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An application of expanded polystyrene board in frozen regions

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ABSTRACT: During winter, water-conveyance structures and channels will be freezing, and this problem of frozen damage seriously affects the operational safety of hydraulic engineering works. Therefore, in the design stage, construction stage and operation stage of projects, the preventive measures of frozen damage must be done properly. This paper mainly deals with the problems, which exist in the application of Expanded Polystyrene Board in the hydraulic engineering works in Heilongjiang province of China. According to the frozen damage characteristics of such hydraulic structures in Heilongjiang province and in combination of field simulation, the design method of using Expanded Polystyrene Board for hydraulic structure to prevent frozen damage, is explained in this article.

1 INTRODUCTION

Heilongjiang province is situated in the cold regions in the north of China, most of which is seasonal frozen regions. In order to reducing the frozen damage to the foundation of hydraulic structures (such as retaining wall, sluice bottom, channel, etc.), expanded polystyrene foamed plastic sheet with excellent thermal insulation property and higher compressive strength are often used in hydraulic engineering in seasonal frozen regions. Which can be classified into expanded polystyrene (EPS) and rigid extruded polystyrene foam board in terms of their production technology. EPS has a wider application in foundation works of hydraulic engineering and highway engineering in the north of China, on account of its easier production technology, larger production scale, flexibility and relatively low cost. EPS with not too high density is often used as thermal insulation filler of walls, but EPS with actual low density is also used in some important hydraulic structures.

This paper mainly introduces "the design parameters of polystyrene foamed plastic sheet in frozen regions", a project of Heilongjiang Provincial Department of Science and Technology, which is undertaken by our institute. Through the research of this issue, and aiming at the defects of the existing antifreeze design standard for hydraulic structures with respect to polystyrene foamed plastic sheet parameter design method and requirement, we put forward the basic idea of designing according to the requirements for thermal insulation property, strength and durability, and also provide basis for "Antifreeze design standard for channel system projects" which is being revised at present, and parts of the content in this paper was adopted in the revision.

2 PROBLEMS

Now, researches mostly focus on the thermophysical analysis and study of EPS, at home and abroad. To provide a reliable theoretic basis for design and construction and to guide the frozen damage prevention of constructed works, the existing research achievements still have deficiency in research depth and direction, which is mainly embodied in the following respects:

(1) It mainly uses EPS as thermal insulation measures, and don't consider the others performances of it comprehensively, such as the capability of resisting the blister deformation of earth body and durability, and other parameter indexes.
(2) Since 1970s, some of the researches we did about the application of EPS in frozen regions are theoretical discussions and general researches on temperature characteristics, but the researches on thermal insulation foundation works under specific conditions are fewer, especially studies on the

effect of thermal insulation layer on the frozen damage prevention for structures under the actions of water, soil, temperature and pressure. These specific conditions include geographical and topographical condition, atmospheric temperature condition, engineering geology and hydrological geology condition, and so on.

Aiming at some problems exposed in the prevailing application of "Design specification of hydraulic structures against ice and freezing action", which urgently needed to be solved, Heilongjiang Provincial Hydraulic Research Institute makes "the design parameters of polystyrene foam in frozen regions". And we are trying to give the physical and mechanical design parameters and indexes of the EPS thermal insulation boards suitable for the foundation load of hydraulic structures in frozen regions qualitatively and quantitatively, to provide a scientific basis for revising "Design specification of hydraulic structures against ice and freezing action", to improve the antifreeze design level of hydraulic structures in frozen regions, to save construction investment and prolong the service life of structures.

3 FIELD SIMULATION EXPERIMENT

Wanjia frozen soil experiment station was chosen as experiment site, which is located approximately at longitude 125°36′47″E and latitude 45°43′55″N. The frozen soil experiment station has a smooth terrain and the soil is low liquid limit clay. Mean annual temperature of the frozen soil station is 3.5°C, the minimum temperature is –38.5°C and the freezing index is 1600-1900 (°C • d). The earth freezes firmly from the first 10 days of November every year, the earth surface does not melt until the middle 10 days or the last ten-day of March of next year, and in the middle 10 days of June the frozen soil layer will thoroughly melt. The freezing period is about 6-7 months. The freezing depth is 160 cm or so for general earth and the average freezing rate is 1.33 cm/d – 1.6 cm/d.

In the experiment station, 10 field observation works with different density and thickness of EPS thermal insulation board foundations were constructed, with the sides that $4 \times 4m^2$, and was covered with 5 cm concrete. The observation of temperature fields under the thermal insulation boards on the conditions of the same natural factors and the equal type and water content of soil, to research on the laws of temperature changes and the effect of thermal insulation under EPS boards with different density and thickness, through the contrast experiment.

Figure 1 and Figure 2 show the result of two tests. One field observation model wasn't treated with EPS thermal insulation board, the other was typical model treated with EPS thermal insulation board with the density of 30 kg/m^3 and the thickness of 15 cm, which showed the observed results of the whole winter of 2003 to 2004. According to the analysis of the temperatures of the earth layers above and below the thermal insulation board and the temperature field of the earth body, it is clearly that the foundation which has been treated with thermal insulation measures can guarantee the surface temperature of the field above zero to keep the soil unfrozen, and the stability of the foundation temperature field. So the heat physical capability of EPS thermal insulation board

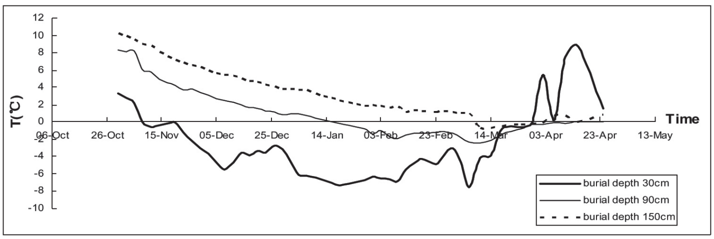

Figure 1. Ground temperature-time curves for different foundation earth layers.

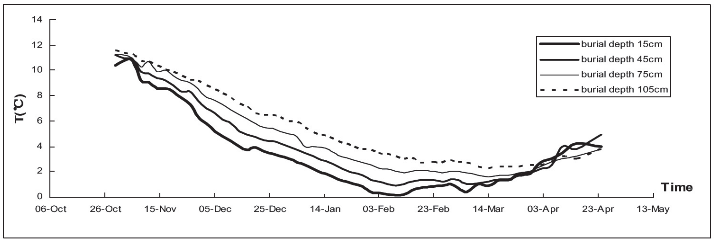

Figure 2. 30 kg density 15 cm thickness benzene board temperature-time curves.

makes an important role to the stability of the soil temperature field.

4 SLECTION OF DESIGN PARAMETERS

4.1 *Determining the design heat conduct coefficient*

As hydraulic structures contact with water permanently, according to Figures 3 and 4 the thermal conductivity is related to water absorption rate, it has to be corrected in choosing thermal insulation materials so that the corrected thermal conductivity can be used for the design calculation of hydraulic structures. This requires the introduction of a correction factor α. If the thermal conductivity in the standard is λ_0, the design thermal conductivity λ_d is:

$$\lambda_d = \alpha\lambda_0 \qquad (1)$$

Where: λ_d – the design value of thermal conductivity (the material thermal conductivity used for actual calculation in the thermophysical design of hydraulic structures in combination with material correction), W/(m·K);

λ_0 – the standard value of thermal conductivity (the thermal conductivity in dry condition), chosen according to National Standard, W/(m·K);

α – the correction factor of thermal conductivity; it is equal to the ratio of λ_{wet} to λ_0 and can be found in Figure 5.

4.2 *The calculation of design thickness of thermal insulation boards*

The correlation analogy method is generally applied for the design calculation of thickness of thermal

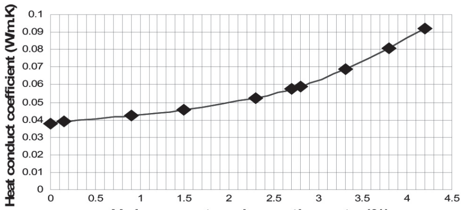

Figure 3. Thermal conductivity – volume water absorption rate curve.

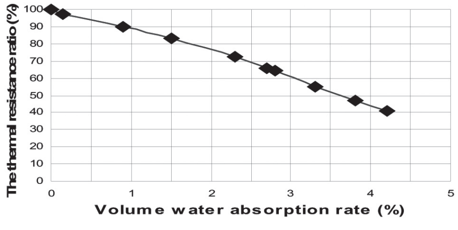

Figure 4. Thermal resistance ratio-volume water absorption rate curve.

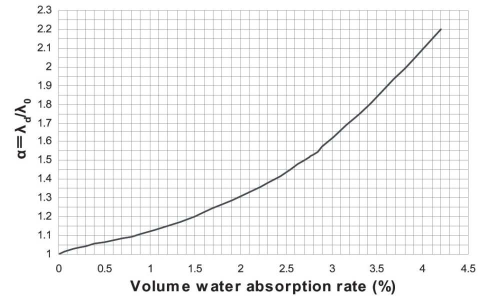

Figure 5. Correction factor of thermal conductivity – water absorption rate curve.

insulation boards. The essence of this method is to find the critical thermal resistance value R_0 of the thermal insulation foundation, where there is just no frozen layer under the model board, and to consider it as the design reference thermal resistance of similar project thermal insulation bottom board, then to calculate the thermal resistance value of the thermal insulation foundation of the project to be constructed, in connection with the relation of thermal resistance ratio and freezing index. The thermal insulation foundation on the model site and the freezing index are related with the following expression:

$$R = R_0\sqrt{\frac{I}{I_0}} \qquad (2)$$

Where: R – the thermal resistance of thermal insulation foundation of the project to be constructed, m^2·K/W;
R_0 – model thermal resistance (found by experimental method), m^2 · K/W;
I – the freezing index of the site of the project to be constructed, °C · d;
I_0 – the freezing index of the site of the model project, °C · d;

The model thermal resistance of full thermal insulation foundation (there is just no freezing layer under the foundation board) is: R_0 = 2.6 m^2·K/W. Substitute the corresponding actually measured freezing index I_0 = 1870°C · d into the below formula to find the thermal resistance value of the thermal insulation foundation of the project to be constructed.

$$R = 0.06\sqrt{I}\,KK_w \qquad (3)$$

Where: K_w – thermal resistance coefficient of correction. When I_0 = 100-2800°C · d, K_w = 0.71-1.19, the K_w value can be taken by interpolation method.

K – safety factor, which depends on factors such as structure region, constructional form, hydrology, geology, etc., and generally take 1.1-1.2

In terms of the thermophysical principle, the thermal resistance of the thermal insulation foundation of the project to be constructed is equal to the sum of

Table 1. Thermal resistance value correction factor K_w.

I_0	50	100	300	500	800	1000	1200	1500	1870	2000	2200	2400	2600	2800
Kw	0.71	0.71	0.74	0.77	0.81	0.85	0.88	0.93	1.00	1.03	1.06	1.11	1.15	1.19

Table 2. Calculation of the thermal insulation board thickness D_0 (cm).

Coefficient of heat conductivity (W/(m·K))	Freezing index I_0(°C · d)													
	50	100	300	500	800	1000	1200	1500	1800	2000	2200	2400	2600	2800
0.039	1.2	1.8	3.3	4.4	5.9	6.9	7.8	9.3	10.8	11.8	12.8	13.9	15.0	16.2
0.040	1.3	1.9	3.4	4.5	6.0	7.1	8.1	9.5	11.1	12.1	13.1	14.3	15.4	16.6
0.045	1.5	2.1	3.8	5.1	6.8	8.0	9.1	10.7	12.5	13.6	14.7	16.1	17.3	18.7
0.050	1.6	2.4	4.3	5.6	7.5	8.9	10.1	11.9	13.9	15.1	16.4	17.9	19.3	20.8
0.055	1.8	2.6	4.7	6.2	8.3	9.8	11.1	13.1	15.3	16.6	18.0	19.7	21.2	22.8
0.060	2.0	2.9	5.1	6.8	9.0	10.7	12.1	14.3	16.7	18.2	19.7	21.5	23.1	24.9
0.070	2.3	3.3	6.0	7.9	10.5	12.4	14.1	16.6	19.4	21.2	22.9	25.0	27.0	29.1
0.080	2.6	3.8	6.8	9.0	12.0	14.2	16.1	19.0	22.2	24.2	26.2	28.6	30.8	33.2

Note: The values in the table can be interpolated

surface thermal resistance, concrete foundation thermal resistance and thermal insulation layers thermal resistance, that is:

$$R = \frac{1}{a} + \frac{s}{\lambda_s} + \frac{\delta_0}{\lambda_h} \tag{4}$$

$$s = \left(R - \frac{1}{a} - \frac{\delta_0}{\lambda_h} \right) \lambda_s \tag{5}$$

Where: a surface heat emission coefficient, $a = 13\sqrt{V}$; generally take a = 15 for engineering;
S – thermal insulation layer thickness, m;
λ_s – thermal conductivity of thermal insulation layer material, W/(m·K);
λ_h – thermal conductivity of the corresponding thermal insulation layer, concrete, W/(m·K);
δ_0 – thickness of concrete (plastered as a liner) foundation, m;
V – local average wind speed, m/sec.
The design thickness of thermal insulation board is calculated according to the following formula:

$$D = a\left(K_d \lambda_0 R - \delta \frac{\lambda_0}{\lambda} \right) \tag{6}$$

Where: K_d – correction factor based on sunshine and shading and can be chosen according to "the channel system project antifreeze design standard."
δ – thickness of foundation board, cm;
λ – thermal conductivity of foundation material, and it is 1.74 W/m·K for reinforced concrete and 1.55 w/m·K for concrete.
D_0 – the product of λ_0, thermal conductivity of thermal insulation material, and R, the thermal resistance value of thermal insulation foundation of the project to be constructed and can be found according to Table 2.

5 CONCLUSION

EPS thermal insulation board is light weight, high strength, low water absorption rate, good thermal insulation and convenient in transportation. The application of EPS thermal insulation board as the antifreeze thermal insulation body for the foundation earth of hydraulic structures in frozen regions is an effective method.

In calculating the thermal insulation board thickness, using the correlation analogy method is effective.

In choosing the design thermal conductivity of EPS thermal insulation material, the thermal conductivity used in normal conditions cannot be chosen, and the factors such as project site condition, hydrology, geology (ground water, soil water condition, moisture, etc.) should be considered in a most unfavorable way (hydraulic structures in a water saturated conditions permanently) to choose the design thermal conductivity.

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