neither economical nor ecological.

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