

## Teaching earth pressure theory using physical models: an example in civil engineering

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### ABSTRACT

*The transition from basic Engineering courses in the first year of Civil Engineering curriculum, into the analysis and design of Civil Engineering structures can be challenging for students. Indeed, most students find it difficult in learning some of the theoretical courses in later years of their engineering studies. In this paper, discussions will be directed to the role of physical models in assisting the teachings of advanced Civil Engineering courses. Examples of physical models will be shown by making use of those developed by the authors in the teaching of Geotechnical Engineering at University of Southern Queensland, Australia.*

**Keywords:** *civil engineering, geotechnical engineering, technical teaching, physical model*

### INTRODUCTION

In a Civil Engineering teaching curriculum, the basic concepts of Engineering are usually introduced in the first year, accompanied with some standardized team based and problem based learning as well as fundamental mathematics and physics. More advanced technical and theoretical courses are then presented by introducing complex boundary value solution techniques and numerical methods to different forms of Civil Engineering structures. The transition from basic engineering courses into the analysis and design of Civil Engineering structures can be challenging for students. Indeed students find it difficult in learning some of the theoretical courses in later years of their engineering studies.

Much of research in engineering education nowadays is centred on assessment and other "surface" areas of more general education research. One area that is particularly important is the enhancement of "technical" teaching in higher level engineering courses that is still an area to explore.

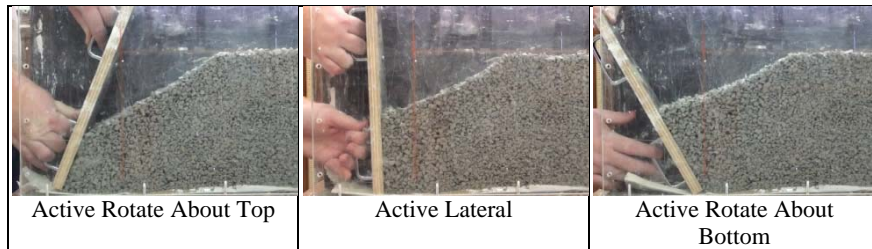
This paper describes the procedures involved in the use of retaining wall models in the teaching of earth pressure theory in Geotechnical Engineering at University of Southern Queensland, Australia. These models are used to demonstrate different failure modes of rigid retaining walls. The resulting active and passive failure modes are compared with textbook solutions. High definition video is also taken during the process of testing so that images can be analysed using PIV (Particle Image Velocimetry). It is expected that this novel approach will enhance student understanding of earth pressure theories.

## **EARTH PRESSURE AND PHYSICAL MODELS**

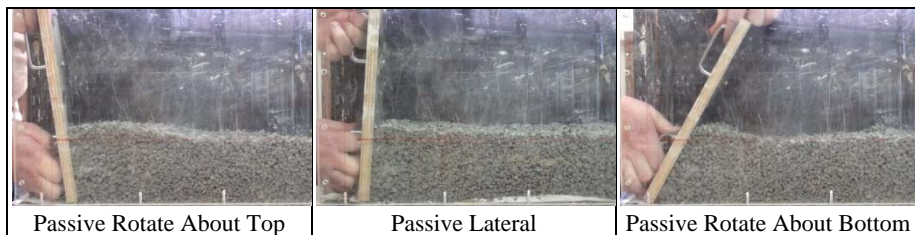
Lateral earth pressure calculation is required for the design of many geotechnical structures such as retaining walls, sheet piles, bridge abutments, anchor blocks, and group pile caps. Factors that affect the magnitudes of earth pressures have been reviewed in Duncan and Mokwa (2001). The most influential parameters for rigid walls are considered to be wall movement, interface friction and adhesion, and wall shape. Traditional analytical approaches, such as those attributed to Rankine and Coulomb and the Log-Spiral method can cope with some, but not all of these parameters.

Both Rankine and Coulombs' can be simulated using the so called physical models. The models used for the purpose of teaching the earth pressure concept have been wooden cases. These cases are a rectangular shape made out of ply wood with a Perspex front screen. The case is approximately 45cm long, 30cm tall and 8cm wide. The side wall has been removed to facilitate the motion of the retaining wall. The Perspex screen is so that it is possible for students to view the effects of the motion of the retaining wall and for the video for the PIV. The retaining wall is made of another piece of plywood, approximately the same size as the side of the tank. This wall has been fitted with 2 handles to give a method of moving the wall and controlling the motion.

The active and passive tests performed are for three different failure modes using two different materials. The three different mechanisms are: 1) lateral movement in the horizontal direction; 2) rotation about the bottom of the wall; and 3) rotation about the top of the wall. Along with these mechanisms are two compound mechanisms utilizing both active and passive pressures. These different mechanisms will show how the wall movement may influence the earth pressure distribution.



**Figure 1: Three different modes of failure for active walls.**

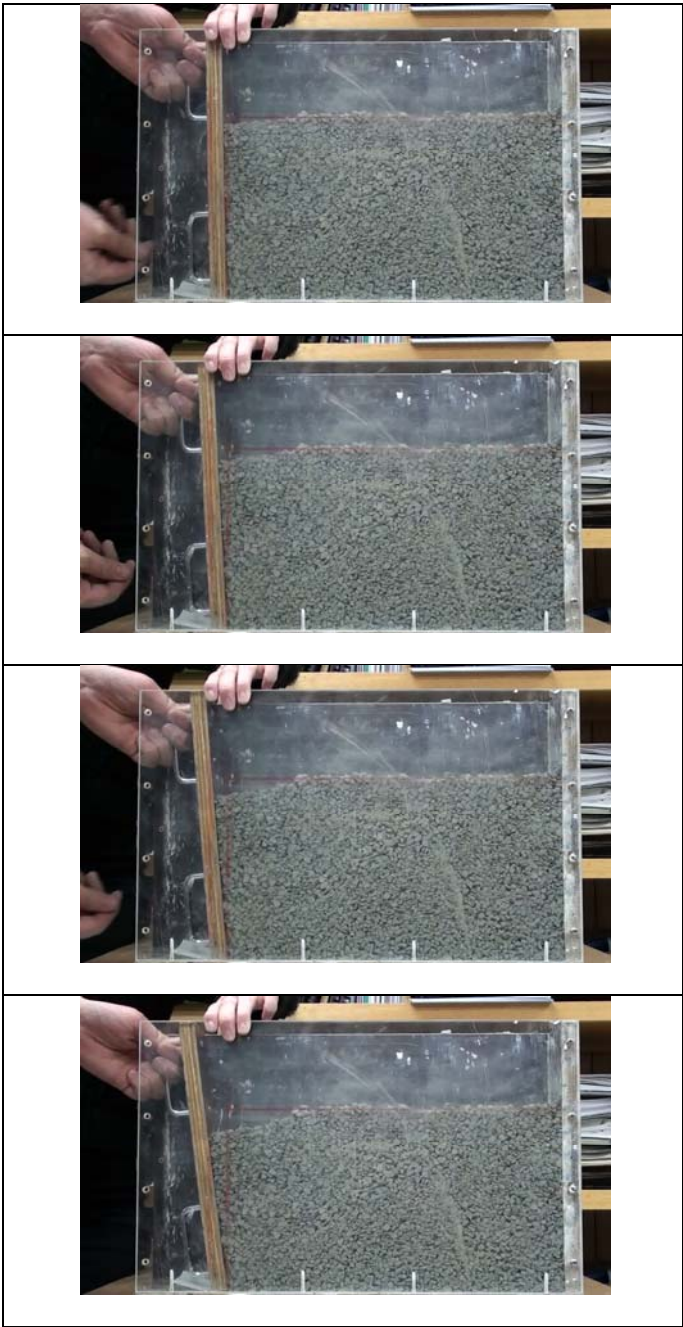


**Figure 2: Three different modes of failure for passive walls.**

These tests will occur utilising both sand and gravel so that the student will appreciate how different materials affect the resulting motion of the sample. The active mechanisms are shown in Figure 1 and the Passive mechanisms are shown in Figure 2 for the gravel case. Figure 3 shows the progressive failure of an active wall subjective to a rotation-about-bottom mechanism.

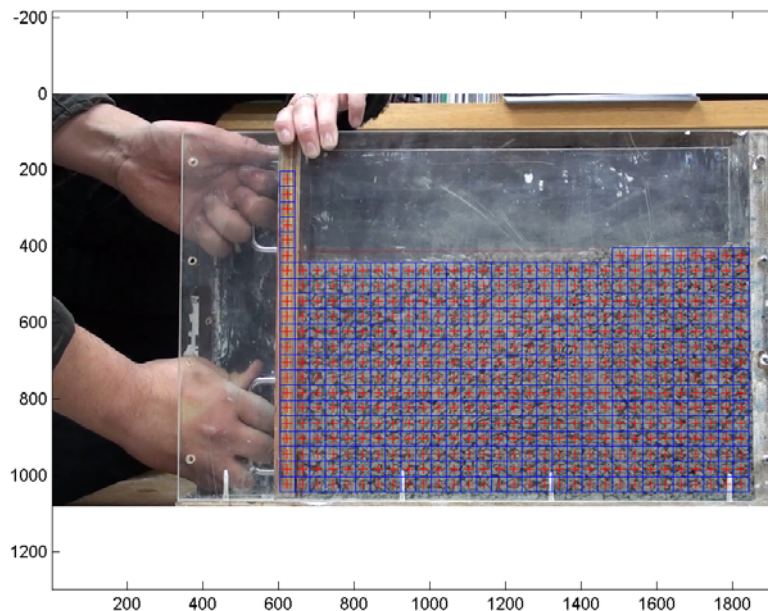
## **PIV (PARTICLE IMAGE VELOCIMETRY) ANALYSIS**

Particle Image Velocimetry (PIV) is a method of tracking the motion of objects in a test. A test is performed and either filmed using a video camera or photographed. From this point a base image is broken down into sections (patches) to provide a base for analysis in the testing (Figure 4). The series of images from the test are then fed to the PIV analysis software with each image being analysed for movement using a previous image as a basis for movement. Being cross-referenced with the previous image this shows the position of the patches throughout the duration of the test. From this point the movement of the patches can be seen as a series of vector plots. These vector plots present the overall displacement field. In this paper GeoPIV (White and Take 2002) is used to perform PIV analyses.



**Figure 3: Progressive failure of an active wall.**

Along with the tanks and material already specified, the equipment used for this has been a High Definition Digital Handycam (Sony HDR-XR150), a tripod to keep the camera stable, a computer and various different programs (Figure 5). In order to keep reflections and wild vectors to a minimum, extra sources of light are eliminated. This means the blinds of the room are shut, the door is shut, and once the test begins the people in the room stay still so excess movement is not reflected off the Perspex affecting the result. Once the test is concluded this video is put onto the computer, where 'Koyote Soft Free HD Converter' is used to convert this video to a high quality avi file. After this step VirtualDub is used to extract every frame of the target zone. It is not necessary to use every frame for cases where movement is low as this will slow analysis significantly, however it will help to reduce the chance of wild vectors.



**Figure 4: Mesh for PIV analysis.**

Having these frames extracted as images of the jpg format enables the PIV analysis through MATLAB using GeoPIV. Figure 4 shows a typical mesh that is made of a patch size of 40 pixels squared. This mesh is then analysed using a leapfrog flag of 1 after which the data is consolidated and exported both as vector fields and vector fields superimposed onto test images.



**Figure 5: The setup for capturing videos for PIV analysis.**

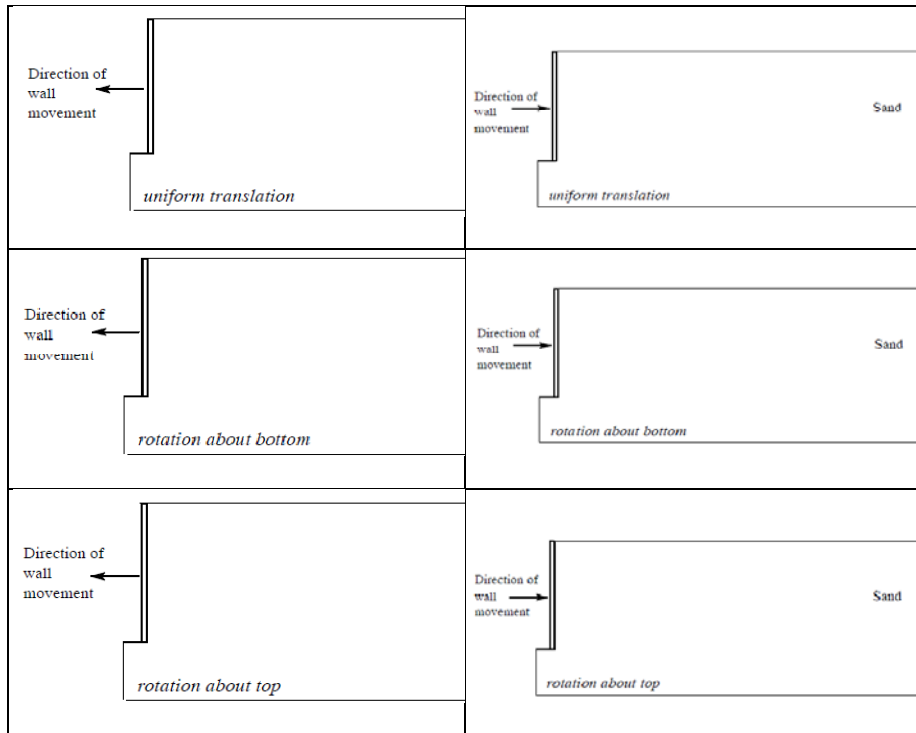
## **TEACHING ACTIVITIES**

The concept of teaching Earth Pressure theory using physical models has been put into practice over 4 weeks, using 4 hours of experimental time and 2 hours per week wherein the students are taught the theory. The first week involves teaching of Active Earth Pressure theory in lecture time. This is then accompanied by a 2 hour practical session revolving around Active Earth Pressure. This 2 hour practical session helps students appreciate how this pressure works. Week 2 involves a lecture about Passive Earth Pressure theory and a 2 hour practical session about Passive Earth Pressure. This will also involve a quick rundown showing the usage of PIV analysis. The lecture of week 3 will be based around the design of anchored and cantilevered retaining walls. The practical session of week 3 will be for testing anchored and cantilevered retaining walls. This section will deal with the practical aspects of this teaching method.

### **Week 1 – Active Pressure**

In the lecture of week 1 the students are provided with sketches of the setup of the cases. The instruction with these diagrams is to sketch the approximate slip surface caused by the motion. These diagrams are provided in Figure 6.





**Figure 6: Sketching the potential failures activity.**

For the demonstrations it is necessary to split the students into groups of 2-3 students. Each group receives a tank with lines drawn on the Perspex to show the start position of the retaining wall and where the material should be filled to. From here the students are encouraged to practice the different modes of failure to start appreciating how it works.

The tanks are marked at a depth of 20cm and a length of approximately 35cm. Once these are filled to the desired level with the wall in place, one student holds the tank in place and another holds onto the wall. For the lateral motion the student holding the wall will pull the wall until the failure condition. The case of rotation about the bottom will involve the student holding the handle at the bottom of the wall in place. This will be used as a pivot for the student to pull the top of the wall. The rotation about the top case will involve the student holding the top handle in place then pulling the bottom handle backwards until failure. The top handle will act as the pivot point for the case. In the active case the failure pressure required will be minimal and therefore the motion required will be fairly minimal.

Once the students are familiar with the method of movement, they will refill the tanks, take them to where the filming will occur and then once the filming begins, move the wall in the appropriate mode of failure for the test. This will then be repeated for the other 2 modes of failure, using a new sample so as to avoid the sample failing along the same slip plane.

### **Week 2 – Passive Pressure**

The Passive Pressure demonstrations will be best suited to groups of 3 students. This is due to the extra pressure required to move the wall. For the purpose of uniformity, the retaining wall will be in the same location as was used for the active pressure. This means that the wall is approximately 35cm from the far end. To combat the extra force, the tanks will only be filled to a depth of 10cm. From here the procedure is much the same as that of the active pressure cases. The students practice the motion utilizing a pushing motion and the same constraints.

This means that the Lateral motion will involve the student pushing with both handles. To keep the case from moving the other 2 students in each group will hold the case stable. This will be required for all three cases. Rotation about the top will require the student to hold the top handle in place and push bottom handle in to the sample. For rotation about the bottom the student will have to hold the bottom handle and push the top handle into the sample.

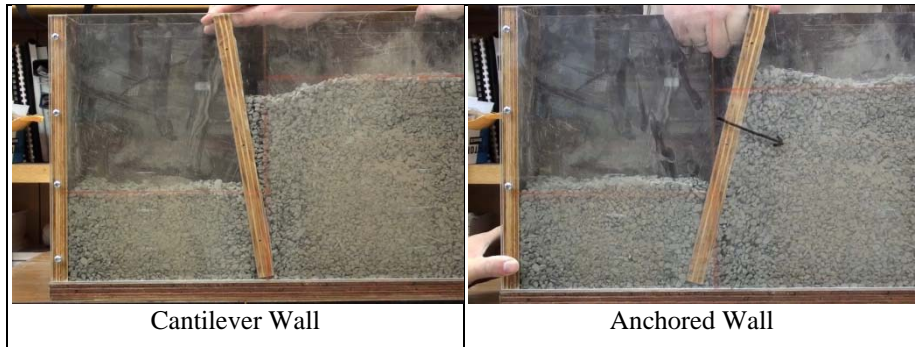
As in the active case, once the students have tried the motion, they will refill the tank to the specified level and place it in the position so it can be filmed for PIV analysis. This will be performed for the 3 different mechanisms for each material, with the material being refreshed after each test to remove the chance of failure along predefined fracture lines.

### **Week 3 – Anchored and Cantilevered Walls**

For week 3 a tank is prepared with a side wall. The retaining wall is much the same as that used for the other 2 cases; however it does not have any handles in it. It will be placed in the centre of the tank with material filled on the left to 10cm depth and on the right to a depth of 20cm. The wall is located in the centre of the tank to attempt to prevent interference from the boundary conditions at each end of the tank.

As there is no definite method of defining active and passive methods of motion in this case the mechanisms have been defined as a Cantilever Wall and an Anchored Wall. The movement of these 2 cases has been shown in Figure 7. As with other cases, the students are provided with the materials and marked tanks with which to practice with. Once students are confident with how the movement will occur the test is again filmed for PIV analysis.





**Figure 7: Images showing failures of cantilever and anchored walls**

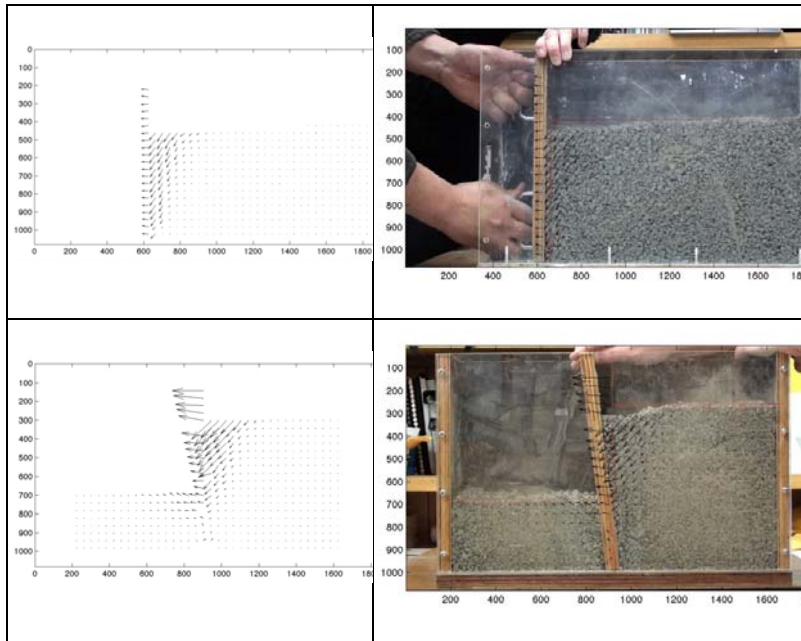
#### **Week 4 – PIV Analysis**

In the practical session of week 4 students are given a demonstration on the workings and the output of PIV. This involves a brief explanation of how PIV works and a chance to ask questions about this technique. At the end of this session the students are provided with the PIV results and plots of the analyses for use in the assessment.

A sample of the results provided to students is shown in Figure 8. The results shown are for the active case with uniform translation and a “real” case demonstrating the failure of a cantilever wall.

### **ASSESSMENT SCHEME**

Previous sections have detailed the procedure involved in the design of a classroom activity. An assessment item is essentially important at the end of any teaching. This assignment would be simply a discussion paper highlighting the differences among different modes of failure. This should include observations of active and passive walls as well as a real wall scenario such as a cantilever style or anchored wall. A comparison between physical modeling and textbook assumptions is equally important. The assignment shall be limited to 3000 words (4-6 pages including analysis images) and is due in two weeks time after the conclusion of practical section. The assignment should be typed and professionally presented. It is expected that students will benefit from such a reflection type of assignment.



**Figure 8: Images showing analysis outputs of PIV**

## CONCLUSION

An interesting and novel teaching activity in Civil Engineering has been described in this paper. The activities involved building physical models and their respective PIV analysis to simulate traditional active and passive earth pressure problems as well as cantilever wall and anchored wall. An assessment item was also designed in a way that students reflect their learning through these activities. This is done through a discussion paper by comparing the different modes of retaining wall failure. This program delivers the earth pressure concept in a non-conventional way and it stimulated student's interests in learning. It is expected that further research can be carried out through student's evaluation of the class at the end of the semester. More funding is required to further invent other physical models for geotechnical teachings.

## ACKNOWLEDGEMENT

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