Thermal Performance Analysis of Hollow Cellular Concrete Block Air Convection Embankment for Cold Regions

International Association of Chinese Infrastructure Professionals

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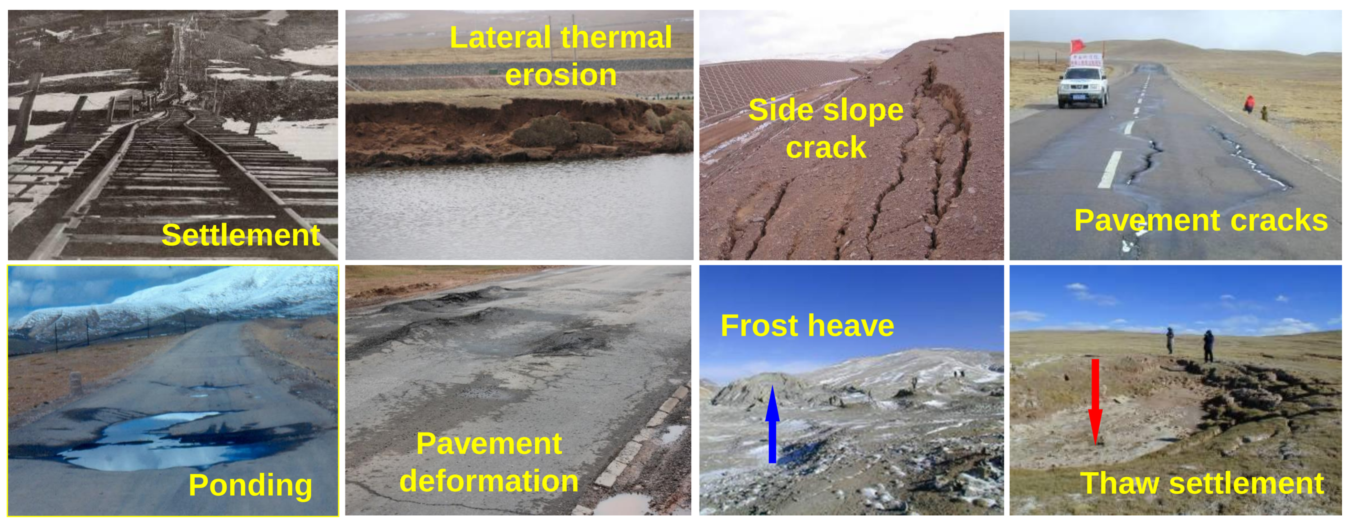
INTRODUCTION

- Much of the interior of Alaska is underlain by thaw-unstable permafrost or frozen ground.
- Engineering projects often cause a disturbance of the pre-existing thermal balance and subsequent permafrost thawing.
- The air convection embankment (ACE) is an excellent technique to protect the permafrost from thawing.
- However, the desired material (i.e., suitable crushed rocks) needed for ACE is not readily available in Alaska. The shipping cost of crushed rocks from the remote area is often prohibitively high.
- Compared several lightweight aggregate materials including cellular concrete, foam glass aggregate, and lightweight expanded clay aggregate. Cellular concrete shows great potential as an alternative material for ACE.
- However, the practicality of the proposed cellular concrete ACE in real construction is still unknown.



Freeze-thaw induced damages.

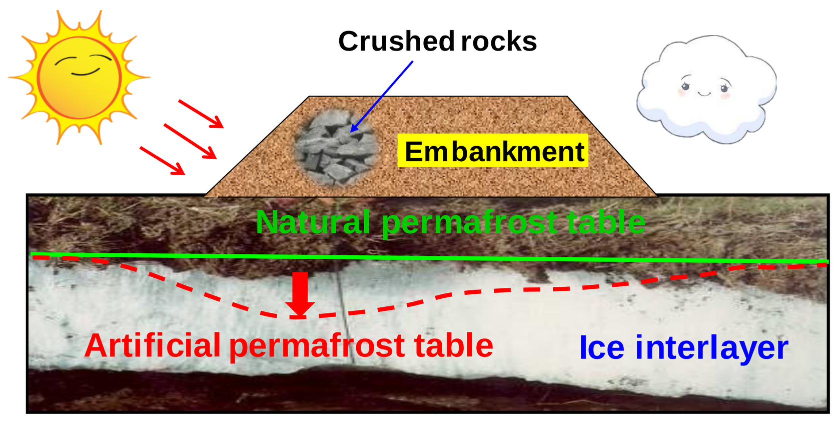
OBJECTIVES

- To develop innovative cellular concrete ACE with desired block configuration to improve the cooling performance of ACE
- To evaluate and compare the thermal stability of the two proposed hollow cellular concrete block ACEs with conventional cases
- To provide recommendations regarding appropriate cellular concrete ACE design and construction

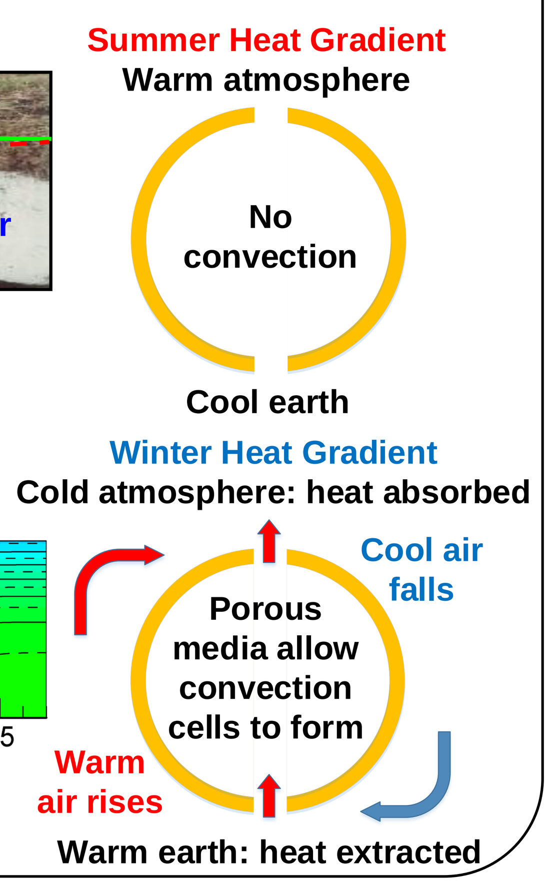
THEORY

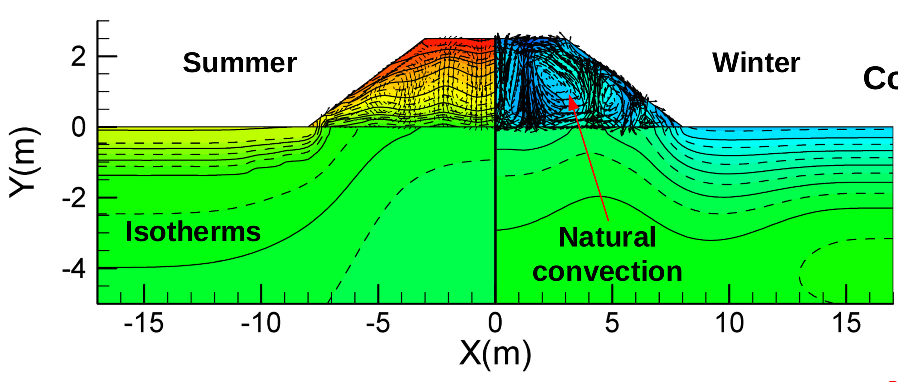
- Buoyancy-driven convection of the pore air occurs in reaction to the air density gradient in the porous ACE

Crushed-rock ACE



Disturbance of the pre-existing thermal balance





Cooling mechanism of ACE

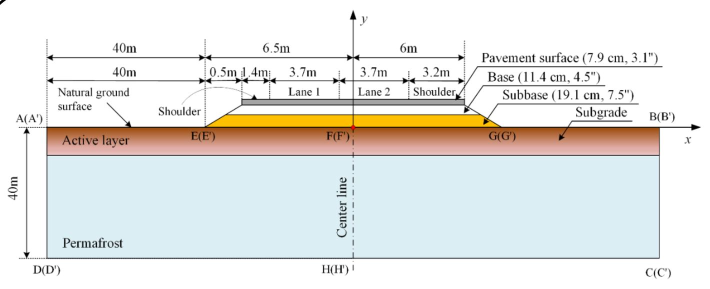
METHODOLOGY

- Two design configurations of cellular concrete block ACEs were proposed in this study.
- A 3-D pore-scale model was developed to simulate airflow dynamic and heat transfer.
- The finite element software ANSYS Fluent was used to perform air convection and thermal analysis.

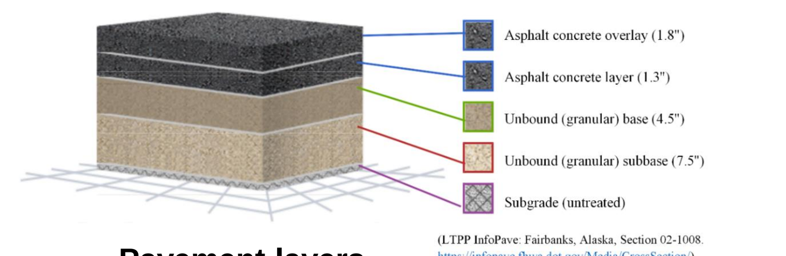
Selected Pavement Structures.

Cases	Pavement structures	Abbreviation
Case 1	Typical flexible pavement in the Northern Region of Alaska	AK
Case 2	Silty sand/gravel embankment	SG
Case 3	Crushed-rock ACE	CR
Case 4	Full cast-in-place cellular concrete embankment (non-hollow)	FCC
Case 5	One-way hollow cellular concrete block ACE	CC1
Case 6	Three-way hollow cellular concrete block ACE	CC3

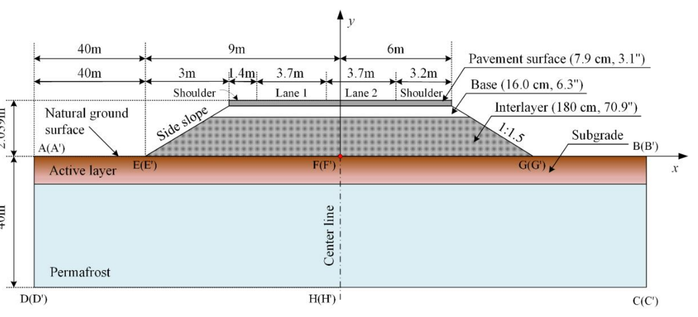
METHODOLOGY



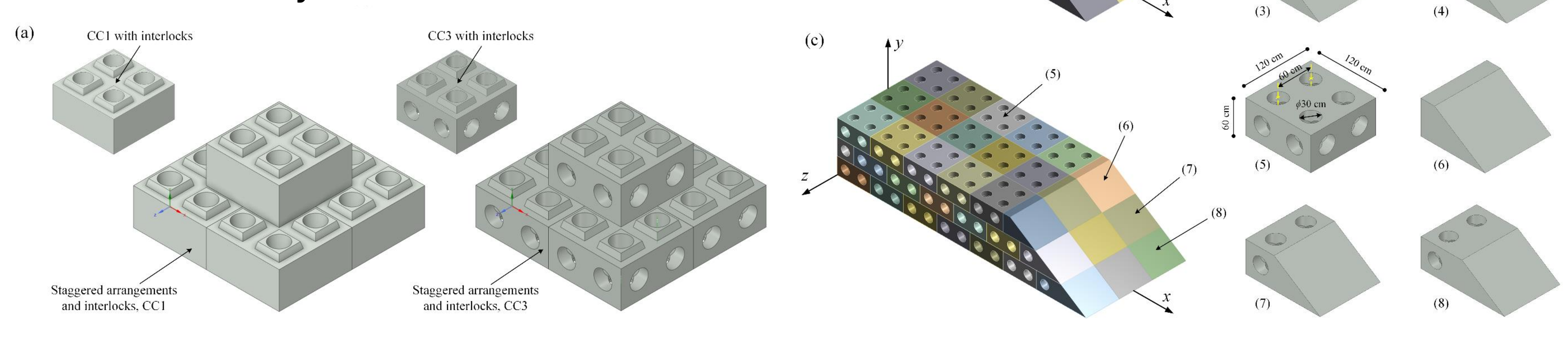
Schematic of the AK.



Pavement layers



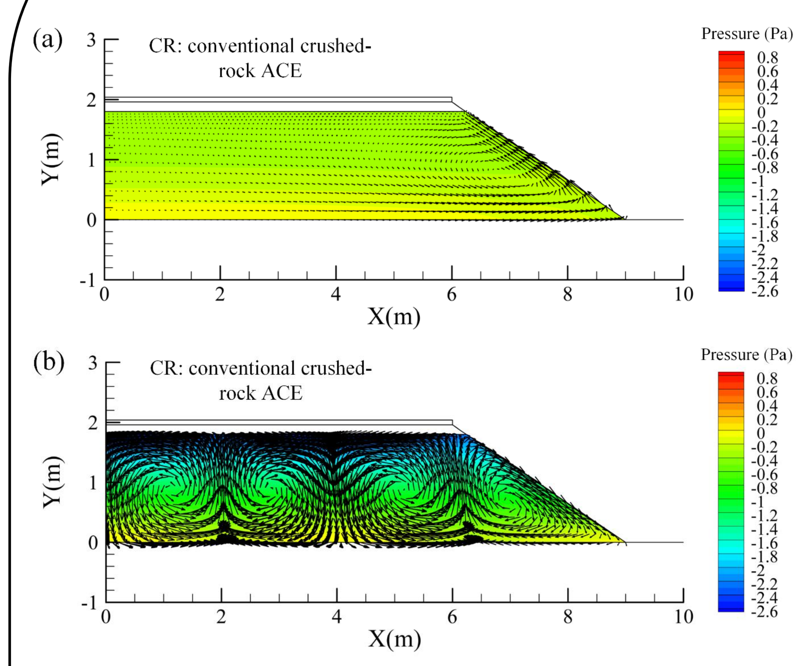
Schematic of the pavement structures (i.e., SG, CR, FCC, CC1, and CC3)



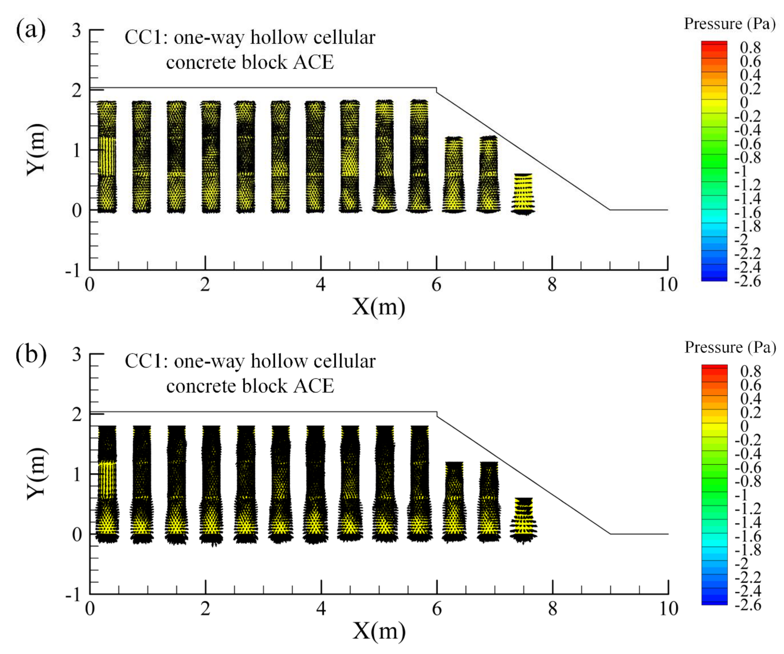
Profiles of cellular concrete interlayers and cellular concrete blocks. (a) staggered arrangements and interlocks. (b) case 5, CC1. (c) case 6, CC3.

RESULTS AND ANALYSES

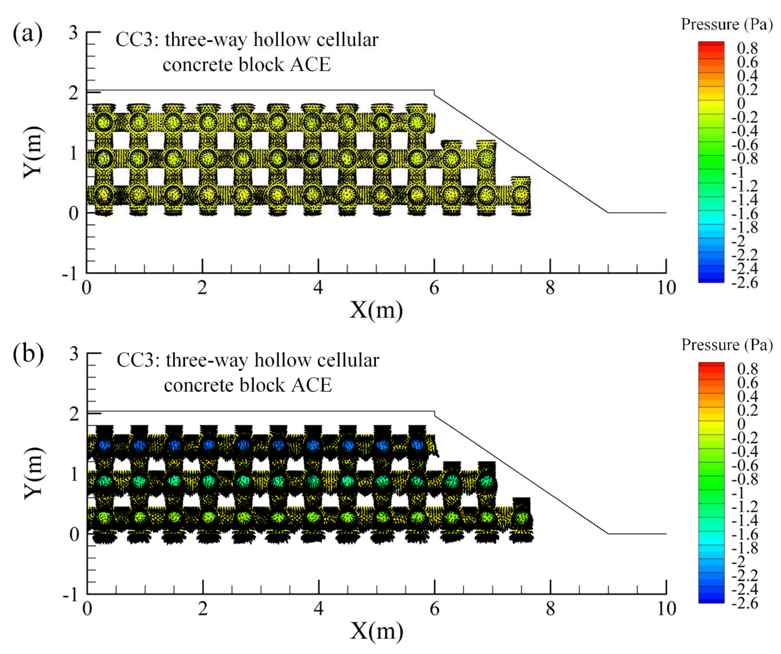
- In summer, the air motion was almost stagnant over most of the embankment due to low pressure gradient
- In winter, the open-graded structures' ventilation enhanced air convection due to high pressure gradient



Air velocity vectors and relative air pressure within the CR. (a) September 1. (b) February 1.

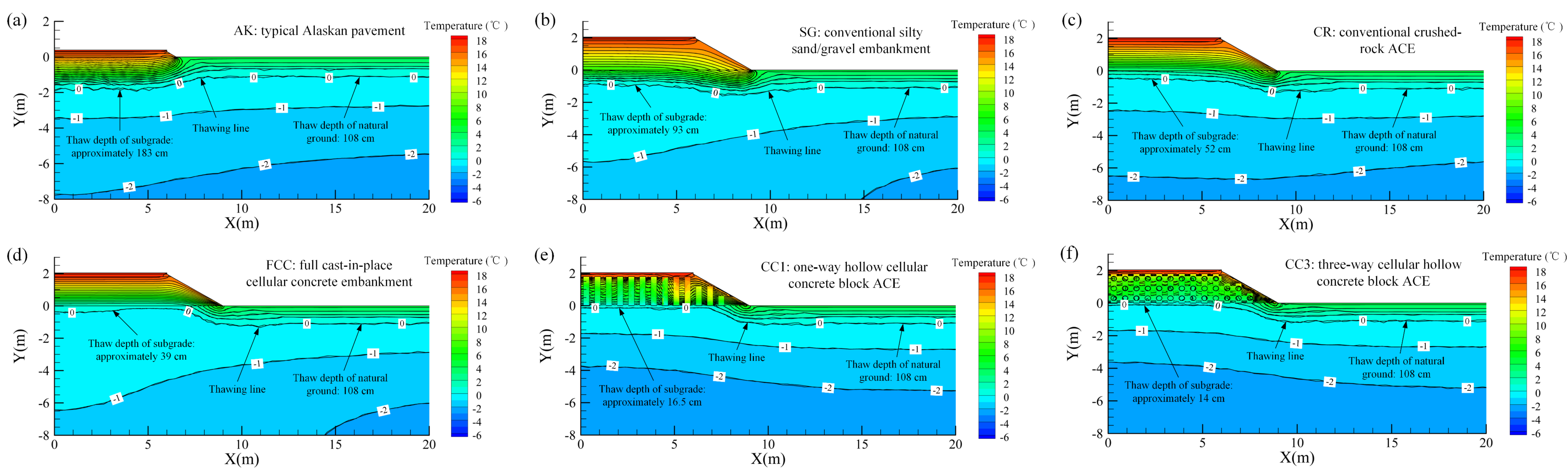


Air velocity vectors and relative air pressure within the CC1. (a) September 1. (b) February 1.

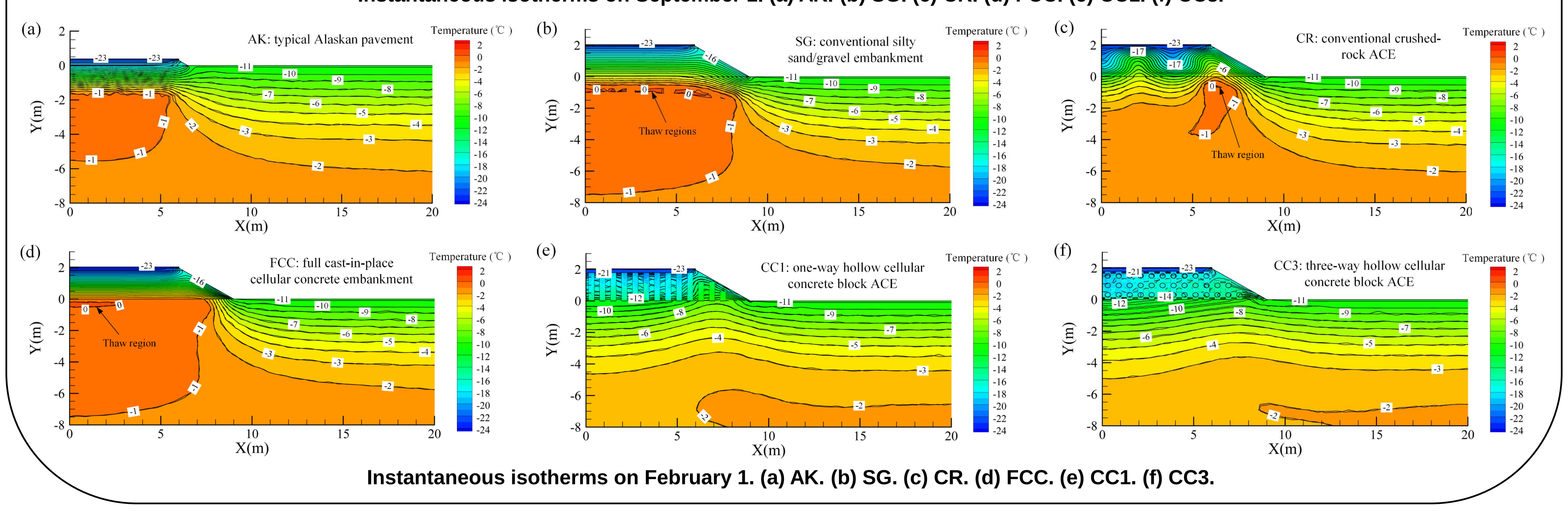


Air velocity vectors and relative air pressure within the CC3. (a) September 1. (b) February 1.

- Cellular concrete ACEs (i.e., CC1 and CC3) had much less total thaw depth than other cases.
- Cellular concrete ACEs (i.e., CC1 and CC3) can effectively slow down the permafrost degradation



Instantaneous isotherms on September 1. (a) AK. (b) SG. (c) CR. (d) FCC. (e) CC1. (f) CC3.



Instantaneous isotherms on February 1. (a) AK. (b) SG. (c) CR. (d) FCC. (e) CC1. (f) CC3.

CONCLUSIONS

- The open-graded structures' ventilation efficiency significantly impacted the ice-rich subgrade for preserving permafrost and avoiding pavement structure failure due to thaw settlement.
- In summer, the one-way and three-way hollow cellular concrete block ACEs effectively improved the heat insulation effect of the pavement structures and prevented subgrade from thawing.
- In winter, the novel ventilation designs significantly accelerated air motion in the porous interlayers and enhanced the cooling performance of ACE.
- This research demonstrated the superiority of the proposed one-way and three-way hollow cellular concrete block ACEs in roadway construction in cold regions.

Adaptive Infrastructure under Climate Change

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