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A study of the insulating and anti-frost heave effects of polystyrene boards under molded bag concrete conditions

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ABSTRACT

In this study, the channel frost heaving actions in the Hetao irrigation area of Inner Mongolia were examined and a field *in-situ* test platform was established. Then, experimental investigations were conducted regarding the insulating and anti-freeze effects of polystyrene boards under the conditions of concrete bags with different thicknesses. In this study's experiments, concrete bags with different thicknesses were set, along with a test block of polystyrene boards with different thicknesses. The research results showed that by adding 2–5 cm molded bags, the total accumulated temperature increased in the range of 3.93–9.22% and the frost heave rate decreased by between 18.28 and 55.44% concrete, on the basis of 10 cm molded bag concrete. In addition, when 4–8 cm polystyrene boards were laid, the total accumulated temperature increased by 207.63–272.25%, and the frost heave rate decreased by between 71.43 and 96.6%. The absolute slope of the curve fitting of the frost heave rates and the soil temperatures decreased by 44.6–58.7%.

Key words: Frost heave rates, Heat preservation and anti-freezing technology, Molded bag concrete, Polystyrene board

HIGHLIGHTS

- The results show that, the biggest bending moment of channel slope is in the 1/3 of canal slope, the biggest shear is in the toe of slope, the biggest bending moment of canal bottom is in the 1/2 of the Canal bottom.
- According to the judgment of Typical Channel, frost heaving damage will occur on the slope and bottom of the South Branch Canal without taking insulation measures.

1. INTRODUCTION

It has been found that with the recent progress in the fields of science and technology, irrigation technology and modern agricultural processes throughout the world have rapidly developed. Currently, there have been increases observed in such trends as permanent crops to cultivated areas, human developmental indexes (HDI), irrigation water requirements, and the percentages of total cultivated drained land areas. Although agricultural water withdrawal as percentages of the total water withdrawal have decreased due to industry and population growth, as well as the applications of pressurized irrigation and management strategies to increase efficiency, more than 40% of the global irrigation potential has not yet developed (Valipour, 2017). The different aspects of irrigation in agricultural water management processes, such as irrigation efficiency, soil salinity, water-saving techniques, sustainable development, soil water management, and crop yields have been investigated in previous research endeavors. In addition, the Food and Agriculture Organization revealed that pressure on water resources for irrigation will continue to increase until 2050. The findings presented warn against trial-and-error policies in regard to cropping intensity and recommend the involvement of specialists to help plan appropriate irrigation systems according to crop/plantation types (Valipour, 2016). According to the climate characteristics of specific areas, the development of appropriate irrigation systems will become important methods to ensure regional economic and agricultural development.

Bag concrete is an integral structure formed by pouring fluidity concrete into bags with high pressure pumps, which solidify after the excess water oozes from the fabric gaps. These bags are made of geosynthetics woven into two layers with certain thicknesses. This technology has the characteristics of fast construction speed, labor and time conservation, easy operation, and strong terrain adaptability. Therefore, they have been widely used in roads, reservoirs, river channels, seawalls, and other projects. From the aspect of the lining technology of concrete channels using molded bags both in China and internationally, research investigations have been carried out mainly for concrete structures, material, and the application effects of molded bags. Li (2016) studied the bag concrete channels constructed in the Hetao irrigation area of Inner Mongolia from the perspective of their mechanical properties. Wang & Huo (2019) proposed an optimized mix ratio for molded bag concrete. Zhang *et al*. (2019a, 2019b) discussed the concrete roughness of molded bags and their influencing factors. Wang & Huo (2019) completed analyses and examinations of the freeze resistance and macroscopic mechanical properties of molded bag concrete via measuring the mass loss rates and relative dynamic elastic modulus of test blocks with different mixing ratios. At the present time, the research regarding the thermal insulation and anti-freeze technology of polystyrene boards used in precast concrete and cast-in-place concrete channels is relatively common. However, the present research regarding the thermal insulation and antifreeze technology of polystyrene boards laid in the concrete channels of molded bags remains minimal (Guo & Lou, 2013). Therefore, in order to address this lack of data, combined with the characteristics of soil and climate in the Hetao irrigation area of Inner Mongolia, this study carried out an experimental study regarding the laying of polystyrene boards with different thicknesses under the conditions of molded bag concrete.

As a means of effective irrigation water management, channels play important roles in seasonal frozen soil irrigation areas. Most of the previous channel studies in China have been focused on precast concrete lined channels. However, as a new material lining channel, molded bag concrete channel has not been studied in depth, especially in Hetao irrigation area of Inner Mongolia. In particular, there are no detailed research results on the suitable laying thickness of molded bag concrete, the suitable laying thickness of polystyrene board under the condition of molded bags, and the insulation effect of molded bag concrete. In this paper, a large amount of research work has been carried out systematically and comprehensively for the first time in the field of molded bag concrete. In the present study, the change laws of the freezing heave actions, freezing depths, and the ground temperatures of the foundation soil under the conditions of molded bag concrete with different thicknesses were analyzed. In addition, the relationships between the thicknesses of molded bag concrete and the freezing heave actions of the foundation soil were examined. In this study's experiments, the insulation effects of 4–8 cm polystyrene boards laid under the concrete condition of 10 cm mold bags were investigated, and optimal schemes for the insulation and anti-frost expansions of concrete linings of molded bags for the backbone channels in the Hetao irrigation area were explored. The goal of this study was that as the ground temperature increased, the frozen depths and frost heaving rates of channel foundation soil could be effectively reduced, thereby improving the anti-frost heaving effects of the molded bag concrete and service life of the project. The findings of this study were considered to be of major significance for the construction of modern irrigation areas and the improvement of irrigation system levels.

2. MATERIALS AND METHODS

2.1. Test design

In the Hetao irrigation area of Inner Mongolia, platforms for the concrete treatments of different molded bags were successfully established. Each test platform had an area of 4 m × 4 m, and a total of six bag concrete treatment platforms constructed. Treatments 1–3 included the laying of 10 cm, 12 cm, and 15 cm molded bag concrete structures without heat preservation. Then, polystyrene insulation boards with thicknesses of 4 cm, 6 cm, and 8 cm were laid under the concrete of the remaining three 10 cm molded bags (4–6). The 6 cm thick polystyrene boards were laid vertically around each treatment block at a depth of 1 m in order to prevent interference from horizontal frost heaving actions.

The schematic diagram of this study's constructed frost heave test platform is shown in Figure 1, and the testing process is detailed in Table 1. The experimental testing was conducted from November of 2015 to April of 2018, with a total of three freezing cycles.

In the Hetao area, the concrete construction thicknesses of the main channel molded bags generally ranged between 10 and 15 cm. In the present study, with consideration given to economic efficiency, insulation boards were laid under the 10 cm molded bag concrete for the purpose of testing the design. The insulating and anti-frost heave effects of the lining structure consisting of the molded bag concrete and the insulation boards were discussed in detail.

2.2. Observational content and methods

Soil temperatures: An automatic temperature sensor was utilized in this study to monitor the changes in ground temperature, with an observation accuracy of ±0.5 °C achieved. The ground temperature data were automatically collected and stored, and then transmitted to this study's central control platform via a GPRS network.

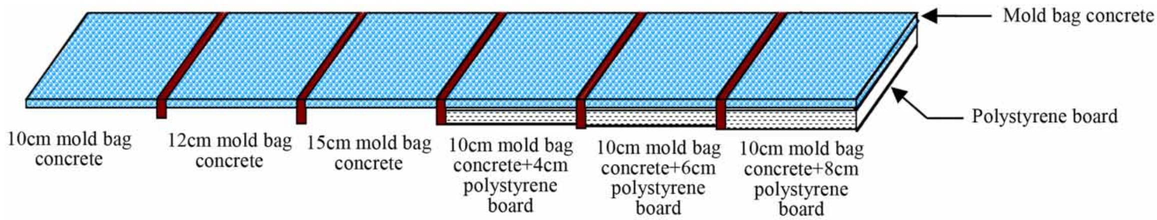

Fig. 1. | Sketch map of frost heave test platform of the different molded bag concrete treatments.

Table 1. | Test design for the different molded bag concrete treatments.

Experimental treatments	Thicknesses of the molded bag concrete/cm	Heat preservation treatments
Treatment 1	10	No insulation
Treatment 2	12	No insulation
Treatment 3	15	No insulation
Treatment 4	10	4 cm polystyrene boards
Treatment 5	10	6 cm polystyrene boards
Treatment 6	10	8 cm polystyrene boards

Frost heaving rates of the foundation soil: A reference pile of frost heave was embedded in the test site, and the frost heaving rates of the foundation soil were monitored by level.

Freezing depths of the subsoil: A set of freezing depth monitoring systems was embedded in the test site for the purpose of monitoring the freezing depths of the subsoil under the concrete treatment conditions of each molded bag. The freezing depths were recorded once every 5 days during the freezing periods.

3. RESULTS AND ANALYSIS

3.1. Insulation effects of the different molded bag concrete treatments

3.1.1. Variation law of the daily mean temperature of the concrete treated with different molded bags

Statistical analyses were conducted on the daily mean temperatures of the concrete treatments with different molded bags (buried 30 cm deep) in the test site from 2015 to 2016. In addition, the daily mean temperature variations of the concrete treatments involving six different molded bags were examined, as illustrated in Figure 2.

As can be seen in Figure 2, the daily mean temperature of the six treatments first decreased and then increased over time. The changes in the three treatments of 10 cm, 12 cm, and 15 cm molded bag concrete were observed to be basically the same, which indicated that the increases of the thicknesses of molded bag concrete had not significantly increased the insulation effects. For example, under the concrete condition of the 10 cm molded bags, the changes in the three treatments in which 4 cm, 6 cm, and 8 cm polystyrene boards were laid, respectively, were found to be basically the same. These results indicated that the differences in the daily average temperatures between the 4 cm, 6 cm, and 8 cm laid polystyrene boards were also small.

However, there were significant differences in the daily mean temperatures observed between the laid insulation boards (4 cm, 6 cm, and 8 cm polystyrene boards) and the non-insulated boards (10 cm molded bag concrete, 12 cm molded bag concrete, and 15 cm molded bag concrete). The average daily temperatures of the laid insulation board treatments were above the zero-temperature line. Meanwhile, the average daily temperatures of the non-insulation treatments were found to be below the zero-temperature line one-third of the time. Therefore,

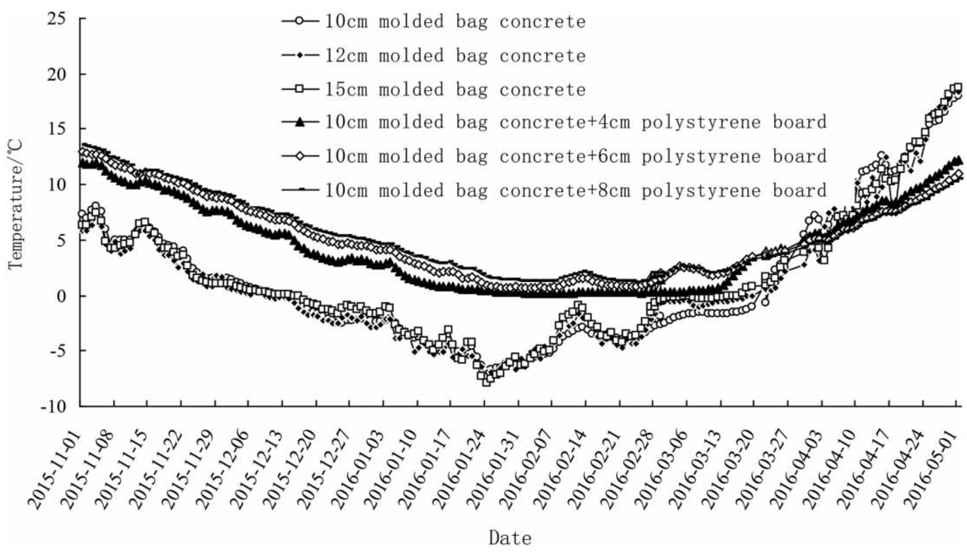

Fig. 2. | Curves of the daily average temperature variations of the concrete treated with different molded bags from 2015 to 2016.

the obtained results showed that the effects of heat preservation were not significantly improved by increasing the thicknesses of the concrete. However, the heat preservation effects could be significantly improved by the laying of heat preservation boards.

3.1.2. Total accumulated temperature and the effects of the increasing temperatures on the molded bag concrete with different thicknesses

The daily average temperature data of the concrete treatments with six different molded bags during three freezing–thawing periods within this study's test site were accumulated in order to obtain the total accumulated temperature values of each treatment. Then, the average total accumulated temperatures and average warming effect values of each treatment were calculated, and the average total accumulated temperature and average warming effect of the concrete treatments utilizing different molded bags were drawn, as detailed in Figure 3.

As can be seen in Figure 3, the average total accumulated temperatures of the molded bag concrete with no insulation treatments at 10 cm, 12 cm, and 15 cm were 278.35 °C, 289.30 °C, and 304.01 °C, respectively, and there were no significant differences observed between them. The average total accumulated temperatures of the concrete in the three types of treatments which included insulation boards were 856.29 °C, 955.10 °C, and 1,036.17 °C, respectively, which were significantly higher than those without insulation. Therefore, on the basis of 10 cm molded bag concrete, adding 2–5 cm molded bag concrete, the heating effects ranged between 3.93 and 9.22%. However, when 4–8 cm polystyrene boards were laid, the heating effects were between 207.63 and 272.25%. These results indicated that the molded bag concrete did not have significant heat preservation effects, but the heat preservation boards had very good insulation effects.

Polystyrene boards have the characteristics of low thermal conductivity. In this study, when the polystyrene boards were laid under the condition of molded bag concrete, the conduction between the temperatures of channel foundation soil and the external temperatures was reduced. Therefore, the polystyrene boards played the role of heat preservation and increased the temperatures of the channel foundations.

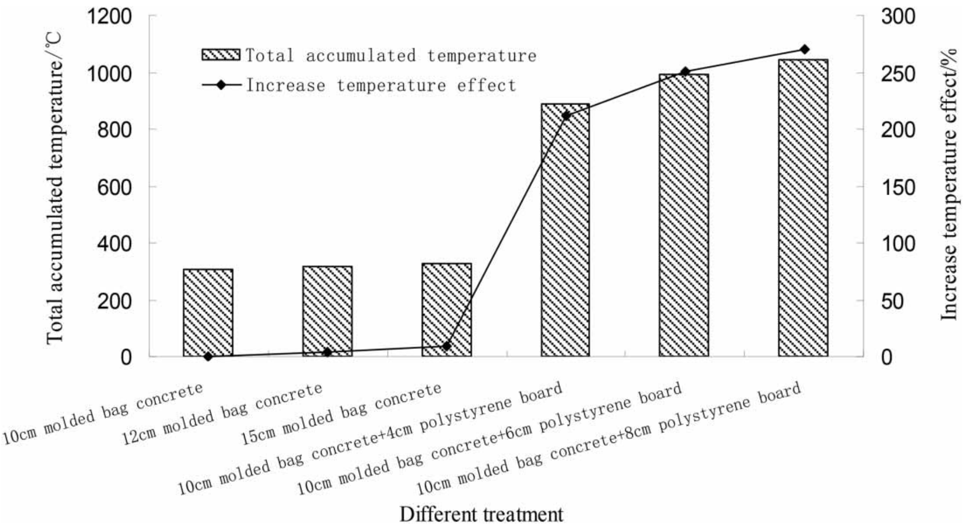

Fig. 3. | Curves of the total accumulated temperature and the increasing temperature effects of the different molded concrete bag treatments.

3.1.3. Effects of the thermal insulation plates on the soil temperatures at different depths

An average ground temperature distribution diagram of 0–50 cm soil layer in the study site without heat preservation (comparison section) is shown in Figure 4.

In the present study, in accordance with the analysis results of the ground temperatures at different depths, it was determined that with the increases in the thicknesses of the insulation boards, the ground temperatures of the 0–10 cm soil layers on the surface had increased less. These findings indicated that the laying of the insulation boards had less influence on the ground temperature of the 0–10 cm soil layer on the surface. However, with the increases in the thicknesses of the insulation boards, the ground temperatures of the 10–40 cm soil layers changed greatly. In particular, without the insulation treatments and the laying of the 4 cm polystyrene boards, the ground temperatures of the 10–40 cm soil layers were observed to change the most significantly. The results showed that when the insulation boards were laid on the concrete foundation of the molded bags, the greatest influencing effects had occurred for the ground temperatures of the 10–40 cm soil layers.

3.2. Anti-frost heaving effects of the different molded bag concrete treatments

3.2.1. Maximum frost heaving capacities and reductions in the frost heaving capacities observed in the different molded bag concrete treatments

Tables 2–4 detail the maximum frost heaving rates and reduction rates of the different molded bag concrete treatments during three complete freezing–thawing periods from 2015 to 2018.

As can be seen from the above tables, the maximum frost heaving rates of the three treatments of molded bag concrete plus insulation boards were all below 3 cm. Meanwhile, the frost heaving rates of the three treatments of molded bag concrete without insulation boards were between 5.4 and 10.3 cm. Therefore, on the basis of 10 cm molded bag concrete, when 2–5 cm of molded bag concrete were added, the frost heave rates were reduced by between 18.28 and 55.44%. Then, when 4–8 cm polystyrene boards were laid, the frost heave reduction reached 71.43–96.6%. Therefore, it was evident that the laying of insulation boards under the molded bag concrete could significantly reduce the frost heaving actions of the foundation soil. In addition, the thicker the laid insulation board was, the more greatly the frost heave rates were reduced. Therefore, the frost heave reduction effects of the polystyrene boards were significantly greater than that of increased molded bag concrete.

3.2.2. Relationships between the concrete thicknesses and the maximum frost heave rates

The obtained statistical data of the maximum and average values of the maximum frost heave in the molded bag concrete, along with this study's comparison of the 10 cm, 12 cm, and 15 cm molded bag concrete during the three test years, are shown in Table 5.

The fitting of the data between the average values of the maximum frost heaving rates and the thicknesses of the molded bag concrete was completed, and the relation curves between the maximum frost heave of the foundation soil and the thicknesses of the molded bag concrete were obtained using Formula (1):

$$f = -0.4406h^2 + 2.2736h + 117.56;\ \mathrm{R}^2 = 0.9767 \tag{1}$$

In the formula, h represents the thickness of the molded bag concrete (cm); and f is the maximum value of the frost heaving (mm).

It can be seen from Formula (1) that there was a binomial relationship between the maximum frost heave of the foundation soil and thickness of the molded bag concrete, and the maximum frost heave decreased with the increase in the thickness of the molded bag concrete.

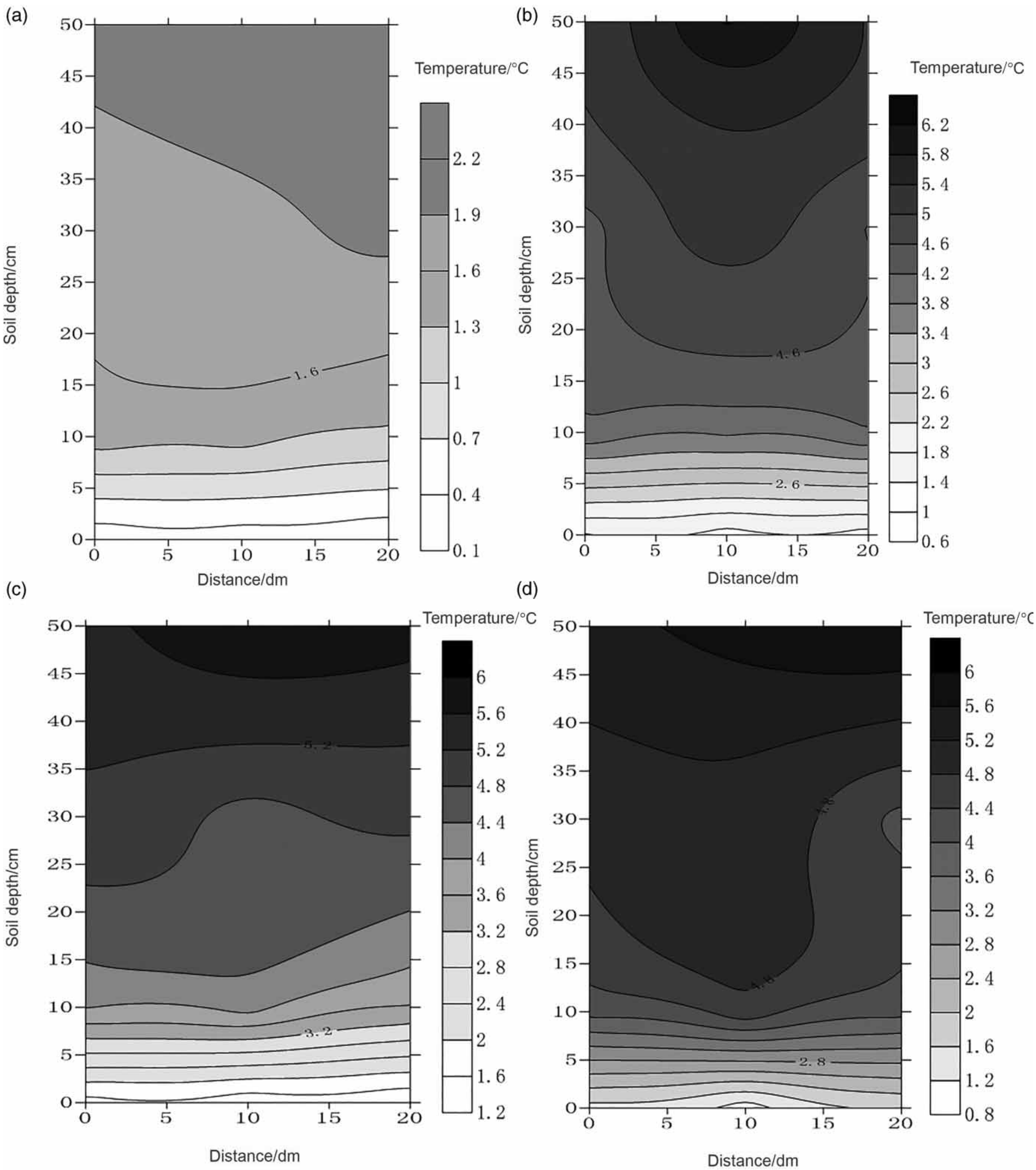

Fig. 4. | Soil temperature distribution map of the different treatments: (a) 10 cm molded bag concrete + no insulation; (b) 10 cm molded bag concrete +4 cm polystyrene boards; (c) 10 cm molded bag concrete +6 cm polystyrene boards; (d) 10 cm molded bag concrete +8 cm polystyrene boards.

Table 2. | Maximum frost heaving rates of the different molded bag concrete treatments from 2015 to 2016.

Molded bag concrete treatments	10 cm molded bag concrete	12 cm molded bag concrete	15 cm molded bag concrete	10 cm molded bag concrete		
				4 cm polystyrene boards	6 cm polystyrene boards	8 cm polystyrene boards
Maximum values/mm	105	82	63	30	17	8
Reductions/mm	0	23	42	75	88	97
Reduction rates (%)	0	21.90	40.00	71.43	83.81	92.38

Table 3. | Maximum frost heaving rates of the different molded bag concrete treatments from 2016 to 2017.

Molded bag concrete treatments	10 cm molded bag concrete	12 cm molded bag concrete	15 cm molded bag concrete	10 cm molded bag concrete		
				4 cm polystyrene boards	6 cm polystyrene boards	8 cm polystyrene boards
Maximum values/mm	93	76	54	26	15	6
Reductions/mm	0	17	39	67	78	87
Reduction rates (%)	0	18.28	41.94	72.04	83.87	93.55

Table 4. | Maximum frost heaving rates of the different molded bag concrete treatments from 2017 to 2018.

Molded bag concrete treatments	10 cm molded bag concrete	12 cm molded bag concrete	15 cm molded bag concrete	10 cm molded bag concrete		
				4 cm polystyrene board	6 cm polystyrene board	8 cm polystyrene board
Maximum values/mm	103	69	45.9	11	6	3.5
Reductions/mm	0	34	57.1	92	97	99.5
Reduction rates (%)	0	33.01	55.44	89.32	94.17	96.60

Table 5. | Relationships between the thicknesses of the molded bag concrete and the maximum frost heave rates.

Thicknesses of molded bag concrete/cm	Maximum frost heaving rates/mm			Average values/mm
	2015–2016	2016–2017	2017–2018	
0	120	105	127	117.33
10	105	93	103	100.37
12	82	76	69	75.67
15	63	54	45.9	54.37

3.3. Variation law of the freezing depths of the different molded bag concrete treatments

3.3.1. Variation law of the freezing depths in the different molded bag concrete treatments

Figure 5 shows the freezing depth variation process lines of the subsoil treated with 10 cm molded bag concrete, 12 cm molded bag concrete, 15 cm molded bag concrete, as well as 10 cm mold bag concrete plus 4 cm polystyrene boards, 10 cm molded bag concrete plus 4 cm polystyrene boards, and 10 cm molded bag concrete plus 4 cm polystyrene boards in the southern section of the test site during the complete freezing–thawing periods from 2015 to 2016, respectively.

As can be seen from the above analysis results, during the complete freezing–thawing periods from 2015 to 2016, the freezing depths for each of the molded bag concrete treatments had displayed the same change rule. All of the treated subsoil began to freeze in mid-November and reached the maximum depth in mid- to late February. Then, the treated subsoil began to melt in early March and was completely melted by mid-April. The freezing depths of the polystyrene boards were significantly lower than that of concrete bags without heat preservation. It was observed that the freezing depths of the concrete bags with 8 cm polystyrene boards had displayed the gentlest changes, indicating that the freezing depths for those samples had undergone the least change.

Table 6 shows the average maximum freezing depths and reduction rates of the treatments involving different types of molded concrete bags in the study site during the three freezing–thawing periods ranging from 2015 to 2018.

As can be seen from Table 6, if the concrete in the 10 cm molded bags was increased by 2–5 cm, the reduction rate of the freezing depth ranged between 17.74 and 29.15%. However, when 4–8 cm polystyrene plates were added, the reduction rate of the freezing depths reached 71.24–85.08%. These results showed that increasing the thickness of molded bag concrete had not significantly reduced the freezing depths. Meanwhile, the laying of polystyrene boards under the molded bag concrete had significantly reduced the freezing depths of the foundation soil.

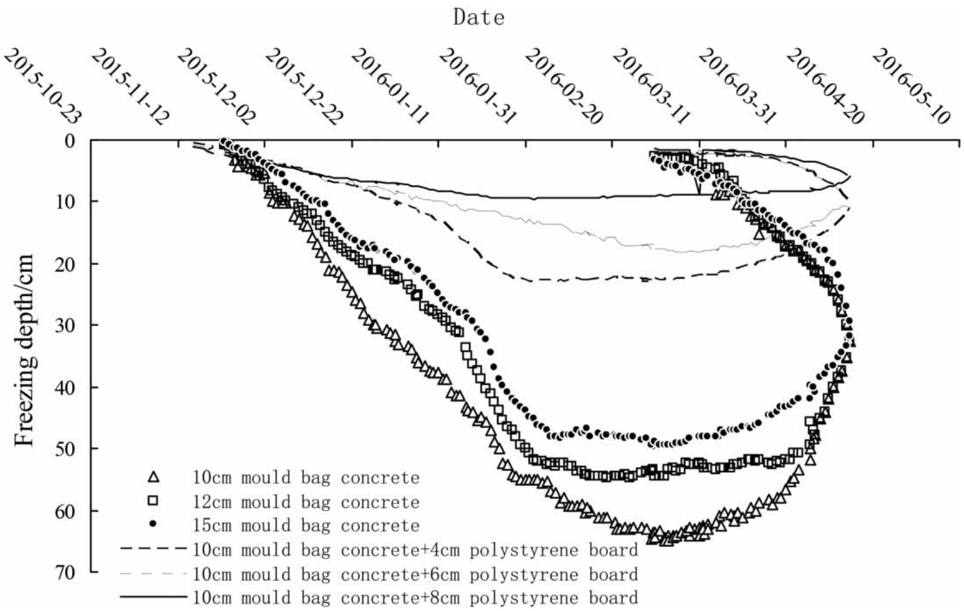

Fig. 5. | Freezing depth variations in the different molded bag concrete treatments for the period ranging from 2015 to 2016.

Table 6. | Average maximum freezing depths and their reduction rates in the different molded bag concrete treatments.

Treatments		Maximum freezing depths/cm					
Molded bag concrete	Polystyrene boards	2015–2016	2016–2017	2017–2018	Average maximum freezing depths/cm	Average freezing depth reductions/cm	Average freezing depth reduction rates/%
10 cm	0	64.9	49.89	60.8	58.53	\	\
12 cm	0	54.7	39	51.6	48.43	10.10	17.74
15 cm	0	49.8	30.5	44.1	41.47	17.06	29.15
10 cm	4 cm	22.9	10.1	17.5	16.83	41.70	71.24
	6 cm	18.3	8.91	8.85	12.02	46.51	79.46
	8 cm	9.5	8.3	8.4	8.73	49.80	85.08

3.3.2. Relationships between the different molded bag concrete and the freezing depths

The calculation results of the maximum freezing depths and mean values of the maximum freezing depths of the 10 cm, 12 cm, and 15 cm molded bag concrete, along with this study's comparison of the data from the three freezing–thawing periods, are shown in Table 7.

The data fitting was conducted between the thicknesses of the molded bag concrete and the average maximum freezing depths. The relationships between the thicknesses of the molded bag concrete and the maximum freezing depths were determined, as shown in Formula (2):

$$\mathrm{d} = -1.5942h + 68.546 \ \mathrm{R}^2 = 0.9673 \tag{2}$$

where h is the thickness of mold bag concrete (cm); and d indicates the maximum freezing depth (cm).

According to the relationships between the thicknesses of the molded bag concrete and the maximum freezing depths, the maximum freezing depth was found to have a linear relationship with the thickness of the molded bag concrete. It was found that with the increases in the thicknesses of the concrete, the maximum freezing depth of the foundation soil had decreased linearly.

3.4. Change laws of the frost heaving rates in the different molded bag concrete treatments

In accordance with the physics of frozen soil, the frost heave rate of soil was defined as follows:

$$\eta = \frac{\Delta V}{V} \tag{3}$$

Table 7. | Relationships between the maximum freezing depths and the thicknesses of the molded bag concrete.

Thicknesses of the molded bag concrete/cm	Maximum freezing depths /cm			Average maximum of the freezing depths/cm
	2015–2016	2016–2017	2017–2018	
0	75.7	53.1	71.5	66.77
10	64.9	49.89	60.8	58.53
12	54.7	39	51.6	48.43
15	49.8	30.5	44.1	41.47

where η is the frost heave rate (%); ΔV represents the deformation amount of the soil during the frost heave (m^3); and V indicates the volume of soil before frost occurs (m^3).

As stated in the theory of frozen soil, in order to facilitate the calculations of the frost heave rates, the formula can be simplified into a one-dimensional formula:

$$\eta = \frac{\Delta h}{H} \quad (4)$$

where Δh is the unidirectional frost heave (m); and H represents the freezing depth of the base soil (m).

Therefore, based on the data analysis results of the freezing depths and ground temperature levels of the different bag concrete treatments for the period ranging from 2015 to 2016, the frost heave rate of each treatment during the frost heave and melting processes were calculated. The fitting curves of the frost heave rates changing with temperature were then fitted, as shown in Figure 6.

As can be seen in Figure 6, there was a linear relationship observed between the frost heave rates of the foundation soil and the soil temperatures under the different molded bag concrete treatments. It was found that the frost heave rates decreased with the increases in soil temperature. This study found that, under the condition of no insulation, the maximum frost heave rate of the 10 cm molded bag concrete was 22.2%. Meanwhile, with the increases of 2–5 cm of the molded bag concrete, the maximum frost heave rate was above 16%, which indicated decreases of 28%. The maximum frost heave rates when 4–8 cm polystyrene boards were laid ranged between 9 and 14%, which indicated decreases of 38–60%. Therefore, it was found that the laying of the polystyrene boards had significantly reduced the frost heaving rates of the subsoil.

The slopes of the curve fitting frost heave rates and soil temperatures are known to reflect the slowness of the soil freezing process. For example, the higher the absolute slopes were, the faster the freezing rates would be.

The data fitting was carried out in this study for the frost heaving rates and temperatures of the different molded bag concrete treatments, and the fitting results are detailed in Table 8.

As can be seen in Table 8, when the molded bag concrete on the foundation of 10 cm molded bags concrete was increased by 2–5 cm, the absolute slope of the curve fitting of the frost heave rates and soil temperatures had not changed. Therefore, the results indicated that increasing the thicknesses of the concrete had not delayed the freezing process of the foundation soil. However, when 4–8 cm polystyrene boards were laid on the foundations of the 10 cm molded bag concrete, the absolute slope of the curve fitting of the frost heave rates and soil temperatures decreased by between 44.6 and 58.7%. The results showed that the change range of the frost heave rates was small, and the freezing durations were longer after the insulation boards were laid. That is to say, the laying of the polystyrene boards had significantly lowered the freezing speed of the subsoil and prolonged the freezing durations, thereby having the effects of thermal insulation.

4. DISCUSSION AND CONCLUSIONS

1. It was found in this study that the molded bag concrete almost had no thermal insulation effects, with the thermal insulation effects observed to be far lower than those of the polystyrene boards. It was found that when the polystyrene insulation boards were laid on the molded bag concrete, the greatest influence on the ground temperature was within the 10–40 cm soil layer range.
2. The frost heaving reduction rates only ranged between 18.28 and 55.44% when 2–5 cm molded bag concrete was added to the 10 cm molded bag concrete. However, the frost heaving reduction rates ranged between 71.43 and 96.6% when 4–8 cm polystyrene boards were laid. Therefore, the frost heaving reduction effects of the polystyrene boards were significantly greater than that of the molded bag concrete.

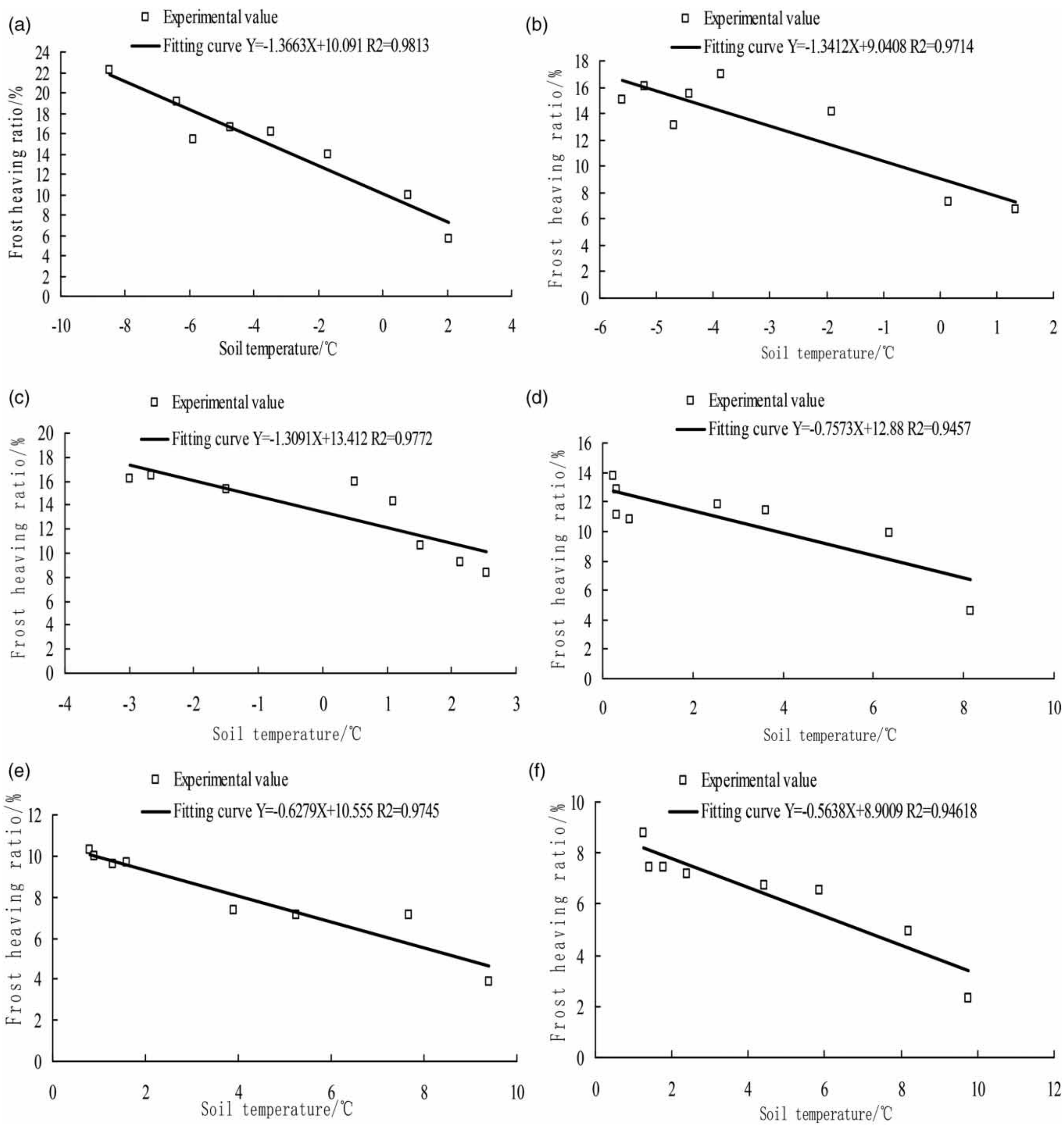

Fig. 6. | Relationships between the frost heave ratios and soil temperatures in the different molded bag concrete treatments: (a) 10 cm molded bag concrete; (b) 12 cm molded bag concrete; (c) 15 cm molded bag concrete; (d) 10 cm molded bag concrete +4 cm polystyrene boards; (e) 10 cm molded bag concrete +6 cm polystyrene boards; (f) 10 cm molded bag concrete +8 cm polystyrene boards.

3. It was observed in this study that increasing the thicknesses of the molded bag concrete had not significantly reduced the freezing depths. However, when polystyrene boards were laid under the molded bag concrete, the freezing depths of the foundation soil had been significantly reduced.

Table 8. | Fitting results of the frost ratios of the different polystyrene board treatments.

Experimental treatments	Thicknesses of the molded bag concrete/cm	Thicknesses of the polystyrene boards/cm	Slope	Intercept	Fitting degree (R^2)
Treatment 1	10	0	−1.3663	10.091	0.9813
Treatment 2	12	0	−1.3412	9.0408	0.9714
Treatment 3	15	0	−1.3091	13.412	0.9772
Treatment 4	10	4	−0.7573	12.880	0.9457
Treatment 5	10	6	−0.6279	10.555	0.9745
Treatment 6	10	8	−0.5638	8.9009	0.9461

4. This study concluded that the laying of polystyrene boards had significantly delayed the freezing speeds of the foundation soil and prolonged the freezing duration, thereby achieving the effects of heat preservation.

The results obtained in this study provided technical support for the safe use of channels and efficient irrigation in seasonal freezing soil areas. The findings were of major significance for reducing the damage caused by channel frost heaving actions, which could reduce the costs of channel maintenance and improve the service life of channels in seasonal freezing soil areas in the future. During the next research steps, additional testing will be completed regarding frost heaving of bag concrete in typical channels. Also, investigations will be conducted regarding insulation effects and frost heaving in bag concrete channels with different treatments in order to achieve further practical value and significance.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Guo, J. & Lou, Z. K. (2013). Application and numerical simulation of polystyrene insulation board in concrete lining canal. *Yangtze River 44*, 57–60.

Li, Y. T. (2016). Testing of channel mechanical properties of active duty lining mold-bag-concrete in large irrigation areas. *China Rural Water Conservation Hydropower 1*, 105–108.

Valipour, M. (2016). How do different factors impact agricultural water management? *Open Agriculture 1*, 100–101.

Valipour, M. (2017). Global experience on irrigation management under different scenarios. *Journal of Water and Land Development 32*, 108–109.

Wang, J. & Huo, Y. Z. (2019). Study on mix proportion optimization and performance of formwork bag concrete. *Sichuan Building Materials 45*, 7–9.

Zhang, H. L., Huo, Y. Z. & Guo, Y. F. (2019a). Research on improvement technology of roughness coefficient of formwork bag concrete lining channel based on flood area model. *Hetao College Forum 16*, 90–93.

Zhang, H. L., Huo, Y. Z. & Guo, Y. F. (2019b). Numerical simulation study on influencing factors of roughness of formwork bag concrete channel. *Yellow River 41*, 157–160.

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