Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-470

Ground movement mitigation for aging rising mains using numerical modelling

Ali Monzer, Phatharaphong Yensri, Asaad Faramarzi
School of Engineering, University of Birmingham, Birmingham, United Kingdom, axm1369@alumni.bham.ac.uk

ABSTRACT: As population growth drives the need for new transportation infrastructure, especially roads and highways, embankments are increasingly constructed near or above existing buried utilities. This raises concerns regarding the potential impacts on the serviceability of buried pipelines. This study aims to assess the effectiveness of structural mitigation measures specifically, a piled concrete slab in protecting ductile iron and PVC rising mains under embankment loading in a soft ground urban setting. A numerical modelling approach using the PLAXIS 3D software package was adopted to simulate soil-structure interaction across two scenarios: one without support and another with a piled slab as a protective measure. A design assessment, including the pile loading capacity, was performed to optimise the protected slab design, ensuring sufficient load-bearing capacity and stability. The modelling included staged construction phases, including initial loading, embankment placement, and surcharge application under realistic stratified soil conditions. The results show that the inclusion of a piled concrete slab led to a reduction in total surface settlement of over 40%, significantly improving ground stability in the vicinity of the pipelines. Furthermore, vertical stress acting on the pipe crowns decreased by approximately 38%, reducing the risk of overstressing the aging infrastructure. The induced bending moments were reduced by 50% for the PVC pipe and 42% for the ductile iron pipe, indicating a substantial improvement in structural performance. These findings demonstrate the effectiveness of using a piled concrete slab to mitigate embankment induced ground movement and protect aging pipeline networks. The study highlights the importance of incorporating soil-structure interaction analysis into infrastructure design and supports the use of structural mitigation strategies to enhance the safety and longevity of buried utilities. Further investigations and long-term monitoring are recommended to validate performance and address potential risks.

KEYWORDS: Ground movement assessment, rising mains protection, Finite Element Analysis (FEA), soil-structure interaction, settlement mitigation.

1 INTRODUCTION

Urbanisation and infrastructure expansion have significantly increased the need to construct highways, embankments, and buildings over or near existing buried utilities. Among these, rising mains commonly used to transport wastewater in sewerage systems are critical assets that often suffer from aging, material degradation, and inadequate protection from surface loading (Zamanian and Shafieezadeh, 2023). These pipelines are susceptible to excessive deformation or structural failure when subjected to additional ground movement caused by embankment loading, especially in soft ground conditions.

The interaction between soil, buried pipelines, and new surface loads has become a central focus of geotechnical research. Construction activities can alter the in-situ stress conditions and induce significant ground movements, such as settlements, that may exceed the tolerance limits of buried infrastructure (Attewell and Taylor, 1984; Kouretzis et al., 2015). In addition, the problem is more severe in urban environments where rising mains are often located at shallow depths and were not originally designed to withstand the heavy loads from modern infrastructure.

Past failures and damage to pipelines due to construction-induced settlements have prompted the development of various mitigation strategies. These include pipe jacking, trenchless technology, flexible joints, encasement in reinforced concrete, and the use of protective slabs or piled foundation systems to redistribute loads away from the pipe alignment (Rajani and Kleiner, 2001; Xi et al., 2024). Among these, the installation of piled concrete slabs has emerged as an effective technique, particularly in cases involving soft soil deposits. This system transfers loads to deeper, more competent strata, thereby reducing the stress and deformation experienced by the buried pipe (Hong and Hong, 2017).

The assessment of such mitigation systems requires robust and realistic numerical modelling. Finite Element Analysis (FEA), particularly with tools like PLAXIS 3D software package, allows for detailed investigation of soil-structure interaction, simulation of construction stages, and incorporation of complex ground conditions. Recent studies have demonstrated the effectiveness of FEA models in capturing both axial and bending responses in pipelines subjected to embankment and surcharge loading (Kang et al., 2008; Neya et al., 2017; Irmawan et al., 2024).

This paper presents a comprehensive numerical study to assess ground movement and mitigation for aging rising mains located beneath a proposed embankment. The primary engineering challenge involves protecting two existing pipelines constructed from ductile iron and PVC by designing a reinforced concrete cover slab. Given the aging condition of these assets and their importance within the regional utility network, minimising construction induced ground disturbance is critical.

The analysis focuses on quantifying anticipated ground movements resulting from embankment construction and assessing the effectiveness of a piled concrete slab in mitigating associated risks. Two scenarios were modelled using PLAXIS 3D: one without any protective structure and another incorporating a piled cover slab above the pipelines. Key parameters such as total settlement, vertical stress distribution, and induced bending moments in PVC and ductile iron pipes were examined to evaluate the effectiveness of the mitigation system. The outcomes of this study provide valuable insights for engineers and asset managers involved in urban infrastructure projects, supporting the safe integration of new transport infrastructure with existing buried services.

2 DESCRIPTION OF THE SITE

2.1 *Site geometry with existing aging rising mains*

The study site is situated within an urban development zone where a new highway embankment is planned to be constructed above existing buried utilities. Two aging rising mains, one made of PVC and the other of ductile iron, run parallel at a shallow depth beneath the proposed embankment footprint.

The existing mains are positioned approximately 2.1 meters below ground level with a centre to centre spacing of 9.7 meters. The surrounding area is densely developed, limiting rerouting options and making in situ protection strategies a critical requirement. The proposed embankment is designed to reach a maximum height of 3.0 meters and spans approximately 50 meters across the pipe alignment. This configuration presents a clear risk of induced settlement and stress concentration on the buried infrastructure, especially in the absence of adequate mitigation measures.

2.2 *Ground conditions*

The stratigraphy consists of a mix of made ground and cohesive soils, underlain by weathered limestone. Table 1 summarises the depth and composition of each stratum identified on site.

The presence of soft and compressible clay layers near the pipe depth increases the likelihood of significant settlement when embankment loads are applied. This geotechnical profile was used as the basis for the numerical modelling carried out in this study.

Table 1. Depth of strata layers.

Soil strata	Top (mBGL)	Base (mBGL)
Made Ground	0.0	1.2
Soft Clay	1.2	4.5
Stiff Clay	4.5	11.5
Very Stiff Clay	11.5	14.5
Limestone	14.5	19.5

2.3 *Proposed development of mitigation plan*

Based on the findings of the ground movement assessment, a mitigation plan has been developed to address potential ground movement impacts on existing rising mains located within the construction footprint. This plan is a critical element of the overall design strategy, aimed at safeguarding utility infrastructure throughout the construction process and into the post-construction phase.

The proposed mitigation involves the construction of a reinforced concrete protection slab supported by bored piles. This structural system is designed to span the alignment of the rising mains, thereby isolating them from direct structural and embankment loading. The slab configuration, including thickness and pile layout, has been developed to ensure adequate stiffness and load distribution capacity based on the geotechnical conditions of the site.

The methodology encompasses detailed design of the slab and pile system, construction sequencing, and integration with adjacent infrastructure works. Key stages include the installation of piles and a concrete slab, and subsequent backfilling and embankment construction. The design parameters have been incorporated into a numerical modelling framework to evaluate the interaction between ground, structure, and existing utilities under various loading scenarios.

3 PILE DESIGN ASSESSMENT

A pile foundation system was developed to support a protective slab structure positioned above existing underground utilities. The design aimed to ensure both structural stability and geotechnical adequacy while minimising settlement in the surrounding soils. The approach followed the principles and requirements of Eurocode 7 (BSI, 2004a) and the associated UK National Annex (BSI, 2004b), with consideration also given to best practices for working near buried infrastructure (Gaba et al., 2003).

3.1 *Design Loads and Criteria*

The design incorporated both permanent and variable loads, with the total factored design action calculated under DA1 – Combination 2 limit state criteria. This ensures appropriate levels of safety against bearing capacity failure and excessive settlement in accordance with Eurocode 7 (BSI, 2004a). The relevant design load values are summarised in Table 2, which includes the permanent load (G_k), variable load (Q_k), and the combined factored action used for geotechnical design.

Table 2. Load parameters used in pile design.

Parameter	Value (kN)
Permanent load (Gk)	781.2
Variable load (Qk)	458.8
Total working load	1240.0
Factored design action (DA1-C2)	1377.6

3.2 *Pile configuration and geotechnical capacity*

As illustrated in Figure 1, pile resistance was evaluated for multiple diameters (ranging from 300 mm to 1000 mm) and lengths (from 5 m to 19 m). The design load line was compared against geotechnical resistance curves to determine minimum acceptable pile dimensions.

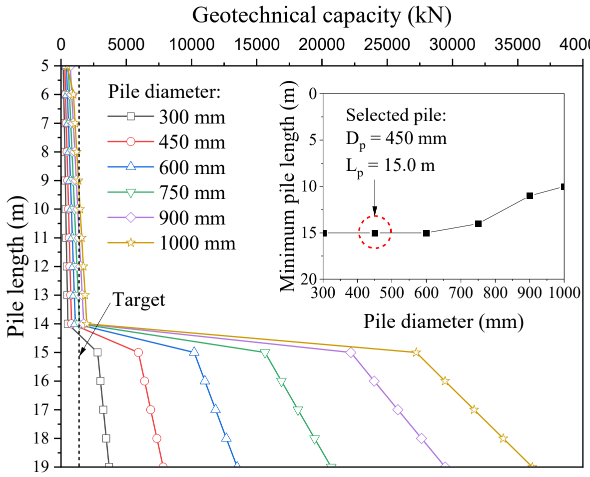


Figure 1. Pile design assessment.

The final selected configuration was a 450 mm diameter bored reinforced concrete pile, installed to a depth of 15.0 m. This design provides an estimated geotechnical capacity of approximately 5933 kN, which significantly exceeds the required ultimate load of 1378 kN. This offers a conservative factor of safety greater than 4, exceeding the minimum requirements of Eurocode 7 (BSI, 2004a). The details of the selected pile configuration are presented in Table 3.

Table 3. Selected pile design configuration.

Pile Parameter	Value
Pile type	Bored reinforced concrete
Pile diameter	450 mm
Pile length	15.0 m
Bearing stratum	Limestone
Geotechnical capacity	5933 kN
Required design capacity	1377.6 kN

3.3 *Ground conditions and constructability*

Subsurface investigations identified a stratigraphy comprising Made Ground, Soft Clay, Stiff to Very Stiff Clay, underlain by Limestone at a depth of approximately 14.5 m. The chosen pile length ensures embedment into the competent limestone layer, which provides enhanced end-bearing resistance and helps control settlement.

Given that the existing underground utilities are located at shallow depths (2.1 m), primarily within soft cohesive strata, a bored piling solution was selected to minimise the risk of vibration induced damage. This is consistent with the recommendations in CIRIA Report C580, which advocates for low impact construction techniques when operating adjacent to critical buried infrastructure (Gaba et al., 2003).

3.4 *Design summary*

The chosen foundation solution comprises 450 mm diameter bored piles installed to a depth of 15 metres. This design exceeds structural load requirements with substantial safety margins, penetrates through weaker soils into a stable bearing layer, and aligns with Eurocode standards and UK best practice. It also minimises settlement and disturbance to nearby buried assets, offering a robust and practical solution for challenging ground conditions and sensitive infrastructure environments.

4 NUMERICAL MODELLING

The cross-section of the embankment supported by a piled concrete slab is shown in Figure 2. The slab was constructed with a thickness of 0.95 m and a span of 18.45 m. Three rows of bored piles were installed, one row at the centre of the slab and two rows located near both ends, each positioned 0.375 m from the edge to the centre of the piles.

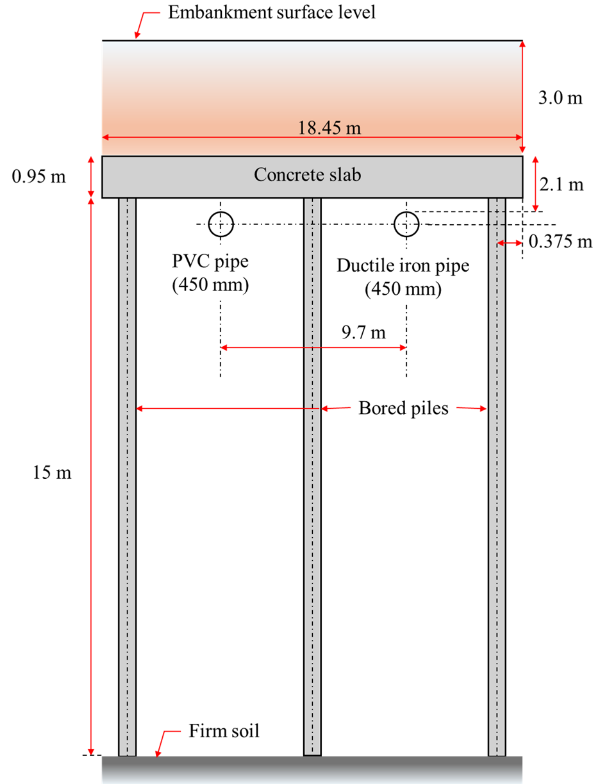


Figure 2. Section view of protective slab over rising mains.

The FE model geometry is presented in Figure 3, involving mesh and boundary conditions. The boundary of the model is 120 m long, 75 m wide and 19.5 m deep. The embankment height is 3.0 m. In this study, the original soils, as well as the embankment, were modelled using the Mohr-Coulomb failure criteria. Table 4 and Table 5 summarise the parameters used in the analyses for the soil and structural elements, respectively. The linear elastic behaviour was implemented for the structure part, including the bored piles, concrete slab and existing rising mains. Figure 4 displays the structural sections, including concrete slab, piles and pipes, conducted in the analysis.

In terms of the analysis, two models were simulated to investigate the potential impact of the embankment on the existing buried infrastructures: one without any mitigation measures, and another incorporating a piled concrete slab for support. Further details of the analysis are provided in Sections 4.1 and 4.2.

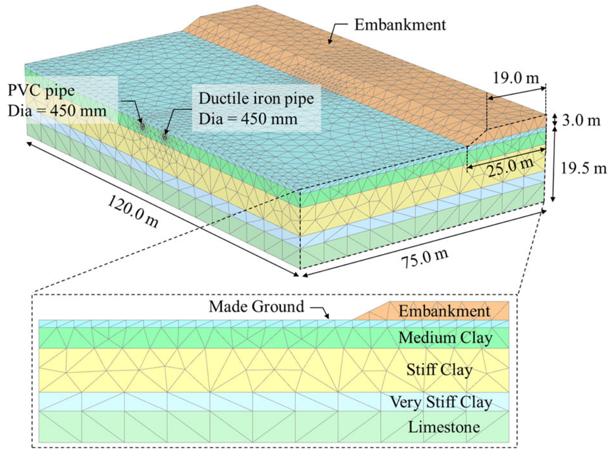


Figure 3. FE model mesh and geometry.

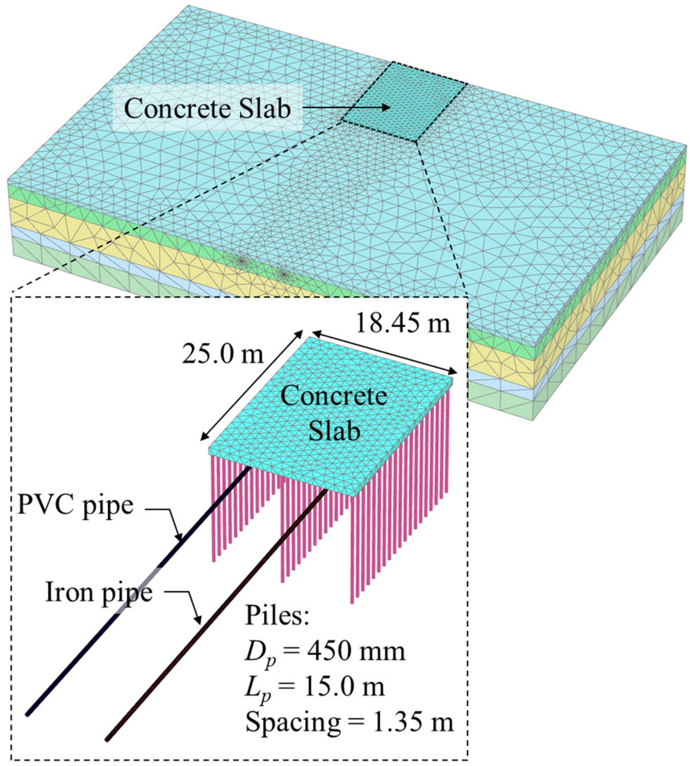


Figure 4. FE model of the piled concrete slab.

4.1 *Analysis without support*

This analysis conducted the simulation of the embankment construction above the existing rising mains without support. Three key stages were considered:

The initial loading stage involved the response of the ground and existing pipes under the initial weight applied.

Secondly, the embankment construction was simulated to investigate the potential impact on the existing buried pipes.

Lastly, an additional surcharge load of 60 kPa was applied on the top of the modelled embankment to simulate the extreme loading and observe the progressive impact on the surrounding soil and the rising mains.

4.2 *Analysis with the support*

In this section, the analysis details of the simulation with the piled foundation support are reported. The construction stages simulated in this analysis:

- The initial loading stage was identical to that used in the previous analysis.
- Bored piles and the concrete slab were then installed.
- Upon completion of the foundation construction, backfilling and additional embankment construction were carried out.
- Finally, after all construction stages were completed, an additional load of 60 kPa was applied to the top of the embankment.

Table 4. Soil parameters.

Material	Unit weight (kN/m3)	E (MPa)	v	c (kPa)	Φ (o)
Made Ground	18.0	9	0.3	34	25
Medium Clay	15.0	15	0.3	58	30
Stiff Clay	18.0	30	0.3	115	40
Very Stiff Clay	18.5	52	0.3	202	50
Limestone	21.0	117	0.3	1	30
Embankment	20.0	20	0.3	14	30

Where: E is Young's modulus, v is Poisson's ratio, c is Cohesion and Φ is Friction angle

Table 5. Structural parameters.

Material	Unit weight (kN/m3)	E (MPa)	v
Bored piles	23.6	22,360	0.2
Concrete slab	23.6	22,360	0.2
PVC pipe	13.8	3,000	0.2
Ductile Iron pipe	72.0	165,000	0.2

5 ANALYSED RESULTS AND DISCUSSION

5.1 *Total settlement and stress distribution*

This section presents and discusses the total settlement and stress distribution following the completion of embankment construction and subsequent traffic loading on the embankment surface. Figure 5 (a) and Figure 5 (b) illustrate the maximum surface settlements observed in the cases without and with piled concrete slab support, which are 40.27 mm and 23.38 mm, respectively. The results indicate that the inclusion of structural support beneath the embankment reduces total settlement by approximately 40%, thereby significantly minimising the impact on existing buried pipelines.

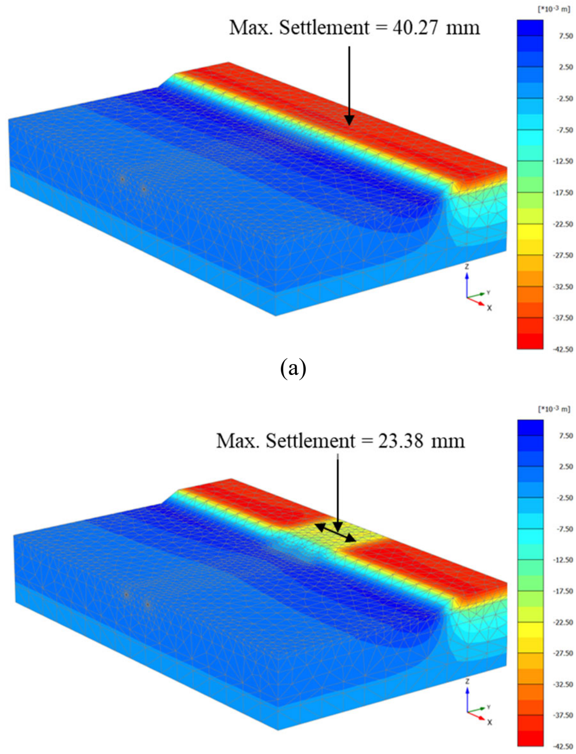
Furthermore, Figure 6 (a) and Figure 6 (b) illustrate the vertical total stress distributions above the pipe crown for the cases without and with structural support. In the unsupported scenario, the maximum vertical stress acting on the pipe reaches 160 kPa, whereas this value decreases to 100 kPa when the piled concrete slab is included. This reduction of approximately 38% in vertical stress leads to a substantial decrease in the induced bending moment within the pipes.

Table 6 summarises the maximum induced bending moments observed in the analyses. The results demonstrate that the implementation of a support system above the pipes significantly reduces the induced bending moment by 50% for the PVC pipe and 42% for the ductile iron pipe. This reduction directly contributes to lowering the risk of structural damage and preserving the integrity of the buried pipelines.

Table 6. Structural parameters.

Analysis case	Max. Induced bending moment (Nm/m)	
	PVC pipe	Ductile Iron pipe
Without support	240	520
With support	120	300

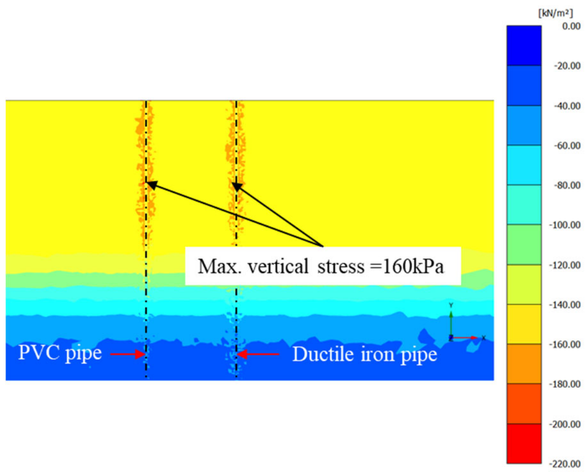
The findings are consistent with the study by Hong and Hong (2017), which demonstrated that embankments supported by piled foundations can significantly reduce pipe settlement, as the load is transferred to a firm soil layer through the mobilisation of the soil arching effect.



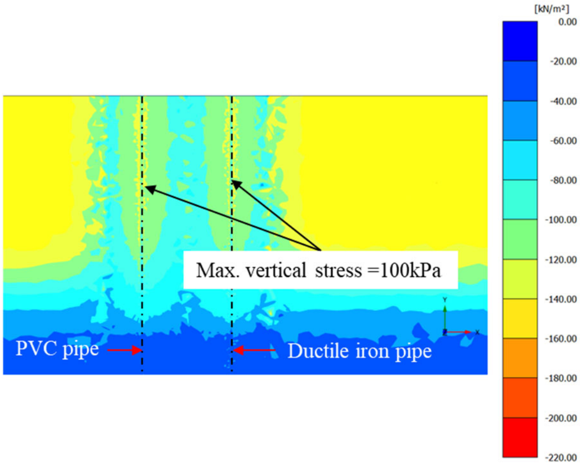
(a)

(b)

Figure 5. Total settlement above the embankment surface obtained from the analysis: (a) without support and (b) with support.



(a)



(b)

Figure 6. Maximum total vertical stress distribution observed above the crown level of the pipes obtained from the analysis: (a) without support and (b) with support.

5.2 *Pipe vertical deformation*

The induced vertical deformation of the PVC and ductile iron pipes is illustrated in Figure 7 and Figure 8, respectively, in response to embankment construction and subsequent traffic loading. For the PVC pipe, the maximum vertical displacement observed at the crown level is 14.58 mm following the completion of embankment construction and application of a 60 kPa surcharge. However, this deformation is significantly reduced to 7.55 mm when a piled concrete slab is installed above the pipe as a support system. These findings suggest that the support system plays a crucial role in mitigating vertical pipe movement and helps reduce differential deformation along the pipeline.

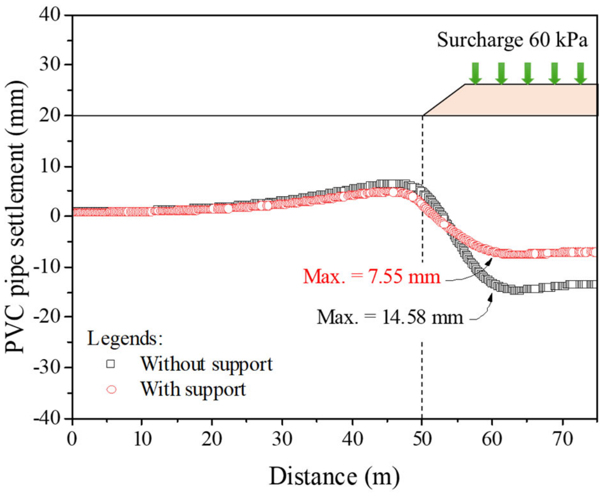


Figure 7. Vertical deformation of the PVC pipe.

A similar trend is observed for the ductile iron pipe, where the maximum settlement is 14.51 mm without any mitigation measures. When the piled concrete slab is introduced, the deformation is reduced to 7.53 mm. This consistent reduction in deformation further highlights the effectiveness of the support system in protecting buried pipelines from excessive ground-induced movement.

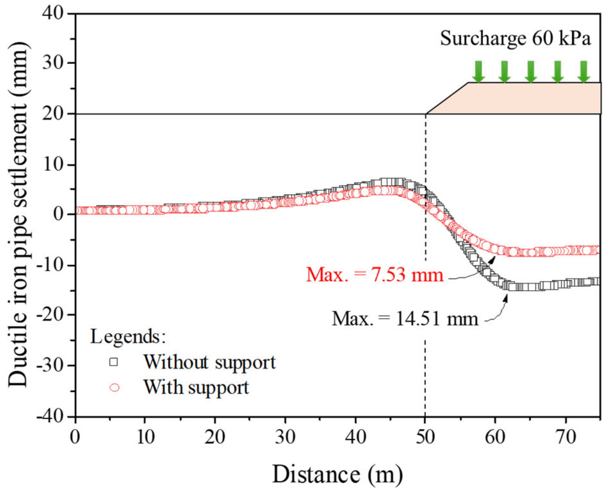


Figure 8. Vertical deformation of the ductile iron pipe.

6 CONCLUSIONS

This study investigated the use of a piled concrete slab as a mitigation strategy to protect aging rising mains from ground movement induced by embankment construction in soft ground conditions. Through advanced numerical modelling using the PLAXIS 3D software package, the research assessed the performance of this mitigation system by comparing two scenarios: one without protection and one incorporating a piled concrete slab. The outcomes clearly demonstrate the effectiveness of the mitigation strategy, with the following key findings:

- Total surface settlement above the pipe alignment was reduced by approximately 40% when a piled concrete slab was introduced, significantly improving ground stability and reducing the risk of settlement.
- The vertical stress acting on the pipe crowns decreased by about 38%, reducing the likelihood of overstressing the pipes due to embankment and surcharge loads.
- The induced bending moments in the buried utilities were also substantially reduced by 50% for the PVC pipe and 42% for the ductile iron pipe. This suggests a marked improvement in the structural response and a reduction in long-term fatigue risk.
- The maximum vertical deformation of the pipelines was nearly halved, decreasing from 14.58 mm to 7.55 mm for the PVC pipe and from 14.51 mm to 7.53 mm for the ductile iron pipe. This highlights the slab's effectiveness in limiting pipeline displacement.

These findings underline the value of implementing structural mitigation strategies, particularly piled slabs, to ensure the safety and longevity of critical buried infrastructure in urban environments. The approach not only addresses the technical challenges posed by embankment loading in soft soils but also aligns with best practices for working near sensitive underground assets. Future research should incorporate field monitoring to validate numerical predictions and explore the long-term behaviour of the mitigation system under varying load conditions.

7 ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the National Buried Infrastructure Facility (NBIF) at the School of Engineering, University of Birmingham, for their invaluable support throughout this research. The resources and collaborative environment provided by the facility played a crucial role in enabling the successful completion of this study (Grant reference number: EP/P013635/1).

8 REFERENCES

Attewell, P.B., and Taylor, R.K., 1984. *Ground Movement and Their Effects on Structures.* Surrey: Surrey University Press.

British Standards Institution (BSI), 2004a. *Eurocode 7: Geotechnical Design – Part 1: General Rules (BS EN 1997-1:2004).* London: BSI.

British Standards Institution (BSI), 2004b. *UK National Annex to Eurocode 7: Geotechnical Design – Part 1: General Rules (NA to BS EN 1997-1:2004).* London: BSI.

Gaba, A.R., Simpson, B., Powrie, W., and Beadman, D.R., 2003. *Embedded Retaining Walls: Guidelines for Economic Design.* London: Construction Industry Research & Information Association (CIRIA), Report C580.

Hong, W.P., and Hong, S., 2017. Piled embankment to prevent damage to pipe buried in soft grounds undergoing lateral flow. *Marine Georesources & Geotechnology,* 35(5), 719–729.

Irmawan, M., Yudoprasetyo, K., Refani, A.N., Indrasurya, K., and Parwita, D.N.P.A., 2024. The evaluation of pipeline protection influenced by causeway embankment using the finite element method (FEM). *Applied Sciences,* 14(11), 4382.

Kang, J., Parker, F., and Yoo, C.H., 2008. Soil–structure interaction for deeply buried corrugated steel pipes Part I: Embankment installation. *Engineering Structures,* 30(2), 384–392.

Kouretzis, G.P., Karamitros, D.K., and Sloan, S.W., 2015. Analysis of buried pipelines subjected to ground surface settlement and heave. *Canadian Geotechnical Journal,* 52(8), 1058–1071.

Neya, B.N., Ardeshir, M.A., Delavar, A.A., and Bakhsh, M.Z.R., 2017. Three-dimensional analysis of buried steel pipes under moving loads. *Open Journal of Geology,* 7(1), 1–11.

Rajani, B., and Kleiner, Y., 2001. Comprehensive review of structural deterioration of water mains: Physically based models. *Urban Water,* 3(3), 151–164.

Xi, D., Lu, H., Zou, X., Fu, Y., Ni, H., and Li, B., 2024. Development of trenchless rehabilitation for underground pipelines from an academic perspective. *Tunnelling and Underground Space Technology,* 144, 105515.

Zamanian, S., and Shafieezadeh, A., 2023. Age-dependent failure probabilities of corroding concrete sewer pipes under traffic loads. *Structures,* 52, 524–535.