DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2006/51

Stimulation protocol for establishing hydraulic fractures in three set-ups

Deliverable D4

Bertel Nilsson, Bill Slack, Thomas Brøker & Knud Erik Klint

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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ABOUT THIS DOCUMENT

This report is a report of the deliverable D4 of the STRESOIL Project.

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Purpose	Deliverable report of D4 to EU in relation to Contract No. SSPI-CT-2003-004017
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1. Scientific Summary

This report presents the work done in Work Package 2 (Task 2-2) in the EU funded STRESOIL project on development of stimulations protocols. This stimulation protocol describes a step by step procedure, that has been followed when installing 21 hydraulic fractures within the Central Refuelling Station at the Kluczewo.

In summary, these steps include:

1. Installing a dedicated well by hammering to desired depth a piece of steel pipe fitted with a drive point.
2. Dislodging the drive point downward to expose a short section of open hole.
3. Cutting a thin notch in the wall of the borehole by means of a horizontal hydraulic jet.
4. Pressurizing the notch with liquid so as to nucleate a horizontal fracture from the hoop that constitutes its outer edge.
5. Delivering sand-laden slurry to the open borehole section of the well so as to propagate the fracture.
6. Monitoring the injection pressure and surface deformation, which permits deduction of the fracture form.

It is important to remember that the protocol needs to be adjusted to specific project objectives and site constraints.

2. Introduction

This report was written as part of the STRESOIL project - Work Package 2 (Task 2-2). The report outlines the stimulation protocol that has been followed when installing hydraulic fractures at the field site in Kluczewo, Poland.

This report covers the documentation of the following deliverable:

- D4: Development of stimulation protocols

The report was prepared according to the following milestone:

- M5: Guidelines for establishment of hydraulic fractures at the Kluczewo site.

2.1 The STRESOIL project

The "fractured soil" stipulated in the STRESOIL project title (In Situ STimulation and REmediation of contaminated fractured SOILs) is glacial till – one of the most common geological sediments in the European countries. The low permeable, fractured till – while contaminated – represents a great challenge for environmental cleanup procedures. Particularly, if the contamination is present in the unsaturated zone removal of the pollutants becomes very difficult.

A combination of field experiments involving various approaches, laboratory, and investigation of soil and water samples as well as computer simulations will be employed to solve the problem. A combined effort of a team from Greece, France, Poland, Denmark and USA should within a three years period result in selection of a suitable method for cleanup of the Kluczewo site in NW Poland – the site selected by STRESOIL for field experiments. It is expected that findings of the project will have significant practical applicability in several Community countries and else where with same geological setting.

2.2 Goals and scope

The scope of Work Package 2 is to design and install the stimulation technology in three locations at the Polish field site.

The following tasks are specified in WP2:

Task 2-1 Soil mechanics and hydraulic fracture propagation
- Simple fracture propagation modelling will be employed
- Geotechnical and textural properties of the glaciogenic clayey deposits will be determined with lab-tests

The reporting of this task is identical with Section 4.1 in this report (D4).

Task 2-2 Development of stimulation protocols

- Combining geotechnical / geological / hydrogeological / NAPL data (WP1) with results of task 2-1 in order to formulate some instructions for the optimal adjustment of the directional permeability in the low permeability soils

This subtask will be reported in report D29 (Recommendation scheme for remedial strategies in fractured low permeable soils).

- Development of stimulation protocols

The reporting of this subtask is identical with this report (D4).

- Selection of three locations

This subtask is reported in report D8

Task 2-3 Installation of *on-site* stimulation set-ups in Cell 1, 2 and 4

- Installation of a number of fractures at three locations. Each set-up will cover an area of approximately 10x10m.

The reporting of this task is given in the deliverable D8 (Installation of on-site stimulation set-ups).

Task 2-4 Hydrogeological characterisation of the hydraulic conditions in Cell 1, 2 and 4.

- Performance of hydraulic tests on all three cells prior and after installation of the hydraulic fracture set-ups

The reporting of this task is given in the joint deliverable report D5 and D14 (Results of hydraulic tests performed before and after stimulation of the three cells in Kluczewo, Poland).

3. The hydraulic fracturing method

The fractures were created according to methods outlined by the United States Environmental Protection Agency as the result of technology demonstration projects conducted in the late 1980s and early 1990s (e.g. USEPA, 1991; 1993; 1994).

3.1 Fracture Wells

Fracture wells were installed by a direct-push / vibratory method. The drilling machine weighed 12 ton and had a stroke of 6.2 meters, so wells shallower than 6 meters (all wells for this work) could be constructed with a single length of casing. Still, deeper wells utilized multiple pieces of casing welded together, and some shallower wells were composed of welded multiple sections to realize efficiencies in casing use. The well casings were nominal 3-inch thick wall (1/4 inch) ferrous pipe. In preparation of well construction, each casing was fitted with a steel drive point at the lower end (Figure 1a & b), and the upper end was fitted into the socket of a vibratory hammer. After confirming vertical orientation, the casing was inserted by application of the machine weight and hammer vibration. The hammer vibrated up to 500-600 vibrations per minute (or 9-10 Hz), but the speed of advancement and frequency were varied to optimize installation. Insertion of casing typically required less than 30 seconds. When casing segments needed to be joined, the hammer was move upwards, and a jig attached to the upright casing to align the subsequent section. A blacksmith welded the pieces together with an electric arc. When the casing was installed to target depth, the drive point was dislodged to expose a short segment of open hole, and a stub of threaded thick-wall pipe was welded onto the upper end of the casing to provide for subsequent attachment of hoses, etc. Cutting and welding could be performed at will to adjust the stick-up – the elevation above ground surface – for each well.

The drive points in these wells were dislodged 20 cm downwards to expose 10 cm of open borehole. Two-inch PVC filter and riser were installed in the wells in one of the test cells (Cell 2) at the Kluczewo field site in Poland, so that preliminary pneumatic conductivity tests could be performed (Nilsson et al., 2006)).

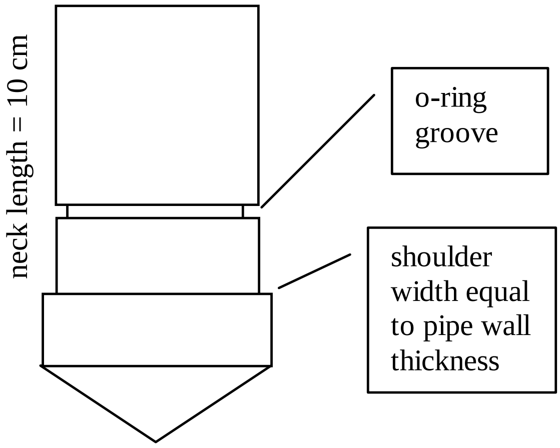

Figure 1a. Schematic of Drive Point

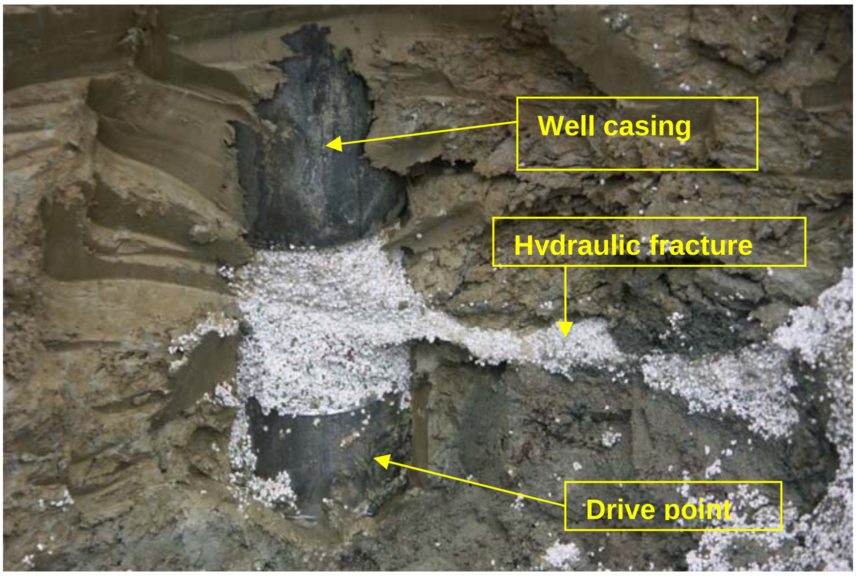

Figure 1b. Picture of drive point, well casing and the resulting sand filled hydraulic fracture in excavation of cell 5.

3.2 Mixing and Injection Equipment

Fracturing slurry was prepared according to typical practices. Guar solution was prepared and allowed to hydrate in 600 litre mud-mixing vats. Borax and breaker solutions were prepared in 20 litre buckets (Fig. 2a). Sand was staged in an elevated hopper. Guar, sand and additives were mixed in an inclined screw conveyor that could be positioned arbitrarily and operated at a range of speeds to obtain desirable consistency. Guar was fed to the mixer at constant rate by a variable speed positive displacement pump, while sand was metered from the hopper by means of a variable speed screw feeder (Fig. 2b). Additive solutions were transferred by small pumps, and their rates adjusted by valves integral to variable area flow meters. All of these components derived power from electric motors.

The slurry discharged from the mixer into a small receiving hopper fixed to the inlet of a progressing cavity pump (Fig. 2c). The discharge of the pump was conducted by either 10 cm (4-inch) or 5 cm (2-inch) hose to the injection well (Fig. 2d). The pump was driven by hydraulic power.

a) Guar gel, borax and breaker solution

b) Mixture of guar and sand slurry

c) The slurry discharged from the mixer into the small receiving hopper

d) 2 inch hose to injection wells

Figure 2. Slurry mixing equipment and procedure

3.3 Coated sand filling

The three coloured sand fill materials have all been coated with an epoxy impregnation, that are resistant against the types of petroleum products and aviation gasoline, which are contaminating the field site. The grain size range between 0.9 and 2.0 mm and has a grain size distribution as shown in Figure 3.

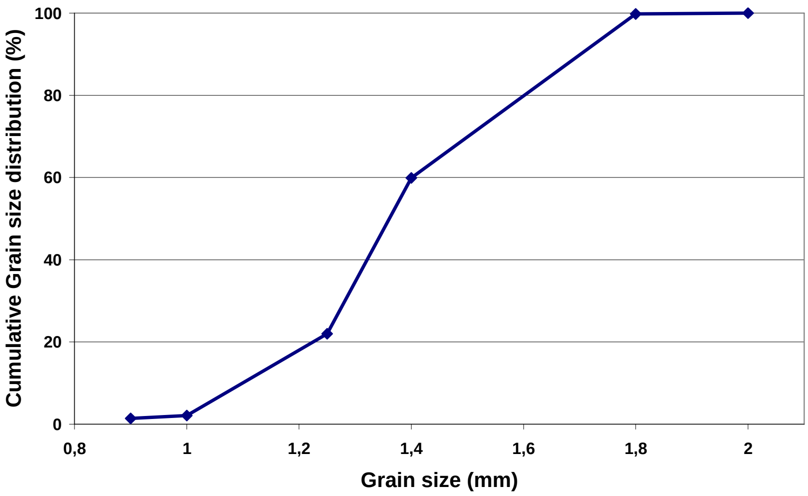

Figure 3. Cumulative grain size distribution of the sand materials that are filling the hydraulic fractures.

3.4 Notching

Notching was accomplished by a trio of horizontal hydraulic jets operated at 150 to 200 bar driven by a 5kW pump. The nozzles were mounted symmetrically such that the stand-off (distance from the face of the nozzle to the face of the borehole) was about 1 cm. For each fracture, the jets were operated at the target elevation and at a second elevation 1 cm above the target for a total of five minutes. Notching activity produced a stream of soil particles suspended in water. The soil particles were generally characteristic of the particular unit targeted. The produced stream was discharged to ground surface where biodegradation can be expected to consume any contaminating fuel/oil discharged.

Figure 4. Notch the borehole by applying a trio of hydraulic jets.

3.5 Monitoring

Fracture creation was monitored by two sets of measurements, pressure and uplift. Injection pressure was indicated by a gauge (0-10 bar) fixed to the discharge of the progressing cavity pump, and injection well head pressure was sensed by an electronic pressure transmitter (0-6 bar). The electronic signal was recorded by a data logger, which later was queried by a computer. Uplift was monitored by surveying with a Sokia auto level and a collection of graduated staffs that were driven a few centimetres into the ground and extended ~150 cm upwards (Figure 5). Surface elevations were recorded before and after fracture creation at as many as 19 locations, which were distributed along six symmetrically placed rays that emanated from or near the injection well. The uplift array was oriented with north-south generally parallel to the long wall of the service building; a compass indicated this nominal north to be approximately N12°W.

Figure 5. Survey measurements of terrain uplift during injection of hydraulic fractures in the subsurface

4. Stimulation protocol – step by step

Hydraulic fractures have been created in the subsurface at the Kluczewo Airfield field site following the following stimulation protocol – step by step. In summary, these steps include (1) installing a dedicated well by hammering to desired depth a piece of steel pipe fitted with a drive point, (2) dislodging the drive point downward to expose a short section of open hole, (3) cutting a thin notch in the wall of the borehole by means of a horizontal hydraulic jet, also referred to as notching, (4) pressurizing the notch with liquid so as to nucleate a horizontal fracture from the hoop that constitutes its outer edge, (5) delivering sand-laden slurry to the open hole section of the well so as to propagate the fracture, and (6) monitoring the injection pressure and surface deformation, which permits deduction of the fracture form.

Since two projects are commonly not identical in sense of design and implementation, then a description of fracturing methods may need to satisfy specific project objectives and site constraints. The site-specific factors that are critical include target depths for the fractures, remedial processes to be used, surface access, subsurface obstructions such as utilities or existing wells, schedule and available budget.

4.1 Insert casing

Push casing equipped with a drive point to desired depth (Fig. 6a). Either hammering or direct push can provide the required force. If convenient, a pilot hole may be drilled to a depth a few feet above the fracture target zone. Also, a small diameter soil core may be taken through the target zone prior to installation of the casing. The casing should be inserted at least 1 ft into native soil, so that stress induced by lateral displacement of soil can affect a sufficient seal for subsequent fracturing pressures. The drive point can be designed to include a sump or rat-hole, which permits subsequent installation of a pump below the level of the fracture.

4.2 Expose borehole

Displace the drive point downward by a few inches to expose a cylindrical wall of soil (Fig. 6b). The casing remains stationary. Generally the drive point can be moved with less force than used to drive the casing.

4.3 Notch the borehole

Nucleate the fracture by applying pressure to the well and notch (Fig. 6c). The disc shape of the notch focuses stress along its perimeter, and the fracture nucleates along that edge.

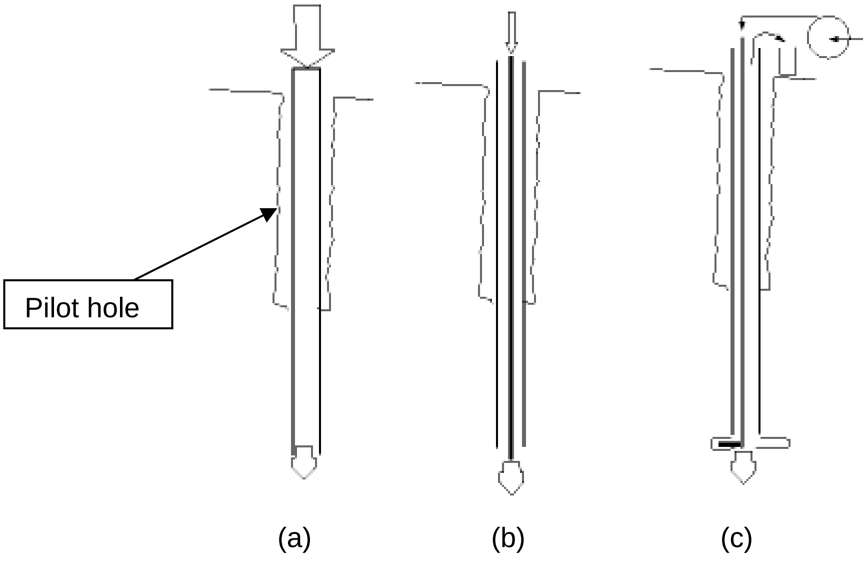

Figure 6a-c. Expose the borehole (a); notch the borehole (b) and nucleate the fracture by applying pressure to the well (c) (From www.frx-inc.com). The sump is not shown in this sketch. Remark: In the STRESOIL project has the fracturing wells been installed without pilot holes to minimize the risk for by pass flow of injected steam along the outer side of the casing.

4.4 Propagate the fracture

Propagate the fracture to desired size by injection of slurry of granular material in a suitable carrier fluid (Fig. 6d (initial condition) & 6e). The carrier fluid contains commonly guar gum gel, which is a food additive and when mixed with water forms a short chain polymer with the consistency of molasses. A cross-linker is added to lengthen the polymer chains and create a thick gel with rheological properties that allow it to suspend large concentrations of solid particles yet permit the slurry to flow when pumped. An enzyme is added to the gel that breaks down the polymer chains in a few hours to a thinner liquid. Fluid and solids are mixed prior to pressurization. Generally positive displacement pumps are best suited to granular slurries, so propagation usually is conducted at constant volumetric rate. An optional hollow drive point, not shown in this sketch, provides a rat hole below the fracture. During subsequent remedial operations a pump can be installed in the rat hole, thereby effecting maximum drawdown on the formation surrounding the fracture.

4.5 Data collection

Monitor process and geophysical parameters to facilitate interpretation of resultant fracture form (Fig. 6f). Common measurements include:

I. Pressure provides real-time information about fracture orientation because horizontal and vertical fractures generate distinctly different signatures in pressure logs.
II. Upward displacement of the ground surface (also known as heave or uplift) observed by use of surveying equipment. The observation station is placed well outside the expected radius of the fracture and remains stationary. Arrays of as many as three dozen graduated staffs have been used to define surface movement over a fracture. The topology of uplift provides indication of fracture plane and aperture.
III. Angular deformation of the ground surface as measured by tilt meters. Small changes in surface orientation, which may be critical under some structures or equipment, can occur without significant uplift, so tilt meters can provide assurance of adequate fracture control. In any case, tilt data can be integrated and compared to uplift measurements.
IV. Measurement of electromagnetic potential or current. When the injection well and fracture fluid are excited electromagnetically (not indicated in the schematic), the resultant field can be measured by an appropriate sensor. An inversion algorithm that is calibrated for the properties of the soil matrix and fracture material can be run on a suitable computer to obtain a real-time description of fracture form.

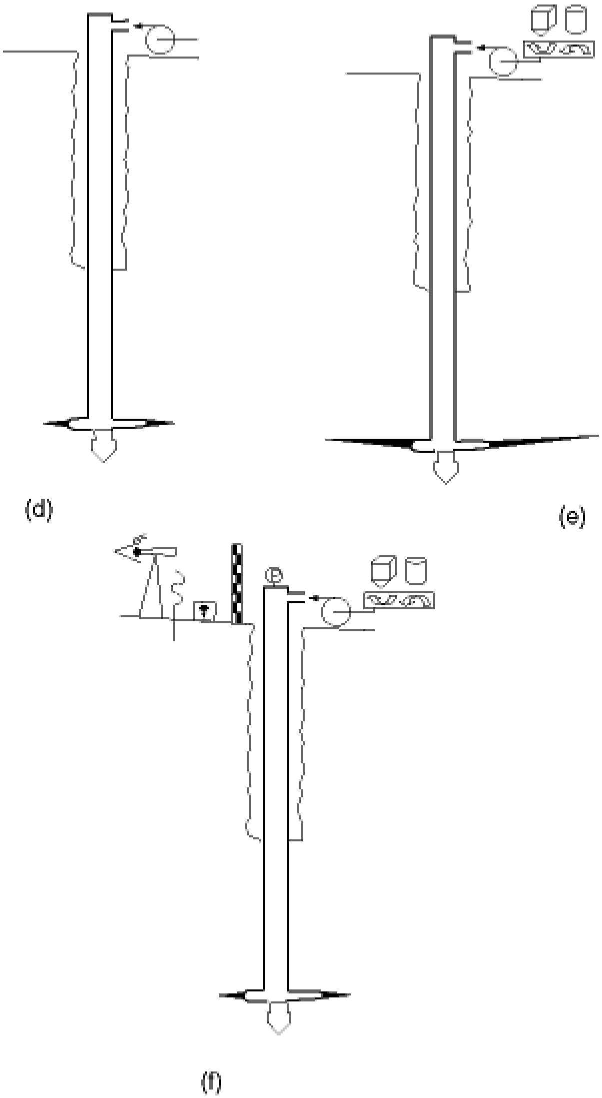

Figure 6 d-f. (d) Initial fracture propagation; (e) further development of fracture and (f) monitoring of slurry pressure / rate and surface uplift (From www.frx-inc.com).

5. Conclusion

This report presents a step wise stimulation protocol that has been followed when installing 21 hydraulic fractures within the Central Refuelling Station at the Kluczewo field site.

In summary, these steps include:

1. Installing a dedicated well by hammering to desired depth a piece of steel pipe fitted with a drive point.
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6. Monitoring the injection pressure and surface deformation, which permits deduction of the fracture form.

It is important to remember that the protocol needs to be adjusted to specific project objectives and site constraints.

6. Acknowledgement

The present work was carried out within the project In Situ STimulation and REmediation of contaminated fractured SOILs (STRESOIL). The project is funded by The European Commission (Contract Number SSPI-CT-2003-004017) within the Sixth Framework Programme (Global change and ecosystems).

7. Literature

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