Chapter 7

Conclusions and Recommendations

7.1 Conclusions

7.1.1 Experiments on the Three-tube Configuration

At the onset of the three-tube configuration testing, the intent was to produce two distinct scenarios. The first scenario was to overtop the stacked configuration with the tubes remaining stable. The second scenario was to have the tubes fail in a sliding manner. The two scenarios were to have been achieved by adjusting the drainage layer location under the bottom two tubes.

After performing 13 trials of the three-tube arrangement, the first scenario of overtopping the top tube was not achieved, but the second scenario of having the tubes fail in a sliding manner was achieved. Throughout the trials, it became evident that the strapping system played an integral role in the stability of the three-tube configuration. Without a strapping system that restricted the tubes from rolling away from the increasing headwater levels, the configuration failed in a rolling manner. With the proper strapping system, though, the tubes were relatively stable and experienced minor deformations until a sliding failure occurred.

For the trials where sliding failures occurred, a relationship existed between the critical headwater height and the location of the drainage layer. Figure 7-1 shows a typical cross-section of a trial setup for the three-tube configuration and the drainage layer. If the location of the drainage layer relative to the vertical tangent of tube #2 is referenced as a distance X, then this distance X can be correlated with the critical headwater height, H, at the point where a sliding failure occurred. Figure 7-2 depicts this relationship. Data are given in Table 7-1.

It can be seen in Figure 7-2 that as the distance X decreases, the critical headwater height where a sliding failure occurred tends to increase. A straight line of best fit, represented with a solid line, has been drawn based on the five data points to represent a possible trend line for the data. This relationship only holds true as long as the distance X is greater than approximately 12 inches; otherwise, the risk of a piping failure through the sand foundation material begins to control the failure mode.

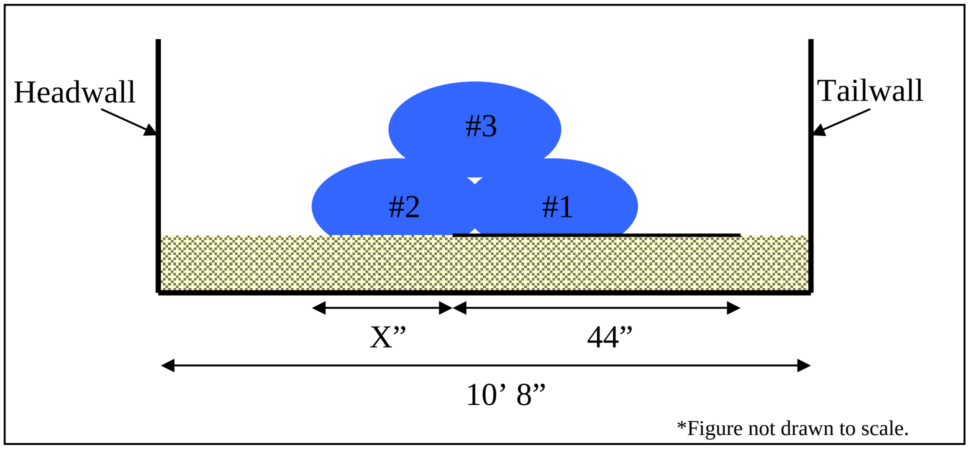

Figure 7-1: Typical Cross Section of Trial Setup

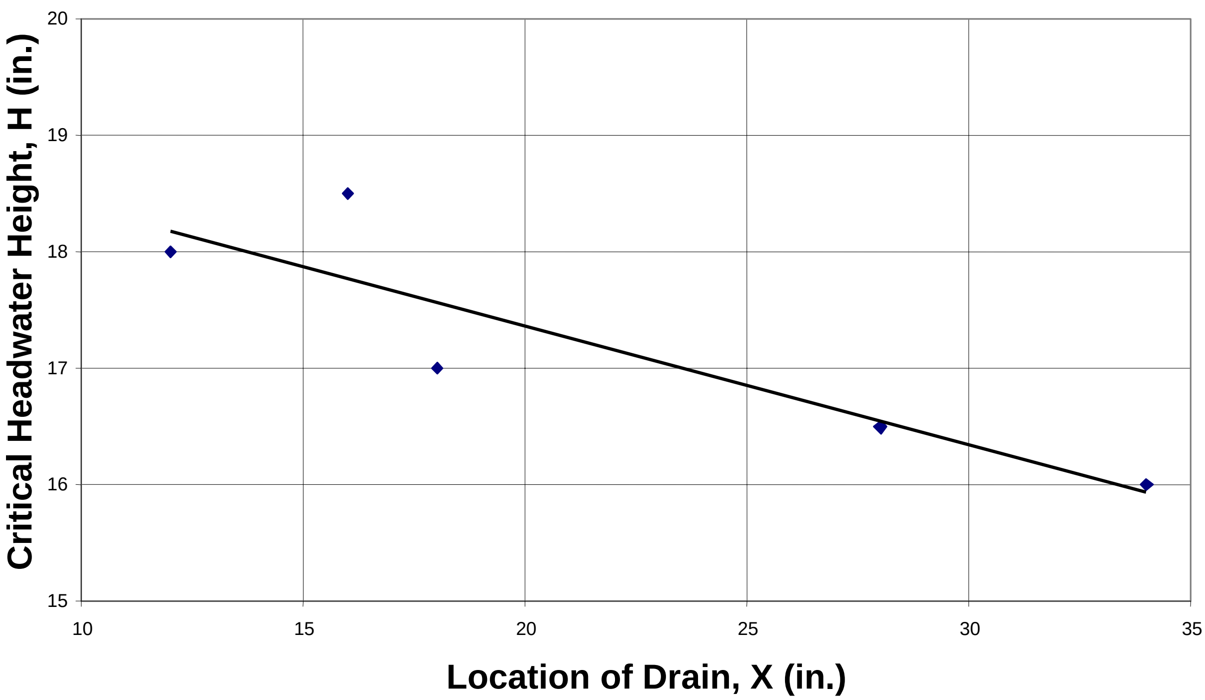

Figure 7-2: Critical Headwater Height vs. Location of Drain

Trial Number	H critical (inches)	Location of Drain - X (inches)
8	18.5	16
10	16	34
11	18	12
12	16.5	28
13	17	18

Table 7-1: Location of Drain and Critical Headwater Height

The highest point on Figure 7-2, which corresponds to Trial 8, does not fit the trend line very well. For Trial 8, deformation measurements were not taken and the headwater elevation was increased continuously until the sliding failure occurred. This trial took approximately three hours to reach failure, while the other trials, due to measurement procedures, took about five hours. This leads to the possibility of time-rate loading effects on the sand foundation material and bentonite paste used to seal the ends of the tubes. The time-rate loading effects could cause an increase in the critical headwater elevation needed to achieve a sliding failure. Likewise, the point corresponding to Trial 13 also does not fit the trend line very well. The point is only about ½-inch below the expected trend line value, and could be associated with simple scatter among the data.

In terms of characterizing the movement of the tubes during the sliding failure trials, the movement was in the direction away from the headwater. This movement was generally minimal until the headwater reached a value of 10 inches. At subsequently higher headwater elevations, the tubes continued to move away from the headwater until a sliding failure abruptly occurred. Overall, the three-tube configuration was a stable system as long as the critical headwater height was not exceeded.

The deformation measurements gathered for the trials quantify the amount and type of movement that the three-tube configuration experienced during loading. With this information, comparisons can be made with analytical and numerical models of the movement of the tubes.

7.1.2 Analysis of Tube with an Apron Attached

After analyzing the tubes with an apron attached, the derivation produced acceptable results, compared with the FLAC analysis and experimental data explained in Chapter 6. Mathematica was able to solve the system of equations and unknowns without any major difficulty.

From the analysis, one important observation to be noted is the change in height of the tube, depending on whether the internal hydrostatic pressure is constant or not. When the internal pressure is constant, the overall height of the tube decreases as the external headwater is increased. However, when the internal pressure is free to change, the height of the tube increases as the external headwater increases, thus allowing resistance of higher external headwater pressures to be achieved.

Another observation involves the change in tension of the tube as the external headwater is increased. When the internal pressure remains constant, the tension in the tube from point E to point G in Figure 5-2 remains almost constant as well. However, when the internal pressure is free to change, the tension in the tube from point E to point G is nearly constant initially, but then begins to increase as the headwater pressure is increased further. Therefore, the material in the case where the internal pressure is free to change (a sealed tube) must be stronger than in the case where the internal pressure is constant.

7.2 Recommendations for Further Research

7.2.1 Experimental Work

Based upon the information gained through this research project, there are areas in which future research could be conducted. First of all, additional research related to the interface strengths of the reinforced PVC and the strapping material could be carried out. The information gained, so far, in Chapter 2, especially concerning the peak shear stress at various normal compressive stresses, was very interesting. It would be beneficial to further investigate the frictional properties of these types of materials.

A second area in which further research could be conducted concerns other configurations of tubes. More than three tubes stacked together in a similar pyramid configuration might withstand even higher headwater elevations. If more than three tubes were stacked into a configuration, though, the tubes would have to be more resistant to leaks. This is due to the fact that the tubes would be subjected to quite large pressure heads and might fail in terms of excessive leakage. If this avenue were pursued, the tubes used in tests would have to be constructed in a different manner so that they could withstand the high-pressure heads.

7.2.2 Analysis

Several assumptions were made and variables neglected during the analysis that can be introduced in further research. The bending stiffness of the tube and the friction between the tube and the foundation can be included in further studies. Determination of the behavior of the tube on a deformable foundation can also be considered. Since the results of this research closely matched the FLAC analysis results, as explained in Chapter 6, which included these additional parameters, it is expected that introducing these new variables will produce results similar to those of this study.

In this analysis, it was assumed that the density of the fluid in the tube was the same as that of the external fluid (water). Determination of the behavior of the tube with different internal fluid densities can be considered in future research.