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ABSTRACT

Passive loading tests were conducted on a rigid concrete retaining wall to study the effect of wingwall orientation on lateral earth pressure development. Loads were applied at the top of the wall to produce a rotational wall movement. Six tests were conducted (three of which are described herein), two with the wingwalls oriented parallel (0°) to the main wall, two with the wingwalls oriented at an angle of 45° to the main wall, and two with the wingwalls oriented at an angle of 90° to the main wall. Based on these tests the distribution of passive earth pressure at the centerline of the main wall for different wall displacements and the displacement of the wingwalls for different wall orientations were determined. Results from these tests indicate that passive earth pressures show a triangular distribution, reaching a maximum passive condition in the upper 1/3 portion of the wall after which they decrease to near zero at the base of the wall. This maximum value of earth pressure is dependent on wingwall orientation for the same relative wall movement.

KEYWORDS

Retaining Walls, Abutments, Passive Earth Pressures, Instrumentation

INTRODUCTION

The use of integral bridges and integral bridge abutments has become increasingly popular in the past 10 years. These type of bridges have the advantage of having few or no expansion joints thereby limiting the amount of degradation that occurs in the bridge superstructure. These bridges are not without their drawbacks, however. Passive pressures that may develop behind the abutment can exceed recommended tolerances. In addition, the influence of wingwall geometry is not considered in current design. A study was therefore conducted to investigate the development of passive earth pressure and the influence of wingwall orientation on a prototype scale bridge abutment.

Previous research studies evaluating passive earth pressures behind rigid walls and bridge abutments have been performed using both model scale and full scale walls. Laboratory tests conducted by Narian et al. (1969), Bros (1972), Vogt (1982), and Fang et al. (1994) concentrated on the effect of type of wall movement (i.e., wall rotation or wall translation) on developed passive earth pressures. Full scale studies on production retaining walls have been conducted by Lee and Sarsam (1973), Carder et al. (1977), and Maroney et al. (1994). Earth pressures on actual bridge abutments have been reported by Broms and Ingelson (1971), and Elgaaly et al. (1992).

TEST FACILITY

A reinforced concrete retaining wall measuring 15 feet (4.57 m) in length by 8 feet (2.44 m) in height with a thickness of 18 inches (45.7 cm) was constructed to act as the center section of a typical abutment. This main wall was rigidly attached to a 3 feet (0.91 m) wide spread footing embedded 2 feet (0.61 m) into a 6 feet (1.83 m) deep bed of compacted granular fill. The footing to wall connection was made in such a way as to allow the wall to be removed from the footing and piles to be driven for future tests using a deep foundation system. Two adjacent wingwalls 6 feet (1.83 m) in length by 8 feet (2.44 m) in height by 18 inches (45.7 cm) thick were also constructed. The wingwalls were placed on spread footings similar to that of the main wall. The wingwalls were left unattached to the main abutment wall so that the geometry of the facility could be varied. Test Series 1 was an exception to this, for this Test Series the wingwalls were attached to the main wall with the use of steel bars and tubes. Figure 1 shows a schematic of the test facility along with the various geometries tested.

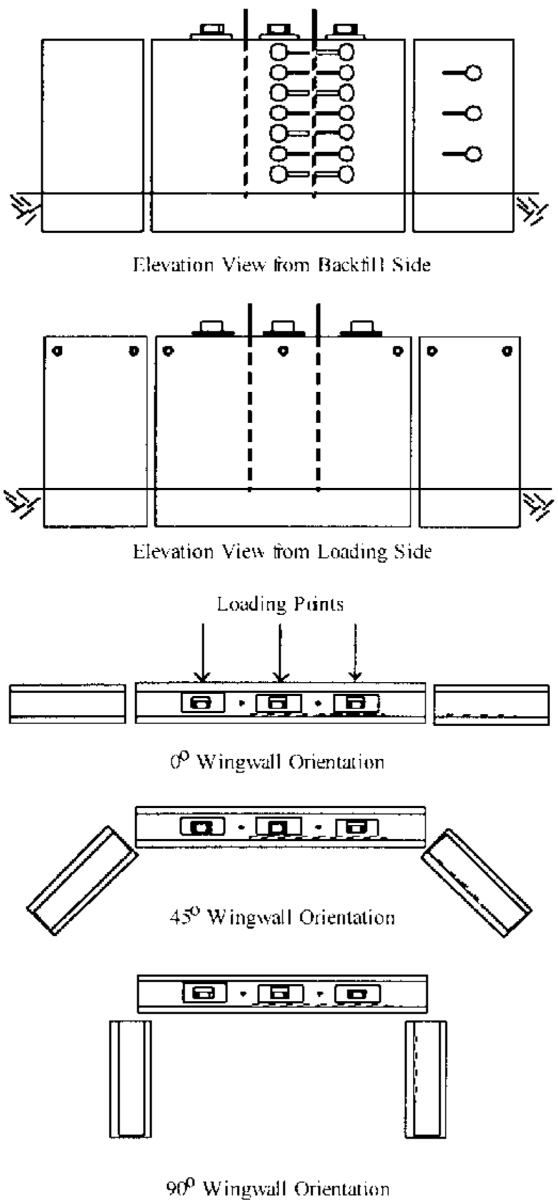

Fig. 1. Schematic of test facility.

A concrete reaction block was also constructed parallel to the main abutment wall to provide sufficient reaction for passive loading tests. A schematic of this block and the main wall is shown in Figure 2. The reaction block measured 21 feet (6.40 m) in length by 15 feet (4.57 m) in height with a width of 4.5 feet (1.37 m). The base of the block was placed 5 feet (1.52 m) below grade. The reaction block was braced on one side with steel H-beams attached to a 21 foot (6.40 m) by 5.5 foot (1.68 m) footing. Attached to the wall side of the reaction block were 3 steel cradles used to support hydraulic cylinders for loading the wall.

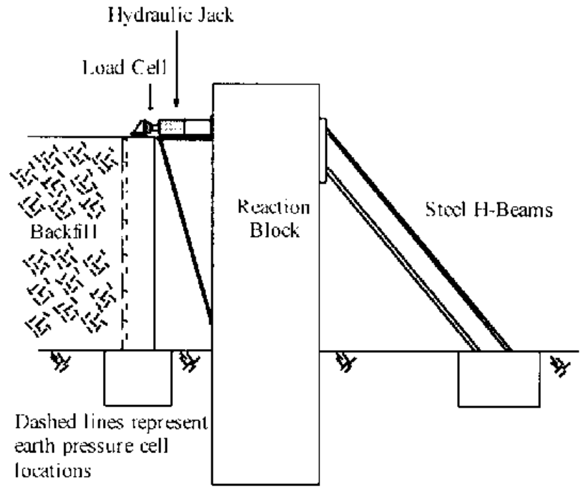

Fig. 2. Schematic of reaction block and main abutment wall.

Seventeen hydraulic earth pressure cells with vibrating wire transducers were placed flush with the wall surface in two vertical lines of seven cells and one vertical line of three cells. Flush mounting of the cells was accomplished through the use templates mounted on the formwork during casting of the walls to form a recess in the wall. Two lines of cells were placed on the main abutment, one at the centerline and the other at the 'quarter-point'. Only three cells were used along the 'quarter-point' in Test Series 1. The third line of pressure cells was placed along the centerline of one of the wingwalls. Wall deflections were monitored by two methods. Inclinometer tubes were cast into the wall at the third points along the length of the main abutment wall and tiltmeters were placed on the loading side of the abutment wall at the two ends and at the center. Two tiltmeters were also used on each wingwall. Electrical resistance strain gaged load cells were placed in each of the three jacking points along the wall to measure applied load.

A well-graded granular backfill conforming to Massachusetts Highway Department specifications was used for this study. The backfill properties are; a mean grain size, D_{50}, of 0.12 inches (3.05 mm); a uniformity coefficient, C_u, of 14; and a curvature coefficient, C_c, of 0.4. Maximum and minimum density tests (ASTM D4253 and D4254, respectively) were also conducted with the results found to be 133 pcf (2.17 Mg/m^3) and 112 pcf (1.86 Mg/m^3), respectively. This backfill was placed in 12 inch (30.5 cm) lifts in a direction perpendicular to the main abutment starting at the wall face. Each lift was compacted with a double-drum vibratory roller. A vibratory plate compactor was used against the wall surface where the roller could not reach. In-place density and moisture content were measured on each lift using a nuclear density gage. Figure 3 presents the results of in-place density tests for Test Series 1, 3, and 6 (0°, 45°, and 90° wingwall orientations, respectively). Backfill was extended back a length of 30 feet (9.14 m) level with the top of the wall after which it was sloped back at approximately 1:2. The width of backfill was kept level with the top of the wall length after which the sides were sloped away at the natural angle of repose.

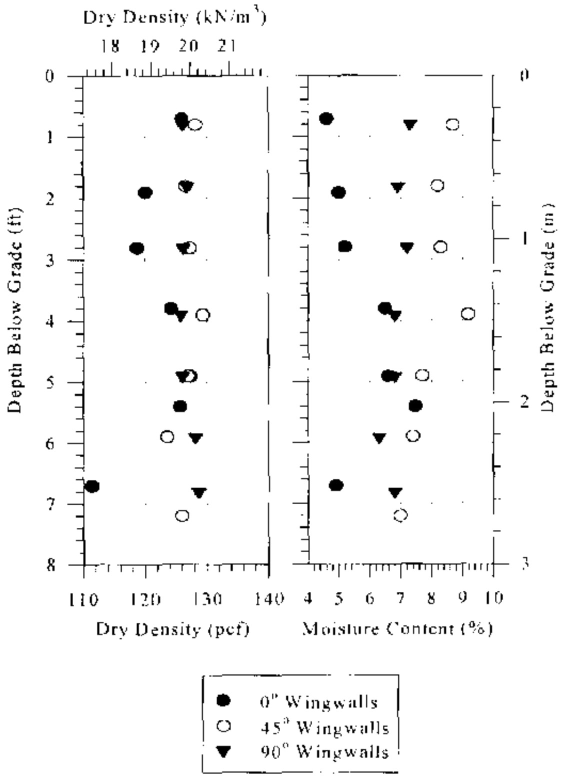

Fig. 3. Dry densities and moisture contents for Test Series 1,3, and 6.

TESTING SEQUENCE

Passive loading tests were grouped together to form individual 'Test Series'. A typical Test Series consisted of data obtained during backfilling, initial passive loading, and one passive reloading of the wall. Two Test Series were performed for each wall configuration (i.e., Test Series 1 and 2 were performed with the wingwalls parallel (0°) to the main abutment, Test Series 3 and 4 were performed with the wingwalls at a 45° orientation to the main abutment, and Test Series 5 and 6 were performed with the wingwalls 90° to the main abutment). For each phase of the Test Series, earth pressures, wall deflections and applied loads were monitored.

The initial loading phase was started within seven days after the completion of backfilling. Following the setup of the hydraulic jacks and pumps, initial readings were taken on all of the instrumentation. Tests were conducted by incrementally displacing the top of the main wall a distance of 0.25 inches (0.64 cm) and were continued until a total wall displacement of 2 inches (5.1 cm) was achieved. Each load increment was held for one hour during which time readings of all instruments were obtained. At the end of the last increment, the wall was unloaded in 0.25 inch (0.64 cm) increments. The unloading portion of the test was performed continuous and was only stopped long enough to read the instruments. Once the load was removed, final readings for the loading phase were taken. This segment of the testing took approximately 12 hours to complete.

The following day the reload phase of the test series was performed. Prior to reloading, 'rebound' of the wall was determined by comparing the inclinometer readings taken that day to the initial and final inclinometer readings from the previous initial loading phase. The rebound, expressed as wall displacement, was used to determine how much to push the wall for the reloading phase of the test (i.e., the wall was only reloaded only as much as the measured rebound). Once this magnitude had been determined the test progressed in the same manner as in the initial loading phase.

RESULTS

Results for Test Series 1 (0° wingwalls), Test Series 3 (45° wingwalls), and Test Series 6 (90° wingwalls) are expressed as earth pressure at the abutment centerline versus height. Comparisons of the results for the three Test Series are shown in Figs. 4 and 5 and in Tables 1 and 2. Figure 4 shows earth pressures at the abutment centerline versus wall height for four different normalized wall displacements. Figure 5 shows earth pressures at the abutment 'quarter-point' versus height for the same normalized displacements. The displacements are normalized by dividing the measured displacement by the height of the wall and expressing the result as a percentage. Also shown on this plot is the theoretical passive pressure line. This line was calculated by determining the average wet density and assuming a friction angle of 45° (γ_{ave} = 134 pcf and $\phi = 45°$ then σ_h, psi $= \sigma_v \times \tan^2(45+\phi/2) = 5.83\sigma_v$, psi). Note that wall friction was ignored in this calculation. Table 1 lists the wingwall displacements for each Test Series and each normalized displacement as in Fig. 4. Table 2 lists the applied loads for each Test Series for the same normalized displacements. For Test Series 6, the load cells were not performing properly and as such the loads are not reported here.

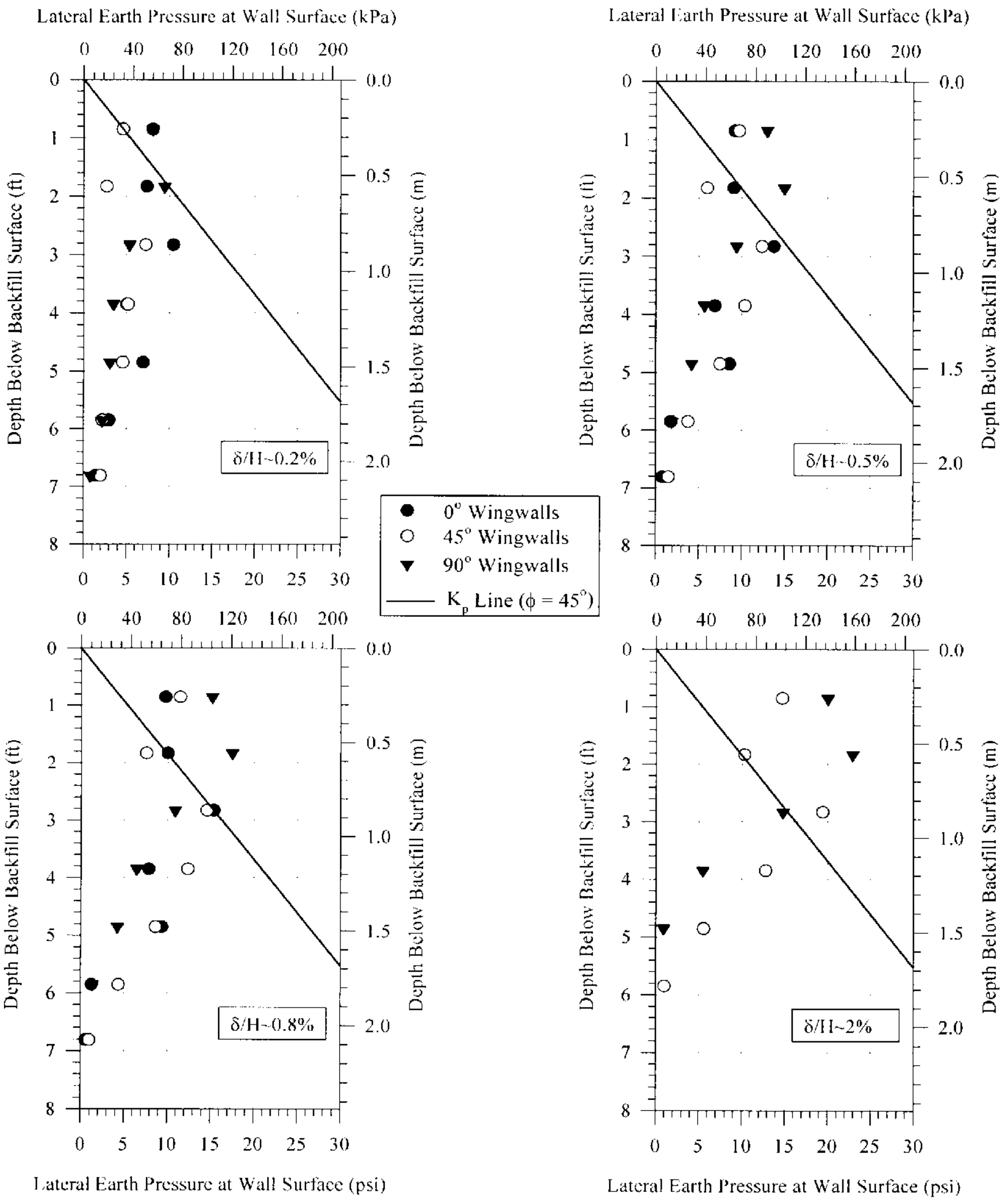

Fig. 4. Comparison of earth pressure versus normalized displacement for Test Series 1, 3, and 6 - Abutment Centerline.

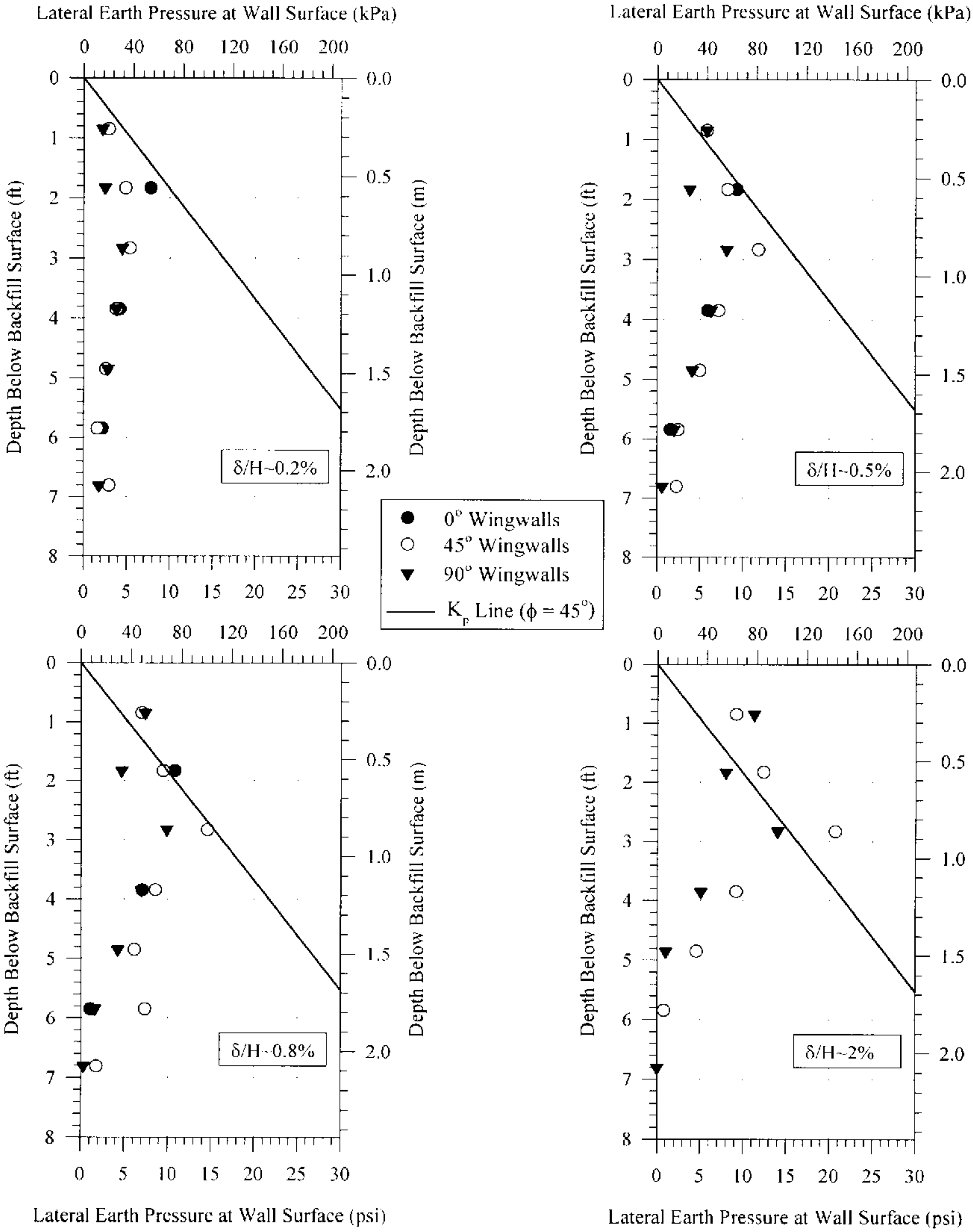

Fig. 5. Comparison of earth pressure versus normalized displacement for Test Series 1, 3, and6 - Abutment 'Quarter-line.'

Table 1. Normalized Wingwall Displacement for Test Series 1, 3, and 6.

Normalized Displacement at Main Wall δ/H (%)	Test Series 1 0° Wingwalls δ/H (%)	Test Series 3 45° Wingwalls δ/H (%)*	Test Series 6 90° Wingwalls δ/H (%)*
0.2	0.07	0.01	0.00
0.5	0.12	0.00	0.00
0.8	0.18	-0.07	-0.22
2.0	---	-0.11	-0.35

* Negative δ/H indicates deflection away from backfill.

Table 2. Applied Loads for Test Series 1, 3, and 6.

Normalized Displacement at Main Wall δ/H (%)	Test Series 1 0° Wingwalls kips (kN)	Test Series 3 45° Wingwalls kips (kN)	Test Series 6 90° Wingwalls kips (kN)
0.2	25.2 (112)	40.0 (178)	---
0.5	30.9 (137)	60.1 (267)	---
0.8	35.1 (156)	68.1 (303)	---
2.0	---	79.3 (353)	---

DISCUSSION OF RESULTS

Earth Pressure Distribution

Results from these tests indicate that passive earth pressures do not increase linearly with depth to the bottom of the wall as is commonly assumed in current design procedures. Measured earth pressure distributions at the center of the main wall show more of a triangular shape, as can be seen in Fig. 4, with a maximum value approximately 1/3 down from the top of the backfill surface. This maximum value approaches passive conditions at normalized displacements as little as 0.5% (based on the assumptions stated above). After this maximum value, earth pressures decrease linearly to zero near the base of the wall. The implications of this suggests that designing for full passive pressure leads to an over conservative abutment design. If seismic loadings are then considered these results suggest that the soil stiffness is actually less than what would have been thought if classic design principal were used.

Influence of Wingwall Orientation

It can be seen from Fig. 4 that there is a difference in earth pressure distribution between wingwall orientations. Although the shape of the earth pressure distribution is very similar for the 3 Test Series, slight differences do exist. Up to the point where the maximum pressure is reached for each Test Series it can be seen that in general Test Series 6 has the highest overall magnitude. It can also be seen that this maximum pressure occurs closer to the backfill surface for this wingwall orientation in comparison to other orientations. After this maximum pressure, however, the distribution of pressure decreases much more dramatically than observed in Test Series 1 and 3. Comparing Test Series 1 and 3 (0° and 45° wingwalls, respectively) shows that the distribution is essentially the same.

Correlating these results with the normalized wingwall displacements measured in each Test Series (see Table 1) shows that the wingwalls in Test Series 6 have moved the greatest amount. Furthermore, the direction of the displacement is seen to be away from the backfill (i.e., in an active direction). Test Series 3 also shows the same direction of wall movement however to a lesser degree. Test Series 1 shows a small amount of wingwall displacement into the backfill (undoubtedly due to the fact that the walls were connected in this series). These results are as expected. One would expect the 90° wingwall orientation would have the greatest degree of soil confinement and therefore a greater force acting on the wingwall itself. This greater confinement causes an increase in pressure on the main wall when external loads are applied. As the degree of confinement is reduced (i.e., as the wingwalls are rotated outward) the measured pressure on the main wall is less for the same external load. Results from the measured load also reinforce this observation (see Table 2). Although the loads for Test Series 6 were not measured because of an instrumentation error it is strongly suspected that they were the greatest.

Measured earth pressures on the main wall are observed to reduce to zero just above the base of the wall. For Test Series 6 the point where the pressure becomes zero is almost 3 feet (0.91 m) above the wall base. This suggests that the point of wall rotation may actually be above the base of the wall. Although there were no explicit measurements of deflection made at the base of the walls, movement of the foundation was evident at higher normalized displacements. This movement was observed to be a 'passive wedge' at the foundation level. Whether or not a slight degree of sliding took place is unclear, however, it is evident from Fig. 3 (and to a slight degree from Fig. 4) that this movement was enough to reduce the earth pressures to near zero values. The implications of this suggest that if shallow foundations are to be used on integral abutments and if the wall deflections are the in the range of those obtained in these tests then sliding failure between the foundation and sub-base material may be a concern. The anticipated deflection of the wall controls the point at which the zero pressure is reached. A solution to this would be to use a less stiff material in the area directly behind the abutment face.

Figure 5 shows the same general trend of earth pressure distribution to hold true for the abutment 'quarter-line.' The magnitude of earth pressure is less which is indicative of three-dimensional wall 'edge' effects. This trend is much less evident at the lower normalized displacements.

CONCLUSIONS

A series of passive loading tests were performed on a rigid prototype concrete abutment. Based on results from these studies three conclusions can be reached. Firstly, passive earth pressure distributions are not as thought in classical design procedure. An approximate model for the earth pressure distributions can be idealized as triangular with a maximum pressure point occurring in the top 1/3 of the wall. Secondly, wingwall orientation to the main wall has a significant influence on the magnitude and distribution of earth pressures. The greater the backfill confinement supplied by the wingwalls (as obtained using different orientations) the greater the pressure distribution behind the main wall for a given external force. This confinement also increases the 'edge' effects (as measured by earth pressures at the main wall 'quarter-line'). Thirdly, as the degree of confinement increases the rate at which the earth pressure decreases increases. This leads to magnitudes of earth pressure that reach zero well above the base of the wall. Whether or not this is associated with a sliding failure is unclear however.

REFERENCES

Broms, B.B and Ingelson, I. [1972]. "Lateral Earth Pressure on a Bridge Abutment", Proc. of the 5th European Conf. on Soil Mech. and Found. Eng., Madrid, Spain, Vol. 1, pp. 117-123.

Bros, B. [1972]. "The Influence of Model Retaining Wall Displacements on Active and Passive Earth Pressure in Sand", Proc. of the 5th European Conf. on Soil Mech. and Found. Eng., Vol. 1, Madrid, Spain, pp. 241-249.

Carder, D.R., Pocock, R.G., and Murray, R.T. [1977]. "Experimental Retaining Wall Facility - Lateral Stress Measurement With Sand Backfill", TRRL Report No. LR 766, Crowthorne, England.

Elgaaly, M., Sandford, T.C. and Colby, C. [1992]. "Testing an Integral Steel Frame Bridge", Transportation Research Record 1371, pp. 75-82.

Fang, Y.S., Chen, T.J. and Wu, B.F. [1994]. "Passive Earth Pressures with Various Wall Movements", Journal of Geotech. Eng., ASCE, Vol. 120, No. 8, pp. 1307-1323.

Lee, H.W. and Sarsam, M.B. [1973]. "Analysis of Integral Abutment Bridges", South Dakota Department of Highways, Pierre, p. 135.

Maroney, B., Jutter, B., Romstad, K., Chai, Y.H., and Vanderbilt, E. [1994]. "Interpretation of Large Scale Bridge Abutment Test Results", Unpublished paper presented at Caltrans Research Conference, June 1994, Sacramento, California.

Narain, J., Saran, S. and Nandakumaran, P. [1969]. "Model Study of Passive Pressure in Sand", Journal of the Soil Mech. and Found. Div., ASCE, Vol. 95, No. SM4, pp. 969-983.

Vogt, N. [1982]. "Large Scale Model Tests with Partial Mobilization of the Passive Earth Pressure and Cyclic Movements of the Wall", IUTAM Conf. on Deformation and Failure of Granular Materials, Delft, Netherlands, pp. 643-652.