Journal of Engineering and Applied Sciences 12 (8): 2029-2038, 2017
ISSN: 1816-949X

Comparing Experimental and Software Results of Changing the Water Transmission Pipe Diameter under the External Load of Surrounding Soil (Case Study: Pipes with a Diameter of 2400 mm)

Fariborz Rahimi Klarijani and Nima Ranjbar Mali Darreh
Department of Civil Engineering, Mahmoudabad Baranch, Islamic Azad University,
Mahmoudabad, Tehran, Iran

Abstract: Water networks and main underground drinking water transmission and distribution pipelines are among the infrastructures of urban areas and giving attention to the problems of these pipelines is a priority management program. One of the most important factors in the design of water channels is the analysis of external forces affecting the pipe and its surrounding texture and finally the pipe deformation. Many factors affect the design of water transmission pipelines, one of these factors is controlling the pipe diameter change or pinch flat. Behavior assessment of culverts and interaction analysis of the bed around culverts under in normal loadings can provide appropriate analysis to carry out the right design of such projects. In this study, 5 different methods in terms of the materials filling around the pipeline were studied and laboratory results obtained were compared with American Water Works Association (AWWA) and modeling by ABAQUS finite elements software. The results showed that as the soil around the pipe is filled with dense and harder materials, the latitude pipe diameter change or the pinch flat will be decreased where the results were consistent with the regulation and software.

Key words: The pipe diameter change, ABAQUS Software, regulations of American Water Works Association (AWWA), the around backfill, behaviour

INTRODUCTION

Transmission lines in water and irrigation networks are considered as vital arteries for designs. Vital arteries are the most important signs of development in any society. The term "vital" is referred to the above systems for two reasons: first, the survival of project depends on maintaining the the performance of these systems; Second, failure of these systems can cause worsening the crisis situation and social and economic damage to be beneficiaries (Spangler, 1941).

Subsidence or deformation of water pipes and its surrounding texture is an effective factor in the pressure on pipeline. It should be noted that how to apply these pressures on the pipe is affected by planting conditions. In most urban water transmission lines projects in the country, the pipelines are planted by full deployment in trench; in this way, the culvert is planted in a relatively narrow trench dugout in an intact soil. In addition to the loadings applied on the pipe, trench filler materials column, the layer of surface structure and density of these materials will play a significant role in the subsidence level of culvert and its surrounding soil. Subsidence or deformation of the pipe crown is a result of pressure on the pipe and on the other side the supporting resistance or loading capacity of culvert is a function of the form, type of materials, bedding and implementation of bulwark in and on the wings while operating the culvert (Jayadevan *et al*., 2006).

Just as like the majority of the country's water transmission pipelines projects, the pipeline planting in water transmission lines system of the second part of tropical plan was performed by the full deployment in the channel and using spiral steel pipes with the size of 2400 and 2000 mm. In addition to enough strength, these pipes because of their relative flexibility show proper stability in front of the forces applied on the pipeline. Steel pipes fully planted in the channel will be under the loadings resulted from the soil pressure and external loads and the bed reactions (Salehian, 1967; AWWA, 2011). To prevent damaging the pipes due to the reactions in effect of forces, it is necessary to backfill around the pipe in a way that a proper bed is created for the pipe and the channel bed is smooth with steady and dry slope. Lack of detailed studies about the behavior of culverts and determining the exact amount of subsidence and also controlling this phenomenon made us to study steel pipe in large diameter

Corresponding Author: Fariborz Rahimi Klarijani1, Department of Civil Engineering, Mahmoudabad Baranch, Islamic Azad University Mahmoudabad, Tehran, Iran

(Kawabata *et al.*, 2006). Spangler (1941) was the first person who addressed the metal pipes and their relative hardness function.

Jayadevan *et al.* (2006) studied the rapture and creep of steel water transmission pipelines on the ground using numerical method. The results of the study showed that there is a direct correspondence between the effect of pipe diameter and thickness ratio on the tension on the pipe wall and creation of crack on it (Jayadevan *et al.*, 2006).

Arab Zadeh and Zinedini in 2010 performed a 3D review of collision using the finite element method and validate the model by laboratory results to examine the impact of parameters such as internal pressure level of fluid, the effect of soil bed compared with the rigid bed, geometric conditions of pipeline, geometry of the collided body and etc. and showed that the forces are relatively increased linearly for the dents above average.

Given the importance and application of this issue in this study, we calculated the change in water transmission steel pipe diameter under different backfill modes and ultimately the results were compared with the relationship proposed in AWWA and the results obtained with ABAQUS FEM Software.

MATERIALS AND METHODS

To perform the experiments in this study, a channel in a width of 3200 mm and depth of 4350 mm should be dug up to place the steel pipe in it. Then, the most efficient method and the best type of soil that imposes the lowest pressure on the pipe is determined by applying various methods of backfill around and on the pipe.

Soil: The soil and materials filling around the pipeline are important because some changes occur in the geotechnical specifications of materials in the operation of placing and planting the pipe in the channel that considering these parameters with favorable degrees of density and material are all effective to determine the subsidence and capacity of culverts. Given the importance of the issue, specifications and values of the soil used in this study were investigated on five types of tests. Therefore, these specifications and values used in any type test are as Table 1-6. The specifications and values of the soil and the amount of water used in each layer in the first type test are shown in Table 1. The specifications and values of the soil and the amount of water used in each layer in the second type test are shown in Table 2.

The specifications and values of the soil and the amount of water used in each layer in the third type test are shown in Table 3. The specifications and values of the soil and the amount of water used in each layer in the fourth type test are shown in Table 4. The specifications and values of the soil and the amount of water used in each layer in the fourth type test are shown in Table 5.

Steel pipes: Mechanical properties of the ST52 type steel pipe with a thickness of 14.27 mm used in all types of test are the same as shown in Table 6.

Methods: There are different methods to fill around and on the pipe where the type of backfill and density of flooded soils directly affect the amount of pinch flat. For this purpose in this research the pipe's surrounding is filled with riddled soil and backfill by 5 different ways and full description of each experiment and its results are in the following. It is to be mentioned that each of these experiments were performed in several stages and the details of experiments and specifications of pipes and channels are provided in each part.

Table 1: Specifications and values of the soil used in the first type of test

1st layer (900 mL) Z2		2nd layer (900mL) Z3		3rd layer (900 mL) Z4	
Type	Volume	Type	Volume	Type	Volume
Clay riddled with flooding	16 cubic meters	Clay riddled with flooding	9.5 cubic meters	Clay riddled with flooding	24 cubic meters

The amount of water used: the materials (soft sand) used for a meter of channel floor length: 0.64 m^3 The materials and water used for a meter of first layer length: 1.33 m^3 of materials and 0.66 m^3 of water the materials and water used for a meter of second layer length: 0.79 m^3 of materials and 0.4 m^3 of water The materials (soft sand) used for a meter of third layer length: 2 m^3 of materials. The materials used for a meter of backfill length (with a 2 m crown and 1 m heel): 12.46 m^3

Table 2: Specifications and values of the soil used in the second type of test

1st layer (1800 mL) Z2		2nd layer (1800 mL) Z3	
Type	Volume	Type	Volume
Processed clay	39 cubic meters	Riddled Clay	28.08 cubic meters

Table 3: Specifications and values of the soil used in the third type of test

1st layer (900 mL) Z2		2nd layer (900 mL) Z3		3rd layer (900 mL) Z4	
Type	Volume	Type	Volume	Type	Volume
50% of riddled clay and 50% of flooded pea and almond materials	16 cubic meters	50% of riddled clay and 50% of flooded pea and almond materials	9.5 cubic meters	Riddled clay	24 cubic meters

The amount of water used: the materials (soft sand) used for a meter of channel floor length: 0.64 m^3. The materials and water used for a meter of first layer length: 0.66 m^3 of riddled clay and 0.66 m^3 of rock materials and 0.66 m^3 of water. The materials and water used for a meter of second layer length: 0.4 m^3 of riddled clay and 0.4 m^3 of rock materials and 0.4 m^3 of water. The materials (soft sand) used for a meter of third layer length: 2 m^3. The materials used for a meter of backfill length (with a two-meter crown and one-meter heel): 12.46 m^3

Table 4: Specifications and values of the soil used in the fourth type of test

1st layer (1500 mL) Z2		2nd layer (1200 mL) Z3	
Type	Volume	Type	Volume
33% of sand and 33% of pea and almond materials	22 cubic meters	Riddled clay	27.6 cubic meters

The amount of water used: the materials (soft sand) used for a meter of channel floor length: 0.64 m^3. The materials used for a meter of first layer length: 1.83 m^3 of rock materials. The materials used for a meter of second layer length: 2.3 m^3 of riddled clay. The materials used for a meter of backfill length (with a two-meter crown and one-meter heel): 12.46 m3. Description: In the fourth piping method, there is no need to density test for layers

Table 5: Specifications and values of the soil used in the fourth type of test

1st layer (1500 mL) Z2		2nd layer (1200 mL) Z3	
Type	Volume	Type	Volume
33% of sand and 33% of pea and almond materials	22 cubic meters	Riddled clay	27.6 cubic meters

The amount of water used: the materials (soft sand) used for a meter of channel floor length: 0.64 m^3. The materials used for a meter of first layer length: 1.33 of materials and 1.83 m^3 of water. The materials used for a meter of second layer length: 0.79 m^3 of materials. The materials used for a meter of third layer length: 2 m^3 of riddled clay. The materials used for a meter of backfill length (with a two-meter crown and one-meter heel): 12.46 m^3

Table 6: Mechanical properties of pipe

Mechanical properties	
Variables	Values
Elastic properties	
Density	7850
Modulus of elasticity	210e9
Poisson's ratio	0.3

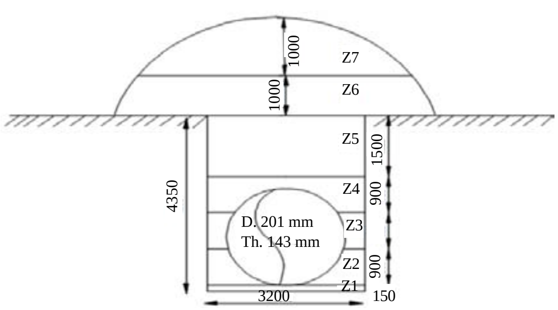


Fig. 1: Type 1 of piping

Type 1 piping: In this way as shown in Fig. 1, first a channel in a depth of 4350 and width of 3200 mm is dug up, then the floor is filled with soft sand up to 15 cm high and is condensed to 85%. After that, the pipe is deployed in the channel and the riddled clay will be shed in 3 layers named Z2-Z4 to the identical height 90 cm. We have to wait for 3 days to infiltrate water into the soil layers of Z2 and Z3 where 500 L of water will be added for every cubic meter of soil. It is noteworthy that Z4 layer is 90 cm of dry riddled clay. Finally, the channel is filled with the materials from drilling to reach the normal level and then wait for 3 another day. After that, the layers Z6 and Z7 will be performed with the same one meter in height.

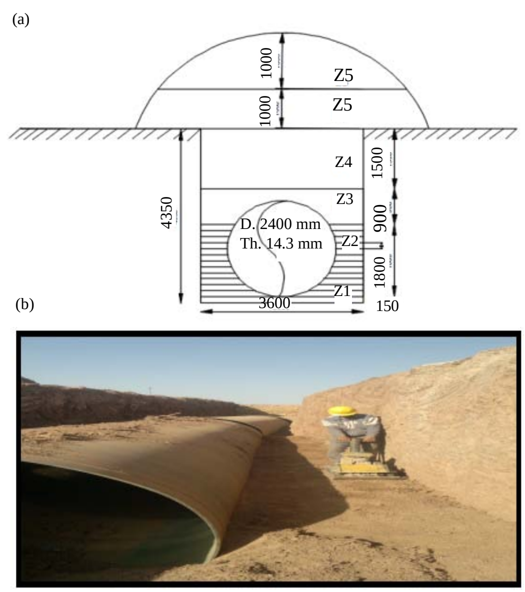


Fig. 2: Type 2 piping

Type 2 piping: In this way, as shown in Fig. 2, first a channel in a depth of 4350 and width of 3200 mm is dug

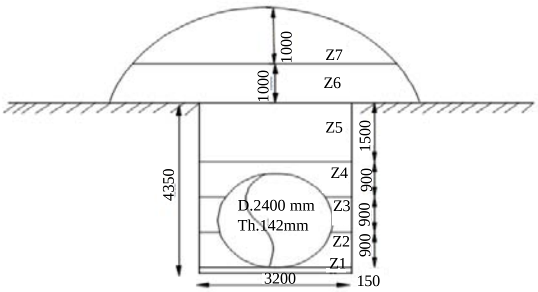


Fig. 3: Type 3 piping

up then the floor is filled with soft sand up to 15 cm high and is condensed to 85%. After that, the pipe is deployed in the channel and the riddled processed clay will be compacted in 12 layers named Z2 to the height 150 cm using a hitting compactor. Then, the layer Z3 containing riddled dry clay will be shed to the identical height of 90 cm. Finally, the channel is filled with the materials from drilling to reach the normal level and then wait for 3 another day. After that, the layers Z6 and Z7 will be performed with the same one meter in height.

Type 3 piping: In this way, as shown in Fig. 3, first a channel in a depth of 4350 and width of 3200 mm is dug up then the floor is filled with soft sand up to 15 cm high and is condensed to 85%. After that, the pipe is deployed in the channel and the layers Z2 and Z3 with a height of 900 mm of materials including 50% of riddled clay and 50% pea and almond materials will be flooded. Then, the layer Z4 containing riddled dry clay will be shed to the identical height of 90 cm. Finally, the channel is filled with the materials from drilling to reach the normal level and then wait for 3 another day. After that, the layers Z6 and Z7 will be performed with the same one meter in height.

Type 4 piping: In this way, as shown in Fig. 4, first a channel in a depth of 4350 and width of 3200 mm is dug up, then the floor is filled with soft sand up to 15 cm high and is condensed to 85%. After that, the pipe is deployed in the channel and the layer Z2 with a height of 1500 mm of materials including 33% of sand, 33% of pea materials and 33% almond materials will be performed. Then, the layer Z3 containing riddled dry clay will be shed to the height of 120 cm. Finally, the channel is filled with the materials from drilling to reach the normal level and then wait for 3 another day. After that, the layers Z6 and Z7 will be performed with the same one meter in height.

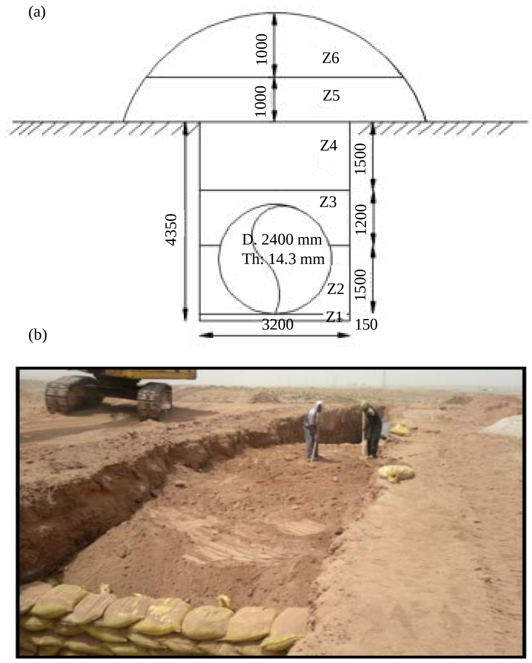


Fig. 4: Type 4 piping

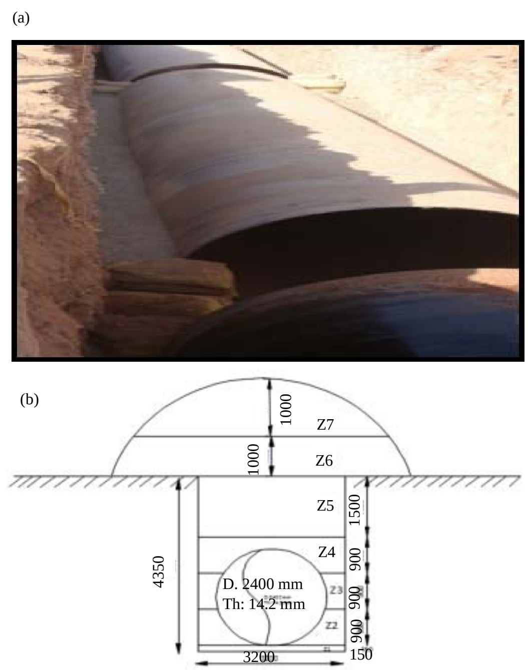


Fig. 5: Type 5 piping

Type 5 piping: In this way, as shown in Fig. 5, first a channel in a depth of 4350 and width of 3200 mm is dug up, then the floor is filled with soft sand up to 15 cm high and is condensed to 85%. After that, the pipe is deployed in the channel and the layer Z2 with a height of 900 mm of

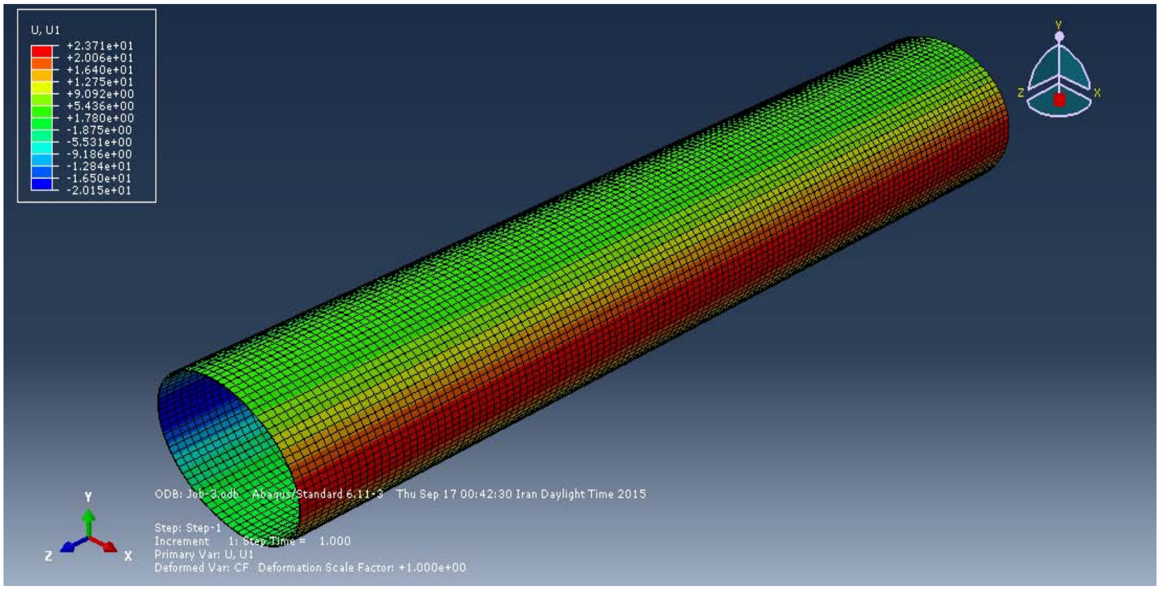


Fig. 6: Displacement in the type 1 pipe in the final stage of backfill

riddled clay will be flooded. Then, the layer Z3 containing 33% of sand, 33% of pea materials and 33% almond materials will be shed to the height of 900 mm. also, the layer Z4 with a height of 900 mm of riddled dry clay will be performed. Finally, the channel is filled with the materials from drilling to reach the normal level and then wait for 3 another day. After that, the layers Z6 and Z7 will be performed with the same one meter in height.

Modeling with ABAQUS Software

Forces on the pipe: To model the loads exerted on the pipe, you must first calculate the loads caused by the soil weight. On the upper level of pipe, i.e., the level of 2400 mm, only the loading is applied to the pipe in the vertical direction but as the level decreased from 2400 mm, horizontal load is exerted in addition to the vertical loads. The vertical load is directly related to the load exerted vertically. K is the vertical to horizontal stress conversion ratio in the soil and that is different for soil types.

Given that the soil around the pipe is variable, the relationship used to calculate the coefficient K is different. One of the following relations is used according to the type of soil:

$$\sigma_h = K\sigma_v$$

For normally consolidated clay:

$$K = 0.95 - \sin \varnothing$$

For granular soil with normal density:

$$K = 1 - \sin \varnothing$$

$\varnothing$ in the above relation is the soil internal friction angle which is different in different soils.

Modeling: Software outputs are presented by different stages and types of tests including displacement of pipes and the stress of pipes. It should be mentioned that the outputs defined in this study include stress and displacement in the vertical and horizontal direction of the pipe, that has been shown for the final stage of backfill on the pipe in type 1-5 tests.

Type 1 model: Figure 6 shows the software model output for changing the type 1 pipe diameter 1 in the traverse direction where the maximum amount of change in the pipe diameter in the final stage of backfill is 20.1 mm.

Type 2 model: Figure 7 shows the software model output for changing the type 2 pipe diameter 1 in the traverse direction where the maximum amount of change in the pipe diameter in the final stage of backfill is 18.4 mm.

Type 3 model: Figure 8 shows the software model output for changing the type 3 pipe diameter 1 in the traverse direction where the maximum amount of change in the pipe diameter in the final stage of backfill is 14.5 mm.

Type 4 model: Figure 9 shows the software model output for changing the type 4 pipe diameter 1 in the traverse direction where the maximum amount of change in the pipe diameter in the final stage of backfill is 14.7 mm.

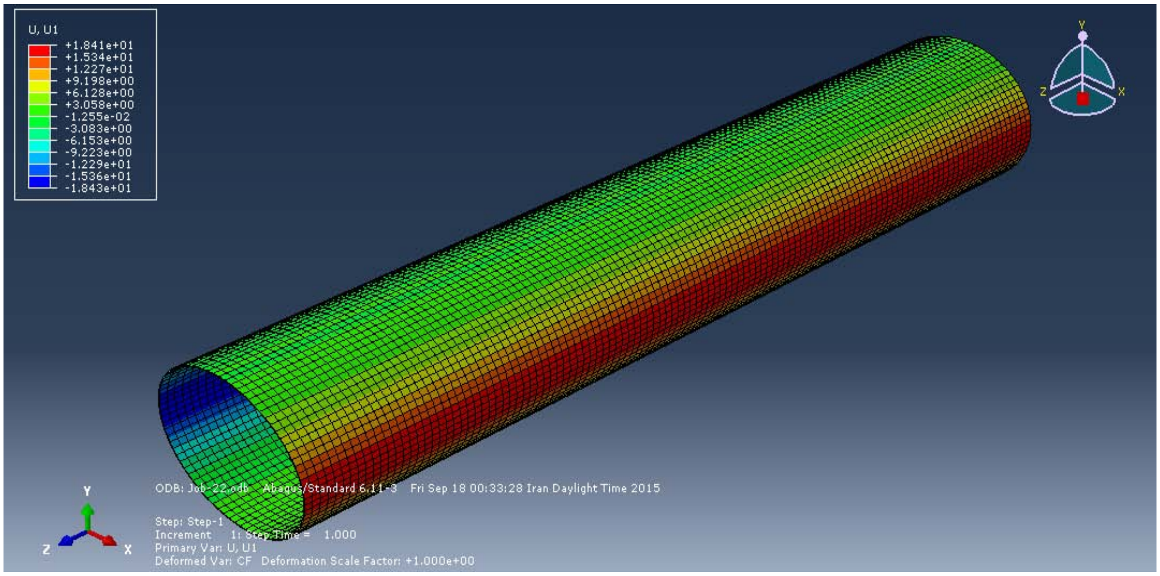


Fig. 7: Displacement in the type 2 pipe in the final stage of backfill

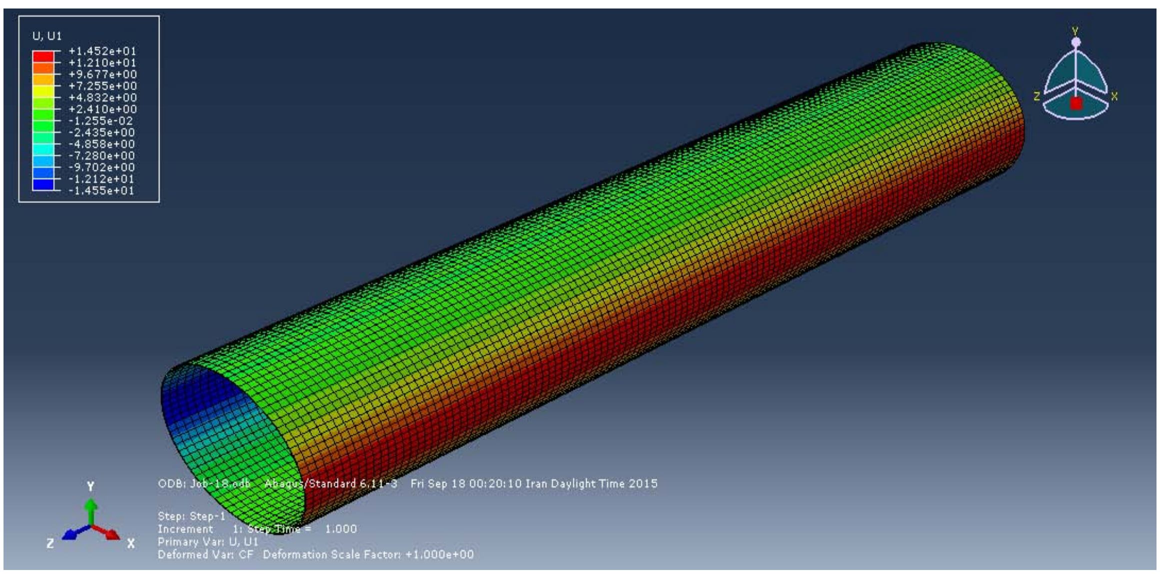


Fig. 8: Displacement in the type 3 pipe in the final stage of backfill

Type 5 model: Figure 10 shows the software model output for changing the type 5 pipe diameter 1 in the traverse direction where the maximum amount of change in the pipe diameter in the final stage of backfill is 14 mm.

AWWA: In this study, numerical analysis has been done using AWWA to calculate the pipe diameter change in horizontal direction or to calculate the pinch flat from the following relationship:

$$\Delta_x = D_l\,(kWr^3 / EI + 0.061E\,r'^3)$$

Where:

D_l = Delay rate that varies between 1-1.5
K = Bed constant factor 0.1
W = Total loads exerted on the pipe in kilogram per cm^2
E = Modulus of elasticity of pipe in kilogram per cm^2
r = Average radius of the pipe in cm
I = The pipe moment of inertia in traverse direction and the length of one centimeter which is equal to $t^3/12$ (t is the wall thickness in inches)

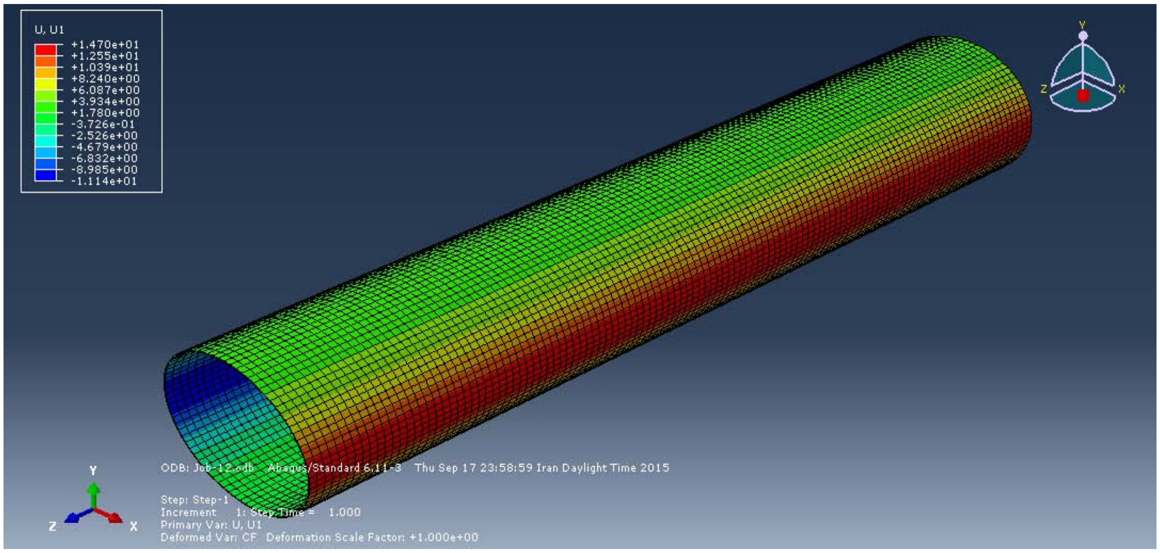


Fig. 9: Displacement in the type 4 pipe in the final stage of backfill

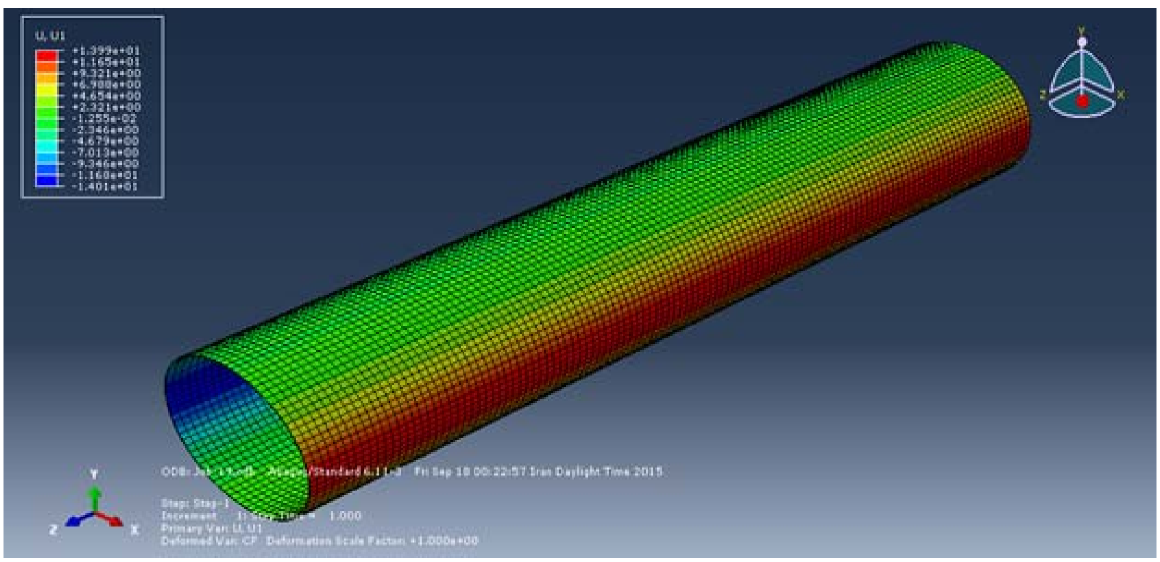


Fig. 10: Displacement in the type 5 pipe in the final stage of backfill

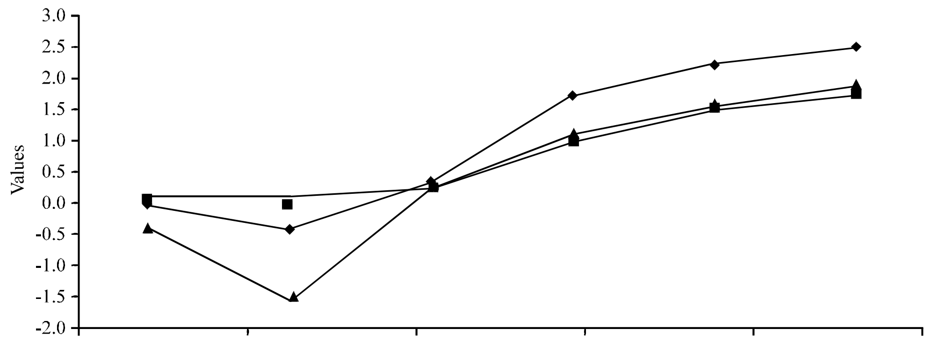
RESULTS AND DISCUSSION

The results of displacement in the first to sixth phases of all types (1-5) were calculated using laboratory analysis, software modeling and numerical analysis of AWAA. Then, the results have been compared with each other and every type is presented as a figure.

Comparison of the results of type 1: It can be seen by examining Fig. 11 that the maximum displacement in the final stage of type 1 test is related to the laboratory result and the most overlap was between laboratory result and numerical modeling in the first and third stages and their difference in the final stage is 25.5%.

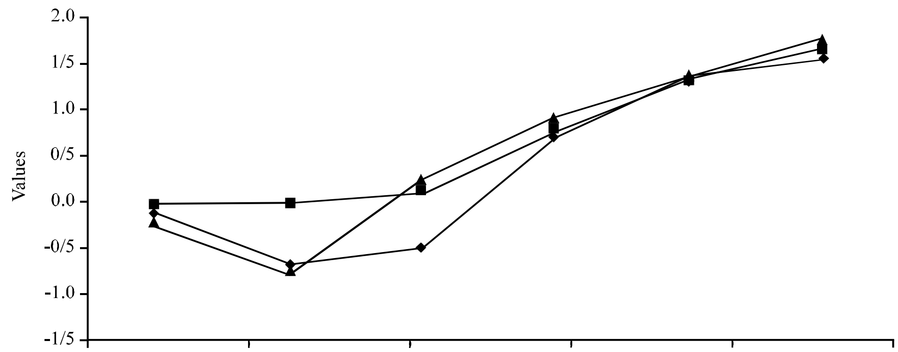
Comparison of the results of type 2: It can be seen by examining Fig. 12 that the maximum displacement in the final stage of type 2 test is related to the numerical modeling and the most overlap was between laboratory result and numerical modeling in the first, second and fifth stages and their difference in the final stage is 13%.

Comparison of the results of type 3: It can be seen by examining Fig. 13 that the maximum displacement



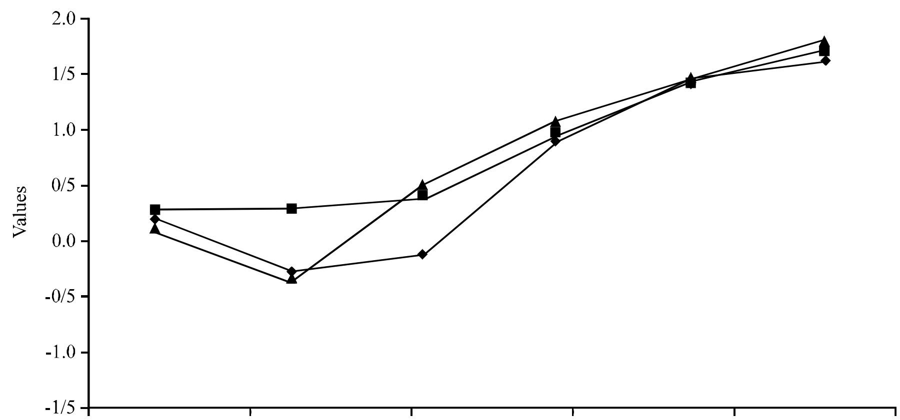
	1st step	2nd step	3rd step	4th step	5the step	6th step
ΔxExperiment	0	-0.366666667	0.366666667	1.866666667	2.4	2.7
ΔxTheory	0.00	0.00	0.19	0.97	1.52	1.79
Abaqus results	-0.3366	-1.58	0.3368	1.24	1.69	2.01

Fig. 11: Graph of lab, theory and software results of type 1 test



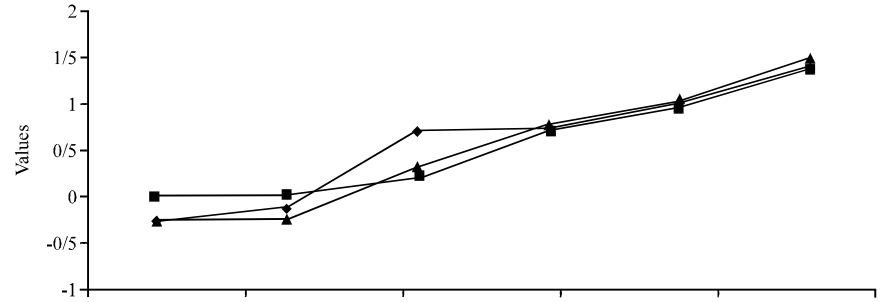
	Ist step	2nd step	3rd step	4th step	5th step	6th step
ΔxExperiment	-0/2	-0/766666667	-0/6	0/666666667	1/366666667	1/6
ΔxTheory	0/00	0/00	0/14	0/85	1/32	1/79
Abaqus results	-0/303	-0/88	0/2/82	0/95	1/39	1/84

Fig. 12: Graph of lab, theory and software results of type 2 test



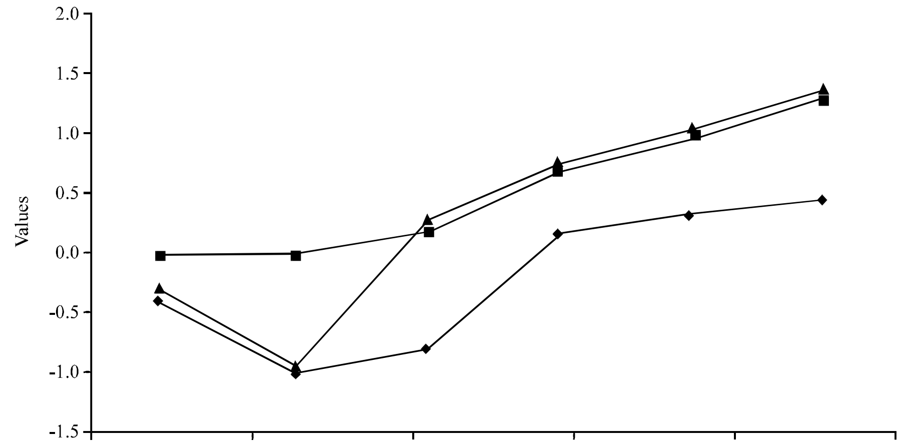
	Ist step	2nd step	3rd step	4th step	5th step	6th step
ΔxExperiment	-0/2	-0/766666667	-0/6	0/666666667	1/366666667	1/6
ΔxTheory	0/00	0/00	0/14	0/85	1/32	1/79
Abaqus results	-0/303	-0/88	0/2/82	0/95	1/39	1/84

Fig. 13: Graph of lab, theory and software results of type 3 testg 4



	1st step	2nd step	3rd step	4th step	5th step	6th step
ΔxExperiment	-0/3	-0/267	0/7	0/73	1	1/33
ΔxTheory	0/00	0/00	0/11	0/68	0/95	1/29
Abaqus results	-0/291	-0/722	0/297	0/82	1/01	1/47

Fig. 14: Graph of lab, theory and software results of type 4 test final stage of backfill



	1st step	2nd step	3rd step	4th step	5th step	6th step
ΔxExperiment	-0.466	-0.966	-0.8	0.2	0.33	0.466
ΔxTheory	0.00	0.000	0.11	0.68	0.95	1.290
Abaqus results	-0.291	-0.822	0.297	0.75	1.03	1.400

Fig. 15: Graph of lab, theory and software results of type 5 test

in the final stage of type 3 test is related to the numerical modeling result and the most overlap was between laboratory result and numerical modeling in the fourth and fifth stages and their difference in the final stage is 26%.

Comparison of the results of type 4: It can be seen by examining Fig. 14 that the maximum displacement in the final stage of type 4 test is related to the numerical modeling result and the most overlap was between laboratory result and modeling in the first, second, fourth and fifth stages and their difference in the final stage is 9%.

Comparison of the results of type 5: It can be seen by examining Fig. 15 that the maximum displacement in the final stage of type 5 test is related to the numerical modeling result and the most overlap was between laboratory result and numerical modeling in the first two stages and their difference in the final stage is 66%.

CONCLUSION

The following results were obtained by analyzing the laboratory results, software results and the results of AWWA: The results show that the soil and materials filling around the pipeline are important because some changes occur in the geotechnical specifications of materials in the operation of placing and planting the pipe in the channel that considering these parameters with favorable degrees of density and material are all effective to determine the subsidence and capacity of culverts. The results indicate that the most effective part in reducing the displacement of the middle of the pipeline is to increase the hardness of the middle 90 cm and raising the density of middle layer. The best conclusion according to this criterion is achieved when the middle layer is made of sand and clay and the initial 90 cm density occurs by flooding in clay. There is no access to high densities by manual compactor due to the low space.

Examining the laboratory results, software results and the theoretical results of the proposed relationships according to AWWA, it becomes clear that all the results are consistent and at the same software modeling can be used instead of laboratory modeling. The most overlap in type 1 test was between laboratory result and numerical modeling in the first and third stages and their difference in the final stage was 25.5%. The most overlap in type 2 test was between laboratory result and numerical modeling in the first, second and fifth stages and their difference in the final stage was 27%. The most overlap in type 3 test was between laboratory result and numerical modeling in the fourth and fifth stages and their difference in the final stage was 26%.

The most overlap in type 4 test was between laboratory result and numerical modeling in the second, fourth and fifth stages and their difference in the final stage was 9%. The most overlap in type 5 test was between laboratory result and numerical modeling in the first two stages and their difference in the final stage was 66%.

REFERENCES

AWWA. Staff, 2011. Steel Pipe: A Guide for Design and Installation, (M11). 4th Edn., American Water Works Association, Bloomington, Minnesota, ISBN:1-58321-274-4, Pages: 242.

Jayadevan, K.R., E. Berg, C. Thaulow, E. Ostby and B. Skallerud, 2006. Numerical investigatio of ductile tearing in surface cracked pipes using line-springs. Intl. J. Solids Struct., 43: 2378-2379.

Kawabata, T., Y. Mohri, H. Tamura, D. Shoda and T. Oda, 2006. Field test for buried large steel pipes with the 2006 Conference on Pipeline Division Specialty, July 30-August 2, 2006, American Society of Civil Engineers, Chicago, Illinois, pp: 1-8.

Salehian, F., 1967. The assessment of manhole structures of sewage network against earthquakes. Masters Thesis, Texas Tech University College of Agricultural Sciences & Natural Iran.

Spangler, M.G., 1941. The Structural Design of Flexible Culverts. Iowa State College of Agriculture and Mechanic Arts, Iowa, USA., Pages: 84.