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Thermal stress analysis of reactor containment building considering severe weather condition

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HIGHLIGHTS

- We examine that through-wall crack risk in cold weather is high.
- It is predicted that cracking in concrete wall will not happen in hot region.
- Cracking due to hydration heat can be controlled by appropriate curing condition.
- Temperature differences between inner and outer face is relatively small in hot weather.

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ABSTRACT

Prediction of concrete cracking due to hydration heat in mass concrete such as reactor containment building (RCB) in nuclear power plant is a crucial issue in construction site. In this study, the numerical analysis for heat transfer and stress development is performed for the containment wall in RCB by considering the severe weather conditions. Finally, concrete cracking risk in hot and cold weather is discussed based on analysis results. In analyses considering severe weather conditions, it is found that the through-wall cracking risk in cold weather is high due to the abrupt temperature difference between inside concrete and the ambient air in cold region. In hot weather, temperature differences between inner and outer face is relatively small, and accordingly the relevant cracking risk is relatively low in contrast with cold weather.

1. Introduction

Thermal cracking problems due to the heat of hydration of cement in concrete structures were first noted in the many large-sized concrete dams that were constructed in the United States in the 1930s. Fundamentally, concrete structures show early age behaviors after being placed at construction sites due to the stress-inducing mechanisms of hydration heat and the corresponding heat transfer. For the verification and prediction of concrete behavior, numerical schemes such as the finite element method (FEM) and the finite difference method (FDM) are considered powerful tools.

In this paper, the numerical analysis for heat transfer and stress development is performed for the containment wall in Reactor Containment Building (RCB) wall by considering the severe weather conditions and construction sequences. From the analysis, the concrete cracking risk in hot and cold weather will be discussed based on thermal stress results.

In this paper, a thermal stress analysis implemented with the hydration based concrete material model is performed to simulate the early age cracking behavior of a concrete structure. As the outcome of numerical analysis, the variations of stress and deformation with time and cracking behaviors are investigated for RCB wall.

In Section 2, the theoretical considerations for the treatment of the hydration heat and heat transfer are introduced. In Section 3, the methodology of the thermal stress analysis executed in this study is introduced briefly. In Section 4, a numerical analysis of RCB wall is presented. To estimate the effects of severe weather conditions on the early age cracking behavior of concrete, the numerical analysis is performed for two types of severe conditions (i.e. UAE; severe hot weather condition and Finland; severe cold weather condition).

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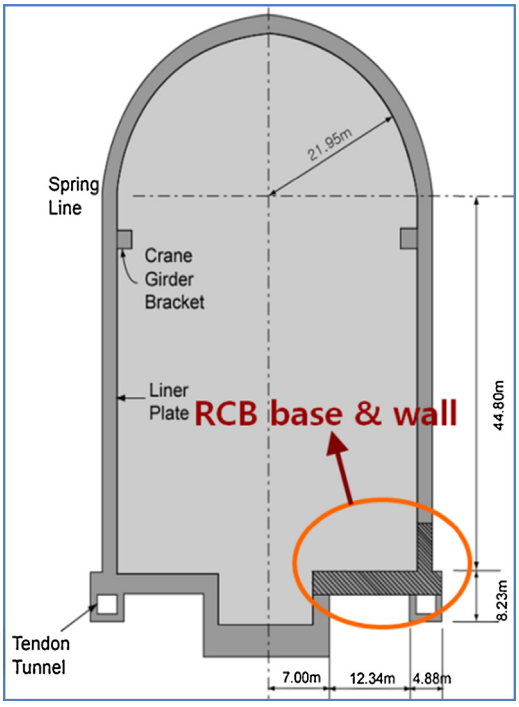


Fig. 1. RCB base mat and containment concrete wall.

2. Hydration heat and transfer in concrete

2.1. Generation of heat of hydration

Because hydration reaction of Portland cement is exceedingly complex and goes on continuously, it is impossible to express this reaction in a simple equation of chemical reaction. Hydration reactions of cement at normal temperature can be expressed as follows.

Alite phase

$$2C3S + 6H \rightarrow C3S2H3 + 3CH$$

Belite phase

$$2C2S + 4H \rightarrow C3S2H3 + CH$$

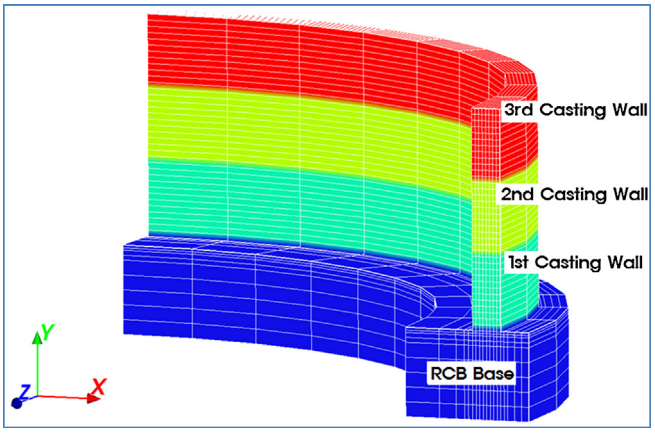
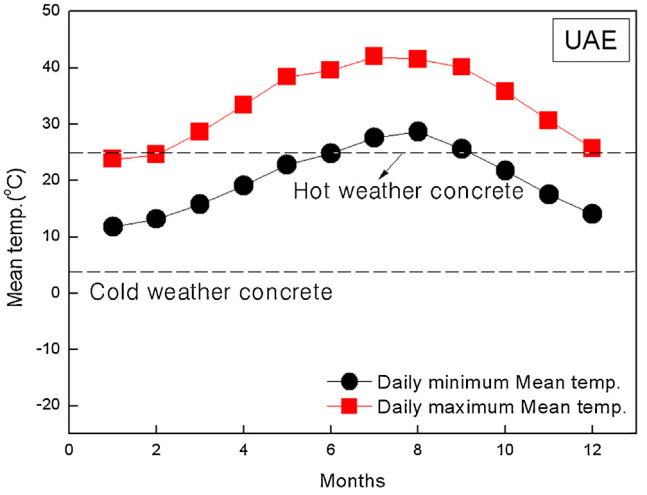
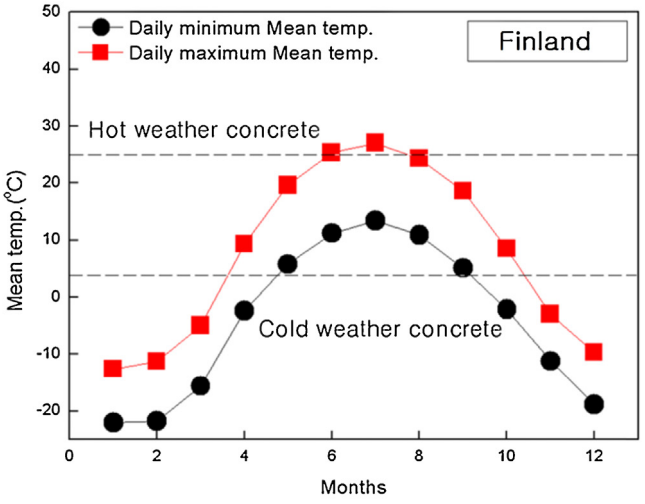


Fig. 2. Mesh modeling of RCB base mat and containment concrete wall.



(a) UAE



(b) Finland

Fig. 3. Annual ambient temperature profiles in hot and cold region.

Ferrite phase

$$2C3A + 27H \rightarrow C4AH19 + C2AH8$$
$$C4AH19 + C2AH8 \rightarrow 2C3AH + 15H$$
$$C3A + 3CaSO_4 + 32H \rightarrow C3A \cdot 3CaSO_4 \cdot 32H$$
$$2C3A + C3A \cdot 3CaSO_4 \cdot 32H + 4H \rightarrow 3C3A \cdot CaSO_4 \cdot 12H$$

Aluminate phase

$$C4AF + (8 + n)H \rightarrow C2AH8 + C2FHn$$

$$C4AF + 3CaSO_4 + 32H \rightarrow C3(AF) \cdot 3CaSO_4 \cdot 32H + CH$$

Table 1
Input data for thermal stress analysis of the concrete wall.

Parameter		
Thermal conductivity (W/(m K))		2.1
Casting temperature (°C)	26.7 (UAE)	12.8 (Finland)
Ambient temperature (°C)	32 (UAE)	4.8, 9, 11, 13 (Finland)
Convection heat transfer coefficient (W/(m^2 K))	w/o form	14
	Steel form	14