A Study on the Effects of Mode of Abutment Wall Movements in Integral Abutment Bridges

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Abstract

Integral abutment bridges (IABs) provide an attractive alternative to bridges with expansion joints as they minimise the construction cost and eliminate the costly and traffic retarding maintenance works associated with the expansion joints. However, the settlement of the soil at the bridge approach and the escalated lateral earth pressure acting on the abutment are inherent problems in IABs. These problems are induced by the abutment movements in response to the thermally induced expansion and contraction of the superstructure of the bridge. The aforementioned issues have limited the lengths of IABs in practice. The approach settlement and lateral stress ratcheting effects vary from one IAB to another depending on the factors such as the length of the bridge, the amplitude and number of abutment displacement cycles, in addition to the way in which the abutment moves. In this research, a small wall experimental model has been used to study the effects of different modes of wall movements. The first part of this article investigates the influence of the mode of wall movement on the soil settlement and the lateral earth pressure acting on the wall. In the second part, the effectiveness of expanded polystyrene geofoam (EPS) as a compressible inclusion, to alleviate the approach problems in IABs, has been discussed.

Keywords: Integral Bridges, Abutment, Settlement, Lateral soil pressure.

1. INTRODUCTION

The abutment walls in the Integral Abutment Bridges (IABs) undergo lateral displacements under temperature induced movements of the super structure of the bridge. These movements impose significant impact on the soil-structure interaction between the approach backfill and the abutment, and result in long term problems in bridge approaches (Horvath, 2000). Settlements in the approach soil, in the vicinity of the wall, and the escalation of lateral soil pressures acting on the abutment are the primary issues associated with the abutment movements. Studies found in the literature have revealed that the severity of these effects depends on various factors such as the displacement amplitude, number of the movement cycles, properties of the backfill soil in addition to the mode of the abutment wall movement (Cosgrove and Lehane, 2003; Huntly and Valsangkar, 2013).

According to Ng. et al. (1998), the movement occurring in the abutment in an integral bridge, as a result of temperature changes, is a combination of two different modes, rotation and translation. This means the abutment will translate and rotate at the same time as a result of deck expansion and/or contraction. The rotation and translation components of the movement are usually unequal and the influence of one or the other mode is dependent on several factors including the type and height of the abutment and the properties of the backfill (Huntly and Valsangkar, 2009). The mode of movement has a considerable impact on the magnitude and distribution of the lateral earth pressures acting on the abutment (Huntly and Valsangkar, 2013). It also affects the extent and depth of the potential soil settlement in the approach soil, which consequently influence the relevant design criterion of the run-on slab. Understanding the soil-structure interactions induced by the mode of abutment movement would facilitate better insights to the abutment issues in IABs and to plan their possible remedies.

A series of tests was conducted on a small abutment wall retaining loose sand on one side and subjected to cyclic movements caused by temporal temperature fluctuations. The experimental program involves individual tests for absolute translational movements as well as rotational movements. However, it is worthwhile noting that the physical model discussed in this study is not intended to represent a down-scaled model of a large prototype. Also the stress levels in this model are not expected to replicate those developed in a wall with prototype dimensions. The current physical model, however, is intended to investigate the overall trend of the wall-soil interaction behavior under certain conditions, which is likely independent of the dimensions of the physical model.

1.1. The Experimental Setup

The testing chamber, as shown in Figures 1a and 1b, is 0.7m long, 0.3 height and 0.25m wide with 50mm thick clear acrylic panel forming its face. The wall is represented by a 300mm high, 248mm wide and 13mm thick steel plate placed inside the chamber. The wall is designed to displace in one of two ways depending on the mode of the movement.

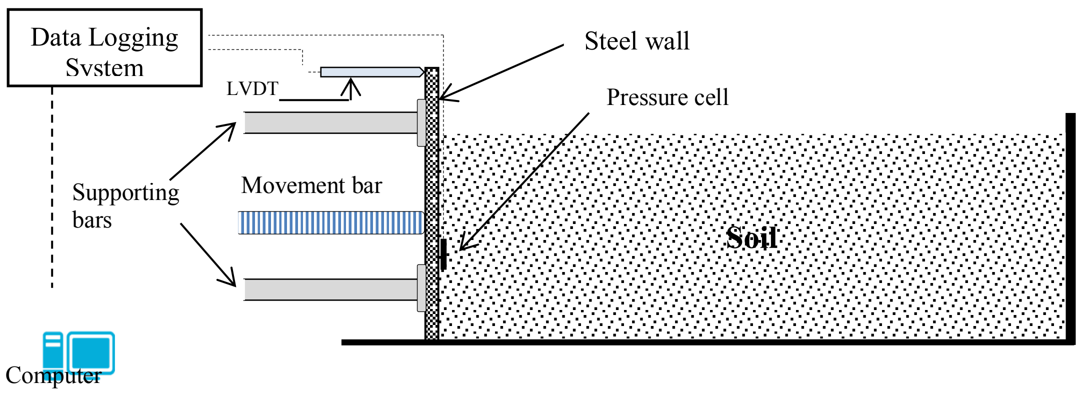

Figure 1a The experimental setup (translational mode)

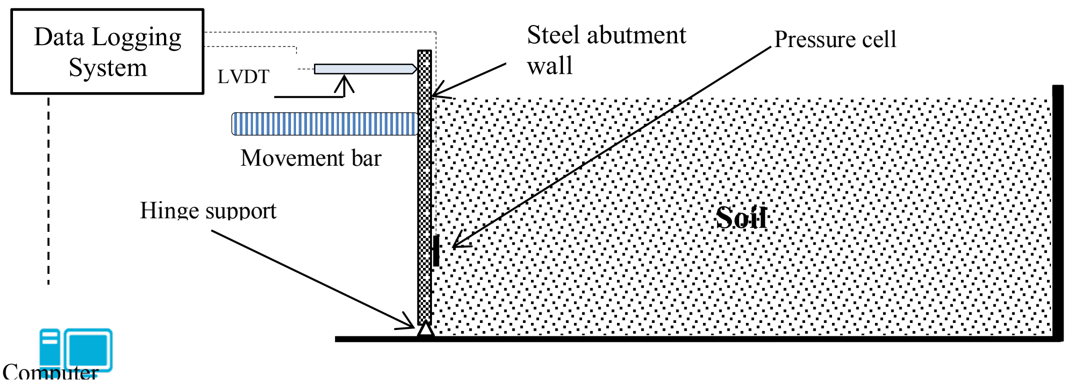

Figure 1a The experimental setup (Rotational mode)

The chamber on one side of the wall was backfilled with dry siliceous sand supplied from a local dealer in Sydney, Australia. A standard sieve analysis was conducted to identify the particle size distribution of the sand. The sieving results showed that the sand is quite uniform with a particle size ranging between 150-300µm. The sand had been placed loosely in the testing chamber without compaction as the objective was to obtain upper-bound values of the settlement for a given number of loading cycles. The height of the soil backfill was 240mm. The lateral soil pressure was measured using a pressure cell, located at 80mm from the bottom of the wall, and readings were logged by a PC using a data logging software. The settlement at the soil surface was measured and recorded manually during the test. Each test consisted of an application of 30 cycles of ±2mm perturbations. The sides of the wall were properly sealed to prevent leaking of sand particles during wall movements.

1.2. The Use of Expanded Polystyrene Geofoam (EPS) inclusion

The testing program also involved the use of an EPS inclusion in order to produce comparative results for the lateral pressures and soil settlements for the cases with and without the presence of EPS inclusion. Such results will provide an actual data on the potential performance of the EPS in alleviating the approach problems in IABs. Accordingly, two types of tests have been carried out as follows,

- Physical modelling of the wall and the retained sand backfill without EPS geofoam. These tests are used as the control cases.
- Physical modelling of the wall and the retained sand backfill with the presence of EPS inclusion at the wall-soil interface.

In consequence, the experimental program involves a total of four tests, depending on the aforementioned factors. For the simplicity of citing the tests, they will be referred by their corresponding symbols, T1, T2, T3 and T4 as illustrated in Figure 2.

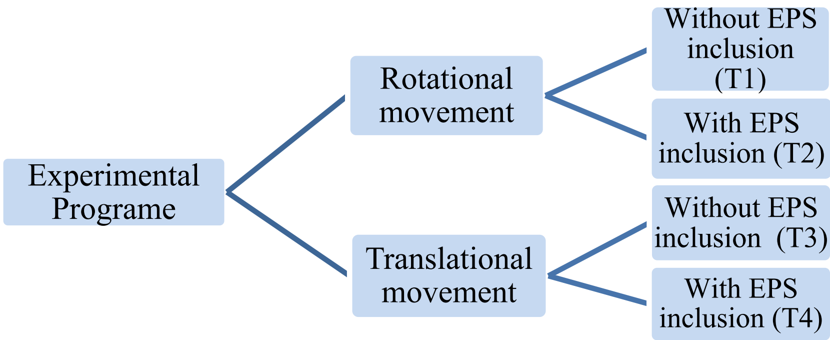

Figure 2 The test program

The EPS geofoam utilized in the test has a density of EPS 20kg/m^3 and has been cut to the required size, using a hot wire from a large block of EPS supplied by a local manufacturer.

2. TEST RESULTS AND DISCUSSION

2.1 Soil without EPS Geofoam Inclusion

The effects of wall movements on the soil without the presence of EPS inclusion has been investigated in two different modes of wall movements, translation and rotation. The results of these tests showed significant variations in terms of the developed lateral pressures. Figure 3 illustrates the progression of the soil pressures recorded in tests T1 and T3 with the number of the wall movement cycles.

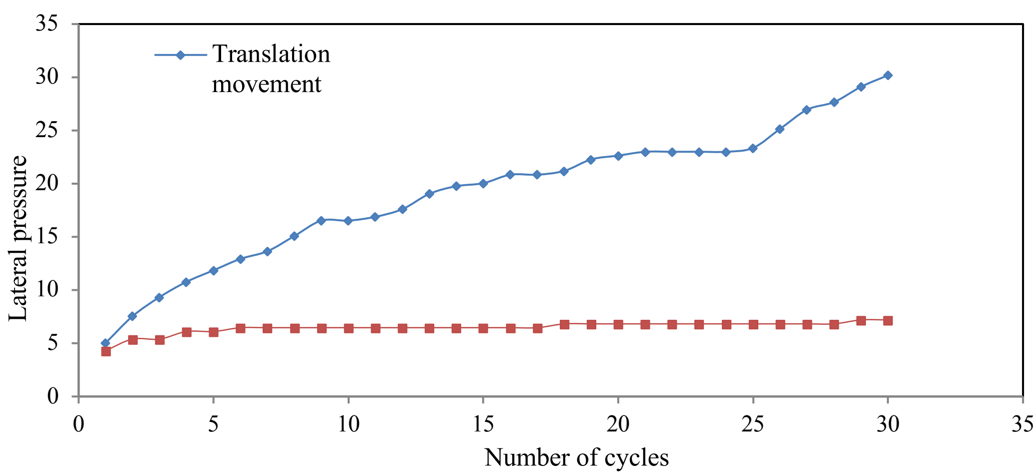

Figure 3 Lateral soil pressures recorded at the passive position for tests T1 (rotational) and T3 (translational)

The maximum soil pressures recorded in test T3 was 30.19kPa, which is approximately four times higher than that in Test T1 (7.2kPa). Also, the results revealed different patterns of lateral pressure (σ_h) escalation between the two tests. The magnitude of σ_h increased during the first five cycles in test T1 then tends to asymptote to reach 7.2kPa after 30 cycles. In test T3, the lateral pressures increased at a considerably higher rate and did not show signs of asymptoting after 30 cycles.

Similar behavior was also observed in the settlement results. According to Figure 4, the maximum settlements measured in test T3 are considerably higher than those of test T1. After 30 cycles of wall movements, the settlement at the soil-wall interface was measured as 74.3mm, which is almost three times higher than the corresponding value of 24.2mm measured in test T1. In test T1, the settlement rate was noticeably decreased after five cycles and the settlement curve tended to level progressively. This behavior was not observed in test T3, where the settlement rate reduction was insignificant compared to that in test T1. The results of test T3 also showed an amount of heave at the soil surface between 150mm and 200mm from the wall. This behavior was not observed in test T1, where the soil did not exhibit any heave during the test.

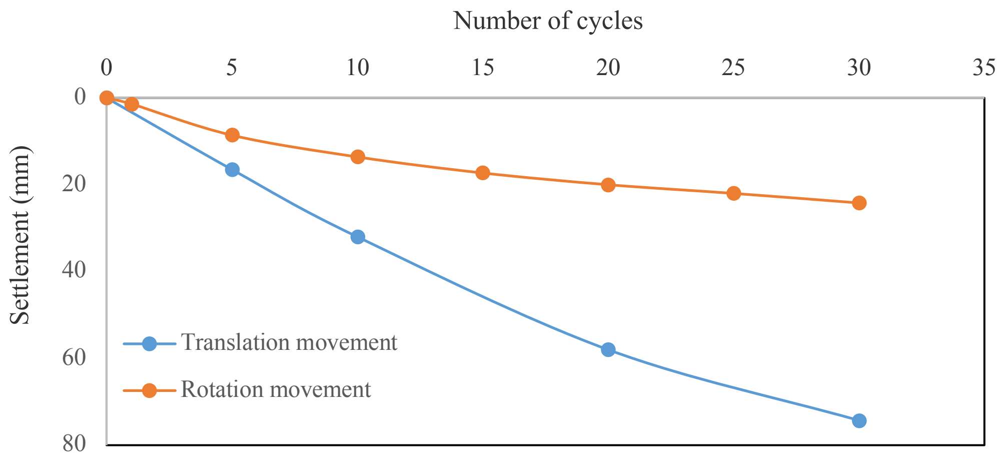

Figure 4 The settlement results of tests T1 (rotational) and T3 (translational)

2.2 Soil with EPS Inclusion

Two tests have been carried out with the presence of an EPS inclusion at the wall-soil interface. In test T2, a rotational movement was applied while in test T4 a translational mode was enforced. In both tests, an EPS block of 80mm thickness and 240mm height was cut, using hot wire, and placed at the interface between the soil and the wall. The results of these two tests, T2 and T4, have been benchmarked against the corresponding results of tests T1 and T3, respectively, to assess the effectiveness of the EPS inclusion in minimizing the settlements and lateral pressures.

Figures 5 and 6 show the lateral soil pressures and settlements recorded in tests T2 and T4 (with EPS inclusion) compared to those in tests T1 and T3 (without EPS inclusion). Evidently, the EPS block has performed well by attenuating both the lateral pressures as well as the soil settlements. The lateral soil pressures were reduced by more than 65% in the translational movement test and by 60% in the rotational movement. Similarly, the settlement results showed a considerable improvement with an EPS inclusion, especially with the translation mode of movement. Maximum settlement in that mode was reduced by approximately 50% while that of the rotational movement was reduced by 40%.

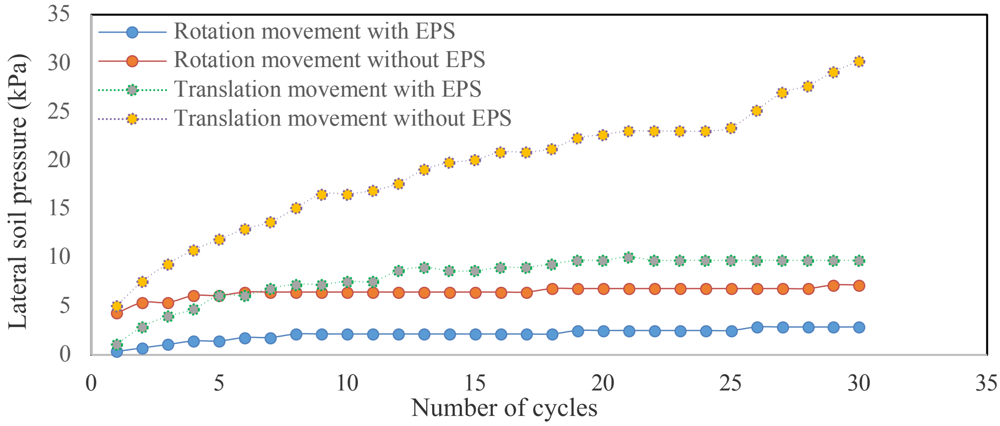

Figure 5 Lateral soil pressures vs. number of cycles

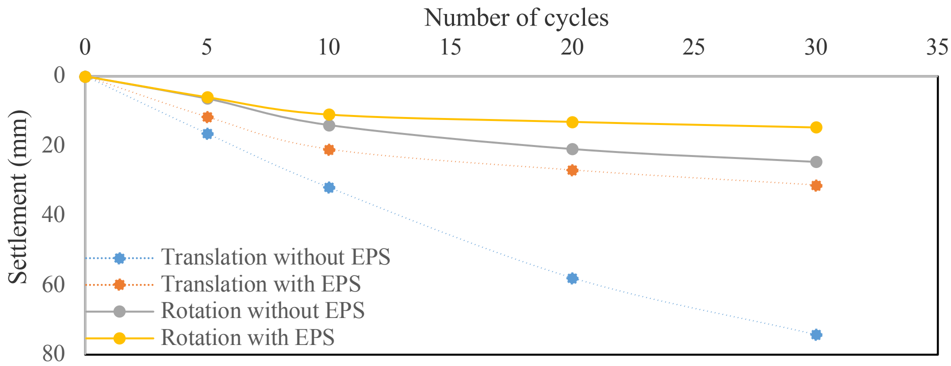

Figure 5 Maximum settlements vs. number of cycles

3. DISCUSSION

3.1 Effects of Mode of Movement

In order to analyse the influence of different wall movements on the retained soil, it is worthwhile first to discuss the soil-wall interaction mechanism under cyclic displacements. Generally, the movement of the wall in both modes (rotational and translational) involves cycles of passive and active movements. During the passive phase, the wall compresses the adjacent soil, which results in a densified passive wedge of soil. When the wall moves back towards the active position, an active soil wedge will slide down and slightly translate towards the gap behind the wall. In the following passive movement, the wall will encounter additional pressure to overcome the resistance, from the "formerly moved" active wedge, until it reached the passive position. This additional pressure, imposed by the active wedge resistance, will result in additional densification in the passive wedge. The repetition of such scenario over successive cycles will lead to,

- Highly densified soil in the passive soil wedge, which eventually dilates and heaves under shearing,
- Escalation in the lateral pressure acting on the wall and
- More settlements in the loosened soil in the active wedge.

Although the aforementioned mechanism and the subsequent effects on the soil are the same irrespective of the mode of movement, the latter yet, imposes significant variations in the measured lateral pressures and soil settlements. Evidently the translational movement has greater effects on the retained soil than the wall rotation as illustrated in Figures 3 and 4. This is basically because the volume of soil affected or displaced during the translational movement is larger (theoretically two times) than that for the rotational movement. Consequently, the volumetric strain in test T3 is greater than that in test T1.

$$\varepsilon_{v3} > \varepsilon_{v1} \quad (1)$$

$$\Delta x_3 . \Delta y_3 . \Delta z_3 > \Delta x_1 . \Delta y_1 . \Delta z_1 \quad (2)$$

As a plane-strain case, the deformation in y direction (Δy) is constant. Accordingly,

$$\Delta x_3 . \Delta z > \Delta x_1 . \Delta z_1 \quad (3)$$

Therefore, the larger volumetric strain in test T3 was reflected as a greater amount of settlement (Δz) and soil densification (Δx). The heave in the soil surface observed in test T3 indicates the increase in the density of the passive wedge of the soil, which normally dilates during shearing. This behaviour was not observed in test T1 because the applied amplitude together with the mode of movement were not sufficient to densify the passive soil wedge.

3.2 Effects of EPS Geofoam

In both modes of wall movements, rotation and translation, the EPS inclusion has functioned effectively in alleviating the lateral pressures and the soil settlements. This could have a significant influence on the initial design requirements and the in-service maintenance works necessary for the bridge approaches. Therefore, in addition to its potential structural and geotechnical advantages, the use of EPS will incur considerable cost savings in the long term.

The function of the highly compressible EPS inclusion is to absorb the wall displacement, without disturbing the adjacent soil, and subsequently dissipating the lateral pressures associated with the movement. However, in the results collected from test T2 and T4, this function seems to be only partially achieved. A degree of lateral pressure, due to wall displacement, is evidently being transferred to the soil and consequently the settlement and lateral earth pressure were attenuated but not substantially vanished. At the soil-EPS interface, based on the general equilibrium in the lateral (normal) direction,

$$\sigma_{EPS} = \sigma_{soil} \quad (4)$$

$$\sigma_{EPS} = \varepsilon_{soil} . E_{soil} \quad (5)$$

$$\varepsilon_{soil} = \left(\frac{\sigma_{EPS}}{E_{soil}}\right) \quad (6)$$

where it is assumed that the initial soil strain $\varepsilon_{soil}^{0} = 0$, and $\Delta(\cdot)$ denotes the stress increase over the initial stress σ^{0}. According to eq. 6, the lateral strain (disturbance) in the retained soil is a function of the transmitted stress $\Delta\sigma_{EPS}$ and the stiffness of soil. The advantage of the EPS inclusion is that the transmitted stress $\Delta\sigma_{EPS}$ is much smaller relative to the case if no inclusion was used. Hence the use of EPS inclusion will significantly reduce the disturbance to the retained soil.

4. CONCLUSION

In this paper, the effects of mode of movement of the abutment of IABs have been studied. The study found that the translation mode is the more severe of the two modes, for the same displacement of the bridge superstructure. EPS geofoam inclusion has been found to be quite effective in ameliorating the effects of lateral pressure increase and approach settlement in IABs.

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