Characterization of postglacial clay for the design of building foundations

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ABSTRACT: Postglacial clay, for two sites at 800 m distance, in a glacial basin in central Switzerland was characterized using in-situ and laboratory tests. CPT-U tests reached down to 25 m depth and a boring with DMT tests reached 40 m deep. The conversion factor N_k for estimating S_u from tip resistance q_c was calibrated on the undrained shear strength obtained with measurements from the flat Dilatometer DMT. Preconsolidation stresses estimated from CPT-U tests indicated 100 kPa, from incremental oedometer tests 60 kPa, whereas from CRS (Constant Rate of Stress) 200 kPa.

In the first site the average foundation load on the surface is about 40 kPa, the detailed site investigating allowed a raft foundation at the ground surface. The second site involves an excavation where the net load is smaller. The savings of the pile foundation amounts to forty times the cost of the site investigation.

1 INTRODUCTION

Various phases of glaciations have left complex surface conditions in Switzerland. Moraines and fluvioglacial deposits form generally good foundation areas. However, glaciolacustrine deposits left by the retreating glaciers behind terminal moraines poses substantially more difficult ground conditions for infrastructure and building construction. The denser urbanization requires building in such zones. Cost for foundations, deep excavations and basements may form a substantial part of the total construction costs. Reliable ground investigations with good characterization of soil properties are necessary to control the works technically and economically. Over the past several decades the author has applied new and improved techniques (Steiner et. al. 1992; Steiner, 1994; Steiner et al. 1998) and made good experience with CPT and DMT tests combined with laboratory tests.

The zones of glacial and postglacial may extend only over few decameters or in some zones over several kilometers and cover several square kilometers. Often such clay deposits may be covered; by fluvioglacial deposits of a few meters thickness or layers of organic soils (paleo-soil, peat or boglime). Two recent case histories located 800 m from each other in a large zone of glacial clay are presented.

2 GEOLOGIC CONDITIONS AND CONSTRUCTION

2.1 *General geologic conditions*

The two cases are located about 8 kilometers (5 miles) south of the city center of Bern, Capital of Switzerland, inside a former flood plain three kilometers wide and several kilometers long. The shorter Gürbe valley joins the principal Aare valley, both valleys are divided to the south by a 300 m high mountain ridge; formed by horizontally bedded tertiary sedimentary rock. Below the valleys bedrock was encountered in a several sufficiently deep borings only in two to three hundred meters depth. Up to forty meters depth the over-deepened valleys are mainly filled by fluvo-glacial deposits and moraine and are thus not sensitive to settlements. In zones where the glacier had stopped or re-advanced during the ice age, terminal moraines may reach to the ground surface. Historically such zones with moraines had been used to build villages and roads. Today infrastructure projects and new industrial areas are located in zones with poorer ground. The poorer ground is covered in this area with several meters of gravel deposits from the Aare River. The groundwater table is on average about 1.5 meters below the surface, but during spring time flooding may occur in some areas.

2.2 *Planned and built construction*

The first site is located in the industrial zone, which has already buildings of different construction; some have one or two basements, thus leading to a compensation of surcharge load. In case of a single basement and several above ground floors a waterproof basement is the chosen solution, for two basements uplift may become a problem. Many of the at-ground level buildings were founded on driven or micro-piles. The planned building consist of two parts, the production hall some 30 m wide and 60 m long joined by a 15m long office part with at first two stories and the possibility of adding later a third story. The loads are in the order of 40 kPa evenly distributed. The site investigation included a core boring drilled to 40 m with DMT tests at four different depths and two undisturbed sample taken with an Osterberg sampler, and three CPT-U tests to 25 m depth. In the overlying 4m thick gravel pre-drilling and backfilling with sand was necessary for the execution of the penetration tests in the underlying clay.

The second site is a replacement structure for a wastewater treatment plant, built in the 1960, which will be closed and the sewer system will be linked with a pumping station to the wastewater treatment plant of the city of Bern. The existing plant was built without piles and had performed well. However, during planning in a geologic report, based only on a single boring with two SPT tests, the statement was made that piles would be required. The new pump station and the storage basins are a 5m interior deep, 12 meter wide and 30 meter long, covered concrete structure. Based on the experience from the first site the author proposed a site investigation with in-situ (CPT-U and DMT) tests. The site investigations included a 15 m deep boring, where two samples with Osterberg sampler were taken and two series of DMT tests over 1.8 m with readings every 20 centimeters were carried out. Two CPTU tests to 25 m with 7 m pre-boring were carried out. In addition the report for the site investigation of the initial treatment plant appeared (Zeindler, 1966).

3 CHARACTERIZATION OF THE SOIL

3.1 *Borings, in-situ tests and samples*

The main objective of both site investigations was to characterize the geotechnical properties of the clay, in particular the deformation characteristics and the preconsolidation stresses and the undrained shear strength with depth for the possibility of design of piles. The results and interpretation will be described together, as this will allow to compare the results from the in-situ and laboratory tests and to draw conclusions. The tests carried out and the samples taken are shown on Table 1.

The flat dilatometer test (DMT) have been carried out every 20 cm over nearly two meters depth, below the borehole as can be seen on Figures 3 and 4.

Table 1. Types of tests carried out

Type of test	RB1-1 m	CPTU-1-1 m	CPTU 1-2 m	CPTU 1-3 m	RB 2-1 m	CPT 2-1 m	CPT 2-2 m
Begin	0	5	5	5	0	7.5	7.5
End Depth	40	25	25	25	15	25	25
DMT 1	16.2-18.0				8.2-10.0		
DMT 2	21.2-23.0				12.2-14.0		
DMT 3	28.2-30.0						
DMT 4	36.2–37.4						
Osterberg	19.3-19.6				10.5-11.0		
Sample	25.3-26.7				14.4–15.0		

3.2 *Results of laboratory tests*

For each undisturbed sample a consolidation test and classification tests were carried out. The classification tests presented in Table 2 indicate that the lean clay (CM) is similar to other glacial clays.

Table 2: Results of laboratory classification tests on samples

	Density	Dry Density	Water Content	Liquid Limit	Plastic Limit	Plastic Index	Liq.	Clay Cont	Akt.	Class
Symbol	ρ	ρ_d	w	LL	PL	PI	LI	q	A	USCS
Units	t/m3	t/m3	%	%	%	%	--	%	--	
RB1- 1	1.93	1.44	34							
RB1 - 2	1.94	1.48	31.5	37.6	22.1	15.4	.607	52.5	0.293	CM
RB1 - 3	1.91	1.44	33.3	38.4	21.4	16.9	0.7	56.8	0.298	CM
RB1 - 4	1.92	1.47	31.1	40.4	21.4	19	0.51	----		CM
B4-1	1.966	1.522	29.2	32.7	18.5	14.2	0.79	47	0.302	CM
B4-2	1.945	1.486	30.9	31.6	17	14.6	.952	48	0.304	CM

The deformation parameters determined from laboratory tests are shown in Table 3. The preloading stresses are shown on Figures 1 and 2. For site 1 (Figure 1) two consolidation tests were carried out with standard 24 hours load increments, the estimated preconsolidation stresses over vertical stress are 58 and 81 kPa only in comparison a constant-rate-of-strain oedometer gave a difference of 206 kPa. For the second site (Figure 2) stress increments were applied after t_{100} + one hour which correspond to a stress increment of about 2 hours.

Table 3: Data of compressibility from consolidation tests

Symbol Units	Void Ratio e_0	Reloading C_r	Unloading C_{ru}	Initial Loading C_c	Coefficient of consolidation c_v m^2/s
RB1 - 2	0.851	0.012	0.039	0.322	
RB1 - 3	0.902	0.009	0.046	0.375	
B2-1	0.82	0.073	0.045	0.25	8-12 x 10^{-7}
B2-2	0.78	0.072	0.045	0.225	7-1.1 10^{-7}
Design	0.90	0.034	0.034	0.285	

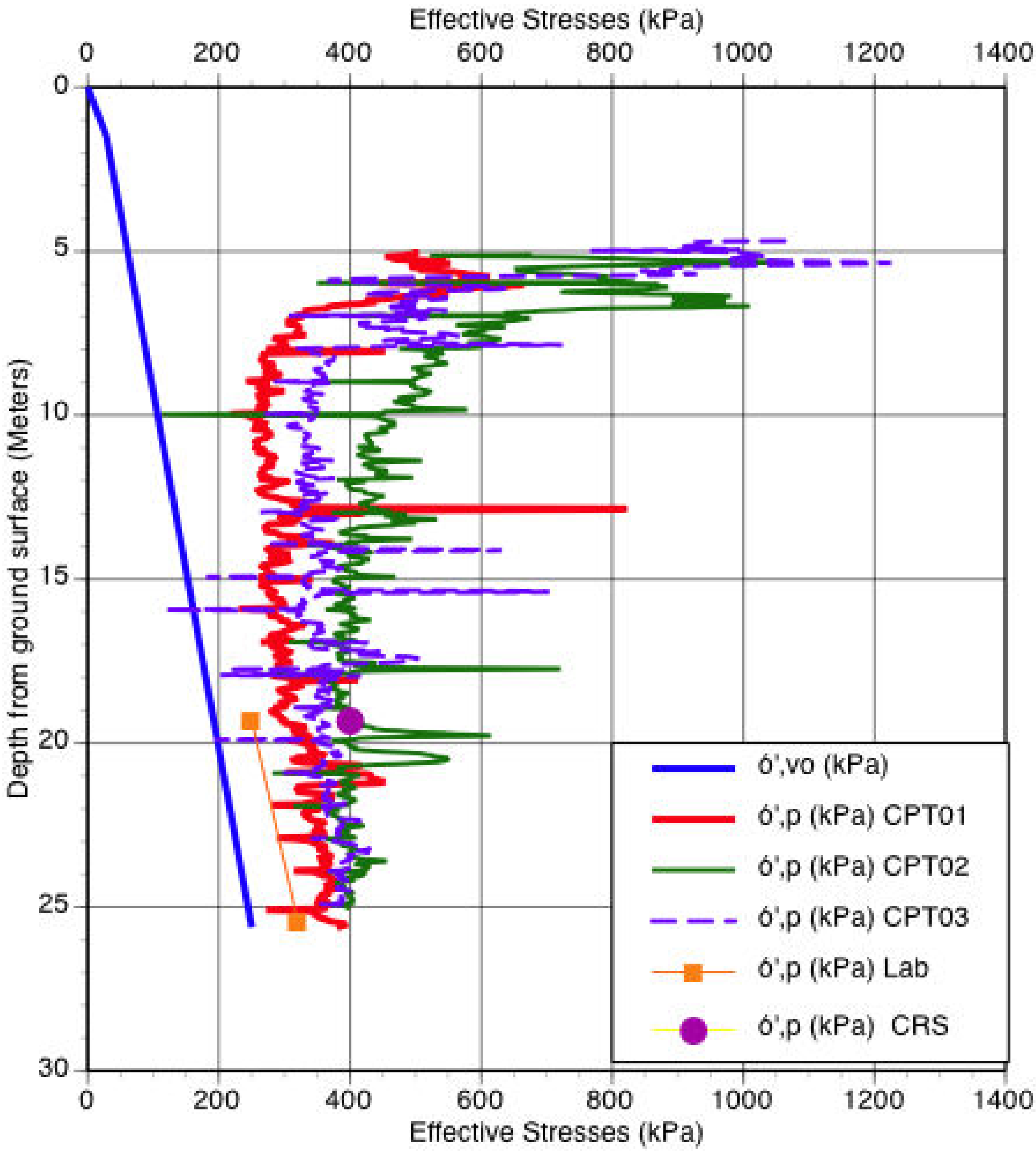

Figure 1. Preconsolidation stresses evaluated from CPT tests and from laboratory consolidation tests for site 1.

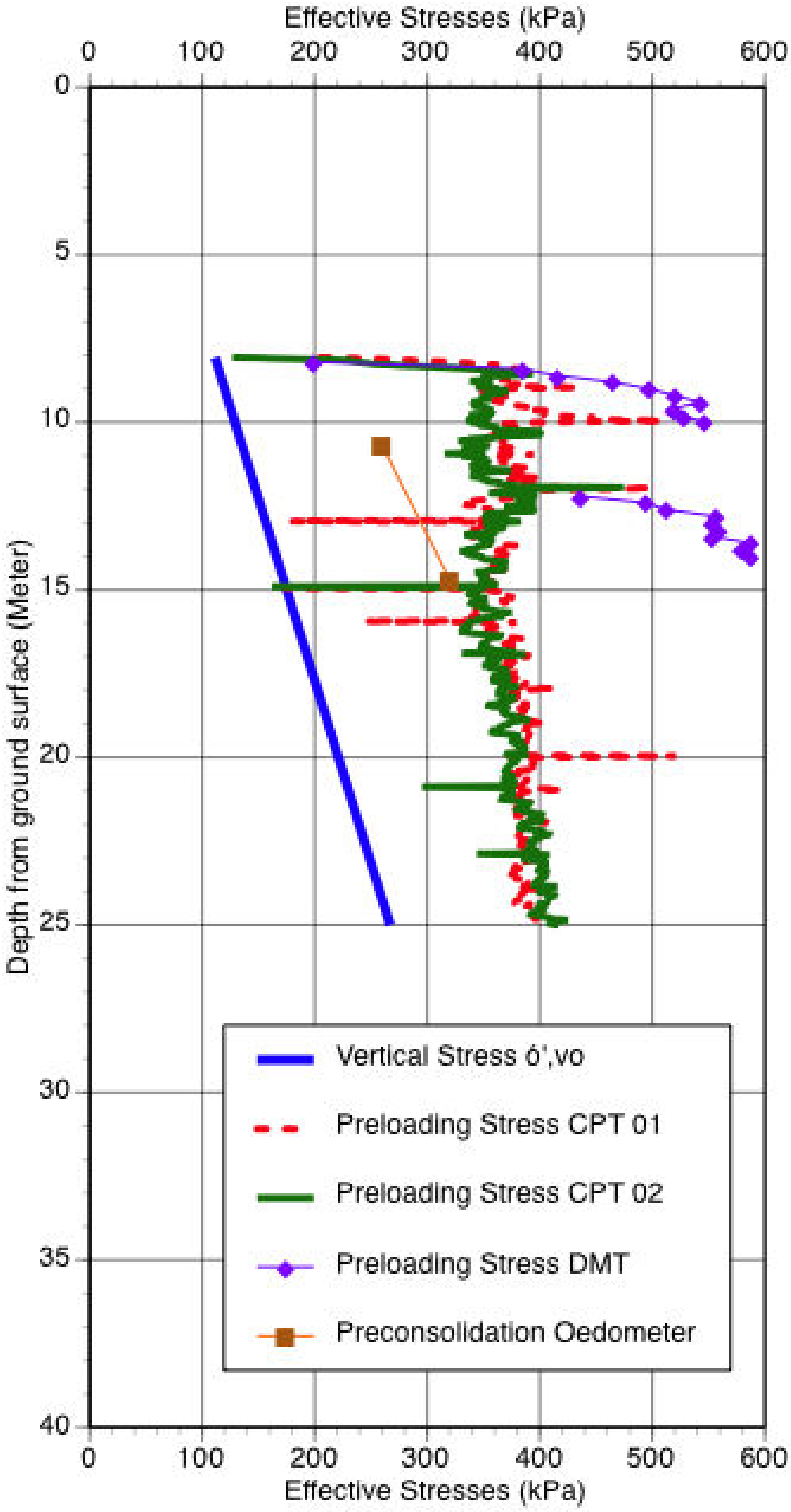

Figure 2. Preconsolidation stresses evaluated for CPT, DMT and consolidation test for site 2

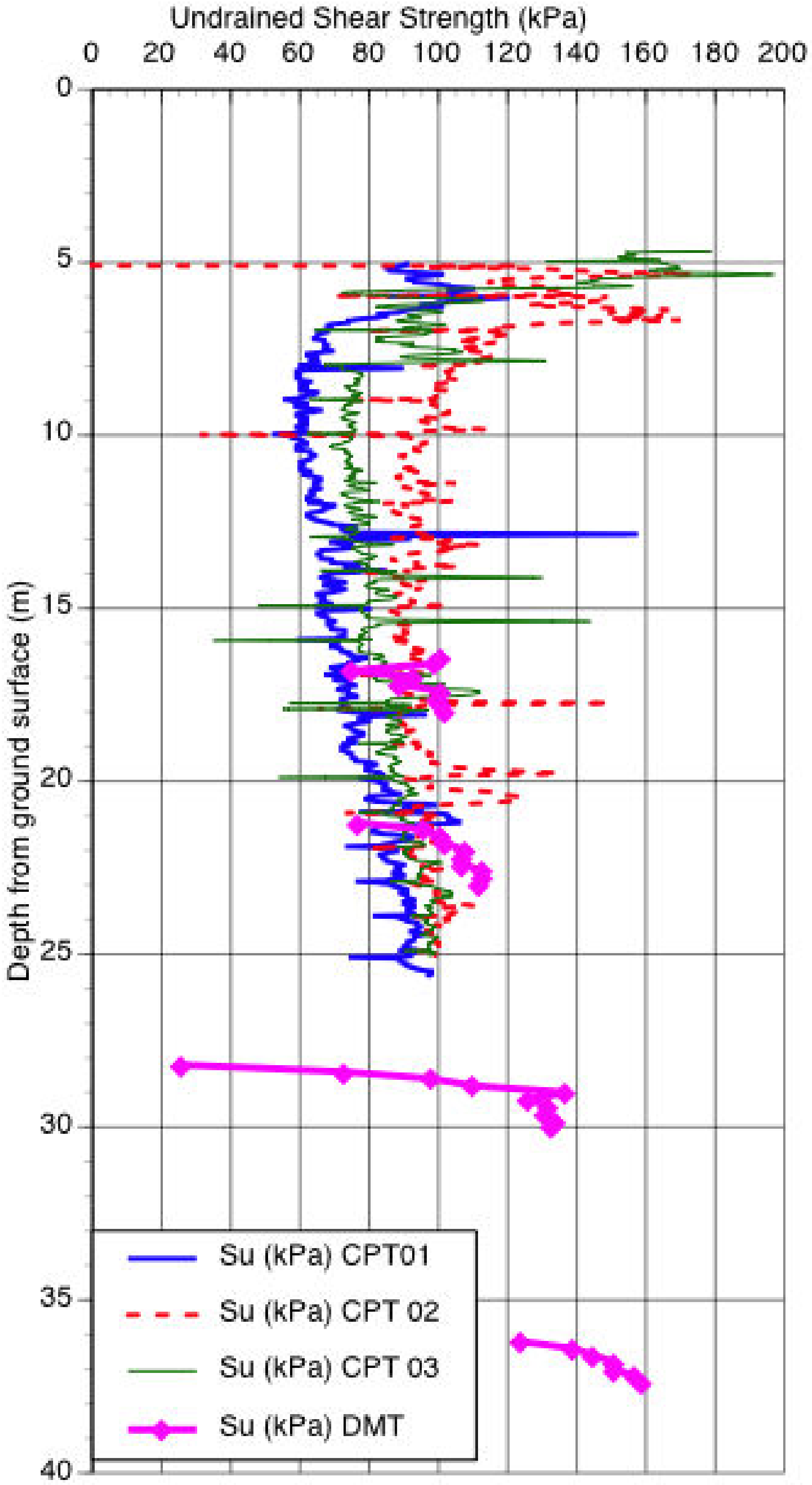

Figure 3. Undrained shear strength obtained from DMT and CPT with N_k= 11 calibrated on DMT for site 1

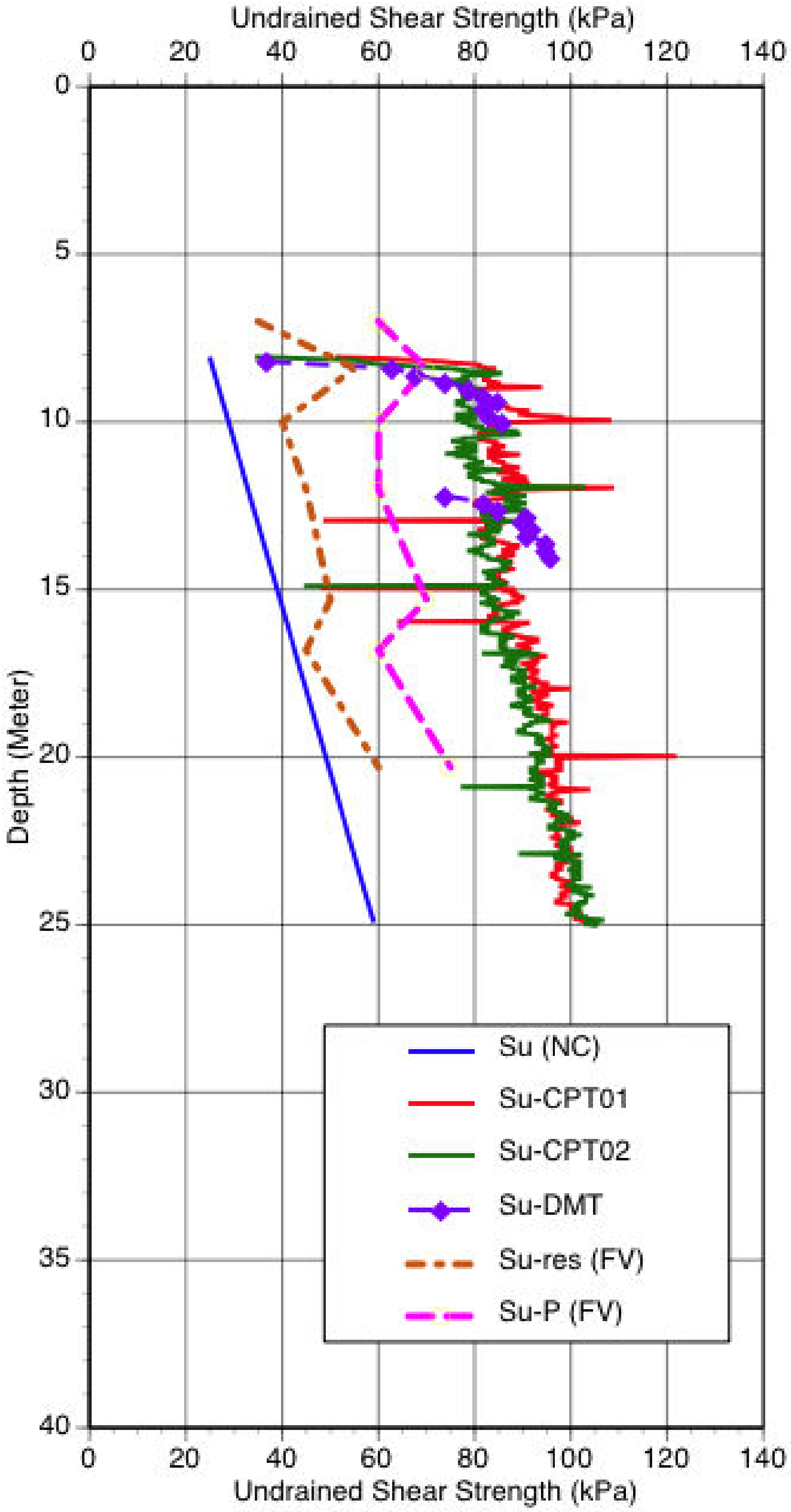

Figure 4: Undrained shear strength for site 2 obtained from DMT and CPTU with factor Nk= 11 for CPTU calibrated on DMT and compared to undrained shear strength obtained from field vanes during the site investigation in1966 for existing plant.

The resulting difference of pre-consolidation stress to overburden stress is 124 to 147 kPa which is closer to those obtained from in-situ tests. Longer load increments lead to a lower preconsolidation stress (Ladd, 1977 &1990; Steiner et al. 1992).

3.3 *Evaluation of preconsolidation stresses and undrained shear strength*

For the two sites a reliable knowledge of preconsolidation stresses and undrained shear strength is important. The data for the DMT and CPTU were evaluated with the software available for instruments, commercially available software (CPeT-IT) and further elaborated with spreadsheets and graphing programs.

The evaluated preconsolidation (Figs.1 and 2) are substantial above 15 m depth and agree for both sites. The preconsolidation stresses based on the DMT-Method (Fig. 2) tend to overestimate the true preconsolidation stresses.

Undrained shear strengths are presented in Figure 3 for site 1 and Figure 4 for site 2. The factor N_k to compute S_u from tip resistance q_c was calibrated on the S_u values determined by DMT, for both sites N_k =11 was estimated. At site 1 the boring reached 40 m deep and the undrained strength measured with DMT indicates an increase with depth and a larger overconsolidation below 25 m depth, this may be due to a temporary advance of the glacier. For site 2 (Fig. 4) the data from field shear vanes determined in 1966 are shown, they underestimate the shear strength. From DMT measurements (Figs. 3 and 4) one has to conclude that soil will be disturbed to a substantial depth (nearly one meter), DMT measurements must therefore proceed sufficiently (2 to 3 m) deep below the bottom of the boring.

4 CONCLUSIONS

The site investigations with a combination of in-situ and laboratory tests allowed a reliable characterization of soft ground for building construction. The clay layer has an over-consolidation pressure of 100 kPa and with a load of 40 kPa the raft is thus loading the ground in the over-consolidated range. For site 1 a raft foundation founded on the gravel layer has been proposed. Driven piles would terminate in similar quality clay as close to the surface. For the second site construction of the concrete structure is completed and has performed satisfactorily.

The costs of the site investigation amount to about 1/40th (2-3 %) of the piles.

REFERENCES

Ladd, C.C., Foott, R., Ishihara, K.; Schlosser, F. & Poulos, H.G. (1977) Stress-deformation and strength characteristics: SOA report, *Proc. 9th ICSMFE, Tokyo, 2, 421 – 494.*

Ladd, C.C. 1990. Stability Evaluation during staged Construction, 22nd Terzaghi lecture, Journal of geotechnical Engineering, 117, No. 4, 537 – 615.

Steiner, W.; Metzger, R.& Marr, W.A 1992. An Embankment on Soft Clay with an adjacent cut, *Proc. ASCE Conf. Stability and Performance of Slopes and Embankments II*, New York, 705-720.

Steiner, W. 1994. Settlement of an avalanche protection gallery founded on loose sandy Silt. *Proc. Settlement '94, ASCE Conference on Vertical and Horizontal Deformations of Foundations and Embankments*, New York, pp.207- 221.

Steiner, W. & Togliani, G. 1998. Experience from Site Investigations in Glacial Soils of the Alpine Region, Proc. First Int. Conf. on Site Characterization, Atlanta, Balkema, 1171-1176.

Zeindler, H. (1966) Site investigation for Wastewater treatment plant, Geotest, unpublished report.