An evaluation of influence factors that affect pressures in backfilled trenches

Une évaluation de facteurs d'influence qui affectent les pressions dans des tranchées remblayées

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ABSTRACT: Infrastructure rehabilitation and development drives part of the economy of many countries. This line of engineering works includes many projects with conduits in trenches, which are commonly used to house service infrastructures such as cables, sewers, and pipes. The design of these subsurface facilities requires a correct evaluation of the loads imposed by the fill material on the buried conduits. The analysis of these stresses necessitates an assessment of the interaction between the backfill and abutment walls. In practice, conduit design is usually based on an overly simplified arching solution proposed by Marston. A number of influencing factors are not taken into account with this approach. In this paper, the authors use numerical simulations to investigate the effect of key influencing factors on the vertical stress distribution in a backfilled trench. The results show how the vertical stresses may change with the filling sequence, trench width, walls inclination, and backfill properties.

RÉSUMÉ : La réhabilitation et le développement des infrastructures conduisent une partie importante de l'économie de plusieurs pays. Cette ligne des travaux d'ingénierie comprend beaucoup de projets avec des conduites dans tranchées qui sont couramment utilisées pour loger des infrastructures de service tels que des câbles, des égouts et des tuyaux. La conception de ces aménagements nécessite une évaluation correcte des charges imposées par le matériau en remblai sur les conduites enfouies. Dans la pratique, la conception de ces conduites est souvent basée sur une solution sur-simplifiée proposée par Marston. Plusieurs facteurs d'influence ont été négligés dans cette approche. Dans cet article, on utilise des modélisations numériques pour investiguer l'effet des facteurs clés sur la distribution des contraintes verticales dans une tranchée remblayée. Les résultats montrent comment les contraintes verticales peuvent changer en fonction de la séquence de remblayage, de la largeur d'une tranchée, de l'angle d'inclinaison des murs, et des propriétés des remblais.

KEYWORDS: Trenches; Backfill; Stress distribution; Arching; Numerical modeling.

1 INTRODUCTION

The rehabilitation and development of municipal and industrial infrastructures are driving the economy of many countries. These works include projects with conduits in trenches, which are commonly used to deliver gas, water and other services. The design of these subsurface facilities requires the evaluation of the loads imposed by the fill on the buried conduits. The analysis of these stresses necessitates an assessment of the interaction between the backfill and abutment walls. Due to the stiffness contrast between the relatively soft fill material and abutment walls, the former usually tends to settle more in the trenches, while the latter holds the fill in place due to frictional stresses along the interfaces. Part of the overburden weight is then transferred to the stiffer walls. This load transfer, known as "arching effect" (Janssen 1895), is a common phenomenon in geotechnical engineering when a particulate material is placed in silos and bins (Blight 2006), behind retaining walls (Goel and Patra 2008), in mining stopes (Li et al. 2005; Li and Aubertin 2008, 2009a,b,c, 2010; Ting et al. 2011; Thompson et al. 2012), and in relatively shallow and narrow trenches (Whidden 2009).

The design methods for conduits buried in trenches are often based on a stress solution proposed by Marston (1930), who made use of Janssen (1895) arching theory. The validity of Marston's solution is limited by several simplifications, including the fact that it has been developed for vertical walls. In practice, trenches with inclined walls are often used, in order to reduce the risk of soil sliding. A common practice for estimating the loads on buried conduits is then to use Marston's solution with the trench width at the top level (crown) of the conduit (Handy and Spangler 2007). The load obtained from this approach corresponds to that of a vertical opening with the width at the crown of the conduit. This approach can however lead to overestimate the magnitude of the stress transfer to the walls, and to underestimate the pressure on the buried conduit. The calculated load is then non-conservative (Handy and Spangler 2007). Efforts have thus been devoted to modifying the basic Marston's solution (e.g., Li et al. 2012a,b). Other limitations of this solution include neglecting the effect of backfill cohesion, dilation, and stiffness, and also of the filling sequence.

This paper presents results from a numerical investigation on influence factors that may affect the vertical stress distribution in trenches with inclined walls.

2 MODELING WITH FLAC

Analytical solutions are practical for engineers, but numerical modeling constitutes a more powerful tool to handle complex problems. In this investigation, the commercialized software FLAC (Fast Lagrangian Analysis of Continua; Itasca 2002) was used; this code is well adapted to help solve geotechnical problems with sequential excavation and/or backfilling.

Figure 1 shows a trench having walls inclined at an angle α, a width L_b at its base, filled to a thickness H_b. The backfill obeys an elasto-plastic law with the Coulomb criterion. Its response is controlled by the values of E_b (Young's modulus), μ_b (Poisson's ratio), γ_b (unit weight), ϕ'_b (internal friction angle), c' (cohesion), and ψ'_b (dilation angle). The modeled trench is filled to a height of 10 m. The walls inclination α is varied from 90° to 20° (with respect to the horizontal). The material surrounding the backfill is homogeneous, isotropic, and linearly elastic, described by E_r (Young's modulus), μ_r (Poisson's ratio), and γ_r (unit weight).

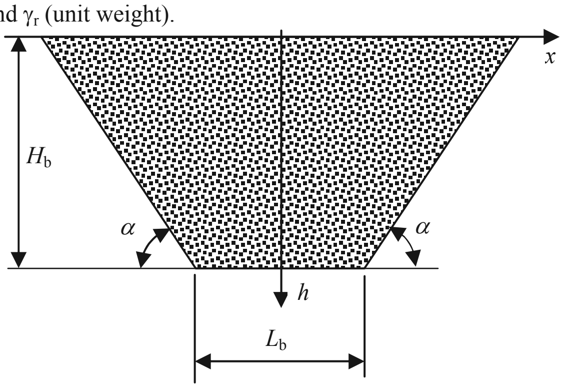

Figure 1. Geometry of the backfilled trench with inclined walls.

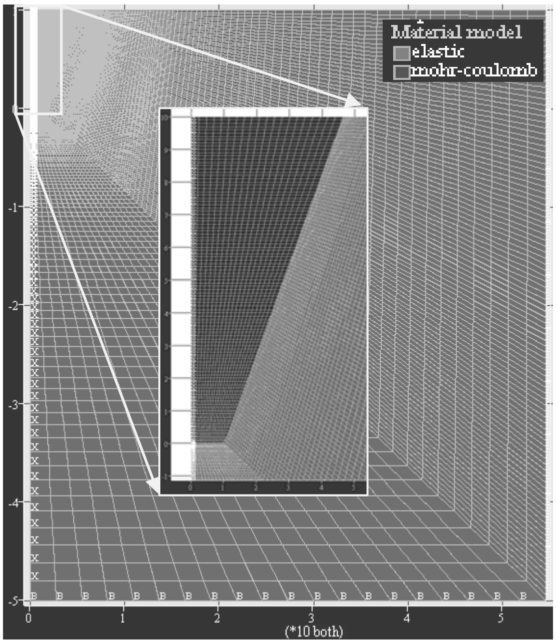

Figure 2. Model discretization of the trench with an enlarged view.

Figure 2 shows a typical discretization used for numerical modeling with FLAC; symmetry is taken into account so that only half of the trench is considered. The numerical simulation is performed in steps, with the excavation of the trench being completed at first. The trench is then filled in layers, after initial walls displacements.

Figure 3 shows the vertical stress distribution along the vertical central line (VCL) when the number of filling layers varies from 1 to 20 (to attain the full height H_b). It is noted that the stress magnitude increases slightly when the number of layers goes from 1 to 10. The stress is about the same for 10 or 20 layers. In the following, all simulations are performed with 10 layers of filling (i.e. 1 m / layer).

Table 1 presents details of the numerical simulations conducted to investigate influencing factors related to the trench geometry and properties of the backfill, which may affect the vertical stress distribution along the VCL of inclined walls

3 VERTICAL STRESS DISTRIBUTION

In this section, the influence of the trench geometry, properties of the backfill, is assessed in term of the vertical stress distribution along the VCL.

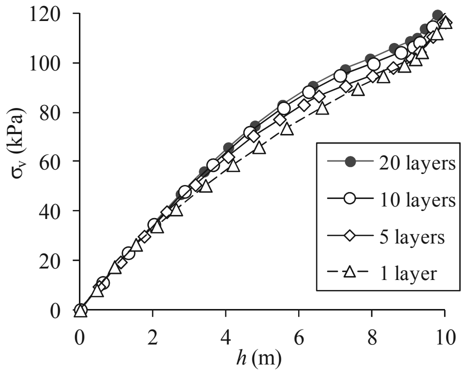

Figure 3. Vertical stress distribution along the vertical central line (VCL) of the trench with different filling layer number; details are given in Table 1.

Table 1. Details of the numerical simulations conducted for investigating influence factors. Other properties include γ_b = 18 kN/m^3 for the backfill; E_r = 30 GPa, μ_r = 0.25, and γ_r = 27 kN/m^3 for the linear elastic material forming the two walls.

Fig.	α	L_b	c'_b (kPa)	ϕ_b	ψ_b	E_b (MPa)	μ_b
3	70°	2 m	0	30°	0	200	0.2
4†	var‡	2 m	0	30°	0	200	0.2
5†	70°	var‡	0	30°	0	200	0.2
6†	70°	2 m	var‡	30°	0	200	0.2
7†	70°	2 m	0	var‡	0	200	0.2
8†	70°	2 m	0	30°	var‡	200	0.2
9†	70°	2 m	0	30°	0	var‡	0.2
10†	70°	2 m	0	30°	0	200	var‡

†simulation performed with 10 layers of filling;
‡var = varying value.

3.1 *Effect of trench geometry*

3.1.1 *Wall inclination*

Figure 4 shows the variation of the vertical stress distribution along the VCL with the wall inclination angle α. One sees that the stress magnitude increases when the wall inclination angle α decreases from 90° (vertical trench) to 20°. The vertical pressures obtained by the numerical modeling remain below the linear vertical stress distribution calculated from the overburden (i.e. $\sigma_v = \gamma_b h$), indicating the occurrence of some arching effect.

These results shown in Fig. 4 are not unexpected. Keeping the width at the base of the trench (L_b) constant, a decrease in the wall inclination angle (α) leads to an increase of the trench width in the upper part. This tends to decrease the arching effect and leads to an increase in the vertical stresses in the backfill. These results also indicate that the direct application of Marston (1930) solution to a trench with inclined walls would tend to underestimate the loads on the conduits, leading to non conservative design (Li et al. 2012a,b).

All other calculations are performed with α = 70°.

3.1.2 *Trench width*

Figure 5 presents the vertical stress distributions obtained from the simulations along the VCL for different width at the base of the trench (L_b). Without any surprise, it is seen that an increase of width L_b leads to a significant increase in the vertical stresses in the backfill.

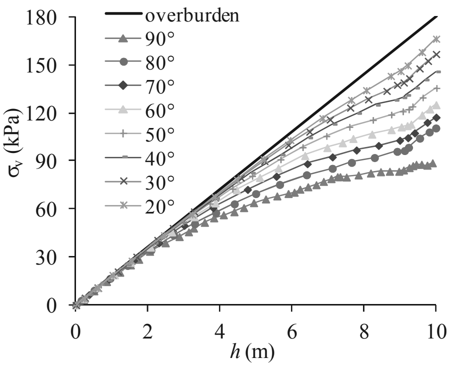

Figure 4. Vertical stress variation along the VCL of the trench for different wall inclination angle α; other parameters are given in Table 1.

3.2 *Effect of backfill properties*

3.2.1 *Cohesion*

Figure 6 shows the vertical stress distributions obtained by numerical simulations along the VCL for different values of the backfill cohesion c'_b. These results tend to indicate that the stress magnitude may change significantly with the cohesion within the interval between 1 kPa and 100 kPa. Below a value of 1 kPa, the effect of cohesion can be considered negligible; once the backfill cohesion value reaches 100 kPa, further increase does not have any effect on the vertical stress distribution (in the cases considered here).

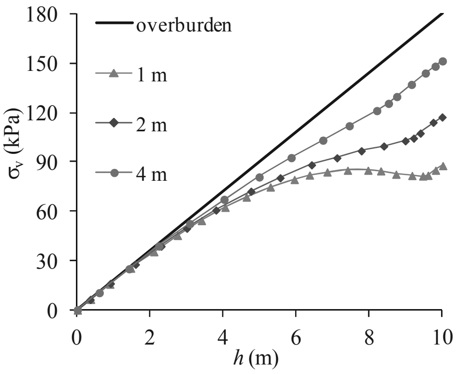

Figure 5. Vertical stress distribution along the VCL for different width at the base of the trench (L_b); details are given in Table 1.

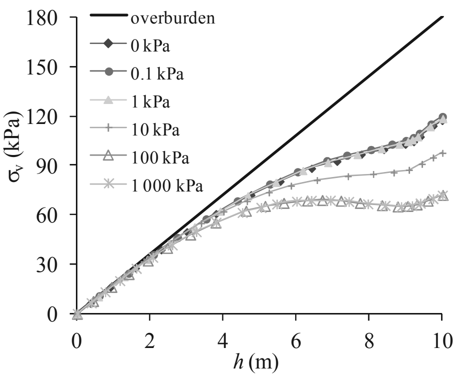

Figure 6. Vertical stress distribution along the VCL for different backfill cohesion c'_b; details are given in Table 1.

3.2.2 *Internal friction angle*

Figure 7 presents the vertical stress distributions along the VCL with the trench. These simulations results indicate that a stronger backfill, with a higher friction angle ϕ_b, induces more stress transfer to the walls, due to arching effect, so the vertical stresses are reduced.

It is worth noting here that these results are somewhat different from those obtained for vertical and inclined backfilled mine stopes, where the vertical stresses becomes almost insensitive to ϕ_b when the friction angle is greater than about 20° (e.g. Li and Aubertin 2009c; Singh et al. 2010).

3.2.3 *Dilation angle*

Figure 8 illustrates the vertical stress distribution along the VCL in the trench, obtained for different backfill dilation angle ψ'_b. Results tend to indicate that the stress magnitude tends to decrease slightly when the dilation angle increases from 0° to 30°.

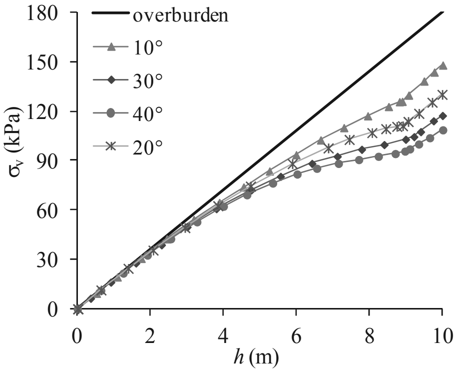

Figure 7. Vertical stress distribution along the VCL for different backfill friction angle ϕ'_b; details are given in Table 1.

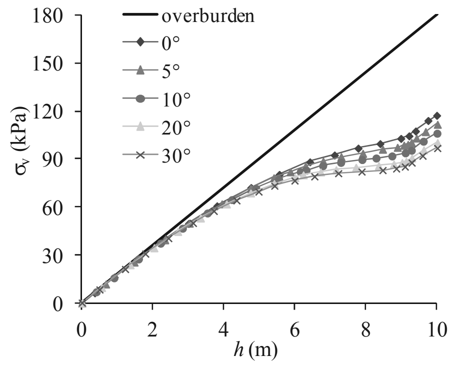

Figure 8. Vertical stress distribution along the VCL for different backfill dilation angle ψ'_b; details are given in Table 1.

3.2.4 *Young's modulus*

The influence of the backfill stiffness on the vertical stress distribution along the VCL is presented in Figure 9. It is observed that the vertical stress is almost constant when the value of the Young's modulus of the backfill is smaller than about $1/30^{th}$ of that of the material forming the walls. Beyond that value, the vertical stress can increase significantly with an increase in backfill stiffness.

It is also seen that the vertical stress magnitude is always below the linear overburden solution, even when the backfill is stiffer than the wall, indicating that there is no negative arching in these cases. This response is due to the fact that the settlement of the soil adjacent to the trench takes place before the fill is put in place. This differs from results predicted by some conventional solutions.

3.2.5 *Poisson's ratio*

The influence of the Poisson's ratio of the backfill on the vertical stress distribution along the VCL is presented in Figure 10. One sees that the influence of this parameter on the vertical stress distribution is very limited. This observation is quite different from that for inclined mine backfilled stope where the vertical stress decreases significantly with an increase in backfill Poisson's ratio (Li and Aubertin 2009c).

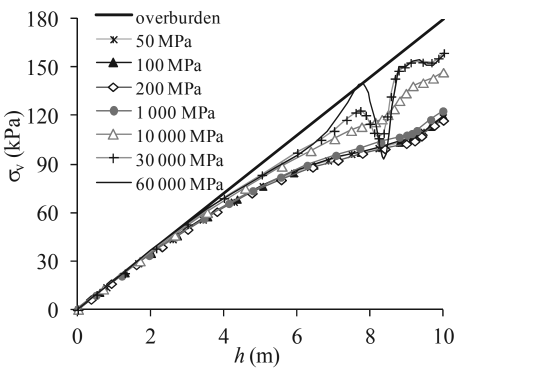

Figure 9. Vertical stress distribution along the VCL for different Young's modulus of the backfill E_b; details are given in Table 1.

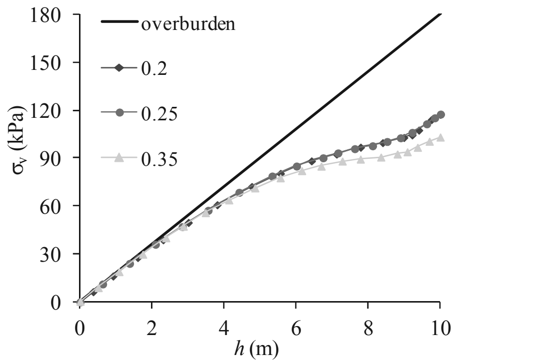

Figure 10. Vertical stress distribution along the VCL for different Poisson's ratio of the backfill μ_b; details are given in Table 1.

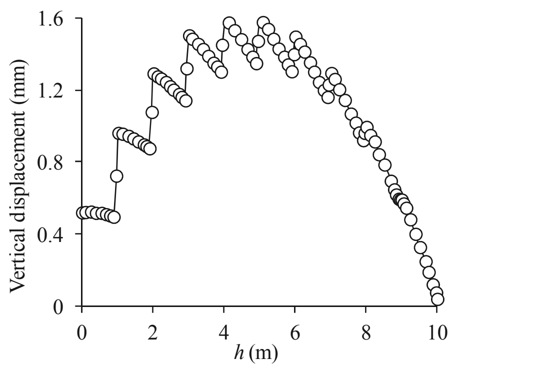

Figure 11. Vertical displacement distribution along the VCL for filling in 10 layers; case shown in Figure 3, with details given in Table 1.

4 DISCUSSION AND CONCLUSION

In this paper, influencing factors related to trench geometry and properties of the backfill are investigated using numerical simulations to assess their effect on the vertical stress distribution.

The results show that the most influential factors are the walls inclination angle, trench width, and backfill cohesion, friction angle and stiffness. The vertical stress distributions along the VCL of trenches are less sensitive to variations of the Poisson's ratio and dilation angle of the backfill.

The Young's modulus of the backfill may also significantly influence the vertical stress distribution when its value is larger than about $1/30^{th}$ of that of the material along the walls. Below this value, the vertical stress distribution can be considered insensitive to the backfill stiffness.

It is finally noted that most of the vertical stress distributions along the VCL show an upward curvature at $h \sim 8$ to 9 m, followed at greater depth by a quasi-linear trend (almost parallel to the overburden pressure). This indicates a reduced stress transfer near the base of the trench. Figure 11 shows the vertical displacements along the VCL for a trench filled in 10 layers (case shown in Figure 3). It is seen that the displacements of the backfill tend to increase with depth *h* from the surface down, reaching a maximum near mid-height of the trench. Below, the vertical displacements decrease with depth, becoming nil at the base of the trench. This behavior is associated with a decrease of the downward displacements that is due in part to the narrowing geometry of the opening and presence of the trench floor, and which reduces the shear strains (and stresses) along the fill-wall interfaces. In turn, this leads to a less pronounced arching effect and an increase of the vertical stresses. This explains, at least partially, the tendencies observed on the results presented above.

5 ACKNOWLEDGEMENTS

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