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Stress and Deformation Characteristics of Transmission Tower Foundations on Permafrost

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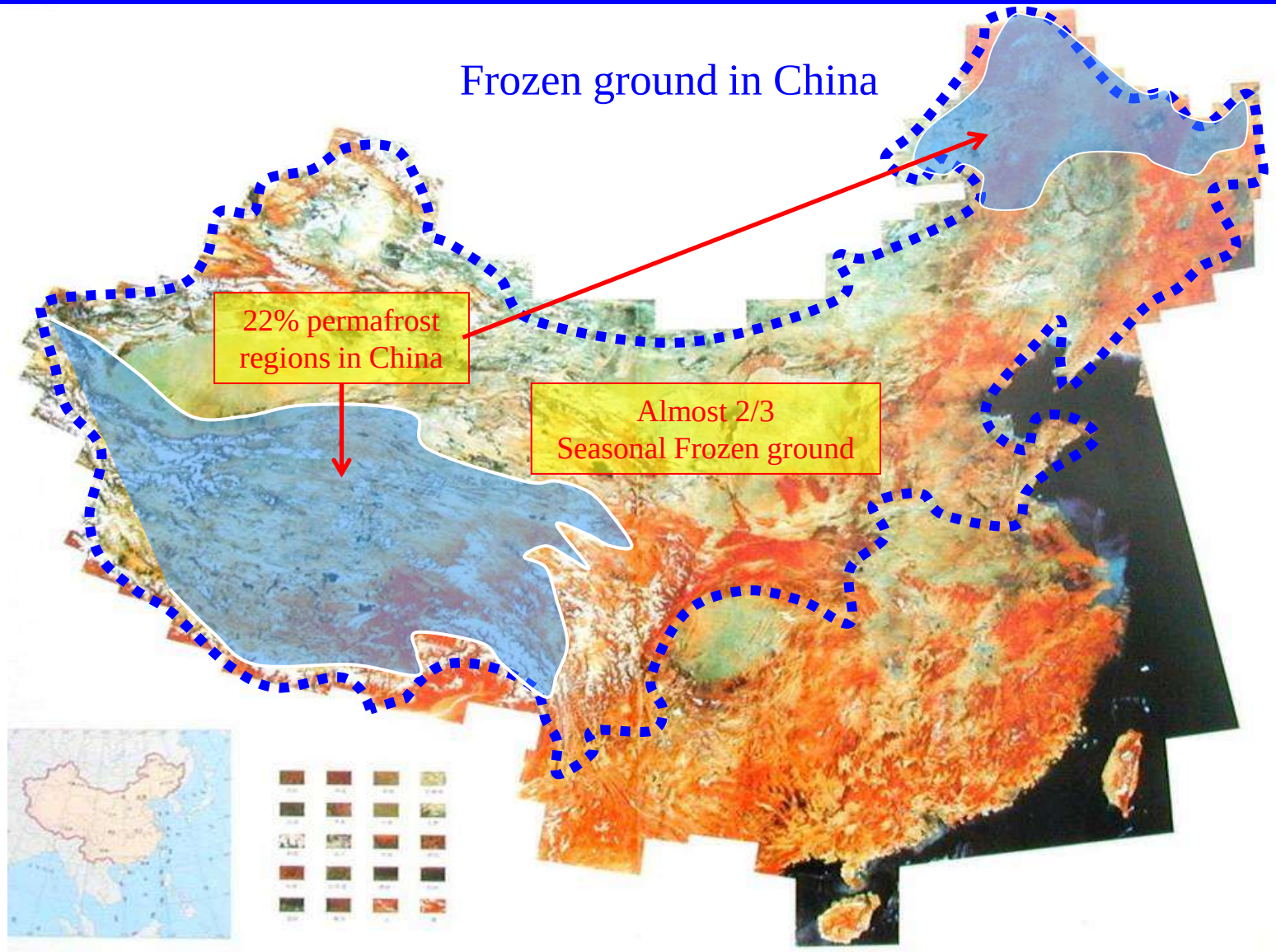
Outline

1. Engineering problems related to frozen ground
2. Observation on stress and deformation dynamics of Transmission Tower Foundations on Permafrost
3. Simulation of stress and deformation dynamics
4. Conclusions

1、Engineering problems related to frozen ground



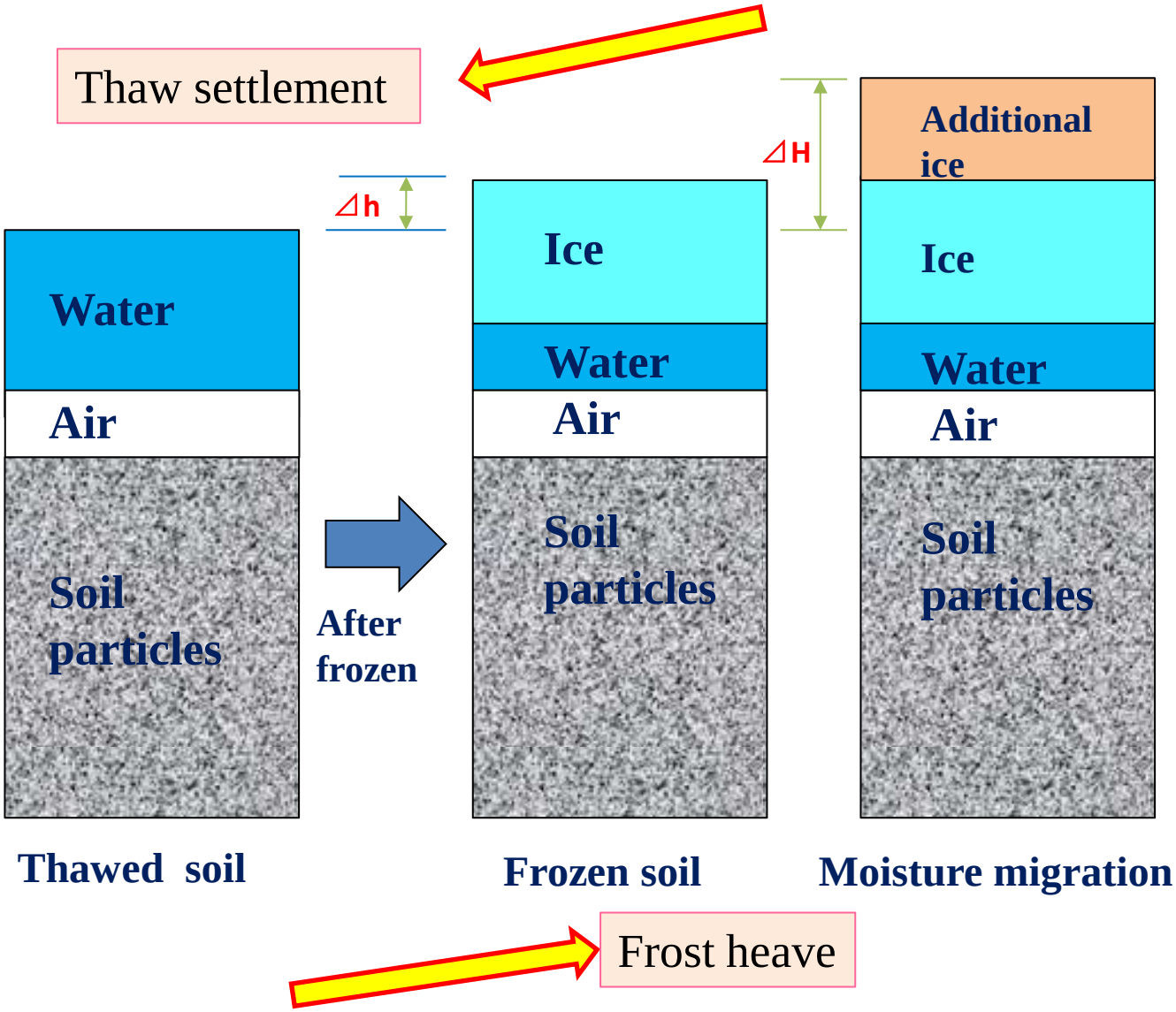
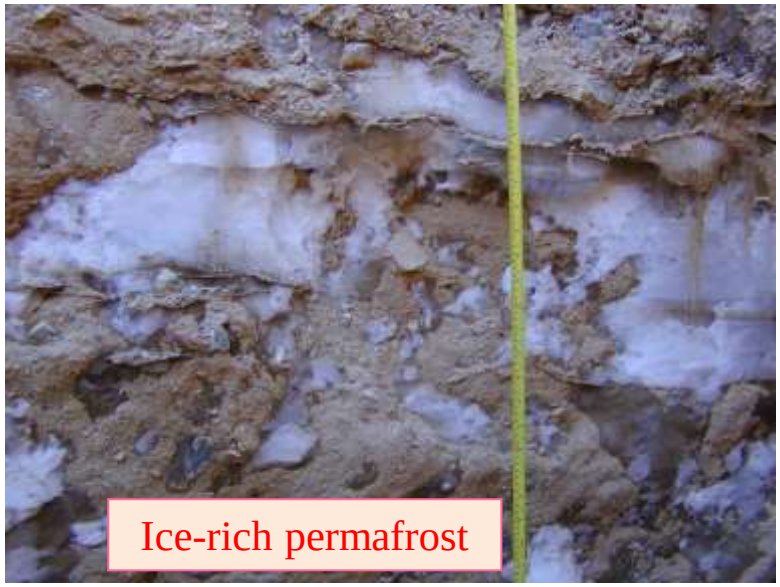
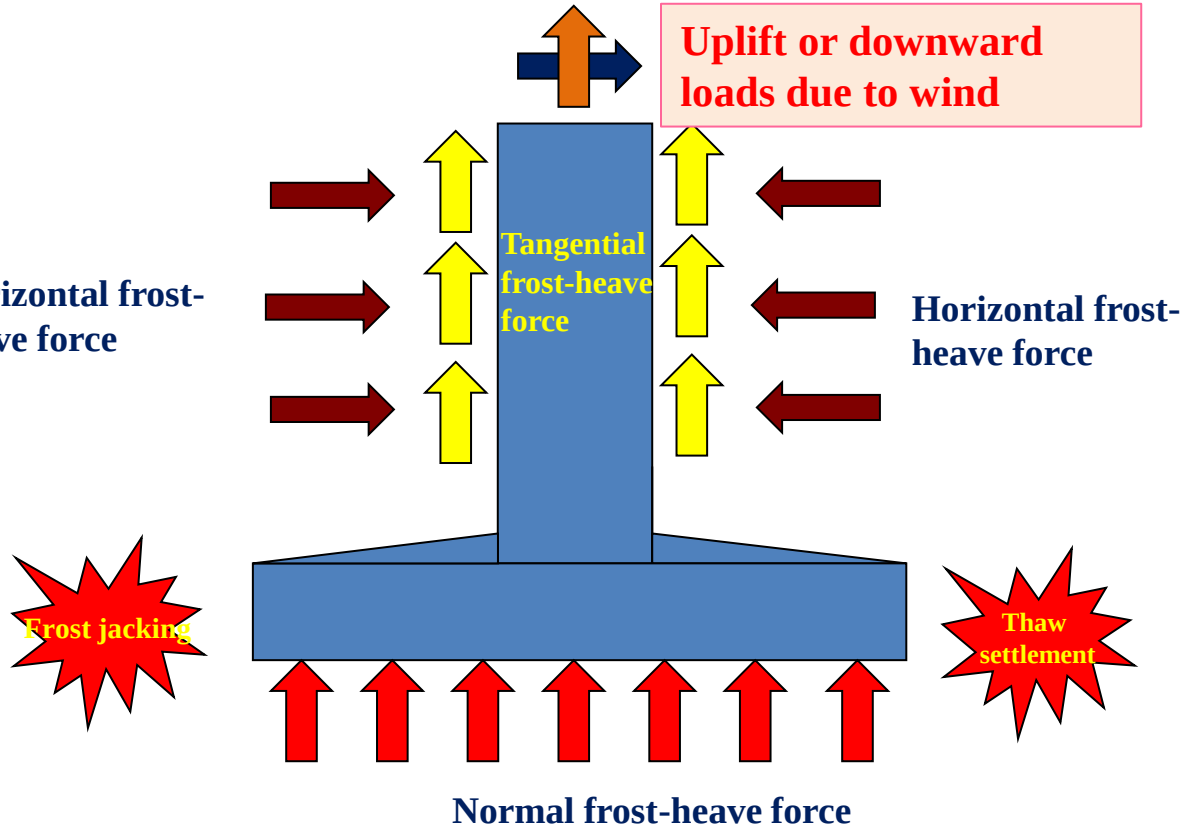


Diagram of frost heave and thaw settlement

Damages related to frost heave

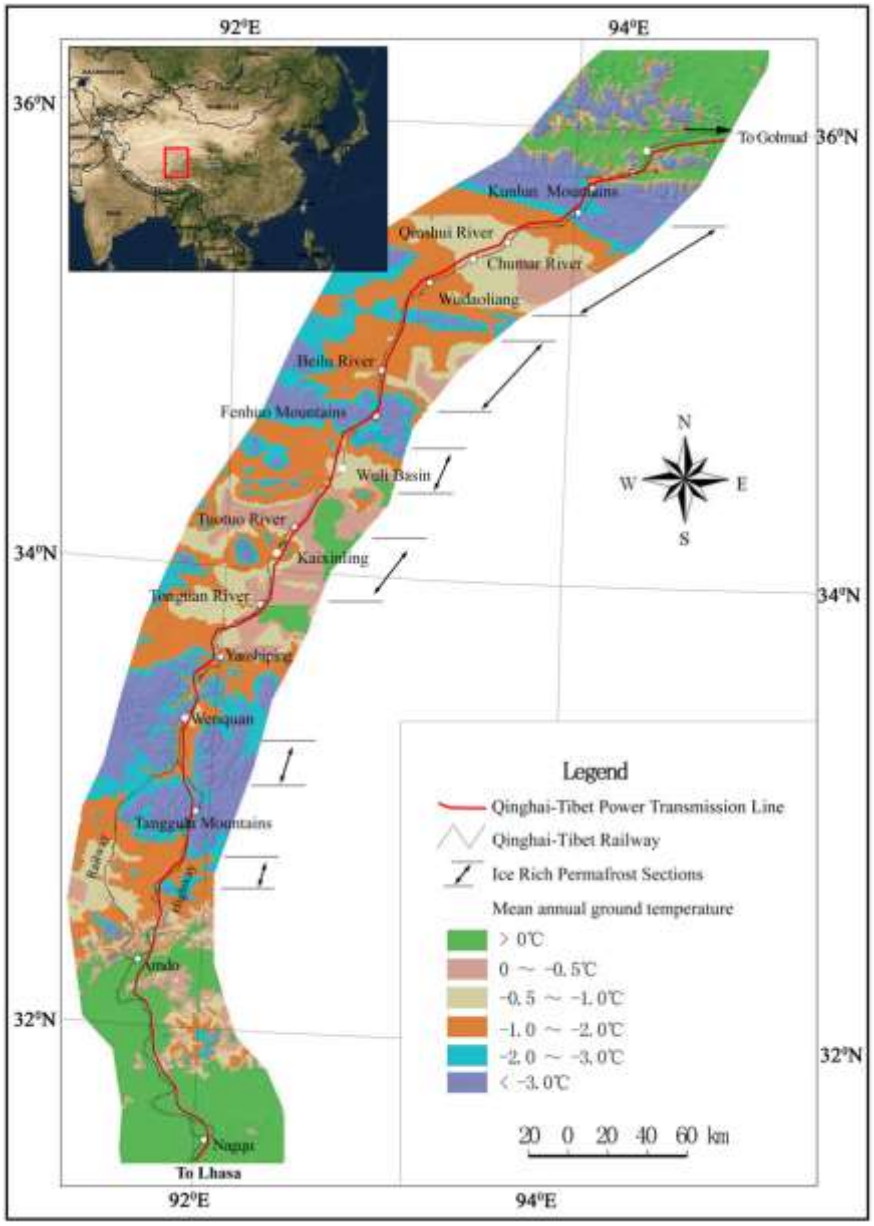


Damages related to thaw settlement due to thawing of ice-rich permafrost



Force diagram of pier foundation in frozen ground

- Past studies paid more attention on the statics analysis and risk assessment, and focused on the measurement of frost heave force, deformation, adfreezing strength, etc (Perameswaran, 1978; Weaver and Morgenstern, 1981; Tong et al., 1985; Ladanyi and Foriero,1998; Wen et al., 2013).
- However, the stress and deformation dynamics during freezing-thawing cycle have not been fully understood.

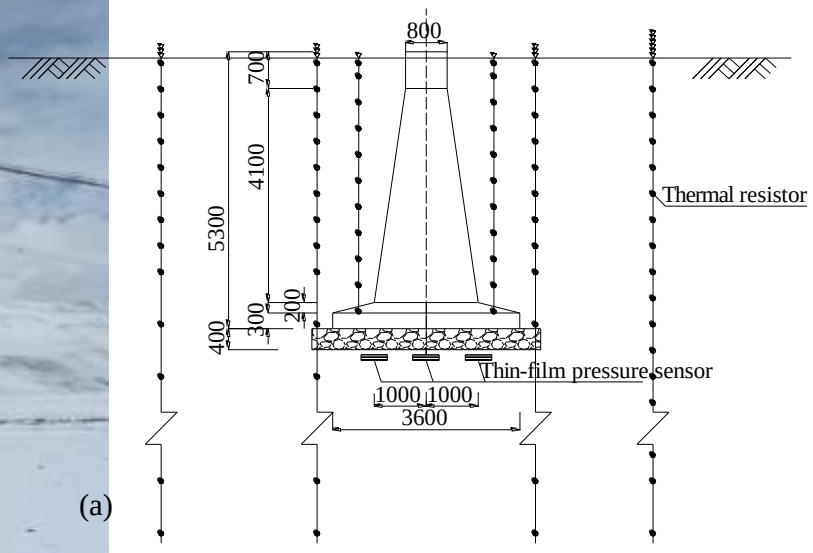


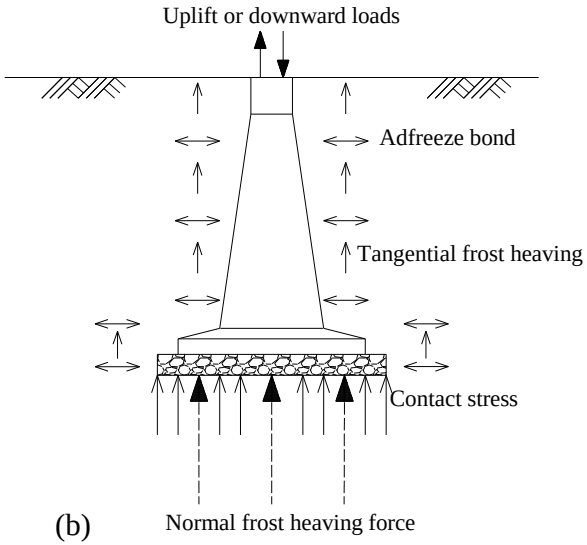
Transmission project from Golmud to Lhasa in permafrost regions

- Stress and deformation dynamics subjected to both freezing-thawing cycle and wind loads?
- Long-term stress and deformation dynamics influenced by global warming?
- Validation of thermosyphons to mitigate thaw settlement hazard?

2、Observation on stress and deformation dynamics of Transmission Tower Foundations on Permafrost

(a)





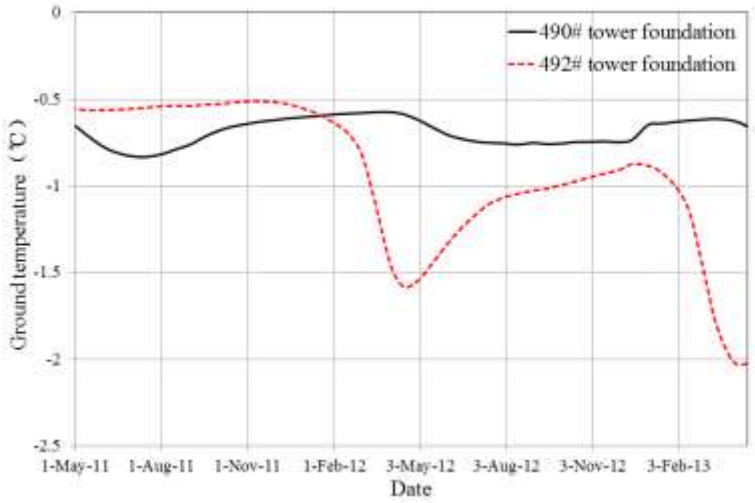
(b)

Observation in the Qinghai-Tibet Power Transmission Line project

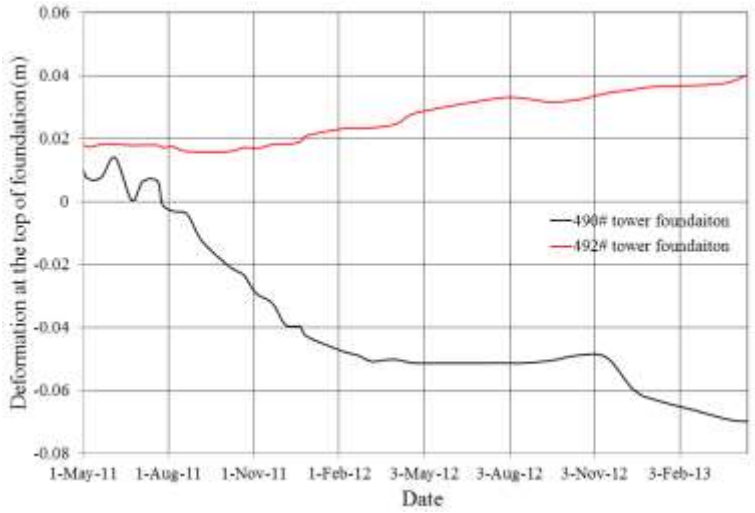
(1) 490# foundation (2) 492# foundation with thermosyphons

- Ground temperature
- Base pressure
- Deformation

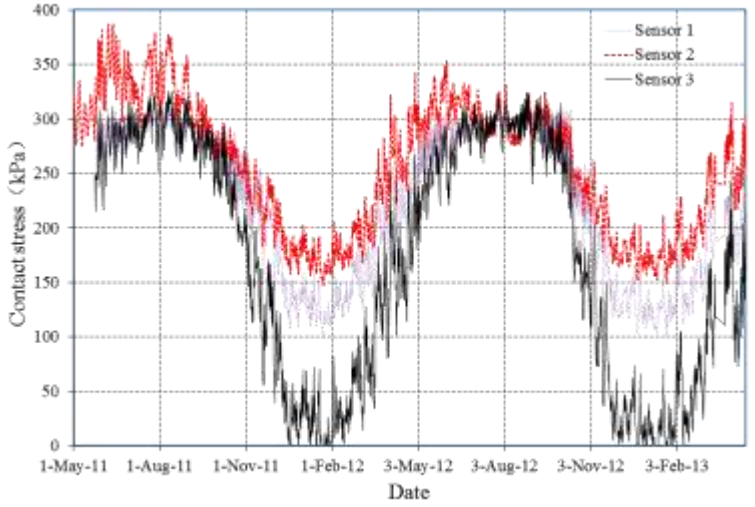
- Air temperature
- Wind speed



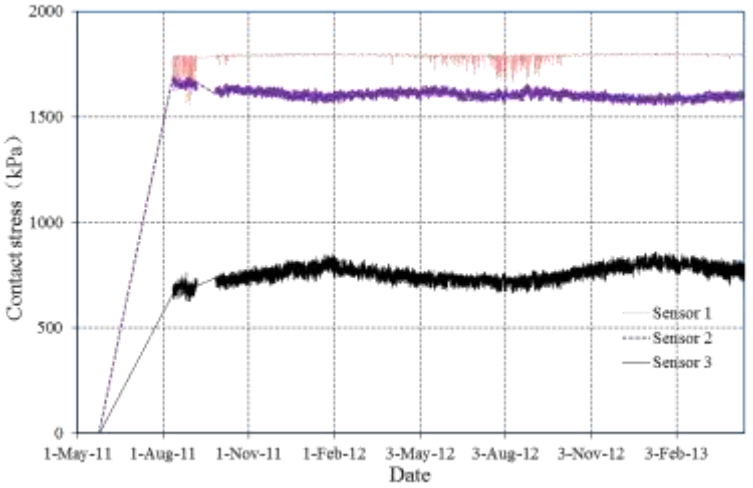
Ground temperatures at the base



Deformation at the top of foundations

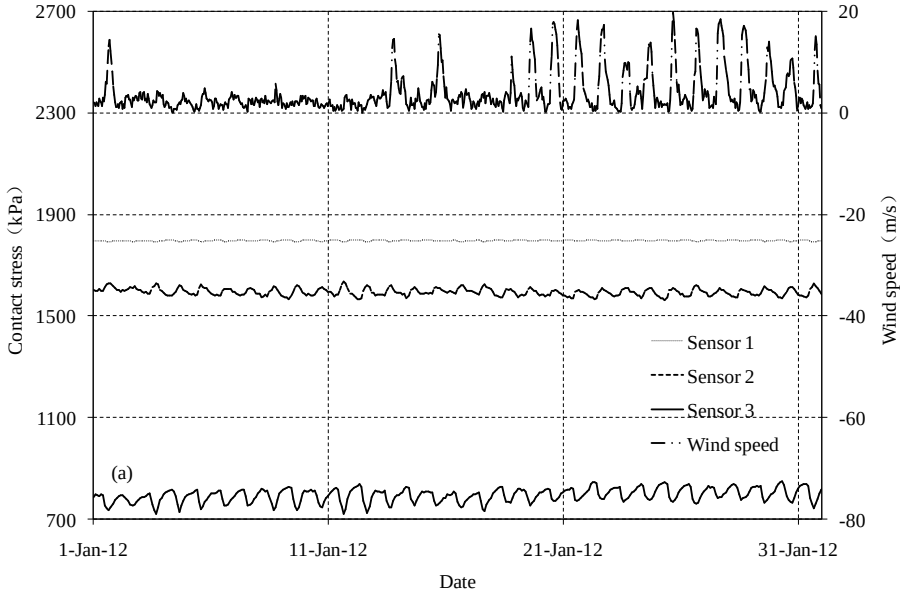


Contact stress dynamics at 490# foundation



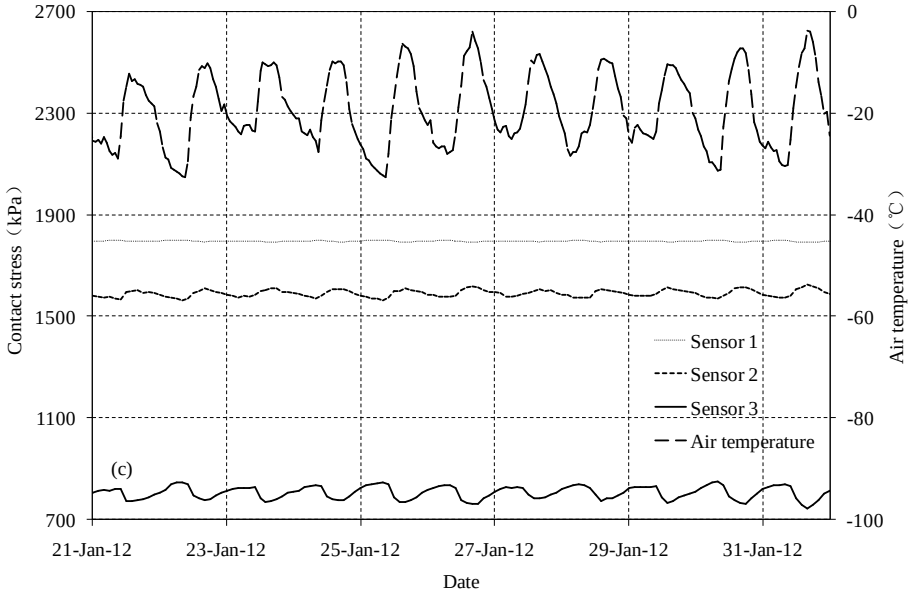
Contact stress dynamics at 492# foundation

- Seasonal variations in the contact stress depended on the seasonal freezing and thawing of foundation soil.
- The cooling of the underlying soils led to the occurrence of frost heave, which pushed the foundations upward and caused a significant stress bulb under the bases of tower foundations.



Contact stress VS Wind Speeds

- The contact stress was free of the wind influence.



Contact stress VS Air temperature

- The stresses at the bases of tower foundations had a close relationship with air and ground temperatures.

3、Simulation stress and deformation dynamics

$$\rho c\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}(\lambda\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(\lambda\frac{\partial T}{\partial y})+\frac{\partial}{\partial Z}(\lambda\frac{\partial T}{\partial Z})$$

$$\lambda_f\frac{\partial T_f}{\partial n}-\lambda_u\frac{\partial T_u}{\partial n}=L\rho w_0\frac{\partial \zeta}{\partial t}$$

$$T_f(\zeta(t),t)=T_u(\zeta(T),T)=T_m$$

$$\varepsilon=\varepsilon^e+\varepsilon^p+\varepsilon^{th}+\varepsilon^{ry}+\varepsilon^f$$

$$\{\varepsilon\}=[B]\{u\}$$

$$\{\sigma\}=[D]\{\varepsilon\}$$

$$\{\varepsilon^e\}=[D^e]^{-1}\{\sigma\}$$

$$\{\dot{\varepsilon}_{ij}{}^p\}=\dot{\lambda}\frac{\partial Q}{\partial \sigma_{ij}}$$

$$W_u=aT^{-b}$$

$$b=\frac{\ln w_0-\ln w_u}{\ln T-\ln T_f}$$

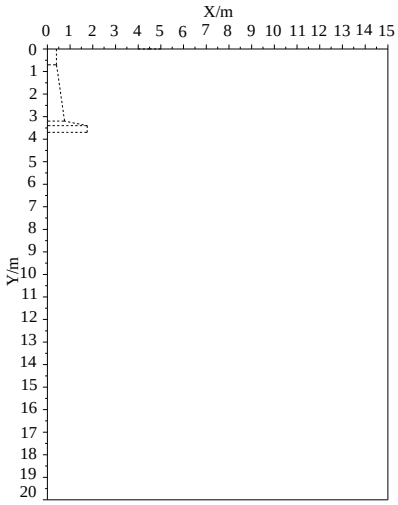
$$a=w_0T^b$$

$$\varepsilon^{th}=\alpha\dot{T}$$

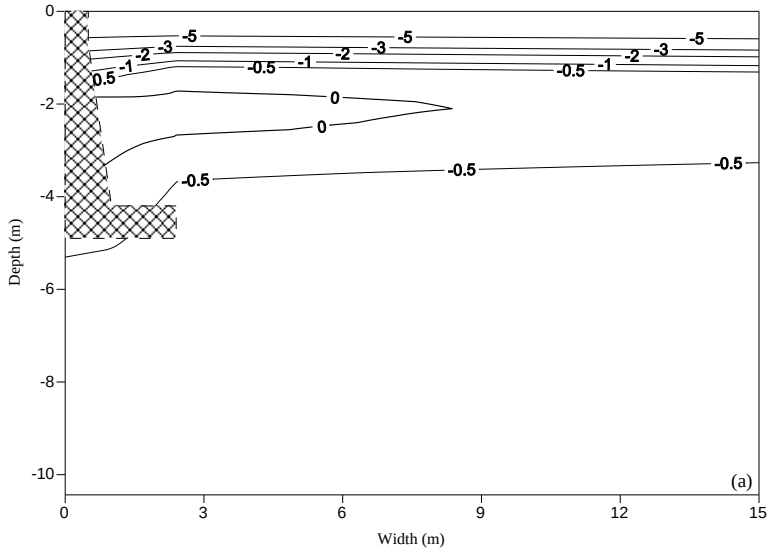
$$\varepsilon^{ry}=(A_r+A_yP)\dot{H}_{ry}$$

$$\varepsilon^f=A\sigma^Bt^Ce^{-\frac{D}{T}}$$

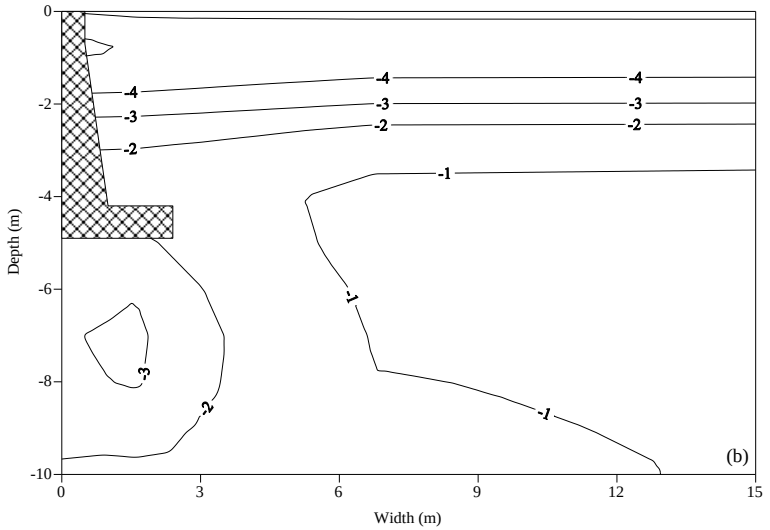
$$[D^p]=\frac{1}{S_o}\begin{bmatrix}S_1^2 & \text{对} & \\ S_1S_2 & S_2^2 & \text{称} \\ S_1S_3 & S_2S_3 & S_3^2\end{bmatrix}$$



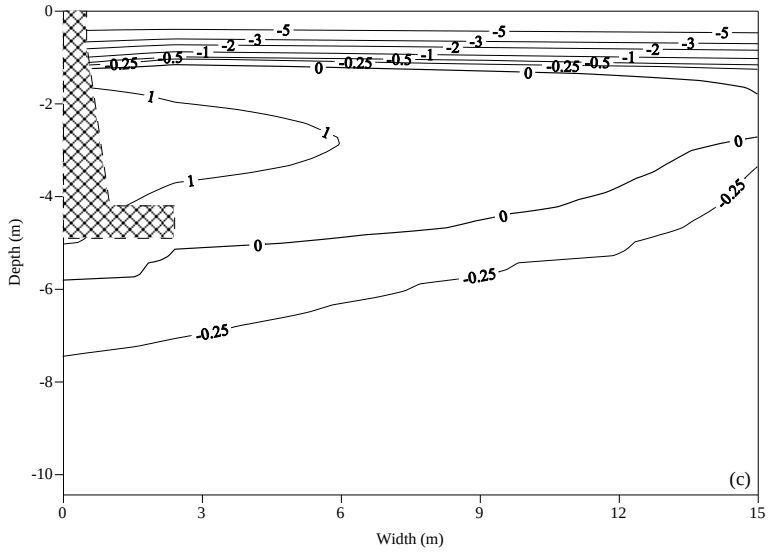
a thermal-elastico-plastic finite element model
for the tower foundation-soil system



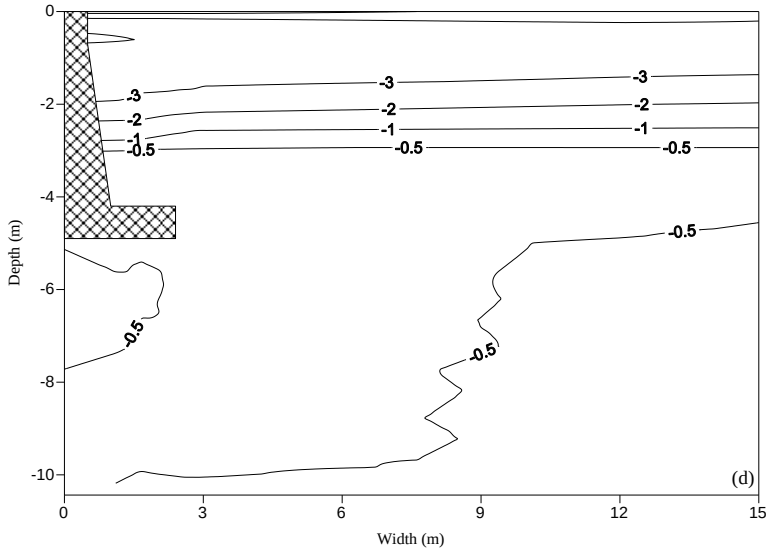
On Nov. 30, 1 year after construction



On Apr. 1, 1 year after construction

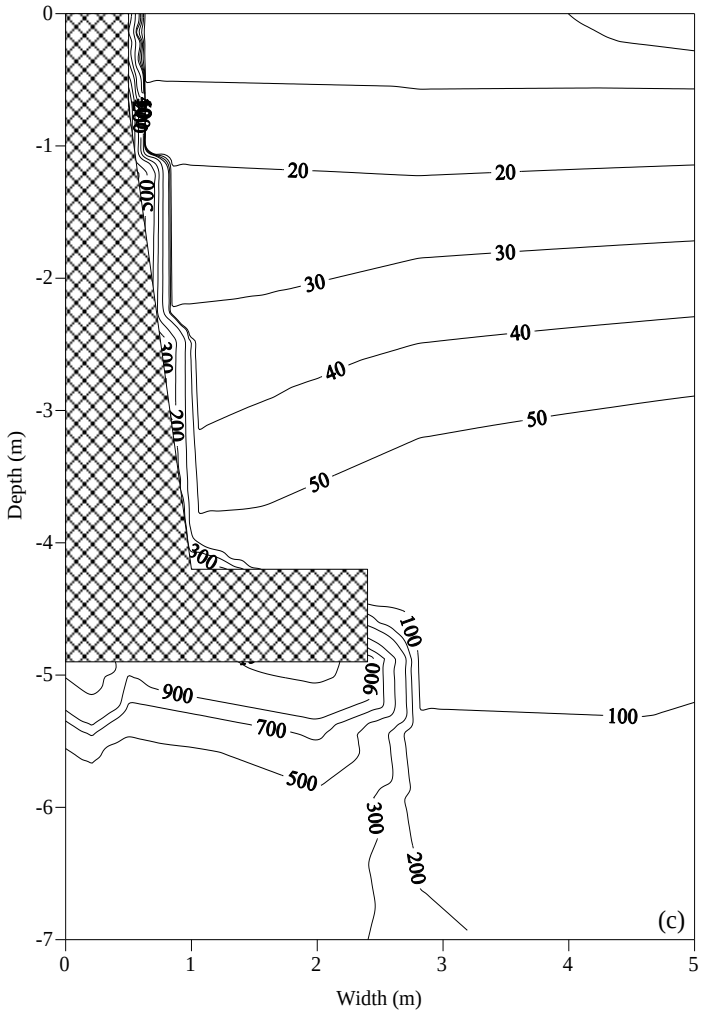


On Nov. 30, 50 year after construction

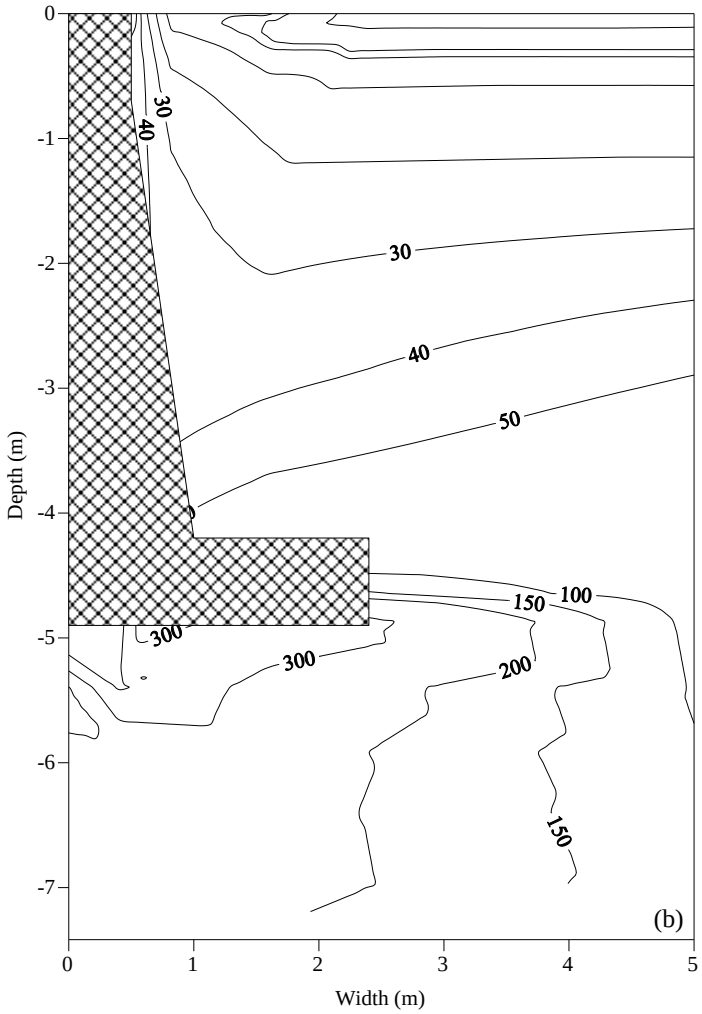


On Apr. 1, 50 year after construction

Thermal regime variations with thermosyphons in 50 years (℃)

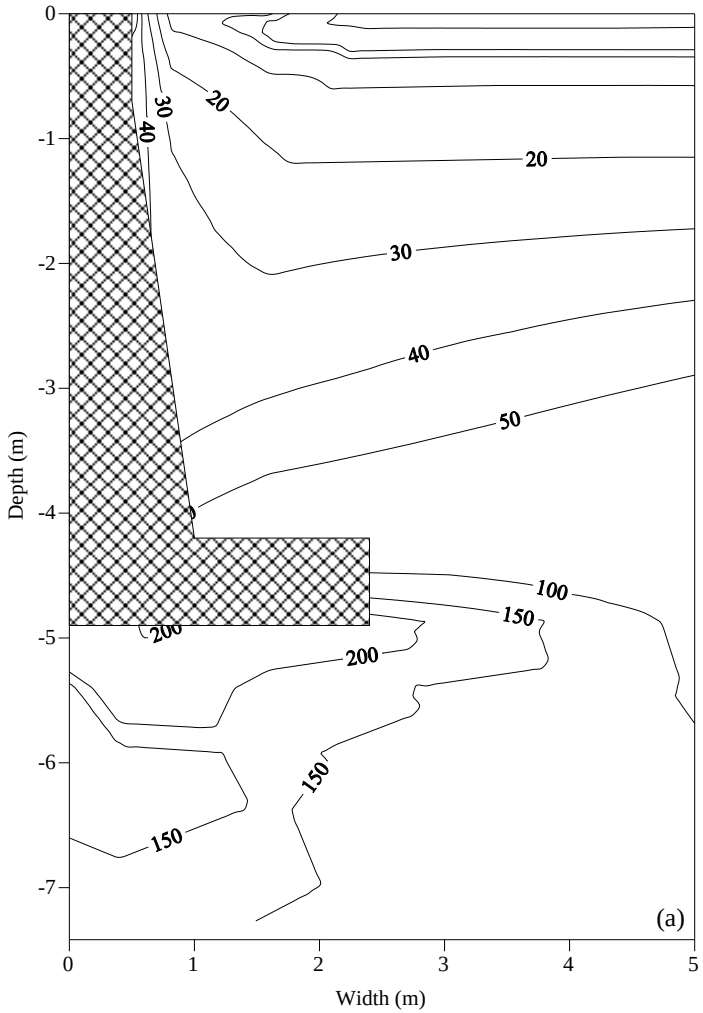


Stress distribution on Apr. 1, 1 year after construction

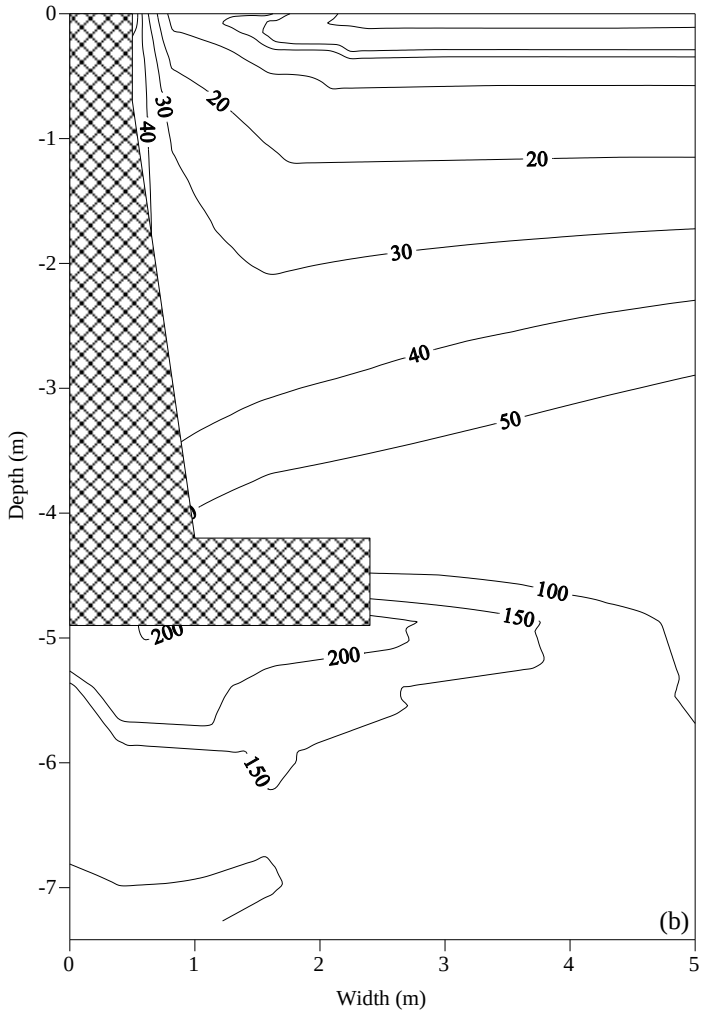


Stress distribution on Apr. 1, 50 year after construction

- In the freezing period, similar to observation data, significant frost heave occurs. The contact stress decreases significantly due to global warming.

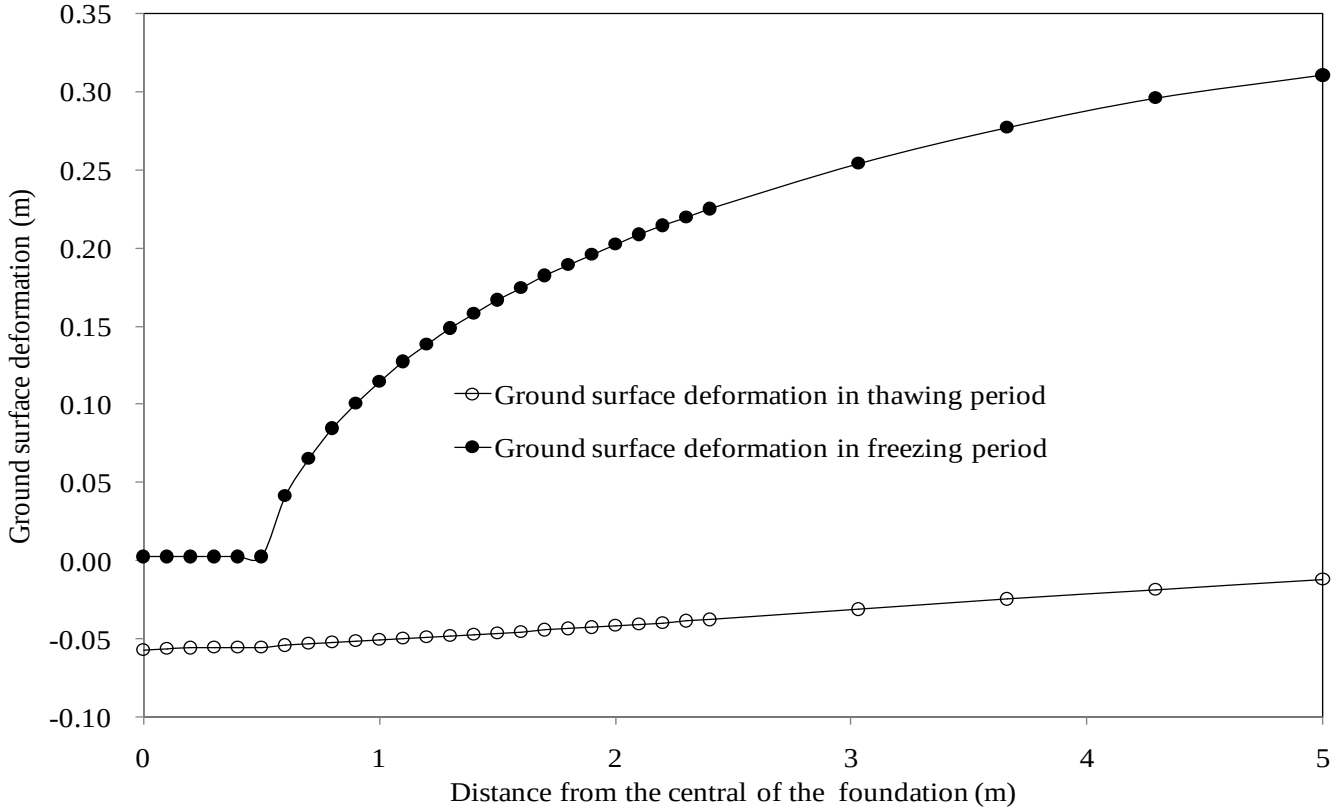


Stress distribution on Nov. 30, 1 year after construction

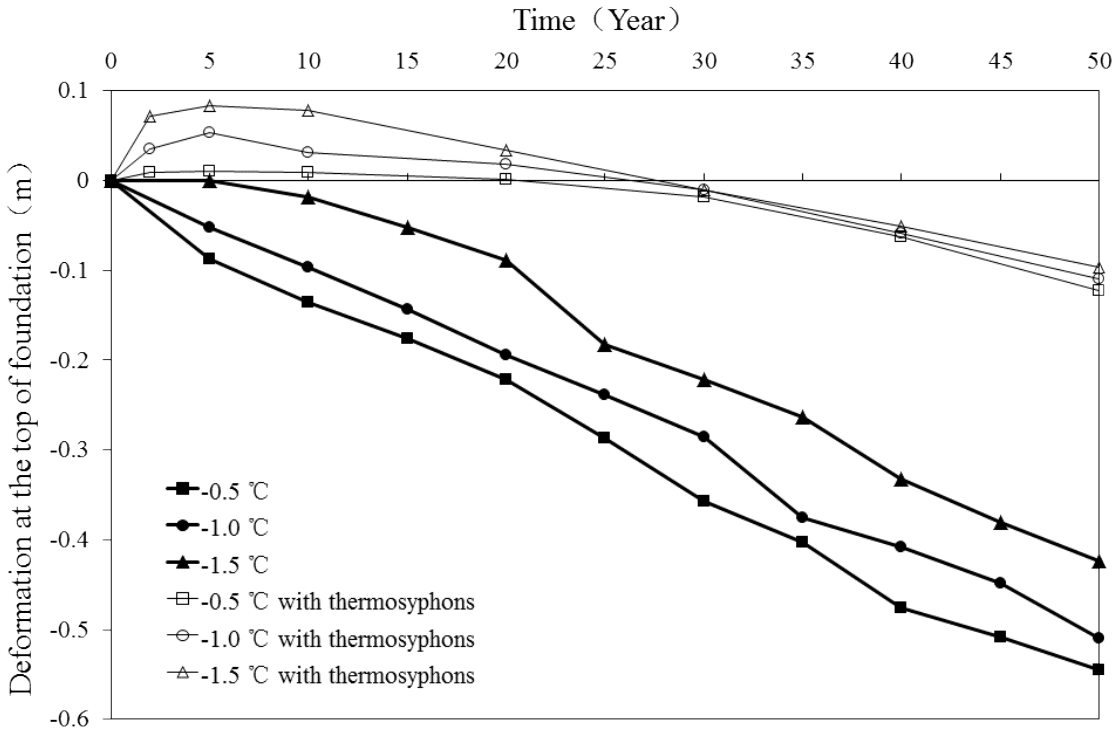


Stress distribution on Nov. 30, 50 year after construction

- Stress distribution of simulated tower foundation in thawing period has not significant change in the following 50 years.



- deformation in the ground surface was very small in the thawing period.
- In the freezing period, significant frost heave occurs. The amount of frost heave is the smallest at the foundation and it increases gradually far from the foundation.



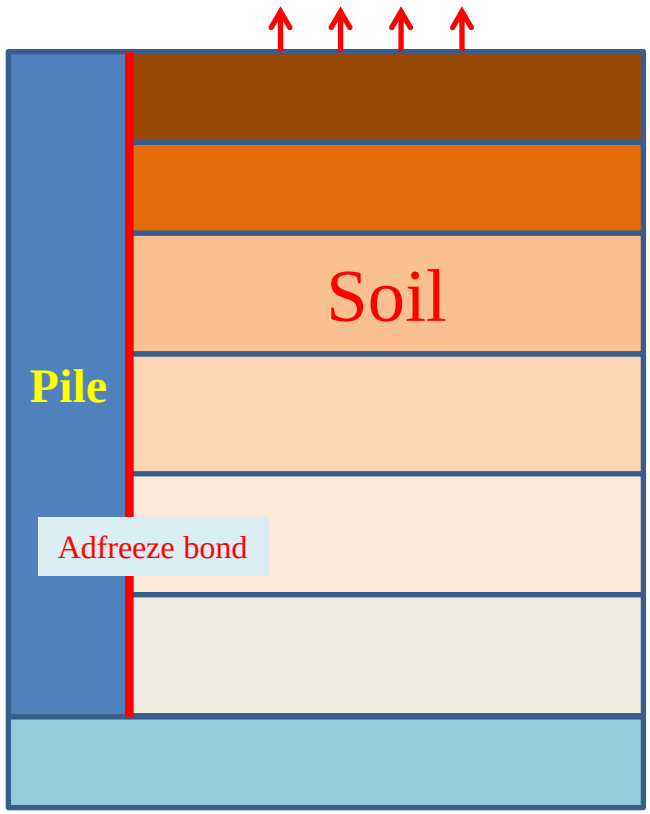
Deformation at the top of the foundation in the following 50 years.

- Continuous settlement occurs after the construction of the foundations and the amount of the deformation at the top of the foundation reaches approximately 0.5 m in the 50th year.
- Thermosyphons have a significant cooling effect on permafrost beneath the foundation and can significantly reduce the deformation at the top of foundation.

Highlights

- Ground temperature is the dominant factor that determines the stress variation.
- The refreezing of foundation soil results in significant increase in contact stress.
- Thaw settlement deformation may lead to harmful deformation of tower foundations.
- Application of thermosyphons can significantly reduce the deformation of foundation.

Thanks for your attention !



Frost jacking