The methodology of choice Cam-Clay model parameters for loess subsoil

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Abstract

The paper deals with the calibration method of FEM subsoil model described by the constitutive Cam-Clay model. The four-storey residential building and solid substrate are modelled. Identification of the substrate is made using research drilling, CPT static tests, DMT Marchetti dilatometer, and laboratory tests. Latter are performed on the intact soil specimens which are taken from the wide planning trench at the depth of foundation. The real building settlements was measured as the vertical displacement of benchmarks. These measurements were carried out periodically during the erection of the building and its operation. Initially, the Cam Clay model parameters were determined on the basis of the laboratory tests, and later, they were corrected by taking into consideration numerical analyses results (whole building and its parts) and real building settlements.

Keywords: Cam Clay model, FEM model, CPT test, DMT test, settlements, loess subsoil

1. Introduction

The constitutive Cam-Clay model is primarily used to model a subsoil. The model describes a material behavior in the elastic-plastic range and it is suitable for subsoils which are normally consolidated and lightly overconsolidated [1, 2], and thus it corresponds to the loess characteristics. Moreover the model can be used to numerical analysis with small displacements and the stress state far from the limit state. These types of work conditions usually exist under buildings.

2. The description of the analysed object

The subject of the analysis is the four-storey residential building which consists of three separate segments. The building is directly based on footings and continuous footings on the subsoil composed of aeolian loess sediments which are represented mainly by silt with small volumes of clay and sand. The subsoil model is identified using drilling test, CPT static tests (Fig. 1), Marchetti dilatometer DMT tests (Fig. 1), and laboratory tests. Latter are performed on the undisturbed soil specimens which are taken from the wide planning excavation at the foundation bottom.

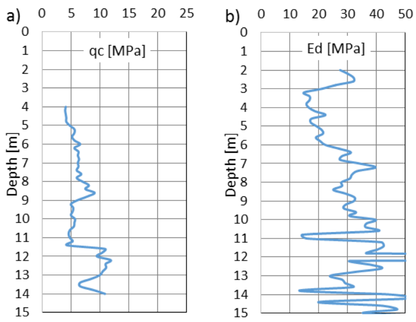

Figure 1: Results of in-situ tests a) q_c – CPT-2, b) E_d – DMT-5

The classical method of determination of the Cam Clay model is based on oedometric and three-axial laboratory tests. Parameters, which are obtained from the compressibility laboratory test, describe primary and secondary compressibility. The research shows that the building settlements estimated on the basis of parameters obtained in the laboratory are much overestimated [3, 4]. In order to perform this analysis the building settlements measurements are applied. These measurements were carried out periodically during the erection of the building and its operation. Several benchmarks were attached on the building, and in the subsequent stages of construction their vertical displacements were measured with using geodetic methods [5]. The results of these measurements are treated as building settlements in particular points. The location of measurement points and their measured displacements are shown in Figure 2 and Table 1, respectively.

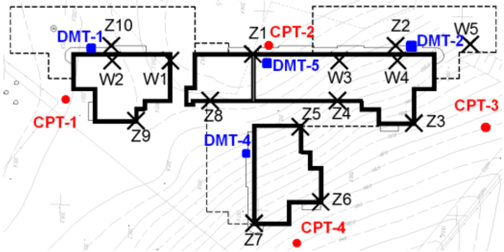

Figure 2: The location of points of settlements measurements and in-situ tests

3. The description of the FEM model

Numerical models are created in the Abaqus.6.12 program. The main model of whole building is made from shell elements and frame elements as columns. Foundations and subsoil are described by 3D elements (Fig. 3). In order to model walls, ceiling and bars S4R four-nodes shell elements with thickness 20 cm are used (comp. [6]). The columns in the basement are modelled as frame elements. The foundations are modelled by C3D8R elements and subsoil by C3D20R elements. The connections of reinforced concrete and masonry elements are declared as rigid ones. The correctness of the building model is verified on the basis of free vibration measurements and described in the work [7].

The structural parts of buildings are declared using elastic material model with concrete parameters and the subsoil is modelled by the Cam Clay elastic-plastic model. For the second model, values of initial parameters were taken from the oedometric laboratory tests.

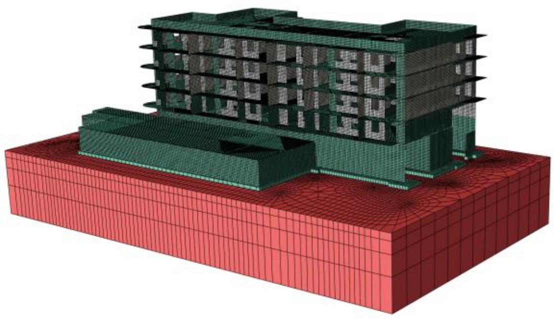

Figure 3: The FEM model of the building (different shades are related to different materials)

4. The choice of Cam Clay model parameters

The choice of Cam Clay model parameters is initiated from the calculation of the building with the assumption that the boundary conditions of walls at the foundation are the rigid boundary condition. In this stage, the force distribution in the building and distribution of stresses transmitted through the particular foundations on the subsoil are initially determined. Next, for the part of the B segment, the fragmentary models of the building with foundations and the subsoil in pieces with benchmarks, were prepared. These numerical models, shown in Fig. 4, consist of 3D elements and they are used to calibrate the Cam Clay model parameters.

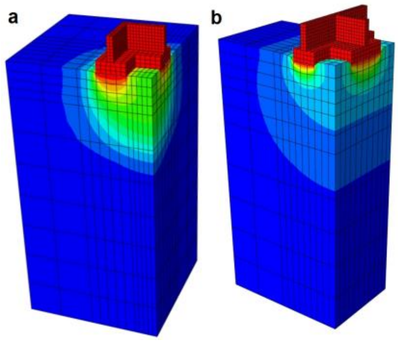

Figure 4: The model used in the calibration process with the displacement maps after the final load: a) Z3, b) Z4

The calculation results are settlements values which, after comparison with in situ measurements (Table 1), prove to be significantly overstated. Next step is to determine corrected model parameters based on the results of CPT static tests. On the basis of cone bearing resistance q_c the deformation modulus E_0 was determined [8]. Then, applying the relations (comp. [9])

$$M_0 = E_0 \frac{1-\nu}{(1+\nu)(1-2\nu)} \tag{1}$$

(where E_0 – deformation modulus, ν – Poisson's coefficient) and basic parameters of analysed subsoil the substitution Cam Clay model parameter are determined.

The next analysis is performed on improved parameters. Now, the estimated settlements values are close to settlements which are obtained from measurements. In the next step, the calculation for the whole building with consideration of subsoil solid is made. In this calculation the subsoil solid is described by parameters obtained from smaller models. Revised force distribution for building and revised stresses transmitted through the particular foundations on the subsoil are determined this way. The revised stresses are again used as loads act on small calibrating models and the final building subsidence are calculated.

Table 1: The comparison of the geodetic measurements results

Benchmark	October 2014 [mm]	July 2015 [mm]	July 2016 [mm]
Z1	**-2.69**	**-4.24**	**-4.05**
Z2	**-3.24**	**damaged**	**-**
Z3	**-2.72**	**-6.34**	**-7.11**
Z4	**-4.35**	**-5.25**	**-5.78**
Z5	**-3.90**	**-5.30**	**-5.05**
Z6	-3.00	-5.67	-7.17
Z7	-5.08	-7.02	-7.78
Z8	-3.17	-2.35	-2.28
Z9	-5.17	-6.07	-5.83
Z10	-2.39	-5.54	damaged
W1	-2.00	damaged	-
W2	-8.58	damaged	-
W3	-6.02	-6.69	damaged
W4	damaged	-	-
W5	damaged	-	-

5. Conclusion

The presented results are the part of the research which purpose is to analyse the static work of the building taking into consideration the cooperation building and its subsoil. The presented analysis allows to calibrate the subsoil model so that estimated settlements corresponds to values which are measured in the reality. It is found that the compressibility parameters obtained from oedometric tests cause that the building settlements from calculation are too big. Therefore, it is proposed to estimate the susceptibility parameters of the subsoil on the basis of CPT static tests of the subsoil performed in-situ.

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