

CAM-SAT:  
COMPUTER CONTROLLED SATURATION  
FOR GEOTECHNICAL MODELLING

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CUED/D-SOILS/TR348  
(October 2009)

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# CAM-Sat: Computer controlled saturation for geotechnical centrifuge modelling

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November 10, 2009

## Abstract

CAM-Sat is a computer controlled saturation system which has been developed to improve the saturation of geotechnical centrifuge models. This report sets out a procedure for using the system and also highlights some key areas where model disturbance could occur if care is not taken.

## 1 Introduction

The use of centrifuge modelling to study liquefaction problems has become an accepted technique and is practised at many centres around the world. The study of these problems requires that completed sand models are saturated with a pore fluid. The scaling laws presented by Schofield (1981) highlight a discrepancy between the time scaling of consolidation and dynamic events. A commonly used approach to correct for the discrepancy is to use a pore fluid with an elevated viscosity. However, this presents some challenges during the saturation process. In an ideal situation, models could be saturated at high speeds, while still achieving a final saturation ratio of 100%, where saturation ratio,  $S_r$  is the ratio of volume of pore fluid to total pore volume. To a first order approximation, Darcy's law governs the flow of the pore fluid during the saturation process and therefore, if the rate of saturation is increased beyond a critical level, then the model can become unacceptably disturbed. Examples of the model disturbance which can occur include fluidisation of the model, piping and soil plugs being driven upwards in the models. Examples of the latter two types of model disturbance are shown in Figure 1. It is also clear in Figure 1(b) that the saturation front becomes uneven at high rates of flow.

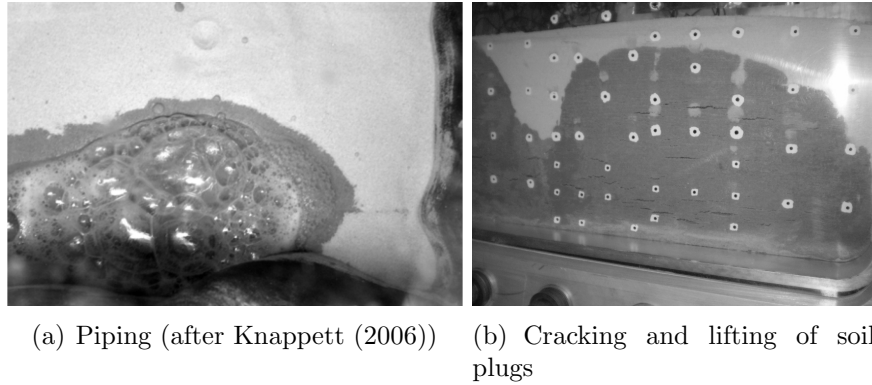


Figure 1: Examples of model disturbance

The CAM-Sat system has been developed to aid the saturation of models with high viscosity pore fluids. The design and application of the system are described fully in Stringer & Madabhushi (2009) and subsequent improvements to the system are discussed in Stringer & Madabhushi (2010). The system aims to improve model quality by continually monitoring the mass flux into the model and maintaining it within user-defined tolerances which are low enough to avoid model disturbance, but not so low that the saturation process takes an unnecessary length of time.

The basic principles of the system can be summarised as:

- Positive pressure difference drives fluid flow from a reservoir into the model.
- The model is placed under vacuum to improve the degree of saturation.
- The rate of saturation is controlled by altering the vacuum applied to the reservoir.

The system is easy to use, but with everything, the first few times can be tricky, and especially at the end of saturation, care needs to be taken that positive pressure does not end up somewhere unexpected! This technical report aims to guide you through the saturation process and help avoid potential problems.

## 2 Preparing for Saturation

The pore fluid should be prepared during the initial stages of preparing a centrifuge model. Stewart *et al.* (1998) describes the use and preparation of viscous solutions of hydroxy-propyl methyl cellulose.

The CAM-Sat system is shown schematically in Figure 2.

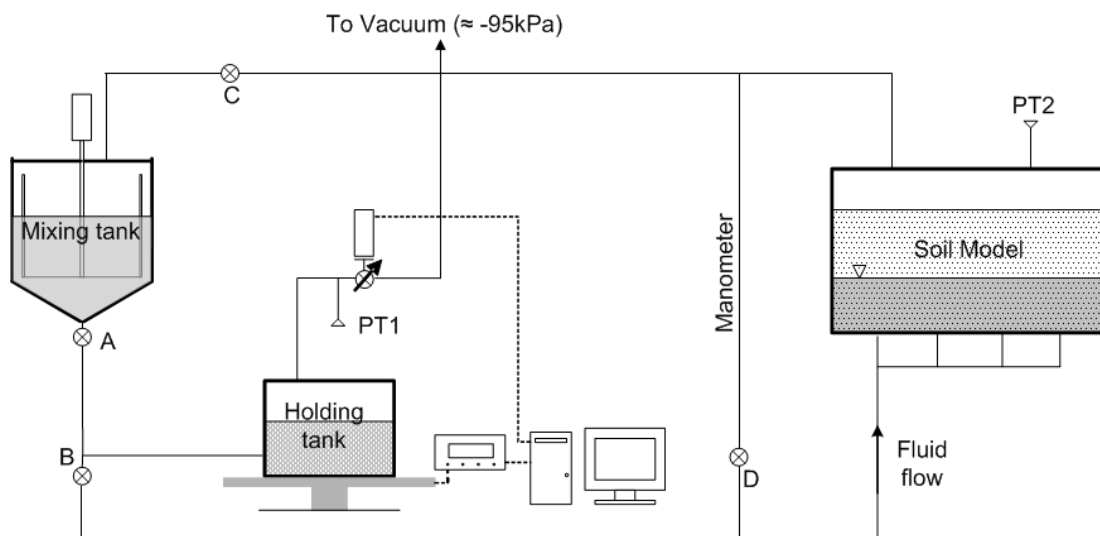


Figure 2: CAM-Sat layout

You need to gather the following items:

- Mobile datalogger (with both outlook and “express click yes” installed if you want emails to be sent with monitoring information. Note: Outlook Express does NOT work)
- CAM-Sat controller box + leads
- RS232 to USB convertor
- Scales electronic display
- External power supply (needs to supply 7.5V DC)
- Junction box with 2 channels set up with a gain of 10 and excitation voltage of 10V.

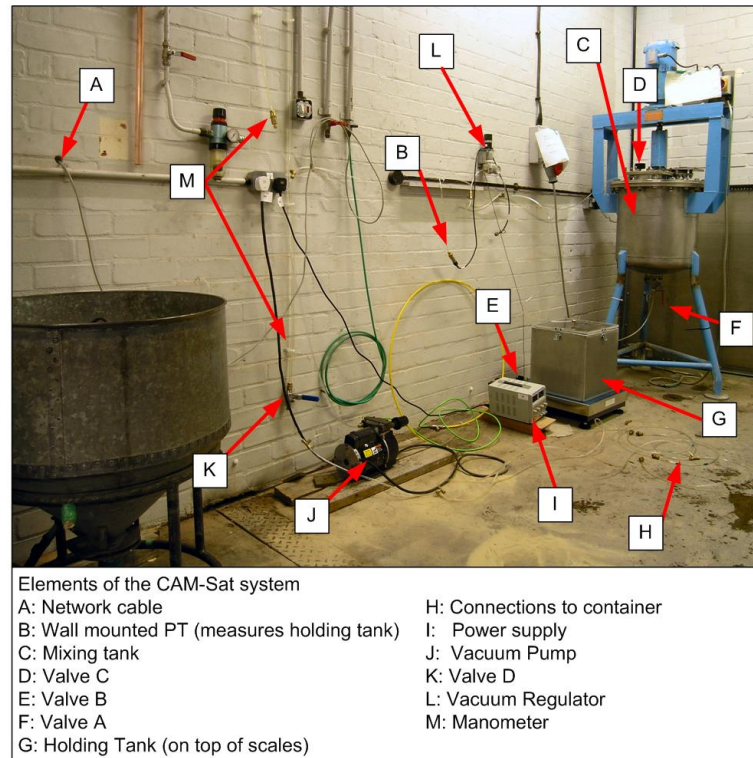


Figure 3: Components of the CAM-Sat System

Start your preparations by ensuring that valves A - D, shown in 2 are closed.

Position the datalogger where you want it, checking that the network cable can reach the computer if you intend receiving monitoring emails.

Connect the digital display to the main body of the scales and check that the power cord is both connected and on at the mains. Connect the USB cable to the scales digital display and one of the computer's USB ports. Remove the holding tank from the scales and turn on the digital display to the scales, allowing it to display a reading before replacing the holding tank back on the scales. The order of attaching the USB cable and turning on the scales' display is important as the computer may otherwise interpret the scales' output signal as a mouse device.

On the CAM-Sat control box, attach the leads to the 12V Power Supply, ensuring that the voltage being delivered is set to 7.5V and that you observe the polarity. (red to red, black to black). Connect the control box and the motor mounted on the vacuum regulator on the wall using the 4-pin cable. Connect the remaining cable to the the D/A output on the Datalogger.

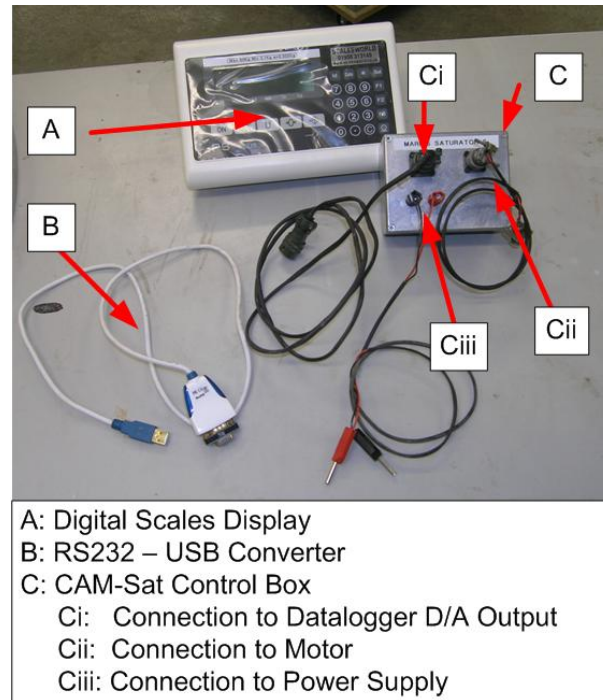


Figure 4: Additional CAM-Sat components

If you have been mixing methyl cellulose in the mixing tank, then firstly stop the stirrers, and let the vacuum off the tank. Once the vacuum is off the tank, open valve A and allow methyl cellulose to drain into the holding tank until you have enough methyl cellulose for the saturation process plus about 2kg. Once you have enough methyl cellulose, close valve A and also valve C - this isolates the mixing tank from the system.

Attach the lid to your model container, checking that the sealing surfaces are clean before you put on the lid.

Move your model to the preparation room and check that the model is roughly level. Check for and remove any sand on the connections at the end of the plastic pipes, or on your model baseplate where they screw into. Attach the 4 plastic pipes to the connections in the base of your model container and also the connection at the top of your model container.

Connect the wall mounted pressure transducer (PT) and the PT on your container (if using) to the junction box and connect the junction box to the data logger.

Check that the fasteners are in place on the holding tank, and turn the vacuum on.

On the datalogger, open DasyLab 9.0 and open the file “c:\DasyLab Programs\Cam-sat Prep”. A screen shot of this program is shown in Figure 4.

Check that the channels are correct on the junction box input module, altering the connections in the worksheet if necessary so that input 0 to the module “Scaling00” is the wall-mounted PT and that of the PT on your container is in

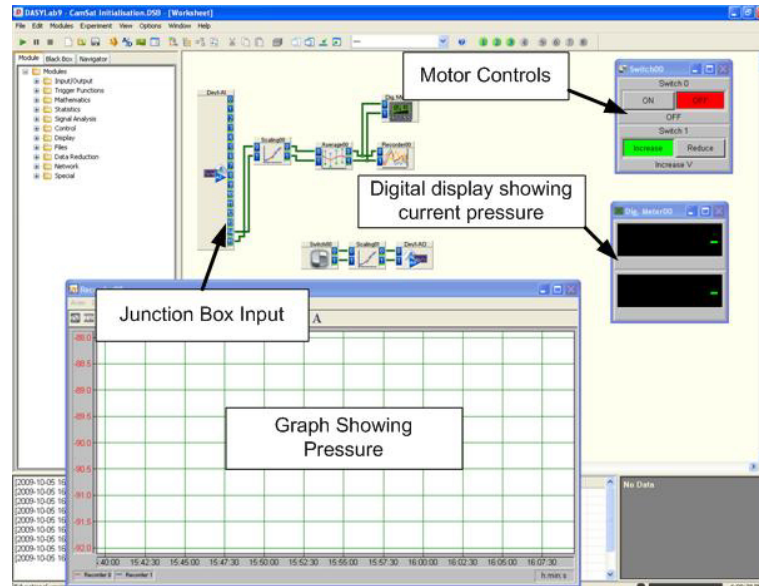


Figure 5: CAM-Sat initialisation program

input 1. Use the motor controls to incrementally increase the vacuum on the methyl cellulose holding tank until it has reached the maximum vacuum (further changes with the motor do not increase the vacuum).

### 3 Flushing with $CO_2$

In order to enhance the saturation process, flushing with  $CO_2$  can be carried out. Takahashi *et al.* (2006) carried out tests which show that flushing a model with  $CO_2$  before the pore fluid is introduced to the model leads to higher degrees of saturation. It was also found that the procedure described in this document without the flushing of  $CO_2$  was found to give acceptable saturation ratios.

If the centrifuge model is to be flushed with  $CO_2$  before saturation, then these additional steps in this section should be followed.

The package lid requires three openings for the safe flushing of geotechnical models. One hole is used to attach a pressure gauge (capable of both vacuum and positive pressures). The second opening is used to attach a 0.5bar pressure release valve. The third hole is used to attach a t-piece which connected (via valves) to the vacuum pump and the carbon dioxide. A 0 - 2bar regulator is attached to the carbon dioxide bottle to ensure low pressures are delivered to the model. The combination of the pressure relief valve and the pressure regulator are essential to ensure that the model container is not subjected to high pressures, which could either damage the model container or in the worst case cause an accident to the researcher.

The model is put under vacuum and left for at least one hour.

The carbon dioxide regulator is set at a very small positive value (for example,

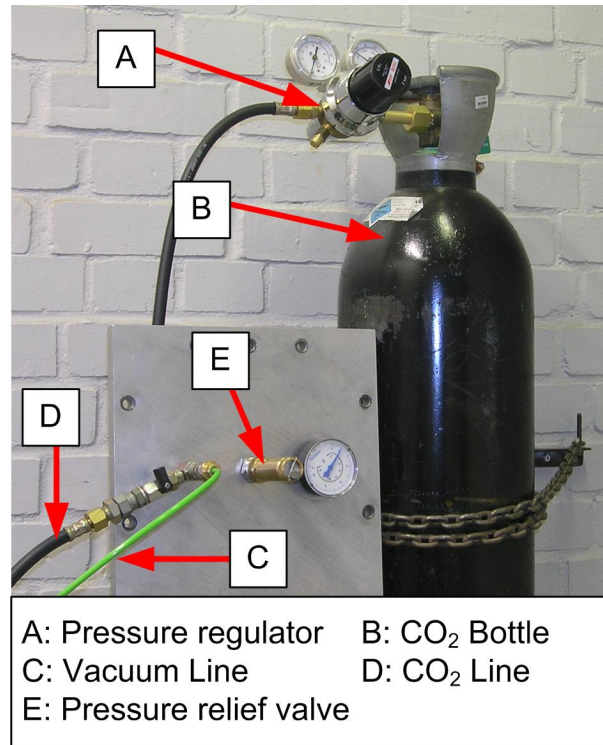


Figure 6: Elements for CO<sub>2</sub> flushing

approximately 0.2bar), and the valve opened to allow the package to return to atmospheric pressure (and slightly over). Pressures should be monitored on the gauge while this process occurs. The carbon dioxide should then be switched off and the vacuum reapplied and left for another hour. The same process can be repeated to attempt to remove any traces of air left in the model. The package is finally returned to vacuum before saturation commences.

## 4 Saturating your model

Once you are satisfied that you have reached the maximum vacuum, stop the program and open the file “c:\Dasylab Programs\Cam-Sat v3.” A screenshot of this program is shown in Figure 7.

Note: at the time of writing the program is at version level 3.

Use the slider bars to set the thresholds for the mass flux during your saturation. An approach for selecting a maximum rate of saturation is described in Stringer & Madabhushi (2009). For Fraction E sand, you should aim not to exceed 0.5kg/hour based on model cross-sectional dimensions of 250mm x 500mm. You always need to have a range of acceptable flow rate for the system. The test described in Stringer & Madabhushi (2010) showed that 0.1kg/hour was an acceptable difference between the two flow rates with a pore fluid of 50cSt and the model dimensions previously mentioned. (Any less than this and the system may be unable to control the flow rate within the thresholds). For sands coarser than



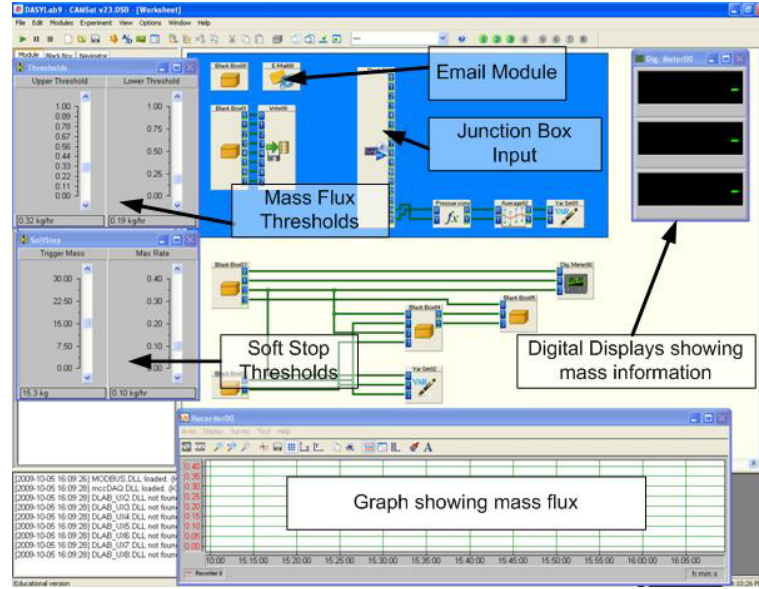


Figure 7: CAM-Sat program

Hostun sand (ie Fraction C, B or A) a wider range may be required.

A soft-stop function, discussed in Stringer & Madabhushi (2010) has been incorporated into the program which allows the user to set a reduced rate of saturation to be used near the end of saturation. The soft-stop function is controlled by the second group of slider bars, marked “Soft Stop Thresholds”. To use these, estimate how much Methyl Cellulose you expect to enter the model and decide at what point you want to enter the reduced rate mode (for example, 95% saturation). The soft stop trigger mass is calculated as:

$$M_T = M_0 - M_{100}S_{r,T} \quad (1)$$

where:  $M_T$  = Trigger Mass (kg)

$M_0$  = Initial mass of holding tank and methyl cellulose

$M_{100}$  = Mass of holding tank at 100% saturation ratio

$S_{r,T}$  = Saturation ratio at soft-top trigger

Select the maximum allowable mass flux during soft stop, allowing the maximum mass flux to be at least 0.1kg/hour. (The minimum rate set at 0kg/hour)

Check that the connections on the Junction Box Input in DasyLab are correct - the connection leading to channel 0 on the module “Pressure Conv” should be the pressure transducer on the holding tank. Channel 1 on the “Pressure conv” module should come from the model container, if you are using it.

Double click the module titled “Write00” and click the button “File”. Navigate to your directory in the c:\users folder and choose a filename for the saturation log. Return to the main screen.

If you want the program to send you emails with monitoring information, double click the module “E-mail00” and ensure that your email address is entered, returning to the main screen when you are finished. Open Microsoft Outlook and also “Express Click Yes.” Check that express click yes is enabled - right click on the icon in the system tray (bottom right of the screen) and then click “Resume”. The emails sent to you will contain the following information:

- Current Mass
- Mass 1 hour ago
- Current mass flux
- Current vacuum on the holding tank

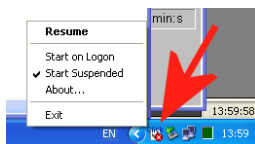


Figure 8: Click Yes

Start the DasyLab program and open Valve B. When the program is started, you will be prompted if you want to receive emails; enter 1 to receive emails, or enter 0 if you don't wish to receive the emails.

Once the program is running, you can safely change the thresholds if desired or required using the slider controls.

Note about Remote Access: It is possible to use Remote Desktop to log in to the PC so that you can view the program during the saturation process from your own PC. However, under certain circumstances, this can lead to DasyLab no longer running properly. It is therefore advised that you do not access the computer in this manner during the saturation process.

## 4.1 The Manometer

The manometer was put in as an alternative method of estimating the flow rate when the system was in its original configuration (as described in Stringer & Madabhushi (2009)), but is now not required. However, it does provide a useful way of removing any air bubbles coming from the methyl cellulose solution, preventing them from reaching your model. The downside is that if you are not careful, you can destroy your model, very, very quickly.

If you want to use the manometer, find the T-connection which joins the base of the manometer to the pipes carrying fluid to your model and ensure that the connection is orientated so that the pipe leading to the manometer is orientated upward, (best is to have it at an angle) and the pipe leading to your model is

orientated downward. Once fluid has begun flowing to your model, open Valve D.

## 5 Shut-Down Procedure

Models should always be oversaturated so that a layer of fluid exists above the sand surface. This means that as any air pockets collapse when the vacuum is released, more fluid will be drawn into the model.

When you are satisfied that enough fluid has entered your container, end the saturation process by firstly stopping the DasyLab program and then closing Valve B and Valve D. After closing the valves, turn the vacuum off. Note: It is essential that you make sure Valves B and D are closed before you turn the vacuum off. If you don't, you can end up destroying your model as air could be drawn into the base of the model. An example of this is shown in Figure 6.

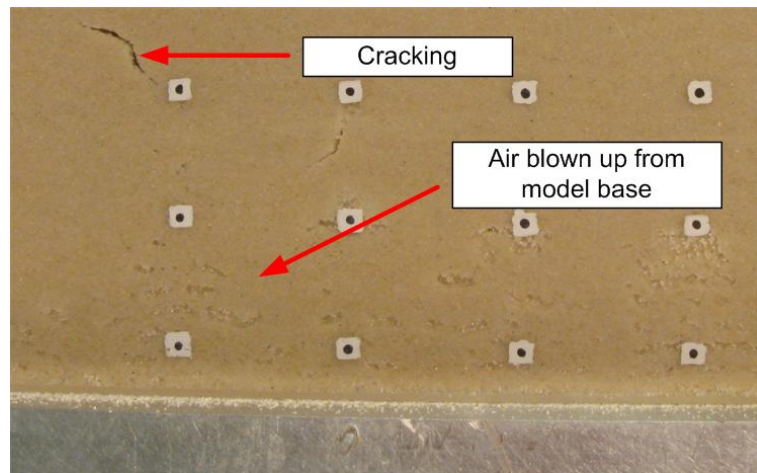


Figure 9: Example of disturbance caused by leaving Valve D open after turning off the vacuum

Once the vacuum has been released, remove the connections between your model and the CAM-Sat system and plug the ports in your baseplate to prevent fluid leaking back out of your box during your centrifuge test.

Open the holding tank and clean out any remaining methyl cellulose, flushing the lines with fresh water.

## 6 Saturation log file

The file which you specify at the start of the saturation process contains information which can be loaded into Matlab. The data is ordered as follows:

- Column 1: Elapsed time (s)
- Column 2: Mass of holding tank (kg)
- Column 3: Vacuum on holding tank (kPa)
- Column 4: Mass flux (kg/hour)
- Column 5: Upper Threshold for mass flux (kg/hour)
- Column 6: Lower Threshold for mass flux (kg/hour)
- Column 7 & 8: Motor on/off and direction
- Column 9: Vacuum on model container

## 7 Conclusions

The CAM-Sat system has been developed to aid the saturation of geotechnical centrifuge models requiring a highly viscous pore fluid. This document has described a procedure to be followed when saturating a model which will help prevent some common errors.

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