Abstract

This research thesis presents the anisotropic behaviour of undisturbed and reconstituted Boom clay at small strains. It describes in full detail the test set-up and measurement capabilities, shows the test results and experimental investigations on the mechanical behaviour of both the undisturbed and the reconstituted Boom clay. The undisturbed Boom clay is sampled at the research site Sint-Katelijne-Waver in Belgium, a research site was intensively studied by Mengé (2001), Haegeman & Mengé (2001) and Karl (2005) due to the fact that it has a homogeneous Boom clay layer at outcrop. In order to compare the undisturbed Boom clay results, reconstituted Boom clay samples are made at the same void ratio and natural water content.

Within the framework of this research, two prototype triaxial apparatuses are constructed to investigate the small strain anisotropic stiffness of the Boom clay incorporating both multi-directional bender element and local strain measurements. The two prototype triaxial apparatuses are capable of measuring local vertical and horizontal strains down to 10^{-3} %. A first triaxial apparatus with local strain sensors offers the possibility to consolidate a soil sample under isotropic stresses, secondly, an anisotropic triaxial apparatus with instrumented Bishop & Wesley (1975) stress path cell and local strain devices offers the possibility to consolidate a soil sample under anisotropic K_0- or K-condition. These apparatuses include multi-directional bender elements for measurement of shear wave velocities, $V_{s(vh)}$, $V_{s(hh)}$ and $V_{s(hv)}$ to calculate shear moduli G_{vh}, G_{hh} and G_{hv}. Thus, Boom clay samples are consolidated under both isotropic and anisotropic stresses ($K = 2.0$). At the end of each consolidation phase, multi-directional bender element tests are performed to measure the initial shear moduli (G_{vh}, G_{hh} and G_{hv}) of Boom clay at very small strains.

The combination of isotropic and anisotropic tests offers the opportunity to separate the effect of stress-induced anisotropy from the effect of inherent anisotropy for the undisturbed Boom clay. Investigation leads to the void ratio function of the Boom clay expressing the dependency of the shear moduli on the void ratio. This void ratio function of Boom clay is $F(e) = e^{-1.21}$. Stress-induced anisotropy of undisturbed Boom clay is found during regression analysis of virgin load data and shown in the stress exponents $nv = 0.28$ and $nh = 0.17$ and also during regression analysis of the unload-reload data expressed

by the values of $nv = 0.21$ and $nh = 0.14$. nv and nh express the dependency of the shear moduli on respectively the vertical and horizontal stresses. The value of nv is higher than the value of nh reflecting the Boom clay has the stress-induced stiffness in the vertical direction higher than in horizontal direction. Inherent anisotropy of undisturbed Boom clay is found during regression analysis of virgin consolidated data and shown in the ratios of $S_{hh}/S_{hv} = 1.57$ and $S_{vh}/S_{hv} = 1.37$ and for unload-reload data in ratios of $S_{hh}/S_{hv} = 1.58$ and $S_{vh}/S_{hv} = 1.28$. The values of the stress exponents n and these ratios show that the Boom clay is a significantly anisotropic material.

The tests on the young reconstituted Boom clay present the stress-induced and the strain-induced anisotropy without any effect of soil ageing. Stress-induced anisotropy of reconstituted Boom clay is obtained by regression analysis on the measurement data. For virgin load data, the values of $nv = 0.27$ and $nh = 0.21$ are found and consistent with the stress-induced anisotropy for undisturbed Boom clay. For the unload-reload data, the values are $nv = 0.09$ and $nh = 0.16$ and significantly lower than the virgin consolidated data possibly caused by the swelling effect of the reconstituted Boom clay. Strain-induced anisotropy of reconstituted Boom clay is found during regression analysis of virgin load data and shown in the ratios of $S_{hh}/S_{hv} = 1.47$ and $S_{vh}/S_{hv} = 1.00$. The ratio $S_{vh}/S_{hv} = 1.00$ shows the existence of the cross-anisotropy. For unload-reload data, the ratio S_{hh}/S_{hv} is 1.43 and the ratio S_{vh}/S_{hv} is 1.19 and consistent with undisturbed Boom clay as both are overconsolidated materials. Comparisons between undisturbed and reconstituted Boom clay show that the undisturbed Boom clay is stiffer than the reconstituted Boom clay due to the ageing of the material shown through higher S_{ij}.

At the end of each virgin consolidation phase, Boom clay samples are sheared with multiple mini stress path excursions (MMSPE). Combining the MMSPE data with the multi-directional bender element results, five independent elastic parameters of the cross-anisotropic elasticity model are evaluated. The three parameters E_v, ν_{vh}, F_h formulation proposed in Lings et al. (2000) offers the possibility to evaluated the five independent elastic parameters for the cross-anisotropy out of the anisotropic triaxial testing. This enables the application of a cross-anisotropic elastic constitutive law on both the undisturbed and the reconstituted Boom clay. The strain energy method is very useful for comparison of the small strain elastic moduli at the same strain energy and calculation of the five independent elastic parameters for the cross-anisotropy. The small strain elastic moduli increase with increasing confining stresses compared at the same strain energy level and are independent of stress path directions.

The research also compares the field and the laboratory data. The laboratory $V_{s(vh)}$ is higher than the field SCPT data but the increase with depth is similar. The laboratory test data of $V_{s(hh)}$ and $V_{s(hv)}$ are compared with SRT and SASW tests and show that the laboratory $V_{s(hh)}$ and $V_{s(hv)}$ are lower than the field data. Possible reasons are that in the field horizontally propagating waves pass along layers of high stiffness while the laboratory test data is performed on small, possible less stiff material or the inversion calculation of the horizontal shear wave velocity by the SRT and the SASW tests is based on a linear elastic isotropic assumption which is not valid for the Boom clay.

Finally the measurement data is also used to assess the possible disturbance of the material through sampling since the undisturbed Boom clay is sampled with two soil sampling techniques. Firstly, an open-tube sampler is a common soil sampling method used in Belgium. This open-tube sampler uses the thin-walled tube for soil sampling quality class A. Secondly, the rotary core drilling with triple tube wire line coring sampling system is originally designed for taking cores in rock, but stiff clay sampling is also applicable. This second technique is new in Belgium and operates faster than the first technique. However, its fast operation might cause soil sample disturbance. Therefore, the research compares the possible disturbance caused by the two sampling techniques using isotropic triaxial tests with bender elements and found that the new sampling technique can obtain as high quality samples as the open-tube sampler.

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