Ove B HALLBERG
M. Sc., president GeoNordic AB

GENERAL USE IN SWEDEN OF PORE PRESSURE MEASUREMENTS IN CLAY LAYERS AS A GEOTECHNICAL TOOL FOR JUDGEMENT OF THE STATE OF CONSOLIDATION AND STABILITY

SPLOŠNA UPORABA MERITEV PORNIH TLAKOV V GLINENIH SLOJIH NA ŠVEDSKEM KOT OSNOVA ZA PRESOJO STOPNJE KONSOLIDACIJE IN STABILNOSTI

1. SWEDISH GEOTECHNIQUE
-the early days

Sweden is one of the largest countries in Europe with a range from south to north of approx 1.700 km and an area of approx 450.000 km2. When travelling in Sweden, you will very soon notice major changes regarding the geological conditions, specially when going in the south-north direction. Generally speaking, the southern part of Sweden is very similar to Denmark and northern Germany. In the northern part, specially close to the Norwegian borderline, we find most of the high mountains.

Almost everywhere we can see traces of our last glacial period that ended approx 10.000 years ago. Some of the most obvious traces are caused by iceriver streams, e.g. gravel drums and large presences of clay. We have a lot of geotechnical problems, related to clay such as consolidation and low stability. Therefore, geotechnical science has always been very important in our country, a large number of geotechnical tools, instruments and investigation techniques have been developed. Swedish geotechnicians have a very good reputation internationally.

Swedish geotechnique was more or less born due to the extensive external erection of Swedish infrastructure (roads, railways, harbours) in the beginning of this century. An interesting fact is that the Swedish Geotechnical Institute has its origin in the geotechnical commision of the Swedish Railway Company, SJ.

The geotechnical commision was founded after a landslide in Getå (170 km south of Stockholm) in 1914. The landslide destroyed a part of the railway, only a few minutes before the train arrived. The catastrophe was a fact. The train fell down and caught fire. A lot of passengers were killed, many of them in the flames of the burning train. There is a terrible story about a man, walking through the train, trying to help the people jammed. The ones he could not help getting free, he killed by use of an axe before the flames reached and tortured them. We do not know for sure whether this story is true or not but we know that Swedish geotechnique of today would not be what it is without the landslide in Getå, 1914.

2. CLAY RELATED PROBLEMS IN SWEDEN
-pore pressure readings as a way of solving the problems

The clay related problems are varying when you compare different parts of Sweden. In most parts however, in the Stockholm area for example, the main problems have been related to consolidation, usually due to a falling groundwater table. One good example is Huddinge, a suburban south of Stockholm. In the early 1960's, large areas in Huddinge were built upon. The clay layer thinkness was usually 20-30 meters. Long piles, installed to contact with the bedrock, were used for all buildings but for open areas, reinforcement was not regarded as necessary. Usually, the ground of these areas were made tight, covered with stone or asphalt. Due to this, the rainwater was not infiltrated as before but was led into the sewer systems. Soon, the groundwater table began to fall and the clay layer was slowly consolidated. Settlements of more than 2 meters have been noticed.

Another example of the influence of a falling groundwater table is a problem caused by tunnels in the bedrock for electrical lines, telephone lines and for the subway in the Stockholm area. At first, we did not realize the importance of making these tunnels water tight. Therefore, they became excellent horisontal drains and the clay layers above were consolidated which caused settlements.

Today, we have an understanding of the major importance of keeping the groundwater table at a constant level. Pore pressure is today measured on a regular basis in thousands of points in the Stockholm area. Due to this, we do not only have an effective checking of the groundwater table, we can also soon discover the exact location of leakage points (in a tunnel or similar), provided the measurement points are not too distant from each other.

In the Gothenburg area (south-west part of Sweden), a more typical problem is low stability in clay layers. Close to Göta Älv (the river from lake Vänern to Gothenburg), there are large, low stability areas. In the thick clay layers on both sides of the river, there are thin sand layers with a certain degree of inclination.

In some cases, the sand layers stand in hydraulic connection with high groundwater aquifers. After peroids of extensive rainfall, high water pressures can be transfered through the sand layers which might cause landslides. At least 40-50 small size landslides occur every year. Large land slides are fortunately not usually occuring. The most well known large size slides in this region were in Surte 1951 and in Tuve 1976. In the latter case, 10 persons were killed and more than 50 houses were totally destroyed. The Tuve landslide started in the afternoon about 4 pm. Most of the inhabitants in Tuve were still on the way home from school or work. If the slide had occured only one hour later, the number of victims easily could have been 10 times higher or even more.

In low stability, built upon areas, it is from a security point of view, necessary to have a careful control of the stability situation. For this purpose, pore pressure measurements are very important. In "high risk areas", there are hundreds of measuring points in which pore pressure as well as inclination is measured. In many cases, these measuring stations are totally automatical. Pressure transducers and inclinometers are connected to data loggers and remote reading is performed by use of telephone modem. Warning systems are built in and when a critical value is noted, measures can be taken. These measures are usually pumping in vertical drain wells in order to lower the pore pressure temporarily. Under extreme conditions, the inhabitants are evacuated until the area is regarded as safe again.

3. "ACTIVE DESIGN" IN SWEDISH GEOTECHNIQUE

The conseption "active design" in the geotechnical science has its origin in Sweden. Active design means that we perform very careful geotechnical investigations prior to the building phase. These investigations make it possible to decide exactly where and how much to reinforce. During the building phase, we keep on measuring and we can therefore, in all phases and at any time, make changes regarding reinforcement.

A successful active design is provided skillful engineers as well as high quality and accurate instruments. Well performed, active design is an excellent way of lowering costs and avoiding future problems. On the other hand, if the active design failes, we might get very high and unexpected costs and a lot of technical problems.

4. A NEW GENERATION OF SWEDISH GEOTECHNICAL INSTRUMENTS FOR PORE PRESSURE READINGS

The decire for active design made it necessary to develope more accurate geotechnical tools. The most important and also most commonly used tool for making active design possible, is pore pressure readings. Until the early 1970's, there were a lot of different types of pore pressure devices, hydraulic systems as well as electronic, vibrating wire systems. However, the accuracy and the reliability was usually very poor.

A wellknown Swedish geotechnician, Dr Bengt-Arne Torstensson, soon realized that in order to raise the quality of geotechnical investigations, it was absolutely necessary to develope more accurate instruments for pore pressure readings. So he did! This was the birth of BAT Groundwater Monitoring System, a Swedish system of equipments, used all over the world, today manufactured and offered for sale by GeoNordic AB.

By using one single transducer for measurements in a large number of points, Dr Torstensson achieved major advantages. This way of measuring made it possible to perform a reference reading of a known pressure after each pore pressure reading. Due to this, the accuracy raised from several decimeters of H2O to plus/minus 10-15 mm of H2O. This new instrument was more or less a revolution regarding geotechnical field measurements. Since then, the BAT system has been further developed. In the early 1980's, Dr Torstensson developed a new leakproof quick connect, "the BAT needle connection", which made it possible to shorten the time needed for a pore pressure reading from up to 60 minutes to approx 2-3 minutes. The BAT connection also made it possible to develope the BAT Groundwater Sampler and the BAT Permeameter. During the past years, development of the BAT system can mainly be refered to instruments such as data loggers (for pore pressure measurements) and field computors (for permeability measurements).

5. PORE PRESSURE MEASUREMENT IN SWEDEN TODAY -examples

For what purposes are we today using pore pressure readings and in what ways? In fact, a general answer is already given. Pore pressure reading is an important part of a control system for state of consolidation and stability. Pore pressure reading is also of great importance for all kinds of standard geotechnical investigations. Below, I give more detailed examples of how the pore pressure tool is used in Sweden.

5.1 Control of state of consolidation

Swedish hydrogeological conditions are usually easy to describe. The different layers in the soil profile are easily defined and there is in most cases only one groundwater table.

A typical Swedish soil profile (e.g. in the Stockholm area) is a 5-10 meter clay layer on top of a 2-3 meter friction soil layer (usually morain) on top of the bedrock. The groundwater table is usually 1-2 meters below the ground.

In order to have control of the state of consolidation in clay layers, a number of "pore pressure stations" are installed. Such a station usually consists of 2-4 piezometers at different depths in the clay layer and an open pipe (or in some cases, an additional piezometer) installed in the friction soil below the clay. We compare the pore pressure values with the water level in the open pipe ("the hydrostatic line value"). If the pore pressure values are higher than the hydrostatic line value at a certain depth, we know that we have ongoing settlements in this part of the soil profile.

Pore pressure stations are usually checked 2-4 times yearly. Continous measurements (by use of loggers) is in most cases not needed.

A special kind of consolidation control is measurement of pore pressure in preloading projects. In most cases, preloading is performed in combination with vertical drains, either standard geotextile drains or lime columns. This kind of reinforcement is usually performed for highways and railways. A special example is Arlanda International Airport in Stockholm. The third strip is now under construction. Soil conditions are very bad, the strip will pass through a huge gravel drum, through a rock hill and through an area with an up to 25 meter thick clay layer with peat on top. The peat is removed. The clay area is drained by use of vertical geotextile drains 0.5 meter distant from each other. 0.5 meter of course sand is loaded and on top of that, a temporary landfilling of 15 meter of blasted rock. The consolidation is going on rapidly which of course is the whole idea. The settlement is measured continously (settlement gauges) as well as pore pressure in a large number of points.

5.2 Control of stability

As mentioned before, high permeability (thin) sand layers are the usual reason for general stability problems in clay areas. In order to control the stability situation, the water pressure in these sand layers must be measured. If we suspect that we have a stability problem, the first task is to find out whether there are sand layers or not and if there are, to vertically locate the sand layers very carefully. After that, we know exactly where to install the piezometers. The need for high accuracy in location of the sand layers is due to the fact that these layers might be very thin. In Sweden, the most commonly used tool for search and location of sand layers in clay is Cone Penetration Test (CPT) sounding.

By way of distinction from the standard kind of consolidation control, stability control usually requires continous measuring. This is easily realized considering that the water pressure in sand layers might change dramatically within a very short period of time. Critical values can be reached within hours or even faster. Due to this, control stations in low stability areas are usually connected to data loggers and measuring values are automatically transfered by remote reading to data equipments with built in warning systems. In this way, measures in order to locally and temporarily lower the pressure by pumping, can be taken. In some cases, even these measures are taken automatically. One example of such an automatical system, is installed on the east side of Göta Älv close to Lilla Edet.

5.3 Standard geotechnical investigations

For all kinds of geotechnical investigations in clay areas, it is essential to get knowledge regarding the groundwater table. In some cases, separate measurements are enough, in other cases, it is preferable to get results of automatical readings over a longer time period.

In Sweden, the BAT pore pressure device is almost the only one used. There are mainly two ways of using the device:

*separately (manually) performed measurements

*measurements by automatical data logging.

In either case, installation is performed in the same way. A BAT pore pressure filter tip is installed in the ground. Installation is easily performed, mainly due to the fact that there are no built in electronic parts. The tip can therefore be pressed down with large force or even hammered down to the depth decired.

Separate readings is the original BAT procedure. The field operator goes to the first measuring point, the pressure transducer, hanging in the cable, is lowered down the pipe until it reaches the filter tip. The BAT needle connection makes the transducer connect to the filter tip, the water pressure is transfered through the needle to the transducer and within a few minutes, we can read a stable pressure value (in meter H2O) on the display of the read-out unit. The transducer is taken up again, the operator goes to the next measuring point and repeats the procedure.

For automatical readings (autologging), it is necessary to use one transducer cable for each filter tip installed. After connection of the transducer to the filter tip, the logger mode is entered on the read-out unit, measurement frequency is chosen and logging is started. Measurement frequency can be chosen from one measurement/3 sec to one measurement/59 hours. Logging capacity is 4.000 values and the maximal battery capacity is approx 12 months, using a standard 9 volt Alcaline battery.

6. SUMMARY

In order to perform careful and accurate geotechnical investigations, it is of great importance to use reliable tools and instruments. Development of geotechnical investigation procedures are also provided we can measure geotechnical parameters with a high degree of accuracy. For investigations in clay areas, pore pressure is one of the most important parameters.

When we claim that it is necessary to measure with high accuracy, we mean in fact two different kinds of accuracy:

*the pore pressure value shown in the display must be accurate

*the value must be related to a very specific depth or part of the soil profile, e.g. when we measure the water pressure in very thin sand layers. The pressure must be related to the sand layer, even when the layer has a thickness of only 10 mm.

BAT Pore Pressure device, included in BAT Monitoring System, is probably the most accurate and cost effective pore pressure device available. It can be installed with a very high degree of accuracy and due to the "high tech" transducers used, measuring accuracy is very high within a large pressure range.