Chapter 10

Numerical results and evaluation

10.1 Results presentation and analysis

Figure (10.1) summarizes the results of the numerical modeling. The obtained load-displacement curves for static and low-frequency dynamic tests, in all three available soil conditions (dry, saturated drained and saturated undrained) are all together in the figure. Note that the y-axis -displacement- has as maximum value 2cm, the force corresponding to this displacement if the failure force, according to the criteria established for the experimental tests. It is important to remark that the fact that the numerical model pile had 2cm in radius instead of 1,666cm has been corrected as for the interpretation of the numerical results it was required to multiply obtained stresses by the area. Multiplying the stresses for the area the simplification is compensated and the results are correct and comparable with the experimental ones.

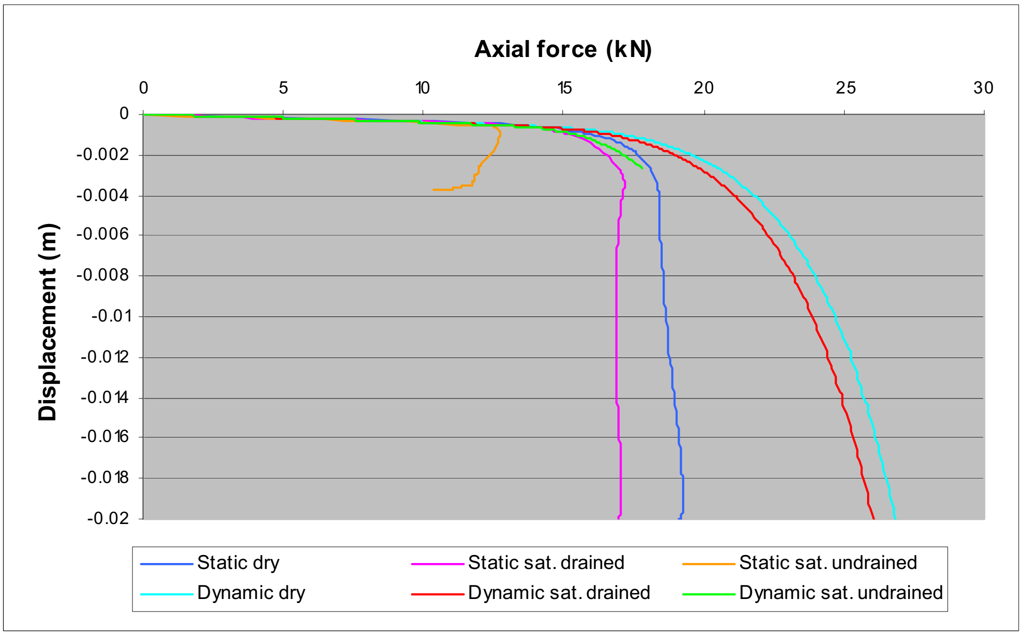

Figure 10.1: Numerical load-displacement curves

All the calculations were performed with exactly the same model and soil properties, only the definition of the calculation and/or the presence of water changed. A first glimpse at the load-displacement curves should note that, the difference between static and dynamic calculations turns out not to be only the failure load, but also the shape of the curve. For the static calculation a displacement was imposed, for the dynamic one, a load at the pile top the value of which was increased as half-harmonic cycle. This different, may it be called, loading process implicitly introduced variations in the soil model itself and behavior. For the static case a brusque change in stiffness occurs when the soil plastifies, even with some softening. Softening could perhaps take place in the dense sand package, considering the input parameters used and taking into account that experimentally we kept re-vibrating once and again the same sample due to the preparation system inefficiency. Hardening soil model can not, explicitly, account for softening, thus this shape is not due to any stress or stiffness incorrect input. The experimental curves for static dry tests (see Dijkstra [5]) also showed this sudden failure, but not the saturated curves. On the contrary, the dynamic curves display a much more gradual plastification and hardening is visible. However, the defined pulse clearly represented the pseudostatic pulses as defined in the literature. The different application of the load is the only responsible for the differences. In both type of calculations, for the undrained case, failure of the soil was accompanied by a large numerical divergence making the calculation to stop almost immediately after plastifying the soil.

To check the precision of the results, these have to be compared with the recorded experimental values. Archeewa [20] already calculated the average recorded values and related them to those of Dijkstra [5]. The comparison can be extended to the numerical values in he following table:

Model	**Condition**		**Test**	**Fail.force(kN)**
Experimental	Dry		Static	24.7
			Pseudost.	27
	Saturated		Static	14.5
			Pseudost.	19.75
Numerical	Dry		Static	19.5
			Dynamic	26.8
	Saturated	Drained	Static	17
			Dynamic	26.1
		Undrained	Static	12.5
			Dynamic	17.8

Table 10.1: Comparison between experimental and numerical results

Note that experimentally there is only one result for the 'saturated' case. On the contrary, in PLAXIS, while defining the calculations, it is needed to specify the assumed behavior of the soil, therefore, two options are available for the saturated model, namely, drained and undrained. The conclusions of experimental and analytical models agreed in defining the problem as partially drained, but with PLAXIS only fully drained or undrained calculations have been performed as there is not explicit partial drainage option, although it could be considered through a proper definition of Skempton's B parameter (see recommendations in chapter 11). For these considerations, the best option to check the accuracy of the numerical results is comparing the dry ones.

- The static calculation slightly underpredicts the failure force, however the fit is of a 80% which can be considered good.

- The dynamic calculation result fits surprisingly good the experimental one, 26,8kN versus 27kN, this is a fit of a 99, 25%.

It can be concluded that the numerical results fit very well the experimental ones. Then, the computed results for saturated conditions can be used to analyze the soil response to the fast load. The coming graphs compare the load-displacement curves for saturated soil under static and pseudostatic loading.

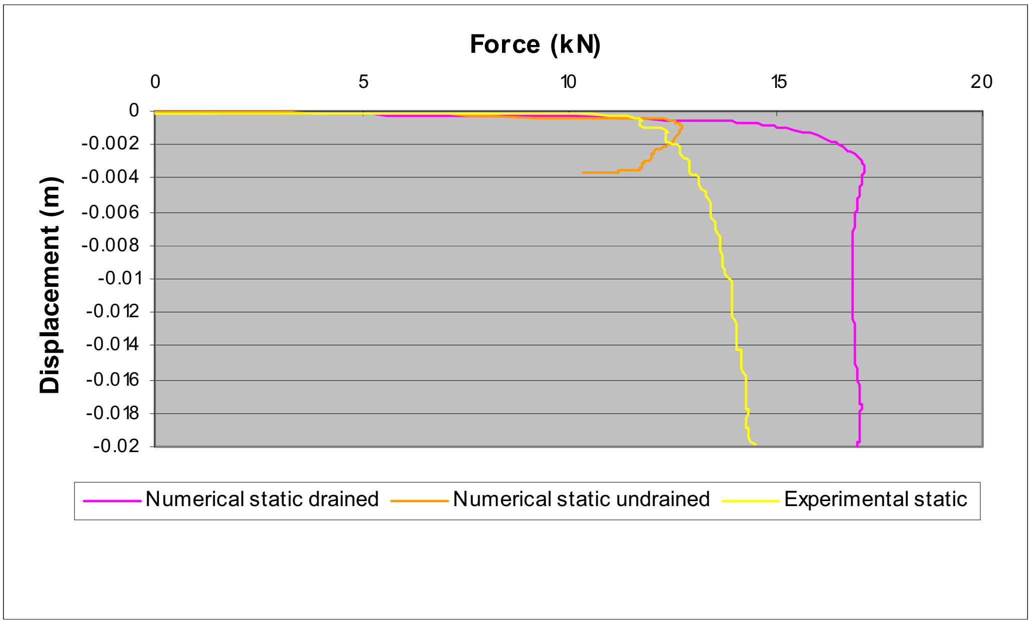

Figure 10.2: Static load-displacement curve

For both cases, the yellow curve is the experimental one and it falls in-between the drained and undrained results of PLAXIS, also for the pseudostatic case. Hence, once more the model corroborates that the experimental tests were not carried out under undrained conditions. Even for the pseudostatic loading, the numerical undrained approach fails for too low loads, whereas the drained loads are too large, demonstrating that it is a partially drained situation.

Also according to the experimental conclusions, the computed failure forces for the dynamic calculation are larger than for the static one. In the evaluation of the experimental results there was information about the tip and shaft resistances and one could calculate the correspondent bearing capacity. Despite the larger forces on pile top for pseudostatic tests, the calculated bearing capacities for static and pseudostatic were almost the same for dry and saturated tests. From that it was concluded that there was no loading rate effect on the pile bearing capacity. There was a rate effect on the pore pressures but the pore pressure generation did not affect the pile bearing capacity. Unfortunately all these reasonings cannot follow from PLAXIS results. The problem is as follows: Some numerical artifacts occur in particular stress points in the values of effective stresses and pore pressures around locations were the gradients are expected to be large (i.e. pile tip, shoulder position of the cone). These anomalies do not affect the general comput of the

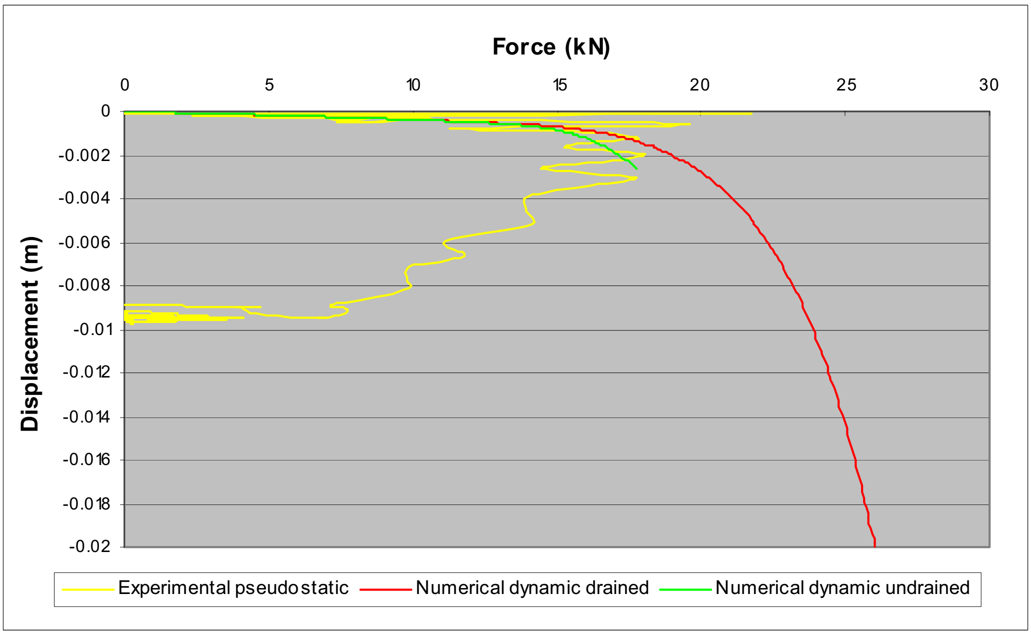

Figure 10.3: Dynamic/Pseudostatic load-displacement curve

load-displacement curves, but when evaluating the output and looking for concrete values at concrete points it is more complicated. More understanding on the problem could not be achieved due to the existence of numerical artifacts. Even if the rest of the points in the geometry have reasonably appropriate values of pore pressures or effective stresses, at least one of them is unrealistic and this should be enough to question the reliability of the other points. This problem is common in some finite element discretizations of complex geometries or stress distributions but does not affect the main results as the load-displacement curves. To sum up, the only reliable results are the load-displacement curves and it is not possible to (a) predict the excess pore pressures that generate or (b) separate which part of the resistance is due to shaft friction and which one belongs to the tip resistance, in other words, the corresponding bearing capacity can not be calculated.
The larger values of the force at the pile top, which also occurred experimentally, could be explained as due to the inertia effect. This was the conclusion for the tests and could perfectly be valid here as well. Therefore, that the failure forces for dynamic calculations are larger than for static is not a reason to held responsible for it neither (a) loading rate or (b) excess pore pressures. Yet, be careful: on the other hand, as it is not possible to derive the exact bearing capacity for the numerical case, stating out load there there is no loading-rate or pore pressure effect would be incorrect form a logical point of view. One can just 'suppose' that is the cause but unfortunately no more insight is available.

As mentioned in the beginning, for saturated experimental static the softening product of the numerical model was not observed. A better shape-fit could not be achieved as it would require to manually redefine one of the available soil models or use a fully user-crafted one.
For the dynamic curves, the numerical results would represent the 'theoretical' behavior of a pseudostatic or quasistatically tested soil. The set-up used is not the commercial **statnamic** and the hitting of the mass onto the pile did not occur so neatly. The irregular shape, especially visible comparing to the numerical results, is produced by the reboundings of the load on the pile head as it is let to fall freely inside the guiding aluminium

tube. The undrained calculation detects soil complete failure, leading to large divergences in the numerical procedure and the calculation stops.

10.2 Model evaluation

In the previous chapter, when the model was defined, some of the limitations were already presented, as the impossibility to model large deformations (i.e. CPT/installation of the pile), the lack of an explicit definition of the loading rate as the velocity at which the load is applied, the fact that saturated soil could only be modeled as a drained or undrained material, etc. As happens in the analytical model, or in any model, a model is just a model, an approximation to the reality, that will be more or less precise, but is always a simplification. In reality, either it is in-situ or in the scaled calibration chamber tests, the situation is always much more complicated and there are a large number of factors involved. The aim of this part of the research was to see if the numerical model confirmed some of the experimental findings, which, to some extent, is indeed the case. It is true that it failed to provide detailed information of the behavior of the soil resistance but, on its favor, the achieved load-displacement curves successfully fitted the experimental ones. For this, the numerical model has been successful.

A number of modifications were introduced in the model to represent and account for inputs that could not be included or to palliate the lack of good data about it, for instance, the expansion to model the effects of the pile installation or the OCR and K_0 values. They turned out to give good results, so, besides confirming some of the conclusions that were seen in the tests or analytical mode, the PLAXIS model could somehow fill one of the gaps existing in the experimental testing: it provided information over the stress state in the soil. Therefore, the soil in the tank can be categorized as overconsolidated, with larger confining horizontal stresses than vertical ones.

As said before, the final global output, the load-displacement curves, may be satisfactory but there were some questions PLAXIS could not answer (accurate detail in the distribution of excess pore pressures for instance). A good fit with the experiments was achieved but one has to be realistic and certainly it could not be said that the results of the numerical model could be used as a prediction tool for pile bearing capacity analysis. It has been a very good tool to get more insight on the soil behavior but no quantitative extrapolation may be derived.

10.3 Conclusion

The obtained load-displacement curves fit really well the experimental ones. Besides, they help to corroborate two ideas that had been previously introduced:

- **Drainage**:it is not the case of undrained loading. The soil response is in-between, partially drained.
- **In-situ stresses**:the soil in the tank is overconsolidated.

However, no explicit values of excess pore pressure or effective stresses could be derived, strongly limiting the practical applicability of the results. Three points had been defined were quantitative detail was interesting. It could not be fulfilled:

- Relationship loading rate-excess pore pressure
- Relationship excess pore pressure-bearing capacity
- Relationship soil strength-excess pore pressure