The Effect of Ceramsite Replacement Ratio on Frost-Heave Deformation of Power Transmission and Transformation Foundation in Extreme Condition

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Abstract. Under the impact of frost heave and thaw settlement of seasonal frozen soil, freezing pulling and horizontal tilt of piles often occurs. Aim to the above problems, this paper proposed a material using ceramsite replacement concrete as the foundation to reduce heat exchange with atmosphere. The results showed that when the replacement rate of ceramsite is 80%, the density of the blocks is 1896 kg/m³, which is 19.3% lower than that of plain concrete. Also, the addition of ceramsite significantly reduced the thermal conductivity of concrete. The minimum thermal conductivity of tested blocks is 0.524 W/(m·K), which is 58.6% lower than that of ordinary concrete. Meanwhile, the strength of concrete decreased the addition of ceramsite. When the replacement rate is 80%, the compressive strength and splitting tensile strength are 18.1 and 2.7 MPa, respectively, which are 54.7% and 42.6% lower than that of plain concrete. Taking the climatic environment in the Hexi area as the boundary conditions, a numerical simulation on the design and optimization of the thickness of the insulation system was carried out. It was found that the installation of 2 m insulation concrete can effectively increase the temperature of the soil in extreme environments and avoid frost heave.

1. Introduction

In the seasonal frozen area, due to poor thermal stability of permafrost and intense hydrothermal activity, the foundation of power transmission engineer are extremely sensitive to environmental changes, which will drive construction and operation and other security threat. If the project directly uses concrete as the cushion, it will not play the role of thermal insulation. Porous thermal insulation concrete belongs to the category of thermal insulation materials. It is a special concrete with certain physical and mechanical properties that covers the surface of thermal equipment and pipelines, can prevent or reduce heat exchange with the outside, and reduce heat dissipation. Compared with traditional concrete, porous concrete has the characteristics of light weight and good thermal insulation effect. At present, the common thermal insulation concrete includes aerated concrete and foamed concrete. Among them, the thermal conductivity of foamed concrete with a density range of 300kg/m³ ~1000kg/m³ is between 0.08 W/(m·K) ~0.27 W/(m·K), which is only that of traditional concrete 1/10 ~1/20, the heat preservation effect is remarkable. Foam concrete can be divided into several categories according to standards such as cementitious materials, main fillers, and bubble methods.

By comparison, clay ceramsite was selected to replace a certain volume of coarse aggregate. Ceramsite is an artificial expanded silicate porous lightweight aggregate fired by clay under high
temperature. Most of its appearance features are round or oval spheres, and its internal structure features fine honeycomb-like micropores. There is a "micropump" function between the capillary water absorption and moisture return of ceramsite [1]. This "micropump" function can exert "self-vacuum", "self-compacting", "self-wetting" and "self-wetting" in ceramsite concrete. "Self-curing" function, thus greatly improving the structure and performance of ceramsite concrete.

Considering the use of porous thermal insulation concrete as the thermal insulation layer, the improvement of thermal insulation performance will inevitably lead to the decrease of concrete strength. Therefore, it is necessary to find a suitable solution that can not only meet the requirements of thermal insulation performance, but also meet the requirements of the cushion. Required strength requirements. Sun Wenbo et al. [2] studied the influence of ceramsite content, foam content, cement content, sand ratio, water consumption, and fly ash content on the strength of ceramsite foam concrete, and determined the optimum of each component Doping. Zheng Qiuhua and Zhang Baosheng [3] found that as the pre-wetting degree of shale ceramsite increases, the early strength of lightweight aggregate concrete decreases significantly and the frost resistance decreases. Ji Yiqi et al. [4] found that when the substitution amount of ceramsite is less than 50%, the strength of concrete remains basically unchanged. Jiang Yaqing et al. [5] found that mixing a proper amount of saturated lightweight aggregate in high performance concrete can increase the internal relative humidity and promote the maximum hydration of the cement. Qiu Jisheng et al. [6] conducted low-field nuclear magnetic resonance tests on concrete with the volume substitution rate of coal gangue ceramsite (0%, 20%, 40%, 60%) , and studied the effects of coal gangue ceramsite on the microscopic pore structure and compression resistance of concrete. The impact of intensity. Han et al. [7] used expanded shale as artificial lightweight aggregate to study the stress-strain relationship and Poisson effect of concrete. Experiments show that when the density and strength of lightweight aggregates are high, the volume fraction of lightweight aggregates will non-monotonically affect the compressive strength of concrete. From the perspective of the ratio of transverse strain to axial strain, shale aggregate The Poisson effect of higher content concrete is more obvious. In the ceramic industry, about 30% of the production is waste, Senthamarai et al. [8][9] tried to find the applicability of ceramic industrial waste as a possible substitute for conventional crushed stone coarse aggregates. The test results showed that ceramic waste aggregate concrete has good workability and its strength characteristics are comparable to conventional concrete. And recycled aggregate concrete has higher permeability than conventional concrete. However, there is still a lack of relevant research on the thermal insulation performance of ceramsite concrete with high substitution rate, which limits the practical application of ceramsite concrete.

This paper studies the mix design of high-replacement ceramsite concrete, and tests the thermal insulation and mechanical properties of high-replacement ceramsite concrete. In order to verify the application of insulated concrete in the foundation of power transmission and transformation engineering, examples are used as research object, combined with site survey results and actual engineering experience, using large-scale finite element numerical calculation software ANSYS to carry out numerical calculation and analysis of different thermal protection structure forms.

2. Experimental Program

2.1. Experimental Materials
Herein include materials selected P O42.5 ordinary Portland cement and the particle size of 3~18mm ceramic. The bulk density of ceramsite is 480 kg/m³. The ceramsite saturated with water in advance will release the originally adsorbed water due to its own water absorption during the hardening process of the concrete, which will form a water film between the ceramsite and the cement paste, causing the local water-cement ratio in the area to increase, Resulting in a decrease in strength, so the ceramsite does not adopt pre-wetting treatment in advance.

2.2. Experimental Set-Up
The concrete slump is required to be 40~60mm. According to field experiments, the initial mix ratio is determined to be 1 : 0.46 : 1.67 : 1.67 (cement: water: sand: stone), and the replacement rate of
ceramsite is 0%, 20%, 40%, 60% and 80% calculated ceramsite dosages are 0, 47.3, 94.6, 142, 189kg/m³ respectively. As ceramsite concrete is prone to ceramsite floating, it causes problems such as layering and segregation of ceramsite concrete and difficulty in molding. There are two ways to solve the problem of ceramsite floating. One is to improve the cohesion of concrete itself; the other is to minimize the slump of ceramsite concrete. The effective way to improve the cohesiveness of concrete is to increase the amount of unilateral cement. Therefore, considering the water absorption of ceramsite and the floating phenomenon of ceramsite during sample preparation, based on the initial ratio, the cement replacement rate increases by 0% and 10%, 20%, 30%, 40%, water-cement ratio is 0.46, 0.48, 0.50, 0.52, 0.54. Specific concrete matching ratio is as follows:

| Ceramsite replacement rate | cement (Kg) | water (Kg) | gravel (Kg) | Ceramsite (Kg) | sand (Kg) |
|---------------------------|-------------|------------|-------------|----------------|-----------|
| 0%                        | 514         | 236.4      | 860         | 0              | 860       |
| 20%                       | 565.4       | 271.4      | 688         | 47.3           | 860       |
| 40%                       | 616.8       | 308.4      | 516         | 94.6           | 860       |
| 60%                       | 668.2       | 347.5      | 344         | 142            | 860       |
| 80%                       | 719.2       | 388.4      | 172         | 189            | 860       |

2.3. Sample Preparation
The sample molds for measuring thermal conductivity and mechanical properties are 70mm×70mm×70mm, 100mm×100mm×100mm, and three samples are prepared for each working condition. First, pour the cement, ceramsite, gravel, and sand into the forced mixer to mix evenly, and then pour the water into the mixer three times for full mixing. In the process of concrete vibrating, the density difference between the aggregate and the cementitious material is proportional to the moving speed of the aggregate [10]. The weight of the ceramsite is lighter. When the fluidity is large, the ceramsite will float up. In order to avoid the phenomenon of ceramsite floating and make the test block fully compact, the test block cannot be placed on the shaking table to oscillate. The mixed concrete should be put into the mold twice, and after the mixture is put into the mold, the ramming rod should be used for ramming. When ramming, the ramming rod should be kept vertical and evenly inserted in the mold. When ramming the bottom concrete, the ramming rod should reach the bottom of the test mold. It should penetrate the underlying concrete. After inserting and pounding, use a spatula to insert and pull out the inner wall of the test mold several times, and gently tap the surroundings of the test mold with a rubber hammer to ensure that the concrete is fully dense.

3. Test Results
3.1. Sample Densities
After the test block is formed, let it stand for one day in a curing box with a temperature of 25°C and a humidity of 99%. After removing the mold, the test block is immediately put into a curing box with a temperature of 25°C and a humidity of 99% for curing. The curing period is 28 days. After curing, the quality of the test block and the thermal conductivity measurement are carried out. The following figure shows the density comparison of the test block:
It can be seen from the above figure that with the increase of the ceramsite replacement rate, the density of the test block shows a clear downward trend. When the ceramsite replacement rate is 80%, the density of the test block is 1896 kg/m\(^3\), which is compared with the original concrete drop by 19.3%, indicating that the addition of ceramsite effectively reduced the quality of concrete.

3.2. Thermal Conductivity Measurement

The thermal conductivity of the test block is measured by the hot wire method. The hot wire method is a non-steady state thermal conductivity measurement method, which is suitable for the measurement of the thermal conductivity of homogeneous materials with thermal conductivity less than 2 W/(m·K). The basic principle is that a slender metal wire is buried in a sample with uniform initial temperature distribution. After voltage is applied to both ends of the metal wire, the temperature of the metal wire increases, and its temperature rise rate is related to the thermal conductivity of the sample.

In the experiment, the heating voltage was 0.8V, and the thermal conductivity of the test block was measured at room temperature 25°C, 50°C and 75°C. Figure 2 shows the comparison of the thermal conductivity of different ceramsite substitution rates and the test temperature. It can be seen from the figure that at room temperature, the thermal conductivity of plain concrete is 1.266 W/(m·K), and the thermal conductivity of the test block with 80% ceramsite substitution rate is 0.524 W/(m·K). The thermal conductivity of the test block is 58.6% lower than that of plain concrete, indicating that the addition of ceramsite significantly reduces the thermal conductivity of concrete. This is because ceramsite is a coarse aggregate with high porosity, which helps to form a porous structure inside concrete. Thereby improving the thermal insulation performance of concrete. And it can be seen that with the increase of the test temperature, the thermal conductivity of the test block shows a downward trend. This is because when the temperature is less than 100°C, the water content has a great influence on the thermal conductivity of concrete. The thermal conductivity of concrete increases with temperature. When the temperature is above 100°C, the influence of water content on the thermal conductivity of concrete will gradually decrease with the increase of time and temperature due to the evaporation of water.

4. Numerical Simulation of Thermal Insulation Foundation

In order to verify the application of thermal insulation ceramsite concrete in the foundation of power transmission and transformation, the typical tower foundation of the 750kV Hexi Power Grid Strengthening Project was taken as the research object, combined with the field survey results and actual engineering experience, the large-scale finite element numerical calculation software ANSYS was used to Numerical calculation and analysis of the thermal protection structure are carried out, and the temperature change results of the tower foundation and surrounding soil under different working conditions are obtained.
Figure 3. Model grid division: (a) original stratum; (b) thermal protection structure form 1.5-0.5; (c) thermal protection structure form 0.5-1.5; (d) thermal protection structure form 2-0

Figure 3 shows the grid division of three thermal protection structure models with different protection layer thicknesses at the upper and lower ends of the original stratum and the upper and lower ends of the cap. The top-down soil materials of the stratum are silt, fine silt, round gravel, gravel sand, and round gravel. Gravel: In the foundation part of the tower foundation, the green part is the cap part, the pink is the backfill, and the orange is the thermal protection material. The thermal conductivity of the thermal protection material ceramsite concrete is 0.28 W/(m·°C). The width of the upper surface of the tower foundation is 2.0 m, the excavation foundation is 5.0 m deep, and the cap height is 3.0 m. The depths of the bottom layer of the first 1-5 soil layers are 1.5 m, 3.0 m, 5.0 m, 8.0 m, and 11.0 m respectively.

Figure 4 shows the temperature change of the model center line in each structure. It can be seen from the figure that the temperature value of the center line increases as the depth increases, and it changes linearly in the same material. The freezing point temperature of the original formation model can be reached at a depth of -6.3 m, and the model with thermal protection materials can significantly increase the depth to the freezing point temperature. The depths of the bottom of the caps of the thermal protection structures of 1.5-0.5, 0.5-1.5, and 2-0 thermal protection structures are respectively -4.5 m, -3.5 m, -5 m, and their centerline temperatures are -2.0°C, -12.7°C, 4.9°C. Therefore, the 2-0 heat protection structure has the best effect.
For the pile cap, not only the thermal protection of the pile cap structure must be realized, but also the deformation and stress requirements for the entire foundation. Figure 5 is a structure 2-0, the formation of different depths (0, -1.5, -3.0, -5.0, -8.0m) in the Y direction displacement value and lower ends of insulation X- , Y direction stress values. From FIG. 6(a) can be seen, the formation of different depths Y direction displacement direction horizontally symmetrically, foundation excavation region at a depth of 0 m having a maximum Y direction displacement -9 mm , at a depth of -8.0 m when The Y- direction displacement is the smallest, the other depths (-1.5, -3.0, -5.0m) Y- direction displacement change trend and size are basically the same, the Y- direction displacement of the bottom of the platform is ~8mm, There is no obvious uneven settlement of the foundation. From Figure 6(b), it can be seen that the maximum X and Y stresses of the 2-0 thermal protection structure are 31.8 and 13.8MPa, respectively. In summary, the deformation and mechanical properties of the caps meet the actual engineering requirements.

5. Conclusion
Through the research of this article, the following conclusions are obtained:
(1) The addition of ceramsite effectively reduces the quality of concrete. When the substitution rate of ceramsite is 80%, the density of the test block is 1896 kg/m³, which is 19.3% lower than that of plain concrete.

(2) The addition of ceramsite significantly reduces the thermal conductivity of concrete. The thermal conductivity of 80% of the test blocks is 0.524 W/(m·K) , which is 58.6% lower than that of plain concrete.

(3) Taking the climatic environment of Hexi area as the boundary conditions, a numerical study on the optimization of the thickness design of the insulation system was carried out. Through comparison,
it is found that the installation of 2-meter-thick insulation concrete can effectively increase the temperature of the soil in extreme environments and avoid frost heave.

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