RECENT RESEARCH ON FLEXIBLE CULVERTS IN SLOPING TERRAIN[1]

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The performance of buried flexible steel structures is directly influenced by the quality of the backfill soil and its configuration around the conduit. The economical choice of these structures stimulates practitioners to expand their different applications including their performance in sloping environment. The presence of steep surface slopes induces unbalanced loading and asymmetrical soil support around the conduit.

This paper outlines the latest research efforts on how a flexible culvert would perform in sloping terrain environment. The paper focuses primarily on the structural behaviour of soil loading effects. The investigation highlights the use of numerical simulation in predicting the performance of a case study of flexible culvert under different construction schemes, where the influence of slope intensity and depth of soil cover are briefly presented. Soil slope stability as a major concern is also discussed.

The research outcome clearly underlines the importance of soil configuration around steel culverts. The asymmetrical response of the conduit is predictably observed from the results and greatly influenced by the presence of shallow depth of soil covers. Sectional forces tend to increase with the increase of surface slopes. The results also underline the necessity of soil stability investigation when constructing flexible culverts in sloping terrain.

Key words: sloping terrain, flexible culvert, soil–steel composite bridge, finite element method, snowshed, avalanche load.

1. INTRODUCTION

The use of flexible culverts, also known as soil-steel composite bridges, is getting more popular for being economical alternatives to traditional bridges. The performance of these structures is very much dependent on the composite action between the soil and the corrugated steel. Therefore, the overall bearing

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capacity is directly dependent on the soil quality around the conduit as well as the compaction efforts during the construction. On the other hand, the soil configuration (i.e. the presence of surface slopes) is another important factor that could affect the structure on two levels, the bearing capacity and the structural response represented in the deformation and sectional forces.

The need to explore the constructability of flexible culverts in sloping terrains is believed to emerge as a direct outcome of being cost effective. While the construction of these structures in asymmetrical soil configuration might not be a usual practice, yet, there is a wide range of applications in such environment. For instance, the high cost for concrete avalanche protection galleries makes flexible culvert a strong alternative in this area. Other applications such as tunnels under ski slopes or a protection canopy for a tunnel entrance are also interesting areas of application. In fact, there has been a usage of relatively small flexible culverts in Norway (compare Figure 1) built in hillside location and have proven to perform successfully [1]. It is worth mentioning that the Norwegian document [2] endorse the use of flexible culverts as avalanche protection structures provided that a maximum 10% slope is extended to at least three times the span from the conduit wall.

Figure 1. A 6.47 m span flexible avalanche protection culvert built in 1988 in Troms, Norway [1]

Current design methods for flexible culverts have a set of design limitations and one of which involves maximum permissible longitudinal slopes above the structures. For instance, Swedish design method [3], also known as the Pettersson-Sundquist design method, defines a maximum longitudinal slope of 10% for the validity of the design procedure. Similar condition exists in the AASHTO [4] as well. Therefore, in the absence of dedicated studies regarding the performance of flexible culverts in sloping terrain, this article outlines the recent research efforts in realizing the different factors that may affect the performance of flexible culverts in sloping terrain. This paper highlights part of the research work on the topic [5,6], and elaborate more on the performance prediction of a pipe arch case study when constructed in different asymmetrical soil configurations. The load effects from soil are the main focus of this paper.

It is worth mentioning that a separate study [6] was performed to realize the effect of avalanche loading in combination with different surface slopes. The study also highlighted the effect of soil covers and the soil configuration on the downhill side of the structures.

2. METHOD

This investigation is mainly based on numerical simulations in predicting the performance of flexible culverts using finite element program called Plaxis 2D. The idea is to introduce different slopes with different soil covers representing the various support conditions. A pipe arch of 8.9 m span (Figure 2) is selected for this particular investigation. This is a real structure which was built in Poznan city in Poland [7]. Although the selected structure was not built under slopes, the intention of this study is to use its geometrical shape as bases for introducing slopes in a simulated environment.

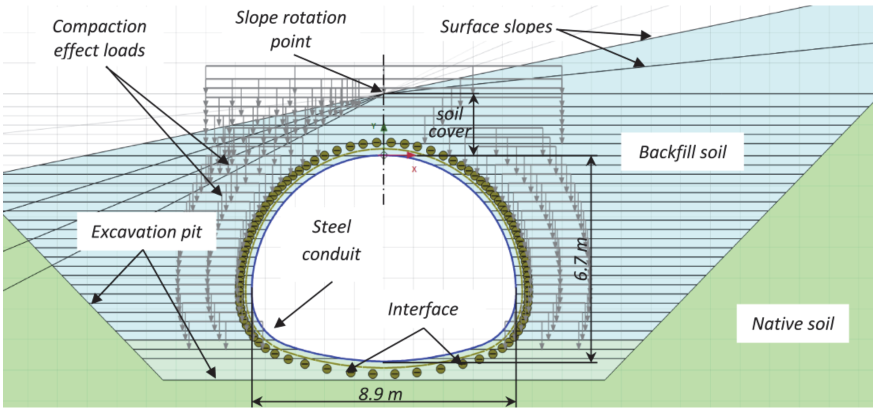

Figure 2. Model configuration and geometry for the case study

2.1. Model configuration

The different slopes were introduced above the structure by keeping a fixed rotation point on the ground surface above the crown (Figure 2). The slopes were created from 0% to 50% in an interval of 10%. Each slope was combined with three soil covers 1 m, 2 m and 3 m. The soil was modelled using a 15-node triangular element with the Mohr-Coulomb material model. The soil elastic modulus was set to increase linearly with depth starting from crown level at a rate of 2 MPa/m. The corrugated steel was idealized by a five node plate elements with an equivalent bending stiffness *EI* and axial stiffness *EA*. The interface between steel and soil was assumed flexible by setting the strength interaction parameter R_{inter} to 0.8. The construction process was included in the analysis by having the staged backfilling process. Compaction effects were simulated by activating momentarily a 25 kN/m load on each backfill layer. More details on the modelling assumptions can be found in [5]. Table 1 shows the main input parameters for the case study.

Table 1. Main input parameters for the case study

Steel plate		Soil	Native	Backfill
		Density, ρ (kN/m^3)	20	20
Bending stiffness, *EI* (kNm^2/m)	571	Soil elastic modulus, E_s (MPa)	30	20
Axial stiffness, *EA* (kN/m)	1.86×10^6	Friction angle, θ (degree)	38	36
Axial capacity, N_p (kN/m)	2794	Cohesion , *c* (kN/m^2)	10	1
Moment capacity, M_p (kNm/m)	30	Dilatancy angle, ψ (degree)	5	5
Poisson's ratio, *v*	0.3	Poisson's ratio, *v*	0.28	0.3

3. RESULTS

3.1. Displacements

The presence of asymmetrical soil support will rationally induce asymmetrical deformation upon the completion of the backfilling. The level of this deformation is highly depended on the steepness of the final slope and the depth of soil cover. Considering the slope configuration under study, the increase in soil cover would reduce the effect of slope presence. In other words, the lower height of cover, the structure is less resistant to asymmetrical soil loading. This effect is realized in Figure 3, where the cases of 1 m and 3 m soil covers are illustrated. The figure also shows the effect of steep slopes on the deformation response of the structure.

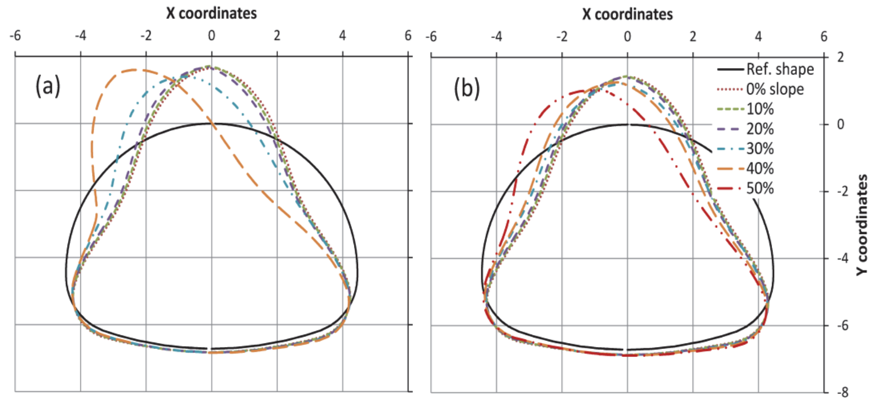

Figure 3. Deformation shape (scaled up 10 times) for (a) 1 m cover depth, (b) 3 m cover depth

3.2. Sectional forces

The design of flexible culverts entails the estimation of sectional forces including normal force and bending moments. In the presence of surface slopes, the overall stiffness of the structure is potentially affected, which therefore may have an impact on the resultant forces in the wall section. Figure 4 shows a linear increase in the maximum normal force with respect to the increase of surface slopes. In addition, one may note an increase in maximum bending moments with respect to slopes, and this increase is more obvious in the case of low depth of soil cover, where less soil support exits at the downhill side. The ratios of sectional forces presented in Figure 4 are calculated with respect to axial and moment capacities as mentioned in **Table 1**. Figure 5 also illustrates the distribution and increase of sectional forces when slopes are in presence.

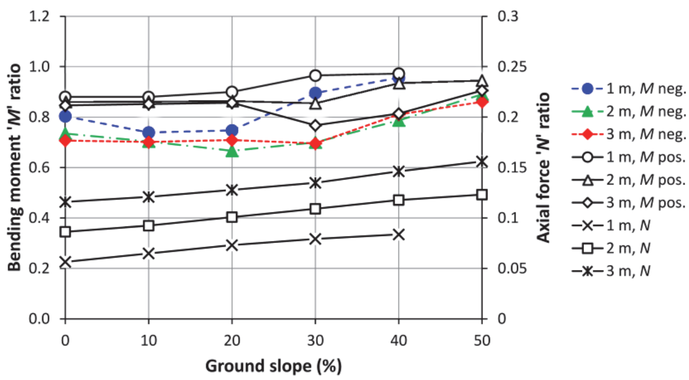

Figure 4. Normal force and bending moment (max. positive & negative) ratios shown for the different slopes and soil covers

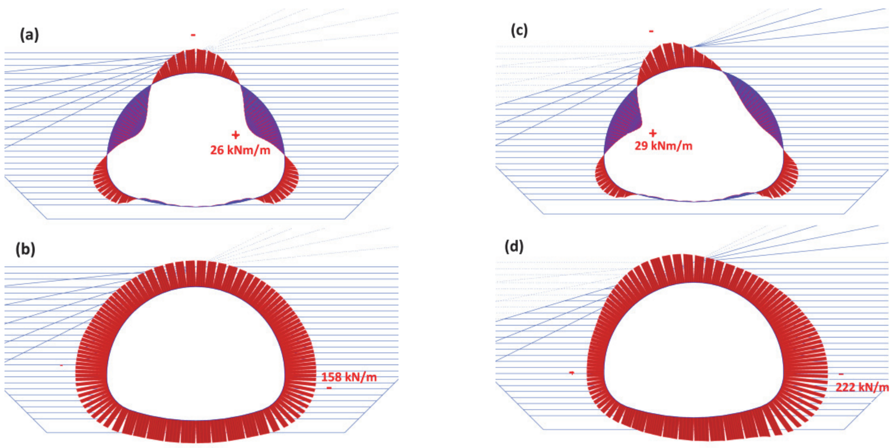

Figure 5. Bending moment distribution at (a) no slope (c) 30% slope. Normal force distribution at (b) no slope (d) 30% slope. All shown for 1 m soil cover

3.3. Slope stability

A study was performed to see the effect of culvert presence in a sloped ground. A drained safety analysis was carried out to calculate the safety factor for slope stability. The results show the importance of slope stability analysis when designing flexible culverts in sloping terrain. It is obvious from Figure 6 that the presence of culverts in a sloped soil would probably increase the risk of soil failure, when compared to the sloped soils without steel conduits. It is also seen that increasing the depth of soil cover could enhance the performance against slope stability. Figure 7 illustrates an example case for the most critical surface of failure.

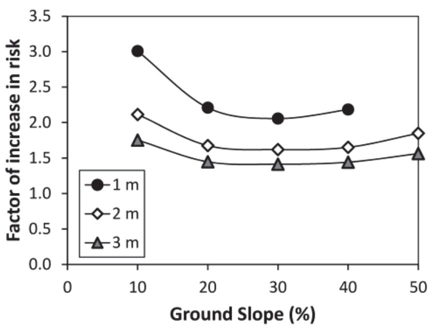

Figure 6. Factor of increase in risk of soil failure when the steel conduit is introduced in the sloped soils

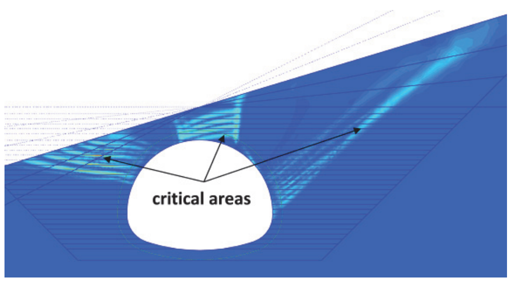

Figure 7. An example showing the soil failure mechanism for the case of 2 m soil cover & 30% slope

4. CONCLUSIONS

The presence of soil asymmetrical support around flexible culverts has considerable effects on the performance of soil steel composite bridges. The study shows how the change in soil configuration has a major impact on the deformation shape of the structure. While shallow depths of soil covers make the structure more prone to asymmetrical soil support, larger soil cover might help in reducing this effect. The introduction of surface slope tends to increase steel wall sectional forces. It is also found that the presence of flexible culvert might have a negative impact on the soil stability around the conduit.

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