



The Effect of Rail Head Corrosion on Emergency Brake Activation in Electric Multiple Unit (EMU) KCIC400AF-2208 on Track I-11G2 at KCIC Tegalluar Depot, Bandung Regency, Indonesia

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ABSTRACT

Railway transportation requires a reliable signaling system to ensure operational safety. This study analyzes the effect of rail head corrosion on track circuit detection failures that triggered Emergency Brake (EB) activation on Electric Multiple Unit (EMU) KCIC400AF-2208 at Track I-11G2, KCIC Tegalluar Depot, Bandung Regency. A descriptive qualitative method was employed using field observations, documentation, literature review, and secondary data from failure reports, the Dynamic Monitoring System (DMS), Centralized Signal Monitoring (CSM), and Track Circuit Reader (TCR). The results indicate that corrosion on the rail head increased wheel–rail contact resistance, causing bad shunting and inaccurate track occupancy detection by the track circuit. Consequently, the Automatic Train Protection (ATP) system interpreted the condition as unsafe and automatically activated the Emergency Brake. High rainfall and limited track utilization accelerated corrosion development. To mitigate this issue, a combined operation pattern using Full Supervision (FS) and Shunting (SH) modes is proposed to reduce dependence on track circuit detection while maintaining operational safety.



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INTRODUCTION

Railway transportation plays an important role in supporting national development by improving connectivity, mobility, and economic growth. As one of the safest and most efficient modes of transportation, railway operations require a highly reliable signaling system to ensure operational safety and service continuity (Schouten, 2021). One of the essential components of the signaling system is the *track circuit*, which detects train occupancy through electrical contact between the wheel and rail (*shunting*). The occupancy information generated by the *track circuit* is used by the signaling and train protection systems to regulate train movements and prevent operational conflicts (Puspitasari & Paurwaka, 2017). Railway rails are made of steel and are a vital component of rail transportation systems. In addition to supporting the load of trains, rails play an essential role in maintaining the stability and safety of railway operations. A well-designed rail helps distribute the load evenly to the ground, thereby reducing the risk of deformation or damage. Regular maintenance is necessary to prevent accidents and ensure efficient railway operations (Montanasyah et al., 2025).

The performance of a *track circuit* is highly dependent on the condition of the rail head surface. Rail head corrosion forms an oxide layer that increases the electrical resistance at the wheel–rail interface, reducing the effectiveness of the *shunting* process and causing *bad shunting* (Satria et al., 2023). As a result, the *track circuit* may fail to detect train occupancy accurately, even when the train

is physically present on the track. Under the *fail-safe* principle, the Automatic Train Protection (ATP) system interprets this condition as unsafe and automatically activates the *Emergency Brake* (EB) to prevent potential operational hazards (Federal Railroad Administration [FRA], 2021). Environmental factors such as high humidity, frequent rainfall, and low track utilization further accelerate rail head corrosion, increasing the likelihood of *track circuit* detection failures (Xu et al., 2021).

This phenomenon was identified on Track I-11G2 at KCIC Tegalluar Depot, where *Emergency Brake* activations occurred during shunting operations involving EMU KCIC400AF-2202 on 6 February 2026 and EMU KCIC400AF-2208 on 10 February 2026. Technical investigations using the Dynamic Monitoring System (DMS), Centralized Signal Monitoring (CSM), and Track Circuit Reader (TCR) indicated that the signaling equipment was operating normally, suggesting that the disturbance was associated with the condition of the rail head rather than equipment malfunction. These findings demonstrate the importance of evaluating the influence of rail corrosion on the reliability of *track circuit* detection in depot operations.

Several previous studies have investigated the influence of rail surface conditions on *track circuit* performance and railway signaling reliability (Federal Railroad Administration [FRA], 2021; Xu et al., 2021; Satria et al., 2023). However, studies specifically addressing the relationship between rail head corrosion, *track circuit* detection failure, and *Emergency Brake* activation in high-speed railway depot operations remain limited, particularly in the Indonesian railway system. Moreover, previous studies have primarily focused on technical aspects of *track circuit* performance without proposing operational mitigation strategies based on actual operational data.

Therefore, this study aims to analyze the effect of rail head corrosion on *track circuit* detection failure that triggered *Emergency Brake* activation on EMU KCIC400AF-2208 at Track I-11G2, KCIC Tegalluar Depot, Bandung Regency. The novelty of this study lies in the integration of field investigation, signaling monitoring data (DMS, CSM, and TCR), and operational analysis to explain the mechanism by which rail head corrosion affects *track circuit* performance and ATP response. Furthermore, this study proposes a combined operation pattern using Full Supervision (FS) and Shunting (SH) modes as an operational mitigation strategy to reduce unnecessary *Emergency Brake* activation while maintaining railway operational safety.

RESEARCH METHODS

Research Location and Time

This study was conducted at KCIC Tegalluar Depot, Bojongsoang District, Bandung Regency, West Java, Indonesia. The research focused on Track I-11G2 (K2+460), where repeated *Emergency Brake* activations occurred during shunting operations involving EMU KCIC400AF trains. Data collection and analysis were carried out from November 2025 to June 2026 through field observations, internship activities, and preparation of the research report.

Data Collection Technique

This study employed a descriptive qualitative approach using both primary and secondary data. Primary data were obtained through direct field observations of the rail head condition on Track I-11G2 to identify corrosion characteristics and evaluate their potential influence on wheel–rail electrical contact. Field documentation was also collected in the form of photographs showing the actual corrosion condition of the rail head. In addition, operational observations were conducted during shunting activities involving EMU KCIC400AF-2208 to record the occurrence and operating conditions of *Emergency Brake* activation.

Secondary data were collected from official KCIC documents and supporting literature. These included the *Emergency Brake* investigation report for EMU KCIC400AF-2208, operational data from the Dynamic Monitoring System (DMS), Centralized Signal Monitoring (CSM), and Track Circuit Reader (TCR), as well as technical documents related to the signaling system, Automatic Train Protection (ATP), track circuit, and rail specifications at KCIC Tegalluar Depot. Relevant regulations, technical standards, previous studies, and environmental data, including rainfall information for Bandung Regency, were also used to support the analysis.

Data Analysis Technique

The collected data were analyzed using a descriptive qualitative approach to identify the relationship between rail head corrosion, track circuit performance, and *Emergency Brake* activation.

The analysis consisted of four stages. First, the chronology of the Emergency Brake events and the ATP system response were examined using operational records, DMS, CSM, and TCR data. Second, the technical performance of the track circuit was evaluated by comparing occupancy voltage, low-frequency values, and input current under normal and disturbed conditions. Third, the root cause of the disturbance was identified by eliminating the possibility of signaling equipment failure and assessing the influence of rail head corrosion, wheel–rail contact resistance, environmental conditions, and track utilization on the occurrence of bad shunting. Finally, an operational evaluation was conducted to compare the existing Full Supervision (FS) operating mode with a proposed combined Full Supervision (FS) and Shunting (SH) operating pattern in order to reduce the risk of unnecessary Emergency Brake activation while maintaining railway operational safety.

RESULTS AND DISCUSSION

Existing Condition of Emergency Brake Events

The results showed that *Emergency Brake* (EB) activation occurred when EMU KCIC400AF entered Track I-11G2 at KCIC Tegalluar Depot during shunting operations under *Full Supervision* (FS) mode. Based on the operational disturbance reports, four *Emergency Brake* incidents were recorded at the same location on 21 October 2025, 5 December 2025, 6 February 2026, and 10 February 2026. Among these incidents, the events involving EMU KCIC400AF-2202 and EMU KCIC400AF-2208 were selected for detailed analysis because complete investigation data, including the Dynamic Monitoring System (DMS), Centralized Signal Monitoring (CSM), and Track Circuit Reader (TCR), were available.

Table 1. Summary of Emergency Brake Events on Track I-11G2

No	Date	EMU Train Set	Location
1	21-Oct-25	KCIC400AF-2207	Track I-11G2 (K2+460)
2	5-Dec-25	KCIC400AF-2206	Track I-11G2 (K2+460)
3	6-Feb-26	KCIC400AF-2202	Track I-11G2 (K2+480)
4	10-Feb-26	KCIC400AF-2208	Track I-11G2 (K2+460)

Source: Analysis Results, 2026

As presented in Table 1, all *Emergency Brake* activations occurred while the train was entering Track I-11G2 at low speed during shunting operations. Although the ATP system initiated an *Emergency Brake*, the investigation confirmed that the track was clear and no operational conflict existed. These findings indicate that the *Emergency Brake* activation was not caused by train movement conflicts but by a failure of the *track circuit* to detect train occupancy accurately. To determine the source of the disturbance, further analyses were conducted using DMS, CSM, and TCR data to evaluate whether the problem originated from signaling equipment failure or external factors affecting *track circuit* performance.

Analysis of Track Circuit Performance

To identify the cause of the *Emergency Brake* activation, an analysis was conducted using operational data from the Dynamic Monitoring System (DMS), Centralized Signal Monitoring (CSM), and Track Circuit Reader (TCR). These systems were used to evaluate the performance of the *track circuit* and determine whether the disturbance originated from signaling equipment failure or from external factors affecting train detection.

Table 2. Dynamic Monitoring System (DMS) Results During the Emergency Brake Incidents

Parameter	Normal Condition	EMU KCIC400AF-2208 (10 February 2026)	EMU KCIC400AF-2202 (6 February 2026)
Train number	According to operating schedule	0G1059 (2208-00), shunting operation at KCIC Tegalluar Depot	0G1063 (2202-00), shunting operation at KCIC Tegalluar Depot
Incident location	According to operating route	Track I-11G2, Km 2+460 (21:35:29 WIB)	Track I-11G2, Km 2+480 (22:39:47 WIB)
Track circuit voltage	Normal signal voltage	0.56 V	0.46 V
ATP response	No intervention	Emergency Brake activated	Emergency Brake activated

Source: Analysis Results, 2026

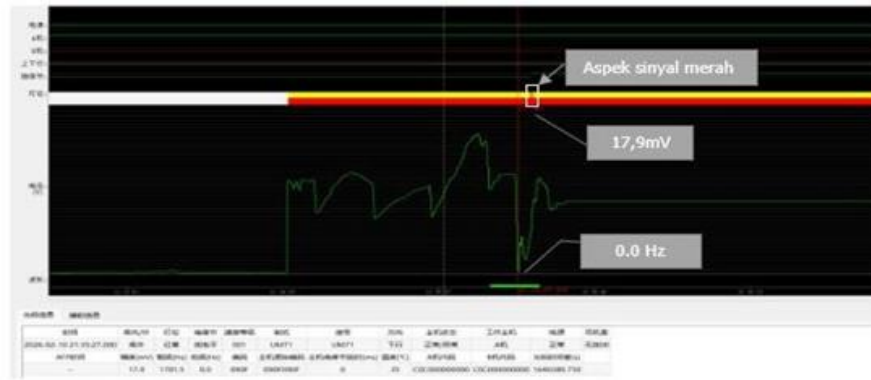
As shown in Table 2, both *Emergency Brake* incidents occurred during shunting operations at KCIC Tegalluar Depot and exhibited similar operational characteristics. The *track circuit* voltage recorded by the DMS was 0.56 V for EMU KCIC400AF-2208 and 0.46 V for EMU KCIC400AF-2202, both lower than the normal operating condition. Consequently, the ATP system automatically activated the Emergency Brake because the track circuit could not provide valid track occupancy information. To verify whether the disturbance was caused by signaling equipment failure, the Centralized Signal Monitoring (CSM) data were further analyzed.

Table 3. Centralized Signal Monitoring (CSM) Results During the Emergency Brake Incidents

Parameter	EMU KCIC400AF-2208	EMU KCIC400AF-2202
Incident date	10 February 2026	6 February 2026
Train number	0G1059	0G1063
Location	Track I-11G2 (Km 2+460)	Track I-11G2 (Km 2+480)
Recording time	21:35:29 WIB	22:36:15 WIB
Peak track circuit voltage	11.25 V	15.51 V
Normal threshold	< 10 V	< 10 V

Source: Analysis Results, 2026

Based on Table 3, the track circuit voltage increased beyond the normal threshold of 10 V, reaching 11.25 V during the EMU KCIC400AF-2208 incident and 15.51 V during the EMU KCIC400AF-2202 incident. However, the CSM records did not indicate any failures in the interlocking system, communication network, or signaling equipment. These findings suggest that the signaling system operated normally and that the disturbance was related to the track circuit detection process rather than hardware malfunction. A more detailed investigation was then carried out using the Track Circuit Reader (TCR), which records the electrical characteristics of the track circuit during train movement.



Source: PT KCIC, 2026

Picture 1 Track Circuit Reader (TCR) Voltage Reading During the Emergency Brake Incident

As illustrated in Picture 1, the track circuit signal voltage fluctuated significantly when the train entered Track I-11G2. At 21:35:27 WIB, the signal voltage dropped to 17.9 mV, which was considerably lower than the minimum operating value of 240 mV required for the ZPW-2000A track circuit. Simultaneously, the low-frequency signal decreased to 0.0 Hz, preventing the ATP system from receiving valid occupancy information. Consequently, the signal aspect changed to Red (H), and the ATP system activated the Emergency Brake according to the fail-safe principle.

The combined results from the DMS, CSM, and TCR analyses demonstrate that the Emergency Brake activation was associated with abnormal *track circuit* detection rather than signaling equipment failure. These findings indicate that an external factor affected the wheel–rail electrical contact, which is further discussed in the following section.

Analysis of Rail Head Corrosion as the Cause of Bad Shunting

After confirming that the disturbance was not caused by signaling equipment failure, the analysis focused on the physical condition of the rail head as the primary cause of the track circuit detection failure. A Shunt Tester was used to evaluate the track circuit parameters before and after removing the corrosion layer from the rail surface. The results showed that, before cleaning, the occupancy voltage remained at 11.95 V, and the track was not detected as occupied. After the rail surface was cleaned, the occupancy voltage decreased to 2.83 V, while the short-circuit current increased from 360 mA to 978 mA, exceeding the minimum operating requirement of 500 mA. These findings indicate that the track circuit equipment functioned properly and that the disturbance originated from the condition of the rail surface rather than equipment malfunction.



Source: Author's Documentation, 2026

Picture 2. Track Circuit Parameter Test Results Before and After Rail Corrosion Removal

A visual inspection of Track I-11G2 revealed the presence of surface corrosion characterized by a brown oxide layer on the rail head. The corrosion increased the electrical contact resistance between the wheel and rail, reducing the effectiveness of the *shunting* process. However, the observed corrosion was limited to the rail surface and had not affected the mechanical strength of the rail.



Source: Author's Documentation, 2026

Picture 3. Rail Head Corrosion on Track I-11G2

The formation of corrosion was also influenced by environmental conditions and track utilization. Rainfall data indicate that Bandung experiences relatively high humidity, accelerating the oxidation process on the rail surface. In addition, Track I-11G2 was operated on only 22 days during April 2026, limiting the natural removal of the oxide layer by wheel–rail contact. Consequently, corrosion accumulated more easily on the rail head than on frequently used mainline tracks.

Table 4. Annual Rainfall Data in Bandung Regency

Year	Total Rainfall (mm)	Average Monthly Rainfall (mm)
2022	2.311,40	192,62
2023	1.751,00	145,92
2024	2.215,00	184,58
Average	2.092,50	174,38

Source: Statistics Indonesia (BPS) Bandung City, 2026

As presented in Table 4, Bandung Regency experiences relatively high annual rainfall, resulting in high environmental humidity that accelerates the oxidation process on the rail surface. Such conditions promote the formation of oxide layers, particularly on depot tracks that are not used continuously. Therefore, environmental factors significantly contribute to the development of rail head corrosion on Track I-11G2.

Table 5. Track I-11G2 Utilization Frequency During April 2026

Description	Date(s)
Track in operation	1–9, 11–12, 15, 17–21, 23–26, and 29 April 2026
Track not in operation	10, 13, 14, 16, 22, 27, 28, and 30 April 2026
Total operating days	22 days

Source: Analysis Result, 2026

As shown in Table 5, Track I-11G2 was used for train operations on only 22 days during April 2026, indicating a relatively low utilization frequency compared with the mainline. The limited train movements reduced the natural wheel–rail friction that normally removes oxide layers from the rail surface. Consequently, corrosion was able to accumulate and persist on the rail head, increasing the electrical contact resistance between the wheel and rail.

The combination of high environmental humidity and low track utilization accelerated the formation of corrosion on the rail head. The resulting oxide layer increased the wheel–rail contact resistance, reducing the *shunting* current flowing through the *track circuit*. This condition led to *bad shunting*, in which the train physically occupied the track but could not be reliably detected by the *track circuit*. These findings are consistent with Xu et al. (2021), who reported that oxide layers on the rail surface increase wheel–rail contact resistance and reduce the reliability of *track circuit* systems. Similar findings were reported by Satria et al. (2023), who identified rail head corrosion as one of the primary causes of *bad shunting* in railway signaling systems. Therefore, it can be concluded that rail head corrosion was the dominant factor contributing to the *track circuit* detection failure that triggered the *Emergency Brake* activation on Track I-11G2 at KCIC Tegalluar Depot.

Proposed Operational Mitigation

Based on the analysis results, the primary cause of the *Emergency Brake* activation was not a signaling equipment failure but rail head corrosion, which increased the wheel–rail contact resistance and resulted in *bad shunting*. Therefore, the proposed mitigation should reduce the system's dependence on *track circuit* detection in sections susceptible to corrosion. This study proposes an operating pattern in which the train remains in Full Supervision (FS) mode until Track I-11G1 and then switches to Shunting (SH) mode before entering Track I-11G2. In *Shunting* mode, train movement is no longer fully dependent on *track circuit* occupancy detection but primarily relies on balise information while maintaining the prescribed shunting speed limits.

Table 6. Comparison of Existing and Proposed Operating Patterns

Aspect	Existing Operating Pattern	Proposed Operating Pattern
Operating mode	Full Supervision (FS)	Full Supervision (FS) + Shunting (SH)
Route	XL → D154 → I-11G2	XL → SI-11 → I-11G1 (FS), then SH → I-11G2
<i>Track circuit</i> dependency	High	Reduced on Track I-11G2
Train movement validation	<i>Track circuit</i> + Balise	FS (<i>Track circuit</i> + Balise) → SH (Balise)
Risk of <i>Emergency Brake</i>	High during <i>bad shunting</i>	Significantly reduced
Sensitivity to <i>track circuit</i> voltage	High	Low

Source: Analysis Result, 2026

As shown in Table 6, the proposed operating pattern reduces the dependence on the *track circuit* along Track I-11G2, thereby minimizing the risk of *Emergency Brake* activation caused by *bad shunting* while maintaining the safety functions of the Automatic Train Protection (ATP) system. Compared with periodic *rail grinding* or corrosion cleaning, which provide only temporary improvements, the proposed operating pattern addresses the root cause of the disturbance more effectively. The low utilization frequency of Track I-11G2, combined with the high rainfall and humidity in the study area, allows rail head corrosion to reoccur, making repeated maintenance necessary. In contrast, the proposed combination of Full Supervision (FS) and Shunting (SH) modes utilizes the existing CTCS-2 operational functions without requiring infrastructure modifications or signaling equipment replacement. Therefore, the proposed operating pattern offers a more effective, efficient, and sustainable solution for preventing *Emergency Brake* activation caused by *track circuit* detection failures.

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