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# *Research on Integrated BIM-FEM Analysis for Temperature of Hydraulic Structure*

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***Abstract:*** Building Information Model (BIM) technology is widely used worldwide nowadays. BIM can integrate precise geometric and other essential information into a three-dimensional model for construction. It has natural advantages for connecting finite element analysis of related structures. However, there is a gap between BIM and Finite Element Method (FEM) because of the challenge of dividing the finite element mesh from complex building geometries, particularly in hydraulic structures. This study examines the feasibility of integrating BIM and FEM to analyze the temperature of hydraulic structures, using a sluice as a typical example. Revit is used to develop the BIM model, while ABAQUS is employed for conducting finite element analysis. Results show that the geometry of a hydraulic structure can be converted to a finite element mesh through reasonable geometric analyses, leading to successful thermal finite element analysis. Research findings can be a valuable reference for similar hydraulic projects.

## 1. Introduction

The concept of Building Information Model (BIM) was proposed by Chuck Eastman [1]. It has undergone substantial development and has been widely applied in construction projects worldwide [2], gradually becoming a paradigm for engineering delivery [3]. Due to the inherent integration of precise structural design information, along with details related to materials, construction, and other aspects during the creation process [4], BIM offers natural advantages in terms of information completeness and dimensional accuracy. Seamless integration of BIM with numerical calculations has the potential to significantly improve the accuracy and efficiency of engineering structural analysis. Numerous scholars and engineers have made efforts in this area, achieving significant accomplishments. For general conversion, Jia et al. [5] proposed a method to automatically generate finite element models based on BIM, using OpenBIM and ontology technologies in combination.

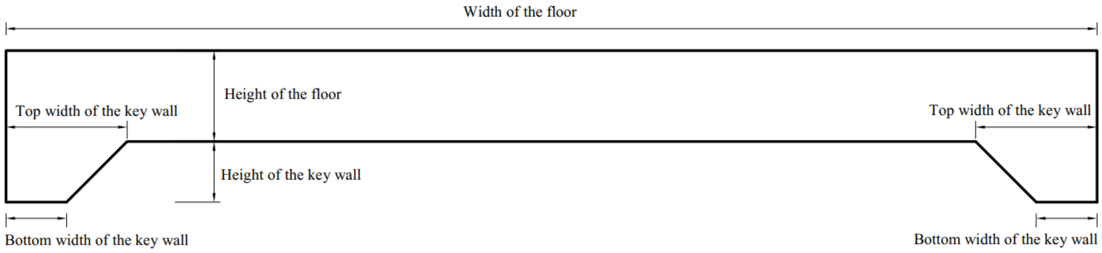
Zhou et al. [6] introduced an integrated modeling and simulation technique for complex geological volumes and engineering structures. This technique allows for seamless transformation to numerical simulation models, facilitating collaborative computation in geotechnical engineering BIM. Yang et al. [7] used BIM and the Finite Element Method (FEM) to develop methods for quickly assessing the stability of high slopes under different conditions. In the field of transportation engineering, Klinc et al. [8] developed a semi-automatic parametric method based on the I-BIM concept for tunnel engineering, effectively integrating it with FEM for analysis. Wang et al. [9] used Revit and ANSYS to develop a method for converting between BIM and finite element models. They also conducted finite element analysis based on their research achievements. Pan et al. [10] proposed a method for rapidly converting high-piled wharf BIM models into finite element models through secondary development using Revit.

However, hydraulic structures exhibit more complex spatial characteristics compared to the structural types studied in the aforementioned research, making the BIM creation process inherently more intricate. Taking a sluice project as an example, researchers have invested significant effort in parametric BIM design. Liang [11] conducted research and applied parametric design using BIM technology, achieving comprehensive application of BIM technology in digital design through collaborative design, parametric template libraries, refined modeling, and finite element analysis. Luo et al. [12] used the parametric modeling features in Revit to create template files for BIM of sluices. Simultaneously, finite element analysis has gradually become one of the primary methods for analyzing sluice structures, as evidenced by the literature review. For instance, Fang et al. [13] proposed a structural safety analysis method for sluice chambers based on the finite element method. Hou et al. [14] utilized ABAQUS software to assess potential risks of a sluice on soft soil foundations. Therefore, establishing an effective connection between BIM and FEM in sluice structures has become a valuable research topic. Some researchers have investigated the integration of Building Information Modeling (BIM) with basic hydraulic calculations. For example, Niu et al. [15] conducted secondary development on Revit to simplify seepage calculations based on Revit models of the sluice. However, there are still relatively few successful examples of integrated BIM-FEM analysis in sluice structures.

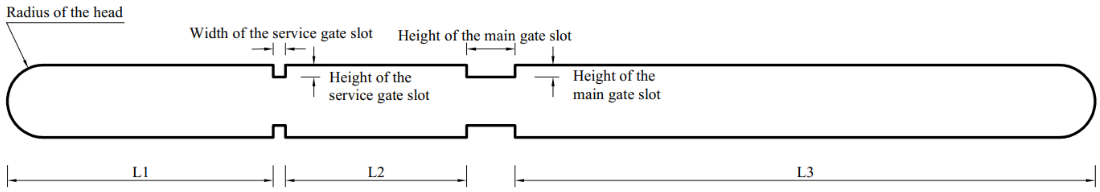
This paper aims to investigate the integration of BIM and FEM in the context of a typical sluice structure. Utilizing parametric modeling in Revit, exporting geometric structures through analysis of geometric volumes, and employing the open-source software Gmsh for mesh generation, the study will utilize ABAQUS software to conduct thermal calculations for the sluice structure. The objective is to utilize BIM-FEM integrated analysis for the temperature analysis of concrete structures in a sluice project.

## 2. Parametric modeling

In Revit, Building Information Modeling (BIM) effectively consists of various family instances. When creating family files, parameterizing components can be achieved by designing suitable dimensional parameter groups, thus enabling parametric design in BIM. The sluice structure is mainly composed of a floor and several piers. Conventional sluice structures adhere to specific design paradigms. We have summarized the structural parameters, leading to the parameter group of the sluice structure as shown in Figure 1. Subsequently, family files were created, and after assigning specific parameter values, the sluice model depicted in Figure 2 can be obtained. Simultaneously, a rational geometric model of the foundation was developed based on the shape of the bottom face of the floor, with the length, width, and depth of the foundation being three times that of the sluice structure, as illustrated in Figure 2.




(a) Floor




(b) Pier

Figure 1: Dimensional parameter groups of typical cross-sections.

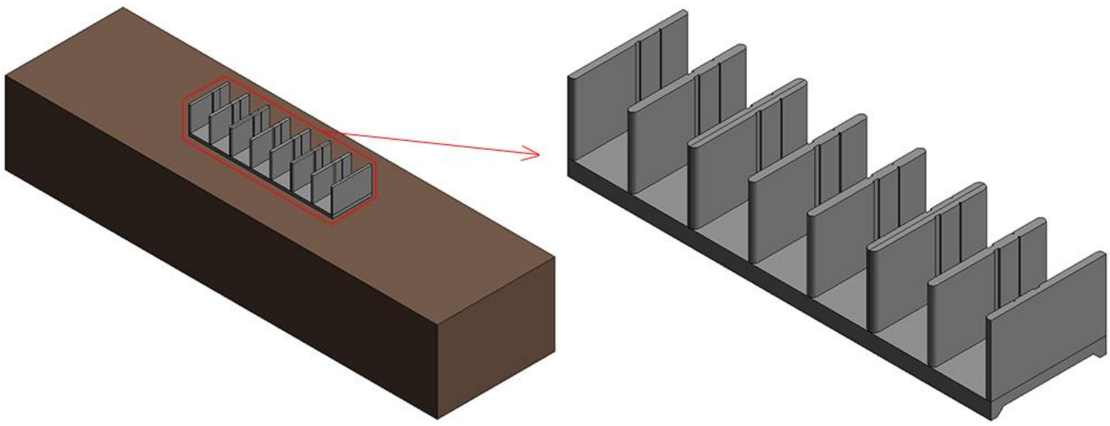
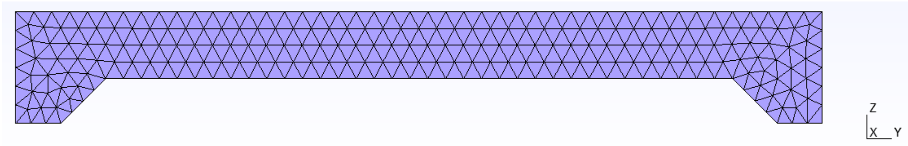


Figure 2: Complete build information model (BIM) of the sluice.

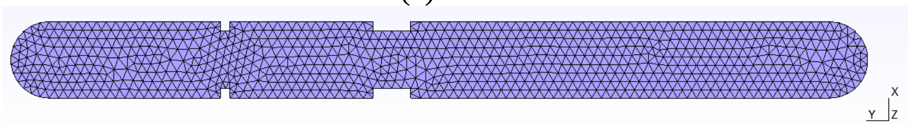
## 3. Conversion from BIM to Finite Element Mesh

The analysis of the developed geometric model of the sluice reveals that it mainly comprises the foundation, floor, and piers. Each part is mainly based on the extruded geometries of the same cross-section. Thus, by leveraging the secondary development capabilities of Revit and the established BIM model, it is possible to extract geometric information of the cross-section from the geometric model. Subsequently, this cross-sectional geometric information is passed to Gmsh, and appropriate meshing parameters are configured in Gmsh. The meshing function of Gmsh is then used to create meshes for the cross-sections of the foundation, floor, and piers. Figure 3 illustrates two-dimensional meshes of the floor (*a*), piers (*b*), and foundation (*c*).

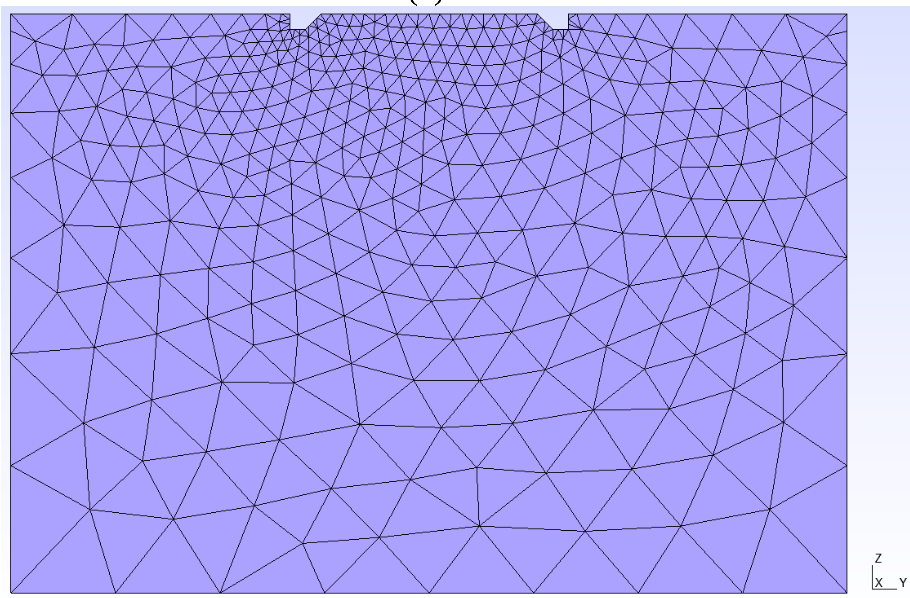
Based on the two-dimensional elements created for the cross-sections, a complete three-dimensional finite element mesh for the sluice, as shown in Figure 4, can be obtained by extruding the cross-sections with appropriate line division and bias factors along the extrusion direction. Additionally, in the process of meshing, considerations should be given to the construction sequence, particularly the division of concrete pouring sections. In this project, the meshing process has already been well coordinated with the construction sequence.




(a) Floor




(b) Pier




(c) Foundation

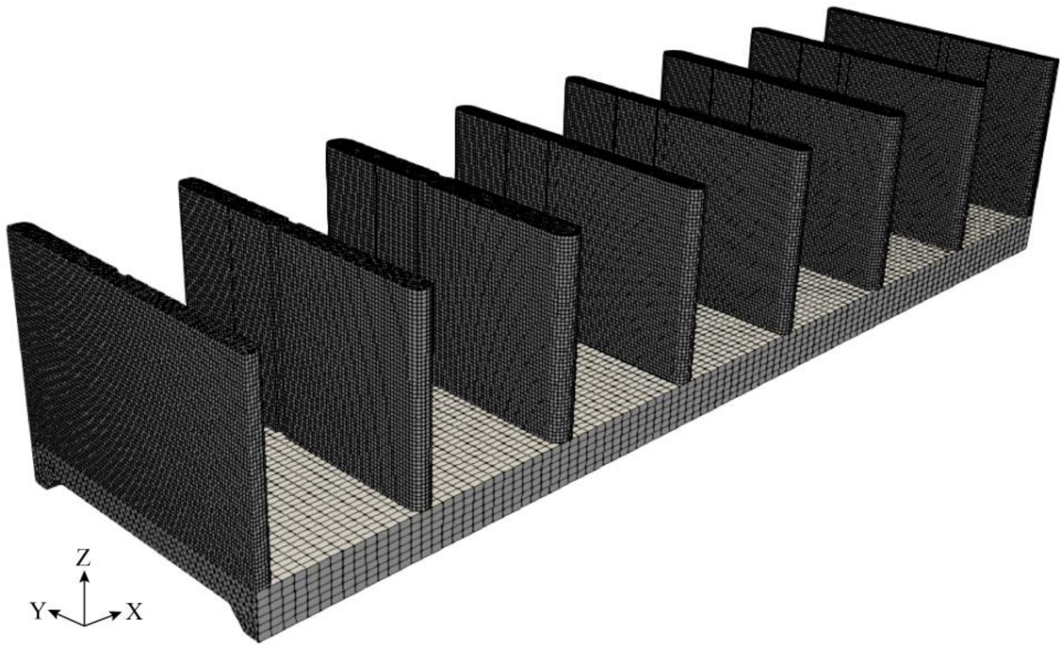
Figure 3: This caption has one line so it is centered.

## 4. Finite Element Analysis

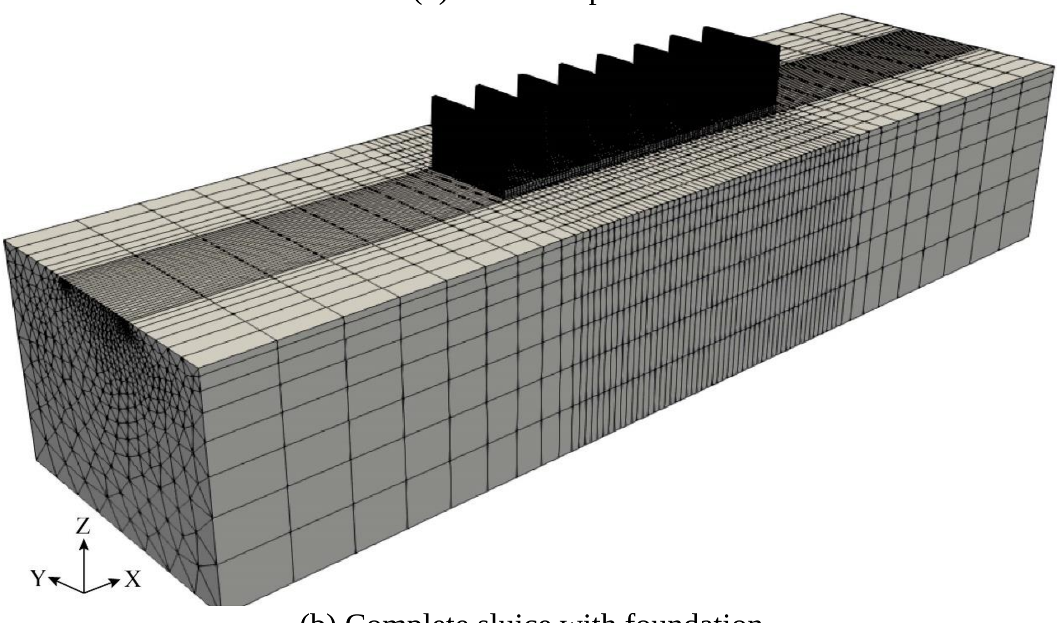
The thermal analysis of the sluice project was conducted using the finite element model converted from BIM of the sluice. The construction process is outlined in Table 1. The construction began with pouring the floor on October 15th. During the pouring process, formwork was installed around the perimeter of the floor. Insulation measures were applied to the top surface of the floor immediately after it was poured. After a 7-day curing period, the formwork for the floor and the top curing measures were removed, allowing the concrete to continue gaining strength. Three days later, the pouring of the piers began, using formwork around the perimeter during the pouring process. After completion, insulation measures were promptly applied to the top surface, mirroring the process used for the floor, and then removed after 7 days. The total calculation period is 20 days.

Table 1: Setup of simulation steps.

| Step No. | Process | Duration (h) |
|---|---|---|
| 1 | Casting floor | 168 |
| 2 | Dismantling floor formwork | 72 |
| 3 | Casting Pier | 168 |
| 4 | Dismantling pier formwork | 72 |




(*a*) Floor and piers




(b) Complete sluice with foundation

Figure 4: Finite element mesh of sluice components.

In the context of heat transfer between the sluice project and the surrounding air, the air temperature is initially determined using Equation (1) to calculate the monthly average temperature. Subsequently, interpolation is used to calculate the daily average temperature for each day of the month. The temperature for each hour is then calculated using Equation (2). The convective heat transfer coefficient for contact between the soil and air is 0.06007J/(mm$^2$·h·℃), for contact between concrete and air is 0.050213J/(mm$^2$·h·℃), for the concrete with formwork is 0.01802J/(mm$^2$·h·℃), and for the concrete with insulation measures is 0.01202J/(mm$^2$·h·℃).

$$T_a(\tau) = 14.08 + 12.884\cos\left[\frac{\pi}{6}(\tau - 7.192)\right] \tag{1}$$

where $T_a$ represents the monthly average air temperature, and $\tau$ is the time in months.

$$T_a^d(\tau) = T_{am}^d + 6.5\cos\left[\frac{\pi}{12}(\tau - 14)\right] \tag{2}$$

where $T_a{}^d$ is the instantaneous temperature, $T_{am}{}^d$ is the interpolated daily average air temperature, and $\tau$ is the time in hours.

The casting temperatures for the floor concrete and the pier concrete are set to 17.92℃ and 15.84℃, respectively. The initial temperatures for the foundation are set in three parts: (1) from 0 to 6m, it is 11.67℃, (2) from 16m to the bottom of the foundation, it is 14.08℃, and (3) from 6m to 16m, the temperature is linearly interpolated based on the depth.

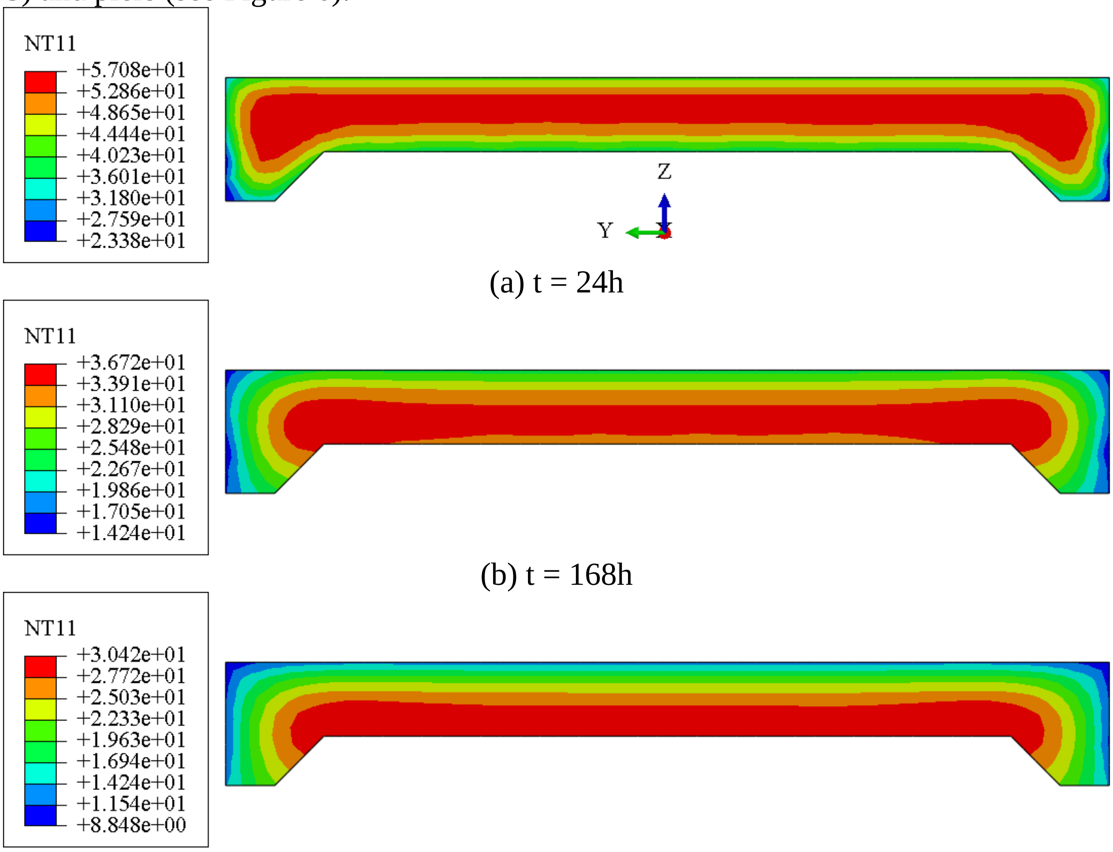
The thermal parameters for the concrete and foundation soil of the sluice project are presented in Table 2. In addition, concrete generates heat through hydration, which can be quantified using the adiabatic temperature rise formula as given in Equation (3).

$$\theta(\tau) = 40.53\left(1 - e^{-0.65\tau^{0.92}}\right)\ {}^\circ\text{C} \tag{3}$$

Table 2: Thermal parameters of the soil and concrete.

| | Conductivity (J/(mm·h·℃)) | Specific heat (J/(g·℃)) | Density (g/mm$^3$) |
|---|---|---|---|
| Soil | 10.838 | 0.82 | 0.00167 |
| Concrete | 9.432 | 0.97 | 0.002356 |

The calculation based on the above settings results in temperature contour maps for the floor (see Figure 5) and piers (see Figure 6).

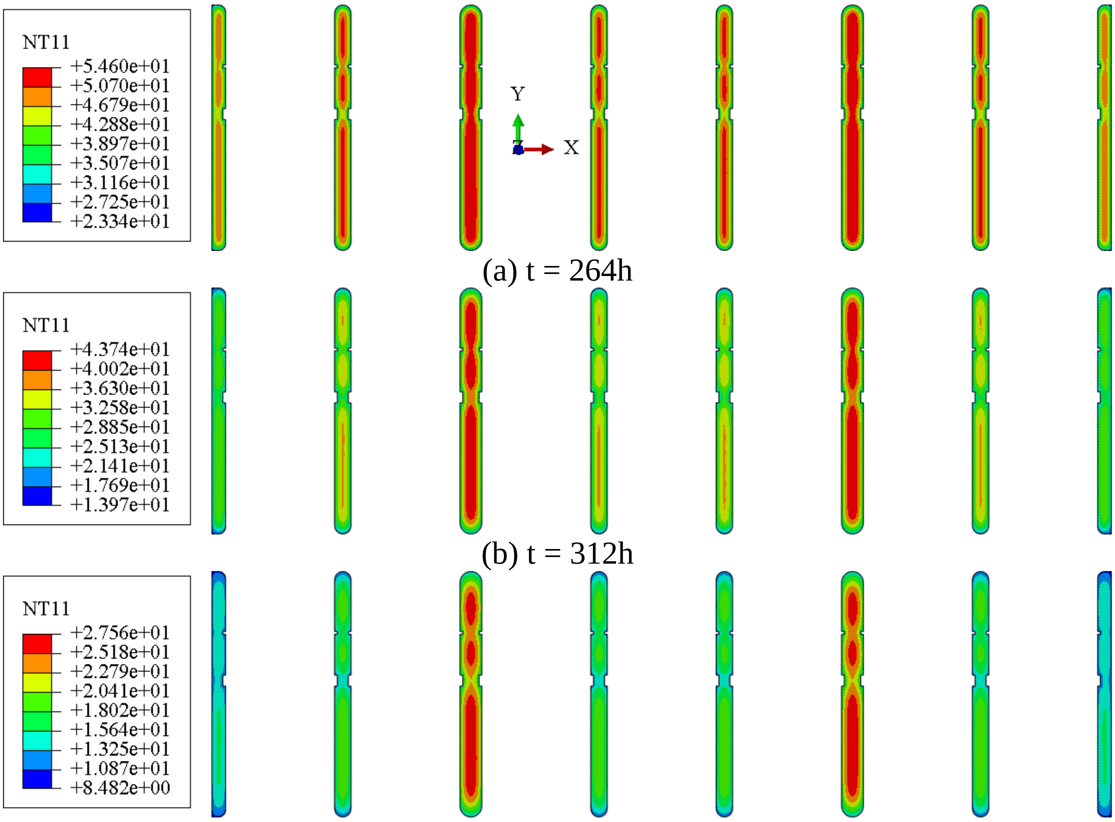



(a) t = 24h

(b) t = 168h

(c) t = 240h

Figure 5: Temperature contours of the center cross-section of the floor.




(a) t = 264h

(b) t = 312h

(c) t = 408h

Figure 6: Temperature contours of the center cross-sections of piers.

## 5. Conclusions

This study presents an integrated BIM-FEM analysis workflow for sluice structures. The workflow involves parameterized BIM modeling, conversion of finite element mesh based on BIM, and finite element thermal calculation. Based on the research, several valuable conclusions are outlined below:

(1) Expanding on the analysis of geometric spatial types, a three-dimensional modeling method for conventional sluice structures can be developed, establishing a parameterized modeling process. This parameterized modeling technique significantly accelerates the speed of creating BIM for the sluice project.

(2) By analyzing the geometric structures, advanced tools can be used to segment facial meshes, and three-dimensional finite element meshes can be created using custom extrusion techniques. This enables the successful conversion of the BIM into a finite element model.

(3) The finite element model, which includes construction process information, allows for the easy input of material and boundary information, leading to successful finite element analysis.

(4) This study primarily aims to bridge the gap between BIM and FEM, and the chosen geometric model is not intricate. More complex geometric models require additional in-depth investigation. Additionally, it was discovered that the process could be standardized and automated through programming. Further study is also required.

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