Construction site investigation at Tønsberg hospital area by combined shear wave reflection seismics and geotechnical drilling

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Aim of the survey

In Nordic countries, so called quick-clays play a important role regarding safe building settlements, especially for essential infrastructures. Deposited in a marine or brackish environment originally, quick-clay formations composed of silt and clay are exposed to freshwater due to the isostatic uplift above sea level after deglaciation. This caused leaching to low salinity, which may destabilize the formation, up to a sudden liquefaction collapse. The detection of safe building ground e.g. bedrock and the knowledge of the internal soil structure above is therefore essential in areas prone to quick-clay deposits.

The central hospital of Tønsberg (Sykehuset I Vestfold, SIV), Norway, planned to expand the hospital by new buildings towards an area prone to quick-clay. Former drilling investigations indicated a complex bedrock topography below soil, clay, silt, and anthropogenic infills estimated up to 25 m thickness. Included boulders caused a high uncertainty to distinguish between bedrock, weathered bedrock and boulders by drilling, requiring a dense drilling grid in the whole area. Ground Penetrating Radar (GPR) failed due to the high electric conductivity in the soil and the disturbing urban environment. Seismic Refraction could not provide the resolution required. Therefore SIV requested NGU as geophysical project leader to prove shear wave reflection seismic prior to a focused drilling campaign. Due to the paradigm of this research target in Norway, NGU established a joint research expertise including GEOSYM and LIAG, enabling the full range from shallow reflection seismic acquisition and geotechnical analysis towards geological model building for construction site planning.

Acquisition parameters

Period:	6. – 11. June 2016
Instrument:	GEOMETRICS GEODE
Channels/rec:	71+ 1 aux
Seismic Source:	ELVIS version 3-S8 shear wave source system,
Sweep Type:	20-120 Hz linear, 10 s, 200 ms taper
Recording:	12 s , 2 s after correlation
Sampling int.:	1 ms
Recording filter:	out
Spread type:	variable split-spread
Geophone type:	SM6 H (10 Hz), single units mounted on GEOSYM land streamer system, or commonly planted in soil at non paved areas
Receiver interval:	1 m
Source interval:	2 m
Vertical stack:	2-fold [+Y]-[-Y] alternated vibrations
Total length:	1389 m
Total data:	4.36 Gb
No. of Records:	1440

Results

Due to the actual building density and construction activity the area since the early mid-age, the subsurface top partly consist of man-made infills of different material which hampered the seismic imaging and the drilling. In the eastern part of the investigation area the bedrock was detected only 1-3 m below the surface, whereas in the northern and western part up to 16 m sediment cover were reached. The resulting bedrock topography and the internal bedrock structure show a significant tectonic overprint beside the expected glacial erosion at the top. In most of the cases, the clay and silt layer prone to liquefaction was found either underlaid with sand or in direct bedrock contact. The seismic imaging of the sediment structures above bedrock was impaired both by the shallow investigation depth and the huge anthropogenic infills at the surface. The final interpretation of the depth-to-bedrock layer benefited from seismic and drilling results and from surface outcrop manifestations.

In the Southeast part of the investigation area the bedrock was detected very shallow to the surface with only thin or no cover of clay and silt. Foundation of new buildings in this part is expected to be carried out with small effort. In the Northwest area, close to the existing hospital buildings, the situation requires more effort due to a sediment cover of 10 m and more and a >16 m deep hole in the bedrock topography.

Conclusions

Despite surprisingly difficult and unexpected subsurface and environmental conditions regarding undisturbed wave propagation in the subsurface and an also difficult target geometry, the challenging mission to map the bedrock topography in the hospital expansion area could be solved successfully. This result benefited mainly from the close combination of shallow high–resolution seismic with geotechnical drilling investigation, which enabled precise depth referencing of the top bedrock and its expansion in the area of interest. Even some open questions still remain, this experimental project highlighted the capabilities to combine the methods.

Fig. 1: Satellite maps of the survey area. Tønsberg is estimated to be the oldest village in Norway, founded prior to 871 a.D. by the vikings. West of the hospital area (red circle) are the ruins of the castle funded around 1150, the heard of the settlement. The famous Oseberg ship was found 6 km Northeast in 1904, which construction is estimated to around 820. On the hospital expansion area buildings will rise up to ten levels.

Fig. 2: Seismic profile grid (black lines) in the hospital expansion area. Totally 14 profiles were arranged under strongly varying conditions, partly close to buildings or along a railroad track in the East. Profile label indicate profile name and receiver location at the line end position of the label. Bedrock outcrops are marked by red circles, green dots denote drilling locations.

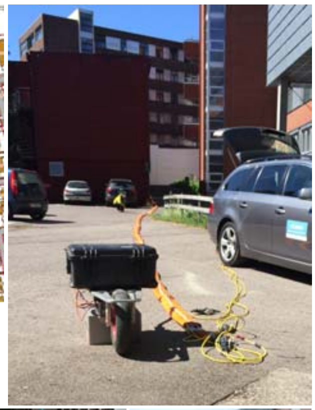

Fig. 3: Seismic data acquisition along the hospital extension area within ongoing traffic and hospital operation business. Precise positioning gained to a major challenge during seismic and drilling surveys in order to map the bedrock topography below surface.

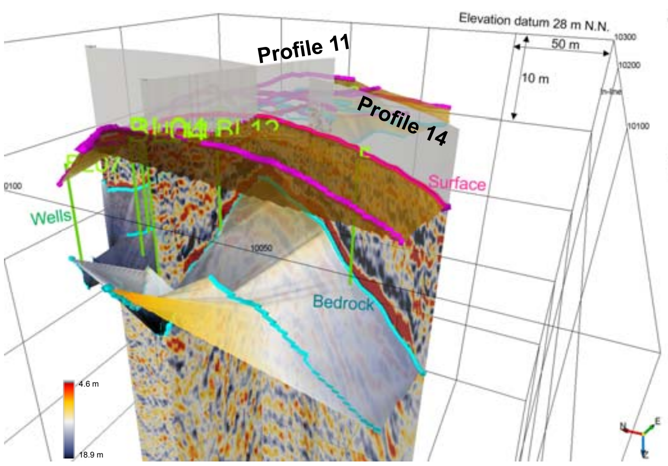

Fig. 5: 3D view (from Southwest) including the surface layer and the interpolation of the interpreted bedrock horizon (colour coded elevation) based on the seismic and drilling results. The top of the volume is referenced to elevation datum 28 m N.N.. Magenta lines show the geometry of the seismic profiles at the surface, light blue lines show the interpreted bedrock horizons. Wells are marked green and end at the top of the drilled bedrock. Since no cores have been generated during drilling, the depth-to-bedrock uncertainty is nearly 0.5 m. Further uncertainty of at least 0.5 m vertical is introduced by the GPS surveying in the area.

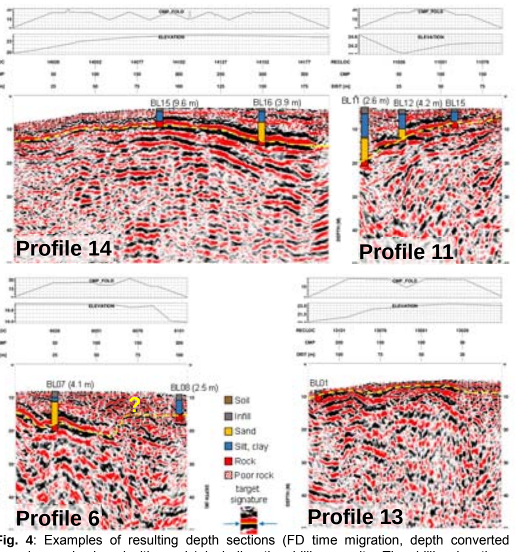

Fig. 4: Examples of resulting depth sections (FD time migration, depth converted based on seismic velocities only) including the drilling results. The drilling locations were selected subsequently to the seismic survey based on preliminary seismic results and the feasibilities in the area. Numbers in brackets show well distance in m perpendicular to the profile.

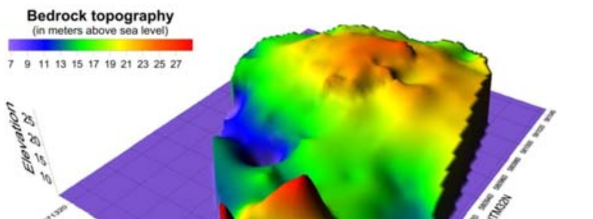

Fig. 6: 3D-model of the bedrock topography relative to elevation datum 28 m N.N. derived from seismic, boreholes and surface outcrop observations. The deep synclinals partly filled with soft clays close the existing buildings were the most surprising result compared to the initial asumptions based on existing well data.

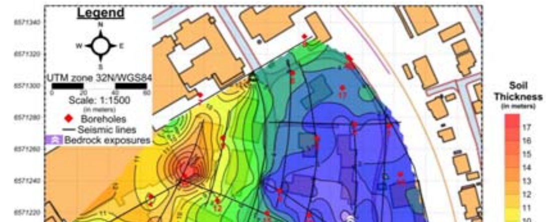

Fig. 7: Resulting map of soil thickness above bedrock. With the benefit of hindsight, the dense profiling and drilling grid was essentially required to map the subsurface structure sufficiently, in contrast to early cost-benefit estimations during the planning phase.

Acknowledgements

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