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The Analysis on Ground Treatment Methods Used in East Coast Rail Link (ECRL) Project, Section 6 Maran

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Abstract

The The East Coast Rail Link (ECRL) project is a major 665-kilometer railway development in Malaysia, designed to enhance regional connectivity and economic growth by linking the East Coast states of Kelantan, Terengganu, and Pahang with the Klang Valley on the West Coast. Managed by Malaysia Rail Link Sdn Bhd (MRL) in collaboration with China Communications Construction Company (CCCC), the project faces significant geotechnical challenges due to diverse soil conditions, particularly in Section 6, Maran. Effective ground treatment methods are crucial to ensuring the railway's stability and longevity. This study focuses on addressing the challenges posed by soil compositions in Maran, primarily silty clay, fine sand, and a granite bottom layer.The research objectives were threefold: to identify parameters for the usability of soil and settlement behavior to ensure stability and safety of construction activities, to analyze these parameters using suitable settlement monitoring methods, and to propose the best ground treatment methods for the varied soil structures in the ECRL Section 6, Maran project. The findings indicated that methods like preloading with vertical drains and deep soil mixing were particularly effective in stabilizing the soil layers, minimizing settlement, and ensuring residual settlements remained within acceptable limits.The significance of this research lies in its potential to inform the design and construction of durable and sustainable railway tracks. By providing a comprehensive comparative analysis of ground treatment methods, this study contributes to the development of effective engineering solutions for the ECRL project and offers insights for future geotechnical practices in railway infrastructure.

1. Introduction

ECRL The East Coast Rail Link (ECRL) is a significant railway project in Malaysia, spanning 665 km and connecting the East Coast states of Kelantan, Terengganu, and Pahang with the Klang Valley. The project, owned by Malaysia Rail Link Sdn Bhd (MRL), involves the planning, development, and implementation of the railway, with a key focus on enhancing regional connectivity and economic development. MRL, in collaboration with China Communications Construction Company (CCCC), oversees this complex project, ensuring regulatory compliance and effective coordination. The project traverses urban and suburban areas with varying soil compositions, primarily silty clay, fine sand, and granite. Understanding these soil types is crucial for ensuring the railway's stability and addressing potential geotechnical issues such as differential settlement and slope stability, which are vital for maintaining the track's alignment and preventing soil erosion and landslides. The research aims to provide geotechnical insights that will guide the design and construction of a resilient railway track, contributing to the development of engineering solutions for long-term stability and safety in diverse soil conditions. The research aims to analyze the behavior of soil, rocks, and other materials in ECRL Section 6, Maran, to ensure the stability and safety of the construction activities. It seeks to compile a comprehensive comparative analysis of the ground treatment methods used concerning ground settlement in this section. Additionally, the research aims to propose the most suitable ground treatment method that aligns with the various soil structures encountered in ECRL Section 6, Maran. The study focuses on ground-based treatment case studies specific to the ECRL Project Section 6 in Maran. It includes examining the types of soil predominantly present at the site and evaluating the methods used, such as prefabricated vertical drains and deep soil mixing. The research aims to identify the most suitable ground treatment method to address soil issues effectively.

2. Literature review: Deep Soil Mixing (DSM)

Deep Soil Mixing (DSM) is utilized for ground treatment using the wet mixing technique, combining cement, water, and additives to create a binder slurry. DSM columns vary in diameter from 0.5 to 1.2 meters and are designed to achieve an unconfined compressive strength (UCS) of 1.0 MPa at 28 days. Before starting the DSM work, laboratory trial mixes are conducted to determine the appropriate cement content. The trial mix report, including UCS and modulus of elasticity, must be approved by the site consultant (SC) and provide details on stabilizing materials, mixing methods, and test results. Original clay from the site is used in these tests, and samples are cured and tested at 7, 14, and 28 days according to ASTM D2166 standards. The DSM rig must be powerful enough to reach the specified depths and ensure uniform soil-cement mixing. The rig is positioned accurately, and the insertion and rotation of the mixing tool are carefully controlled. Key parameters such as rotational speed, penetration and withdrawal speed, grout pressure, flow rate, number of cycles, and blade rotation number are closely monitored. Grout injection starts when the mixing tool reaches the design cut-off level and continues until it reaches the required depth. The tool is then withdrawn at a controlled speed to ensure proper mixing. Post-construction quality checks involve coring selected DSM columns to verify the integrity of the installation.

2.1 Literature review: Prefabricated Vertical Drain (PVD)

Ground treatment for the East Coast Rail Link (ECRL) project in Section 6, Maran, utilizes Deep Soil Mixing (DSM) and Prefabricated Vertical Drains (PVD) to address settlements in soft or compressible soils. DSM involves wet mixing of cement, water, and additives to form a binder slurry, creating columns with diameters ranging from 0.5 to 1.2 meters. These columns aim to achieve an unconfined compressive strength (UCS) of 1.0 MPa at 28 days. Laboratory trials are conducted to determine the appropriate cement content, with samples cured and tested at 7, 14, and 28 days according to ASTM standards. The DSM rig ensures uniform soil-cement mixing and controlled grout injection, closely monitoring parameters like rotational speed, penetration, withdrawal speeds, and grout pressure to ensure proper mixing and integrity of the columns. PVDs, also known as wick drains, accelerate consolidation by providing vertical pathways for excess pore water to escape, making them ideal for areas with high water content and low permeability. Materials for PVD installation are sourced from approved manufacturers, inspected for quality, and stored appropriately. The installation involves marking out positions in a triangle grid pattern. Figure 1 plan view of PVD installed, using a hydraulic leader attachment on an excavator base rig for minimal soil disturbance. After PVD installation, embankment fill and surcharge material are placed, monitored, and validated by engineers. This systematic approach reduces settlement times and ensures stability, providing a reliable and efficient solution for managing challenging soil conditions in the ECRL project.

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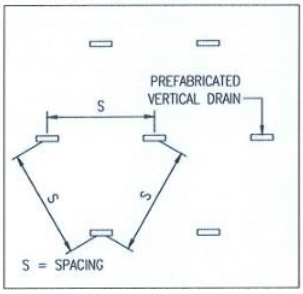

Fig. 1 plan view of PVD installed

2.2 Methodology

Effective construction on geotechnically challenging sites requires meticulous evaluation of ground treatment methods to ensure stability and performance. Two key techniques, prefabricated vertical drain (PVD) and deep soil mixing (DSM), are essential for transforming problematic soil conditions into stable foundations. Both methods reinforce settlement and involve soil testing with the plate load test. Understanding the complex interplay of geological, hydrological, and structural factors is crucial for tailoring effective and sustainable solutions. This study explores these methodologies through literature reviews, site-specific investigations, and engineering analyses, providing a comprehensive guide for the judicious application of PVD and DSM methods. By employing a systematic and holistic approach, the study aims to equip practitioners with the knowledge to address unique soil challenges, monitor settlements, and advance geotechnical engineering practices. For the MRL Section 6 project, PVD and DSM are preferred due to their efficacy and compatibility with the peat and swampy soil conditions.

2.3 Plate load test

The Plate Load Test (PLT) is a field test used to determine the bearing capacity and settlement characteristics of soil, which can be particularly useful for assessing the effectiveness of soil improvement techniques such as Deep Soil Mixing (DSM) and Prefabricated Vertical Drains (PVD). Plate load test in the context of DSM, the Plate Load Test helps to verify the improvements in bearing capacity and stiffness of the treated soil. The procedure begins with conducting the DSM process, where the soil is mixed with stabilizing agents such as cement or lime. After allowing sufficient curing time for the mixed soil to gain strength, the PLT is performed on the treated area.
A test pit is excavated to the desired depth, typically at the level of the improved soil layer, and a rigid steel plate is placed on the soil surface. Incremental loads are applied to the plate using a hydraulic jack, and the settlement of the plate is measured at each load increment using precision instruments like dial gauges. The load-settlement curve is then plotted, and the ultimate bearing capacity and modulus of subgrade reaction are determined in figure 2 show the placement of the plate load.

Fig. 2 placement of plate load

This test provides a direct measurement of the improved soil properties, allowing for validation of design assumptions and confirmation of the DSM treatment's effectiveness. It's essential to ensure proper curing time before testing and to conduct multiple tests across different locations to account for variability in soil conditions and mixing effectiveness. Based on figure 3 display flowchart for plate load test work sequence.

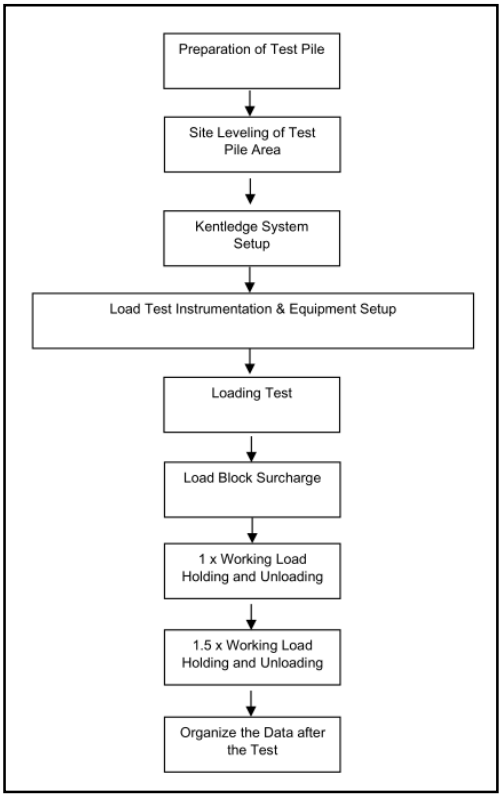

Fig. 3 flowchart for plate load test work sequence.

Plate load test For PVDs, the Plate Load Test is used to monitor the settlement behavior of soil and evaluate the accelerated consolidation process. After installing PVDs according to design specifications, a preload (such as a sand or soil embankment) is applied to accelerate soil consolidation. The PLT is then performed at various stages of consolidation initial, intermediate, and final stages to monitor the settlement behavior. The procedure involves placing a rigid steel plate on the soil surface and applying incremental loads using a hydraulic jack. The settlement under the plate is measured at each load increment, and the data is compared with predicted settlement based on consolidation theory. This application of the PLT allows for real-time monitoring of settlement during the consolidation process, helping to verify design assumptions and the effectiveness of PVD installation. It's crucial to ensure proper PVD installation and preloading and to conduct multiple tests over time to monitor the progress of consolidation. The PLT results should be correlated with other settlement monitoring data, such as settlement plates or piezometers, for a comprehensive understanding. Based on The Plate Load Test is a valuable tool for assessing the effectiveness of soil improvement techniques like Deep Soil Mixing and Prefabricated Vertical Drains. For DSM, it helps verify improvements in bearing capacity and stiffness, while for PVD, it aids in monitoring settlement behavior during the consolidation process. Proper implementation and interpretation of the PLT provides critical insights into the performance of these soil improvement methods, ensuring the success of construction projects on challenging soils.

3. Result

The successful execution of large-scale infrastructure projects, such as the East Coast Rail Link (ECRL) in Maran Section 6, relies heavily on effective ground treatment methods. This study focuses on assessing the structural integrity enhancement achieved through two (2) key approaches: prefabricated vertical drain and deep soil mixing. By delving into the efficacy of these methods, the aim is to contribute valuable insights into optimized soil stabilization by monitoring the settlement. This practices for the longevity and stability of crucial transportation infrastructure.

3.1 The displacement at the plate via LVDTs

The displacements at the plate were monitored by 4 numbers of LVDTs. The corrected displacement of these LVDTs is summarized in Table 1 respectively. Figure 4 plots the corrected displacements of plate and loading sequences over elapsed time. Figure 5 plots the displacement of pile top corresponding to each applied load. In Cycle 1, the maximum load at 100% of WL (i.e. approximate 183kPa), the maximum displacement at plate registers at **12.12mm**, did not exceed the 25mm required by the specification. Upon completion of unloading, the plate

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rebounds and registers a residual settlement of **10.22mm**. In Cycle 2, the maximum load at 150% of WL (i.e. approximate 274kPa), the maximum displacement at plate registers at **14.61mm**, did not exceed the 40mm required by the specification. Upon completion of unloading, the plate rebounds and registers a residual settlement of **12.10mm.**

Table. 1 Summary of the displacement at pile top

Cycle	%of WL	Applied Load (kPa)	Elapsed Time (min)	Settlement(mm)					Reference Beam Settlement (mm)	Corrected Settlement (mm)
				LVDT 1	LVDT 2	LVDT 3	LVDT 4	Average Settlement		
Cycle 1	25	46	15	3.44	5.26	7.35	5.88	5.48	0	5.48
	50	92	30	5.82	8.91	11.11	8.22	8.52	0	8.52
	75	137	45	7.31	11.29	13.55	10.01	10.54	0	10.54
	100	**183**	**105**	**8.54**	**13.14**	**15.41**	**11.39**	**12.12**	**0**	**12.12**
	75	137	120	8.44	13.01	15.28	11.28	12.00	0	12.00
	50	92	135	8.24	12.73	15.00	11.03	11.75	0	11.75
	25	46	150	8.05	12.47	14.75	10.78	11.51	0	11.51
	0	**0**	**210**	**7.13**	**10.94**	**13.19**	**9.62**	**10.22**	**0**	**10.22**
Cycle 2	50	92	225	8.24	12.69	14.99	11.03	11.74	0	11.74
	100	183	240	8.60	13.28	15.54	11.41	12.21	0	12.21
	125	229	255	9.45	14.77	16.93	12.25	13.35	0	13.35
	150	**274**	**435**	**10.50**	**16.30**	**18.30**	**13.35**	**14.61**	**0**	**14.61**
	100	183	450	10.36	16.10	18.12	13.13	14.43	0	14.43
	50	92	465	10.01	15.64	17.63	12.61	13.97	0	13.97
	0	**0**	**525**	**8.61**	**13.39**	**15.44**	**10.94**	**12.10**	**0**	**12.10**

Figure 4 show the corrected displacement over elapsed time for LVDT of plate in cycle 1 and cycle 2. In Cycle 1, the process begins with a series of incremental increases in load, starting at 25% with a corresponding pressure of 46 kPa. At this initial load, the settlement observed is around 5.48 mm. As the load is progressively increased, moving to 50% (92 kPa) and 75% (137 kPa), the settlement continues to increase correspondingly. When the load reaches 100% (183 kPa), the settlement measures approximately 12.12 mm. In Cycle 2, the process once again involves incremental increases in load, but starting at a higher initial percentage compared to Cycle 1. The cycle begins at 50% with a pressure of 92 kPa, then progresses to 100% (183 kPa), 125% (229 kPa), and finally reaches a peak load of 150% (274 kPa). As the load increases, the settlement also increases in a corresponding manner. By the time the load reaches 150%, the settlement reaches about 14.61 mm.

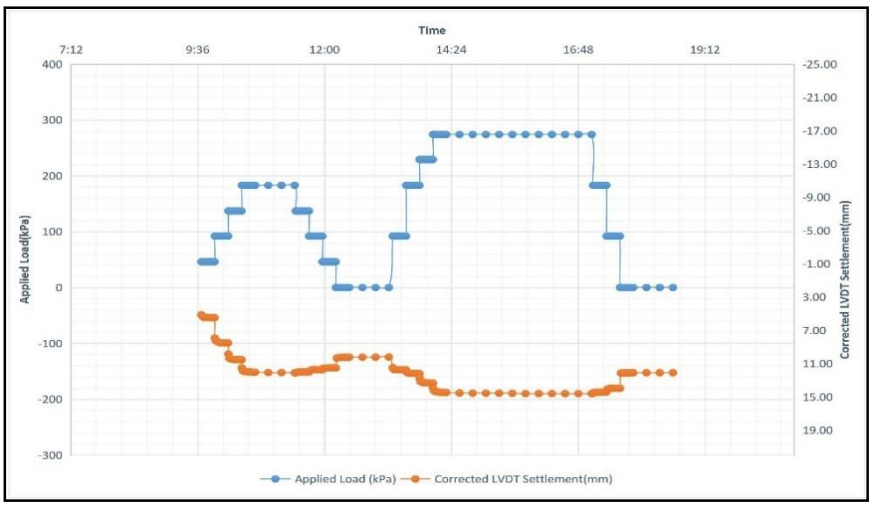

Fig. 4 The corrected displacement over elapsed time for LVDT of plate in cycle 1 and cycle 2

Figure 5 illustrate the load-displacement curve at plate the load-displacement curve provides essential insights into the soil's behaviour under loading and unloading conditions. It highlights the soil's settlement response to different load levels, showing the effects of initial loading and subsequent cycles. Understanding this behaviour is critical for geotechnical engineering applications, ensuring safe and efficient design and construction practices.

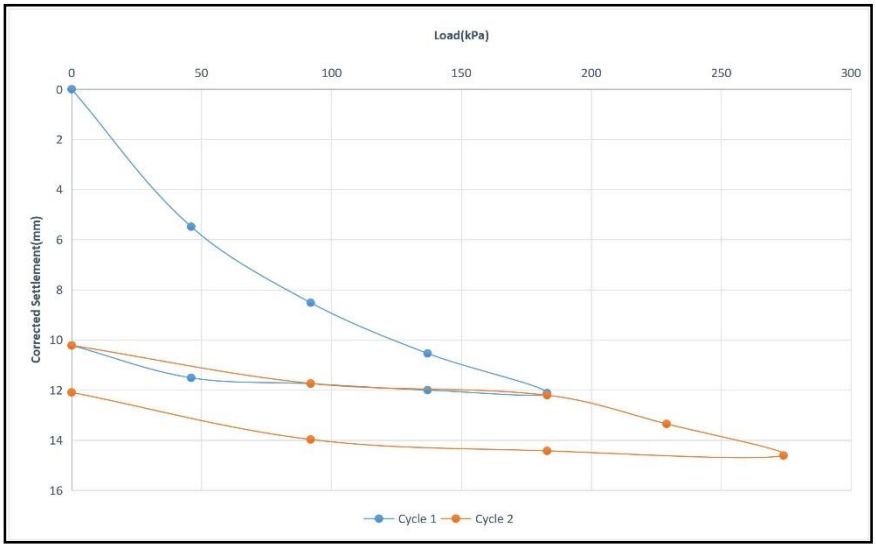

Fig. 5 The load-displacement curve at plate

The instrumented plate loading test was conducted with the measured settlement at test plate. By considering for the necessary correction, the settlements were analysed corresponding to the applied load, and the key findings are summarized in Table 2 based on the settlement data gathered from two load cycles, the findings provide a clear indication of the ground stability under varying applied loads. In Cycle 1, an applied load of 183 kPa resulted in a plate settlement of 12.12 mm and a residual settlement of 10.22 mm. These values are well within the total settlement requirement of 25 mm specified in the technical specifications, suggesting that the ground exhibits stable behaviour under this load. In Cycle 2, the applied load was increased to 274 kPa, leading to a plate settlement of 14.61 mm and a residual settlement of 12.10 mm. These results also conform to the total settlement requirement of 40 mm, further indicating that the ground remains stable even at higher loads. The residual settlements observed after both cycles, 10.22 mm and 12.10 mm respectively, reflect minimal long-term deformation and good recovery of the ground. Overall, the data demonstrate that the site can handle loads up to 1.5 times the working load without significant risk of excessive settlement, ensuring the safety and longevity of structures to be built on this ground. Given these findings, the ground at the tested site meets the required specifications for settlement and stability, providing a reliable foundation for construction activities. Continued monitoring is recommended to ensure ongoing compliance with settlement limits under various load conditions.

Table. 2 Summary of key finding

Cycle	Applied Load (kPa)	Plate Settlement (mm)	Residual Settlement (mm)	Total Settlement Requirements of Technical Specification(mm)
Cycle 1	183(1.0*WL)	12.12	10.22	25
Cycle 2	274(1.5*WL)	14.61	12.10	40

3.2 Result for PVD

Settlement observation is than being monitor by monitor plate. Settlement plates are simple, yet effective tools used to monitor vertical soil settlement. They typically consist of a flat metal plate, which can be square or circular, connected to a rod or pipe that extends above the ground surface. The plate is installed at the ground surface or at a specific depth within the soil to provide a reference point for settlement measurements. There are three (3) points that this monitoring test take such as the left side, centre and right side of the ground site and for the deep settlement and surface settlement gauge. Based on table 3 the deep settlement gauge for monitoring report for the chainage 314+112 centre part where it shows how many days and the total settlement for the PVD method.

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Table 4 Deep settlement gauge for monitoring report for the chainage 314+112 centre part

Deep Settlement Gauge (ρ)Monitoring Report								
测点 里程(Chainage)：		CH 314+112 Centre		初测时间（Initial Time）：		2023/08/17		
总天数 days	时间(date&time)		时间间隔 Time interval（d）	标高 Level（m）	本次沉降量Difference between last time Q（mm）	沉降速率 Rate（mm/d）	累积沉降量 Total settlement（mm）	备注 remark
	年月日（YYYY/MM/DD）	时（time）						
0	2023/08/17	14:00	0	19.7031	0.0	0.0	0.0	
7	2023/08/24	10:00	7	19.7027	0.4	0.1	0.4	
14	2023/07/01	11:00	7	19.7014	1.3	0.2	1.7	
21	2023/07/08	9:00	7	19.7004	1.0	0.1	2.7	
28	2023/07/15	17:00	7	19.7003	0.1	0.0	2.8	
35	2023/07/22	17:00	7	19.7001	0.2	0.0	3.0	
42	2023/07/29	9:00	7	19.7001	0.0	0.0	3.0	
49	2023/08/05	14:00	7	19.7001	0.0	0.0	3.0	
56	2023/08/12	17:00	7	19.7000	0.1	0.0	3.1	
63	2023/08/19	11:00	7	19.7000	0.0	0.0	3.1	
70	2023/08/26	9:00	7	19.7000	0.0	0.0	3.1	
77	2023/09/02	17:00	7	19.7000	0.0	0.0	3.1	
84	2023/09/09	17:00	7	19.7000	0.0	0.0	3.1	
91	2023/09/16	8:30	7	19.7000	0.0	0.0	3.1	
98	2023/09/23	10:00	7	19.7000	0.0	0.0	3.1	
105	2023/09/30	15:20	7	19.7000	0.0	0.0	3.1	
112	2023/10/07	9:40	7	19.7000	0.0	0.0	3.1	
119	2023/10/14	8:00	7	19.7000	0.0	0.0	3.1	
126	2023/10/21	16:00	7	19.7000	0.0	0.0	3.1	
133	2023/10/28	17:00	7	19.7000	0.0	0.0	3.1	
140	2023/11/04	10:20	7	19.7000	0.0	0.0	3.1	
147	2023/11/11	17:00	7	19.7000	0.0	0.0	3.1	
154	2023/11/18	9:00	7	19.7000	0.0	0.0	3.1	
161	2023/11/25	14:00	7	19.7000	0.0	0.0	3.1	
168	2023/12/02	17:00	7	19.7000	0.0	0.0	3.1	

Figure 6 From graph we can analyse that for the deep settlement gauge the settlement reach constant stage is at day 56 until day 168. The total settlement end at 3.1mm. from this graph we can conclude that centre part of the PVD area have the least water content.

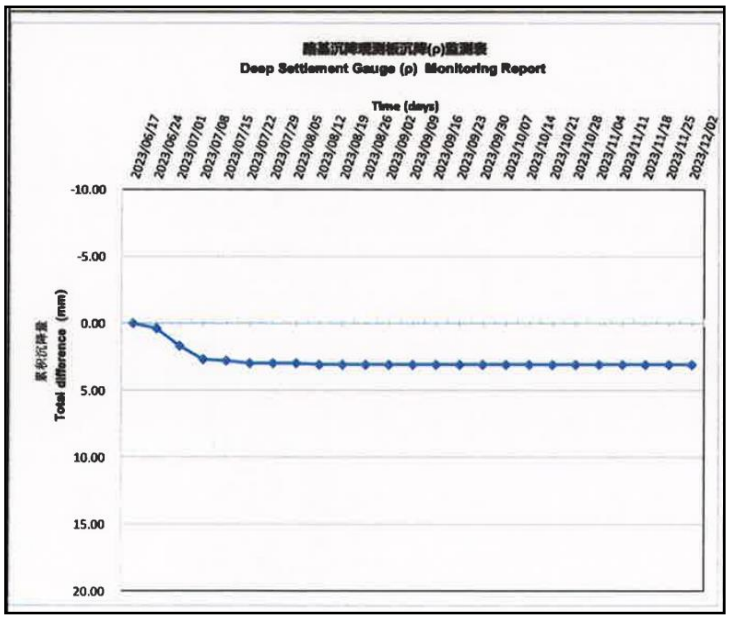

Fig. 6 Graph for deep settlement gauge monitoring report for the chainage 314+112 centre part

Based on table 5 the surface settlement gauge for monitoring report for the chainage 314+112 left part where it shows how many days and the total settlement for the PVD method. Figure 7 show surface settlement gauge monitoring report for the Chainage 314+112 left part. In this figure it shows the left part a massive drop from 5.0mm to 58.2mm and then stay constant 58.6mm it shows that the left part has more water content than the centre part.

Table 5 Surface settlement gauge for monitoring report for the chainage 314+112 left part

Surface settlement marker monitoring report

测点里程(Chainage)：		CH 314+112 Left		初测时间（Initial Time）：			2023/08/17	
总天数 days	时间(date&time)		时间间隔 Time interval（d）	标高 Level（m）	本次沉降量Difference between last time Q（mm）	沉降速率 Rate（mm/d）	累积沉降量 Total settlement（mm）	备注 remark
	年月日（YYYY/MM/DD）	时（time）						
0	2023/08/17	14:00	0	19.8198	0.0	0.0	0.0	
7	2023/08/24	10:00	7	19.8194	0.4	0.1	0.4	
14	2023/07/01	11:00	7	19.8186	0.8	0.1	1.2	
21	2023/07/08	9:00	7	19.8160	2.6	0.4	3.8	
28	2023/07/15	17:00	7	19.8156	0.4	0.1	4.2	
35	2023/07/22	17:00	7	19.8148	0.8	0.1	5.0	
42	2023/07/29	9:00	7	19.8004	14.4	2.1	19.4	
49	2023/08/05	14:00	7	19.7890	11.4	1.6	30.8	
56	2023/08/12	17:00	7	19.7752	13.8	2.0	44.6	
63	2023/08/19	11:00	7	19.7683	6.9	1.0	51.5	
70	2023/08/26	9:00	7	19.7631	5.2	0.7	56.7	
77	2023/09/02	17:00	7	19.7622	0.9	0.1	57.6	
84	2023/09/09	17:00	7	19.7619	0.3	0.0	57.9	
91	2023/09/16	8:30	7	19.7616	0.3	0.0	58.2	
98	2023/09/23	10:00	7	19.7612	0.4	0.1	58.6	
105	2023/09/30	15:20	7	19.7612	0.0	0.0	58.6	
112	2023/10/07	9:40	7	19.7612	0.0	0.0	58.6	
119	2023/10/14	8:00	7	19.7612	0.0	0.0	58.6	
126	2023/10/21	16:00	7	19.7612	0.0	0.0	58.6	
133	2023/10/28	17:00	7	19.7612	0.0	0.0	58.6	
140	2023/11/04	10:20	7	19.7612	0.0	0.0	58.6	
147	2023/11/11	17:00	7	19.7612	0.0	0.0	58.6	
154	2023/11/18	9:00	7	19.7612	0.0	0.0	58.6	
161	2023/11/25	14:00	7	19.7612	0.0	0.0	58.6	
168	2023/12/02	17:00	7	19.7612	0.0	0.0	58.6	

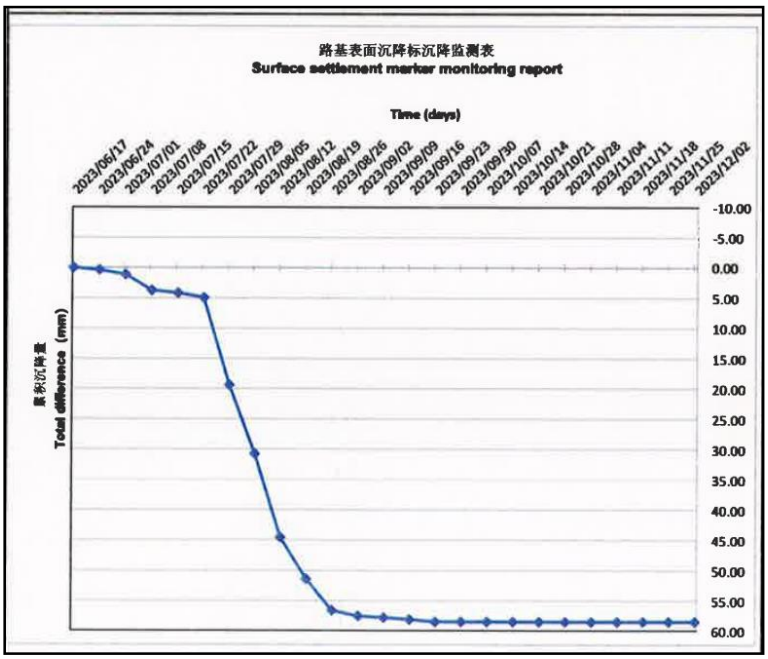

Fig. 7 Surface settlement for gauge monitoring report for the Chainage 314+112 left part.

Table 6 show surface settlement gauge monitoring report for the Chainage 314+112 right part. In this table it shows the right part a significant drop from 0.5mm and end at 8.6mm and then stay constant 8.6mm suggesting that the soil has reached a stable state by the end of the monitoring period.

Table 6 Surface settlement gauge monitoring report for the Chainage 314+112 right part

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Surface settlement marker monitoring report

测点里程(Chainage)：		CH 314+112 Right		初测时间（Initial Time）：		2023/06/17		
总天数 days	时间(date&time)		时间间隔 Time interval（d）	标高 Level（m）	本次沉降量Difference between last time Q（mm）	沉降速率 Rate（mm/d）	累积沉降量 Total settlement（mm）	备注 remark
	年月日（YYYY/MM/DD）	时（time）						
0	2023/06/17	14:00	0	19.7678	0.0	0.0	0.0	
7	2023/06/24	10:00	7	19.7673	0.5	0.1	0.5	
14	2023/07/01	11:00	7	19.7667	0.6	0.1	1.1	
21	2023/07/08	9:00	7	19.7648	1.9	0.3	3.0	
28	2023/07/15	17:00	7	19.7642	0.6	0.1	3.6	
35	2023/07/22	17:00	7	19.7637	0.5	0.1	4.1	
42	2023/07/29	9:00	7	19.7621	1.6	0.2	5.7	
49	2023/08/05	14:00	7	19.7611	1.0	0.1	6.7	
56	2023/08/12	17:00	7	19.7603	0.8	0.1	7.5	
63	2023/08/19	11:00	7	19.7603	0.0	0.0	7.5	
70	2023/08/26	9:00	7	19.7600	0.3	0.0	7.8	
77	2023/09/02	17:00	7	19.7597	0.3	0.0	8.1	
84	2023/09/09	17:00	7	19.7592	0.5	0.1	8.6	
91	2023/09/16	8:30	7	19.7592	0.0	0.0	8.6	
98	2023/09/23	10:00	7	19.7592	0.0	0.0	8.6	
105	2023/09/30	15:20	7	19.7592	0.0	0.0	8.6	
112	2023/10/07	9:40	7	19.7592	0.0	0.0	8.6	
119	2023/10/14	8:00	7	19.7592	0.0	0.0	8.6	
126	2023/10/21	16:00	7	19.7592	0.0	0.0	8.6	
133	2023/10/28	17:00	7	19.7592	0.0	0.0	8.6	
140	2023/11/04	10:20	7	19.7592	0.0	0.0	8.6	
147	2023/11/11	17:00	7	19.7592	0.0	0.0	8.6	
154	2023/11/18	9:00	7	19.7592	0.0	0.0	8.6	
161	2023/11/25	14:00	7	19.7592	0.0	0.0	8.6	
168	2023/12/02	17:00	7	19.7592	0.0	0.0	8.6	

Figure 8 the graph effectively illustrates the settlement behaviour of the ground at Chainage 314+112 Right part over the monitoring period. The initial rapid settlement followed by stabilization suggests that the ground conditions have normalized, which is a positive outcome for construction activities. This type of monitoring is essential for ensuring the safety and stability of engineering projects

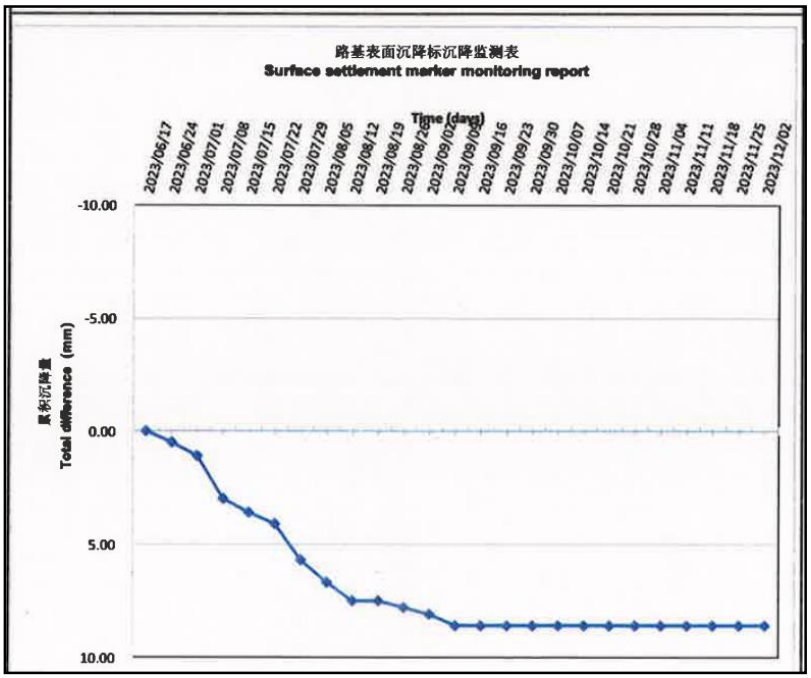

Fig 8 Show surface settlement gauge monitoring report for the Chainage 314+112 right part

4. Conclusion

This chapter provides an outline of the research goal and a discussion of the key findings about the degree to which these goals were met. Additionally, the study's significance is underlined for potential future advancements. Future suggestions were also covered. The objectives of this research were achieved through comprehensive geotechnical investigations and analyses for the ECRL Section 6, Maran project. The project identified soil usability and settlement behavior parameters, ensuring construction stability and safety by analyzing soil composition and groundwater conditions, including silty clay, fine sand, and granite. These analyses highlighted potential geotechnical challenges like soil settlement and slope stability. The research utilized suitable settlement monitoring methods, finding preloading with vertical drains and deep soil mixing particularly effective for stabilizing silty clay and fine sand layers. Consequently, the project proposed tailored ground treatment methods: deep soil mixing for enhancing soft clay bearing capacity and preloading with vertical drains for loose sand and soft clay, optimizing stability, safety, and cost-effectiveness for the rail link construction.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Author I.A, Author M.N.Y;* ***data collection:*** *Author I.A, Author A.A.A.A;* ***analysis and interpretation of results:*** *Author I.A, Author M.N.Y, Author A.A.A.A;* ***draft manuscript preparation*** *Author I.A, Author M.N.Y, Author A.A.A.A. All authors reviewed the results and approved the final version of the manuscript.*

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