Technical Note

TN 6.23 Structural Design of StormTech® arch-shaped, corrugated wall thermoplastic chambers made of PE or PP used for retention, detention, transportation and storage

Overview

This Technical Note summarizes key components of structural design and national standards for subsurface thermoplastic structures.

ADS StormTech was developed in North America and is designed and manufactured to fully comply with the relevant North American standards. This Technical Note is an expansion of TN 6.21. The purpose of TN 6.23 is to provide a single point of reference for North American structural design principles and a cross-reference to Eurocode structural design methodology.

Although the focus of this guidance is on arch-shaped chamber systems, the principles apply to the wider category of buried products of various structural shapes and material properties

Design Requirements for Thermoplastic Structures

1. The structural design must evaluate short-term live loads, intermediate-term loads and long-term soil loads
2. The materials used in production must provide necessary short-, intermediate- and long-term properties
3. The structural design must be completed by experts in the field of soil-structure interaction
4. The product must be designed and manufactured to meet meaningful standards
5. The structural design of the subsurface stormwater system must be up to the standards that a professional engineer expects from short-, intermediate- and long-term soil loads.

Structural Design of a Subsurface Thermoplastic System

The objective of structural design is to ensure a proper safety factor over the intended service life of the buried system. Typically, the intended service life of a subsurface storm drainage system ranges from 20 to 100 years.

The polypropylene and polyethylene thermoplastic materials used for subsurface structures are very stable in the stormwater environment; the limiting criterion for service life is generally long-term structural stability.

The primary benefit of subsurface systems is to facilitate additional paved surfaces for the purpose of parking or traffic flow. For such applications, where public safety is of paramount importance, “structural survival”, i.e. lack of failure, is not sufficient. For a design to be safe, structural safety factors must be demonstrated for the entire service life of the project to account for uncertainties in loading, installation, and material performance.

North American Structural Design Approach

AASHTO design procedures mandate load factors of 1.75 for live loads to account for impact effects and the presence of multiple or overweight loads and 1.95 for earth loads on buried culverts.

There are two components to ensuring long term performance of any structural product:

1. The product must be designed, tested and manufactured to meet meaningful product standards
2. The system must be designed to meet meaningful design standards.

AASHTO and ASTM have developed standards for buried structures. AASHTO is the American Association of State Highway and Transportation Officials. ASTM International is an international standards organization based in the United States.

Short-Term Properties, Intermediate-Term Properties, Long-Term Properties, Strain and Deflection

Buried thermoplastic products must be designed for three conditions:

- Short duration live loads under shallow cover
- Minimum 1-week sustained loads
- Permanent earth loads

Load duration is a key criterion for the design of thermoplastic structures since the “apparent strength” and stiffness decrease with increasing load duration. For live load design, the thermoplastic product must be able to withstand the dynamic load from moving vehicles.

Live load design is based on short duration loads and short-term material properties.

Intermediate load design requires the thermoplastic product to withstand 1-week sustained loads from parked oversized loads. Intermediate load design is based on 1-week duration loads and 1-week material properties.

Earth (dead) loads are permanent in duration and magnitude. For dead load design, the thermoplastic product must be able to withstand the continuous dead load and remain stable after 75 years or more under sustained load. For thermoplastic systems using structural aggregate (select embedment and backfill material) support, the performance of the structure is a function of the ability of the thermoplastic structure to a shed significant portion of the load to the surrounding select embedment and backfill material (arching). Earth load design is based on permanent loads and long-term material properties. The material properties that govern long-term design are tensile creep rupture and creep modulus.

Strain limits are the maximum strains that can occur before the structure fails. Long, slender shapes are inherently unstable and fail at lower loads by buckling. Wide, flat shapes may also buckle under continuous load. Design for long-term service life must be based on long duration loads, long-term creep modulus and strain limits. Without proper soil support, thermoplastic structures may reach a strain limit and fail.

Deflection is generally not a failure limit or a service limit for soil-supported chamber systems. When deflection is not limited by soil-support, excessive deflection of thermoplastic structures has been found to cause pavement distress. Without proper soil-support, deflection is a service limit for thermoplastic structures.

Specifying industry standards, not just products, establishes objective, meaningful performance criteria and a defensible basis of design.

AASHTO Standards

The AASHTO LRFD Bridge Design Specifications are the primary source of design standards for soil-structure interaction under traffic loads. Section 3 of these specifications provide for calculation of loads and Section 12.12 provides for structural design of buried thermoplastic structures.

The AASHTO standard:

- Assures design load factors for live loads and long-term loads
- Provides the design method for soil-structure interaction
- Assures a long-term service life by designing for creep and strain limits
- Provides consulting engineers with a defensible basis of design

ASTM Standards

ASTM is an internationally recognized source for a variety of standards including testing methods, standard practices and product specifications.

ASTM has developed two product standards for stormwater chambers, designations ASTM F2418 (polypropylene chambers) and ASTM F2922 (polyethylene chambers).

ASTM F2418 and F2922 standards:

- Assure consistent product quality in a non-proprietary specification
- Establish physical and mechanical requirements for the finished product
- Establish long- and short-term material properties for design
- Require AASHTO load factors and full-scale validation testing

ASTM has developed a design standard for stormwater chambers, designation: ASTM F2787, entitled "Standard Practice for Structural Design of Thermoplastic Corrugated Wall Stormwater Collection Chambers".

ASTM F2787 standard:

- Applies the AASHTO Section 12.12 thermoplastic pipe design criteria and applies it directly to chambers
- Includes an additional design load for a minimum 1-week sustained vehicle load to account for parked vehicles
- Provides design criteria that can be applied to different thermoplastic resins

Product Design

Select embedment and backfill material support is a key component of the soil-structure interaction system. Aggregate-based columns between thermoplastic components provide the load paths from the load above to the foundation below. For select embedment and backfill material-structure designs, the embedment and backfill material reduces the load that the thermoplastic components must carry and limits the deflection and strain of the thermoplastic components. Designs of subsurface thermoplastic structures that purport to require no structural embedment and backfill material or are not designed in accordance with AASHTO requirements may result in excessive deflections or complete failure.

StormTech chambers are designed and rigorously tested in accordance with AASHTO/ASTM standards to provide a reliable subsurface system.

Linking AASHTO/ASTM to Eurocodes

ASTM F2787 functions similarly to the Eurocodes in that load models, limit states, and design factors are prescribed while leaving the method of structural analysis (i.e. determining limiting structural demands) up to the designer.

For buried StormTech chambers, the complexity of the soil-structure system precludes the use of closed-form solutions—thus, finite-element analysis is used to translate design loads into structural demands on the chambers.

The design live load prescribed in ASTM F2787, the AASHTO HL-93 model, is comparable to Load Model 1 (LM1) from EN1991. Both are statistical representations of the maximum expected vehicle traffic on main roads and highways. Both combine grouped wheel loads and uniformly applied lane loads. The wheel and axle spacing of LM1 (1.2 m x 2.0 m) is similar to the design tandem of HL-93 (1.2 m x 1.8 m). The primary difference is nominal magnitude of the wheel loads: for the design tandem of HL-93 each wheel applies 56 kN, while for LM-1 the characteristic value is 150 kN. This difference in the nominal values is generally accounted for elsewhere in the design process by the different the application of partial factors, which vary significantly in ASTM and Eurocode design frameworks.

ASTM F2787 (and the AASHTO LRFD Bridge Design Specifications on which it is based) recommend computing the dispersion of wheel loads through the cover soil using a live load distribution factor (LLDF) of 1.15. The LLDF is just an alternate formulation of the common practice of assuming load dispersion through compacted fill at an angle of 30-degrees from the vertical. This is the same practice recommended in EN 1991, Section 4.9.1. However, use of the AASHTO LLDF is only recommended in ASTM F2787 to modify design load to inputs into 2D plane-strain Finite Element Models. With more sophisticated modeling approaches, such as that used by ADS for StormTech, load distribution through the cover soil occurs directly in the model (as a result of the soil parameters and soil structure interaction).

The effects of chamber interaction are accounted for in the Finite Element Analysis. The typical ADS StormTech model consists of three rows of chambers. Live loads are applied over the center chamber and structural demands on the center chamber are used for evaluation of the limit states. This model arrangement implicitly accounts of the effect of adjacent chambers.

ASTM F2787 and the Eurocodes apply limit state design principles. They differ on the specific application of safety factors at varying points of the analysis. This can make direct comparison of portions of the analysis misleading. In general, ASTM F2787 applies partial factors to the structural demands (i.e. “effects of actions”) and resistances, with characteristic values of the loads (“actions”) and material properties being used in the analysis. In the Eurocodes, partial factors may be applied to the loads, structural demands, resistances, and/or material properties depending on the limit state and design approach.

Direct comparison on the reliability of designs produced through each methodology is complex because of this varied approach: it requires a comprehensive review of each input and analytical step in the design.

For this reason, Eurocode structural design principles were used to model the performance of ADS StormTech chambers, to assess the suitability of the minimum and maximum cover depths, when installed as per the standard ADS StormTech Construction Guides.

Eurocode Modelling Study

To prove that StormTech chambers are structurally adequate under Eurocode standards and principles, a study was undertaken to model their performance using limit state Load Model cases based on the standard minimum and maximum cover depths stated in the StormTech product literature. The standards used, together with related guidance and reports, can be found in the Reference section at the end of this document.

To investigate the performance of the StormTech system, chambers were evaluated using a finite element analysis (FEA) model, which looked at limit state modes of failure as set out EN 1991-2 – Eurocode 1 – Actions on Structures – Part 2.

Engineers may be familiar with CIRIA C737, relating to the design of thermoplastic crates for underground water attenuation, which also suggests Eurocode modelling as a means of demonstrating structural adequacy. Note that, whilst CIRIA C737 design guidance is in the same application field, the structural behavior of arch-shaped structures is different to cuboid thermoplastic boxes.

Load models for four different stress and fatigue cases were applied, according to EN 1991-2. Cover depths were in accordance with the ADS StormTech Construction Guides and are detailed in the table below.

Maximum and minimum cover per chamber type

Chamber	Minimum Cover mm (in)	Maximum Cover mm (in)
SC-160LP	350 (14)	3000 (120)
SC-310	450 (18)	2400 (96)
SC-740	450 (18)	2400 (96)
DC-780	450 (18)	3700 (148)
MC-3500	450 (18)	2400 (96)
MC-4500	600 (24)	2100 (84)
MC-7200	600 (24)	2100 (84)

Load Cases and Analysis

The cover is defined from the top of the chamber crown to the bottom (i.e. underside) of the flexible pavement.

- Load case 1: minimum cover and Load Model 1 (min cover, LM1, subclause 7.2)
- Load case 2: maximum cover and Load Model 1 (max cover, LM1, subclause 7.3)
- Load case 3: minimum cover and Fatigue Load Model 3 (min cover, FLM3, subclause 7.4)
- Load case 4: minimum cover and Load Model 1 with braking forces (min cover, LM1, braking, subclause 7.5)

The strength of the chambers can be drawn directly from testing with minimum requirements for stiffness, bending moment and thrust capacity.

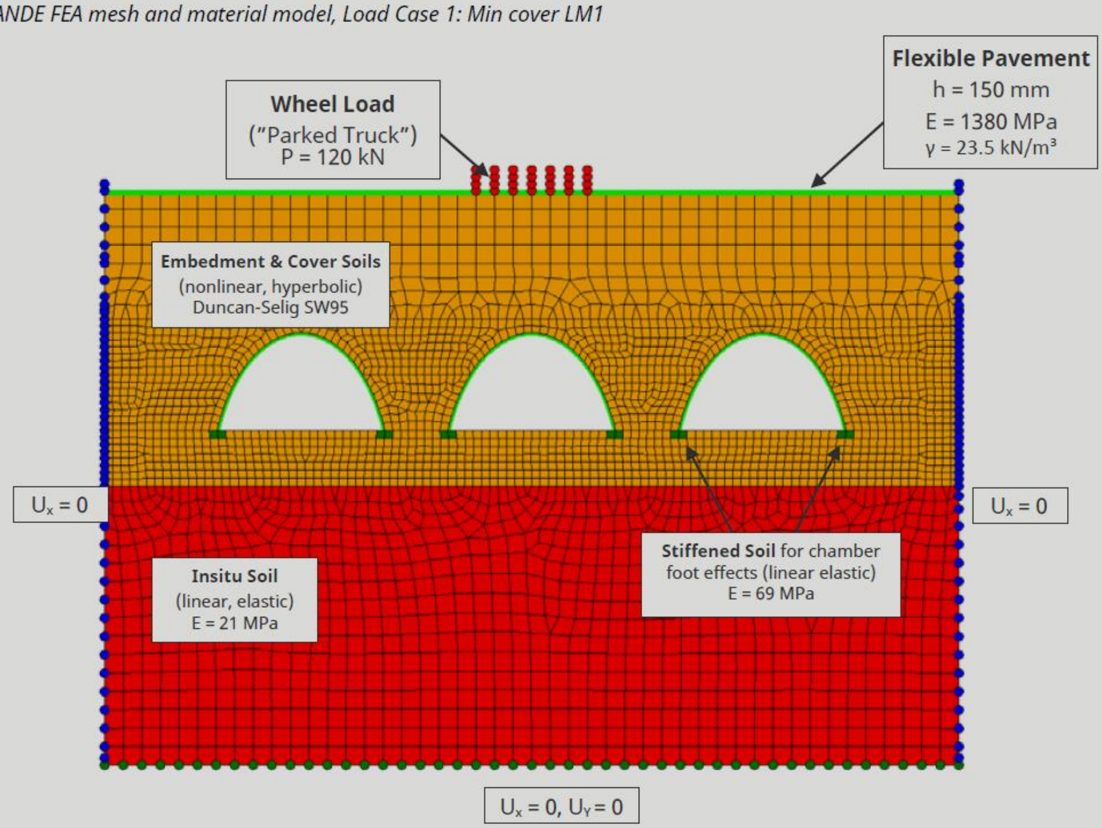
The bases for strength of the chambers are flattening test data for moment capacity and stub compression test data for thrust capacity, both performed for the European Technical Assessment (ETA) [see Reference section].

To derive bending moment capacity from the flattening test, a two-dimensional (2D) Finite Element Analysis is completed.

Eurocode principles require that the assessment of structural adequacy must include derating factors to take into account performance over time. Strength reduction factors in accordance with EN 1778 were applied and the elastic modulus of the thermoplastic material was derated, to take into account the long-term performance of the material under loading.

The Culvert ANalysis and DEsign (CANDE) FEA model was used to evaluate the chambers in the most demanding loading scenarios. At shallow depths it is live traffic loads at the surface that are most likely to cause failure. For maximum depths it is the long-term loading of the backfill material which will determine failure.

Example CANDE FEA mesh and material model, Load Case 1: Min cover LM1



Results

The FEA model was used to calculate the bending moments in the crown and shoulder of each StormTech chamber and the thrust at the foot of the chamber, for the relevant Load Model cases. These were then expressed as a Capacity Factor: the percentage of the chamber’s actual strength taken up by the acting loads. Any result below 100% demonstrates structural adequacy.

For all chambers, and in each of the four Load Model cases, the Capacity Factor was below 100%. Generally speaking, Load Case 2, with maximum cover depth had the highest Capacity Factors, although still all comfortably below 100%.

Capacity Factor	Load Case 1	Load Case 2	Load Case 3	Load Case 4
Average for all Chambers	56	77	47	50
Range	43-74	52-92	36-63	41-58

References

North American Standards:
AASHTO LRFD Bridge Design Specifications
ASTM F2787 *Standard Practice for Structural Design of Thermoplastic Corrugated Wall Stormwater Collection Chambers*
ASTM F2418 *Standard Specification for Polypropylene (PP) Corrugated Wall Stormwater Collection Chambers*
ASTM F2922 *Standard Specification for Polyethylene (PE) Corrugated Wall Stormwater Collection Chambers*

European and International Standards:
EN 1778: *Characteristic values for welded thermoplastic constructions – Determination of allowable stresses and moduli for design of thermoplastic equipment; 12-1999*
EN 1990: *Eurocode: Basis of structural design; 10-2021 BD-220177*
EN 1991-2: *Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges and other civil engineering works; 09-2021*
EN 1997: *Eurocode 7: Geotechnical design; 03-2014*
ISO/DIS 4982: *Plastics piping systems for non-pressure underground conveyance and storage of non-potable water – Arch-shaped, corrugated wall chambers made of PE or PP used for retention, detention, transportation and storage of storm water systems – Product specifications and performance criteria; 04-2022*
CIRIA C737: *Structural and geotechnical design of modular geocellular drainage systems; 2016*
BÜV-Empfehlung – *Tragende Kunststoffbauteile im Bauwesen (TKB) – Entwurf, Bemessung und Konstruktion; BauÜberwachungsverein;*
08-2010 (Recommendation – Load-bearing plastic components in building – Design, dimensioning and construction)
DVS 2205-1: *Berechnungen von Behältern und Apparaten aus Thermoplasten; 09-2013 (Calculations of containers and apparatus made of thermoplastic)*
ISO 12162: *Thermoplastics materials for pipes and fittings for pressure applications – Classification, designation and design coefficient; 11-2009*

Reference documents and software:
BBA Agrément Certificate Product Sheet 07/4480, 2017
European Technical Assessment, ETA-22/0555, Deutsches Institut für Bautechnik (DIBt), 15-08-2022
European Assessment Document, EAD 180017-00-0704, European Organisation for Technical Assessment (EOTA)
Culvert ANalysis and DEsign (CANDE) program, Michael G. Katona, Version 2022
Inventor Nastran 2022, Autodesk, Version 2022
ADS StormTech Construction Guides: Versions relate to chamber type. Available at adspipe.com
Test report PT 19656091: *Zulassungsprüfungen an einem PP- Werkstofftyp 'Formosa, Formolene ® PP 6613N' – 30 Norm-Zugstäbe DIN EN ISO 527-2, Typ 1A; Polytest Ingenieure GmbH; 05.12.2019 (Approval tests on a PP material type 'Formosa, Formolene ® PP 6613N' standard tensile bars DIN EN ISO 527-2, type 1A; Polytest Engineers)*
Test report: Flattening test data, ADS, 06-2022
Test report: Stub Compression Test Report EAD180017-00-0704 Annex D, ADS, 06-2022

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