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Weighted Prioritization Index for Culvert Sequencing: A Track Settlement Analysis in KVDT Phase 2 (Seremban Line)

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Abstract

The jacking method was mostly used in areas where the interval level depth is higher, and its purpose is to reduce disruptions on the surface environment. However, delays of the post jacking construction and end structure backfill specifically headwall and wingwall, leaves the jacked culverts in an unsupported state, resulting in culvert movement and track settlement due to active railway traffic above. Therefore, statistical analysis (Jamovi) was conducted based on secondary data recorded, to establish a sequencing prioritization framework for six sections of jacked culverts which there were two sections from Bangi to Batang benar and four sections from Labu to Seremban along KVDT Phase 2 Seremban line. These six sections were selected because the jacking process had been completed exclusively in this area at the time this research study was conducted. As the KVDT 2 project is currently ongoing, additional culverts may be jacked along the Seremban line in the future. Consequently, this research utilizes secondary data limited to the six sections where the jacking process was completed within the timeframe of this study. Furthermore, to maintain the stability of the structure and environment surrounding, accelerating the building of headwalls and wingwalls can prevent from culvert movement, track settlement and reduce maintenance interventions by securely trapping and permanently locking the jacked culvert and unstable soil condition in place.

1. Introduction

Railway infrastructure was important for safety and efficient train operations. One crucial component of infrastructure was the culvert, a structure that allowed water to flow beneath the tracks to prevent water accumulation. Culverts were installed using two methods, an open-cut excavation or the trenchless jacking method. Open cut was the most common method used to install culvert, while jacking method mostly used in areas where the interval level depth was higher and its purpose was to reduce disruptions to the surface environment or existing infrastructure. The jacking method introduced different risks to the subgrade integrity compared to open-cut installation. Track settlement could occur if the installation was executed improperly or completion work specifically end structure was managed inadequately, resulting in track deformation and even culvert movement that might affect train safety and ride quality. Track settlement was one of the primary issues

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in the railway industry, as it leads to uneven track geometry which posed safety risks, increased maintenance needs, and caused ride discomfort.

To address these core infrastructure challenges, this study was significant because it addressed a critical challenge in railway infrastructure construction which focused on differential track settlement caused by culvert installation using the jacking method. Such settlement directly affected track stability and more critically, the safety of train operations. Unmitigated settlement at culvert locations also reduced passenger ride comfort, increased maintenance costs, and could lead to operational delays. By analyzing historical maintenance and track geometry data from actual field data of culvert installation sites, the research provided a significant understanding of settlement patterns at these locations, enabling more predictive maintenance planning and mitigate track geometry problems. Moreover, the development of a statistical model incorporating factors like soil type, jacking parameters, and settlement marker offered insights into how post-jacking construction quality control influenced track performances. The correlations identified promoted better field practices to reduce the need for frequent maintenance interventions in the future.

However, looking closer at actual field execution, in the implementation of the KVDT 2 project, installing culverts via the jacking method frequently resulted in delays regarding the completion of end structures such as headwalls and wingwalls. This sequence left the jacked culverts in an unsupported state, making them susceptible to longitudinal movement or track settlement and vibration induced displacement caused by active railway traffic. Currently, construction sequencing lacked a technical basis for prioritization, often overlooking critical parameters such as soil type, jacking force, and culvert dimensions. This absence of a data-driven approach could lead to excessive track settlement in high-risk section, compromising the structural integrity of the tracks and the safety of railway operations. Therefore, this study aimed to analyze settlement behavior and establish prioritization ranking system to ensure high-risk sections were stabilized immediately following the jacking process.

To systematically bridge this gap, this research addressed three core research question: first, what was the correlation between track settlement magnitude and the specific parameters of soil type, jacking force, and culvert dimensions across six constructions section; second, what are the impact and patterns of excessive settlement and ground movement during the post-jacking phase; and third, how could a prioritization framework for end structures be established based on settlement severity and parametric influence? By addressing these inquiries, the study directly fulfilled its research objectives, which were to identify and analyse correlation between track settlement magnitude and parameters influencing settlement, specifically soil type, jacking force, and culvert dimensions across six construction sections, to evaluate the impact and patterns of excessive settlement and ground movement during the post-jacking phase, and finally to establish a prioritization framework for the construction of end structures (headwalls and wingwall) based on settlement severity and parametric influence.

2. Literature Review

The Jacking method is categorized as one trenchless technique. Pipe jacking and box jacking have emerged as a preferred approach for culvert installation beneath active railway lines. This method involved and relied on the thrust power to push prefabricated culvert by unit through the ground using the hydraulic jack equipment [2]. as shown in figure 1 the schematic concept of pipe culvert installation using jacking method. For certain complex project, this method includes establishing grouting curtain walls to reinforce the surrounding soil and seal up a closed box, followed by filling the sealed area with grout materials to enhance the integrity of the reinforcement [3]. Numerous engineering practices highlight its suitability for high-speed rail system, soft ground conditions, and large span under track crossing [3][4] During the jacking phase, the pipe was maintained in a state of continuous compression by the hydraulic system. However, once the jacking rig was decommissioned, the culvert often transitioned into vulnerable or unrestrained post-jacking state.

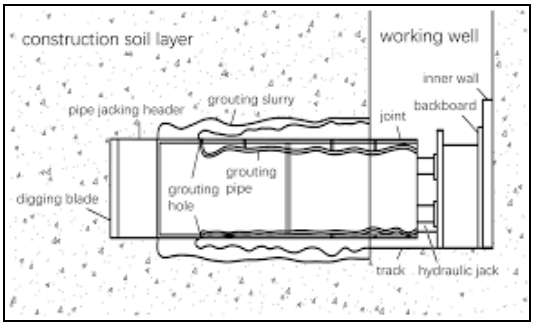


Fig. 1 *The schematic concept of pipe culvert installation using jacking method*

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A key advantage of this method is its ability to maintain continuous railway operations, as surface excavation is limited to the jacking shafts and receiving shafts as shown in figure 2. This significantly reduces service disruptions and improves the overall environment and risk safety. Furthermore, research study emphasizes the importance of controlling surface stability, managing over cutting and preventing ground loss to minimize surface settlement [3]. In the jacking process, overcut is a critical technical consideration in the jacking process, which is required during the bore excavation to facilitate culvert steering and reduce friction [2]. Research has demonstrated that in projects involving sandy soils, the factors exerting the greatest influence on both the magnitude and the risk of surface settlement are soil cohesion, the depth of the box culvert below the ground surface, and the extent of the overcut. These parameters play a decisive role in shaping settlement behavior and must be carefully considered during design and excavation [2].



Fig. 2 *Jacking shaft and receiving shaft of pipe culvert installation by DMIA project (taken on November 2025)*

Despite its benefits, jacking introduces distinct engineering challenges. High jacking loads may induce structural stress on the culvert and influence its alignment. Soil heterogeneity can cause deviation or differential ground movement, making real-time monitoring essential. Studies involving large culvert installations also stress the role of soil reinforcement (e.g., sleeve-valve grouting, jet grouting) in enhancing stability and reducing settlement during jacking operations [4]. While this method demands greater technical expertise and higher initial cost, its ability to minimize track interruption and control ground deformation makes jacking the preferred solution for complex or high-traffic railway projects.

2.1 Post Jacking Stability and End Structure

During the jacking phase, the pipe is maintained in a state of continuous compression by the hydraulic system. However, once the jacking rig is decommissioned, the culvert often transitions into vulnerable or unrestrained post-jacking state. If the pipe is not immediately secured at the ends, it becomes it becomes highly vulnerable to axial movement (longitudinal creep). This occurs as the stored energy withing the pipes is released after the jacking force is removed. This instability is significantly worsened by the repeated vibration or repeated loading from passing trains, which decrease the friction between the outer surface of the pipe and the surrounding soil. This process effectively weakens the soil's grip on the culvert, making it easier for the structure to have movement and shift out of its intended position [5].

2.2 Role of Headwalls and Wingwalls as Structural "Lock"

Figure 3 shows the end structure consisting of headwall and wingwall as its primary structures. The end structures construct after the jacking phase is done. These are critical in culvert jacking and railway underpass construction to ensure structural integrity, maintain railway traffic continuity, and manage ground stability, especially when operating underneath active railway.



Fig. 3 *End structure (taken on October 2025)*

Despite its primary design for hydraulic flow and erosion control, the end structure specifically headwall and wingwall acted as a primary structural "lock" to ensure structural integrity. These structures provided the necessary lateral and longitudinal resistance to prevent the culvert from shifting or moving under the dynamic loads of the railway track. Recent geotechnical research indicates that the timely installation of these end-structures efficiently "pins" the culvert strings, maintaining the stability of the soil structure interaction and avoiding the formation of voids that can lead to surface settlement [6].

2.3 Track Settlement at Culvert Interfaces

Ballast characteristics, specifically its type and lifespan are particularly critical, influencing both the initial likelihood of defect occur and the subsequent of deterioration. This condition is further intensified by a combination of material, operational, and environmental factors [7]. Other structural elements such as soil, subgrade, and rail pads contribute significantly. With research indicate that soil and subgrade properties along with performance characteristic of rail pads have influence on overall infrastructure performance. Variation in asset characteristics and operating conditions further prevents the effectiveness of maintenance activities for structural components such as culvert and level crossing [8]. From environmental perspective, global warming has been recognized as a major factor that contributes to significant damage in railway infrastructure. The combine impact of extreme climatic conditions and train loading can triggers subgrade issues, leading to settlement, ballast fouling, and mud pumping [9]). From operational insight, the quality of maintenance work especially tamping is heavily influenced by the track's initial condition, indicate that pre maintenance quality is major factor in subsequent performance [10].

2.4 Monitoring and Measuring Track Settlement

The most common signs of track geometry degradation are settlement caused by train repeated loading or the accumulation of permanent deformation. The settlement that occurred will reduce the performance of track functionality and serviceability [1];[11] Comprehensive monitoring of track settlement involves a spectrum of tools, ranging from traditional manual gauges such as mechanical gauges and levelling devices to sophisticated satellite-based systems, all aimed at precisely quantifying track geometry degradation. For culvert installations, tracking settlements on track is required to measure how many settlements happen during culvert installations. Usually, surveyors used total stations as surveying tools to monitor settlement markers as depicted in figure 4.



Fig. 4 *Total stations set for surveying work [12]*

Total stations are high precision, ground-based surveying instruments commonly employed to establish control points and supply external reference data for the validation of advanced measurements technologies [13]. These instruments deliver millimetre-level accuracy and are typically operated in static or slow-moving setups to generate highly reliable, absolute coordinate values (X,Y,Z) for designated track locations [13]. In addition, this equipment use for track settlement marker works. A track settlement marker is a fixed reference point installed near or on the railway track structure. Its role is to monitor vertical and horizontal movement of the track over time, especially after construction, maintenance, or under heavy traffic loads. Settlement markers act as fixed checkpoints on the track, and the Total Station measures their exact position over time to detect any ground movement or track deformation.

3. Methodology

This chapter outlines the methodology adopted to investigate the differential railway track settlement caused by culvert installation using the jacking method. This study adopted a case study approach focused on an actual railway culvert installation project using jacking method, which enabled researchers to examine the settlement behavior under real site conditions. Furthermore, the research study was based primarily on secondary data obtained from Klang Valley Double Track (KVDT) Phase 2 project of DMIA, Seremban line section. The use of secondary data allowed this research to reliable field measurements where the data reflected actual construction practices and constraints. To achieve the objectives listed, the study employed quantitative modelling techniques, where statistical analysis and mathematical modelling are used to evaluate relationship between characteristics of construction activities using jacking method for culvert installation and differential track settlement behaviours. This quantitative approach strengthened the reliability of the findings, settlement trends and correlations were analysed to support data driven conclusions and recommendations.

3.1 Case Study Description

The secondary data obtained from Klang Valley Double Track (KVDT) Phase 2 project of DMIA, Seremban line section as depicted in Table 1. These table outlines culvert types, various culvert sizes, and various existing ground soil conditions across six sections (A–F) of the project alignment. The (A-F) sections represent the culvert installation using jacking method in different chainage, along Seremban line. Section A and B were located between Bangi to Batang Benar, meanwhile section C, D, E, F were located between Labu to Seremban. Despite having the same and consistent construction method, the various types of soil and size of the culvert significantly influence the track settlement where the track settlement had been recorded at the selection sections. This sectional division allows for a comparative assessment of variations in jacking method constructions.

Table 1 *Details of the selected sections*

Location	Seremban Line (KVDT phase 2)					
Track type	Ballasted					
Installation method	Jacking Method					
Section	A	B	C	D	E	F
Culvert type	Pipe	Box	Box	Box	Box	Box
Culvert size	1800mm	3600mm X 2400mm	2400mm X 1800mm	2400mm X 1800mm	3000mm X 1500mm	2400mm X 1200mm
Existing ground soil	Stiff sandy silt	Silty sandy clay	Silty sandy clay	Silty sandy clay	Silty sandy clay	Silty sandy clay

3.2 Data Collection Method

3.2.1 Baseline Elevation and Post-Jacking Elevation

The baseline elevation ($Z_{baseline}$) referred to the original vertical coordinate of the monitoring markers record before jacking process started. Six jacking sections (Sections A-Section F) with 15 distinct markers were placed at the railway track. The steady, undisturbed condition of the KVDT 2 railway track is represented by this dataset, which acts as the "control" or reference level. These values, which are determined by qualified site surveyors, served as the standard by which all future ground movements are evaluated. The post-jacking elevation ($Z_{recorded}$) represented the vertical coordinates of the same 90 markers taken just after the jacking process (culvert has been jacked) completed. These measurements show the track's new location following exposure to the soil displacement and mechanical loads that came with the jacking procedure. In order to offer

the strong sample size (n=15) needed for inferential statistical analysis in Jamovi, 15 points from settlement marker were deliberately set for each section. This high-density data was essential for finding "hanging" or unstable track portions through settlement records that needed to be stabilised immediately by giving wingwall and headwall construction priority.

3.2.2 Jacking Records

Construction data related to the culvert jacking operation were obtained from the KVDT phase 2 project. The data were sourced from project construction records and site monitoring documents prepared during the execution of the culvert jacking works beneath the railway track. As the study relies on secondary data, the availability and scope of parameters are limited to those systematically recorded during construction. The collected from secondary dataset shows specifically jacking force and culvert installation length, which were key operational parameters influencing ground response during jacking activities. Despite this limitation, these are considered critical indicators of construction stress and soil structure interaction during trenchless installation works. As was shown in table 2 the details data of jacking force and culvert installation length were recorded by section.

Table 2 *Data of jacking force and culvert installation length by section*

Section	A	B	C	D	E	F
Jacking force	14,439 kN	57,149 kN	20,213 kN	20,213 kN	37,665 kN	17,597 kN
Culvert installation length	30m	41m	22m	18m	26m	23m

3.3 Construction Prioritization Model

3.3.1 Weighted Priority Index (WPI)

For the end structures prioritization, weighted priority index (WPI) used as decision support tools to constructed the construction completion order of (headwall and wingwall).

$$WPI = (w_1.S_{max}) + (w_2.\bar{S}) + (w_3.\sigma) \quad (1)$$

The formula uses the structure of a standard linear combination weighted index WPI $WPI = \sum(w_i.S_i)$. This was structurally engineering standard for analytic hierarchy process [14]. The weightage factors were explicitly defined as $w_1 = 0.5,\ w_2 = 0.3, w_3 = 0.2$ (where $\sum$=1.0). This specific weight factor distribution was justified based on rational engineering hierarchy derived from multi criteria risk management framework applied in contemporary railway infrastructure tracking [15]. The weightage factor for this research, the highest weight was assigned to maximum settlement, as it represents the worst-case scenario and ultimate foundational failure. The second highest weight was allocated to mean settlement to evaluate average structural failure. Finally, the least factor weight was assigned to differential settlement to assess the serviceability limit of the structure, serving as a risk-balancing factor.

3.3.2 Regression Modelling

To determine the relationship between track settlement behaviour and the jacking construction method, the track geometry data were analyzed alongside the construction recorded data. In this study, the settlement parameter was classified as the dependant variable and others construction parameter were classified as independent variables. This regression model was used to identify the significance and connection influence of each jacking construction variable on settlement rate. It also helped to identify the primary contributors to differential settlement and provided insights into how jacking-induced ground disturbance affected track stability. The results also supported engineering recommendations for mitigating settlements during future culvert installations.

3.3.3 Correlation Analysis

In this study, correlation analysis was conducted to determine relationship strength and direction between two pairs of variables parameters. This analysis supported the identification of potential relationship between two variables, whether variables move together (when one variable increased, the other also increased) or in opposite directions (when one variable increased, the other decreased).

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4. Results and Discussion

4.1 Descriptive Analysis

A comprehensive descriptive statistical analysis was performed on the vertical settlement data (ΔZ) collected from the monitoring markers distributed across six distinct construction sections (A to F). The descriptive statistics established the baseline variations in track stability following the unrestrained jacking procedure. Furthermore, the accuracy of the analysis depends and reliable on the data recorded by DMIA team. As a result, the collected data may contain inconsistencies or errors, which could affect the accuracy of the statistical analysis. These data quality issues mean that results must be interpreted with caution, and slight inconsistency in measurement could influence the statistical modelled outcomes. In addition, missing markers on some points due to site damage (specifically soil erosion, being run over by machinery or loss of access) prevent a full 15-point profile for every single section. This reduction in data point decreased the total sample size (n) across specific section. Consequently, the statistical power regression tests were lowered, and slightly increased the risk of errors.

Table 3 *Summary of Descriptive Statistics for Settlement by Section*

Section	Soil Type	N	Mean Settlement	Max Settlement	Standard Deviation
A	Stiff sandy silt	15	20.8 mm	66 mm	24.4 mm
B	Silty sandy clay	7	126.0 mm	490 mm	175.0 mm
C	Silty sandy clay	13	115.0 mm	216 mm	79.0 mm
D	Silty sandy clay	15	39.0 mm	149 mm	47.2 mm
E	Silty sandy clay	15	47.7 mm	148 mm	51.7 mm
F	Silty sandy clay	9	107.0 mm	280 mm	123.0 mm

Based on table 3 summary of descriptive statistics for settlement by section, it can be concluded that the most stable zones were section A. Section A, constructed in Stiff Sandy Silt, exhibited the most stable ground conditions with the record of lowest mean settlement, 20.8 mm and maximum individual settlement of only 66mm. Meanwhile, section B displayed the most severe instability or high-risk zones, with the highest mean settlement of 126 mm and an extremely maximum settlement of 490 mm which indicated highly localized track failure. Following were sections C and F, which also demonstrated highly erratic post-jacking behaviors with maximum settlement reaching 216 mm and 280 mm respectively.

4.2 Statistical Analysis

To validate the significance of the observed settlement patterns and identify the driving parameters, inferential statistical tests were conducted using Jamovi.

4.2.1 Impact of Soil Properties

The dataset was categorized into two primary soil conditions which are Silty Sandy Clay and Stiff Sandy Silt. An independent samples T-Test as shown in figure 5 was executed to evaluate the variance between these groups.

Independent Samples T-Test

Independent Samples T-Test

		Statistic	df	p
SETTLEMENT ΔZ (mm)	**Student's t**	2.32[a]	72.0	0.023

Note. H_a $\mu_{\text{Silty Sandy Clay}} \neq \mu_{\text{Stiff Sandy Silt}}$

Fig. 5 *Independent Sample T-test (soil type)*

Results: The T-Test revealed a statistically significant difference in vertical settlement between the two soil types, yielding a p-value 0.023
Analysis: Culverts installed in Silty Sandy Clay experienced significantly higher mean settlements (ranging from 72.6 mm to 82.1 mm on average) compared to those installed in Stiff Sandy Silt (mean of 20.8 mm). This statistically validates and indicates that the clay layer soil are the primary drivers of subgrade disturbance resulting in track settlement. In practical engineering terms, conventional ground treatments cannot be done from the surface due to the high excavation depth. Because of that, the jacking operation itself must be conducted as the primary way to maintain ground stability. The silty sandy clay layer shows a high risk of deep soil deformation and settlement, therefore, strict control over the jacking machine's face pressure must be balanced to prevent this excessive movement.

4.2.2 Impact of Culvert Size

To determine if the physical dimensions of the culvert significantly influenced ground displacement, a comparison was drawn between size L and M culverts.

Independent Samples T-Test

Independent Samples T-Test

		Statistic	df	p
SETTLEMENT ΔZ (mm)	**Student's t**	0.360	72.0	0.720

Note. H_a $\mu_L \neq \mu_M$

Fig. 6 *Independent Sample T-test (culvert size)*

Results: The independent samples T-test resulted in a student's *t* statistic of 0.360 and a p-value of 0.720.
Analysis: The p-value was well above the 0.05 threshold, because of that the null hypothesis was retained. In practical engineering for this data analysis, this result indicated that the physical culvert size has no significant impact on ground displacement. Consequently, the selection between the size L and M culverts could be driven by other project metrics (e.g. hydraulic flow capacity, material availability, construction costs) without concern for altering the ground settlement profile.

4.2.3 Impact of Jacking Force

A correlation analysis and linear regression were performed to test the relationship between the applied jacking force and vertical track settlement.

Correlation Matrix

		JACKING FORCE	SETTLEMENT ΔZ (mm)
JACKING FORCE	**Pearson's r**	—	
	df	—	
	p-value	—	
SETTLEMENT ΔZ (mm)	**Pearson's r**	0.158	—
	df	72	—
	p-value	0.180	—

Linear Regression

Model Fit Measures

Model	R	R^2
1	0.337	0.113

Note. Models estimated using sample size of N=74

Fig. 7 *Correlation analysis and linear regression (jacking method)*

Results: The Pearson correlation matrix indicated a weak positive correlation of 0.158, which was not statistically significant (p=0.180).

Analysis: The linear regression model ($R^2 = 0.113$) successfully estimated all coefficient but revealed that individual predictors did not reach strict statistical significance. This occurred due to high multicollinearity within the dataset. Because specific jacking forces were inherently tied to specific location sections and soil types, the model lacked the distinct, isolated variability needed to quantify the true, standalone impact of the jacking force. In practical engineering terms, the jacking machinery adjusted strictly based on the local ground conditions encountered due to operational site safety practices. However, it created a data trap where the machine's force and the soil type were locked together. To resolve this issue and improve future outcome, data analyst must apply a wider range of jacking forces within the same soil profile and geographic section. This would allow engineers to isolate the variables, making it possibles to mathematically predict exactly how much jacking force can be safely used before causing ground movement and track settlement.

4.3 Development of Weighted Priority Index (WPI)

A Weighted Priority Index (WPI) was used to create a data-driven sequencing framework for building headwalls and wingwalls in order to systematically address the crucial problem of unconstrained post-jacking culverts. The proposed mathematical method (1) is used for the WPI to calculate the overall risk score for each section. The sections were assessed using conventional weightage parameters that highlighted maximum localized failure (w_1 = 0.5), mean sectional settlement (w_2 = 0.3), and settlement standard deviation (w3 = 0.2):

Table 4 *WPI Calculation and Risk Ranking by Section*

Section	Max Settlement	Mean Settlement	Standard Deviation	WPI Score	Priority Rank
B	490 mm	126 mm	175 mm	317.80	1 (highest risk)
F	280 mm	107 mm	123 mm	196.70	2
C	216 mm	115 mm	79 mm	158.30	3
E	148 mm	47.7 mm	51.7 mm	98.65	4
D	149 mm	39 mm	47.2 mm	95.64	5
A	66 mm	20.8 mm	24.4 mm	44.12	6 (lowest risk)

According to the empirical WPI risk assessment as shown in table 4, the construction completion order for end structures (headwall and wingwall) should be prioritized as follows: Section B is followed by Section F, Section C, Section E, Section D, and finally Section A. This guarantees that the most vulnerable sections, notably those located in Silty Sandy Clay with severe differential settlement, are stabilized immediately to prevent further geometric destruction of the tracks. Furthermore, it is critical to expedite the construction of the headwall and wingwall structures immediately after completing the jacking process. In practical engineering terms, because the high depth of the culvert jacking method makes conventional surface ground treatments impossible, the immediate installation of these end structures is the only way to keep the ground stable over time. While on-site, the machine faces pressure and slurry function is to protect the pushed culvert, however these steps only offer temporary support. It cannot stop the soil from moving long after the jacking machine leaves the site. By rushing the construction of the headwall and wingwall in these high-risk clay zones, engineers can tightly trap and lock the soil in place. This permanent structural lock stops the soft, unstable clay from shifting and sinking further. This critical safety need is exactly why these specific sections are placed at the very top of the priority list.

5. Conclusions

This study successfully investigated railway track settlement induced by culvert installation using jacking method across six section area. By linking geotechnical variables, structural monitoring data (secondary data), and statistical modelling analysis, this research achieved its goal of defining settlement characteristics and mapping its direct operational and maintenance implications. In conclusion, this study successfully achieved all its core objectives by having utilized secondary data to identify and analyze the significant correlation between track settlement magnitude and key parameters specifically soil type, jacking force, and culvert dimensions across the six construction sections. Furthermore, the evaluation of this historical data effectively revealed the critical patterns and long-term impacts of excessive settlement and ground movement during the post-jacking phase, which ultimately enabled the establishment of a systematic prioritization framework for constructing end structures (headwalls and wingwalls). To build upon these findings and overcome the inherent limitations of relying on existing records, it was recommended that future research expand the scope of investigation by incorporating a wider variety of influential parameters. Additionally, it was noted that future data collection

frameworks required a standardized number (N-value) of settlement markers across all section areas to maintain structural consistency, eliminate analysis bias, and significantly improve statistical reliability.

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