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Size Effect Analysis of Full-Scale Floodwall Tests using Numerical Methods

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Size effect analysis of full-scale floodwall tests using numerical methods

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ABSTRACT: A physical modeling and full-scale testing of floodwalls is a challenging task. The challenge comes from simulating the actual loading conditions of a flood during which water covers a vast area. The tests performed even at full-scale, in terms of wall height and water levels behind the wall, would not be a full-scale when loading conditions considered, because only limited amount of water can be used to simulate flooding. The size effect of the flooding conditions was studied using finite element analysis and comparison to test conditions was investigated. Test conditions, modeled using finite element method, were compared to a full-scale field test data performed by others previously. A finite element analysis tool capable of modeling soil-structure interaction, nonlinear soil behavior, and loading sequence, was used for numerical study. The numerical analyses results and the size effect on the behavior of floodwalls and soil-structure interaction during the flooding conditions are discussed.

1 INTRODUCTION

In many areas of geotechnical engineering full-scale tests are used to better understand material performance, structural behavior, and soil-structure interaction. These tests provide valuable information and aid engineers to improve design practices, develop enhanced materials, perform economical designs, and more importantly design and construct safer structures.

The full-scale tests provide extremely valuable data and many geotechnical engineering design procedures were developed based on the results of these tests and therefore modeling of representative field conditions during the tests is very important. Unless an accurate modeling of the actual field conditions were simulated, the data obtained from the tests would be incomplete and could be misleading. Simulation of actual field conditions, however, can be very difficult, if not impossible, in some situations.

The simulation of flood conditions to test floodwall behavior during flooding, where a very wide area is loaded by water, is quite challenging. While the test conditions are limited to relatively much smaller areas, flooding can cover hundreds of square miles. Hence, floodwall behavior due to a large area loading - size effect - should also be considered during the interpretation of test results. This study presents the results of numerical analyses performed to investigate the size effect on the behavior of floodwalls during test and actual flood conditions. Schematics of test and flood conditions are shown in Figure 1.

2 FLOODWALL TESTS

Full-scale tests performed by Davison (1938) were used for analyses in this study. The test walls involved cantilever type steel sheet pile walls with varying wall penetration depths, \( D \), and water levels, \( h_w \), behind the walls. Total of eight tests were performed with penetration depths ranging from 3.05 m to 6.10 m and water levels ranging from 2.90 m to 6.14 m.

The test walls were erected in the form of a cofferdam having plan dimensions of approximately 20
3 NUMERICAL ANALYSES

3.1 Finite element software and constitutive models

Finite element method was used for numerical analysis during this study. Finite element analyses (FEA) were carried out using Plaxis finite element code (Brinkgreve 2002). Plaxis was chosen due to its commercial availability and ease of use.

The finite element modeling comprised of two-dimensional plane strain analyses. Soil deformation and shear strength properties were estimated based on the results of field tests, due to the complete lack of specific data. Subsurface soil conditions were assumed to be composed of one uniform soil layer. Soil layer was modeled using hardening soil model (Schanz et al. 1999). In addition to a hyperbolic stress-strain relationship in loading, the hardening soil model includes a hardening cap and the shear strength is characterized by conventional Mohr-Coulomb parameters.

The numerical analyses were performed using undrained conditions because the loads are applied temporarily over a relatively short period of time during flooding. Flood water was modeled as the hydrostatic pressure and steady state seepage was not considered.

3.2 Material properties

Soil model parameters used in the analyses were as follow: total unit weight, $\gamma = 19.5 \text{kN/m}^3$; undrained shear strength, $s_u = 45 \text{kPa}$; secant elastic modulus at 50% mobilized strength level, $E_{50} = 4000 \text{kPa}$. The steel sheet pile was modeled using elastic plate elements, with axial and bending stiffnesses of $EA = 2.68 \times 10^7 \text{kN/m}$ and $EI = 40,000 \text{kNm}^2/\text{m}$, respectively.

3.3 Floodwall tests analyzed

Three tests, Tests 1, 2, and 4 were selected from the floodwall test series for this study to investigate the size effect. The three tests selected had same type feet wide and 40 feet long. After the tests were performed on the steel sheet pile, a section of piling wall was cut off and capped with concrete to investigate the stability of this type of wall. A drawing showing the plan view of test set-up is given in Figure 2 and summary of the test series performed is given in Table 1.

The soil at the test site was reported as firm silty clay and clayey silt. Water was maintained at the ground surface just outside the cofferdam during the entire period of the tests to assure maximum degree of saturation. Points were established to measure soil movements and there was no indication of excessive stress in the soil under any of the loading conditions applied (Davison 1938). Wall deflection measurements were taken during the tests as the water levels increased behind the wall.

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Sheet pile</th>
<th>Penetration (m)</th>
<th>Maximum head (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MZ-32</td>
<td>3.05</td>
<td>2.90</td>
</tr>
<tr>
<td>2</td>
<td>MZ-32</td>
<td>3.96</td>
<td>3.66</td>
</tr>
<tr>
<td>3</td>
<td>MZ-32</td>
<td>6.10</td>
<td>5.18</td>
</tr>
<tr>
<td>4</td>
<td>MZ-32 bare</td>
<td>6.10</td>
<td>5.88</td>
</tr>
<tr>
<td>5</td>
<td>MZ-38 concrete wall</td>
<td>6.10</td>
<td>5.94</td>
</tr>
<tr>
<td>6</td>
<td>MZ-38 concrete wall</td>
<td>6.10</td>
<td>4.88</td>
</tr>
<tr>
<td>7</td>
<td>MZ-38 concrete wall</td>
<td>6.10</td>
<td>4.88</td>
</tr>
<tr>
<td>8</td>
<td>MZ-38 concrete wall</td>
<td>6.10</td>
<td>6.14</td>
</tr>
</tbody>
</table>

Figure 2. Plan view of the floodwall test set-up (after Davison 1938).
Table 2. General characteristics of flood wall cases analyzed.

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Penetration, $D$ (m)</th>
<th>Wall height, $H$ (m)</th>
<th>Maximum head, $h_w$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.05</td>
<td>3.05</td>
<td>2.90</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
<td>6.10</td>
<td>6.10</td>
<td>5.88</td>
</tr>
</tbody>
</table>

Figure 3. Displacement at the top of wall versus water level behind the wall (Case 1).

Figure 4. Displacement at the top of wall versus water level behind the wall (Case 3).

Figure 5. Typical deformed wall and finite element mesh.

4 RESULTS AND ANALYSIS

4.1 Water height and wall deformations

Figures 3 and 4 show the effect of water height on the displacements at the top of the wall for Cases 1 and 3, respectively. The wall deformations and deformation rates increase as the water height increases in both test and flood conditions. The rate of increase, however, is much faster for the flood conditions at early stages of loading. The final wall displacements, when the water elevations reach to maximum levels, are larger in flood conditions relative to test conditions. The difference is more significant in Case 1, where the wall penetration depth and the water height are the smallest among the cases analyzed. The maximum deformation in test condition is approximately 36% of the deformations calculated for flood conditions for Case 1. This amount is approximately 80% for Case 3.

4.2 Maximum wall deformations

Figure 5 shows typical deformed shape of a floodwall and finite element mesh obtained from analysis of test conditions. The deformations shown are exaggerated to better present the deformed shape.

Figure 6 shows the deformed wall shape obtained from numerical analyses for test and flood conditions, as well as the displacements reported from the field tests, for Case 1, which had minimum wall penetration depth and wall height of 3.05 m. The wall displacements presented in Figure 6 are for the maximum water level, $h_{w,\text{max}} = 2.90$ m, behind the wall. Figure 6
indicates that the flood conditions result in much larger wall movements than the test conditions. The wall displacement at the top of the wall for flood condition was almost three times more than the test condition.

The wall deflections for Case 3 where wall penetration depth and wall height were maximum \((D = H = 6.10 \text{ m})\) are shown in Figure 7. The wall displacements presented are for the maximum water level of 5.88 m behind the wall. Wall deflection behavior obtained from the analyses of Case 3 shows similar behavior of Case 1, i.e. larger wall deformations occur in flood conditions. The change in wall deflection magnitude between the tests and flood conditions, however, is relatively much smaller. The wall displacement at the top of the wall for flood condition was approximately 25% more than the test conditions.

Wall deformations obtained from numerical analyses of test and flood conditions, along with the field test data are presented in Figure 8 for all three cases analyzed. Results show that as the wall height increases the wall deformations increase significantly, although the higher walls have longer wall penetration depths. The walls in all three cases have experienced larger displacements under the flood conditions. The difference in wall deformations between test and flood conditions decreases as the wall penetration depth and the wall height increase. Although the wall displacements under flood conditions are larger, the relative displacements within the wall are the same for both test and flood conditions. This indicates that in addition to the deformations occur in the wall under tests conditions, the wall also experiences lateral translational movement during flood conditions.

4.3 Wall bending moments

The bending moments along the height of the wall at maximum water levels are given in Figures 9 and 10 for
Cases 1 and 3, respectively. Bending moments for both test and flood conditions are shown in these figures. The figures indicate that although the wall displacements are much higher in flood conditions than the test conditions discussed previously, the peak bending moments in the pile, as well as the moments along the pile, are approximately the same for both conditions. This indicates that the flood conditions, compared to test conditions, do not cause any additional stresses in the wall, but cause pure translational displacement of the wall (Figs 6–8). A similar behavior was also observed for Case 2.

5 CONCLUSIONS

Full-scale floodwall tests performed were analyzed to study the size effect of large area loading that occurs during flood conditions. The study showed that the full-scale tests limited to relatively small area loading are not exactly representative of real flood conditions and resulting soil-structure interaction behavior. Because the area exposed to loading is widespread, floodwall and surrounding soil experience much larger deformations during actual flood conditions compared to the test conditions. The difference in displacements between test and flood conditions is larger at lower water levels behind the wall and the difference becomes smaller as the water levels increase.

Although the deformations for real flood conditions are underestimated by tests conditions, the maximum bending moments, as well as the moments along the wall, can be predicted accurately by test conditions. The bending moments are approximately the same for test and flood conditions, because the flood conditions cause wall to have pure translations without causing any additional relative movements along the wall.

Physical modeling in geotechnical engineering, either small or full-scale in the laboratory or in the field, provide very valuable data and form the foundations of many geotechnical engineering analysis and design procedures. For reliable results, however, actual field conditions must be accurately simulated during physical modeling. In situations where simulation of actual field conditions is impossible, as in the full-scale flood conditions, numerical modeling can complement the findings of physical modeling and help better interpret test results.

ACKNOWLEDGMENT

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REFERENCES

