Soil Steel Composite Bridge (SSCB)

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Abstract:

This project focuses on the design, construction, and implementation of a soil-steel composite bridge, aiming to provide a durable and cost-effective solution for spanning. The study involvesa comprehensive site assessment to understand soil conditions, hydrological aspects, and environmental considerations. Engineering design principles are employed to create a structure that optimizes load-bearing capacity while ensuring adaptability to varying terrains and traffic demands.

The material selection process involves the careful choice of steel components, considering theirresistance to corrosion and compatibility with the surrounding soil. Construction planning includes detailed strategies for assembly, installation, quality control measures, and adherence tosafety standards throughout the project lifecycle.

This abstract highlights the necessity of collaboration between engineers, designers, constructionteams, and stakeholders to ensure successful execution. The expected outcomes include a durable, sustainable, and efficiently constructed soil-steel composite bridge, catering to the specific needs and challenges of the designated site.

The FEM analysis results in showing rational outcome to the field measurement for structuralresponse. The known design method of SSCB are Pettersson-Sundquist design method and Kloppel and Glock design method.

Introduction

1.1. General

The demand for efficient and practical solutions to engineering problem is becoming intense and supplementary competitive. The market for Soil Steel Composite Bridges (SSCB) has grown rapidly. It is one of the most competitive and feasible alternatives to conventional bridge construction.

Soil Steel bridge comprises of structural steel plate and engineering soil which is designed andconstructed to induce a beneficial interaction between the two materials to serve its ultimate purpose.

Better and safer investment in these structures has been a huge demand by the Authorities, whichhas stimulated the engineering research and the industry section into more design and performance investigation. Methods are still being developed from time to time, to cover new manufacturing products and new design challenge.

1.2 Background

Research and development on funerary structures is believed to have begun as early as1913 atIowa State University by Marston, Spanler, and others.

In 1923, the American Railway Engineering Association (AREA) came to an important conclusion about the Illinois Central Railroad; According to this result, measurements showedthat the suction machines could move 60% of the 10.7 m packed column, while the remainingpart was then taken from the adjacent soil (CSPI, 2007).

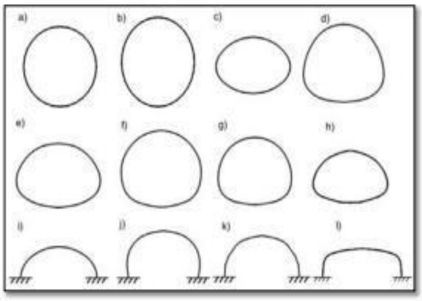
In 1960, Marston-Spangler proposed the concept of ring compression theory (AbdelSayed et al., 1994). Additionally, between 1967 and 1970, extensive research was conducted at the University of Utah under the sponsorship of the American Iron and Steel

Institute (AISI) and significant contributions were made to the field of research (CSPI, 2007).

Figure 1.1: K&G test to failure, 6 m span. Germany 1963.

1.3 SSCB TYPES

Soil steel composite bridges can be built in different shapes.



More advanced types of corrugation, such as deep corrugated Ultra-Cor structural plates

Corrugation pitch and depth 500 mm x 237 mm, thickness range from 7 to 12 mm, has been developed toprovide solutions when needed. Larger openings, less soil cover and more live loads are used.

Larger SSCB spans are possible, reaching more than 20 meters. It requires the use of plate profiles andsoil materials, but everything is there. Solved through intensive research and serious testing.

2. Kloppel and Glock design method.

2.1 General

In 1970, K. Klöppel and D. Glock, in cooperation with Deutsche Bahn through the Technical University of Darmstadt (Germany), published a report on changes in transit pipelines in different soil behavior. They proposed a method to calculate the load capacity for the design. Armco Inc., Ohio (USA) and August Thyssen Hütte AG, Duisburg (Germany), then things accelerated and a new company was founded in 1987 under the name "Hamco Dinslaken Bausysteme GmbH" formed the basis for the adoption of corrugated steel pipe standards in manyEuropean countries. ViaCon Austria provides advice and information on the current market for the use of the K&G design method, knowing that ViaCon Austria starts its designs from the K&G approach using rules and standards. One of the main regulations regulating the design according to the K&G method is ARS 20/97 and adds ARS 12/98, the method of use ofcorrugated steel pipe sizes.

In the design calculation, this report follows the previously mentioned ARS 20 According to theK&G design with additions specified in the German specifications described in ARS 20/97 and ARS 12/98. The results were checked and cross-referenced with an Excel design created by ViaCon Austria, based on K&G's design and including previous German specification.

2.2 Principles for design input and analysis

2.2.1 Backfill Soil Material

This approach uses the restrained soil modulus Sv as stiffness illustration for the backfilling soil fabric, which may be described because the deformation modulus of thecompression check with obstructed lateral growth. This modulus is little better than
the tangent modulus of soil Es.

According to K&G report, the elastic modulus Es for soil material such as gravel and sand is inrange as

Es=(0.64 - 0.775)Sv

2.2.2. Load System Classification.

In general, the structural system is categorized into two main groups based on the level of liveloading compared to the soil cover.

The first category pertains to low fill soil cover, where the criteria dictate that the soil pressure resulting from the dead weight of the soil at the crown (γ Hu) is lower than the equivalent surfaceuniform live load, denoted as Pov. In such instances, the crown pressure, which accounts for both the soil dead weight and the pressure from live loads, is increased by 10% to accommodate for load concentration and dynamic effects. This adjusted crown pressure is distributed over a smaller angle, symbolized as ψB=1.57 radians.

Conversely, when the dead soil pressure exceeds the equivalent surface uniform live load (Pov),the scenario is classified as high fill soil cover. Here, the loading on the upper part of the pipe isdistributed over a wider angle, denoted as ψB=2.36 radians. In this case, the crown pressure is simply calculated by summing the soil dead weight and the crown pressure from the surface liveload.

2.2.3 Loads and loads distribution.

The treatment of dead weight from soil at the crown depends on the classification of the systemas either low or high fill soil cover, as discussed previously.

For live loads, such as traffic loads, the calculation involves distributing the axle load of the vehicle over the effective area beneath the axle tires. In the case of railway traffic, the area is determined based on the sleeper size and the typical distance between sleepers, as detailed in theappendix A of the K&G report, which provides sample calculations.

In these calculations, the equivalent uniform live load is assumed to have a width of 3 meters andacts at a depth of 20 centimeters below the finished road level.

2.2.3.1 Live Load

The report specifies that the live load corresponds to LM1 as per EN 1991-2. The K&G method employs a technique of converting live loads into equivalent uniform surface loads with a standard width, typically 3 meters. As outlined in the original K&G report, the calculation of liveloads involves the distribution of axle loads for both railway and road vehicles over the area beneath the load, which is typically delineated by the geometry and position of the loads.

For instance, in the case of the German standard bridge class 60/30, the equivalent uniform surface load is reported as 45 kN/m². This value is derived by dividing the axle loads, such as those of a 20-ton truck, by a dimensioning area of 1.5 meters (representing the axle-to-axle distance) and then spreading this load over a 3-meter width, which corresponds to the offset ofthe truck's width to the national lane width of 3 meters.

2.3. Case Study

To ensure consistency, the K&G method is applied to assess the Enköping culvert case, as previously analyzed in the SDM. The profile plate range remains similar to the previous study at 200×55 mm. Although the K&G method theoretically allows for a wider range of profiles, this study opts for consistency rather than exploring higher profiles, as they aren't originally supported by the K&G method. However, it's noted that some companies do utilize higher profiles based on their experience and calculations.

The K&G design method primarily focuses on checking the global factor of safety, akin to principles in geotechnical engineering, often referred to as the working load limit. Typically, factors aren't applied for loading or material, except for a standard 10% increase for loads in lowfill cases where load concentrations are expected.

In the Enköping geometry case, all main verifications are conducted within the K&G calculationprocess. However, limitations in selecting soil parameter values for design are maintained to align with current industry practices, as outlined in the sample calculation sheet provided in Appendix B.

3. Finite element modelling (FEM)

3.1 General

A finite element model will be studied here for some research to better understand the structuralbehavior of soil steel bridges.

A two-dimensional finite element modeling software called PLAXIS 2D will be used. The mainfeature of the soil during the backfill process and the soil-steel interaction material, in addition, the software allows easy visualization of the response of the structural system during the construction phase.

Three examples will be simulated here using PLAXIS 2D FEM analysis involving the steel railway bridge. The implications of the results should be investigated and compared with theoretical calculations and field measurements.

3.2 Basics And Potentials "PLAXIS 2D"

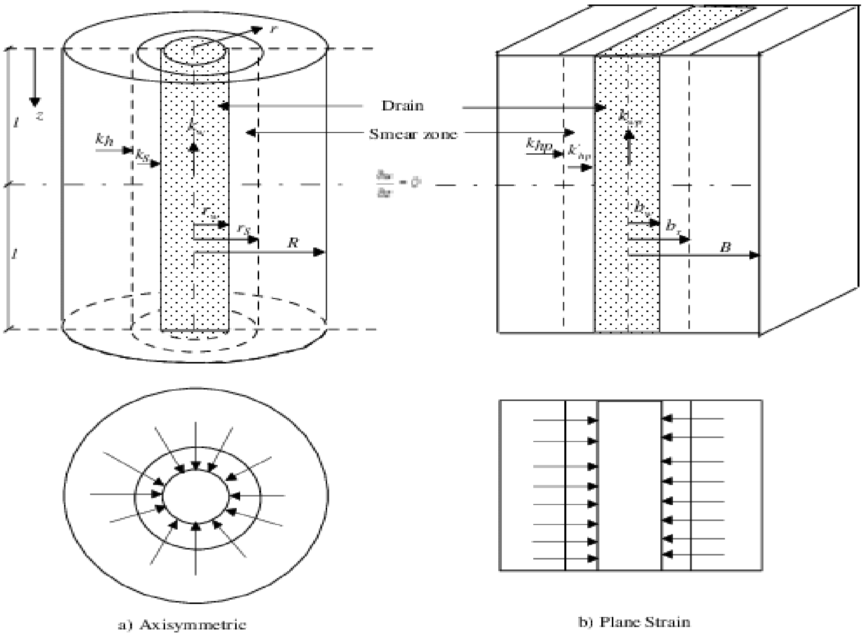
PLAXIS 2D is a finite element modeling software developed to study the stability and deformation of geotechnical engineering projects. The graphic input of the problem can elementmodel, which will lead to complex calculation results when numerically calculated (PLAXIS 2Dmanual).

To solve the problem, the user must create a 2D geometric model using a set of coordinate systems in the x-plane consisting of points, lines, and other hardware. Input constraints and boundary conditions should also be defined and encouraged. Creating an appropriate finite element mesh model can be selected from many options available to achieve the desired modelrepresentation and accuracy acceptable to the end user.

3.2.1 The Model

PLAXIS 2D allows you to choose between two conceptual models, simple strain or axi symmetrical model. One more interesting in representing the problem of ground bridge is asimple strain model with less or less cross-section geometry.

Figure 2.2: Plane Strain and Axisymmetric



Cross-sectional and perpendicular to the stress state associated with the loading pattern in acertain length (z-direction). In this case, the displacements and strains in the z-direction areassumed to be zero, but the normal stress in the z-direction is taken into account.

Often, simple tension is used as an idealization of the 2D problem in the design method, where the paper assumes a flatness approach and shows consistent structural behavior along its length.

3.2.2 Elements

A 6-node or 15-node triangular elements can be used to model the soil layers and other volume.In this study, a 15-point triangular element was selected to model the soil group, structural elements and interfaces. The element type provides standard displacement interpolation and

numerical integration including twelve Gaussian stress points, resulting in more accurate results despite higher memory consumption and lower computational speed compared to simplerelements.

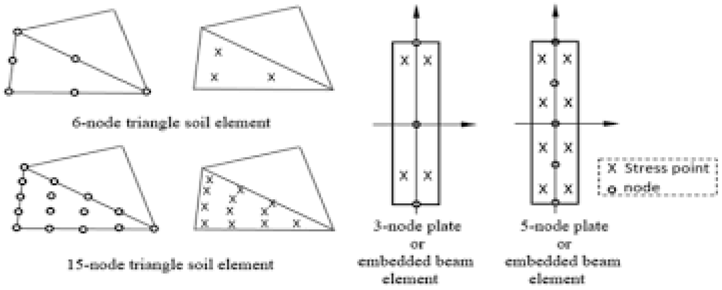


Figure 2.3: 6 nodes and 15 nodes

3.2.3 Soil material models

The soil material in PLAXIS 2D can be simulated using different material models, main modelavailable in PLAXIS 2D are:

1. **The Linear elastic model:** This model represents the law of isotropic linear elasticity ofthe rod. This model is very simple and limited to simulating soil behavior. This model shows that two strength parameters include Young's modulus and Poisson's ratio.
2. **The Mohr-coulomb model:** It is a famous and often used model to simulate the behaviorof soil aggregates and is recommended as the first method of analysis considering the linear elastic model of perfect-plastic approximation. This model requires five main inputparameters (two stiffness parameters and three strength parameters), two stiffness parameters are the average effective soil stiffness (Young's modulus E) and Poisson's ratio v, and the other three strength parameters are the effective cohesion c, friction angleis φ and dilation angle is ψ.

The strain is composed of elastic part and plastic part, hence called elasto- plasticity. In general, the Mohr-Coulomb failure criterion represents a linear curve derived from the fraction of material shear strength compared to the applied normal

stress. This relationship is expressed as $\tau = \sigma \tan(\varphi) + c$, where τ is the shear force, σ is thenormal stress, c is the coupling and θ is the angle of internal friction.

3.2.4 Construction Stages

One of the key advantages of PLAXIS 2D is the ability to simulate the construction process where loading and unloading takes place. The importance is to control the strength and leakageduring the filling operations and ensure that the response of the structure is kept within the permissible limits.

In this study, the construction process will be modeled in the plastic phase to capture theinteraction between the soil and the structure during construction.

3.2.5 Compaction effects

The basic concept of compaction is to compact the soil material to the desired density, while theproperties of the material are changed to achieve higher strength. Previous studies (Abdel-Sayedand Salib, 2002) and (Kung et al 2007) have shown that the type of lateral filler material and compression are critical issues and must be carefully modeled in the soil-steel composite bridge.

In our case, the response of the structure will be very dependent, the compaction of the soil layerduring the excavation activity will cause an increase in horizontal pressure, and in fact some studies show that the effect of compaction in some cases is to increase the lateral pressure of the earth to a passive value. One way to capture the effects of compression in PLAXIS 2D is to activate the surface load for each relevant layer, of course the size and magnitude of this uniformsurface load will largely depend on the desired level of compression and the compression deviceitself.

3.3 Enkoping Case Modelling

The tube structure was built near Enköping, 100 km west of Stockholm. The project, sponsoredby ViaCon AB, aims to test holes over 5m and to investigate the effect of the quality of the soilmaterial and the height of the soil cover, as well as to test the ultimate load.

A full-scale trial was conducted between 1987 and 1990 and later reported as part of Pettersson's(2007) doctoral thesis. In the report, several tests were carried out to investigate various factors and study the response of the structure under different conditions.

To limit the modeling conditions, test case A.1 (Pettersson, 2007) was adopted mainly to investigate the response of the structure during the backfilling operation for a specific coverheight and soil material quality mentioned in the following section.

This model will include a complete structural profile and soil material around and below the pipefittings. The results of the model will be compared with the field measurements contained in the report.

3.4 Kloppel & Glock test case modelling

In 1963, a pipe arch culvert underwent a static load test conducted jointly by Armco-Thyssen Company and the Statics and Steel Institute of Technology in Darmstadt, led by Professor K. Klöppel. The test aimed to assess the culvert's capacity to withstand specified loads according tothe German Federal Railway Administration, with a safety factor of 3.0, under soil cover conditions equivalent to one-sixth of the clear span (1.04 m). Additionally, a load-to-failure test was conducted to determine the culvert's ultimate capacity, with soil cover measuring one-fourthof the span width (1.57 m).

The results of the test, including measurements taken during backfilling stages and loading stages, were documented in a K&G publication in 1970. This study focuses on analyzing the culvert's response during backfilling operations and the standard load test conducted under 1.04m of cover. The model's findings will be compared to the corresponding site measurements detailed in the same report.

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