ISSN : 0974 - 7435 Volume 10 Issue 13

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(13), 2014 [7249-7254]

Ice mechanics similarity scale model test

Zhonghao Zhang[1], Enliang Wang[1]*, Hua Zhong[2]

[1]College of Water Conservancy and Civil Engineering, Northeast Agricultural University, Harbin, (P.R.CHINA)

[2]Heilongjiang Provincial Hydraulic Research Institute, Harbin, (P.R.CHINA)

E-mail : hljwel@126.com

ABSTRACT

The model test on slatic ice pressure was carried out in low temperature laboratory. Through analyzing the thermodynamic model of ice sheet formation, deriving similarity scale of indoor model test, modeling the true field temperature process. It is confirmed that the maximum ice thickness of test value and site observation value is very nearly the same and the laboratory simulation of ice freezing process is according to natural law through the contrast of ice thickness curves of experimental value and site observation value. From slatic ice pressure curves, we can see that the maximum slatic ice pressure occurs in temperature rising period. When the ice sheet is thinner, the rising rate is faster. Conclusions: 1) The test lasted 387.4h, and the maximum ice thickness is 39.8cm. The simulation of ice freezing process corresponds with the order of nature. The simulation of thawing process is too difficult, owing to Solar Radiation. So the temperature control process need to be improved. 2) The maximum slatic ice pressure occurs in temperature rising period, which relating to temperature rising rate. The slatic ice pressure is larger when the rising rate is faster. The slatic ice pressure reaches to maximum value, when the temperature reaches to 0ºC, and then evanesces quickly.

KEYWORDS

Ice pressure; Thermodynamic model; Ice Mechanics; Similarity Scale; Dimensional heat.

INTRODUCTION

The application effect in cold regions and stability in ice freezing conditions of engineering structures should be determined by field test and indoor model test. Indoor model test can simulate varying runtime environment and different conditions, and the cost of which is cheaper. So it has an obvious advantage compare to field test. Yet the key technology is similarity resemblance between field test and indoor model test, which is the basic condition of successful test. The thermodynamic model was analyzed. The similarity scale of model test was derived according to Stefan problem similarity conditions. Indoor model test validated the ice formation process, and the result of which provide theoretical foundation to indoor model test.

SIMILARITY SCALE DERIVATION

When temperature rarely falls below zero, channel water lost heat and the water surface begin to freezing. With the decreasing of temperature, the water under ice sheet lost heat and begin to freezing in order to reach thermal energy balance. The heat conduction mainly occur in vertical direction, so the thermodynamic model of ice sheet formation could be described in one dimensional heat equation.

Take the ice surface as origin of coordinate O. pass O by vertical direction is X-direction. T (x, t) is t point temperature at x-high. Ice and water interface equation is x=S(t), which can be obtained by one dimensional heat equation and one dimensional single-phase Stefan problem (Qiao D. S., 1985, Xiao J. M., 2004, Feng J. S., 2011).

Ice domain equation:

$$\frac{\partial T}{\partial t}=\alpha\frac{\partial^2 T}{\partial x^2},\alpha=\frac{K}{C\rho},0<x<S(t),t>0 \quad \textbf{(1)}$$

Ice temperature:

$$T(0,t)=T(t),t\geq 0 \ \ (T(t) \text{ is known}) \quad \textbf{(2)}$$

Ice an water interface condition:

$$\frac{\partial T}{\partial x}-Q=\lambda\frac{dS}{dt},\lambda\frac{L\rho}{K},Q=\frac{q}{K},x=S(t),t\geq 0 \quad \textbf{(3)}$$

Initial ice thickness:

$$S(0)=S_0 \quad \textbf{(4)}$$

$$T(S(t),t)=0 \quad \textbf{(5)}$$

Where:
T=time
S(t)= ice thickness
C= specific heat of freshwater ice, J/kg·ºC
ρ= density of freshwater ice, kg/m3
K= thermal conductivity, W/m·ºC
L= latent heat of fusion of ice, J/kg
Q= heat flow transmission from water to ice

Stefan put forward a classical approximate hypothesis for single ice sheet thickness. It assumes that ice surface temperature is equal to air temperature, through which ice thickness calculation formula is determined. Only the interface heat balance under ice sheet was considered (Wang X., 2007). The mathematical description is below:

$$\lambda\frac{d\theta}{dh}\cdot dt=L\rho dh,\ \ (0<h(t)<h,\ \ h(0)=0) \quad \textbf{(6)}$$

Based the hypothesis that transient temperature in ice is linear distribution and the parameter L, ρ and λ is constant. Approximate solution is obtained.

$$h=\sqrt{\frac{2\lambda}{L\rho}\int_0^t\left[\theta_i-\theta_a(t)\right]dt} \quad \textbf{(7)}$$

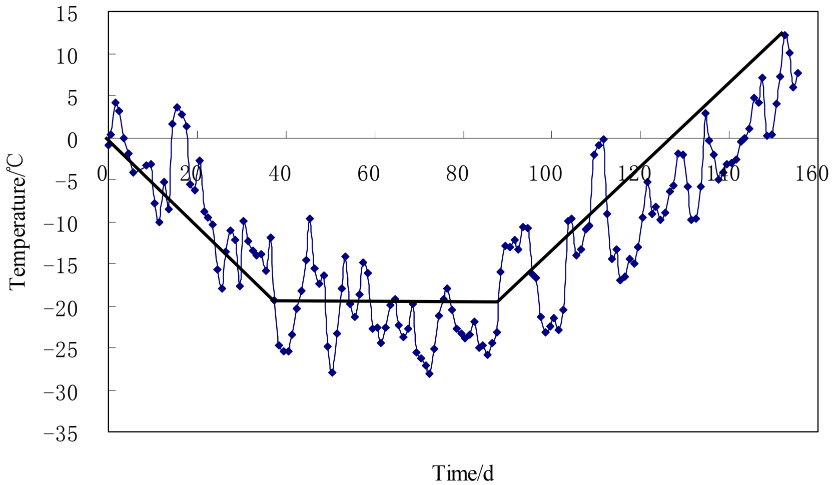

Figure 1 : Changing process curves of daily average temperature in 2010~2011

$\int_0^t [\theta_i - \theta_a(t)]dt$ = freezing index, that is the total ice surface temperature below θ_i in winter. It is called freezing degree days in discipline of ice, and is described as I. So Equation [7] can be simplification as:

$$h = \alpha\sqrt{I} \quad \textbf{(8)}$$

Where: $\alpha = \sqrt{\dfrac{2\lambda}{L\rho}}$ is degree day formula, which is used to calculated ice thickness under ideal condition.

The similarity criterion of ice formation was obtained by integrated analogy method. That is

$$C_I = (C_l / C_\alpha)^2 \quad \textbf{(9)}$$

TEST PROGRAM

Temperature and Time Simulating

It was simulated that the ice freeze-thaw process in Heilongjiang provincial hydraulic research institute Harbin frozen soil experiment station in 2010~2011. Sonar was taken to measure ice thickness. And the temperature measure adopt temperature sensor PT100 and DT515/615 series data acquisition instrument.

Figure 1 gives curves of daily average temperature in ice condition observed field in 2010~2011. Figure 2 shows curves of ice thickness changing process. The ice thickness in which was calculated in Stefan formula.

As shown in Figure 1, river freeze up in Nov.3, 2010. The maximum ice thickness is 96.9cm. From Feb.21, 2011 to Apr.5, 2011, ice thickness is 56.6cm. The observation stopped after water storage of ice pool. The observation lasted 152 days.

The test mainly simulates the static ice pressure forming process. Other conditions being the same, the faster the rising rate, the larger the slatic ice pressure. Ice pressure increases with temperature rising duration in the same rising rate. When the average ice temperature reach to certain level, ice pressure did not increase with temperature rising. Conversely, it often used to decrease.

The results show that this temperature is between -1.5~-2.0ºC (Xu B. M., 1985). Thus it can be seen that the phase of ice sheet thaw has no effect on slatic ice pressure. So the test mainly simulates ice freezing process.

In order to control temperature process conveniently, the temperature changing process was divided into three phases. That is temperature-fall period, low temperature maintenance stage and heating-up period. High temperature maintenance stage was appended to test temperature control process.

Based on the above information, the geometric scale C_l, temperature scale C_T and laboratory scale coefficient C_α takes 2.4, 1.5 and 0.905, respectively. So ice freezing degree days scale C_I is 7.03.

After calculation, test temperature control process was described as follows (Figure 3).

Test Equipment

Low-temperature environment is supplied by the low-temperature laboratory, temperature control scope of which is from -45ºC to 30ºC. Sensors monitoring system is consisted of DT515/615 series data acquisition instrument, temperature sensor PT100 (with control precision±0.1ºC) and pressure sensor. The pressure sensors arranged in ice sheet between 0 and 40cm, which is used to measure static ice pressure.

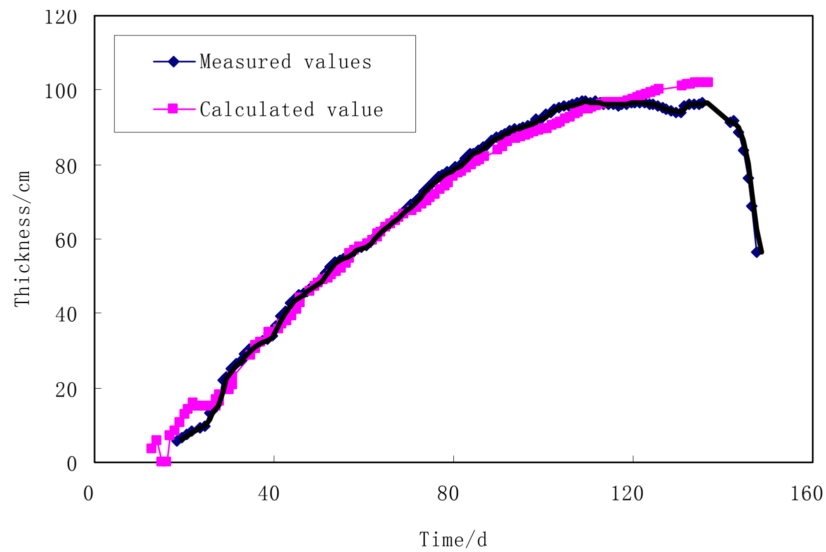

Figure 2 : Changing process curves of ice thickness

Test Equipment

Low-temperature environment is supplied by the low-temperature laboratory, temperature control scope of which is from -45ºC to 30ºC. Sensors monitoring system is consisted of DT515/615 series data acquisition instrument, temperature sensor PT100 (with control precision±0.1ºC) and pressure sensor. The pressure sensors arranged in ice sheet between 0 and 40cm, which is used to measure static ice pressure.

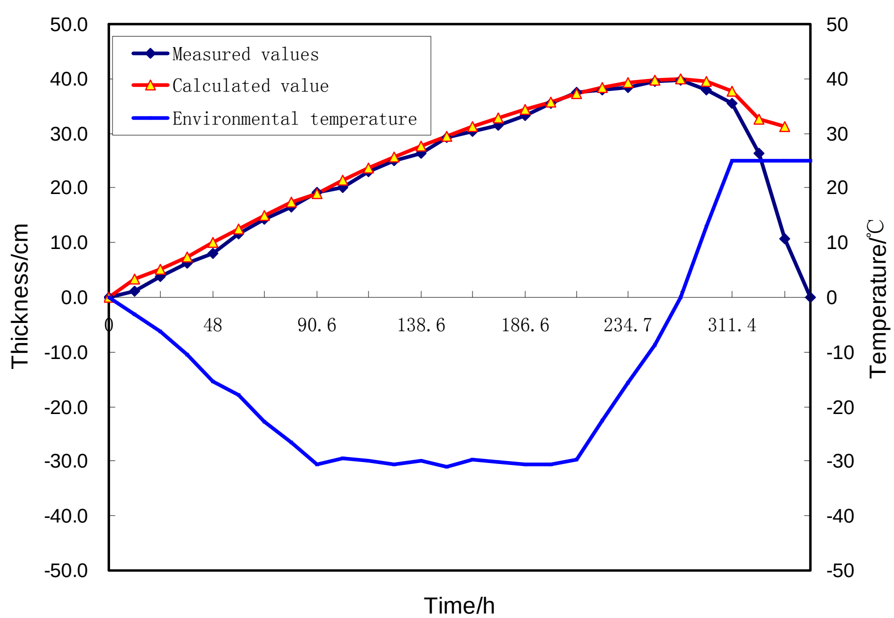

Figure 3 : Changing process curves of ice thickness

TEST RESULTS AND ANALYSIS

Analysis of Temperature Decreasing Process

Figure 3 gives curves of ice thickness and temperature control process. Figure 4 shows ice thickness curves of experimental value and site observation value.

As shown in Figure 4, the maximum ice thickness of test value and site observation value is very nearly the same, which is almost simultaneous. Because solar radiation simulation is difficult, so test value is larger than observation value. That is especially noticeable at the beginning of freezing. Compared with site observation value, the melting process is longer and melting rate is smaller in laboratory due to the absence of solar radiation. Laboratory simulation of ice freezing process is according to natural law.

Results Analysis of Slatic Ice Pressure

Figure 5 gives curves of slatic ice pressure. As shown in Figure 5, the maximum slatic ice pressure occurs in temperature rising period. Slatic ice pressure in different position is significant increases, when the temperature rising from -15ºC to 10ºC. The static ice pressure is greater, when the ice sheet is thinner and the rising rate is faster. The maximum slatic ice pressure occurs in the depth of 5cm, secondly is in the depth of 10cm, thirdly is in the depth of 15cm, and the minimum value occurs in the depth of 30cm. The maximum slatic ice pressure is 1622.5kPa, 1510.7kPa, 951.9kPa and 447kPa, separately.

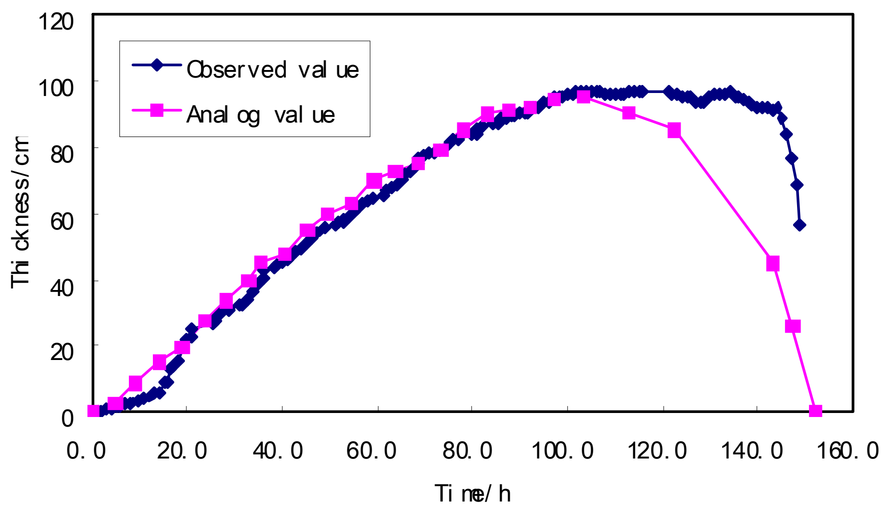

Figure 4 : Ice thickness curves of experimental value and site observation value

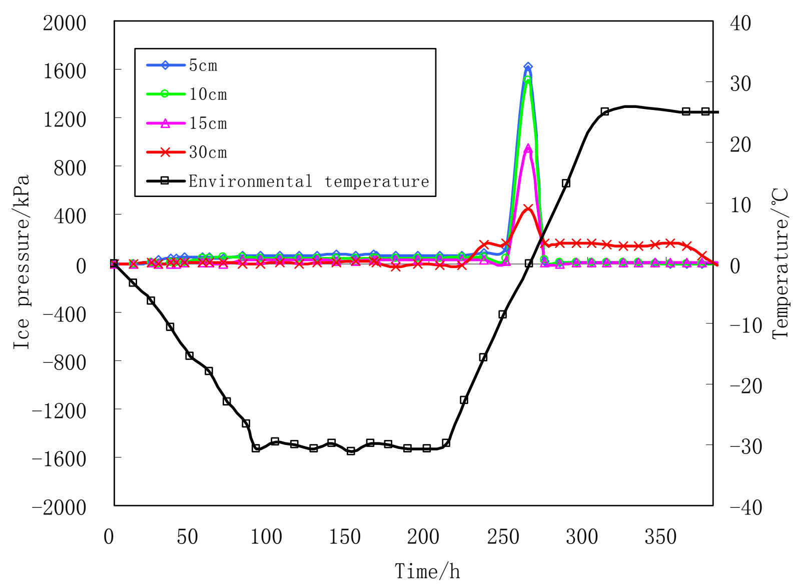

Figure 5 : Slatic ice pressure curves

CONCLUSIONS

(1)The test lasted 387.4h, and the maximum ice thickness is 39.8cm. The simulation of ice freezing process corresponds with the order of nature. The simulation of thawing process is too difficult, owing to Solar Radiation. So the temperature control process need to be improved.

(2) The maximum slatic ice pressure occurs in temperature rising period, which relating to temperature rising rate. The static ice pressure is greater, when the rising rate is faster. The slatic ice pressure reaches to maximum value, when the temperature reaches to 0ºC, and then evanesces quickly.

ACKNOWLEDGEMENT

This research is supported by grants from the Natural Science Foundation of Heilongjiang Province under Grant NO. E201405, Heilongjiang Province Postdoctoral Science Foundation funded project NO. LBH-Z13031.

REFERENCES

[1] B.M.Xu; Calculation of thereservoir ice expansive pressure, WaterResources and Hydropower Engineering, **11**, 16–21 **(1985)**.(in Chinese)

[2] D.S.Qiao; Analysis of the reservoir ice regime, Ice Jam Research,**1**, 14–16 **(1985)**. (in Chinese)

[3] J.M.Xiao, H.L.Jin, Y.G.Xie; Study on mechanism of formation and melting of reservoir ice cover in cold area, Journal of Hydraulic Engineering, **6**:80–85 **(2004)**. (in Chinese)

[4] J.S.Feng, Y.L.Bai, B.Li; Study on numerical simulation ofgrowth in thickness of ice caps in reservoirs of cold regions, Journal of Bohai University (Natural science edition), **32(1)**, 5–9 **(2011)**. (in Chinese)

[5] X.Wang; Calculating principle and correction of different types icethickness, Dalian University of Technology **(2007)**. (in Chinese)

[6] P.R.Holland, D.L.Feltham, S.F.Daly; On the Nusselt number for frazil ice growth a correction to " Frazil evolution in channels" by Lars Hammar and Hung- T ao Shen, Journalof hydraulic research, **45(3)**, 421-424 **(2007)**.

[7] Hung Tao Shen; Mathematical modeling of river ice processes, Cold Regions Science and Technology, **62(1)**, 3-13 **(2010)**.

[8] Fengbin Huang, Hung Tao Shen, Ian Knack; Modeling Border Ice Formation and Cover Progression in Rivers, Zhijun Li&Peng Lu, Ice Research for a Sustainable Environment, Dalian: Dalian university of technology press, 139-149 **(2012)**.

[9] Ian M. Knack, Fengbin Huang, Hung Tao Shen; A Numerical Model Study on St. Marys River Ice Conditions, Zhijun Li&Peng Lu, Ice Research for a Sustainable Environment, Dalian: Dalian university of technology press, 270-281 **(2012)**.