Undergounding HDPE Fibreoptic Cables For Broadband Applications

Preliminary Evaluation

1 Introduction

HydroFoamer has developed a patented method for surrounding buried pipelines with closed-cell, rigid polyurethane (PU) foam. PU foam has a very high stiffness to weight ratio, with compressive strength of 40-50 psi. In layman's terms, this means that an average person can stand on a piece of foam with the dimensions of a cupcake. The foam layer protects the pipe surface against corrosion and mechanical damage. Additionally, the PU foam, which adheres very strongly to pipe and cable surfaces, provides additionally geotechnical stability in all 3 axes.

This set of properties gives unrivalled protection to buried pipes and cables. Supported by studies from NTNU (Trondheim University in Norway, the world's premier hydropower research institute) and a fully commercial project in the Norwegian arctic for Statkraft, the Norwegian state renewables giant, the use of PU foam also allows the use of native backfill, instead of imported aggregate or crushed and sorted material excavated from the trench.

Additionally, the use of PU foam as backfill leads to a very considerable reduction in the risks from exposure to respirable crystalline silica, which has become the subject of intense new 'health and safety' legislation for the construction industry.

Areas such as the hills & mountains covered by projects bringing new cable networks into remote areas are often subject to sub-arctic winter conditions, which cause frost heave, which places stress on buried cable systems, and particularly those that have hitherto been encased in concrete for dynamic loading conditions. The same need to counter cold weather also indicates the use of corrosive chemicals that can reduce the stress crack resistance of HDPE coatings over time.

The strategy of using the paved road network as the path of the cable system means that the buried cable system is subject to continuous, very heavy dynamic loading from traffic; encasing the cables in concrete gives a very high degree of mechanical protection in the short term, but the failure modes of concrete encasement can lead to forces that are intolerable to the relatively soft HDPE-covered cables: effectively, concrete doesn't flex to any degree of utility, and when it breaks, the failure planes shear straight through the cables.

Mechanical breach of the cable covering is likely to lead to a 100% loss of operational availability. In a system that stretches over hundreds of miles, it is highly likely that such failures will occur, and a FMEA analysis indicates that detection and amelioration are likely to be too late to avoid loss of operational availability. Detection of the failure location is difficult, meaning repair times will be long, which is a challenge in a time-critical data network infrastructure system on which businesses and consumers rely.

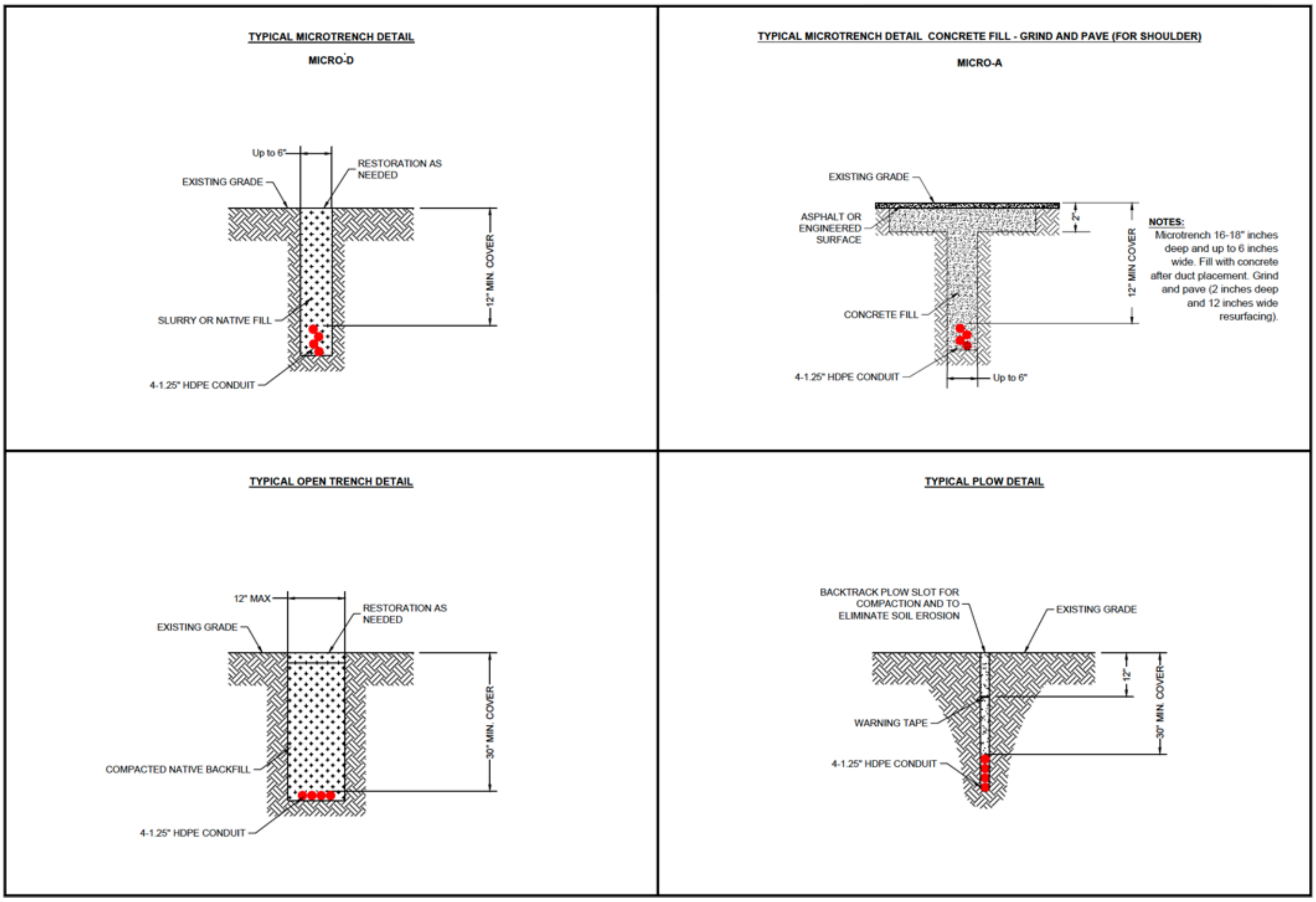
The HydroFoamer method allows a radical and rapid improvement in both the speed of installation and the physical robustness of broadband infrastructure. Rigid, closed-cell PU foam is inert and provides a perfect combination of protection against mechanical and chemical damage of the HDPE-coated fibre-optic cables, with flexibility that ameliorates the risk from the mechanical effects of dynamic loading and geodetic forces.

Aside from the increased level of mechanical protection, and subsequent reduction in risk of outage, HydroFoamer introduces very significant savings in terms of both absolute cost and speed of installation. Reducing the use of concrete and aggregate backfill is also highly beneficial for the environment.

2 Construction Methods

2.1 Standard Cable Laying

The HydroFoamer method fits into the classic laying process: survey, plan, excavate, lay & refill. As opposed to pipeline engineering, there is little geotechnical challenge for undergrounding cabling, because HDPE cable is flexible and continuous. Normally, a very narrow trench is dug, according to the soil and road conditions:



2.1.1 Excavation – 3rd Party

Excavation of the trench / microtrench is carried out according to one of the four methods in the above diagram. Control of the trench dimensions are the responsible of the construction company.

2.1.1.1 Micro-A – Grind and Pave

We do not believe that this method requires a full 12" wide grind, with the use of PU foam. In the case of either rigid or flexible pavement types, the mechanical properties of the PU foam should support a typical road load when covered with a 2" asphalt or engineered surface. We have included calculations for laying speeds for both trench formats, but we expect that Micro-D should be sufficient in most cases.

2.1.1.2 Open Trench

We do not believe that there is sufficient advantage in the use of PU foam to advocate its use as replacement for compacted native backfill, where there is no dynamic loading or other conditions that are likely to cause catastrophic failure of the fibreoptic cables, due to mechanical forces. <u>However</u>, there are benefits that accrue from reduced risk of subsidence due to ground settling, washout and animal burrowing, so the method can still be considered where these issues may arise.

2.1.2 Cable Lay – Collaboration 3rd Party & HydroFoamer

2.1.2.1 Trench Bed

HydroFoamer sprays a single-pass, 2-3" layer of foam into the trench for a given practical distance (typically 3-600', or the maximum of the hose length). This sets sufficiently to withstand the weight of the cable within 5 -10 minutes.

2.1.2.2 Cable Placement

The cable is spooled into the trench and placed in the middle of the top of the foam layer.

2.1.2.3 Upper Foam Layer

As soon as the cable is in place, HydroFoamer sprays a further single-pass 3-28" later of foam onto the top of the cable. The foam is fully cured within an hour. The depth of the foam is dependent on the expected dynamic loading conditions.

2.1.2.4 Backfilling

As soon as the foam has reach cure, the remaining part of the trench can be backfilled, and the (asphalt) surface reapplied or restored.

2.1.3 Wet Weather Conditions

It is likely that the construction will encounter periods of wet weather and rain tends to collect in trenches. Depending on the severity, there are different methods to ameliorate the effect of water in the trench.

2.1.3.1 Bentonite (Montmorillonite Clay)

Bentonite is a highly absorbent, commonly-used construction material that quickly absorbs standing water, leaving a heavy clay in place, and denying water to the polyurethane reaction. A thin layer of Bentonite can be placed into the trench, immediately prior to the production of the Trench Bed foam layer. Bentonite does not react with the polyurethane mixture.

2.1.3.2 Hydrophobic PU Foam

Standard PU foam reaches a hydrophobic composition very quickly in the reaction process. However, with large amounts of standing water, sufficient A-side (isocyanate) component will react with the water that the outer layer of foam becomes 'friable' or brittle on curing, because the reaction leaves an excess of B-side (polyol / MDI).

Normal 'surface wetness' does not lead to a critical level of 'friability'. However, if trench conditions are sufficiently wet that there is a risk of inconsistent or unacceptable foam quality, then there are standard foam formulations that are designed to be sprayed / poured directly into standing water. Such foam has comparable mechanical and long-term creep properties to 'normal' PU foam.

2.2 Cable Stabilization in Drilled Orifices / Tunnelling

Parts of any long-distance, standard cable trace require horizontal drilling, to minimize disruption to other activities. Ordinarily, a concrete mixture would be injected into the aperture between the cable and the surrounding drilled orifice. Our experience shows that use of concrete for stabilization is challenging, because the heavy mixture has a natural tendency to drop into cavities. Post-installation verification is near-impossible. This leads to potential gaps and subsidence risk.

The 'rise' behaviour of PU foam during the expansion phase of the reaction allows the PU mixture to move upwards into gaps and orifices of surrounding materials / soils, in a way that concrete mix cannot, except under unfeasibly higher pressure. PU has been used as grouting for many years, for example in geotechnical stabilization of rock bolts. PU foam has the added environmental advantage of being inert, whereas concrete has known issues with leaching. This is a considerable environmental win for any developer.

PU foam for this application can either be a standard 'hot mixture' for smaller volumes where rapid reaction and expansion is required, or a specialized geotechnical 'cold mixture' for larger volumes, where the foam needs time to enter cavities more slowly, before expanding. The end result is the same.

2.3 HydroFoamer Team & Collaboration with 3rd Party Construction Team

As the Cable Lay involves two foam laying operations, the most efficient method is to utilise two foam teams, fore and aft. The fore-team lays the Trench Bed, and the aft-team lays the Upper Foam Layer. The use of two teams allows near-continuous operation for a 10-hour shift; the foam rigs are self-contained and mobile and the area of operations allows the two spray teams to relocate continuously.

Obviously, HydroFoamer operations are reliant on efficient excavation and control of the trenching operations by the General Contractor, and coordination of the cable placement. This 'choreography' will rapidly reach optimum efficiency as the teams get to know each other.

3 Cable Protection

It is obvious that buried cable systems will not be subject to the same failure modes as those based on cables suspended on pylons and power line posts. The main remaining failure modes are mechanical and chemical, with geodetic as a remote minor failure mode (earthquake).

The cellular structure of closed cell PU foam is both an excellent load spreader and an extremely effective barrier against sharp objects in backfill, or from mechanical machinery such as digging equipment. In addition to this 'common sense' knowledge, calculations and tests show that a sharp, cone-shaped rock, with a base diameter of 3.5" and a length of 8" will penetrate less than 1/6th of an inch into PU foam, with a force of 11.6psi. Such a situation would be highly likely to compromise cable coating. A blunt object, such as a digger bucket, would lead to compression of the PU foam cellular structure, against the native soil behind the compression area, to the point where the backhoe / excavator bucket would be resisted by a combination of solid, load-spreading polyurethane and the solid cable itself.

To assist construction crews, foam can be coloured to give a visual clue to those working in an area with foam-buried cable.

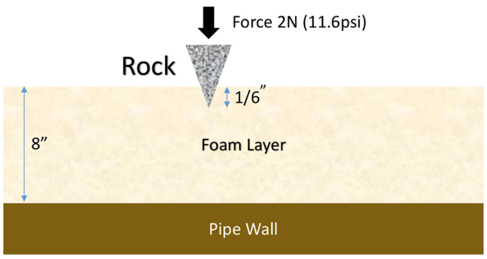


Figure 1 - Sharp stone penetration model

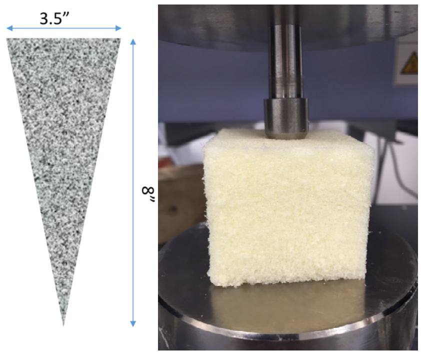


Figure 2 - Foam penetration tests

PU foam is chemically inert, and effectively unlimited in life-cycle period, in underground conditions. **Cable protected in this way could be expected to have a lifetime in excess of 100 years.**

3.1 Dynamic Loading

As mentioned above, an important property of PU foam is the ability to spread load. Typically, dynamic loading leads to pressure being applied to the crown of a pipe or cable; the increased surface area of the PU foam mass and the load-spreading behaviour of the cellular structure distribute the dynamic forces throughout the system, lessening mechanical stresses and potential cable rupture. Compensation is normally built into engineering for known roadways, but it is often expensive and does not protect against unexpected traffic loads.

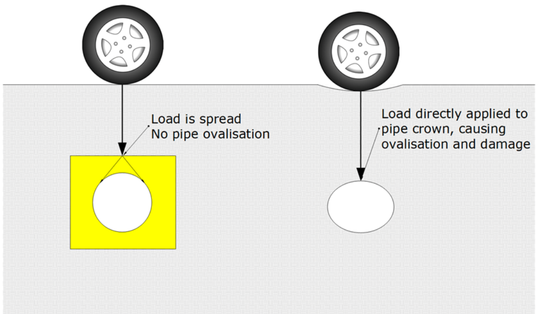


Figure 3 - Dynamic loading foam v. granular

3.2 Fire Hazards

PU foam is used safely in high-risk domestic insulation. It is almost impossible to imagine a situation where moisture from the surrounding soils would reach and breach polyethylene coating of a closed-cell, foam-encased power cable. Although it is highly unlikely in this application, fire retardant chemicals can be added to PU foam as desired, to ensure that arcing results only in local damage.

3.3 Theoretical Basis of Decreased Risk with PU Foam

Classic backfill methods suffer from unpredictability in two ways: production work quality and difficulty in predicting the effect of changing meta-conditions on the interaction between backfill and the object to be protected; those conditions can be geodetic movement or chemical, from spills or the use of anti-icing chemicals in winter.

Analysis shows that the most common cause of failure is incorrect installation of the trench system. Buried systems tend not to fail in the very short term; this means that there may be an incentive for the General Contractor to install to a level that is just enough to allow the system to reach the end of the minimum required warranty period.

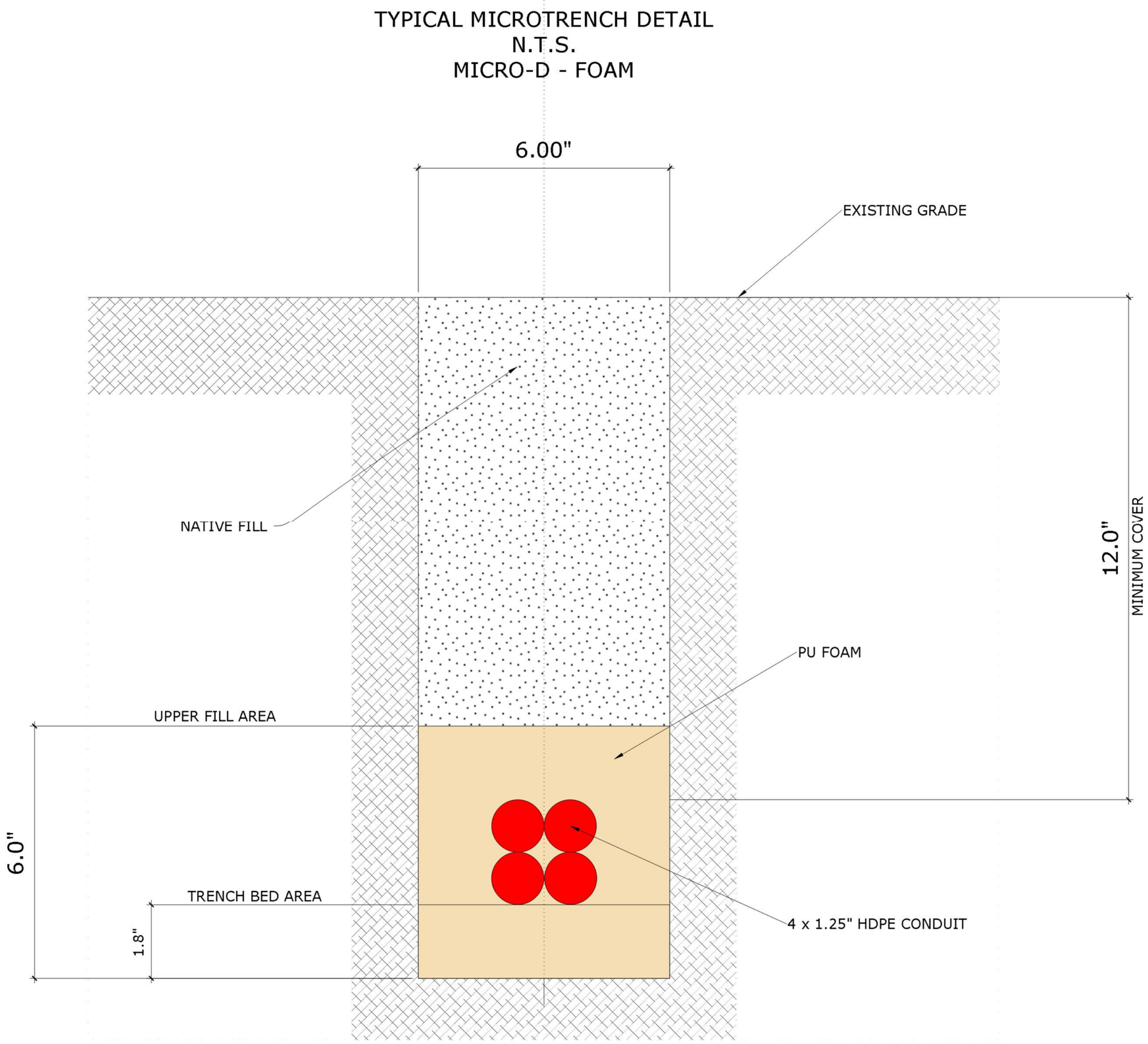
Backfill is either a granular or homogenous material. When backfill is 'native', there is a risk that incorrect sorting and re-grading may lead to failure of the protection system itself, or the function of the surrounding systems, in particular in dynamic loading situations: the backfill compresses or is washed away, and traffic loads lead to the failure of the asphalt surface. When a very rigid, brittle homogenous material such as concrete is used, failure from dynamic loading or geodetic pressures leads to the protective backfill material exerting intolerable shear on the vulnerable cable or pipe it is intended to protect.

PU foam is both sufficiently rigid and flexible to absorb periodic / dynamic loads from both traffic systems and geodetic movements. No system is able to withstand 'mega' forces, such as massive earthquakes that move soil systems more than a few feet, but the advantage of PU foam is that as greater blunt force is applied, the cell structure compresses, until the foam itself becomes a solid mass of polyurethane. In such a 'blunt force' system, the pressure applied to the cable or pipe inside the PU foam mass is distributed quite evenly, due to the cell structure, rather than applying localized point / puncture pressure, as would occur in a typical granular system. Nor will PU foam crack due to earthquake or other strong geodetic forces, unlike concrete, especially in long, horizontal sections, such as those intended with the use of concrete in the dynamic loading scenarios.

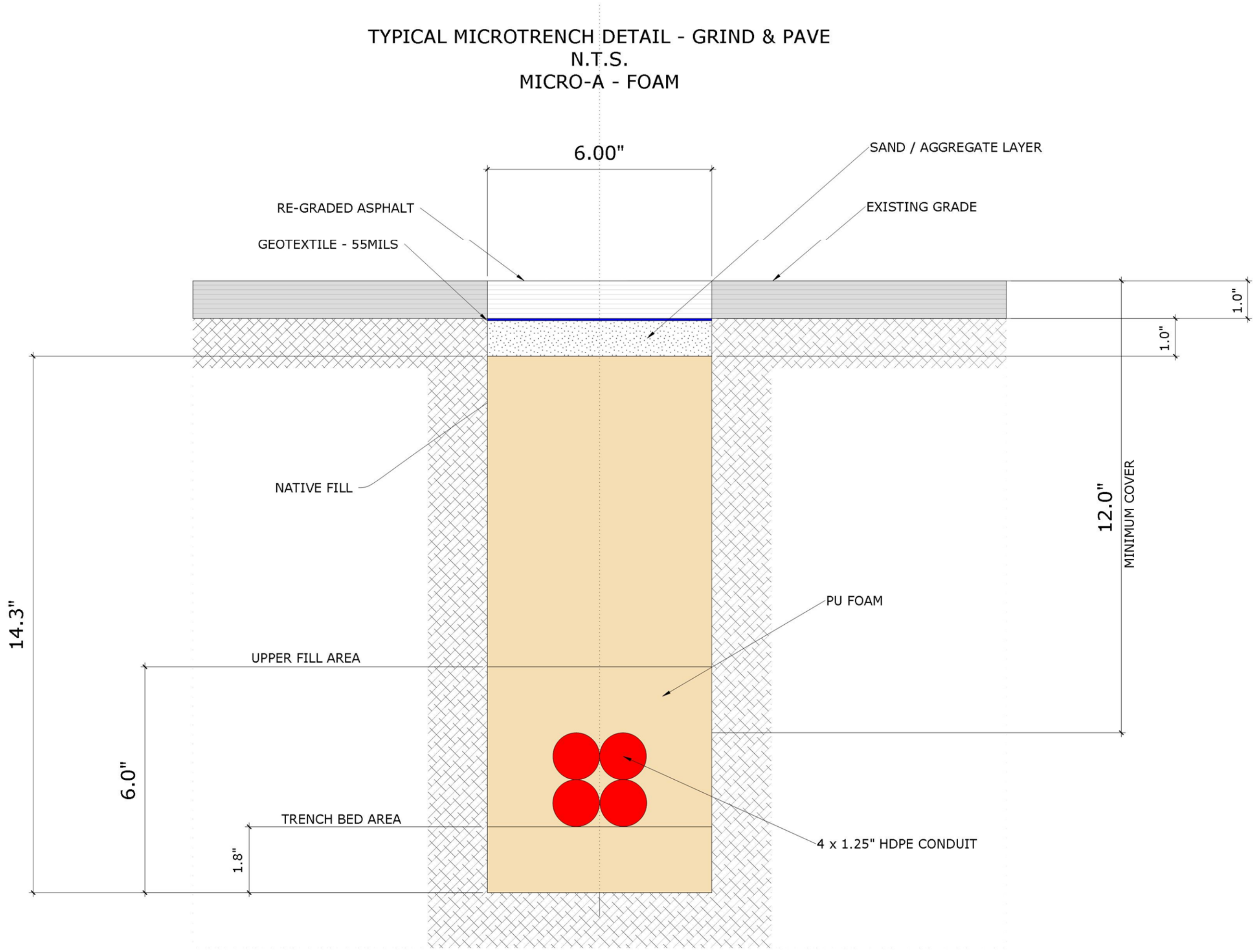
Effectively, because PU foam is produced in a single, highly homogenous mass, the cable protection is unitary. This makes it possible to predict the reaction of the cable-foam system under different scenarios with a high degree of accuracy. Our work in conjunction with Trondheim University and Statkraft has shown that PU foam reacts extremely predictably and that the system is sufficiently elastic to perform in precisely the same way over time.

4 Installation Cross Sections

4.1 MICRO-D FOAM



4.2 MICRO-A FOAM



4.2.1 MICRO-A FOAM – discussion

4.2.1.1 Trench Dimensions

The original MICRO-A trench configuration is presumably designed to provide protection for the cable system in a dynamic loading scenario, with the high column of concrete providing sufficient rigidity in the vertical / ‘y’ axis to resist snapping from heavy axle loads. In other words, the depth is a function of the choice of concrete as backfill material, due to its specific properties.

With the use of PU foam as backfill, it is questionable whether the overhead cover needs to be ≥12”. PU foam will retain its flexibility characteristics indefinitely. Therefore, the upper 60% of the foam mass is probably redundant from a mechanical point of view. Reconfiguring the trench system to provide ±6” of cover between the cable and the bottom of the re-graded asphalt would provide adequate protection for the cable and reduce foam consumption by ±60% and the cost of the HydroFoamer operation by ±50%, with high impact on overall project costs.

NTS-12" Overhead	NTS-6" Overhead	
USD 12.37	USD 6.80	per yard
USD 21,769.51	USD 11,971.77	per mile
USD 9,143,194.74	USD 5,028,143.23	Project

4.2.1.2 Geotextile, Rounding and Frost Resistance

PU foam in spray or pour applications has a slightly uneven surface at the 'open' side once cured, typically with a roughness of ±0.5". To allow proper re-grading of the asphalt, a layer of sand or other available fines / aggregate should be applied and a geotextile membrane applied if necessary. Closed cell PU foam has negligible water absorption and tests have shown that there is little or no effect on mechanical behaviour from repeated freeze-thaw cycles. HydroFoamer does not yet have knowledge of local pavement conditions for the project, but we assume that the pavement must be sealed to prevent water ingress. The 1" sand layer in the diagram above is the only area that might present a freeze-thaw challenge, but by keeping this layer to a minimum, we believe that the inherently flexibility of both asphalt and the underlying PU foam layer will prevent breach of the pavement surface. The choice of whether to use a geotextile layer in this application can be made at a later point, but we have included it this diagram; the membrane should have the effect of spreading the load from the re-grading, thus creating a layered system with minimal unevenness of vertical and horizontal stresses and a uniform spring to transmit forces to the PU foam layer.

5 Installation Velocity

Using a single team, HydroFoamer can maintain the following installation, depending on precise trench configuration and relying on reasonably optimal weather & rigging conditions:

- Micro-D 5,300 ft/hr
- Micro-A 1,200 ft/hr
- Micro-A (6") 1,450 ft/hr (As Micro-A, but 6", not 12" grind)
- Micro-A (6" shallow) 3,100 ft/hr (As Micro-A, but 6" grind and 6" overhead cover)

This assumes a 75% continual capacity usage and two spray teams.

6 Contact

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