

Stress Redistribution of Adjacent Solution Collection Pipes

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Abstract

Corrugated dual-walled polyethylene pipes are commonly used in the solution collection system of heap leaching facilities. Under load, these pipes tend to deflect, thereby developing passive soil support at the sides of the pipe. At the same time, the vertical deflection of the pipe generates vertical movement of the ore column above the pipe, inducing an arching action which relieves the pipe of the major portion of the vertical load. The deflection of the pipe creates stress redistribution near the solution collection pipe with a significant reduction in stress immediately below the pipe and an increase in stress along the sides of the pipe. The zone of stress increase extends to about four pipe diameters to each side of the pipe. There are some instances when the designer specifies two adjacent pipes, with same or different diameters, to have a horizontal separation keeping the second pipe away from the overstressed zone. This specification is founded on the belief that the arching effect of one pipe will increase the stress on top of the adjacent pipe causing excessive deflection.

This paper presents the results of a series of finite element models, which were calibrated with published laboratory tests, to evaluate the effects of stress redistribution on adjacent pipes. Four cases were evaluated: a single pipe, two pipes separated by five-pipe diameters, two pipes separated by one pipe diameter, and two pipes with different diameters separated by one pipe diameter. The results indicate that the arching action of one pipe does not substantially increase the stress on top of the adjacent pipe. The calculated deflection of a single pipe is somewhat similar to the deflection of two adjacent pipes. Adjacent pipes deflect due to the weight of the ore developing their own arching effect and redistributing the stresses on the adjacent zones, in between the pipes and outside the pipes. The overstress generated in the zone between the pipes is larger than that outside the pipes. The results of this paper will help regulators and designers understand the stress redistribution of adjacent flexible pipes in heap leaching facilities and make decisions regarding the proper separation of adjacent solution collection pipes and the adequate geomembrane protection in the overstressed zones.

Introduction

Flexible pipes are commonly used in the solution collection systems of heap leaching facilities. These pipes deflect under the weight of the ore causing a vertical movement of the ore column above the pipes. At the same time, the ore surrounding the yielding ore column remains stationary. The movement between the yielding and stationary portions of the ore causes shear stress to develop. The shearing resistance developed on the stationary ore opposes the downward movement of the yielding ore causing a transfer of loads from the yielding ore to the base of the stationary ore. As a consequence, there is a reduction in stress immediately above the pipe and an increase in stress along the sides of the pipe. This transfer of stresses is known as soil arching phenomenon.

Leduc and Smith (2004) investigated the effects of stress distribution near solution collection pipes using a series of finite element models which were calibrated using results of both small and large scale laboratory tests. They concluded that there was a significant stress reduction immediately below the pipe and that the stress at a distance of about one pipe diameter increased to about 125% of the overburden. They added that the zone of overstress extends to approximately four pipe diameters.

Smith et al (2005) performed laboratory high-load deflection tests with loads up to 2,000 kPa on approximately 30 combinations of pipe and soil. The overliner was compacted from 78% to 88% of standard Proctor (typical overliner field compaction). The results showed a strong correlation between the initial degree of compaction and the vertical pipe deformation. Therefore, the behaviour of solution collection pipes subject to ore loads depends not only on the rigidity of the pipes, but also on the density of the surrounding soil. It is very difficult to place and compact overliner under the haunches of the pipe. Even compacting the overliner on either side of the pipe will leave a low density area beneath the pipe.

There are some instances when the designer specifies two parallel or adjacent pipes, with same or different diameters, to have a horizontal separation keeping the second pipe away from the overstressed zone. It has been assumed that if a flexible pipe is placed within the overstressed zone of another flexible pipe, one or both pipes will be subject to unforeseen higher stresses causing the pipe to undergo excessive deflection or ultimately collapse.

In order to understand the effects of the stress redistribution on adjacent solution collection pipes, a series of finite element models were run and calibrated using the results of published laboratory tests.

Numerical Method

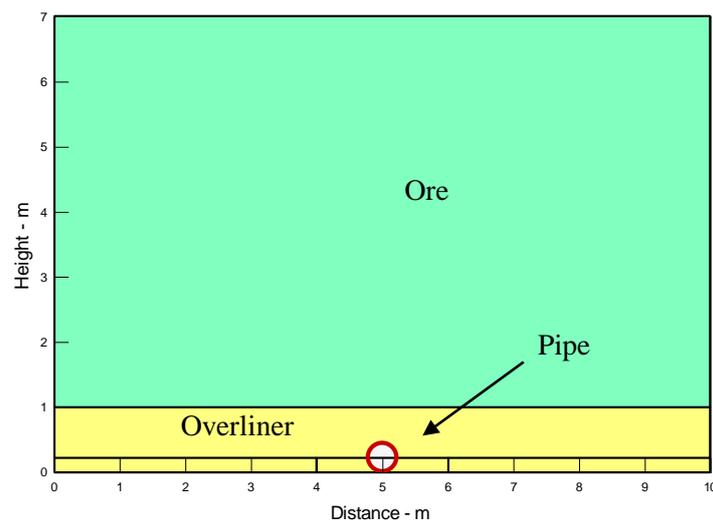
The Finite Element Method (FEM) was used to model the stress distribution around flexible pipes using the software program SIGMA/W, which performs stress and deformation analyses. The section properties of the two flexible pipes used in the modeling are shown in Table 1.

Table 1: Section properties for N-12 pipe per AASHTO

Nominal pipe diameter (mm)	Section area (mm ² /mm)	Moment of inertia (mm ⁴ /mm)
100	1.60	16
450	7.01	1,237

The flexible pipes were simulated assuming a structural beam with a modulus of elasticity (E) for polyethylene of 758 megapascal (MPa) for short-term conditions. A 1-meter (m) thick overliner (drain gravel) was assumed in the model. Figure 1 shows the geometry of the numerical model with the first ore lift 6 m thick. Subsequent ore lifts were modeled applying distributed loads above the first lift.

The elasticity modulus of the overliner used in the model is a function that was developed from results of confined compression-strain tests conducted on 25-millimeter (mm) clean crushed gravel. The overliner was placed in a rigid cylindrical container without compaction. The stress-strain results were used to determine the constrained soils modulus (Ms). The elasticity moduli were calculated by multiplying Ms by a constant k, whose value lies between 0.7 and 1.5 as found by elastic analysis (Chamber et al. 1980). Burns and Richard (1964) indicated that for most flexible pipe installation the value of k is very close to unity. The resulting moduli were compared with the results of the laboratory tests performed by Smith et al. (2005). The elasticity modulus of the ore was assumed constant with a value of 4,376 kilopascal (kPa). The material model for both the overliner and the ore were assumed to be linear elastic. The model was calibrated with the results of the tests conducted by Smith et al. (2005).

**Figure 1: Model geometry**

Four cases were evaluated: a single pipe, two pipes separated by five pipe diameters, two pipes separated by one pipe diameter, and two pipes with different diameters separated by one pipe diameter.

Results

Single pipe

Figure 2 shows the stress distribution around the 450-mm diameter pipe after the first lift of ore has been placed. The weight of the overliner plus the weight of the first lift exert a total stress of about 125 kPa at the floor of the system away from the pipe. The stress above and below the pipe is reduced due to the soil arching effect and the stress on the floor increases to about 165 kPa at about one pipe diameter. This represents a stress increase of about 132% of the overburden, somewhat similar to what Leduc and Smith (2004) estimated; however, the zone of overstress extends to about three pipe diameters. In this case, the pipe deflects 7.4 mm. The 80 kPa contour above the pipe is located about one pipe diameter.

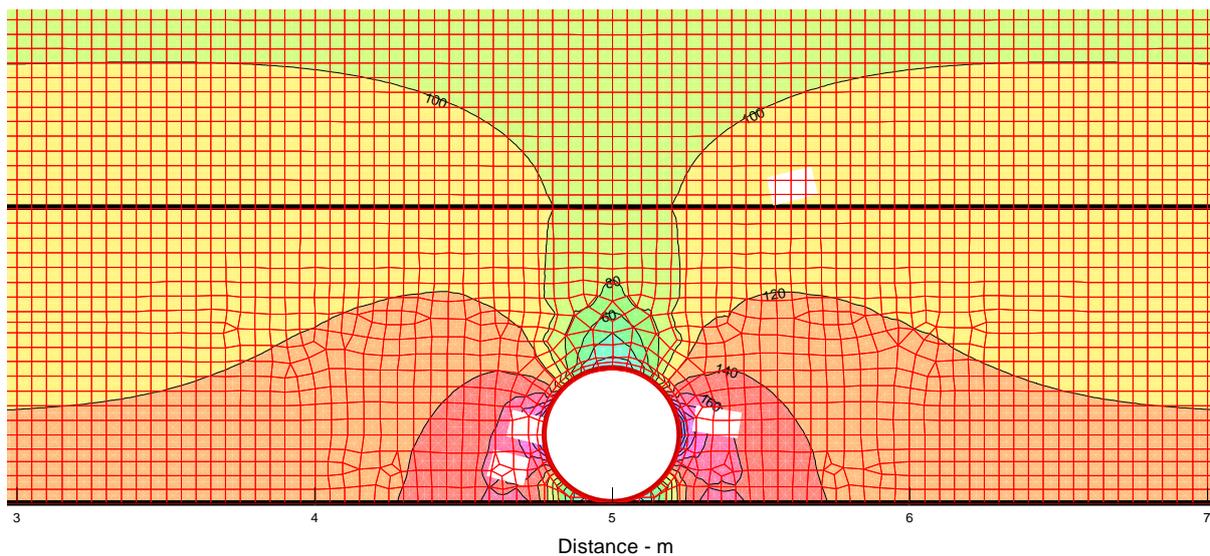


Figure 2: Single pipe with first ore lift

Figure 3 shows the stress distribution after 15 ore lifts equivalent to a height of about 90 m. The stress on the floor away from the pipe caused by the overburden is about 1,534 kPa. The stress on the floor increases to 2,049 kPa within one pipe diameter representing an increase of about 134% of the overburden and the zone of overstress extends to about two pipe diameters. Under this loading condition, the pipe deflects 102.6 mm, corresponding to approximately 22.4% deflection.

As the pipe deflects vertically, the pipe tends to elongate laterally developing passive resistance on the adjacent overliner. In Figure 3, it is shown that the lateral passive stress reaches a maximum value of about 3,400 kPa. Similar modeling was performed for the 100-mm diameter pipe with resulting deflections of 1.5 mm and 20.5 mm for the first lift and 15 lifts, respectively. The 1,200 kPa contour above the pipe is located at about one pipe diameter.

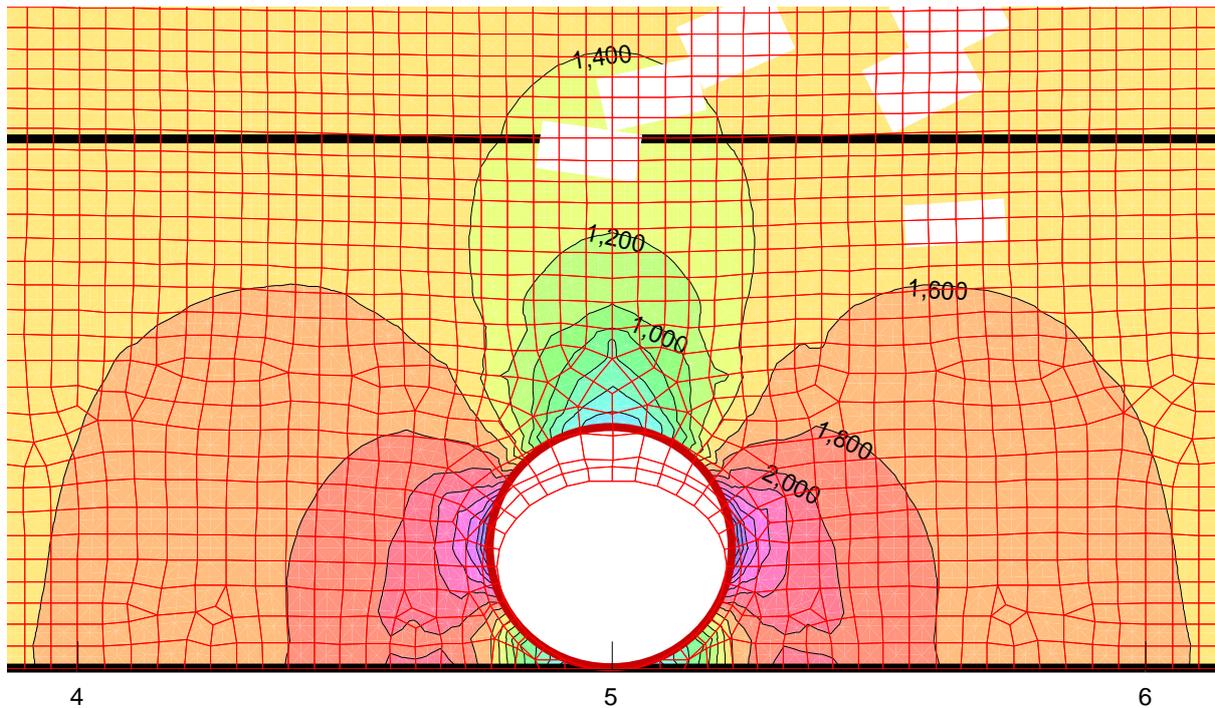


Figure 3: Single pipe with 90 m of ore

Two pipes separated by five pipe diameters

Two 450 mm diameter pipes were placed on the floor separated by five pipe diameters. Figure 4 presents the results of the model with the pipes loaded by the first lift. It can be seen that the stress distribution is similar to that of a single pipe. In this case, both pipes deflect the same amount 7.4 mm, similar to the deflection calculated using a single pipe. The 80 kPa contour above the pipes is located at about one pipe diameter.

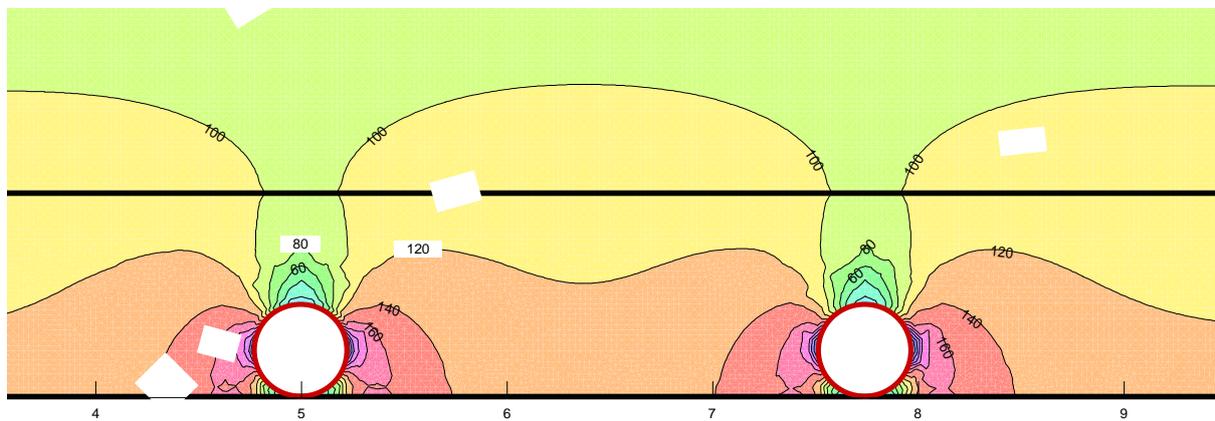


Figure 4: Two pipes separated by five pipe diameters with first ore lift

Figure 5 presents the results of the modeling with the two pipes loaded with 90 m of ore. As shown, the stress distribution around both pipes are similar and these distributions are similar to that of a single pipe. In this case, both pipes deflect the same amount, 103 mm, somewhat similar to the

deflection calculated using a single pipe. The 1,200 kPa contour above the pipe is located at about one pipe diameter.

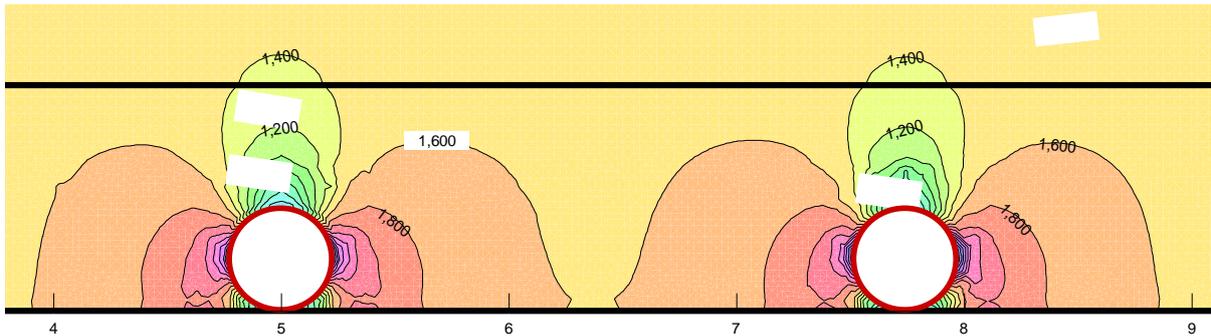


Figure 5: Two pipes separated by five pipe diameters with 90 m of ore

Based on these results it can be concluded that the arching effect on one pipe does not affect the second pipe when they are separated by five pipe diameters. The results show that the arching effect (reduction in stress above the flexible pipes) begins at about one and a half pipe diameter (location of the 1,400 kPa contour) above the pipe, independent of the loading condition.

Two pipes separated by one pipe diameter

The pipes are placed one pipe diameter apart and are now within the zone of overstress caused by the soil arching effect. Figure 6 presents the stress distribution when the pipes are loaded with the first lift. The stress distribution on the exterior sides of the pipes appears to be similar to the two previous cases; however, the stress distribution between the pipes are interconnected and the 180 kPa stress contour extends to the floor creating a zone of overstress between the pipes. This represents a stress increase of approximately 162% of the overburden. In this case, the pipe deflects 8.0 mm, which is 0.6 mm higher than the deflection of a single pipe. The zone of overstress outside the pipes extends to about three pipe diameters and the 80 kPa contour above the pipe is located at about one pipe diameter.

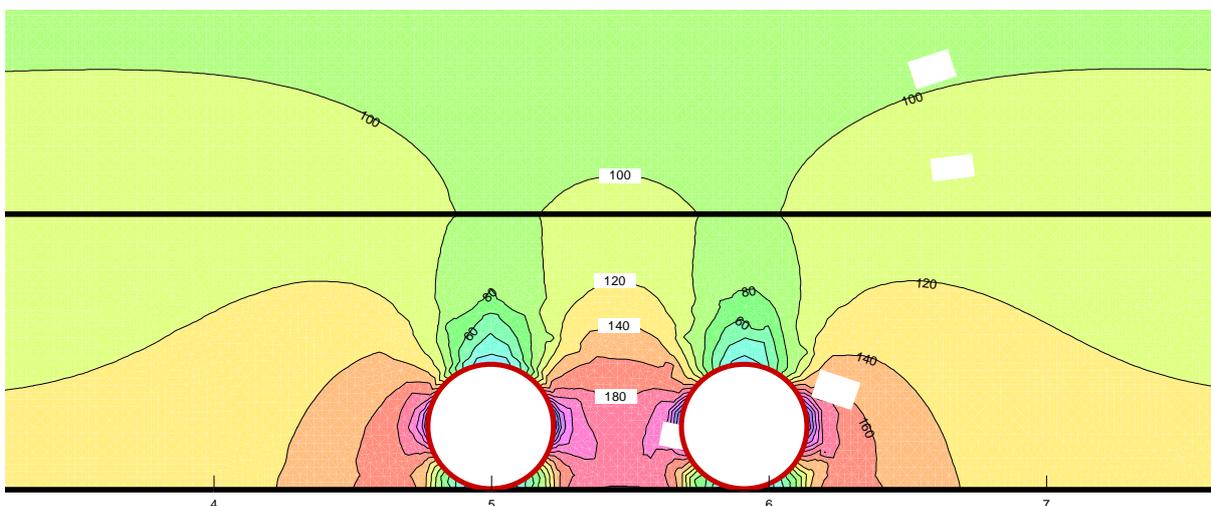


Figure 6: Two pipes separated by one pipe diameter with first ore lift

The same can be said about the stress distribution for the case when the pipes are loaded with 90 m of ore (Figure 7). The stress distribution between the pipes are interconnected and the 2,400 kPa contour extends to the floor creating a zone of overstress. This represents a stress increase of 164% of the overburden. Both pipes deflect 111.1 mm, which is 8.5 mm higher than the deflection of a single pipe. This deflection represents about 24.3% of the original pipe diameter. The zone of overstress outside de pipes extends to about two pipe diameters. The 1,200 kPa contour above the pipe is located at about one pipe diameter.

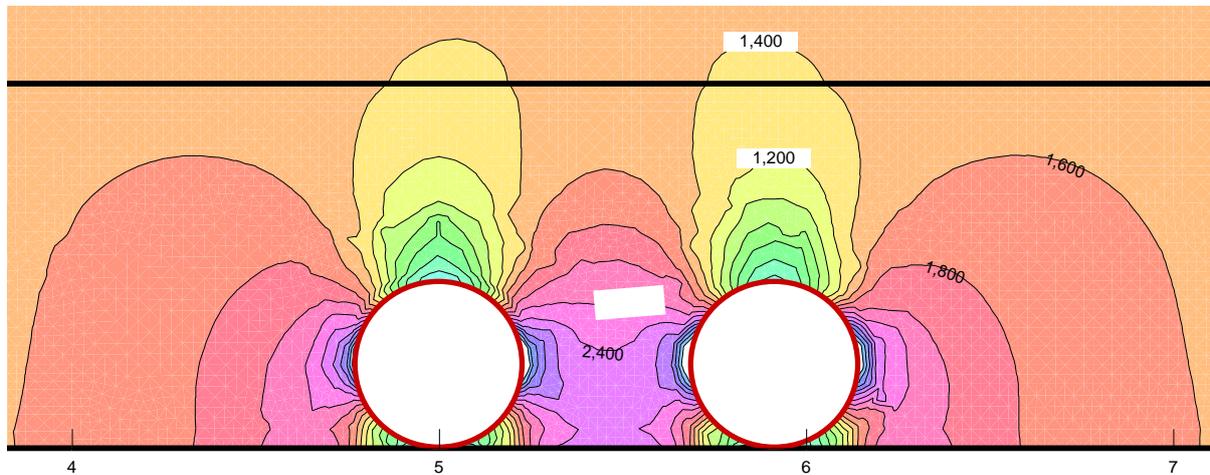


Figure 7: Two pipes separated by one pipe diameter with 90 m of ore

Based on these results, it can be concluded that the arching effect on one pipe slightly affects the second pipe when they are separated by one pipe diameter; however, the stresses in the floor area between the pipes increase substantially. The results also show that the arching effect (reduction in stress above the flexible pipes) begins at about one and a half pipe diameter above the pipe, independent of the loading condition.

Two pipes with different diameters separated by one pipe diameter.

Two pipes with different diameters are placed in the floor separated one diameter (bigger pipe) apart. One pipe has a diameter of 450 mm and the second pipe has a diameter of 100 mm, which is the typical size for laterals in a solution collection system. As expected, the stress distribution of two pipes with different diameters is not symmetrical. The stresses between the pipes are interconnected. For the case when the pipes are loaded with the first lift, the stress in a portion of the floor near the smaller pipe increases to about 167 kPa (Figure 8), representing a stress increase of approximately 134% of the overburden. In this case, the bigger pipe deflects 7.4 mm and the smaller pipe deflect 1.6 mm. These deflections are similar to those of single pipes (7.4 mm and 1.5 mm for the big and small pipes, respectively). The 80 kPa contours above the big and small pipes are located at about one pipe diameter, respectively.

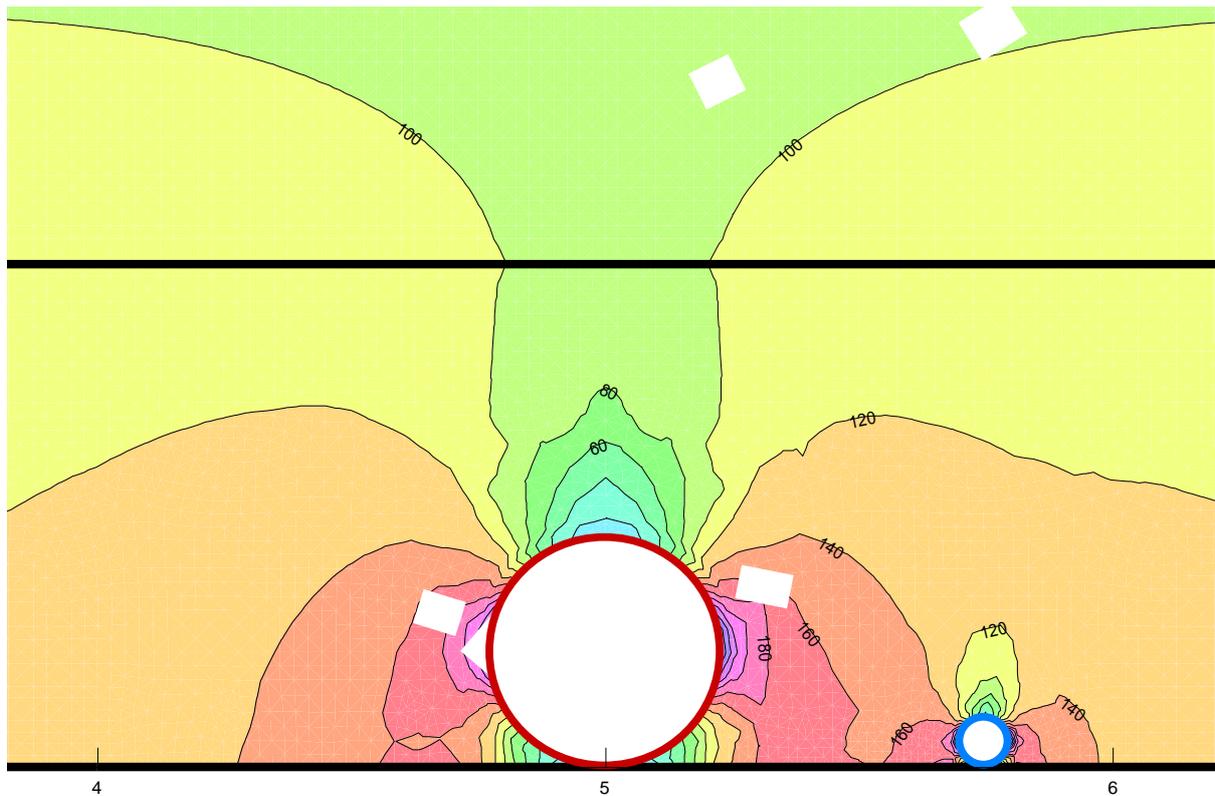


Figure 8: Two pipes different diameters separated by one pipe diameter with first ore lift

Figure 9 presents the stress distribution for the pipes loaded with 90 m of ore. In this case, the stress in the floor between the pipes increases to 2,069.5 kPa, representing a stress increase of about 136% of the overburden. This overstress is smaller (between pipes) than that generated by two same size 450 mm pipes. In this loading condition, the bigger pipe deflects 103.3 mm and the smaller pipe deflect 23.0 mm. These deflections are slightly higher than those of single pipes (102.6 mm and 20.5 mm for the big and small pipes, respectively). The zone of overstress outside de pipes extends to about two pipe diameters. The 1,200 kPa contours above the big and small pipes are located at about one pipe diameter, respectively.

Based on these results, it can be concluded that the arching effect on one pipe slightly affects the second pipe when they are separated by one pipe diameter. The results also show that the arching effect (reduction in stress above the flexible pipes) begins at about one and a half pipe diameter above the pipe, independent of the pipe size and loading condition.

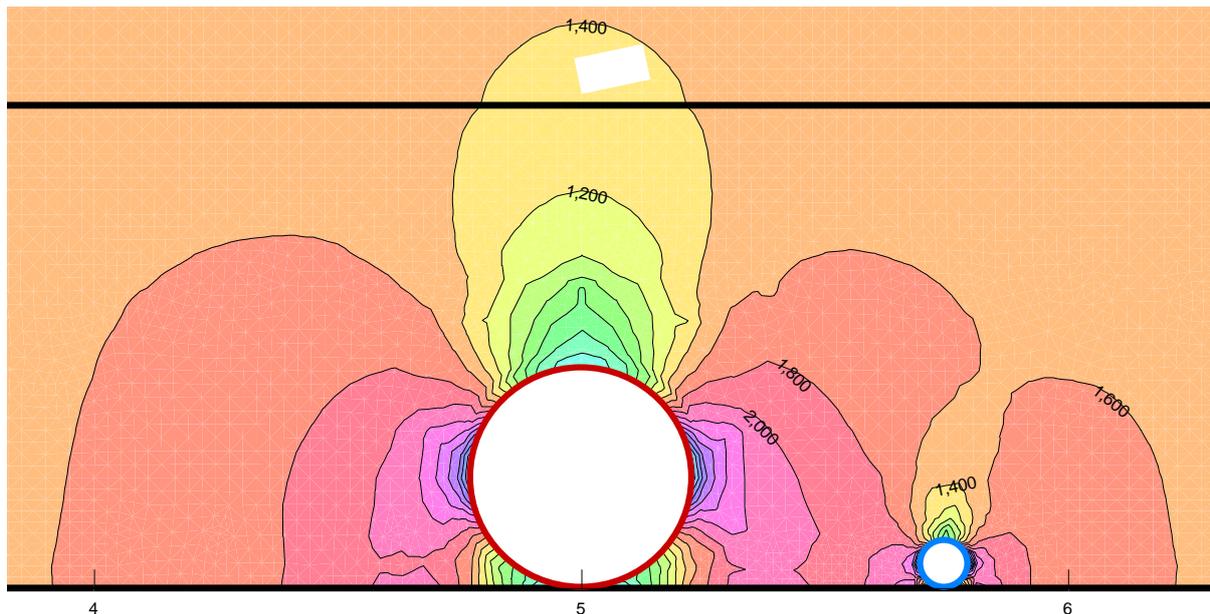


Figure 9: Two pipes different diameters separated by one pipe diameter with 90 m of ore

The pipe deflections and the stress increases are used to evaluate the arching effect on adjacent pipes. Table 2 presents a summary of these parameters obtained from the numerical modeling.

Table 2: Summary of results

Case	Deflection first lift/25 lifts (%)	Stress Increase on the floor first lift/15 lifts (%)
Single pipe 450 mm diameter	1.6/22.4	132/134
Single pipe 100 mm diameter	1.5/20.5	140/141
Two 450 mm pipes separated five pipe diameter	1.6/22.5	134/135
Two 459 mm pipes separated one pipe diameter	1.7/24.3	162/164 (between pipes)
One 450 mm pipe and one 100 pipe separated one pipe (450 mm) diameter	1.6/22.6 (450 mm pipe) 1.6/23.0 (100 mm pipe)	154/155 (between pipes)

Conclusion

The results indicate that the arching action of one pipe does not substantially increase the stress on top of the adjacent pipe. The arching effect (reduction in stress above the flexible pipes) begins between one to one and a half pipe diameter above the pipe and is independent of both the pipe size and the loading condition.

The calculated deflection of a single pipe is somewhat similar to the deflection of two adjacent pipes. Adjacent pipes develop their own arching effect causing a redistributing of stresses on the adjacent zones, in between the pipes and outside the pipes. The overstress generated in the zone between the pipes is larger than that outside the pipes.

Pipes of the same size separated by one pipe diameter generate higher stresses in the floor between the pipes compared to the zone outside the pipes. This is caused by the combined arching effect of both pipes over the zone between the pipes. A big pipe and a small pipe separated by one pipe diameter generate also higher stresses in the floor between the pipes, but the resulting stresses are not as high as those generated by same size pipes.

It is a myth that two adjacent pipes should be separated more than five pipe diameters. Based on the results of this modeling effort, it is concluded that parallel pipes can be placed even at one pipe diameter apart. Shorter separation between pipes is not recommended because it is impractical to place and compact overliner between the pipes.

Provisions should be made to protect the geomembrane in zones of high stress. The overstress zone generated by adjacent pipes for high heaps extends to about two pipe diameters.

An important parameter in pipe deflection modeling is the modulus of soil reaction which is not a soil property. It is an empirical soil parameter that has to be back-calculated with experiments measuring the deflection of pipes subject to different loadings. Another option is to determine the constrained soil modulus performing one-dimensional tests and then calculating the modulus of soil reaction using a constant k , whose value lies between 0.7 and 1.5.

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