

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Application of geogrids in soil-steel culvert

Application des géogrilles dans ponceau sol-acier

N. R. EL-Sakhawy

Zagazig University, Zagazig, Egypt

H. Arafat

Minister of Transportation, Egypt

A. Abd Allah

High institute of engineering, 6 October, Egypt

ABSTRACT: Corrugated flexible Soil Steel composite culvert or bridge (SSCB) having larger spans are being constructed more frequently around the world. Often, also a low height of cover is necessary. To increase the free room other profiles than the circular type are being constructed. The paper presents a parametric study of the performance of another two profiles taking the effect of applying geogrids in the backfilling soil to reduce stresses laying on the steel bridge. Finite element modelling (FEM) were implemented adopting software package PLAXIS 2-D version 8.2 non-linear (2004). The results elucidated that the use of geogrid in backfilling soil had significant influence on reducing bending moments in the corrugated steel sheets. The vertical concrete pedestals with arch culverts reduces the bending moments.

Keywords: Soil steel culvert, vertical concrete pedestals with arch culverts, soil structure interaction, parametric study, finite element, Geogrids, PLAXIS.

RÉSUMÉ: Un ponceau ou un pont en composite d'acier au sol souple ondulé (SSCB) ayant des portées plus grandes sont construits plus fréquemment dans le monde entier. Souvent, une couverture de faible hauteur est également nécessaire. Pour augmenter l'espace disponible, d'autres profils que le type circulaire sont utilisés. Le document présente une étude paramétrique de la performance de deux profils ayant pour effet d'appliquer des géogrilles dans le sol de remblayage afin de réduire les contraintes imposées au pont en acier. La modélisation par éléments finis (FEM) a été mise en œuvre en adoptant le progiciel PLAXIS 2-D version 8.2 non linéaire (2004). Les résultats ont montré que l'utilisation de géogrille dans le remblayage avait une influence significative sur la réduction des moments de flexion dans les tôles d'acier ondulées. Les socles en béton verticaux avec ponceaux en arc réduisent les moments de flexion.

Keywords: Ponceau sol-acier, interaction structure du sol, Les socles en béton verticaux avec ponceaux en arc, étude paramétrique, éléments finis, géogrilles, PLAXIS.

1 INTRODUCTION

The term “soil-steel structure” was first introduced in 1976, in the 1st edition of the Ontario Highway Bridge Design Code (OHBDC) in Canada (El Elshimi, 2011). Since then, many developed design and construction of soil-steel bridges have been searched (King, 1977; Bakht,

1981; Pettersson and Sundquist, 2010; McGrath & Webb, 2007; Esmaeili et al, 2013; Abdel-Sayed, and Salib, 2001; Abdel-Sayed et al., 1993; Williams, 2012). Soil-steel culvert contains a Flexible corrugated metal crust. The main load-carrying element is the engineering backfill that covers the metal crust.

The paper presents a parametric study of the performance of three profiles taking the effect of applying geogrids in the backfilling soil to reduce stresses laying on the steel bridge. The goal of the study is to achieve the least stresses laying on the bridge.

2 MODELING SOIL-STEEL STRUCTURE

Finite element modelling (FEM) were implemented adopting software package PLAXIS 2-D version 8.2 non-linear. Standards fixities are applied at the edges (horizontally fixed edges) and fixed in both ways for the bottom edge. Figure 1 illustrate the FE mesh.

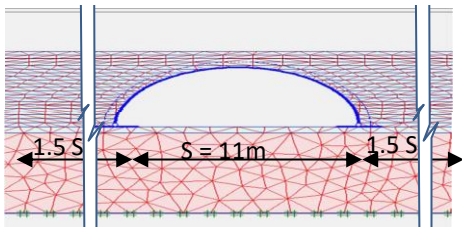


Figure 1. FE mesh

The geometry dimension was determined after several trials to insure taking the effect of surrounding soil. The trials showed that the soil extending up to 1.5 culvert spacing is enough to capture the effect of surrounding soil on the soil steel culvert. The culvert span is taken 11 m. It is surrounded with backfill soil that is compacted in layers; each layer was 33 cm height. The backfill material was modelled as 15-node triangular elements. Mohr- Coulomb failure criterion was adapted to model soil behavior. Physical soil properties were obtained from laboratory testing of available sand in Egypt. It is poorly graded sand, as shown in Figure 2. Shear box test was carried out. The result is shown in Figure 3.

Foundation and pedestals was idealized as elastic plates. This was assumed because the initial studies on the behavior of the foundation system demonstrated that, under the conditions for this study, the foundation and pedestals did not exhibit nonlinear behavior.

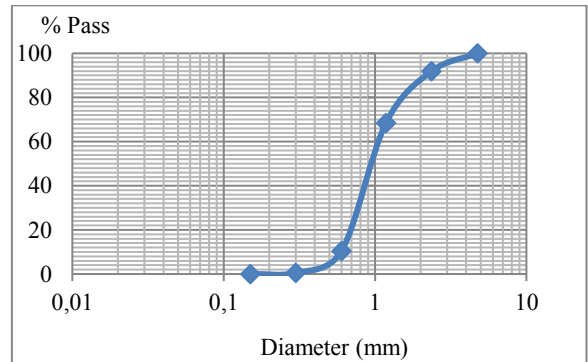


Figure 2. size analysis of sand adapted in the Study

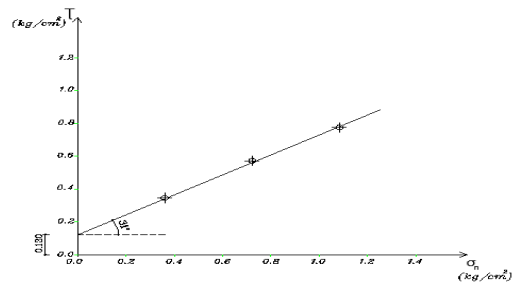


Figure 3. Results of shear box test

Corrugated steel plates of type SuperCor S37 was adopted as the steel structure part. Geometry of the corrugated plates forming the structures was constants as shown in Figure 4. Table 1 shows the physical and mechanical properties of the corrugated steel sheet (Pettersson , 2007).

The corrugated sheets can be modelled adopting orthotropic shell theory with an equivalent thickness equal to the depth of corrugation and the modulus of elasticity is reduced to provide the correct EI value (El-Sawy, 2003). El-Sawy proposed that the corrugated steel plates can be replaced with an equivalent prismatic section using the following equations:

$$\bar{t} = \sqrt{\frac{12I}{A}} \quad (1)$$

$$\bar{E} = \frac{12EI}{\bar{t}^3} \quad (2)$$

Where:

- \bar{t} : Equivalent prismatic section,
- \bar{E} : Equivalent Young's modulus,
- I: Moment of inertia,
- A: Area per unit length of the corrugated plate,
- E: Young's modulus.

Figure 4 demonstrates the concept of the equivalent simulation of corrugated plate. . Then:

$$\bar{t} = \sqrt{\frac{12I}{A}} = 172 \text{ mm}$$

$$\bar{E} = \frac{12EI}{(\bar{t})^3} = 11804.1 \text{ MPa}$$

Hence, the final parameters are Young's modulus $\bar{E} = 11804.1 \text{ MPa}$, equivalent plate thickness $\bar{t} = 172 \text{ mm}$, $A = 0.172 \text{ m}^2/\text{m}$, $I = 4.24 \times 10^{-4} \text{ m}^4/\text{m}$, and $\nu = 0.3$

Table 1: Properties of Corrugated Steel Sheet

Plate thickness	7 mm
Corrugation height	140 mm
Corrugation length	381 mm
Area	9.81 mm ² /mm
Yield strength (fy)	275 MPa
Elasticity modulus	200 GPa
Moment of inertia (I)	24164 mm ⁴ /mm
Section modulus	308.2 mm ³ /mm

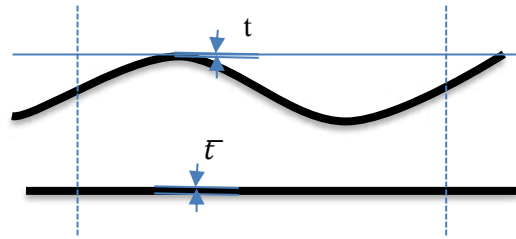


Figure 4. Equivalent simulation of corrugated plate

According to the (Egyptian loads standard, 2008) a four wheel 60 ton truck was implemented as the main live load for all the culverts. The applied force on all culverts was equal to the normal load including the dynamic load factor. The axle loads are distributed by the contact axle area 0.4 m x 0.4 m and can be redistributed over asphalt layers with 1:1 distribution slope. In this study, the truck axle loads are distributed by the contact axle area 0.4 m x 0.4 m and redistributed over asphalt layer thickness 0.3 m, so the load was 306 KN/m over a distance equal to 0.7 m for each loading truck axle. The area around the truck was loaded with 9 kN/m equal distributed load. Figure 5 shows plan of the truck with its dimensions and loads. It was found that placement of the wheel axle of the trucks at the crown of the culverts produces the maximum moment (Abd allah, 2017).

Table 2 illustrates the variables of the parametric study. Geogrids reinforcement with the soil cover was implemented in the model with each backfill layer, while geogrids with the backfill around the culvert sides was implemented each 66 cm as it had shown less or negative effect on the culvert structure.

Table 2 Variables Considered in the Parametric Study

No.	Variable	Range		
1	Culvert profile	Profile 1: Box culvert	Profile 2: circular culvert	Profile 3: Arch culvert with 1m vertical concrete pedestals
2	Depth of soil cover (m)	1.00	1.50	2.00
3	Soil Reinforcement	With Soil Reinforcement		Without Soil Reinforcement
4	Geogrid Stiffness (kN/m)	2000		8000
5	Position of Reinforcement	In backfill cover (upper)		In all backfill soil (total)

In all cases, the length of geogrids was extended until its effect on the results was negligible

Geogrid element are used in practice for the construction of soil reinforcement these elements are used in plaxis by the use of special tension elements it is convenient to combine these elements with interfaces to model the interaction with the surrounding soil.

With regard to geogrid modeling, a geogrid element provided By PLAXIS was employed along with interface elements that are connected with adjacent track substructure layers. The Only property in a geogrid data set is the elastic axial stiffness, in terms of force per unit width. For the parametric study, three levels of value were accounted to gauge the influence of its integrity on culvert structure response.

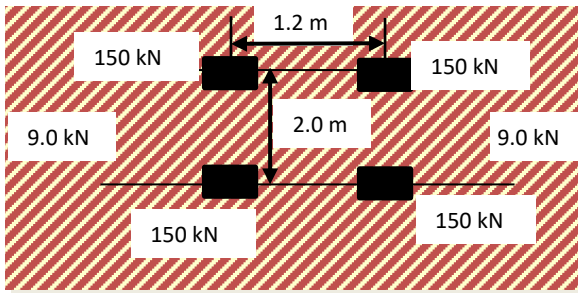


Figure 5. Plan view for the loading truck

3 RESULTS AND DISCUSSION

3.1 Thickness of soil cover

Figure 6 (a) shows the Maximum bending moments with different geogrids stiffness and soil cover, while Figure 6 (b) shows the normalized moment. From Figure 6 (a), it can be seen that bending moment decrease with increasing soil cover. Soil cover leads to more load dissipation and so the bending moments become less. But, also increasing soil cover increases the total weight over the structure giving higher thrust force in the structure, as can be seen in Figure 7. The effect of soil cover on the bending moment of the structure is evidence

for low cover thickness up to 1.50 m and becomes less over this thickness; this is clearly shown in Figure 6.

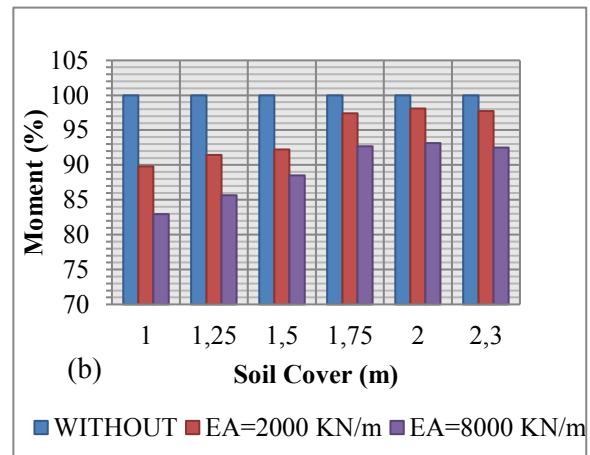
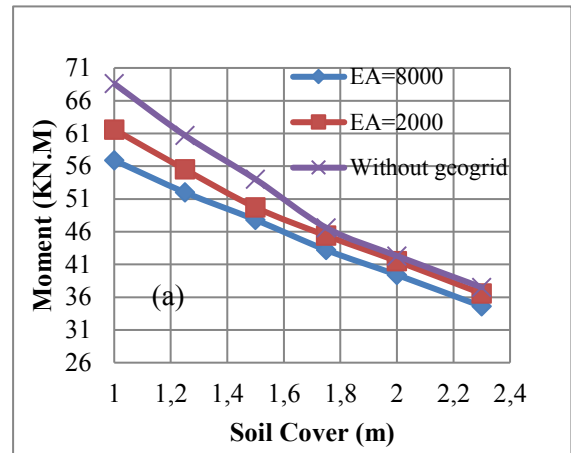


Figure 6. Maximum bending moments with different geogrids stiffness and soil cover, a) determined moment, b) normalized moment

3.2 Geogrids

From Figure 6 (a), it can be seen that the effect of geogrids in reducing bending moments is high for low depth of soil cover up to 1.5 m and becomes less after that. This is due to the low stress distribution in the low depth of soil cover

Figure 7 illustrates the maximum axial force with different geogrids stiffness and soil

cover. As can be seen from the Figure, geogrids increases the maximum axial force in the structure with very low percentage about 4.0% for geogrid stiffness EA= 8000 KN/m and 3.0% for geogrid stiffness EA= 2000 KN/m.

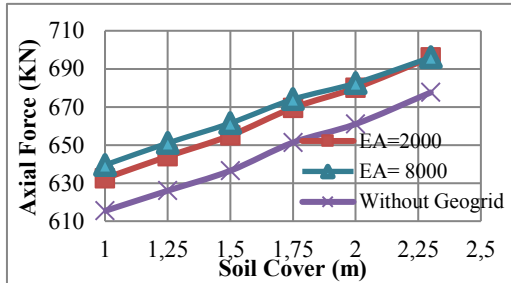


Figure 7. Maximum axial force with different geogrids stiffness and soil cover

3.2.1 Geogrid positioning

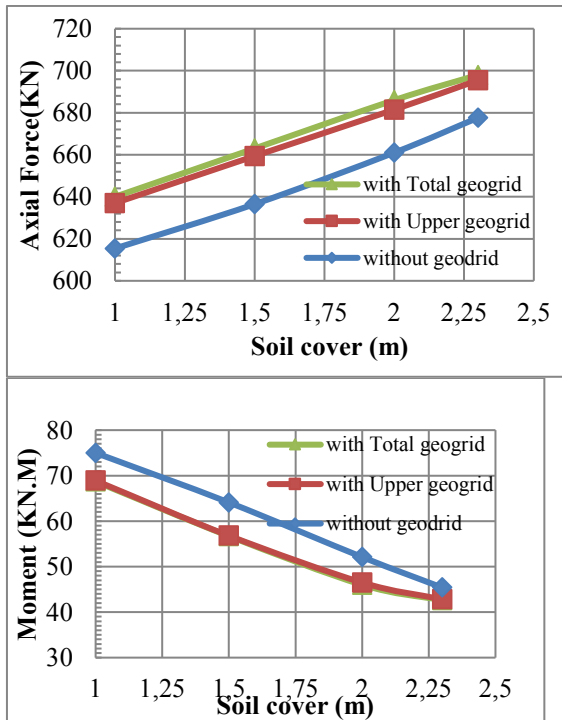


Figure 8. a) Maximum thrust and b) Maximum bending moment with different geogrids positions and soil cover

Figure 8 illustrates a) maximum thrust and b) maximum bending moment with different geogrids positions and soil cover, where geogrids were positioned in all of the backfilling soil (total) and where geogrids were positioned in the backfill soil cover only (upper). From Figure 8 (a), it can be seen that applying of geogrids in all of the backfilling soil gives higher thrust force than the cases with geogrids in backfill soil only. This is due to the fact that geogrids in the side backfills reduces the lateral earth pressure; which play a main rule in the stabilization of these structures. Figure 8 (b) shows that the bending moments for cases with total geogrids is of almost same value as the upper case.

3.3 Geometry of culvert

The effect of culvert geometry was studied for three different geometries of circular arch culvert, box culvert, and arch culvert with 1m vertical concrete pedestals. Figure 9 depicts the results of bending moments for the three culvert profiles with different soil cover. From the Figure, it can be seen that the arch profile with 1m vertical concrete pedestals gives the minimum values for the bending moments; specially for large soil cover, while the box culverts gives the maximum.

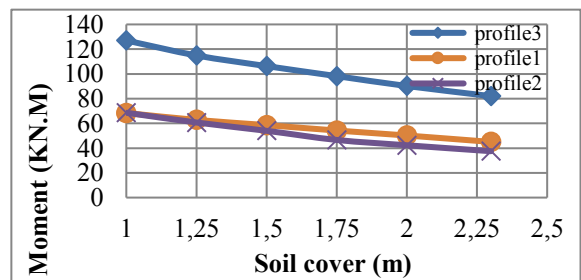


Figure 10. Axial Force Distribution for Different Culvert Profile

Figure 10 illustrates the results of thrust force for the three culvert profiles with different soil cover. Figures 8 and 9, show clearly that the arch profile with 1 m vertical concrete pedestals gives good results for bending moments and thrust force. So, this profile exhibits good behavior; it is particularly useful in meeting needs for structures with limited vertical clearance. It also provides large cross-sectional area for water conveyance.

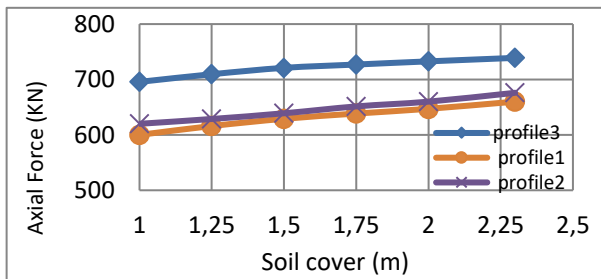


Figure 9. Bending Moment Distribution for Different Culvert Profile

4 CONCLUSION

A parametric study was performed using finite element analysis for long-span soil-steel culvert. Several factors including culvert profile, and geogrids application; stiffness, and position were considered in this study to investigate their effects on the behavior of long-span metal culverts. Two-dimensional finite element analysis was performed in the study employing orthotropic shell theory to model the culvert and Mohr-Coulomb constitutive model for soil modeling. The maximum values of bending moment and thrust force were obtained for each culvert, and the effects of different parameters were examined. Within the limit of this study, the following conclusion can be derived.

A. Increasing soil cover reduces the total bending moments in the box and arch culverts, but also increasing soil cover increases the total weight over the structure giving higher thrust force in the structure.

- B. The use of 1m vertical concrete pedestals with arch culverts reduces the bending moments with 10% and reduces the bending moments with 40% than using culvert profile for the same span and height
- C. The use of geogrids have better effect for bending moment reduction with low soil cover (less than 1.5m)
- D. Using Geogrids with the backfilled soil cover only gives better results than using geogrids with all backfilled soil

5 REFERENCES

- Abd Allah, A. 2017. Study of the Performance of Soil Steel Bridge, PhD thesis, Structural Engineering Department, Zgazig Univ., Egypt.
- Abdel-Sayed, G. and Salib, S. 2001. Minimum depth of soil cover above soil-steel Bridges, *Journal of Geotechnical and Geoenvironmental Engineering* **128**, No. 8, 672-681.
- Abdel-Sayed, G., Bakht, B., Jaeger, L.G. 1993. *Soil-Steel Bridges: Design & Construction*, 350 pp. McGraw-Hill, New York.
- Author, A.N. 1995. *Book Title*, Publisher Name, Publisher Location.
- Author, A.N. 2004. Article title, *Journal Title* **20**, 1012-1030.
- Author, A.N. Author, A.N., Author, A.N. 2012. Article title, *Journal Title* **12**, 12-19.
- Author, A.N., Author, A.N. 2010. Paper title. *Active Geotechnics: Proceedings, 12th INGA Congress* (Eds: Smith, A.L., Bloggs, G.M. & Nobody, A.), 1002-1005. Publisher Name, Publisher Location.
- Bakht, B. 1981. Soil-Steel Structure Response to Live Loads, *Journal of Geotechnical Engineering Division ASCE* **107**, 779-798.
- Egyptian Code for Loads. 2008. [in Arabic]. Ministry of Construction, new communities and populations and facilities, HBNRC.
- El Elshimi T. 2011. Three-Dimensional nonlinear analysis of deep corrugated steel

- culvert. PhD thesis, Department of Civil Engineering Queen's University, Kingston, Canada.
- El-Sawy, K.M. 2003. Three-Dimensional Modelling of Soil-Steel Culverts under the Effect of Truck loads. *Journal of Thin-Walled Structures*. **41**. 3: 747–768.
- Esmaeili et al. 2013. Minimum depth of soil cover above long-span soil-steel railway bridges. *International Journal of Advanced Structural Engineering*. 5:7.
- King, R. A. 1977. Corrosion in Reinforced Earth, Reinforced Earth and Other Composite Techniques, TRRL Supplementary Report 457, Transport and Road Research Laboratory, Crowthorne, Berkshire, England .
- McGrath T.J., Moore I.D., Selig E.T., Webb M.C., Taleb B. 2002. Recommended Specifications for Large-Span Culverts”, National Cooperative Highway Research Program, Report 473, National Academy press, Washington.
- Pettersson, L., 2007. Full scale Tests and structural evaluation of soil steel flexible culverts with low height of cover. PhD thesis, Civil and Architectural Engineering, Division of Structural Design and Bridges, Royal Institute of Technology, Stockholm, Sweden.
- Pettersson, L., and Sundquist, H. 2010. Design of soil-steel composite bridges, TRITA-BKN Rep. No. 112, Dept. for Architectural and Civil Engineering, Royal Institute of Technology, KTH, Stockholm, Sweden.
- PLAXIS. 2004. Finite Element Code for Soil and Rock Analyses. PLAXIS, 2D Version 8, Reference Manual, Edited by Brinkgreve, et al., DUT, the Netherlands
- Williams, k., Mackinnon, S. and Newhook, J. 2012. New and innovative developments for design and installation of deep corrugated buried flexible steel structures, In: Archives of Institute of Civil Engineering, 2nd European conference on Buried Flexible Steel Structures. 23-24. Rydzyna, Poland.

