Drain Groups in Liquefiable Soil

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ABSTRACT

One of the major concerns for engineers in seismically active regions is the prevention of damage caused by earthquake-induced soil liquefaction. Vertical drains can aid dissipation of excess pore pressures both during and after earthquakes. Drain systems are designed using standard design charts based around the concept of a unit cell, assuming each drain is surrounded by more drains. It is unclear how predictable drain performance is outside that unit cell concept, for example, drains at the edge of a group. Centrifuge testing is a logical method of performing controlled experiments to establish the efficacy of vertical drains. Centrifuge testing is used to identify the effect of drains dealing with very different catchment areas. The importance of this is further highlighted by the results of a test where the same drains have been modified so that each should behave as a unit cell. It is shown that drains with large catchment areas perform more poorly than unit cells, and also have a knock-on detrimental effect on other drains.

Keywords: Centrifuge, Earthquake, Liquefaction, Physical Modelling, Pore Pressures, Sand, Soil, Vertical Drains

INTRODUCTION

One of the major concerns for engineers in seismically active regions is the prevention of damage caused by earthquake-induced soil liquefaction. Shear waves in loose, saturated soils cause contractile volumetric strains, which may generate positive excess pore pressures and reduce effective stress, in the absence of rapid drainage. Liquefaction countermeasures used are based around either changing soil properties (by densifying, grouting or replacing soil), or controlling soil behaviour (by installations like drains or walls for example). A catalogue of field performance of remediation techniques is analysed by, amongst others, Mitchell et al. (1995) and Hausler and Sitar (2001). The latter authors conclude by stating that “while there is a growing database of observed field performance, it is still limited by the fact that large earthquakes are infrequent and, unfortunately, the quality of the data from many of the sites is marginal”. Centrifuge testing represents a logical method of performing controlled experiments in this problem area to establish the efficacy of a given liquefaction remediation technique. In this paper the performance of drains in relieving excess pore pressures following soil liquefaction will be investigated.

Charts for the selection of drain spacing for vertical drains as liquefaction remediation were first produced by Seed and Booker (1977) although the discussion by Pickering (1978) implies that engineers had already implemented the method. Two assumptions stand out from
their analysis; that vertical dissipation could be ignored, and that the permeability of the drain relative to the soil could be treated as infinite. This latter assumption has been proved excessively unconservative. Real drains had finite permeability, and charts produced by Iai et al. (1988), Matsubara et al. (1988), and Onoue (1988) showed that this had to be several orders of magnitude higher than the sand in which the drains were installed to be a good assumption. In producing these charts the authors necessarily considered vertical seepage, and therefore circumvented the need for the first assumption. Despite these improvements, the case study by Kerwin and Stone (1997) suggests that the original Seed and Booker (1977) charts are still in use.

The charts of Iai et al. (1988) and Matsubara et al. (1988) were experimentally validated using a model "unit cell". That is, it is assumed that each drain is responsible for the immediate surrounding cylindrical soil volume only and that there are adjacent drains that will drain the surrounding soil. It is unclear how predictable drain performance is outside that unit cell concept, for example, if the drain group contains a small number of drains, or for drains at the edge of a group that are being relied on for protection. There is also discussion in the literature (Boulanger et al., 1998; Papadimitrou et al., 2007) about the reliability of design chart methods based on the simplicity of some of the assumptions and their applicability to field situations. These issues provide the motivation for the research presented.

The aim of this research is therefore to identify the effect of drains dealing with different catchment areas. Centrifuge testing is used to collect data, which is then used to explain drain operation and to determine the amount of fluid conducted by individual drains. Two design charts are then evaluated. This leads to recommendations about situations that are appropriate for drain use, and to guide effective planning of drain group developments.

Centrifuge Modelling

The experiments performed as part of this research have been carried out on the geotechnical centrifuge. By increasing apparent self-weight body forces, a reduced scale geotechnical model may be made to replicate the stress-strain behaviour of a larger prototype. Centrifuging causes the required gravity increase to achieve this. A discussion of scaling laws may be found in many sources, e.g. Schofield (1980) or Taylor (1995). Centrifuge tests were carried out at 50-g on the 10m diameter beam centrifuge at the Schofield Centre, Cambridge University. All data in this paper is reported in prototype scale, with the model value in brackets afterwards.

The earthquake shaker used for these tests was the stored angular momentum actuator described by Madabhushi et al. (1998). For tests reported here, shaking was applied for 25 s (0.5 s model) at 1 Hz (50 Hz) with peak amplitude approximately 0.2 g (10 g). To satisfy boundary conditions, an “equivalent shear beam” (ESB) box was used. Consisting of alternating layers of aluminium alloy and hard rubber, the principle is that under earthquake motion the box vibration is similar to that of free-field soil, so little relative force was generated at the boundary (Brennan et al., 2006). The dimensions of the model container are 673 mm × 253 mm × 427 mm deep.

Figure 1 shows the plan and side view of the centrifuge tests described in this paper, part of the wider series reported by Brennan (2004). Tests are instrumented with Druck 7-bar miniature pore pressure transducers and Birchall type A/23 accelerometers, shown for completeness in Figure 1 by dark circles and white rectangles respectively. Further details of the centrifuge tests are presented in Table 1, which lists the relevant dimensions of each model including half the drain centre-centre spacing b, drain radius a and drain depth h. Details of the shaking applied in each case are also given in terms of shaking duration t_d, number of cycles of shak-
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