Numerical modelling of heavily overconsolidated clay till using BRICK

Modélisation numérique de l'argile lourdement surconsolidée jusqu'à l'utilisation de BRICK

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ABSTRACT: Modelling the mechanical behavior of heavily overconsolidated clay till, as found in the Copenhagen area, is quite challenging especially when it comes to deformation properties. Due to the increased focus on SLS in geotechnical design, a better representation of the small-strain behavior in this soil type will aid in future geotechnical design. The BRICK model has shown capabilities in modelling small-strain behavior in softer clays and is therefore chosen for investigation of whether its application is efficient in modelling the heavily overconsolidated clay till of the Copenhagen (CPH) area.
The parameters of the BRICK model are initially calibrated against experimental data of the CPH clay till in order to be able to evaluate the different BRICK formulations. It is found that a combination of the original formulation and what is called "BRICK theory 2" shows the best results.
A further calibration and a sensitivity study of the model parameters is performed. Through this two new parameters K and S_K are introduced in order to optimize the performance of the model for the CPH clay till.

1 INTRODUCTION

Large amounts of the top soil in the CPH area consist of heavily overconsolidated clay till. The complex loading history along with the unique combination of fines and grains up to size of boulders make this soil hard to represent by a soil model.

Due to the increased focus on SLS in geotechnical design, a better representation of the small-strain behavior in this soil type will aid in future geotechnical design. The BRICK model, as formulated by (Simpson, 1992), has shown capabilities in soft soil and is therefore chosen for an investigation of its applicability on CPH clay till.

2 THE BRICK MODEL

The analogy of the BRICK model with a man pulling a number of bricks (representing a proportion of the soil) ties to him by strings (representing the corresponding amount of strain necessary to mobilize plasticity in that part of the soil), is well known in geotechnical communities. The details of the model though, are less well known and therefore briefly summarized.

The combination of bricks and strings generates the stiffness degradation curve (S-curve) with stiffness degradation corresponding to the "size" of the brick at the strainlevel corresponding to its string as shown in figure 1.

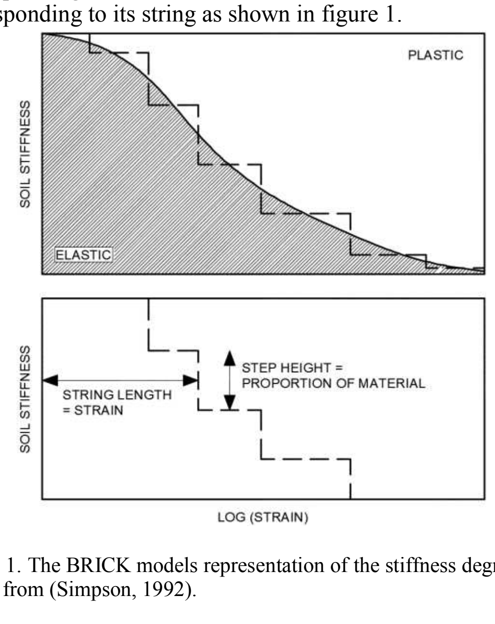

Figure 1. The BRICK models representation of the stiffness degredation curve, from (Simpson, 1992).

When the movement of the man equals the sum of the movement of the bricks all stiffness is depleted and the soil element fails.

The model has volumetric and shear stiffness proportional to mean normal stress with ι^* (corresponding to λ^* and κ^* but for small-strain response) as the parameter in the proportionality for the volumetric case and in combination with ν for the shear case. Further, the stiffness is dependent on the level of overconsolidation by multiplying the stiffness with a factor β_{mod} that increases with the distance to the NCL multiplied by β.

A plastic strain reduction adds capacity for elastic straining with increased mean normal stress by moving the bricks closer to the man as mean normal stress increases.

The model generates both $\sin(\varphi)$ and K_0. Through integration of the S-curve the energy when all stiffness is depleted is found corresponding to $\sin(\varphi)$, and K_0 is linked to $\sin(\varphi)$.

Since the BRICK models response is dependent on the position of the man and the bricks, the stress/strain history of the soil needs to be modeled before further modelling.

2 .1 *Modifications to the original BRICK theory*

The original BRICK theory as presented by (Simpson, 1992) was later improved with some minor changes, presented by (Clarke, 2009) and (Oasys, 2009).

The first of the changes is a decrease of the volumetric plastic strain reduction by dividing ι^* by β_{mod} and by this ensuring straight URLs. The second is a computational change to ease the transition from NCL to URL or vice versa.

The last change is related to β_{mod} that by changing the stiffness in the overconsolidated state also changes the strength since this is dependent on the sting data and thus the stiffness. The two effects are separated by adding a parameter called β_{rat}.

2 BEST BRICK "THEORY" FOR CPH CLAY TILL

For an evaluation of what modifications to the BRICK theory will suit modelling of CPH clay till best a 1D consolidation with an unloading reloading loop is modelled with the different modifications separately.

For this test a representative dataset for CPH clay till was chosen with best guesses for the "new" parameters; string data, ι^* and β, ensuring $\sin(\varphi)$ and $K_{0\text{-}NC}$ within realistic limits.

From this investigation, it was found that the BRICK model does not return to the NCL when reloading from extreme unloading but instead overshoots and generates a new parallel

NCL at higher mean stress. This effect is minimized by implementing all modifications mentioned in section 2.1 but the straight URLs. A compromise is thus made between having straight URLs or a realistic return to the NCL.

3 ADJUSTING THE BRICK PARAMETERS

The parameters necessary in the BRICK model are in short; the well known λ^*, κ^* and ν along with the less known ι^*, β and the sting data with position of the man and all the bricks.

The first three parameters was determined by usual methods. For the later parameters, the string data has been calibrated using the general expression for an S-curve by (Vardanega and Bolton, 2011) as a shape guideline and then trying with different inclinations at different strains.

Since the maximum shearstiffness is expressed by ν and ι^*, and the normalized area under the string data times this stiffness generates $\sin(\varphi)$ calibration of the later parameters is made keeping $\sin(\varphi)$ constant.

From a simulation of 1D consolidation it was discovered that ι^* has a strong influence on the unloading phase as seen in figure 2.

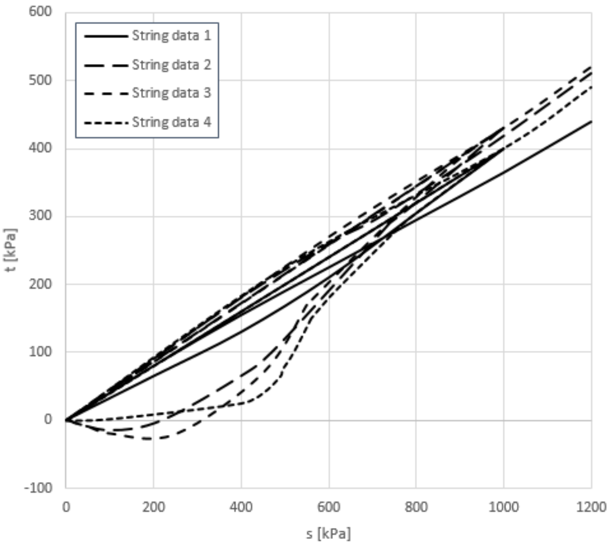

Figure 2. Influence of ι^* on unloading after 1D consolidation.

From seeing these effects a suggestion as how to choose proper value of ι^* is made through the new parameter K defined in a similar way as Λ (see equation 1).

$$K = (\kappa^* - \iota^*) / \kappa^* \quad (1)$$

A value of K above 0.8 is recommended for CPH clay till.

From simulation of isotropic NC shearing it was discovered that the cut-off value of the string data has a strong influence on the behavior of the model close to failure

Further, the cut-off also has a strong influence on how much overconsolidation is needed in order for dilatant behavior to occur since all the bricks need to be placed at a higher level volumetric strain than the man in order for full dilatancy to occur.

Therefore another new parameter is introduced to aid in the choice of the cut-off value. This parameter SK is defined as in equation 2.

$$S_K = S_{longest} / \kappa^* \quad (2)$$

$S_{longest}$ being the length of the longest string. For CPH clay till it is recommended to keep the value of S_K above 15 to ensure a realistic behavior in failure and obtain dilatancy at lower levels of OCR.

The two new parameters have only been tested for the CPH clay till and the suggestions for their values does therefore not extend beyond soils of similar composition. Although this is a fact, the parameters as concepts should still prove useful as a mean for calibration of the BRICK model to other types of soil.

For them to be used more research is necessary on other soil to find there optimum values.

3 .1 *Suggestion for BRICK data to be used on CPH clay till*

In the end, all the calibrations end up with suggesting the BRICK parameters mentioned in table 1 for modelling of CPH clay till. A simulation of the strain history is then needed in order for the bricks and the man to be placed correctly.

Table 1. Suggested BRICK input data for modelling CPH clay till

String length	G/G_{max}	*BRICK parameters*	
0.0000065	0.95	λ^*	0.016
0.000017	0.87		
0.000045	0.69	κ^*	0.0032
0.00011	0.41		
0.00026	0.21	ι^*	0.0003
0.0006	0.09		
0.0013	0.045	ν	0.26
0.0023	0.02		
0.005	0.008	β	11
0.01	0		

These data implies $\sin(\varphi) = 41.8°$ and $K_{0\text{-}NC} = 0.36$.

4 CONCLUSION

The BRICK model shows great potential as a model due to its simplicity. Being formulated in strains instead of stresses expells the need for formulating a yield surface and no flow rules are needed.

The down side to this simplicity is the relative difficult calibration process where parameters must be "guessed" initially and then through iteration calibrated to a wanted behavior in stress space.

In order to ease the calibration of the BRICK model two new parameters K and S_K are introduced to guide in the choice of ι^* and the cut-off strain of the S-curve.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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