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Structural design of buried pipelines under various conditions of loading - Part 3: Common method

Statische Berechnung von erdverlegten Rohrleitungen unter verschiedenen Belastungsbedingungen - Teil 3: Einheitliches Berechnungsverfahren

Calcul de résistance mécanique des canalisations enterrées sous diverses conditions de charge - Partie 3: Méthode commune

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Statische Berechnung von erdverlegten Rohrleitungen unter verschiedenen Belastungsbedingungen - Teil 3: Einheitliches Berechnungsverfahren

This Technical Report was approved by CEN on 11 July 2005. It has been drawn up by the Technical Committee CEN/TC 165.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Management Centre: rue de Stassart, 36 B-1050 Brussels

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Contents

Foreword

This document (CEN/TR 1295-3:2007) has been prepared by Technical Committee CEN/TC 165 “Wastewater engineering”, the secretariat of which is held by DIN.

This document has been prepared by a joint working group of the Technical Committee CEN/TC 165 “Wastewater engineering” the secretariat of which is held by DIN and the Technical Committee CEN/TC 164 "Water supply", the secretariat of which is held by AFNOR.

This document is a composition of two options for the structural design of buried pipelines, including the annexes of each option, which have been combined in one single document. The document includes therefore the followind Annexes:

Annex A , Structural design of buried pipelines – option 1, including the Annexes to option 1 (Annex AA to Annex AG);

Annex B, Structural design of buried pipelines – option 2, including the Annexes to option 2 (Annex BA to Annex BG);

Annex C , Classification of soils;

Annex D, Factors of safety and failure probability;

Annex E, Longitudinal effects;

Annex F, Detailed notes relative to longitudinal effects.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

Introduction

The history

In the mid-eighties the European Commission gave CEN an Order Voucher to develop a so-called "Common Structural Design Method for Buried Pipes" and the work was allocated jointly to CEN/TC 164 (Water supply) and CEN/TC 165 (Waste water engineering). To avoid duplication of work a Joint Working Group (CEN/TC 164/165 JWG1) was created in 1990. As a first step the group produced EN 1295-1, which was published in July 1997 and is a general part describing the "principles and input parameters" for structural design of buried pipelines and gives guidance on the application of these principles to nationally established methods of design. Reference was made to those methods and sources of information on them are given.

The second step was to produce CEN/TR 1295-2, which was published in August 2005 and describes national or regional methods JWG1 continued its work with the aim of developing a single method for the structural design of buried pipes for water and wastewater, planned as EN 1295-3 (WI 00165155).

NOTE The work on WI 00165155 concentrated on pipes, not the piping system involving all components.

In 1992 JWG1 decided to give the work on a "Common Method" to a small group of experts (TG1). By this means it was thought to create optimal conditions for dealing with such a difficult task. The task, however, proved to be much more difficult than had been expected, because different design cultures exist throughout Europe. After much debate and analysis JWG1 finally arrived at a situation where two options were provided for internal TC enquiry, which closed in May 2002. The comments received from CEN members varied widely from strongly against one or both options, to very much in favour of one of them.

Faced with this result, CEN/TC 164 and CEN/TC 165 decided that the two options should not go to CEN enquiry, even though they would have been presented in an informative annex of the document. (A note would have been included in the short normative text, stating that a single "Common Method" could not yet be agreed but, during the next five years, the two options should be checked and reported upon by European experts working in this field. In the meantime, CEN/TC 164 and CEN/TC 165 continued its efforts to develop the "Common Method".

Current European practices

The "designer" is responsible for structural design in accordance with EN 1610,

JWG1 collated the national approaches to the structural design of buried pipelines in the countries of the CEN members who were participating in the work. The outcome was EN 1295-1, which facilitates a common basis of relevant requirements for application to nationally established methods of design. Although widely varying in their approach, these design cultures have been shown to provide continuity of acceptable design practice throughout Europe.

Later, CEN/TC 164 and CEN/TC 165 requested all CEN members to submit their current nationally established method for such structural designs. The collated outcome is given in CEN/TR 1295-2.

A common factor in all of the nationally established methods is that the parameters for pipe material and surface loads (i.e. mainly traffic loads) are well known and (depending on national requirements for the manufacturers' and any third-party quality control) in several countries even quality-controlled. On the other hand, only a few nationally established methods demand that soil parameters are obtained from each prospective construction site and not many of them prescribe test methods for soil parameters.

Furthermore, the multitude of calculation methods employed throughout Europe, now collated in CEN/TR 1295-2, use different soil parameters and these cannot be "transferred" from one calculation method to another.

Whilst pipe material parameters are easily available from product standards and/or pipe manufacturers, the definition of soil parameters is the responsibility of the prospective pipeline owner or his designer. This possibly explains why, in many European countries, the traditional practice continues whereby detailed structural analysis of buried pipelines for water and wastewater systems is not carried out. The pipe manufacturers often provide information about the loading that the chosen pipe will withstand and this can often avoid investigating actual soil conditions.

If the structural design of a buried pipeline for a water or wastewater system is demanded, many construction companies and designers approach the pipe manufacturer, who will usually have the necessary expertise. But here too the same problems can occur, for the pipe material parameters are usually clearly defined (and a quality control system often established), whilst the soil parameters are uncertain. Only in a very few cases is there a quality control system for the earthworks at the construction site.

It is fundamental that, for a "Common Method" to apply throughout Europe, agreement shall first be reached on the definitions and test methods for soil parameters and a certain quality control system for the earthworks on site (see Clause 3), not withstanding that specific pipe material features are more easily recognized and taken into account.

The results obtained so far from the work of CEN/TC 164/165 JWG1 are shown in Clause 4. In 2003 CEN/TC 164 and CEN/TC 165 accepted a recommendation from JWG1 that the two structural design options should be published as a CEN Technical Report (CEN/TR) and work on a European Standard terminated, because there was no prospect of the group reaching agreement on a "Common Method" and the human and financial resources needed to continue were, in any case, no longer available.

CEN/TC 164 and CEN/TC 165 accepted that it would be a pity to lose all the previous work, which should be made available to designers and the general public. The outcome is this document and it is hoped that the two options will provide a basis for continued debate and investigation.

The "Common Method"

Any future proposal for a new work item for the development of a European Standard for a "Common Method" for the structural design of buried pipelines would have to be approved by both CEN/TC 164 and CEN/TC 165, taking into account experience gained with the two options detailed in this document. There would also have to be a reasonable certainty of agreement being reached on a "Common Method" within the three-year limit for developing European Standards.

NOTE 1 Each structural analyst remains responsible for the choice of the calculation or design method.

NOTE 2 Subject to the requirements of the EU Procurement Directives as to the use of European Standards in public sector contracts, any future "Common Method" would be applied on the responsibility of the designer.

NOTE 3 One of the aims of a "Common Method" was to facilitate a general comparison between different pipeline materials and types for certain cases. It would also have been applicable to the general pressure classification of all pipes, as requested in EN 805:2000. For the time being, it would help if product standards indicated a method for that purpose.

Concluding remarks

This document describes the outcome of the work aimed at a "Common Method". Although the resulting two options could not be distilled into a single one, they are believed to be valid for many loading conditions for buried pipes. A survey of differences between option 1 and option 2 is given in Table 1. The report does not reflect the comments received from CEN members on the two options and the answers given by the principal advocates of each one.

CEN/TC 164 and CEN/TC 165 are aware that they did not fully succeed in agreeing a single "Common Method", but the development of two methods still represents considerable progress in underground pipeline applications.

The two options should provide a good basis for future discussions about a single method and time will tell which seems the more feasible. In the meantime it is hoped that they will both be used and experience with them documented. Experts are invited to send experiences or questions to the secretariat of CEN/TC 165.

1 Scope

This document specifies calculation methods for the structural design of water supply pipelines, drains and sewers, and other water industry pipelines, whether operating at atmospheric, greater or lesser pressure.

It applies for the structural design of buried piping systems, made from all materials used for the conveyance of fluids under pressure or gravity conditions.

Pipes to be designed for installations in abnormal or unusual conditions, e.g. in quick soils or a marine sea bed, are not covered by this document, it may require special engineering.

The design of very large diameter pipe installations may require considerations to be given to other additional parameters, e.g. the homogeneity of the surrounding soil.

The design method is intended to be used for pipes operating at different temperatures provided that the corresponding temperature re-rating factors for the relevant pipe properties are used as specified in the referring standard(s). Nevertheless, high services temperatures may require an additional analysis of the longitudinal stresses and strains and/or a special design of the joints.

2 References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including amendments) applies.

EN 1610, *Construction and testing of drains and sewers*

EN 1991-2, *Eurocode 1 – Actions on structures — Part 2: Traffic loads on bridges*

3 Structural design issues

3.1 Soils

Soil is the load-carrying, load distributing and load transmitting structure. Different types of soils may be used for the bedding and embedding of the pipe and the main backfill of the trench.

Soil has also many parameters – as pipe materials – which have to be considered for structural design of earth-buried pipelines. At least the following parameters need to be taken into consideration:

- relative density (Proctor density) D_{pr};
- soil density;
- friction angle;
- soil modulus.

The soil parameters vary depending on the type of soil, its degree of compaction and the presence of groundwater. Option 1 and 2 use different soil moduli (Option 1: Oedometer; Option 2: Pressiometer).

Oedometer moduli can be measured in laboratory or by any on site measurement, where the relation to the Oedometer-modulus is known (e.g. load plate test); specifically in case of dispute these decisive soil parameters can be checked to clarify the guilty party for a damage.

Pressiometer-E-moduli can be measured on site only. Beside the principal difference of the Oedometer/ Pressiometer moduli is the fact that:

- CEN/TR 1295-3, Option 1 states, that the soil modulus is dependent on the vertical pressure and consequently also on the depth of the considered point in the trench. The deeper the considered point in the trench, the higher the Oedometer-E-modules;
- CEN/TR 1295-3, Option 2 states for Pressiometer modulus, that it is independent of the depth, because the Pressiometer-modulus is measured in the depth of the considered point.

Experts for geotechnics have developed several European or national standards for test methods and standards for the classification of soils; the latter shows a wide range of 20 (sometimes 30) soil classes.

For the purpose CEN/TR 1295-3, Options 1 and 2, only seven soil classes are sufficient in order to distinguish between all types of soil. A detailed and formal description is given in the annexes to this document. The seven classes are:

- **Class 1**: pea gravel is normally used only for bedding and embedding; almost “self-compacting”; either from gravel pits or consisting of reinforced concrete debris;
- **Class 2**: sand or gravel, which are the best materials for bedding and embedding next to Class 1 but the best material for main backfill;
- **Class 3**: silty sand or gravel is not easy to be used for bedding and embedding but a good material for main backfill;
- **Class 4**: sandy clay may be used for bedding, embedding and main backfill only in exceptional cases;
- **Class 5**: clay may be used for bedding, embedding and main backfill, after severe consideration only in exceptional cases;
- **Class 6**: organic clay may be used for bedding, embedding and main backfill (off-roads) only in exceptional cases after severe consideration;
- **Class 7**: organic soil shall not be used for bedding, embedding and backfill.

Option 1 specifies that for soils as well as for pipe materials, a short-term and long-term loading is to be considered differently. In option 2 this consideration is made for the pipe material only.

In soils as well as in pipe materials, the relevant test methods for the measurement of the soil parameters are to be determined, in order to provide for both designers and construction companies the necessary basis for the establishment of a “third-party quality control” and a quality control system by the construction company itself, respectively. For the quality control system of the pipe embedment by the construction company, a dynamic plate-loading unit has shown the best and not expensive results for continuous geotechnical quality control in each layer when backfilling.

For the third party quality control, the easiest and not expensive tool for acceptance test is a penetration test 3333333333unit (DPH), every layer of the backfilled trench can then be checked by this test tool from the top of the trench; only if required by the road authority, additional static plate loading tests (which give only an answer of the quality of the upper layers of the trench) may be performed.

Only in case of dispute, more severe tests (Proctor density/soil-modulus) need to be considered necessarily.

Anyhow, before a designer starts with the structural design of earth-buried pipelines, the designer should request preliminary investigation on the construction site

- to have the possibility to classify the native soil material of the embedment and to request goetechnical tests, if necessary. For this purpose, both a core drilling and a penetration test (DPH) approximately every 500 m are suitable. The designer can with these results decide which layers of soil in the trench can be used for bedding / embedding / mail backfill before the tendering documentation is elaborated and that

- the designer can then provide the parameters of the “undisturbed soil in every layer” (result from the penetration test) for the requirements of the degree of compaction in accordance with the agreement of the road authority.

3.2 Pipe materials

Many different kinds of pipe materials are used for the production of components to construct buried pipelines for water and waste water systems. The pipes vary in weight, load bearing capacity and ductility. Next to that many different types of jointing methods are used with the different pipe materials.

In accordance with EN 805 and EN 476, some product standards exist, which include dimensions, as well as material specific information needed for a structural design purpose. All product standards should be completed in this respect.

3.3 Types of loading

Pipes buried in ground are exposed to the following recognisable types of loading:

3.3.1 Soil load

Normally considered as the weight of the soil column above the pipe and the reaction to the side and the bottom. This weight might be increased or decreased with the shear forces exerted by the adjacent soil.

3.3.2 Traffic load

In Europe different types of axle loading exist. Generally the biggest difference exists between the UK and the continent. Care should be taken to take over some of the traffic loading regimes, because mostly they are taken from studies on bridges: here the damping and spreading effect is not covered, on the contrary they utilise high dynamic impact factors. It should be realised that traffic load further compacts the soil and changes the soil properties. It is highly recommended to the future work, to give attention to the issue of load spreading due to surface and traffic load other then the fixed axle loads as currently used.

3.3.3 Groundwater

The effect of groundwater might change the properties of the soil since it loads the pipe with an external hydraulic pressure.

3.3.4 Installation loads

Depending on the type of soil used as embedment and the level of compaction required after installation, more or less energy has to be applied to the soil during the compaction process. When a lot of energy has to be applied, part of that energy will move in to the pipe, will result in a loading and will change the properties of the soil.

3.3.5 Internal pressure

If pressure pipes are considered, the most obvious load is the load caused by internal pressure.

3.3.6 Pipes own weight

This type of loading becomes more important when bigger diameter pipes are considered. Next to the fact that it results in stresses and deformation of the pipe itself, it will also load the foundation of the pipe, which may lead to settlement differences along the pipeline.

3.3.7 Weight of fluid

The same considerations as above are valid.

3.3.8 Subsidence (differential settlement)

Pipes exert pressure on its foundation, the pipe bed. The stiffness of the pipe bed may vary along the pipeline and hence result in differential settlement of the pipe. Next to that subsurface loading, like occurring when the height of cover is increased as a result of highway or dyke (re-) constructions, may have the same effect.

Settlement differences also occur when pipes are laid in mining areas, where differential settlement might occur. Special attention shall be paid to the situation where a service pipe connects a rigid construction (chambers, houses, etc.) to a main pipe.

3.3.9 Temperature differences

Fluids transported through the pipe may vary in temperature. Also the soil might be prone to changes in temperature and as well as the fact that pipes might experience temperature differences before and after installation. The expansion (negative or positive) will activate shear stresses between the soil and the pipe. The last part of a straight sections however, like at bends, such loads will be balanced in another way. Special considerations shall be taken when in that last (sliding) part, joints are present. They should be end thrust resistant or allow the necessary displacement, before the soil balances the load. If the pipe compresses, upheaval buckling might need to be considered by the designer.

3.3.10 Landslide

Landslide occurs where soil against a hill or mountain starts to slide. This situation is typical for areas where vegetation is not present or has been taken away. Especially during the wet season, movements caused by landslide might occur.

3.3.11 Loading by earthquake

Earthquakes result in vertical and horizontal movements. Designers need to consider the effects of earthquakes. Special design in combination with specific measures during installation needs to be considered.

The loading can be divided in loading by force and pressure, and in loading caused by prescribed displacements. As far as forces are concerned they might be acting continuously, so called sustained loading or they might act temporarily.

For structures in soils it is important to recognise if the structure moves into the soil, or if the soil follows the structure. In the first situation, the soil loads the structure with the so-called passive earth load, in the second situation the active soil load shall be considered. Because of the nature of the soil and it’s feature that the properties changes considerably when the soil consolidates, makes the design - when exact analysis is needed - to a difficult task. Therefore, design methods should be looked upon as a means to estimate - not to determinate - the loads, and induced stresses and strains.

Furthermore, the pipe system also involves joints, branches and ancillaries like valves etc, which give rise to specific loading conditions like for instance shear loading. In the document, pipes have been considered. The aspects of design involving system components have been left up to the designer.

All pipe materials have to cope with these types of loading in one or another way. Design methods have to allow the specific material features to be covered by the method.

Some of the loading types shown above or very specific for certain regions in Europe, reason why experience gained in these regions should not be neglected.

4 Principles used in Annex A (Option 1) and Annex B (Option 2)

4.1 General

Next to a number of national established methods as shown in CEN/TR 1295-2, two methods have been developed each claiming that they are for universal use in the normal design practice in Europe. The two methods are introduced hereafter.

4.2 Principles used in Annex A (Option 1)

4.2.1 Introduction

The structural design of buried pipelines has to deal with an interactive system consisting of the pipe and the surrounding soil. Therefore the principles for the theory of structure and soil mechanics shall be used. Consequently the calculation as determined in *Option 1* follows these principles.

Option 1 was developed over a ten year period on the basis of the German *ATV-A127* [6] and the Austrian *ÖNORM B 5012* [12] by European experts, introducing the latest knowledge on pipe design. These two fundamental standards are based on the same mechanical models. The most important models are:

a) theory of the shear stiff beam [1], and the

b) load-displacement relation for a parabolic load stripe acting on the elastic half space with the properties of the soil at the side of the pipe [2].

With the shear stiff beam theory the concentration of the vertical load acting on the pipe is calculated, which is influenced by the different deformation of the pipe and the surrounding soil. The most important loads are taken into account, except own weight and water fill, but including the stiffening effect of the horizontal bedding. Therefore the compatible vertical load is calculated in A.8.3 and A.9.2, taking into account the compatibility in two directions, horizontal and vertical.

The load-displacement formula of [2], valid for a parabolic distribution of the horizontal bedding reaction stress, is based on the *Boussinesq's* theory, replacing the *Kany* formula which was used in *ATV-A 127* [6] and *ÖNORM B 5012* [12] and is based on a rectangular load distribution. Therewith the definitive compatible horizontal pipe deflection and the compatible horizontal bedding reaction stress are calculated. For this calculation step all loads are considered including own weight and water fill.

This separation into two steps offers the possibility for a significant simplification of the calculation without loosing any noticeable accuracy of the results. It is based on the assumption that the vertical load concentration is not significantly influenced by the load cases own weight and water fill. The derivations of the formulae used in A.9.3 are described in [3].

4.2.2 Information on the content of Annex A (Option 1)

4.2.2.1 A.1 to A.4: General, Terms and definitions, Symbols and Principle

One of the essential principles requires that the traffic load have to be taken into account as a short-term load. For long term calculation, a twofold calculation is required. The short-term load (traffic load) shall be considered by using the short-term properties of the pipe material and the soil, the long-term loads using the long-term properties.