ASPECTS REGARDING THE METHODS OF DESIGN OF BURIED CORRUGATED STEEL

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Abstract: Structures of corrugated plate are becoming widely used for road and railway bridges construction, as well as for other transportation objects such as culverts and pipes. Due to the fact that such bridge structures are made of thin corrugated plates (2–7 mm) and that they are often located under main roads (characterised by heavy moving loads), it is necessary to know the methods of design and verification of these structures. Important aspects of design are those on the interaction of the backfill structure. In the current context of infrastructure development in Romania, the use of these types of structures is not very common. This paper presents the designs methods and the specific aspects of a few methods.

Key words: corrugated steel structures, design method.

1. Introduction

The corrugated steel pipe (CSP) provides a strong, durable, economical selection for the construction of sewer systems. Introduced by a city engineer in 1896, countless miles of CSP now provide reliable service throughout the highway system and in large and small municipalities across the North American continent. Since 2010 on the Romanian infrastructure branch there have been developed companies that offered considerable alternatives to concrete bridges and concrete structures, such as corrugated steel structures.

The sewer designer can select from a wide range of corrugated steel products to meet exacting job requirements. Factory-made pipe, in sizes large enough to accommodate most needs, is available with a variety of corrugation profiles that provide optimal strength. For larger structures, structural plate pipe can be furnished for bolted assembly in the field [1]. Shop fabricated fittings, long lightweight sections, reliable and positive coupling systems—all contribute to speed and economy in field installation.

In addition, a range of protective coatings is available to meet rigorous service demands. On the other hand, the assembly of these types of structures is easy and does not require big cranes or highly qualified workers.

2. Description of the Steel Structure

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Depending on their cross-sectional geometry, buried corrugated steel structures are divided into two groups: open structures (including box and arch) structures and closed structures.

Because of the magnitude and character of the changes in displacements and internal forces, resulting from the backfilling process and originating from the live load, box structures differ from the other buried corrugated steel structures. For this reason they should be considered as a separate group [2].

A variety of assembly techniques are available, to suit site conditions, and/or size or shape of the structure. Maintaining the design shape must be a key objective during plate assembly (Figure 1).

The characteristic feature of box structures is their small height/span proportion: $H/L < 0.25$. Also peculiar are the shape of the shell's top part whose curvature radius is large relative to its span: $R > L$, and the curvature radii of the corrugated plate in the corners, several times smaller relative to the crown: $R << R$. At a small soil surcharge thickness the box shell’s high $R/L$ ratio is responsible for the stronger effects of the concentrated forces generated by commercial vehicles, resulting in local effects in the corrugated plate [2].

2.1. Description of Loadings

The safety factors and other specific quantitative recommendations herein represent generally accepted design practice. The design loads are: dead loads developed by the embankment of trench backfill, plus stationary superimposed surface loads, uniform or concentrated; live loads and impact loads.

Live loads can be: some percentage of the weight of vehicle, train, or aircraft moving over the pipe that is distributed through the soil to the pipe. Earthquake load is also considered.

Soil-steel interaction means that a flexible steel conduit acts with the surrounding soil fill to support the loads. Modern research has shown that the ideal underground structure places much of the load on the soil around and over it. Corrugated steel structures approach this ideal condition. Load distribution is more advantageous for flexible structures than rigid structures (Fig. 2).
3. The Design Methods

The calculation principle is based on the cooperation between the steel tube and the structural filler material. When designing a culvert, it is assumed that it has a uniform section in the longitudinal direction of the tube. In the calculation model, one meter of a whole length can be considered the load underlying with forces acting perpendicular to the axis of the tube.

Design methods are: Iowa formula, ring compression theory, Ontario code, AASHTO, Duncan method, Vaslestad, CHBDC, Scottish, Pettersson and Sundquist (SDM) or finite element method (Abaqus, Plaxis, CandeCad, Ansys).

The AISI, AASHTO and CHBDC methods are all recognized for the design of soil-metal structures with a diameter or span greater than 3 m. The AISI and AASHTO methods have been used for many years and can continue to be used unless the CHBDC is specifically required.

In 1941, Spangler M.G. published his work through to establish the original Iowa formula [3]. The resulting equation, known as the original Iowa formula, had the following form:

\[
\Delta x = \frac{D_t \cdot K_e \cdot W_c \cdot r^3}{(E \cdot I + 0.0061 \cdot e \cdot r^4)},
\]

where:
- \(\Delta x\) - horizontal diameter change;
- \(D_t\) - time lag factor;
- \(W_c\) - vertical load on pipe;
- \(r\) - radius of undeformed pipe;
- \(E\) - modulus of pipe material;
- \(I\) - moment of inertia of pipe wall sections;
- \(e\) - modulus of passive soil

The calculations in Sundquist and Pettersson method (SDM) are based on three main theories, which were compared and calibrated with full-scale tests and used through the design process; these important points are summarized as follow:
• The soil culvert interaction (SCI) developed by Duncan (1978–1979)
• The buckling calculations presented by Klöppel & Glock (1970)
• Soil modulus for soil frictional material by Andreasson (1973)
• Arching calculations developed by Vaslestad (1990)

Extensive research on buried corrugated steel structures was sponsored by the AISI and carried out at Utah State University in Logan, Utah, under the direction of Dr. Reynold K. Watkins [4].

This design method has been developed and improved to cope with the prevailing regulations and standards, where it provides ultimate capacity calculations using either the Swedish standards or the European code.

Can be taken into account thrust forces and bending moments, using the maximum stress in the wall of the pipe is calculated using Navier’s equation:

$$\sigma = \frac{N_{Ed,t}}{A_{s1}} + \frac{M_{Ed,t}}{W_{s1}} \leq f_{yd}$$  \hspace{1cm} (2)

where: $N_{Ed,t}$ - normal force; $A_{s1}$ - cross section area; $M_{Ed,t}$ - bending moment; $W_{s1}$ - section modulus.

At the ultimate limit state, a check is made on the maximum loaded section using EN 1993-1-1 expression 6.61. As the plate is presumed not to deflect laterally ($z$-axes), $\chi_{LT}=1.0$ and $\chi_{z}=1.0$. Also, the additional moment $M_{z,Ed}=0$ and, as the neutral axis does not change due to local buckling, $A M_{z,Ed}=0$.

The expression in EN 1993-1-1[5] can thus be simplified to:

$$\frac{N_{Ed}}{Z_{y,Ed}^{N_{Ed}}} + k_{yz} \frac{M_{y,Ed}}{Z_{y,Ed}^{M_{Ed}}} \leq 1$$ \hspace{1cm} (3)

$$\frac{N_{Ed}}{Z_{z,Ed}^{N_{Ed}}} + \chi_{LT} k_{yz} \frac{M_{y,Ed}}{Z_{y,Ed}^{M_{Ed}}} \leq 1$$ \hspace{1cm} (4)

3.1. Using Finite Element Method

Using FEM involves some advantages, such as visualization of results and thus the ability to understand structural behaviour. The main problem in modelling can be the analyses of the soil-structure system.

Dedicated or custom programs can be used. For example, in Canada, several procedures have been developed using finite element methods: CANDE (Culvert Analysis, Design) is an FHWA (Federal Highway Administration) sponsored computer program by M. Katona, et al. The SCI (Soil/Culvert Interaction) Design Method, by J. M. Duncan, utilizes design graphs and formulas based on finite element analyses [4].

The process of designing using FEM is presented in Figure 3.
3.2. Design Based Testing

Model-based testing is an application of model-based design for designing and optionally also executing prototype to perform the design method.

In general, this involves final checks, including tests under static and dynamic load (requirements for the range of tests, ways to perform the tests, results evaluation criteria).

Fig. 3. Process of designing using FEM

Fig. 4. Relative displacement of crown (based on field test ViaCon- Rydzyna-Polonia)
4. Conclusions

Currently in Europe there is no uniform design code for buried flexible steel structures. In different countries throughout Europe there are different regulations concerning design methods, construction and control of such structures. Currently in Romania, there is no implementing specific rule of implementation for design and execution corrugated steel.

There are multiple methods to design corrugated steel plate. Similar experience and real full-test scale certifies the applicability of these methods and encourages their use.

One of the objectives is for the investigation to establish a practical correlation between backfill density and structure-behavior.

Methods of calculation and designing are chosen by the specialist engineer and must be made taking into account the geotechnical characteristics of the natural soil, the backfill and the corrugated steel structure.

References