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Research Article

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Performance of concrete thrust block at several burial conditions under the influence of thrust forces generated in the water distribution networks

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Abstract: This study was prepared to investigate the performance and behavior of concrete thrust blocks supporting pipe fittings. In the water distribution networks, it is always necessary to change the path of the pipes at different degrees or to create new branches. In these regions, an unbalanced force called the thrust force is generated. In order to counter this force, these regions are supported with concrete blocks. In this article, the system components (soil, pipe with its bend and thrust blocks) have been numerically modeled and simulated by the ABAQUS CAE/2019 software program in order to study the behavior and stability of the thrust block with different burial conditions (several burial depths) by the soil under the influence of the thrust force. Accordingly, 45° bend angles were studied with a specified pipe diameter placed on soil with known properties under the influence of internal hydrostatic test pressure. The obtained results that were relied upon to describe the behavior and stability of the block are (the lateral displacement of the block in the direction of the thrust force, as well as the vertical displacement of the block in addition to the Von Mises stresses transmitted by the block to the soil). It was concluded that the case in which the block is fully supported from its back side represents the optimum state of the block as it provides marginal sliding of the block and the least transmitted stress to the soil. It was also concluded that the transition from the first case (thrust block without soil behind it) to the second case (a quarter of the block is supported by soil), in which the maximum change in the performance of the concrete block was recorded, but after shifting to the other cases, the effect was reduced gradually.

Keywords: thrust force, thrust block, pipe fittings, water distribution networks

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1 Introduction

Pipes are the traditional way to transport water and other liquids over distances [1,2]. The generation of thrust forces is very common in water distribution networks due to the bends in the pipe paths stipulated in the network layout [3]. Retaining thrust blocks, as well as the method of restraining joints, are the most popular methods of counteracting thrust forces [4]. Each of these methods is considered scientifically and economically feasible in specific circumstances [5].

The design of concrete thrust blocks depends on fluid mechanics and soil mechanics, regardless of the type of pipe material or its application [6]. Concrete thrust blocks come in several shapes, according to the approved code. In Egyptian code, the thrust blocks are L-shaped, while in the American waterwork association, they are pyramidal [1]. The main objective of the design of the thrust blocks is to find the area of the base of the hierarchical shape that is in contact with soil, but there are infinite values for the base dimensions of the block that provide the same area, so the best dimensions that provide the least possible size of block that can be stable under the influence of thrust force must be found [3]. From a structural point of view, before any judgment on the validity of the block and before examining any activities, the concrete must be cured for 3 days in the case of high early strength concrete or 7 days in the case of using normal concrete [7].

According to [4], the minimum compressive strength of concrete used for thrust blocks at 28 days should be 13.8 MPa. [8] states that the thrust blocks can be unreinforced because the concrete is only under compressive stresses without tensile stresses and has high compressive strength compared to tensile strength [9]. In the case of vertical bends, the block must be under the joint and be supported by a steel rod that is suspended in the joint [10].

2 Case study description

In this section, a comprehensive description of the details and characteristics of the soil, pipe, and concrete thrust block that will be studied is provided. A ductile iron pipe with a horizontal bend angle of 45° with properties listed in Table 1 below will be modeled and studied.

While for internal pressure of the pipe, the operating pressure in water distribution networks is usually from 60 to 75 psi, according to [11], but according to [12], test pressure which is equal to about one and a half times the operating pressure, and in many cases, it is tested under a test pressure of 10 bar, which is approximately equal to 150 psi. Therefore, this value of the internal pressure will be adopted as a worst-case in this study.

As mentioned previously, it is possible for the thrust block to be in different shapes, but the hierarchical form adopted in the American code will be relied upon. Figure 1 shows the preferable shape of the thrust block in the American code.

This shape of the block will be adopted and represented in the study with the characteristics shown in Table 2.

The native soil, which will support the concrete block from the bottom and the back sides, its characteristics, which have been calculated on the site and in the laboratory by making investigations for the soil, and the most important characteristics that enter into the design of the thrust block system are summarized in Table 3.

Table 1: Pipe properties

Property	Magnitude
Outer diameter (mm)	330.48
Inner diameter (mm)	300
Wall thickness (mm)	15.24
Modulus of elasticity (MPa)	170,000
Poisson ratio	0.27

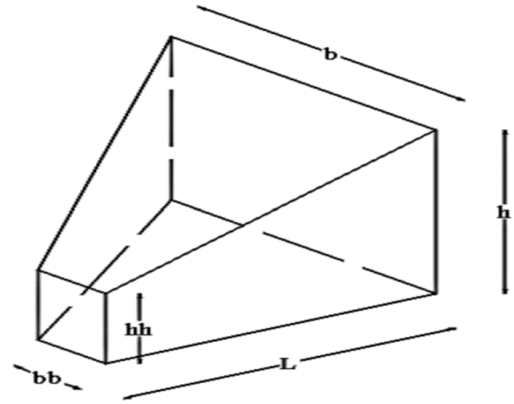

Figure 1: Thrust block of a horizontal bend for AAWA (American Water Works Association 1999, 2004, 2008, 2009) [1].

Table 2: Thrust block properties

Property	Magnitude
Compressive strength of concrete (MPa)	25
Poisson ratio	0.17
Modulus of elasticity (c)	23,500
Mass density (kg/m^3)	2,400

Table 3: Soil properties

Property	Magnitude
Soil type (USCS)	SM
0.17 Of native soil (kN/m^3)	15
Soil cohesive (MPa)	0.006
Internal friction angle (degree)	28.7
Modulus of elasticity (MPa)	12
Poisson ratio	0.3

The recommended values of the modulus of elasticity of the soil were adopted from [13], while the Poisson's ratio was taken from [14].

3 Modeling work

In this section, modeling and simulation of a concrete thrust block system that supports the pipes will be modeled. Five cases will be simulated, and the required results will be extracted related to the structural stability of the block, as well as the transferring stresses to the supporting soil behind.

In all the five cases, the system consists of three parts first, the pipe which is represented as a shell element with a total length of 6.3 m on each side of the bend, meshed using 3,493 linear quadrilateral elements of type S4R, as illustrated in Figure 2.

The second part is the soil, as it was represented as a three-dimensional solid element with cross-section dimensions of (6 m × 2 m), and the third dimension was 8 m, meshed with 12,000 linear hexahedral elements of type C3D8R (Figure 3).

The third part of the system is the concrete block, which is modeled by a three-dimensional solid element in a hierarchical shape and with the base dimensions of (1.05 m × 2 m) with a vertex small base of (0.3 m × 0.6 m) and length of (1.05 m), these dimensions produce a reference volume of the block equal to 1 m^3. The block meshed with 1,183 linear hexahedral elements of type C3D8R (Figure 4).

These three parts (the pipe, the soil, and the block) are assembled to form a system of concrete thrust blocks.

The five cases that will be simulated are as follows:

A) Case 1: Thrust block without supporting soil behind it.

This case was simulated relying on the block weight without any supporting soil behind it, in order to provide structural stability to it under the influence of the thrust force that was generated inside the pipe at the bend as in Figure 5.

After conducting the structural analysis under the influence of thrust force. Figures 6 and 7 show the results obtained from the analysis:

Results reveal that the maximum horizontal displacement occurred in the concrete block toward the thrust force was approximately 1,073 mm, while the maximum vertical displacement in the block was approximately 3.1 mm downward.

B) Case 2: Quarter of the block is supported by soil.

In this case, a quarter of the block height was supported by soil with the same characteristics as the native soil (the height of the supporting soil 0.26 m), which was formed as a second soil part and merged with the original soil to form final soil part as shown in Figure 7.

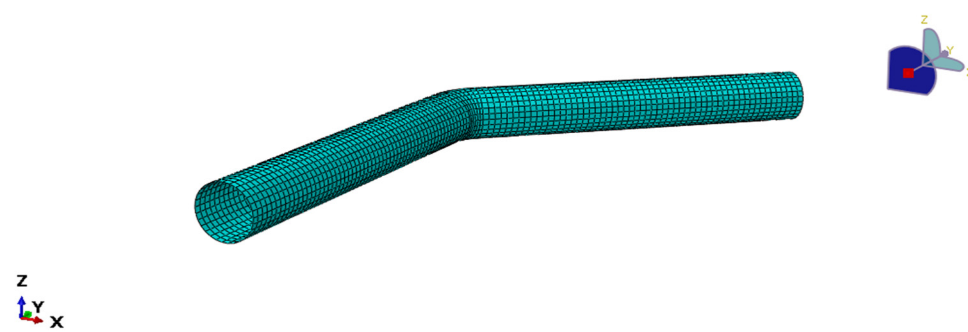

Figure 2: Pipe mesh.

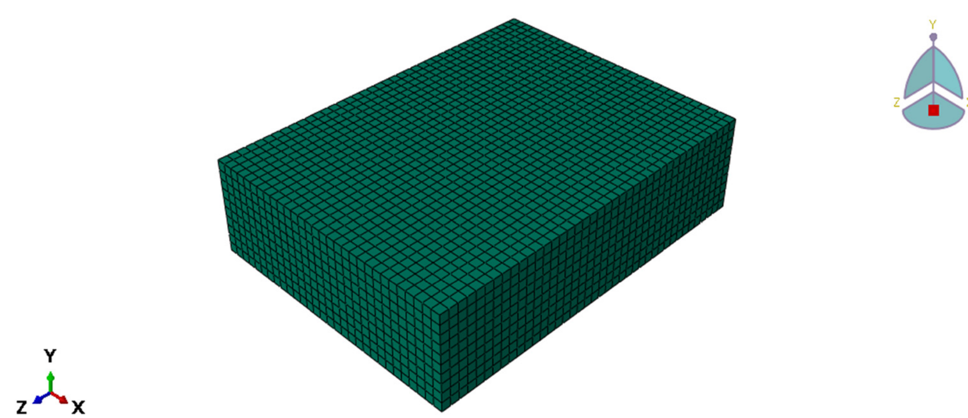

Figure 3: Soil mesh.

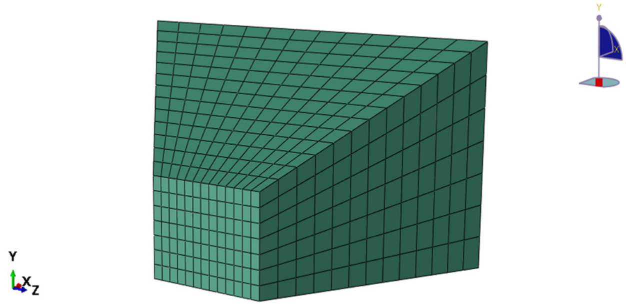

Figure 4: Thrust block mesh.

After the structural analysis, the results obtained from the analysis are shown in Figures 8–10.

It can be observed that the maximum stress in the soil behind the thrust block is 58 kPa and the maximum horizontal displacement of the thrust block is reduced to approximately 46.2 mm, whereas the results showed that the part of the block adjacent to the soil had a vertical movement opposite to its own weight, where the displacement was 2.4 mm upward and decreases as we approach the pipe.

C) Case 3: Half of the block is supported by soil.

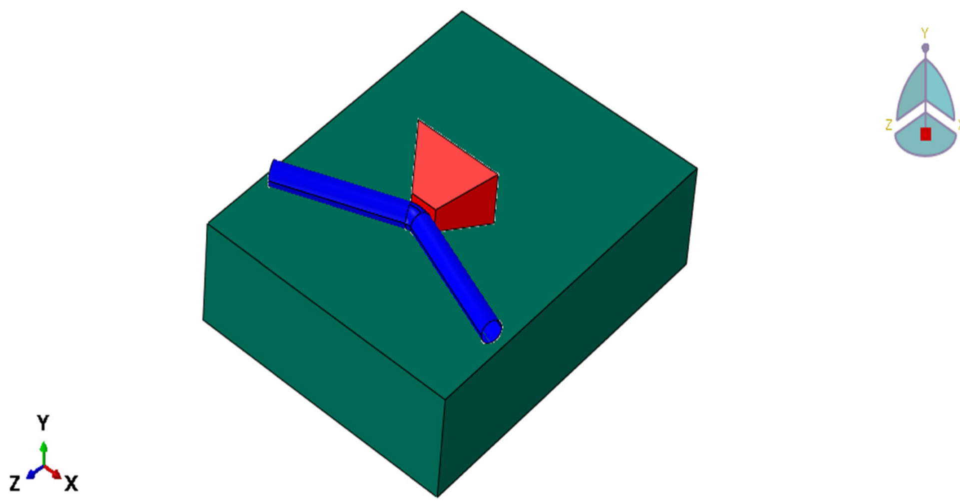

Figure 5: General view of Case 1.

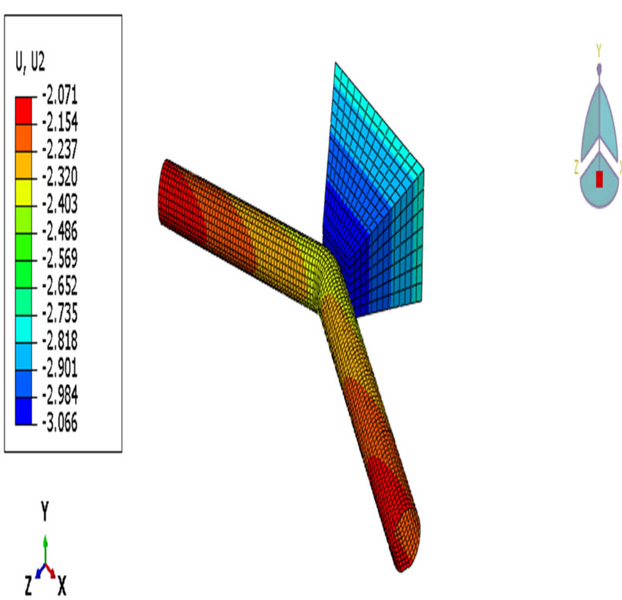

Figure 6: Vertical displacement of thrust block (mm).

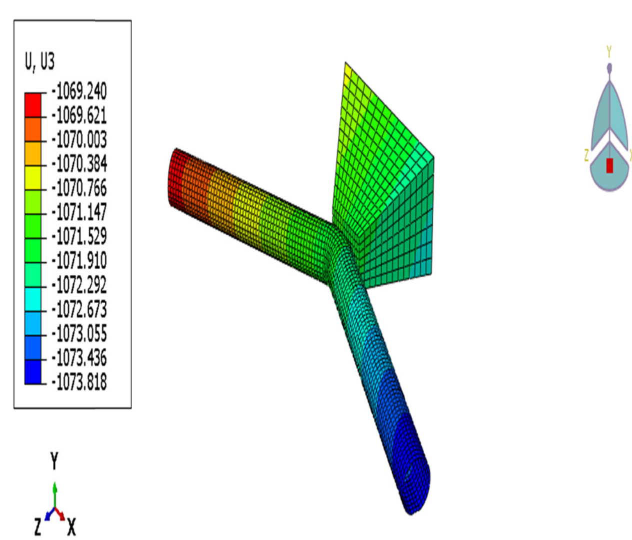

Figure 7: Horizontal displacement of thrust block (mm).

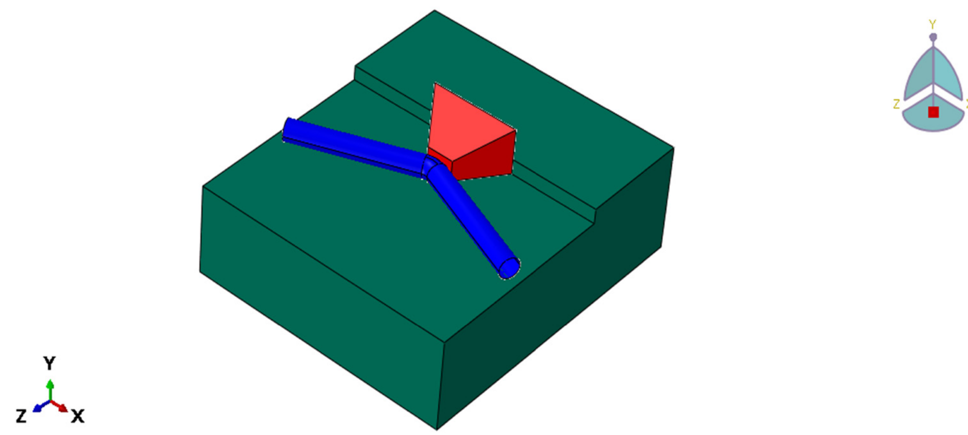

Figure 8: General view of Case 2.

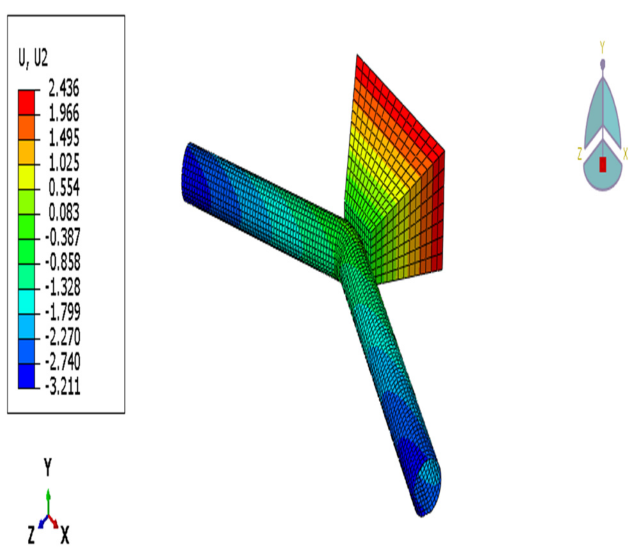

Figure 9: Vertical displacement of thrust block (mm).

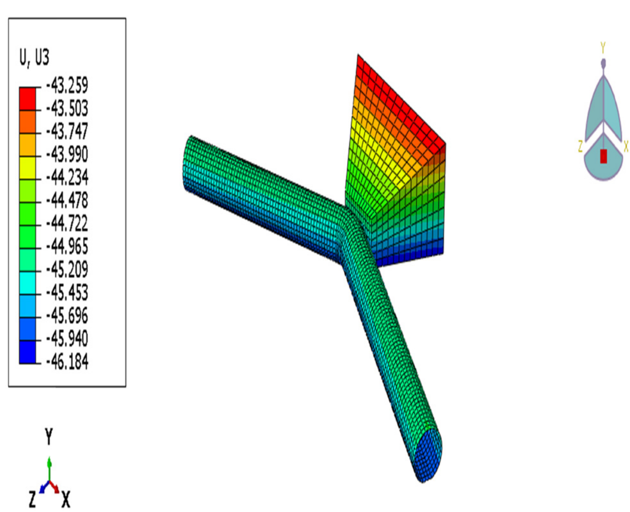

Figure 10: Horizontal displacement of thrust block (mm).

In this case, half of the block height was supported by soil (the height of the supporting soil 0.5 m), which was also represented as a second soil that was merged with the soil under the block and pipe, as shown in the Figure 11.

Also, the structural analysis of the system was performed in order to extract the results of this case, and they were as shown in Figures 12–14.

The results showed that the Von Mises stresses in the soil supporting the block decreased to 31 kPa, also, the horizontal displacement of thrust block in the direction of the thrust force decreased from 46.2 to 3.3 mm, while the maximum vertical displacement of the block due to self-weight was approximately 3.2 mm.

D) Case 4: Three-quarters of the block is supported by soil.

In this case, the burial depth of the concrete block was increased to three-quarters of its height (0.78 m), and in the same way, the soil behind the block was merged with the soil below it. Figure 15 illustrates the view of this model.

After simulating this model, the results are shown in Figures 16–18.

As it is clear in the results, the Von Mises stresses that transmitted to the soil through the concrete block decreased from 31 to 29 kPa with increasing burial depth, while the maximum horizontal displacement that occurred in the block was reduced to 2.4 mm, and for the vertical displacement, its maximum value reached to approximately 3.4 mm downward.

E) Case 5: Entire block backed by soil.

In the last case of the study, the entire block height was supported by the soil by increasing the burial behind the block as in Figure 19.

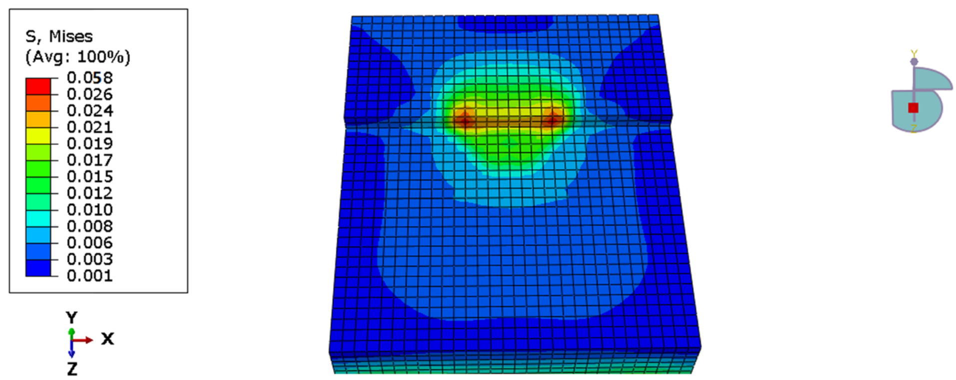

Figure 11: Stress distribution on soil behind thrust block (MPa).

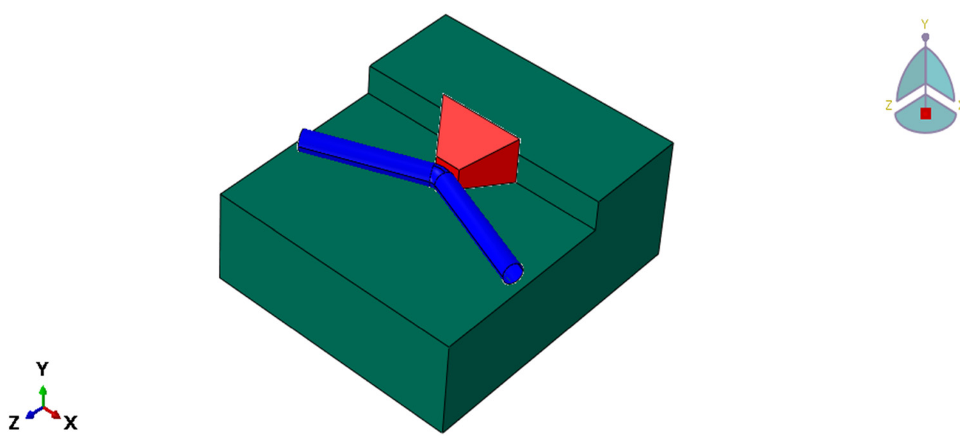

Figure 12: General view of Case 3.

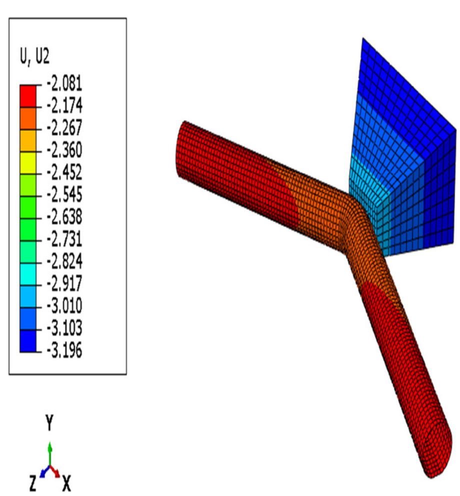

Figure 13: Vertical displacement of thrust block (mm).

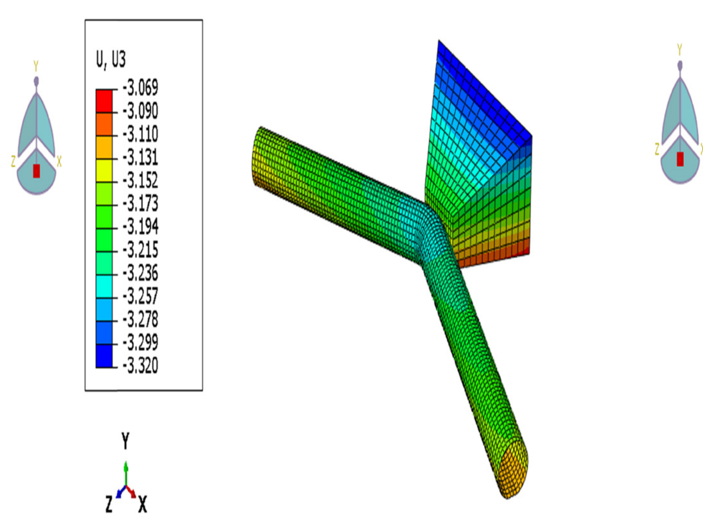

Figure 14: Horizontal displacement of thrust block (mm).

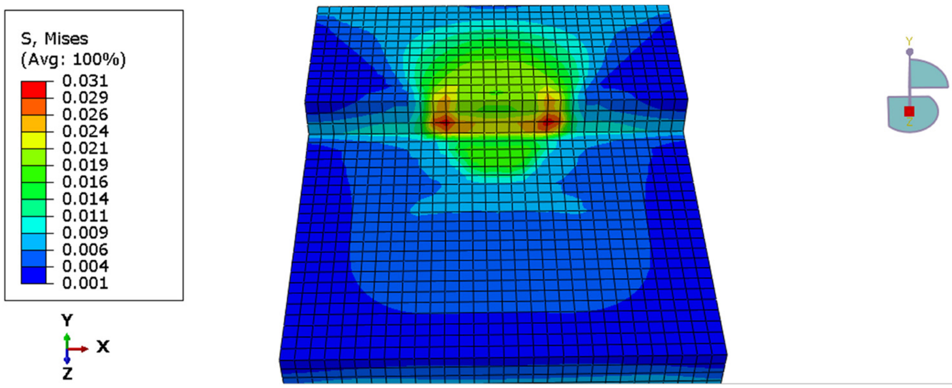

Figure 15: Stress distribution on soil behind thrust block (MPa).

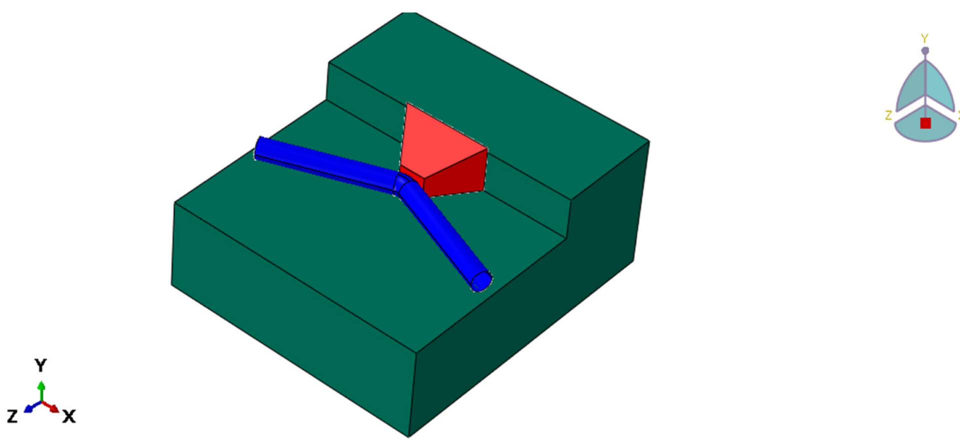

Figure 16: General view of Case 4.

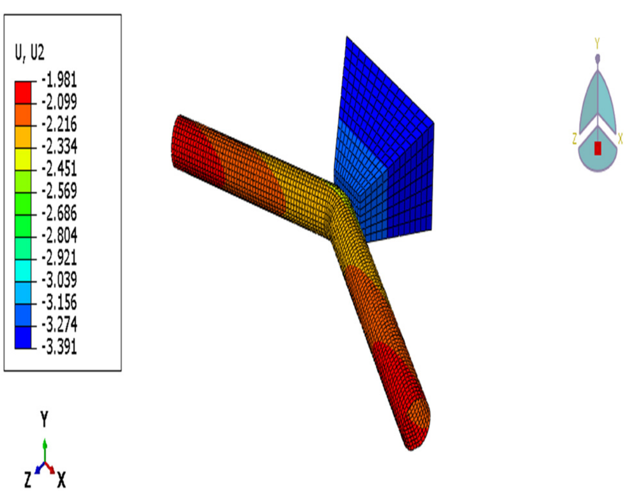

Figure 17: Vertical displacement of thrust block (mm).

After simulation and structural analysis of the model, Figures 20–22 show the results extracted from the analysis:

After the transition to the last case, the greatest stress transferred by the concrete block to the soil is 28 kPa, while the greatest horizontal displacement occurred in the block decreased from 2.4 to 2.2 mm

As for the vertical displacement due to the self-weight of the block, it reached 3.5 mm.

4 Results and discussion

After modeling and simulating the five cases and extracting the required results for each case, a comparison was made between the results of the cases to know the changing in the behavior and structural stability of the concrete thrust block by the transition from one case to another.

The results of the cases will be compared based on the horizontal displacement of the concrete block toward the effect of the thrust force generated in the pipe bend,

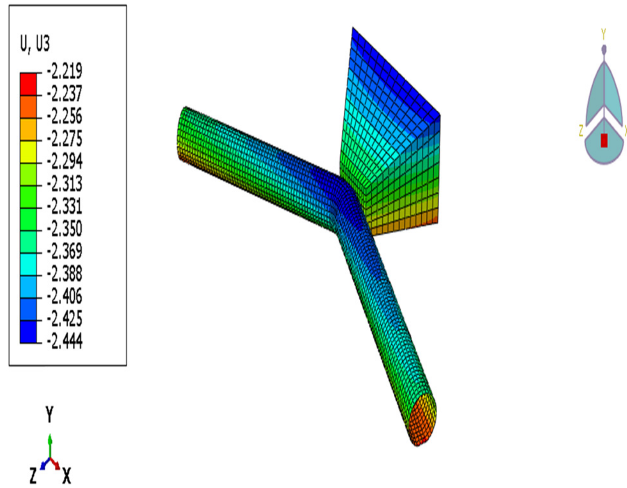

Figure 18: Horizontal displacement of thrust block (mm).

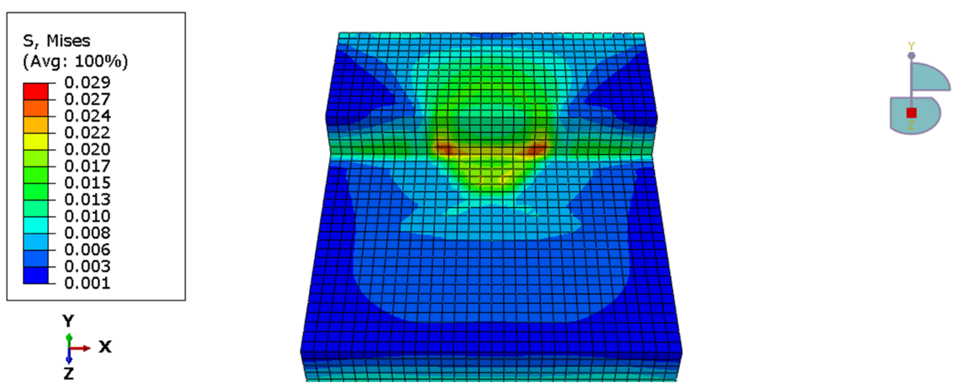

Figure 19: Stress distribution on soil behind thrust block (MPa).

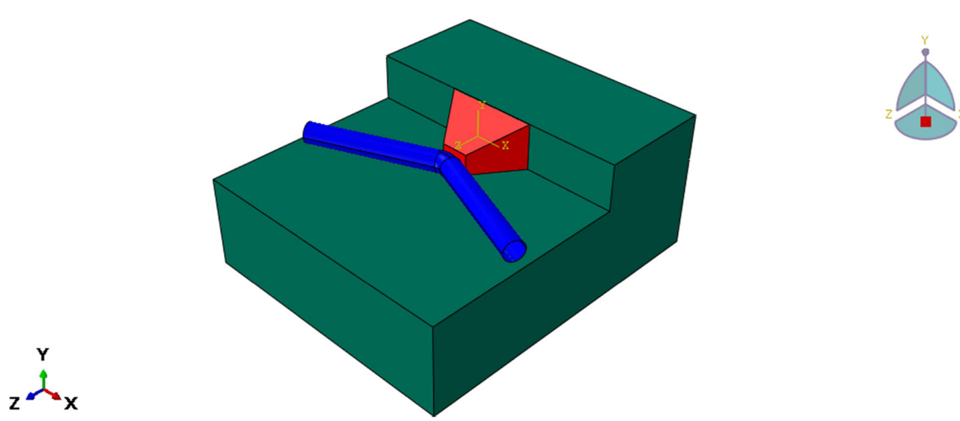

Figure 20: General view of Case 5.

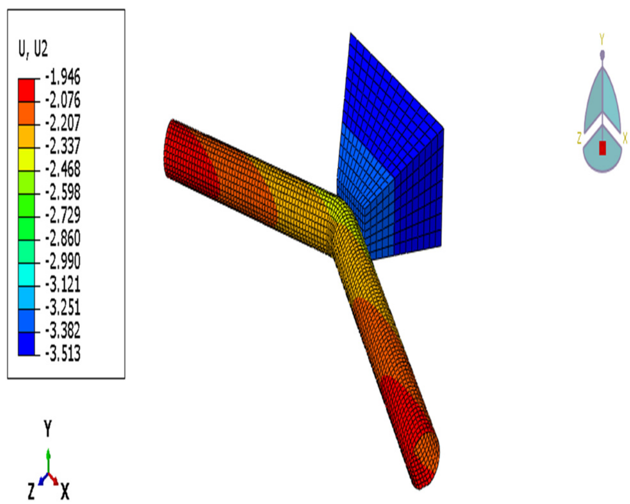

Figure 21: Vertical displacement of thrust block (mm).

as well as based on the vertical movement of the block in addition to the Von Mises stresses that the block will transfer to the soil supporting it.

Table 4 shows the variations of the obtained results in comparison with Case 1 for horizontal displacement and with Case 2 for Von Mises stresses at the soil.

Figures 22 and 23 show the path of the decrease in the lateral displacement and in the stresses transmitted to the soil behind the block by changing the case studied (burial depth).

The results showed that the conditions of burial of the thrust block clearly affect the structural stability of the concrete block and the amount of stress that the block transmits to the soil supporting it.

It was observed that the greatest enhancement in the performance of the block in terms of sliding stability occurs when shifting from Case 1 to Case 2, where the lateral displacement of the block decreased from 1,073 to 46 mm with percentage up to 95.69, but when transiting to the third case, then the fourth and the fifth cases, the decrease in block sliding was reduced gradually, where when shifting from the second to the third and then to the fourth and then the fifth, the decreasing in the lateral displacement for each case relative to the previous case is 92.85, 27.27, and 8.3%, respectively (Figures 24 and 25).

As for the vertical movement, in all cases, it was stable, as the downward displacement was due to its self-weight with a value of approximately 3 mm in all cases, except for

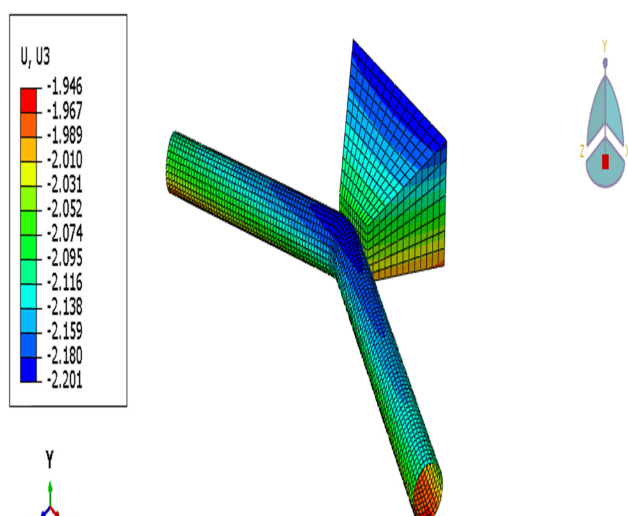

Figure 22: Horizontal displacement of thrust block (mm).

Table 4: Comparison between five cases

Studied case	Horizontal displacement (mm)	(%) Decrease	Von mises stresses at soil (kPa)	(%) Decrease
Case 1	1,073	—	—	—
Case 2	46.2	95.69	58	—
Case 3	3.3	99.69	31	46.55
Case 4	2.4	99.77	29	50.00
Case 5	2.2	99.79	28	51.72

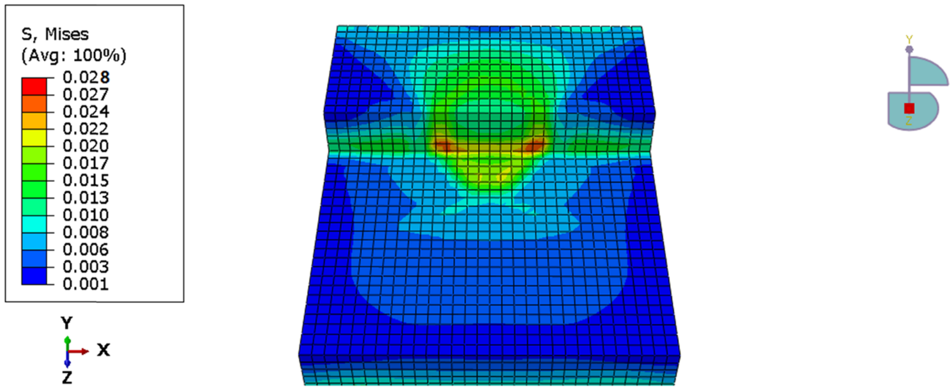

Figure 23: Stress distribution on soil behind thrust block (MPa).

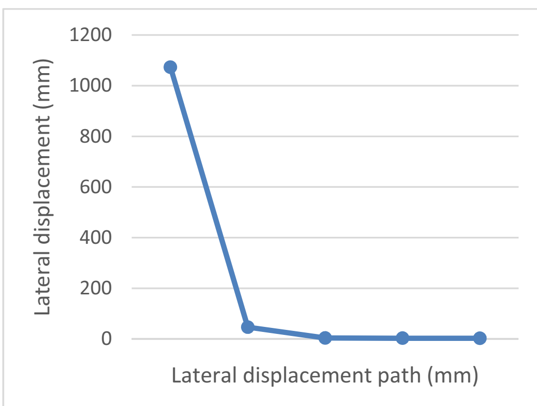

Figure 24: Lateral displacement variation.

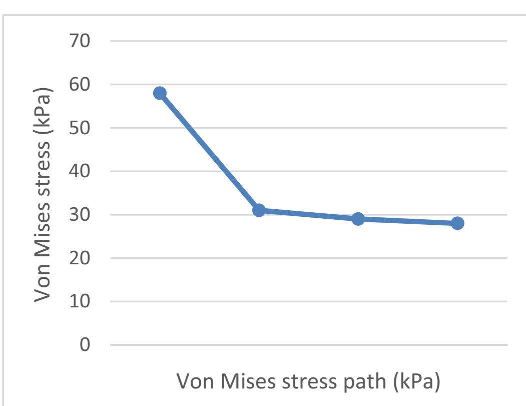

Figure 25: Von Mises stresses variation.

the second case, where another instability type of block occurred, where it was noted that the block moves with differential movement as the side of the block close to the supporting soil had an upward displacement of 2.4 mm and decreases by approaching the pipe.

While, for the amount of stress transferred by the block to the soil supporting it as a result of the effect of the thrust force, the stresses decrease when the depth of burial is increased, as the maximum decrease occurred between two cases when shifting from the second case to the third with a percentage reaching to 46.

5 Conclusion

After viewing and discussing the results, the following main points were concluded:

A) The fifth case of full soil behind supporting represents the optimal condition of the concrete block, as it provides the best performance of the block in terms of stability and reducing the stresses transmitted to the soil.

B) The use of the first case (block without backing soil) is not feasible, as a huge amount of concrete will be needed in order to achieve the required stability, which makes the work uneconomic.

C) The use of burial at a depth of less than half the block (the second case) may cause instability, represented by the occurrence of the block overturning as a result of the upward displacement.

D) The greatest change in the performance of the concrete block in terms of stability has occurred when shifting from the first case to the second, where the change was 95.69%, then the percentage is reduced to 92.85, 27.27, and 8.3 when shifting to the third, fourth, and fifth cases, respectively, while in terms of the transferring of stresses to the soil is when changing from the second case to the third where the changing was 46.55%, then the percentage is reduced to 6.89, and 3.45 when shifting to the fourth and fifth cases, respectively.

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