Replacing Concrete Pipe Systems with Composite and PU Foam

Preliminary Evaluation

1 Introduction

HydroFoamer BV 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.

The strategy of using the paved road network as the path of pipe systems means that the system is subject to continuous, very heavy dynamic loading from traffic; this means choosing between a strategy of designing a 'static' system that is strong enough to withstand all likely forces, or a strategy of designing a 'dynamic' system that tolerates loading. In essence, this document examines the advantages and disadvantages of these approaches and advocates the use of the more flexible system that the HydroFoamer system facilitates.

In addition to the mechanical behaviour of the system, we examine the advantages that the HydroFoamer system brings in installation techniques.

2 Pipe System Types & Installation Methods

This document is not an exhaustive comparison of all pipe systems and all applications; the aim is to highlight the main differences between concrete- and composite-foam-based systems, specifically in water provision applications. It is not possible to cover anything but a general description of installation methods, as the subject area is immense and covered by relevant standards.

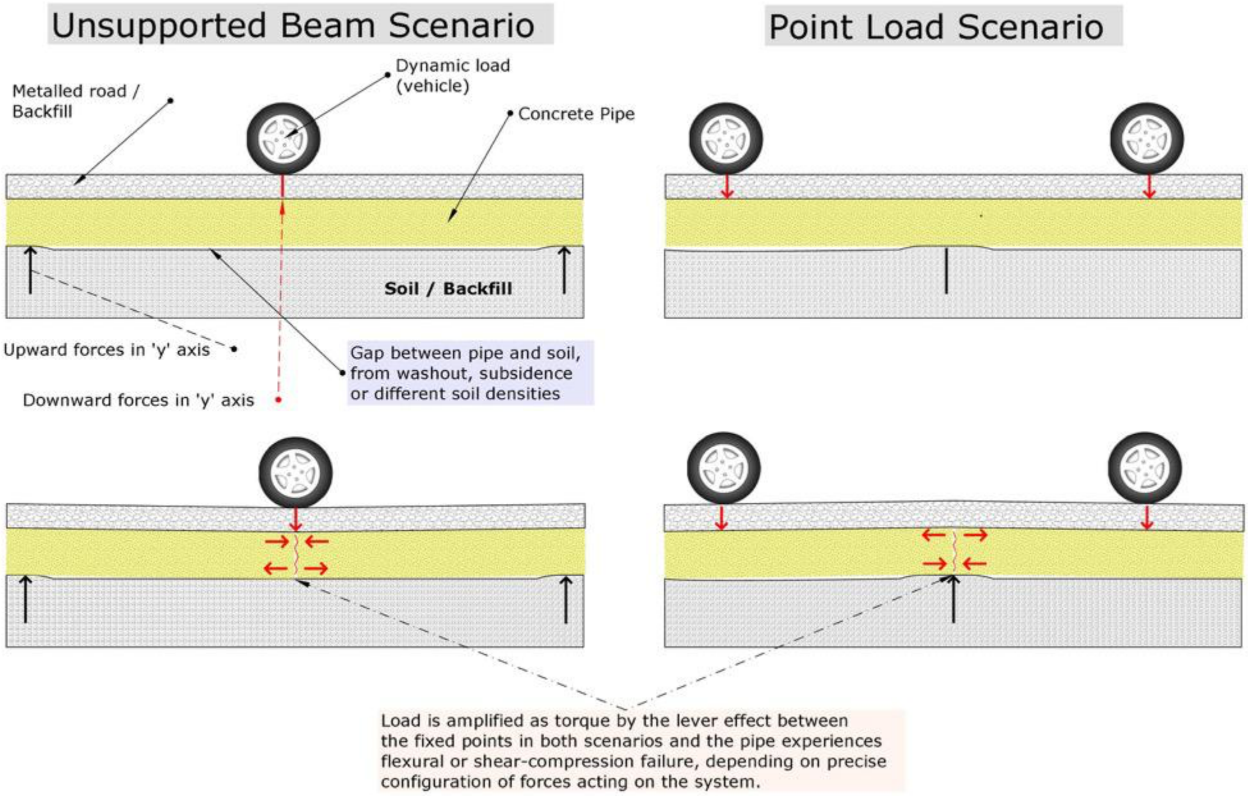
2.1 Concrete Pipe Systems

2.1.1 Advantages

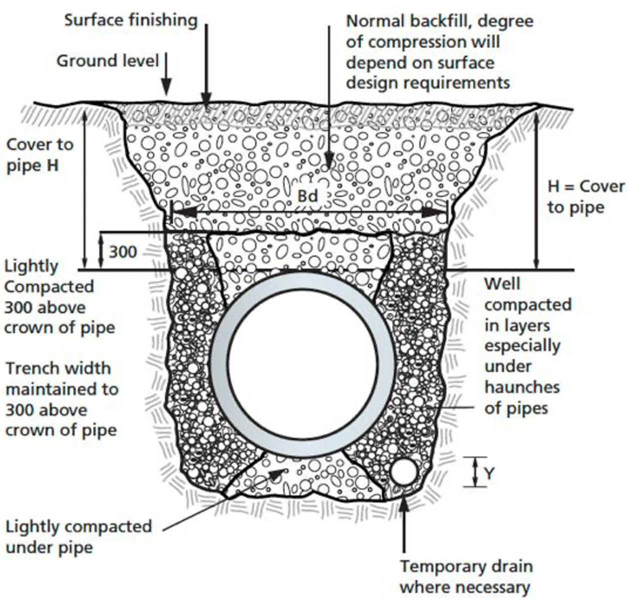
Concrete Pipe Systems (CPS) leverage the massive mechanical strength of reinforced concrete to compensate for otherwise difficult installation conditions. In general, CPS relies 85% on the mechanical properties of the concrete pipe itself and only 15% on the support of the surrounding backfill and soils for overall stability and performance. Concrete pipe is likely to tolerate more handling abuse than composite and metal pipe systems and, in many conditions, the use of CPS allows the use of less expensive / demanding backfill materials. Concrete pipe also has a small advantage in buoyant conditions, due to greater weight.

2.1.2 Disadvantages

Although CPS enjoy very high compressive strength values, the tensile strength of reinforced concrete is only around 10% of the compressive. In effect, this means that although it is unlikely that a CPS in good condition will fail due to insufficient hoop strength, the longitudinal stiffness of the system increases the likelihood that point loads that result from the loss of granular backfill through subsidence, washout or compaction in a dynamic loading system, will lead to the pipe suffering tensile failure. CPS are generally considerably more expensive than composite pipes.



2.1.3 CPS Installation Method



CPS are generally installed in a trench with 3 – 4 layers of compacted backfill material. The main function of the backfill is to provide generic geotechnical stability for the CPS, rather than to support the hoop strength of the pipe, as is the case with composite systems. The diagram below shows a typical CPS trench installation.

CPS does not normally require the same grading of backfill material as composite systems, due to the greater mechanical strength obviating the need to augment hoop strength. However, the backfill material must support durable compaction; there is often a misunderstanding that the choice for CPS means that ‘native backfill’ can be used in all cases. This is incorrect; where the excavated material is granular and homogenous, such as sandy soils, they may be used as backfill with little or no treatment. In most scenarios, this is not the case; for example, where there is a high degree of biological material, this must be removed before backfilling, or the system will not fulfil geotechnical requirements.

2.2 Composite & Plastic Pipe Systems

2.2.1 Advantages

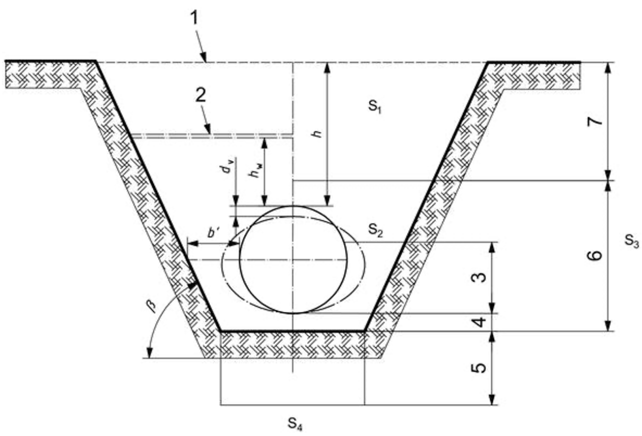
Composite & plastic pipe systems are very much lighter than concrete (and steel / ductile iron). This brings considerable advantages in transport, on-site handling and allows installation using unrestrained joints in soils that would be too soft for heavier pipe systems. Both reinforced concrete and metal pipes suffer from corrosion problems of both typical and cathodic kinds, whereas composites and plastic don’t. Composites and plastics are also relatively strain resistant, due to their high flexibility. This is particularly important when comparing with concrete pipes and when thermal expansion / contraction of metal pipes must be considered.

2.2.2 Disadvantages

Composite & plastic pipe systems have inherently lower absolute mechanical strength properties, due to lighter materials, and composite pipes in particular (GRP / FRP) require careful handling and pre-installation inspection in the field. In our application, where the PU foam replaces backfill and becomes part of the pipe system itself, the effect of lower mechanical strength is offset by the interaction of foam and pipe, in spreading load.

2.2.3 Typical Composite / Plastic Pipe Installation Methods

Typical installation methods use the same 3 – 4 compacted layer, excavated trench system as CPS, but there is a greater requirement for compaction to support the form of the more flexible pipe. The following diagram, taken from the ISO10465 standard, shows the importance of the ‘shoulder’ or ‘haunch’ area to the composite installation method:



If the backfill is not correctly placed and compacted in zones 3 & 4, the weight of the backfill above the pipe, or the forces from dynamic loading, may cause ovalisation or displacement of the pipe, leading to poor flow characteristics or even mechanical pipe failure.

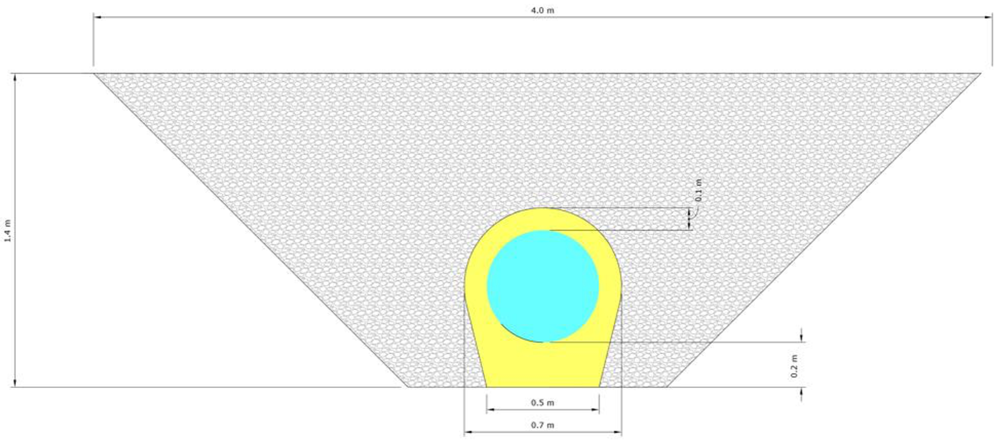
The high requirements for pipe support mean that composite pipes must generally use graded aggregate as backfill to at least the crown of the pipe, to achieve sufficient compaction. The availability of such backfill has a major effect on project finance; it must either be imported to the site or manufactured from crushing excavated materials.

2.2.4 HydroFoamer Installation Methods

The major difference between normal installation methods and the HydroFoamer method is the application of a layer of rigid, closed-cell PU foam around the pipe. There are two main configurations, depending on the application and the specific requirements (dynamic loading, axial stability, thrust forces, etc.)

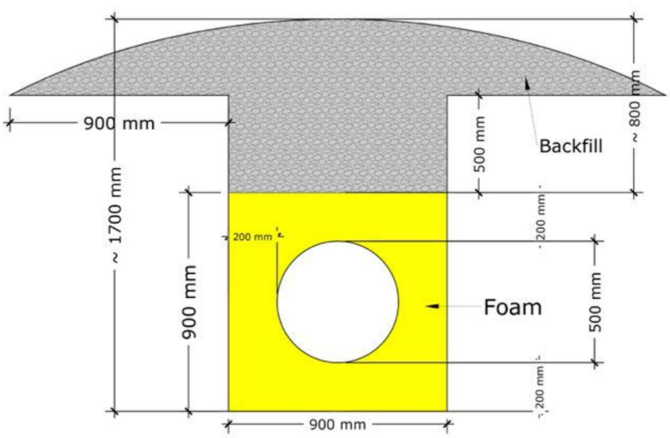
2.2.4.1 Standard 'Keyhole'

This method is used for most normal situations, with loose soil types, or where blasting is required. The pipe is suspended and surrounded with layer of PU foam, using the spray method, and native backfill is used to refill the trench within a few hours.



2.2.4.2 Square Trench

In some situations, it is possible to excavate a square trench, for example with sandstone. The pipe is suspended above the trench bottom and the trench is filled with PU foam, using the pour method. The trench is refilled using native backfill.



2.2.4.3 Micro-Trench Installation Cross Sections

Although not technically part of an evaluation of replacement of CPS with composite / PU foam systems, it is worth noting another application where PU foam can facilitate a better solution to some engineering problems: micro-trenches, which typically use concrete as backfill.

2.2.5 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.

2.2.5.1 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.

2.2.5.2 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.

3 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.

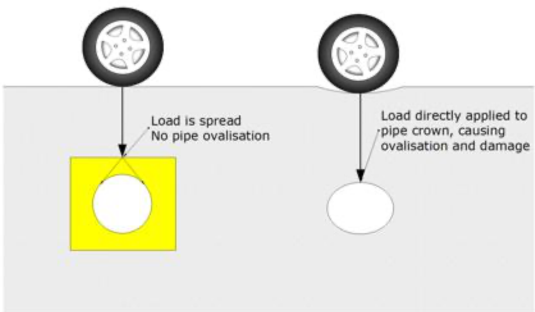


Figure 1 - Dynamic loading foam v. granular

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