

Temperatures and related behavior in embedded mechanically stabilized earth abutment

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ABSTRACT

This study investigated the impact of temperature variations on the performance of embedded mechanically stabilized earth (MSE) abutments. An experimental embedded MSE abutment was constructed in Anhui Province, China, with a series of monitoring instruments deployed. The monitoring results over more than two years after construction revealed that the internal temperature distribution and variation patterns of the abutment were closely related to annual temperature cycles. Additionally, the internal temperature exhibited a lag relative to the environment temperature, and its distribution was influenced by both the exposed face and the embedded piles. The lateral displacement of the abutment facing was also affected by temperature, with the displacement along the wall height showing a bulging distribution pattern. The horizontal earth pressure on the back of the facing was coordinated with the lateral deformation, and there was a load shift phenomenon from the facing to the pile. This study indicated that both temperature and embedded piles influenced the internal deformation and stress distribution of the bridge abutment. It is recommended that the soil pressure redistribution characteristics during the service period of embedded MSE abutments be considered in the design.

Keywords: mechanically stabilized earth (MSE) abutment; embedded type; monitoring; temperature; deformation; pressure distribution

1 INTRODUCTION

The embedded mechanically stabilized earth (MSE) abutment (called mixed abutment by [Anderson et al., 2005](#)), in which the primary load of the bridge superstructure is carried by the substructure placed inside the abutment, represents a novel application of MSE walls in highway and railway bridge engineering. Instead of directly bearing the superstructure load, the MSE wall is responsible for carrying the road traffic load and retaining the soil behind the abutment. The embedded MSE abutment is mainly constructed using facing materials, backfill and geosynthetics (i.e., geogrids and geotextiles). Compared with traditional gravity-type abutments, it significantly reduces construction costs and carbon emissions, as well as the construction period ([Herold et al., 2008](#); [Abullah et al., 2023](#)). Furthermore, as a transition structure between the bridge and the road, the embedded MSE abutment exhibits limited post-construction settlement, which helps alleviate the occurrence of "bump at the bridge end" phenomena. The application of the embedded MSE abutment not only improves engineering efficiency but also contributes to a reduction in carbon emissions.

Due to the interaction between the bridge substructure and the MSE wall, the performance of the

embedded MSE abutment differs from that of conventional MSE walls. The FHWA ([2009](#)) suggests that the supplemental horizontal load exerted by the bridge substructures on the abutment facing be considered in the design of embedded MSE abutments. Similarly, in MSE walls, piles subjected to lateral loads will generate significant additional stresses on the facing ([Han et al., 2018](#); [Jawad et al., 2021](#)). However, the structural form and application of MSE walls differ notably from those of the embedded MSE abutment. Moreover, experiments conducted by Xu et al. ([2023](#)) indicate that the presence of embedded piles serves to limit the deformation of the abutment facing rather than applying additional horizontal load to it. Therefore, further verification is still required to determine whether the embedded piles exert additional horizontal loads on the abutment facing. The interaction between the embedded piles and the reinforced soil remains uncertain, and performance analyses are required for practical engineering.

Currently, research on the embedded MSE abutment lacks a comprehensive evaluation of its performance. There are different interpretations regarding the interaction mechanisms between piles and reinforced soil. The effects of annual temperature on the long-term performance of the embedded MSE abutment, as well

as the long-term interaction mechanisms between piles and reinforced soil, remain unclear, which poses potential risks for the engineering application. To investigate the long-term performance of embedded MSE abutments under the influence of annual temperature, a field experimental project was conducted on the Mingguang-Chaohu Expressway in Anhui Province, China. Monitoring was performed on internal temperatures, lateral displacement of the facing and horizontal earth pressure on the back of the facing and piles during the service period of the abutment. This study focuses on exploring the effects of temperature on the internal stress, deformation, and thermal behavior of the abutment, enhancing the understanding of the performance of embedded MSE abutments, and providing valuable insights for the engineering application of this technology.

2 FIELD EXPERIMENT

The field experimental project was located in a mid-latitude region with a subtropical monsoon humid climate. The average annual temperature was 15.7°C , and the average annual precipitation was approximately 1000 mm. The original design featured a three-span 13-meter T-shaped concrete beam supported by piles and pile caps. The new design proposed a single-span 20-meter T-shaped concrete beam combined with the embedded MSE abutment. This new solution resulted in a cost saving of approximately 1.27 million RMB, accounting for 38% of the total bridge cost. The embedded MSE abutment experimental project was completed in December, 2021, as shown in Figure 1.

The facing of the embedded MSE abutment was composed of concrete masonry unit (CMU) blocks with a slope of 1:0.05 and a wall height of 5.5 meters. The reinforcement spacing was 0.38 meters (twice the CMU height). The diameter of the embedded piles was 1.5 meters, with the distance from the center of the pile to the facing being 4.05 meters. The backfill material for the abutment was well-graded crushed stone with good water stability and permeability, of which the maximum particle size was no more than 10 cm and the internal friction angle was no less than 35 degrees. During construction, the compaction degree of the backfill in front and behind the pile was controlled to be no less than 90% and 96%, respectively. The dimensions of the CMU blocks were uniform at $0.4\text{ m} \times 0.2\text{ m} \times 0.19\text{ m}$. The reinforcement materials used were high-density polyethylene (HDPE) geogrids with high strength and durability. The tensile strength of the geogrids was 23 kN/m and 41.0 kN/m at 2% and 5% longitudinal elongation, respectively. Plastic connectors were used between the geogrids and CMU blocks to facilitate mechanical connection.

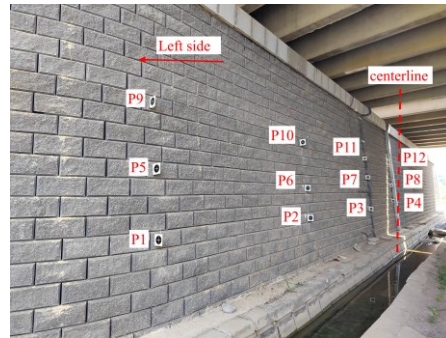


Fig.1 Embedded MSE abutment in Anhui.

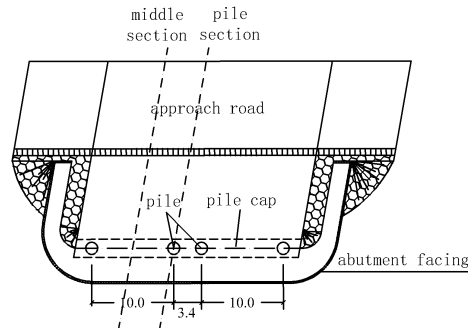
3 INSTRUMENTATION AND ANALYSIS

3.1 Instrumentation Layout

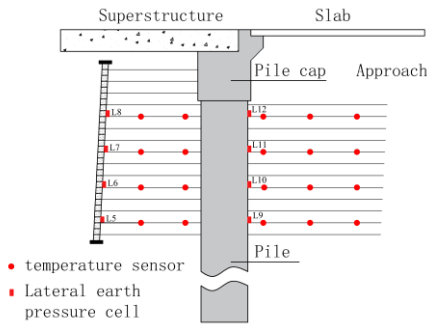
To investigate the long-term performance of the embedded MSE abutment under the influence of annual temperature, a comprehensive field monitoring was conducted. A machine vision-based intelligent measurement system was used to monitor the lateral displacement of the abutment facing, with twelve observation points (P1-P12) set on the abutment facing. Additionally, eight earth pressure cells (L1-L8) were placed at two cross-sections inside the abutment to measure the horizontal earth pressure distribution on the back of the facing and the pile. Furthermore, four rows of temperature sensors were installed at two cross-sections inside the abutment to capture the variation of internal temperature under annual temperature cycles, as shown in Figure 2.



(a) Abutment facing



(b) Layout of the abutment



(c) Layout of the pile section

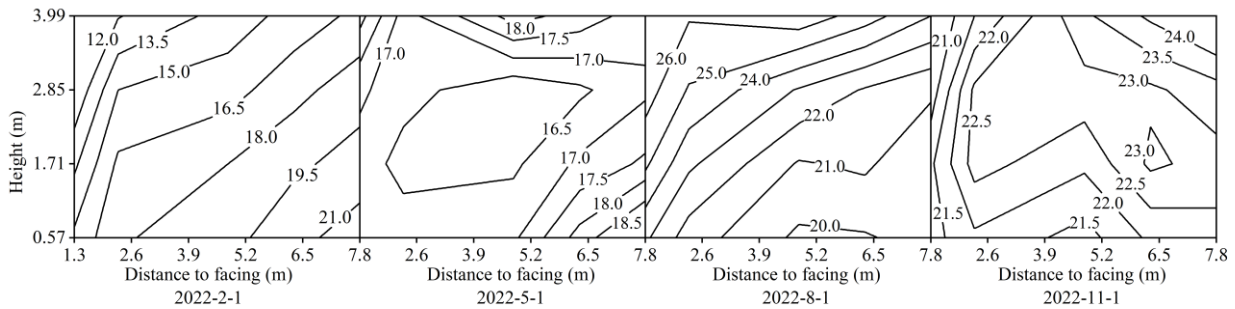
Fig.2 Instrumentation layout (unit: mm).

3.2 Internal Temperature of the Abutment

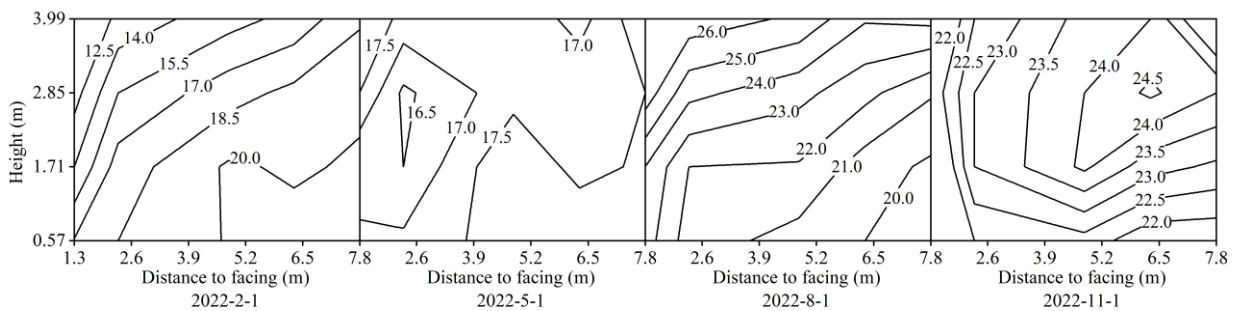
Based on the monitoring results from the internal temperature sensors, [Figures 3](#) presents the temperature distribution contours for the cross-section between two piles and the pile cross-section of the abutment, respectively. The results indicated two patterns of internal temperature distribution under annual temperature cycles. During the low-temperature season and high-temperature season, the internal temperature distribution of the abutment was mainly influenced by the exposed face of the abutment, showing an increasing or decreasing gradient from the exposed face towards the interior of the abutment. Due to the differing thermal conductivity between the abutment facing and the backfill, a larger temperature gradient was observed near the facing, while the internal temperature of the abutment lagged behind the environment temperature, as noted by Kasozi et al., (2015) and Poggiogalle et al., (2018). With the annual temperature increase and decrease, the internal temperature distribution was mainly controlled by both the exposed face and the embedded piles. Due to the

difference between the thermal conductivity of the embedded piles and the backfill, the temperature variation near the piles was influenced by the embedded piles. The impact weakened as the distance from the piles increases, resulting in the formation of both low and high-temperature zones inside the abutment.

The comparison between two cross-sections in [Figure 3](#) showed that due to the difference in thermal conductivity between the embedded piles and the reinforced soil, there was a noticeable variation in temperature distribution between the pile cross-section and the cross-section between two piles, with the latter exhibiting better thermal insulation performance. In both the low-temperature and high-temperature seasons, the temperature distribution forms were similar between the two cross-sections, but the temperature values of the isotherms inside the abutment varied significantly, where the embedded piles affected the temperature magnitude without altering the overall temperature distribution pattern. With the annual temperature increase and decrease, as the environment temperature was higher or lower than the internal temperature of the abutment, the presence of the embedded piles influenced the temperature near the upper part of the pile, leading to a significant difference in the distribution of low and high-temperature zones between the two cross-sections. Specifically, with the annual temperature increase, the embedded piles facilitated the formation of a low-temperature zone in the middle of the abutment, whereas, with the annual temperature decrease, the embedded piles accelerated the dissipation of the high-temperature zone in the middle of the abutment.



(a) Section across piles



(b) Section between piles

Fig.3 Temperature contours inside the abutment.

3.3 Facing Lateral Displacement

Figure 4 presents the lateral displacement of the abutment facing, indicating that the increase of the displacement mainly occurred in the seasons with increasing temperature. This revealed a significant correlation between the lateral displacement of the facing and temperature.

Under daily temperature cycles, the lateral displacement of the facing generally showed a positive correlation with temperature, as shown in Figure 5. This pattern was consistent with the annual results. Furthermore, the lateral displacement of the facing was highly sensitive to daily high temperatures. When the environment temperature fell below the average daily temperature, the displacement tended to stabilize at a minimum value and did not continue to decrease.

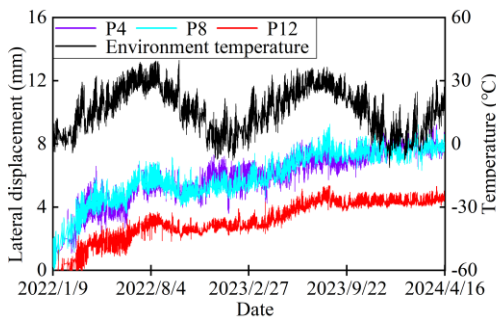


Fig.4 Lateral displacement of the abutment facing under annual temperature cycles.

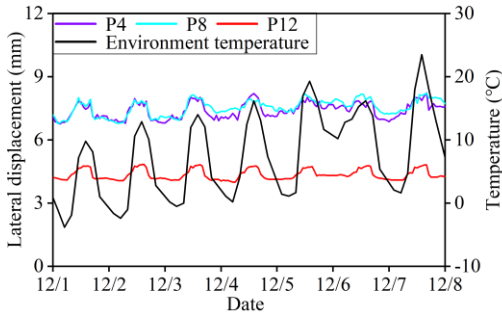


Fig.5 Lateral displacement of the abutment facing under daily temperature cycles.

Figure 6 shows the distribution of lateral displacement along the height of the facing at different distances from the centerline of the abutment. Overall, the lateral deformation of the facing gradually increased over time and stabilized approximately two years after construction. The lateral displacement showed a bulging pattern in the middle, with the maximum displacement occurring at approximately 0.6 times the wall height, which was consistent with the findings of Xu et al. (2023).

At the location near the centerline of the abutment, the lateral displacement of the facing initially exhibited a dip at the middle wall height, gradually transitioning to a bulge within two years after construction. In contrast, at the location farther from the centerline of the abutment, the lateral displacement of the facing

initially showed a bulging pattern, and the degree of bulging increased over time. The monitoring results from the two cross-sections suggested that the embedded piles in the central part of the abutment acted as a barrier to the reinforced soil, reducing the earth pressure transferred to the facing, thereby limiting the bulging in the centerline of the abutment facing. However, as the influence of the piles weakened with distance from the centerline of the abutment, the bulging phenomenon in the middle of the facing became more pronounced.

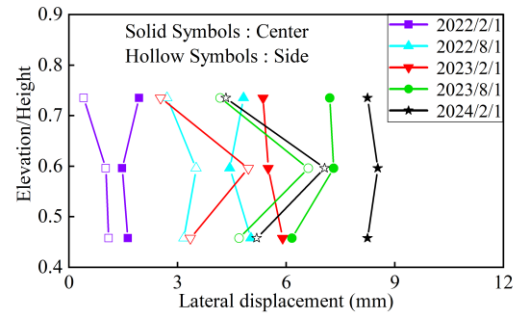


Fig.6 Lateral displacement of the abutment facing along wall height under annual temperature cycles.

3.4 Horizontal Earth Pressure

Figure 7 presents the monitoring results of the horizontal earth pressure on the back of the facing in front of the pile. It can be observed that near the top and bottom of the facing, the horizontal earth pressure showed a positive correlation with temperature. However, in the middle section of the facing, the horizontal earth pressure significantly decreased during the early stage after construction and during the temperature decrease seasons. As discussed above, the lateral displacement of the facing showed a bulging pattern in the middle, which resulted in a gradual release of horizontal earth pressure on the back of the facing. The lateral earth pressure showed a releasing rate up to 71%. However, structural factors such as the backfill soil in front of the wall and the concrete topping on the top of the wall limited the development of the deformation of the facing and prevented the release of the earth pressure, resulting in gradual increase of horizontal earth pressure over time, as noted by Meng et al. (2024).

Figure 8 shows the variation of horizontal earth pressure on the back of the facing under daily temperature cycles at different cross-sections. The results indicated that the horizontal earth pressure on the back of the facing between two piles showed a positive correlation with daily temperature. Since the thermal conduction within the abutment required some time to respond to changes in the environment temperature, the horizontal earth pressure lagged behind the environment temperature variations. The horizontal earth pressure on the back of the facing in front of the pile did not show significant changes under

daily temperature cycles, especially in the bottom part of the facing. As discussed above, the embedded piles acted as a barrier, reducing the thermal effects of the soil on the abutment facing and resulting in little change in the horizontal earth pressure on the back of the facing in front of the pile over a short period.

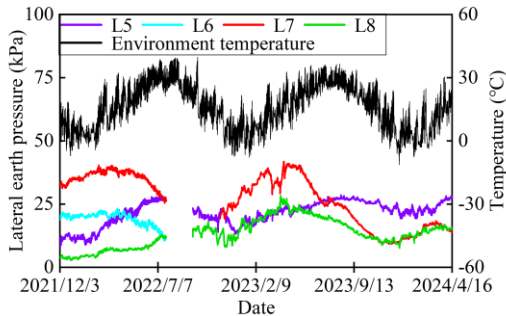


Fig.7 Lateral earth pressures behind the abutment facing under annual temperature cycles.

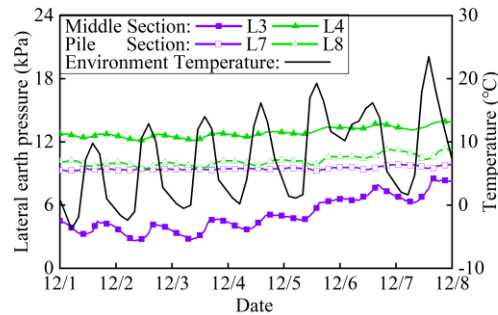


Fig.8 Lateral earth pressures behind the abutment facing under daily temperature cycles.

Figure 9 shows the distribution of horizontal earth pressure along the height of the facing and the pile back. After construction of the abutment, the horizontal earth pressure on the back of the facing was concentrated in the middle section. As the lateral deformation of the facing developed, the earth pressure in the middle section gradually released, and the pressure became concentrated at the top of the facing. Meanwhile, at the early stage of completion, the horizontal earth pressure on the pile back increased with depth. Under annual temperature cycles, as the bulging in the middle of the facing increased, the pile exhibited a certain lateral soil-retaining effect, bearing more horizontal earth pressure. This effect was more pronounced at the middle location of the pile. Within two years after the construction of the abutment, as the bulging of the facing continued to develop, the horizontal earth pressure in the middle of the wall back was reduced by approximately 31 kPa. Meanwhile, due to the soil-retaining effect of the pile, the horizontal earth pressure in the middle of the pile back increased by approximately 33 kPa. This indicated that the soil-retaining effect of the pile in the embedded MSE abutment caused the horizontal earth pressure in the middle of the wall back to gradually shift toward the pile back.

The long-term monitoring results of horizontal earth pressure indicated that in the embedded MSE abutment, the horizontal earth pressure on the back of the facing was coordinated with the lateral deformation. The variation in the horizontal earth pressure on the wall back was influenced by annual temperature and the embedded piles. Furthermore, the horizontal earth pressure in the middle of the facing gradually shifted toward the pile back. During the working period of the abutment, significant changes occurred in both the deformation and stress of the abutment. Therefore, the variation in the horizontal earth pressure on the facing back and pile back should be carefully considered during the design and construction of the abutment.

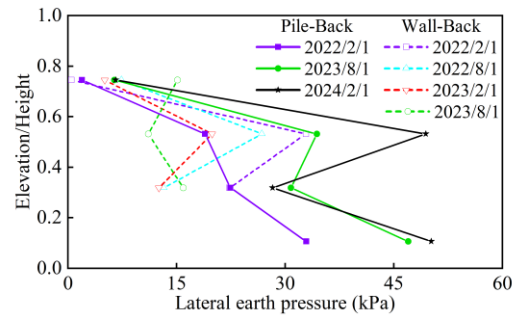


Fig.9 Lateral earth pressures behind the abutment facing and the pile along wall height.

4 CONCLUSION

This study investigated the temperatures and related behavior of the embedded MSE abutment during the working period, based on the two-year monitoring results of the filed experimental project in Anhui Province, China. The following conclusions can be drawn from this study:

- (1) Under annual temperature cycles, the internal temperature variation of the embedded MSE abutment was closely related to the seasonal temperature. However, the internal temperature change lagged behind the environment temperature, and the temperature distribution was influenced by both the exposed face and the embedded piles.
- (2) The lateral displacement of the abutment facing was primarily influenced by environment temperature. Annual temperature increases significantly accelerated the lateral displacement of the facing, with the displacement along the height of the wall showing a bulging pattern in the middle. Meanwhile, the horizontal earth pressure on the back of the facing was coordinated with the lateral deformation. The horizontal earth pressure in the middle of the facing was released as the facing bulges.
- (3) The soil-retaining effect of the embedded

piles reduced the earth pressure transmitted to the middle of the facing, thereby limiting the lateral displacement of the facing in front of the piles. Meanwhile, the horizontal earth pressure in the middle of the wall back gradually shifted toward the pile back.

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REFERENCES

- Abullah N H H, Ng K S, Jais I B M, et al. (2023). Use of geosynthetic reinforced soil-integrated bridge system to alleviate settlement problems at bridge approach: A review. *Physics and Chemistry of the Earth*, 129: 103304.
- Anderson, P.L., Brabant, K. (2005). Increased Use of MSE Abutments. *Proceedings of the 22nd Annual International Bridge Conference*, pp. 5-10.
- Han, J., Jiang, Y., Xu, C. (2018). Recent advances in geosynthetic-reinforced retaining walls for highway applications. *Front. Struct. Civ. Eng.* 12: 239–247(2018).
- He, S., Xia, T., Yu, B. (2020). Effect of temperature on volume strain and consolidation characteristics of calcareous sand. *Journal of Zhejiang University (Engineering Science)* 54(02): 221–232+290.
- Ryan R B, Barry R C, Naresh C S. (2009). FHWA-NHI-10-024 Design of mechanically stabilized earth walls and reinforced soil slopes. Woodbury, MN: The US National Highway Institute, (6-8)–(6-10).
- Jawad S, Han J, Abdulrasool G, et al. (2021). Responses of single and group piles within MSE walls under static and cyclic lateral loads. *Geotextiles and Geomembranes*, 49(4): 1019–1035.
- Kasozi, A. M., Siddharthan, R. V., Mahamud, R.. (2015). Temperature Distribution in Mechanically Stabilized Earth Wall Soil Backfills for Design Under Elevated Temperature Conditions. *ASME. J. Thermal Sci. Eng. Appl.* 7(2): 021004.
- Poggiogalle, T.M., Talebi, M., Meehan, C.L. (2018). Changes in Temperature Distribution in a Geosynthetic Reinforced Soil Abutment and Their Effect on Measured Strain. *Proceeding of IFCEE 2018*, pp. 267–277.
- Xu Chao, Jin Yu, Yang Yang, et al. (2023). Experimental study on deformation of mixed reinforced soil abutment under pavement load. *Rock and Soil Mechanics*, 44(S1):410–418.
- Meng Ya, Xu Chao, Zhao Congxi, et al. (2024). Research on the performance of disconnect-type reinforced soil abutment and the influence of climatic factors on the abutment. *Journal of Huazhong University of Science and Technology (Natural Science Edition)*, 52(09):118-126.