SCPT Downhole Seismic – The key for the evaluation of the stiffness modulus for sensitive silty soils

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ABSTRACT: The postglacial soils of Salzburg are characterized by fine sands and silts. The case histories show that these soils have a certain microstructure and a different soilmechanic behavior then ideal soils. Traditional methods like sampling and laboratory testing do not give representative soilmechanic parameters. In this study the constrained modulus M was determined by a combination of CPT and downhole seismic (SCPT). Post construction measurements confirmed the reliability of the values.

Keywords: salzburger seeton, downhole seismic, settlement calculation, constrained modulus

1. Introduction

1.1. Location

The City of Salzburg is based in the middle of Austria and represents a glacial deep eroded basin which was postglacially refilled with fine sediments up to the flat valley surface which is surrounded by mountains. The sediments, called Salzburger Seeton, are mainly stratified fine sand-silts (upper layer) and sensitive silts (lower layer). Even if the soil is described as "Seeton", which means lacustrine clay, there is only a very low or slightly no clay content; the name refers to the kind of sedimentation of the fine sediments in lakes during the melting of the glaciers after the ice age. The depth of these sediments was prospected up to 300 m [7].

Figure 1. Map of Europe, Austria in red

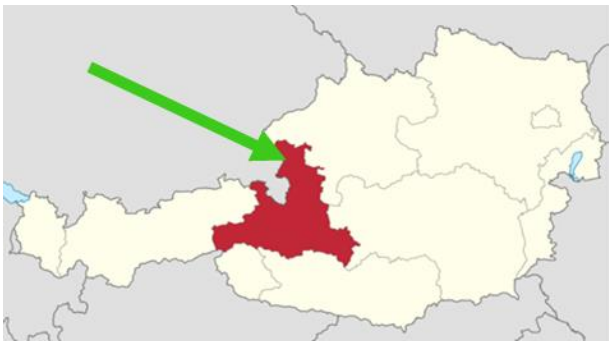

Figure 2. Map of Austria, arrow showing Salzburg

Figure 3. Aerial view of Salzburg

1.2. Geotechnical problems

The evaluation of the stiffness modulus M is still an unsolved problem, because all "traditional" methods show too low values, so that settlement calculations lead to too big settlements, which do not occur in reality [1, 2]. Therefore, often deep foundations are recommended, even if shallow foundations would be possible.

As „traditional" methods drilling, sampling and laboratory tests, certain insitu tests and in recent times also CPT are used. Even CPT with q_t-values of about 1 MPa give a constrained modulus M of about 1 MPa, whereas from further analysis we know that this value is about 30 MPa [6]. Also, DMT gives generally too low values [4, 5].

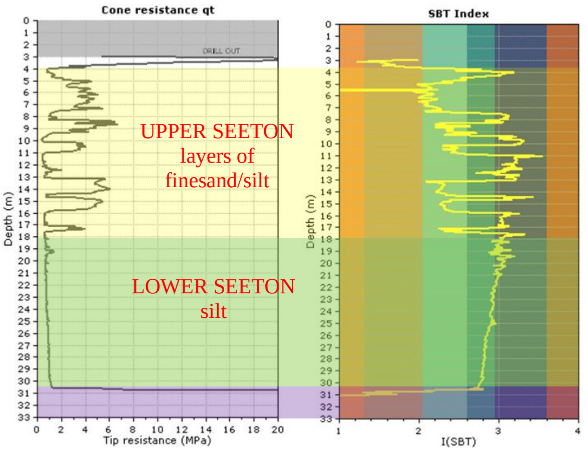

Figure 4. Typical CPT profile from Salzburg

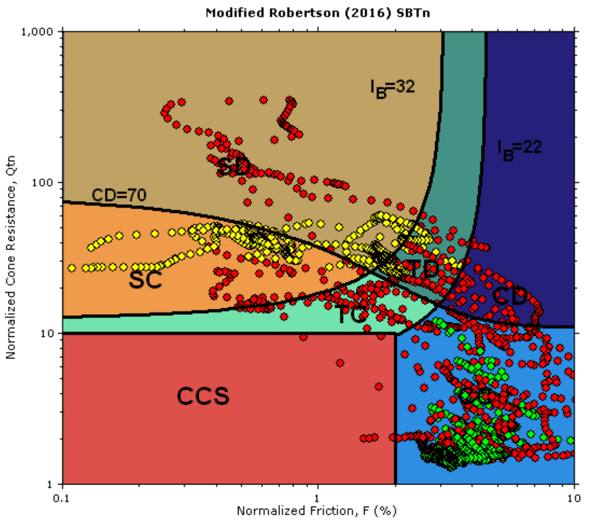

Figure 5. Analysis of the same Profile (yellow: silty fine sand; green: silt)

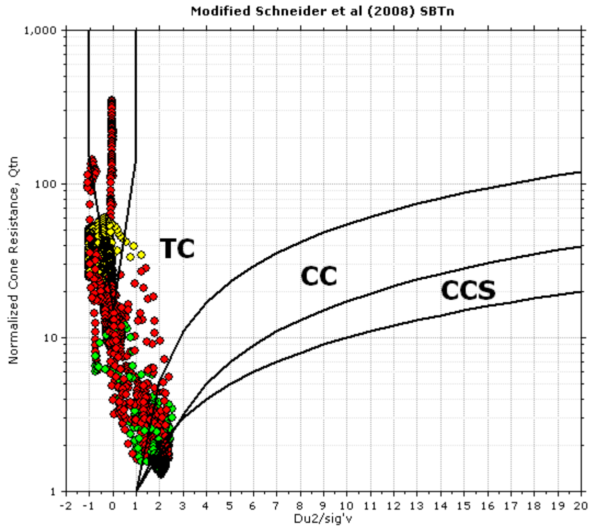

Figure 6. Analysis of the same Profile (yellow: silty fine sand; green: silt)

Figure 4 to 6 show a typical CPT-profile from Salzburg. Under the gravel form the surface to 4 m depth follows the "upper Seeton" down to 18 m; a layered sequence of silty fine sands and fine sandy silts. From 18 m to 30 m, above the bedrock, the "lower Seeton" consists of silts.

2. Seismic CPT (downhole seismic)

As part of a research project, seismic CPT was tested for the determination of the stiffness modulus M [3]. Mostly for the fine sediments, wave velocities from 200 m/s up to 250 m/s were measured, that gives a shear modulus G_o from 80 MPa to 120 MPa and a stiffness modulus M from 20 MPa to 35 MPa. The small strain shear modulus G_0 is calculated via the equation

$$G_0 = \rho V_S^2 \tag{1}$$

The constrained modulus M is then 25 % of the small strain shear modulus G_0 [8].

Only in some small areas the wave velocity is much lower. The total range of the shear wave velocity readings varies from 100 m/s to 350 m/s.

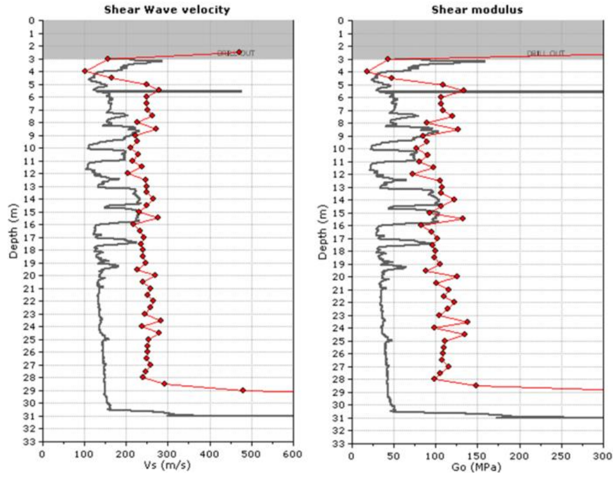

Figure 7. Calculations from the CPT Figure 4 (grey: calculated, red: measured)

Figure 7 shows in detail that in the sand layers, the calculated shear wave velocity v_s and the measured values are nearly fitting, whereas in the silt layers the measured values are much higher. Corresponding thereto the shear modulus G_0 and the constrained Modulus M vary in the same way.

3. Settlement – prognosis and measurement

In order to evaluate the stiffness modulus M, values derived from downhole seismic, the calculated settlement and the measured settlement from different buildings have been compared. The following table shows an overview of the 8 cases which have been investigated thereinafter. The first 3 examples are documented in detail.

Table 1. Case Histories

Number	Building	floors
1	comercial building	20
2	apartments	4
3	apartments	7
4	swimming pool	8
5	business complex	5
6	apartemnts	6
7	residential building	4
8	bridge	

Number	calculated settlement	messured settlement	difference
	[cm]	[cm]	[cm]
1	8,6	10	1,4
2	4	3,8	0,2
3	15	pile foundation	
4	1,7	1,5	0,2
5	6,5	5,8	0,7
6	1,5	2	0,5
7	2,0	2,4	0,4
8	0,8	1	0,2

3.1. Commercial building (Number 1)

Example 1 deals with the foundation stabilisation of a 20-floor commercial building with settlements of 10 cm and too high differential settlements.

The Building was founded in a depth of 5 m in the gravel overburdon. The upper Seeton (layers of fine sands and silts) ranges from 8 m to 19 m. Then the lower Seeton (Silt) follows till to the bedrock in 42 m depth.

Back calculation resulted in a stiffness modulus M value of 30 MPa. In this case, seismic CPT gave a mean wave velocity v_s of 250 m/s and a stiffness modulus M of 30 MPa was derived.

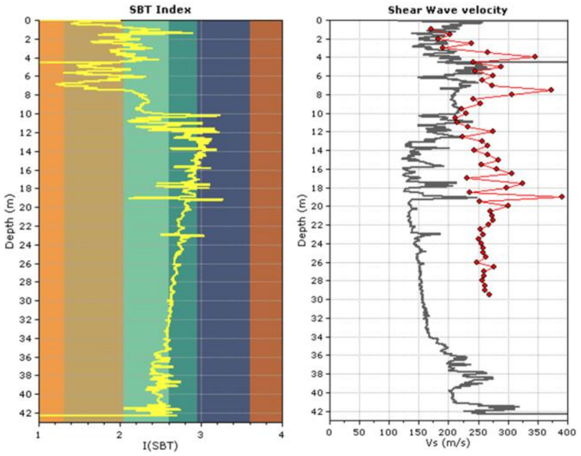

Figure 8. SBT-Index and shear wave velocity (building number 1)

3.2. Apartment house (Number 2)

In example 2, the soil for a 4-floor apartment was investigated in the “traditional” way with drilling and laboratory testing. Due to the low values of the stiffness modulus M a pile foundation was recommended.

The foundation depth is in 4 m, so the organic overburdon was removed till fine sand (upper Seeton) begins, which was detected down to 14 m. The lower Seeton with silts ranges to the bedrock in 44 m.

Additional soil investigations using seismic CPT showed a medium wave velocitiy v_s of 200 m/s and a stiffness modulus M of 20 MPa. The calculated settlements of 4 cm allowed to carry out a shallow foundation. Post construction measurements yielded a settlement of 3,8 cm.

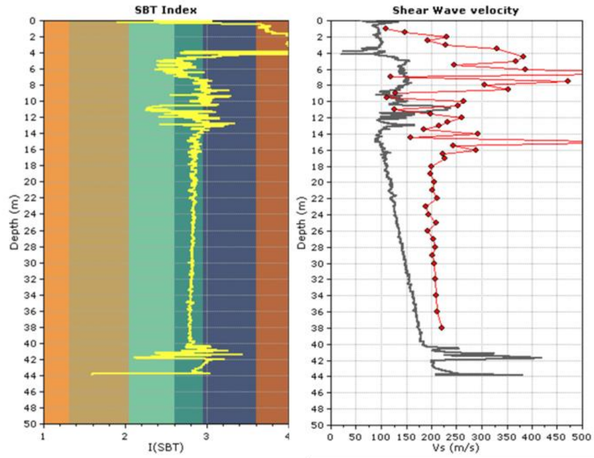

Figure 9. SBT-Index and shear wave velocity (building number 2)

3.3. Residential building (Number 3)

In the 3rd example the soil investigations for a residential building revealed organics and peat till a depth of 4 m. The organic overburden is underlayed by soft silts till to the bedrock in 17 m depth. In this case there exists only the silty lower layer of the Seeton, the upper layer is missing.

The foundation depth is in 4 m on the silty Salzburger Seeton. For this silts a wave velocity of 120 m/s was measured. The reason for the unusual low wave velocity and the corresponding low stiffness modulus M of 7 MPa is the higher clay content in the soil and the lower bonding.

In this case a shallow foundation results in a too high settlement, therefore a pile foundation down to the badrock was carried out.

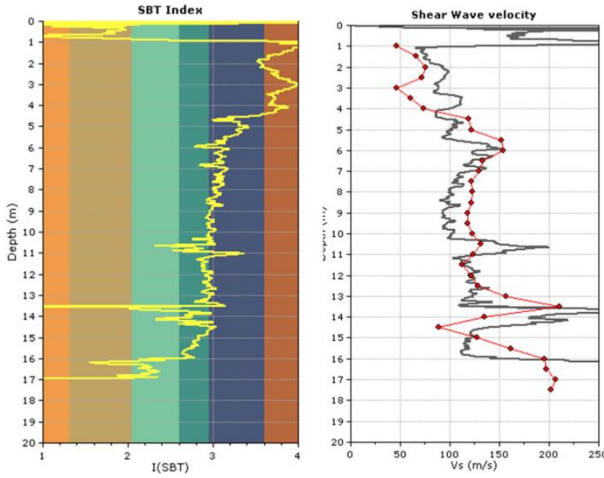

Figure 10. SBT-Index and shear wave velocity (building number 3)

4. Microstructure of the soil

For investigation of the soil structure the small strain rigidity index K^*_G was calculated. Values of generally > 330 show that even these young fine sediments already have a certain bonding of the soil particles (microstructure).

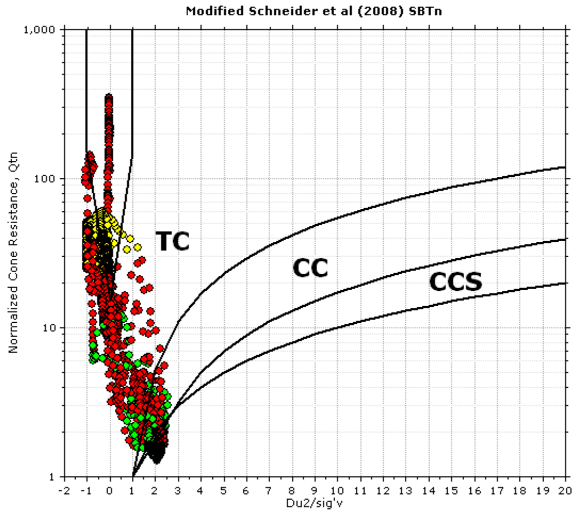

Figure 11. Calculations from the CPT Figure 4; Modified Schneider Plot and Q_{tn} – I_G chart

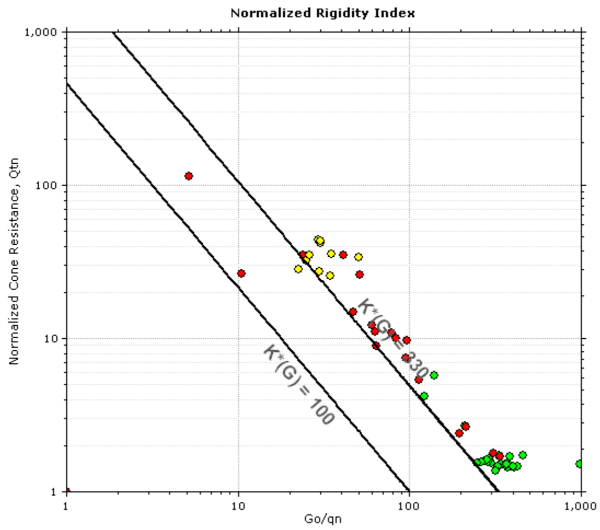

Figure 12. Calculations from the CPT Figure 4; Modified Schneider Plot and Q_{tn} – I_G chart

For the first time electron microscope pictures were made, which gave an impressive insight into the soil structure of the silts. The small soil particles are arranged in a flake-like structure and they are bonded as if they were glued together (significant microstructure).

Figure 13. Electron microscope picture, silt in 20 m depth (CPT Figure 4)

Obviously, probing, taking samples and laboratory testing destroy this structure and falsify the test resulting in a too low stiffness modulus M. In contrast, the shear waves are passing this bounded soil without destroying the microstructure. The small amount of energy of the shear waves is smooth enough to keep the bonding of the soil. Therefore, the calculated values of the stiffness modulus M fit to post construction measurements.

5. Conclusion

The cases given above show that for the determination of the stiffness modulus M the CPT-parameters q_c and f_r are not enough. For ideal soils it might be sufficient, but for structured soils values are definitely too low. Using additional downhole seismic measurements and the calculation of the small strain rigidity index $K^*_{G,}$ the presence of a microstructure can be evaluated.

The shear wave velocity allows to calculate the small strain stiffness modulus G_0 and the constrained modulus M can be derived. Case studies confirmed the resulting values.

References

[1] Robertson, P.K. „CPT-based Soil Behaviour Type (SBT) Classification System – an update“, Canadian Geotechnical Journal 53(12), 2016. https://doi.org/10.1139/cgj-2016-0044

[2] Robertson, P.K., Cabal K.L. “Guide to Cone Penetration Testing for Geotechnical Engineering”, Gregg Drilling&Testing Inc., 6th Edition, 2015.

[3] ISSMGE “TC10-Seismic cone downhole procedure to measure shear wave velocity: A guideline”, ISSMGE Bulletin, Volume 9, Issue 2, pp.17-25, 2015

[4] Premstaller, M. “Drucksondierungen (Cone Penetration Test), Möglichkeiten und Grenzen”, VÖBU.forum, Ausgabe 39, pp 24-25, Juni 2016.

[5] Premstaller, M., Saurer, E. „CPT, DMT, Seismik – Neue Erkenntnisse des Verhaltens des Salzburger Seetones“, 11. Österreichische Geotechnikertagung – Tagungsbeiträge 2.+3. - Baugrund Risiko & Chande, pp. 339-347, 2017

[6] Ausweger, G., Havinga M., Lüftenegger R., Marte R., Oberhollenzer S. „Stiffness of Salzburger Seeton – Comparison of results from cone penetration tests and laboratory tests“, Geomechanics and Tunnelling, 12(4), pp 328-339, 2019. https://doi.org/10.1002/geot.201900011

[7] Breymann, H., Moser, M., Premstaller, M., „Die Gründung des Kongresshauses Salzburg“, Felsbau 21, Nr. 5, pp. 10-17, 2003.

[8] Massarsch, K.R., „Determination of shear modulus from static and dynamic testing“, Proceedings in honour of Prof. A. Anagnostopoulose, Technical University of Athens, School of Civil Engineering – Geotechnical Department. Ed. M. Kavvadas,pp. 335-352, 2015.