FEAST

Forum for Engineering, Applied Sciences & Technology

BOOK oF FULL PAPER PROCEEDING

Full Paper Proceeding Book

FEAST 3rd International Conference on Engineering Technology, Applied Sciences, Computing & Networking

(EACN)

London, UK
Augusty 19-20, 2023
ISBN: 978-969-683-815-9

Email: contact@forum-east.com

Disclaimer

Authors have ensured sincerely that all the information given in this book is accurate, true, comprehensive, and correct right from the time it has been brought in writing. However, the publishers, the editors, and the authors are not to be held responsible for any kind of omission or error that might appear later on, or for any injury, damage, loss, or financial concerns that might arise as consequences of using the book. The views of the contributors stated might serve a different perspective than that of the FEAST.

FEAST 3rd International Conference on Engineering Technology, Applied Sciences, Computing & Networking
(EACN)

Venue: Mercure London Hyde Park Hotel, England

Theme: Bringing together researchers from several fields to collaborate together and create lasting change

SCIENTIFIC COMMITTEE

Prof. Carlos Enrique Pimienta Martinez
Universidad del Norte, Colombia

Dr. Günter Grossmann
University of Liverpool, England

Dr. Rajiv Selvam
Manipal Academy of Higher Education, UAE

Dr. McMaster K. J
University of Nottingham, England

Dr. Behzad Sani
Islamic Azad University, Tehran, Iran

Prof. Doc Surendra Kansara
Symbiosis Institute of Operations Management, India

ORGANIZING COMMITTEE

Charlotte Hargreaves
Conference Chair
Email: Charlotte@forum-east.com

Dr. S. Patel
Conference Coordinator

CONFERENCE TRACKS

- Social and Community Studies
- Arts
- Humanities
- Civic and Political Studies
- Cultural & Global Studies
- Enviromental Srudies
- Organizational Studies
- Educational and Communication Studies
- Economics, Finance & Accounting
- Business and Management Studies
- Engineering and Technology
- Architecture
- Artificial Intelligence
- Bioinformatics
- Biomedical Engineering
- Biotechnology

FEAST 3rd International Conference on Engineering Technology,
Applied Sciences, Computing & Networking
(EACN)

ISBN: 978-969-683-815-9

Predicting Pipeline Deformations Owing To Expansive Soil Swelling: A Numerical Study

[1*] Ayed E. Alluqmani1, H. A. Abas[2]

[1]Associate Professor, Department of Civil Engineering, Islamic University of Madinah, Al-Madinah Al-Munawarah, Saudi Arabia, [2]Assistant Professor, Department of Civil Engineering, Prince Mugrin University, Al-Madinah Al-Munawarah, Saudi Arabia
dr.ayed@iu.edu.sa

Abstract. Buried pipes are critical infrastructures that are usually used to transmit energy and other crucial commodities; it is critical to understand their behavior as a result of a number of environmental conditions, including the influence of swelling expansive soils. This paper describes an approach for predicting the behavior of buried pipelines in expansive soils using the PLAXIS 3D software. The model examines a 12-meter-long High-Density Polyethylene (HDPE) pipe buried in expansive soil and linked to two manholes. To simulate the swelling action of expansive soil, a positive volumetric strain is applied to the active zone under pipe. Two scenarios are investigated to model the heaving effect of expansive soil on the buried pipe. In the first scenario, heaving occurs in the middle of the pipe, representing a situation where the pipe may leak, or water may penetrate from the ground surface to the expansive soil beneath the pipe. In the second scenario, heaving occurs at the end of the pipe on the manhole wall, representing a situation where a leak may occur, or water may penetrate from the ground surface. The model provides realistic assessments of the soil-pipe system's deformations under varying swelling scenarios. The proposed model gives significant ties between the change in volume of expansive soil and the associated pipe deformations. The method can also aid in identifying possible pipeline failure locations and planning mitigation solutions.

Keywords— Buried Pipeline, Expansive Soils, Swelling, Deformations, PLAXIS 3D.

INTERODUCTION

The transportation of fluids and gases over long distances through pipelines is a crucial part of modern society's infrastructure, supporting various industries such as oil and gas, water supply, and wastewater management. Pipelines serve as lifelines, ensuring the efficient and reliable delivery of essential resources to meet the demands of a growing population. However, these pipelines are often exposed to challenging operating conditions and significant deformations throughout their service life, which can compromise their integrity and performance. Buried pipelines, in particular, are commonly located within the upper layer of soil deposits due to practical and economic considerations. This burial arrangement provides protection against external factors and minimizes interference with above-ground activities. However, the presence of expansive soils in these environments poses a significant geotechnical challenge.

Expansive soil conditions are influenced by seasonal climate variations, such as wetting and drying cycles, or water from various sources[1]–[3]. These variations in moisture content cause significant alterations in soil volume, resulting in extensive soil volume change. When the soil absorbs water, it swells, exerting significant pressures on the surrounding buried pipelines. Conversely, during dry periods, the soil shrinks, potentially causing the pipes to experience tensile stresses[4]. These cyclic volume changes induce stress redistribution and deformations in the buried pipelines, thereby exposing their structural integrity and safe operation. Given the significance of this issue, it is imperative to develop effective management strategies to mitigate the potential risks associated with the deformation of buried pipelines on expansive soils.

The failure of underground pipelines occurs when the stresses exerted on them exceed their structural resilience. A robust design analysis of buried pipes must consider multiple factors, including pipe characteristics, internal and external loads, and surrounding conditions such as backfill and side fill materials, installation depth, compaction quality, and road superstructure loads. On the other hand, the presence of expansive soil surrounding the pipes can cause swelling due to changes in water content, leading to altered loading on the pipes. However, existing pipeline design guidelines assume that the soil is either dry or fully saturated, failing to account for the behavior of unsaturated expansive soils surrounding pipelines. The swelling of expansive soils can cause extensive pipe deformations that can push pipelines beyond their failure limits [5]. The resulting structural failures can lead to costly repairs, hazardous conditions, and interrupted services. As a result, a comprehensive understanding of buried pipe responses to expansive soil conditions is necessary to develop modified design and construction practices. Such knowledge could significantly enhance pipeline performance and prolong their service life.

More recently, Finite element analysis (FEA) has been increasingly used to simulate the behavior of the soil-pipeline system and provide a more realistic representation of the uplift mechanism. Numerical modeling provides a rapid and accurate means to evaluate the effects of various variables on pipeline performance. The primary challenge in modeling pipes in expansive soils lies in accurately estimating the extent and modeling the swelling caused by changes in water content. This is a critical issue that requires careful consideration, as the magnitude of swelling can have a significant impact on the behavior of buried pipes. It is therefore essential to develop precise models that can accurately predict the extent of swelling and its effects on the surrounding soil and buried pipes. The preceding analysis highlights the effectiveness of FEM in assessing the performance of buried pipes. However, there has been a dearth of research investigating the behavior and functioning of pipelines in expansive soil conditions. Rajeev and Kodikara, 2011 conducted a numerical analysis on an experimental pipe buried in soil, which was subjected to soil movement resulting from an increase in moisture content. The researchers modeled the pipe as a linear elastic material and the soil as a nonlinear material. Their study aimed to predict the extent of soil movements caused by changes in water flow, and they found that the existing research on the numerical modeling of soil-pipe interaction behavior is limited, despite the significant impact of expansive soils on pipeline performance. This study sheds light on the need for further research in this area [6].

The primary aim of this manuscript is to investigate the performance of buried pipelines in response to expansive soil movements. To ensure the accuracy and reliability in this numerical study, relevant parameters, encompassing soil properties, pipe material properties, and boundary conditions, were carefully incorporated. These parameters were derived from empirical data and established engineering practices. Through systematic simulations conducted under varying swelling amounts (ranging from 0.2% to 1.0%), the research sought to explain the influence of swelling on vertical deformation within the pipe. Particular attention was devoted to assessing the impact of active zone locations, with investigations focused on two distinct positions: one at the middle and the other at the end of the pipe. Additionally, the study explored the significance of active zone width by varying its dimensions to discover its effect on vertical deformation magnitude. Furthermore, to gauge the efficacy of mitigating swelling-induced vertical displacement, the study thoroughly examined the use of sand backfills positioned beneath the pipes. Collectively, these investigations offer valuable insights into the behavior of buried pipelines when exposed to expansive soil conditions, fostering a deeper understanding of potential deformation mechanisms and facilitating the development of effective strategies to ensure pipeline integrity and resilience.

Numerical Model

The aim of this research is to create a complete model that effectively replicates the behavior of buried pipes in expansive soils while accounting for the variety of expansive soil swelling and construction methods widely used in engineering applications. The configuration of the model is a 12-meter-long High-density polyethylene pipe (HDPE). In this study, the HDPE pipe is linked to two manholes and is buried at a depth of one meter in expansive soil conditions. Figure 1 depicts this configuration. Plaxis 3D software was used to acquire a full understanding of the behavior of the buried pipeline under the required conditions.

To model the swelling effect of the expansive soil on the buried pipe, two scenarios were investigated as shown in Figure 1. In the first scenario, swelling was assumed to occur in the middle of the pipe, representing a situation where the pipe may leak at that location or water may penetrate from the ground surface to the expansive soil underneath the pipe. The second scenario involved heaving at the end of the pipe on the manhole wall, representing a situation where a leak may occur at that point or water may penetrate from the ground surface. These two scenarios were selected because they represent the most common and challenging scenarios for pipelines affected by swelling due to expansive soil.

The simulation of swelling deformation action under buried pipes was done by applying a positive volumetric strain (PVS) in vertical direction to the active zone, as shown in Figure 1. This method has been widely adopted by researchers to simulate the swelling of expansive soils under various structures [7]–[9]. Initially, the active zone is defined as soil clusters 1 m ×1 m and a depth of 1 m at two locations, as indicated in Figure 2.

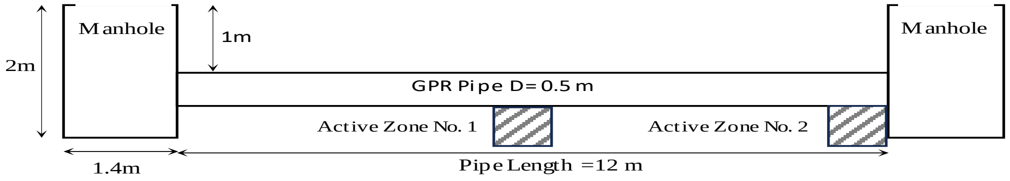

Fig. 1. The adopted model geometry and potential locations of heaving.

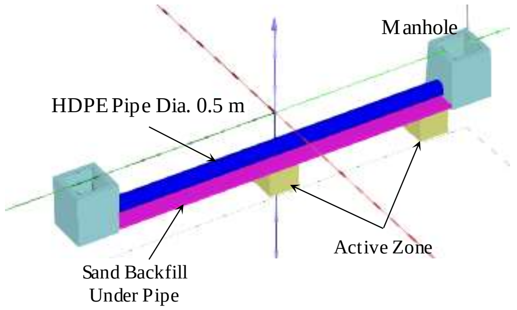

Fig. 2. FEM Modeling screen shoot includes active zone location.

The borehole feature is used to develop a numerical model representing the soil layers. The simulated soil profile consisted of three distinct layers: a 6-meter-thick layer of expansive soil situated above a 10-meter-thick layer of medium stiff clay, followed by a 14-meter-thick layer of stiff clay. To ensure the accuracy and reliability of the simulation, soil parameters crucial for capturing the behavior of the soils were sourced from prior research conducted by H. A. Abas [2], and these parameters are detailed in Table 1. Additionally, Table 1 provides a summary of the parameters relevant to the sand backfill materials positioned below the High-density polyethylene (HDPE) pipe. The researchers modeled the behavior of the soil layers using the Mohr-Coulomb criterion, a widely adopted method for representing the stress-strain response of soils in geotechnical analyses. For the modeling of Manhole concrete elements, Table 2 presents the essential model parameters utilized in the analysis. The HDPE pipe was modeled using plate criteria, considering its material properties such as Young's modulus, Poisson's ratio, and shear modulus. These critical properties were obtained from a comprehensive study conducted by Jiang in 2021 [10]. Jiang's study involved experimental and numerical modeling, focusing on the deformation behavior of buried HDPE pipes in sand. The material properties extracted from Jiang's study are listed in Table 3.

The boundary condition for the modeling was established as the standard fixity. This involves assuming roller supports for the vertical boundary surface and an entirely fixed condition at the base of the soil bed. To ensure optimal and consistent performance, a fine mesh size was employed. The soil elements were modeled using tetrahedral elements, each containing 10 nodes. The initial phase was considered before applying swelling effect under pipe. Once the initial phase is complete, the calculation phase follows, which is divided into phases that are like the construction stage.

TABLE 1

FINITE ELEMENT PARAMETERS FOR SOIL LAYERS.

Parameter	Expansive Soil[11]	Stiff Clay	Sand Layer Under Pipe
Unsaturated unit weight, (kN/m^3)	21, 22.6	19	18
Cohesion, (kN/m^2)	95	200	1
Friction Angle, ($^\circ$)	20	22	34
Elastic Modulus, (MPa)	7	20	10
Passion Ratio	0.3	0.3	0.3

TABLE 2

MATERIAL PROPERTIES Of CONCRETE ELEMENTS.[12]

Parameter	**Values**
Elastic modules, (MPa)	24×10^3
Unit Weight, (kN/m^3)	24
Passion Ratio	0.2

TABLE 3

MATERIAL PROPERTIES OF THE HDPE PIPE [10] .

Parameter	**Values**
Diameter (mm)	500
Elastic modulus, (MPa)	750
Unit Weight, (kN/m^3)	9.5
Wall thickness (mm)	13.5
Poisson's ration	0.35

Results and Discussion

Simulations were conducted under different swelling amounts (0.2%, 0.4%, 0.6%, 0.8%, and 1.0%) to understand how swelling affects vertical deformation in the pipe. The study focused on two active zone locations: one in the middle and the other at the end of the pipe. The study also examined the effect of active zone width on pipe deformation, varying its dimensions to study how changes in

ISBN: 978-969-683-815-9

the active zone width influence the extent of vertical deformation. In addition, the study also explored the impact of sand backfills placed beneath the pipes, examining if they could mitigate the potential for vertical displacement due to swelling effects.

Vertical Deformation

The vertical displacement at the bottom of a buried pipe due to swelling effects caused by expansive soils was examined in this section. A soil cluster with dimensions of $1m \times 1m$ and a depth of 1m was used to represent the active zone where swelling occurs. The study considered different swelling amounts, ranging from 0.2% to 1.0%, and analyzed the resulting vertical displacement at the bottom of the pipe. Results showed that increasing swelling amount led to higher vertical displacement for both cases of swelling at the middle and at the end of the pipe. The maximum displacement at the center of the pipe was 0.71 mm at a swelling rate of 0.2%, while at 1% swelling, it increased to 3.6 mm. This pattern indicates that the pipe experiences bending due to the swelling effect. This bending behavior can result in stress concentration at certain points along the pipe's length, potentially leading to localized stress levels that could pose a risk of pipe failure.

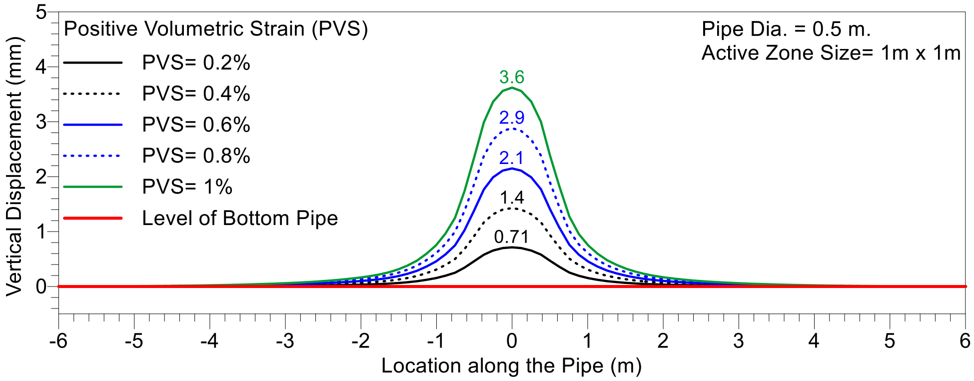

Fig. 3. Distribution of vertical displacement along the pipe length due to swelling at the middle of the pipe.

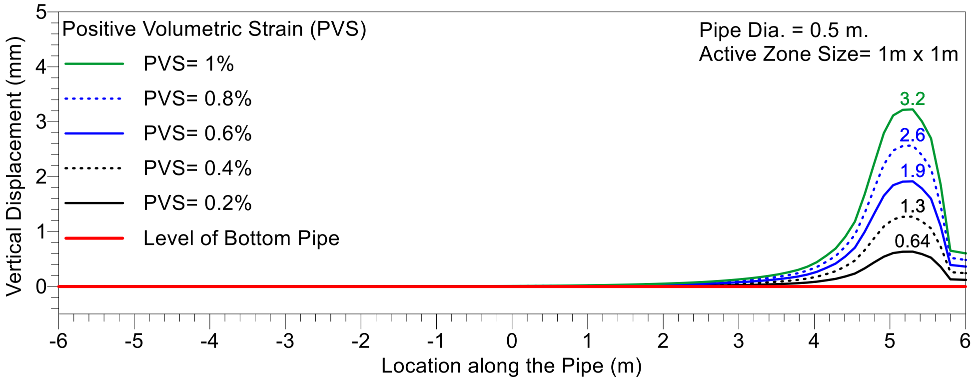

Fig. 4. Distribution of vertical displacement along the pipe length due to swelling at the end of the pipe.

Effect of Active Zone

The study explores the concept of an "active zone" in expansive soils and its potential impact on buried pipelines. The active zone is the area where water infiltrates the soil, causing swelling and increasing volume. This swelling phenomenon affects the stability and performance of buried pipes. Researchers divided the active zone into distinct soil clusters with specific dimensions, keeping the depth constant at 1 meter. The study divided the active zone into distinct soil clusters, each with specific dimensions: $1m \times 1m$, $2m \times 2m$, and $3m \times 3m$. The same soil parameters were employed for all soil clusters to ensure a rigorous assessment. Figures 4 and 5 show that increasing the active zone width significantly impacts the pipeline's displacement behavior. Expanding the active zone width leads to displacement in the longer section of the pipe, indicating swelling-induced movements in the surrounding soil extending over a larger distance, causing increased deformation in the buried pipeline. The peak value of vertical displacement also shows a consistent

ISBN: 978-969-683-815-9

trend with changes in active zone width, indicating that a wider active zone significantly impacts the pipeline's response to swelling effects, resulting in higher levels of vertical displacement.

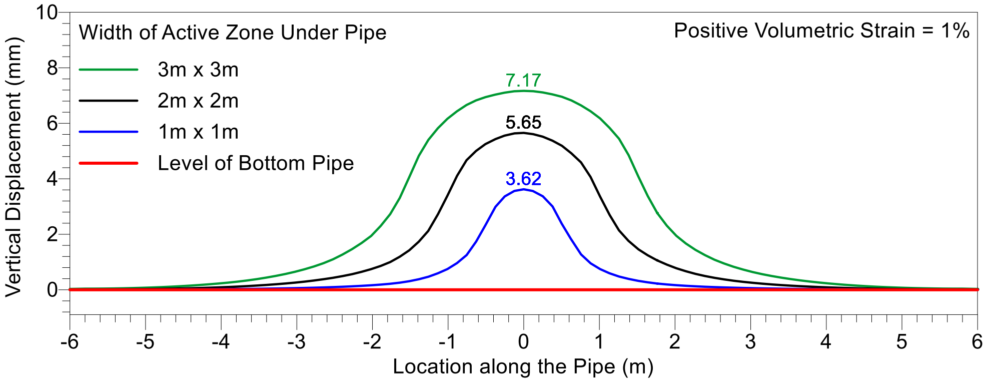

Fig. 5. Vertical displacement along the pipe length due to change in active zone width at the middle of pipe.

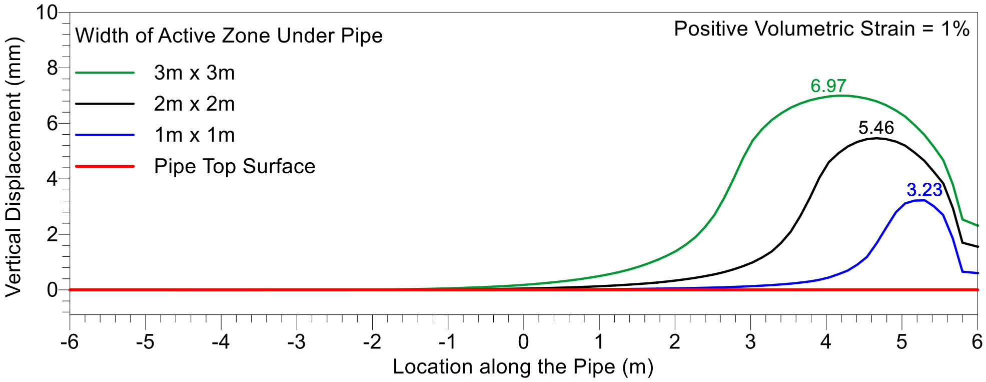

Fig. 6. Vertical displacement along the pipe length due to change in active zone width at the end of pipe.

Effect of Sand backfill Under Pipe

This section aims to evaluate the effectiveness of sand backfill in mitigating swelling effects on buried pipelines. Two models were developed and analyzed, representing different scenarios. The first model was a buried pipe without sand backfill, where the pipe was directly installed in contact with expansive soils. This model served as the baseline scenario, reflecting the practice of laying pipelines without any additional protective measures to counter swelling effects. The second model group simulated a buried pipe with varying sand backfill thicknesses (0.1m, 0.2m, and 0.3m) underneath, evaluating the influence of different thicknesses on the performance of the buried pipeline in expansive soils.

The study compared vertical displacement at the bottom of pipes for both models. Figure 6 illustrates the findings, showing the maximum displacement values for each scenario. The maximum displacement was 4.58 mm in the absence of sand backfill, but sand backfill layers significantly reduced it. The maximum displacement decreased to 3.62 mm with a 0.1 m sand thickness, and 3.17 mm with a 0.2 m sand thickness. The most effective reduction was observed with a 0.3 m sand thickness, with a maximum displacement of only 2.84 mm. These findings indicate that the introduction of sand backfill layers beneath the buried pipeline serves as a preventive measure against swelling effects in expansive soil conditions. As the thickness of the sand backfill increases, the reduction in vertical displacement becomes more pronounced. This suggests that using an appropriate thickness of sand backfill can significantly mitigate the detrimental effects of swelling, thus improving the overall stability and performance of the buried pipeline system.

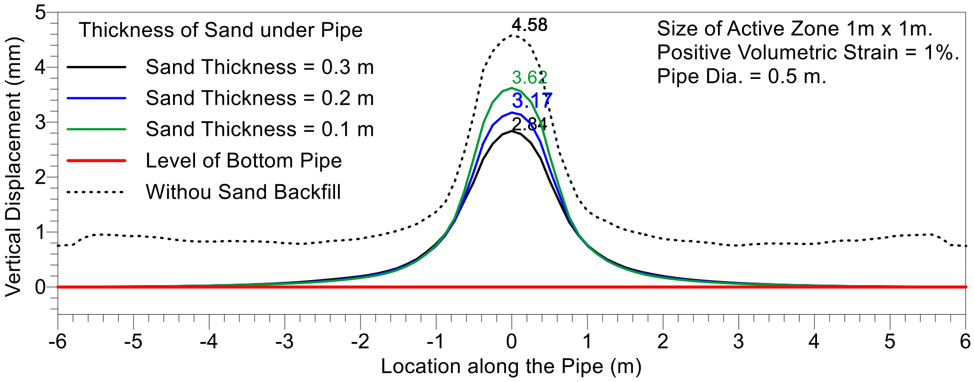

Fig. 7. Effect of sand backfill on the Vertical displacement distribution along the pipe lengt

CONCLUSION

The performance of buried pipes under the influence of expanding soil volume change was assessed in this work using an extensive numerical investigation. The analysis considered several variables, including the impact of sand backfills beneath the pipes, differed swelling amounts, active zone locations, and widths.

The findings of numerical study clearly demonstrate a direct relationship between increasing swelling amounts and higher vertical displacements in the buried pipeline, regardless of whether swelling occurs at the middle or the end of the pipe. For instance, the vertical displacement value at 1% swelling is around five times greater than that detected at 0.2% swelling. This emphasizes the crucial need of considering swelling effects into account during the design, construction, and maintenance phases of buried pipeline projects in expansive soil situations. The potential of vertical deformations and risks associated with them must be addressed in order to preserve the pipeline system's integrity.

The study also highlighted the significance of the active zone in influencing pipeline deformation. Expanding active zone width causes displacement in longer pipe sections, indicating swelling-induced soil volume change. This leads to increased deformation in the buried pipeline. The peak vertical displacement value follows a consistent trend with active zone width changes, indicating a wider active zone significantly impacts the pipeline's response to swelling effects. This finding emphasizes the need to manage and mitigate swelling effects through appropriate engineering practices, especially when dealing with larger active zones.

Moreover, the utilization of sand backfills layers under the pipe proved effective in reducing vertical displacement. The analysis showed that increasing the sand backfill thickness led to a more pronounced reduction in displacement, indicating the practical benefits of employing appropriate sand backfill measures to counteract swelling effects in expansive soil conditions. The maximum displacement was 4.58 mm without sand backfill, but sand backfill layers significantly reduced it. The maximum displacement decreased to 3.62 mm with 0.1 m sand thickness and 3.17 mm with 0.2 m sand thickness. The most effective reduction was observed with 0.3 m sand thickness, with a maximum displacement of only 2.84 mm.

Further research and experimental testing are encouraged to better understand the long-term effects of swelling on buried pipelines and the performance of sand backfill measures. This will aid in refining design guidelines and construction practices for enhanced pipeline resilience in expansive soil environments.

Acknowledgement

This research was made possible with support from the University of Prince Mugrin (UPM) and Islamic University of Madinah (IUM). The authors would like to extend their appreciation to the UPM and IUM for providing such continued support.

ISBN: 978-969-683-815-9

REFERENCES

[1] A. A. Basma, A. S. Al-Homoud, A. I. H. Malkawi, and M. A. Al-Bashabsheh, "Swelling-shrinkage behavior of natural expansive clays," Appl. Clay Sci., vol. 11, no. 2–4, pp. 211–227, 1996.

[2] J. Nelson and D. J. Miller, Expansive soils: problems and practice in foundation and pavement engineering. John Wiley & Sons, 1997.

[3] R. Sharma and R. Sharma, "Mechanical behaviour of unsaturated highly expansive clays," 1998.

[4] J. D. Rogers, R. Olshansky, and R. B. Rogers, "Damage to foundations from expansive soils," Claims People, vol. 3, no. 4, pp. 1–4, 1993.

[5] G. P. Drumond, I. P. Pasqualino, B. C. Pinheiro, and S. F. Estefen, "Pipelines, risers and umbilicals failures: A literature review," Ocean Eng., vol. 148, pp. 412–425, 2018.

[6] P. Rajeev and J. Kodikara, "Numerical analysis of an experimental pipe buried in swelling soil," Comput. Geotech., vol. 38, no. 7, pp. 897–904, 2011.

[7] H. A. Abas, "A Numerical Study of Strip Footing with Granular Pile Anchor Build on Expansive Soils, Wad Medani City–Sudan," 2017.

[8] S. Sangeetha and P. H. Krishna, "Analysis of Heave Behaviour of Expansive Soil Provided with Granular Pile Anchors Using Plaxis," in Advances in Computer Methods and Geomechanics, Springer, 2020, pp. 391–404.

[9] H. A. Abas, "Efficiency of Micropiles Surrounded by Sand to Avoid Uplifting Deformation of Strip Footing over Expansive Soils" International Journal of Academic Engineering Research (IJAER), Vol. 4, no 12, pp. 21-25Dec - 2020.

[10] C. Jiang, "Analysis and Modelling of Buried Pipe Deformations," PhD Thesis, University of Dayton, 2021.

[11] H. A. Abas, "A Numerical Study of Strip Footing with Granular Pile Anchor Build on Expansive Soils, Wad Medani City -Sudan," Int. Res. J. Innov. Eng. Technol. IRJIET, Accessed: Oct. 22, 2020.

[12] H. Abas, "Deformation of Trapezoidal Hydraulic Canal Constructed on Expansive Soils: A Numerical Study," Am. J. Eng. Res., vol. 10, pp. 1–5, Oct. 2021.

— This article does not have any appendix. —