Study on the Influence of Temperature Rise on the Stress Change of Prefabricated Cantilever Composite Subgrade (PCCS)

Xiaoxiang Cao[1], Liang Yin[2], Cheng Peng[1], Zhigang Wu[2], and Shengwei Yang[3](✉)

[1] Anhui Transportation Holding Group Co., Ltd., Hefei 230088, China
[2] Anhui Transport Consulting and Design Institute Co., Ltd., Hefei 230088, China
[3] Hefei University of Technology, Hefei 230009, China
3024319405@qq.com

Abstract. In this paper, a new type of precast cantilever composite foundation structure for mountainous highway is studied, and the influence of temperature rise on the stress of the structure is analyzed. Under the load of temperature rise, the stress state of the PCCS structure is significantly improved, and its value is greater than the stress of the structure under static load. The temperature load mainly has great influence on the stress state of the connecting steel bar and bolt, but has little influence on the concrete members. The stress state of the connected steel bar and bolt under the global temperature rising case has little difference with that under the local temperature rising case, while the stress state of the concrete members under the global temperature rising case is greater than that under the local temperature rising case.

Keywords: PCCS · Global Temperature Rising · Local Temperature Rising

1 Introduction

Cantilevering subgrade structure forms an embankment with wall-pillar retaining wall within the range of stable subgrade, and makes up the under width of the road with the cantilevering structure. The stable subgrade is used to minimize the post-construction settlement, and the artificial foundation excavation avoids the disturbance of surrounding soil to the maximum extent. In the subgrade engineering, it can protect the ecological environment, excavate and fill small, cost low, and construction is simple, which is suitable for different terrain and geological conditions [1]. Although this method has greatly improved the performance of the structure, as a mass concrete structure, its mechanical response under temperature load can not be ignored.

Hou [2] et al. artificially studied the time-varying temperature effect in hydration reaction process of mass concrete, taking Tianinggou Bridge, the second highest pier in Asia in the loess region, as the research object, and analyzed the time-varying temperature effect of hydration heat of mass concrete cap. The influences of concrete entry temperature, thermal conductivity and surface convection coefficient on the adiabatic

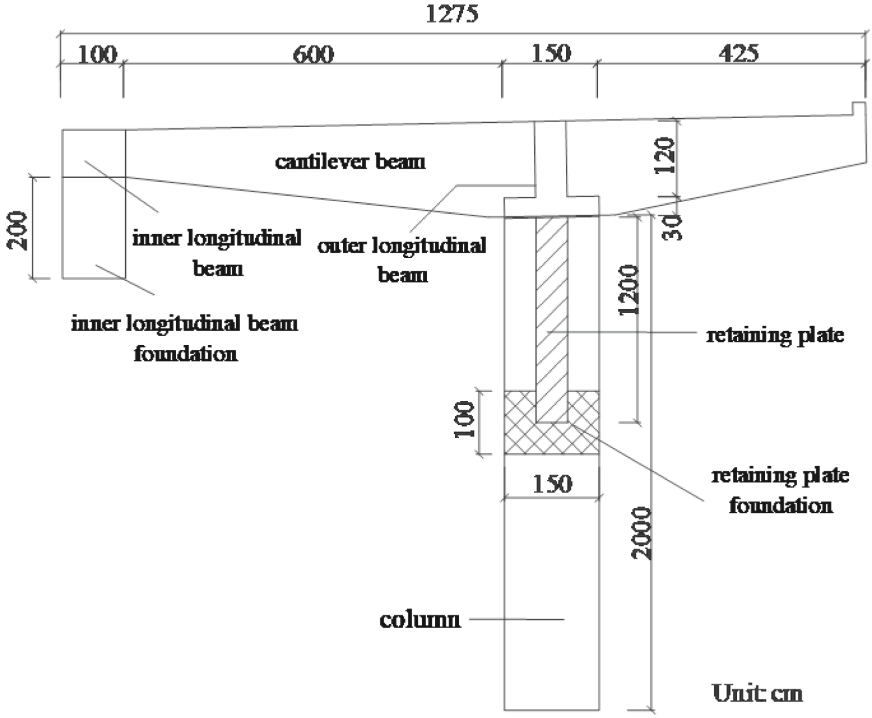
C.-H. Weng (Ed.): ACEER 2023, LNCE 336, pp. 102–111, 2024.
https://doi.org/10.1007/978-981-99-5716-3_8

temperature rise, surface temperature rise and inner surface temperature difference of mass concrete cap are analyzed. Yan [3] et al. set another concrete strength test block with the same mix ratio under the condition of same insulation at the side of a large volume concrete slab, and experimentally studied the development law of concrete strength with time under different insulation measures and the influence of insulation curing time on concrete strength. Based on the test results, the thermal insulation and maintenance scheme of large volume concrete suitable for the severe cold area represented by Harbin is determined, and the relevant construction suggestions are put forward. He [4] et al., considering the large volume and high hydration heat of the concrete on the pylon cap, led to large temperature difference between the internal temperature and the inner surface, which easily resulted in temperature cracks and other conditions, conducted numerical simulation on different pouring schemes of the concrete on the pylon cap of Rongjiang Bridge, analyzed the influences of pouring thickness, cooling water and cooling water temperature on the temperature and stress of the concrete, so as to select appropriate pouring and temperature control schemes. The field measured data is compared with the calculated data. The research results have a certain reference value for the pouring and temperature control of mass concrete for tower bearing. The thawing and freezing of seasonal permafrost due to temperature fluctuations can cause safety hazards to the stability of roadbeds. He [5] et al. conducted on-site monitoring of temperature and water content on typical roadbed sections in the Naqu-Yangbajain segment. They performed regression analysis utilizing 2020 ground temperature data and analyzed the ground temperature amplitude, time lag, and soil thermal diffusivity of the monitored section through indoor experiments. With support from the Kun-Chu Expressway expansion project, Zhao [6] established a numerical model of asphalt pavement for the expressway using finite element software. He analyzed the effect of environmental temperature on asphalt pavement deformation, evaluated the significant factors affecting the deformation of asphalt pavement under continuous temperature changes using the gray correlation method, and estimated the permanent deformation of the asphalt pavement.

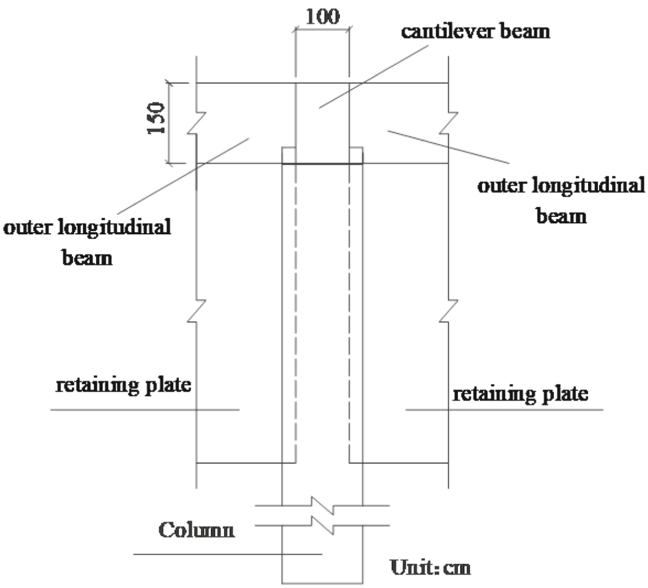
At present, Zhou [7–9] and his team have conducted a large number of researches on the application of cantilever structure in China, and the researches on the influence of temperature effect on concrete structure at home and abroad also tend to be mature and perfect, but the influence of temperature effect on cantilever structure is rarely reported. Therefore, this paper takes the PCCS structure of mountain highway as the research object, analyzes the influence of temperature rise on structural stress, and provides reference for the application and theoretical design of such structures.

2 Prefabricated Cantilever Composite Subgrade (PCCS) Structure

PCCS structure is composed of column, outer longitudinal beam, cantilevering beam, lapping plate, inner longitudinal beam, inner longitudinal beam foundation, retaining plate, retaining plate foundation and anchor rod. The cantilever beam, retaining board, outer stringer and lapping board are constructed with prefabricated standard components, while the column, inner stringer, inner stringer foundation and retaining board foundation are constructed with on-site pouring. The inner side of the beam is placed on the excavated subgrade, and the outer side is suspended on the outer side of the column. The inner

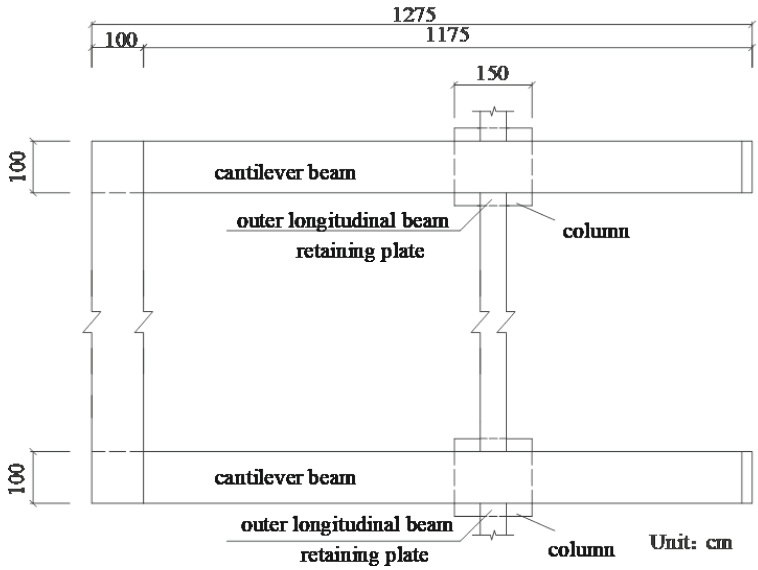


(a) Main elevation



(b) Left elevation

Fig. 1. Layout of prefabricated cantilever composite subgrade.



(c) Top elevation

Fig. 1. (*continued*)

longitudinal beam is arranged longitudinally at the end of the cantilever beam along the route and connected with the cantilever beam by cast-in-place; The outer longitudinal beam is arranged in the beam position at the top of the column, and the retaining plate is arranged between the columns above the ground. In order to ensure the safety and stability of the whole structure, the anchor rod embedded in the rock layer is set at the end of the beam. The PCCS structure is shown in Fig. 1. And the Prefabricated cantilever composite subgrade structure is shown in Fig. 2.

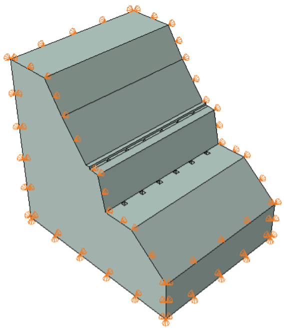
3 Detailed Nonlinear Solid Finite Element Model Establishment

In this paper, ABAQUS is used to establish a refined finite element model of prefabricated cantilever composite subgrade structure. A total of 15 solid units including cantilever beam, outer longitudinal beam, inner longitudinal beam, inner longitudinal beam foundation, retaining wall, retaining wall foundation, column, foam concrete and soil were established. The bolt and reinforcement were simulated by truss unit. C3D8R eight-node linear hexahedron element was used to simulate the solid element, and T3D2 two-node linear three-dimensional truss element was used to simulate the truss element.

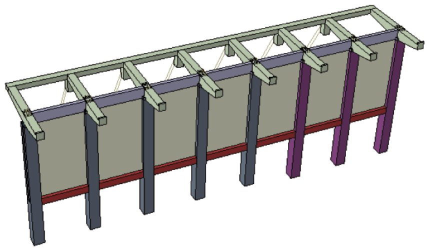
The model mainly adopts HPB300 steel bar, HRB400 steel bar, soil mass, foamed concrete, C50 concrete and C30 concrete. The steel bar adopts the double broken line constitutive model, the concrete adopts the plastic damage model, and the foamed concrete adopts the ideal elastic material model considering the calculation efficiency and the actual situation.

Fig. 2. Prefabricated cantilever composite subgrade structure.

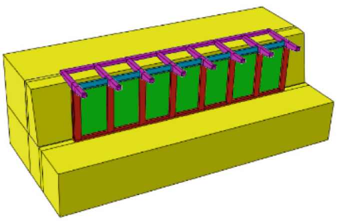
The detailed finite element model of prefabricated cantilever composite subgrade structure is shown in Fig. 3.



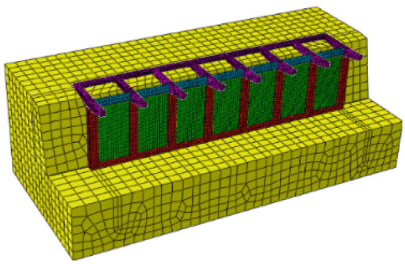
(a) Soil structure



(b) Concrete structure



(c) Finite element model



(d) Mesh diagram

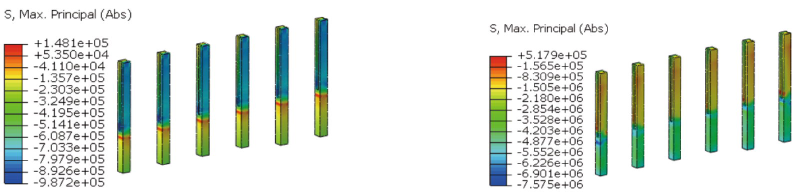
Fig. 3. Detailed nonlinear solid finite element model of PCCS.

This paper mainly discusses the influence of temperature rise on the structure of PCCS. The temperature rise of the structure is 25°. The stress of columns, beams, connecting rods and bolts in PCCS structure before and after temperature rise is analyzed to obtain the influence of temperature rise load on PCCS members. The global temperature rise is the overall temperature rise of the structure by 25°, and the local temperature rise is the temperature rise of the components except the retaining plate, retaining plate foundation and column by 25°.

4 Results Analysis

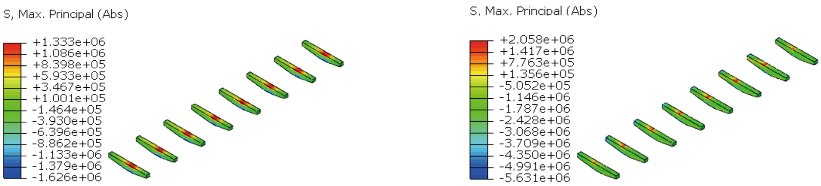
The stress states of column, beam, connecting steel bar and anchor rod in PCCS structure under various working cases are shown as follows.

4.1 Global Temperature Rising Case



(a) Before rising (b) After rising

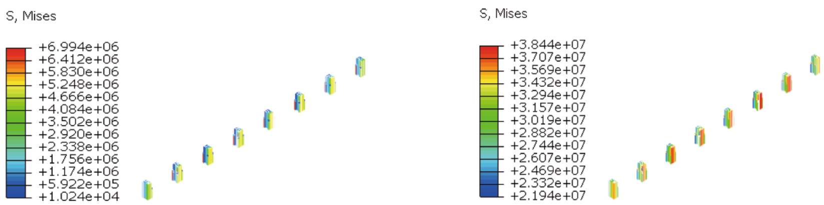
Fig. 4. Stress state of column (Pa).



(a) Before rising (b) After rising

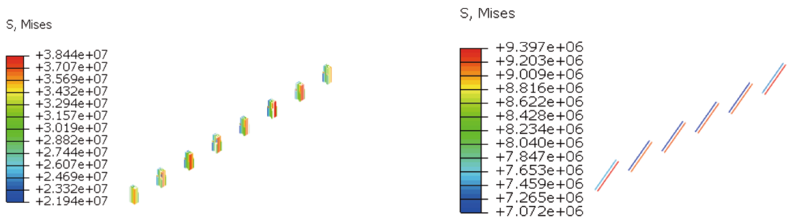
Fig. 5. Stress state of cantilever beam (Pa).

A comparative analysis of Figs. 4, 5, 6 and 7. Shows that the global temperature rise has an impact on the stress state of the column, beam, connecting steel bar and bolt. The maximum tensile stress and compressive stress of the column before temperature rise are 0.148MPa and 0.987MPa, while the maximum tensile stress and compressive stress of the column after temperature rise are 0.518MPa and 7.575MPa, and the ratios between the two groups are 3.50 and 7.67, respectively. The maximum tensile stress and compressive stress of cantilever beam are 1.333MPa and 1.626MPa before temperature rise. After temperature rise, the maximum tensile stress and compressive stress of cantilever



(a) Before rising (b) After rising

Fig. 6. Stress state of connecting bars (Pa).



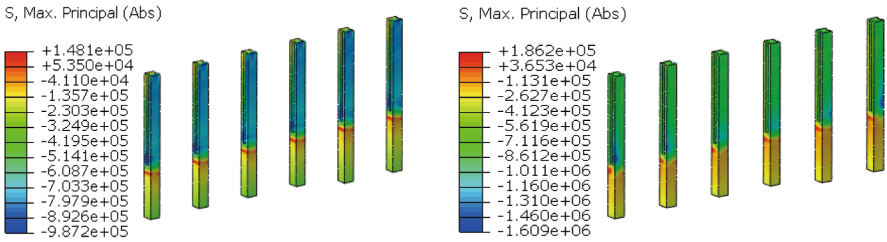
(a) Before rising (b) After rising

Fig. 7. Stress state of bolt (Pa).

beam are 2.058MPa and 5.631MPa, and the ratios between the two are 1.22 and 2.74, respectively. The maximum stress of the connected steel bar before temperature rise is 6.994MPa, and that of the connected steel bar after temperature rise is 38.440MPa, and the ratio between after temperature rise and before temperature rise is 5.50. The maximum stress of bolt is 0.078MPa before temperature rise, and 9.397MPa after temperature rise, and the ratio between after temperature rise and before temperature rise is 120.00. The research shows that the global temperature rise has a great influence on the stress of PCCS structure, and it is necessary to keep it in a safe state under the influence of temperature when designing the structure.

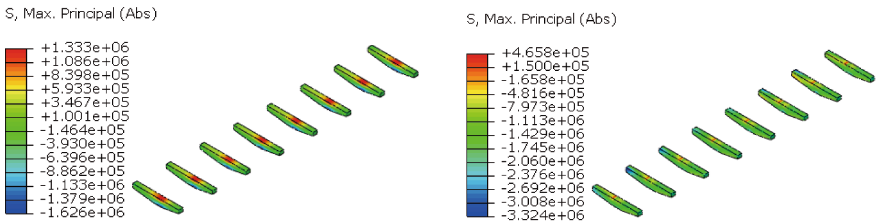
4.2 Local Temperature Rising Case

A comparative analysis of Fig. 8, 9, 10 and 11. Shows that the local temperature rise has an impact on the stress state of the column, beam, connecting steel bar and bolt. The maximum tensile stress and compressive stress of the column before temperature rise are 0.148MPa and 0.987MPa, while the maximum tensile stress and compressive stress of the column after temperature rise are 0.186MPa and 1.610MPa, and the ratios between the two groups are 1.25 and 1.63, respectively. The maximum tensile stress and compressive stress of cantilever beam are 1.333MPa and 1.626MPa before temperature rise. After temperature rise, the maximum tensile stress and compressive stress of cantilever beam are 0.465MPa and 3.332MPa, and the ratios between the two are 0.35 and 2.05, respectively. The maximum stress of the connected steel bar before temperature rise is 6.994MPa, and that of the connected steel bar after temperature rise is 37.280MPa, and



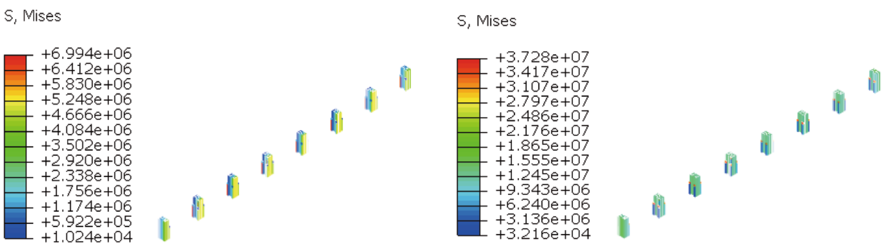
(a) Before rising (b) After rising

Fig. 8. Stress state of column (Pa).



(a) Before rising (b) After rising

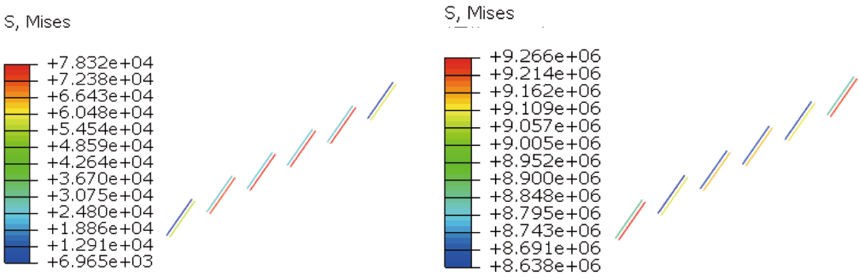
Fig. 9. Stress state of cantilever beam (Pa).



(a) Before rising (b) After rising

Fig. 10. Stress state of connecting bars (Pa).

the ratio between after temperature rise and before temperature rise is 3.33. The maximum stress of bolt is 0.078MPa before temperature rise, and 9.266MPa after temperature rise, and the ratio between after temperature rise and before temperature rise is 118.79. The research shows that the local temperature rise has a great influence on the stress of the PCCS structure, and it is necessary to keep it in a safe state under the influence of temperature when designing the structure.



(a) Before rising

(b) After rising

Fig. 11. Stress state of bolt (Pa).

According to the global temperature rise case and local temperature rise case, the temperature load mainly has the greatest influence on the stress state of the connected steel bar and bolt. This is because when the temperature rises, the structure is heated and expanded, and the connecting steel bars and bolts play their own design performance, restricting the deformation of the structure. Therefore, the stress state of the connecting steel bars and bolts increases.

For concrete members, the influence of global temperature rise is greater than that of local temperature rise. This is because the global temperature rise takes into account the temperature rise of the structure under seasonal changes, while the local temperature rise only considers the temperature rise of the structure under sunshine changes, and the two have different ranges of action on the concrete area. The larger the temperature load range is, the greater the influence on the structure, and the smaller the temperature load range is, the smaller the influence on the structure is.

5 Conclusions

Based on ABAQUS, a fine finite element model of precast cantilever composite foundation structure in mountainous highway is established, and the influence of temperature rise on structural stress is studied. The main conclusions are as follows:

(1) The overall temperature rise and local temperature rise have a great influence on the stress of the precast cantilever composite foundation structure. Under the action of temperature load, the stress state of PCCS structure is significantly improved, and its value is greater than that of the structure under static load.
(2) The temperature load mainly has great influence on the stress state of the connecting steel bar and bolt, but has little influence on the concrete member. The stress state of the connected steel bar and bolt under the global temperature rise case has little difference with that under the local temperature rise case, while the stress state of the concrete member under the global temperature rise case has a big difference with that under the local temperature rise case. The stress state of concrete member under the global temperature rise condition is greater than that under the local temperature rise case.

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