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Finite element analysis of temperature field of reinforced concrete simply supported beam

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Abstract: **Fire is one of the most common disasters. It could cause the collapse of fire architectural structure and harm people's life and properties's afety. Therefore, the fire resistant design of structures is especially crucial. As a result of the integrity of a building's structure, components of a reinforced concrete frame structure have relatively great interaction between each other, and their mechanical properties and isolate members are quite different when they suffer from fire. At present, it is a lack of the research which takes both end constraint and fire resistance of restrained T-beams into account. At the same time, the fire resistance properties of high-level reinforced concrete frames are not discussed deeply.**

Keywords: Simulation; Fire; Beam

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1. Thermal performance of steel and concrete

1.1. Thermal performance of concrete

1) Thermal conductivity

The thermal conductivity of concrete is one of the most important thermal parameters in thermal analysis under fire. There are many factors affecting the heat transfer coefficient, including the moisture content, concrete ratio, aggregate type, etc. according to the European standard EC4 (1994)[1], the curve of the thermal conductivity with temperature is shown in Figure 1.

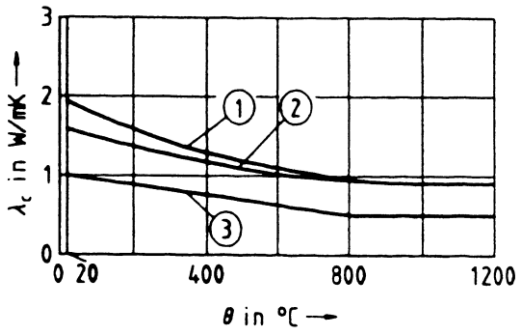

Figure 1: Variation curve of thermal conductivity.

The European standard EC4 (1994) [1] calculates the thermal conductivity of siliceous aggregate and calcareous aggregate at temperatures between 20℃ and 1200℃, as follows:

Ordinary concrete:

$$\lambda_c(T) = 2 - 0.24 \cdot \frac{T}{120} + 0.012\left(\frac{T}{120}\right)^2 \qquad (1)$$

$$\lambda_c = 1.6 - 0.16\frac{T}{120} + 0.008\left(\frac{T}{120}\right)^2 \qquad (2)$$

In style:

$\lambda_c(T)$ - Thermal conductivity (W/ (m · K)) when the temperature of concrete reaches T degrees celsius;

T - Temperature of concrete (℃).

2) Specific heat

The specific heat of concrete is the amount of heat absorbed or released by a concrete of a unit volume of 1 degrees. The factors affecting the specific heat are similar to those of the thermal conductivity. They include water content in the structure, concrete ratio, aggregate type, and so on. The specific heat change curve of concrete given in European standard EC49 (1994)[1] is shown in Figure 2.

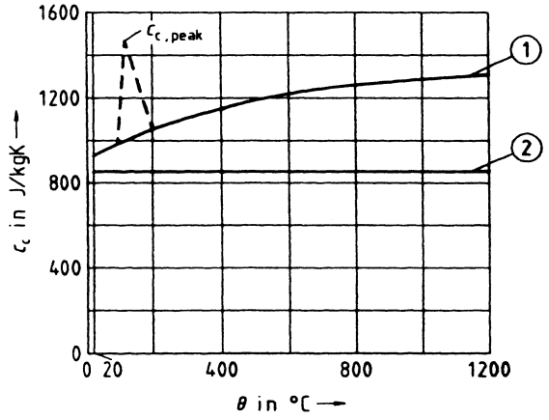

Figure 2: specific heat curve.

The formula for the specific heat of concrete given in European standard EC49 (1994) [1] is as follows:

$$C_c(T) = -4\left(\frac{T}{120}\right)^2 + 80\left(\frac{T}{120}\right) + 900$$

$$20℃ \le T \le 1200℃ \qquad (3)$$

3) Density

In the case of high temperature heating, the density

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of concrete affected by temperature varies little. However, as the moisture inside the concrete evaporates at high temperatures, the density of the concrete decreases slightly.

The formula for the change of concrete density given in European standard EC49 (1994) [1] is as follows:

$$\rho_{c,T} = 2354 - 23.47\left(\frac{T}{100}\right) kg/m^3 \quad (4)$$

Because only a small amount of water evaporates, the drop of the density of concrete is very small and the influence on the overall strength of the structure and the carrying capacity of the member will be very small, so it can be neglected. Therefore, the model is not considered, and the concrete density is determined as follows:

$$\rho_{c,T} = 2400\left(kg/m^3\right) \quad (5)$$

4) Coefficient of thermal expansion

The coefficient of thermal expansion of concrete is defined as volume change per unit volume rise or decrease by 1 degrees celsius. Concrete heat capacity is large, but the thermal conductivity is very small, so the heat transfer performance of concrete is very poor, in a relatively short period of time can make objects reach the same temperature, resulting in different parts of the internal component is not uniformly heated, thermal expansion deformation is not the same. Therefore, in the calculation of thermal analysis, the average coefficient of linear expansion is generally used, and the temperature expansion curve is shown in Figure 3.

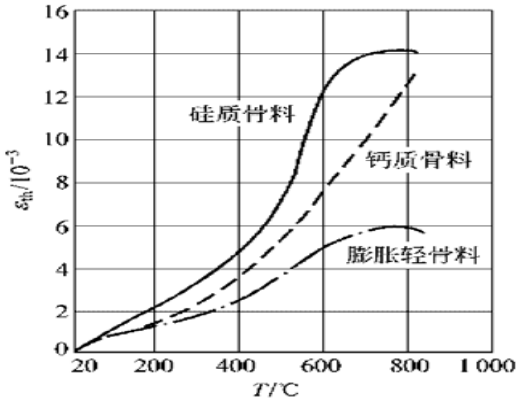

Figure 3: Temperature rising inflation curve.

Its formula is:

$$\overline{\alpha_c}(T) = \frac{\varepsilon_{th}}{T - T_0} \quad (6)$$

All kinds of factors, such as aggregate type and size of component, may lead to the variation of thermal expansion coefficient of concrete.

The formula for calculating the thermal expansion coefficient of concrete given in Eurocode EC4 (1994) [1] is as follows:

$$\Delta l/l = \begin{cases} 2.3\times10^{-11}T^3 + 9\times10^{-6}T - 1.8\times10^{-4} & 20℃ \le T \le 700℃ \\ 14\times10^{-3} & 700℃ < T \le 1200℃ \end{cases} \quad (7)$$

1.2. Thermal performance of steel bars

1) Thermal conductivity

The thermal conductivity of steel is relatively large, so its thermal conductivity is very good. The thermal conductivity of a steel bar varies with the temperature, but the thermal conductivity of the bar remains constant as it passes beyond a certain range of temperature, and can be considered a constant. The European standard EC4[1] proposed the thermal conductivity of steel bars:

$$\lambda_s = \begin{cases} 54 - 3.33\times10^{-2}T & 20℃ \le T < 800℃ \\ 27.3 & T \ge 800℃ \end{cases} \quad (8)$$

2) Specific heat

The specific heat of steel varies greatly with temperature. According to European standard EC4[1], its formula is as follows:

$$c_s = \begin{cases} 2.22\times10^{-6}T^3 - 1.69\times10^{-3}T^2 + 0.773T + 425 & 20℃ \le T \le 600℃ \\ 13001/(738 - T) + 6666 & 600℃ < T \le 735℃ \\ 17820/(T - 731) + 545 & 735℃ < T \le 900℃ \\ 650 & 900℃ < T \le 1200℃ \end{cases} \quad (9)$$

3) Coefficient of thermal expansion

The thermal expansion coefficient of reinforcing steel increases with the gradual increase of temperature, but the degree of change is not great. The thermal expansion coefficient of the steel bar is taken from Lie.T T[2]:

$$\alpha_s = \begin{cases} (12 + 0.004T)\times10^{-6} & 20℃ < T < 1000℃ \\ 1.6\times10^{-5} & 1000℃ \le T \le 1200℃ \end{cases} \quad (10)$$

4) Density

Normally, the density of the reinforcement is considered constant 7800kg/m^3.

1.3. Summary

Through to the domestic and foreign experts and scholars for the thermal performance of steel and concrete under fire two kinds of materials are summarized, the system is described including thermal conductivity, specific heat, thermal expansion coefficient and density, the thermal properties of two kinds of materials. By experts according to the domestic and foreign research results, the reasonable selection of thermal parameters of reinforced concrete under fire of two kinds of materials, and provide a theoretical basis for the research on fire resistance performance of reinforced concrete beams under fire.

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2. Finite element analysis of temperature field

2.1. Finite element parameter design

The size and reinforcement of the beam are designed according to the current code and the method of numerical simulation is adopted. The cross spacing is 4.0m, the grade of concrete strength by C25, longitudinal reinforcement with HRB335 grade, stirrup made of HPB235, in order to ensure that the reinforced concrete beam has enough bending capacity, shear failure occurs, the reinforced concrete beam specimen flexural reinforcement ratio is larger. The dimensions of the beam and the reinforcement are shown in Figure 1.

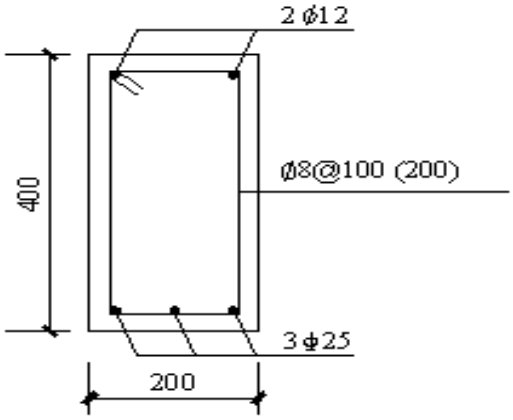

Figure 4: The size and reinforcement of testing beam.

Application of ABAQUS software in the table 1 different parameters of reinforced concrete continuous beams are simulated, including a total of 15 beams, are considered in the main effect of single span beam under shear span ratio on shear performance of reinforced concrete continuous beam.

Table 1 Parameter design

Beam number	Shear span ratio	Constant temperature/℃
L1	1.5	20
L2	2.0	20
L3	2.5	20
L4	1.5	400
L5	2.0	400
L6	2.5	400
L7	1.5	600
L8	2.0	600
L9	2.5	600
L10	1.5	800
L11	2.0	800
L12	2.5	800
L13	1.5	1000
L14	2.0	1000
L15	2.5	1000

2.2. Temperature variation curve of fire simulation

This paper uses ABAQUS to simulate the temperature variation curve of the fire temperature field, as shown in Figure 15. The rising section adopts the international standard ISO834 temperature rising curve [3], and the calculation method is as follows:

$$T = T_0 + 345\lg(8t+1) \qquad (11)$$

2.3. heat transfer simulation

In the case of high temperature, the temperature is transferred from the surface of reinforced concrete structure to the interior of the structure by heat transfer. The differential equation of heat conduction can be derived from the heat conduction theory, and the differential equation is as follows:

$$\frac{\partial H}{\partial t} - \lambda\nabla\cdot(\nabla T) = 0 \qquad (12)$$

In style:

H - the enthalpy value of the internals of the fire during the process;

Thermal conductivity of concrete;

T - fire time of component;

T - component surface temperature;

Hamilton operator— $\nabla = \left(\frac{\partial}{\partial x} \quad \frac{\partial}{\partial y}\right)^T$.

The enthalpy change rate can be defined as:

$$\frac{\partial H}{\partial t} = \rho c \frac{\partial T}{\partial t} \qquad (13)$$

In style:

ρ - Mass density of concrete;

C - specific heat of concrete.

In the case of fire, the temperature rise of the reinforced concrete component is accomplished by the heat transfer between the heat contained in the air and the heat transfer inside the component itself. The corresponding analysis of the temperature field is based on the fundamental differential equation of the heat conduction equation, and the basic differential equations for the transient heat conduction are as follows:

$$\frac{\partial T}{\partial t} = \frac{1}{c\rho}\left[\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right)\right] + \frac{q_d}{c\rho} \qquad (14)$$

In style:

T - the temperature of the object, K;

ρ - density of material;

C - specific heat capacity of object material,;

λ - Thermal conductivity of materials,;

q_d - The amount of heat produced by unit volume material per unit time.

2.4. ABAQUS temperature field simulation process

In this study, the ISO834 standard temperature curve was used to simulate the temperature field. The

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reinforced concrete simple beams were increased to 400, 800 and 1000 degrees respectively, and then they were loaded to failure under the condition of constant temperature. The influence of shear span ratio on shear capacity of simply supported concrete beams under different simulated temperatures is investigated by comparing the failure conditions of reinforced concrete simply supported beams at normal temperatures. The temperature rise of the finite element simulation test is shown in the following figure:

ISO834 standard heating curve:

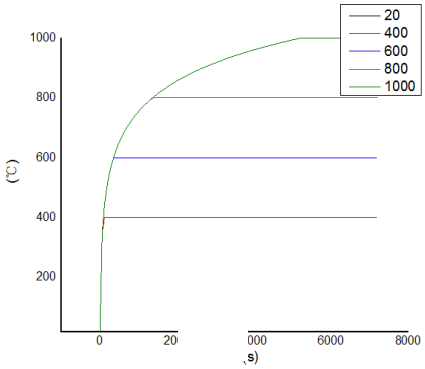

Figure 5. Different constant temperature in simulation test.

In the fire simulation test, the reinforced concrete simply supported beam adopts the mode of three sides fire, the temperature field simulation time is 2h, after reaching the specified temperature, the temperature is no longer changing, and begin to load until the specimen damage.

2.4.1. Define constraints

When the fire surface is defined, the values adopted are calculated according to the international standard temperature rise curve. Convection conditions and radiation conditions are set respectively. Attention is paid to the parameters set by the fire surface and the non fire surface. When the fire face is set, the amplitude of the heating section is selected as the standard temperature rising curve, and the direct temperature range is 20. The amplitude of the amplitude is not required for the non fire face. Finally, as shown in Figure 6.

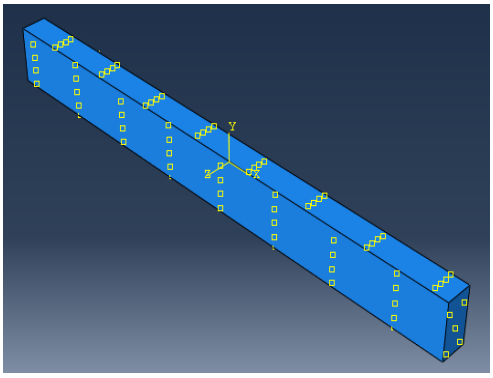

Figure 6: Definition of interaction.

Define the binding between the bar and concrete and select the binding, as shown in figure 7. Since the fire surface is only concrete during the heating process, all the temperature of the steel bar is transferred by the heat of the concrete. Because the steel bar is straight, there is no surface, and the node area should be chosen when the surface type is selected. Because the temperature is transferred from concrete to steel, the concrete is chosen as the main surface and the reinforcement is selected from the surface. This setting allows the concrete to be subjected to heat transfer to the steel bar during thermal analysis, thereby obtaining a temperature field of concrete and steel bars.

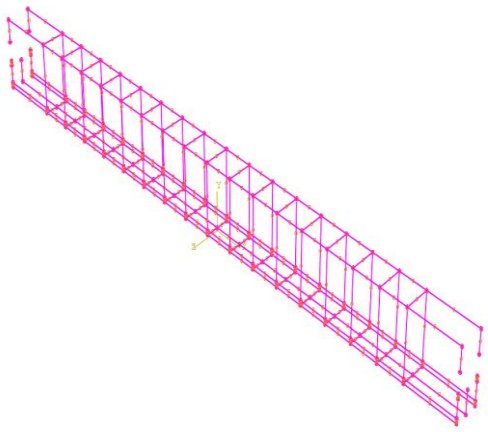

Figure 7: Tie.

2.4.2. Boundary condition

The boundary condition is that the preset temperature field is set by the function of the predefined field, the whole model is set 20, and the initial temperature is 20 DEG when the thermal analysis of the ABAQUS is represented. The model after setting is shown in Figure 8.

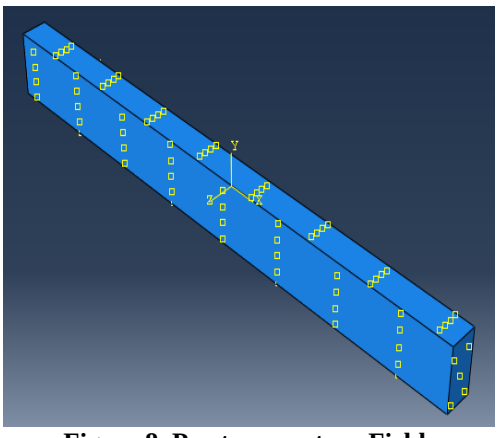

Figure 8. Pre-temperature Field.

2.4.3. Meshing

The concrete structure and reinforcement are divided into grids and set to heat transfer, and the final effects are shown in Figure 9 and 10. It should be noted that when you select the grid size, you should try to keep the nodes consistent, otherwise errors are prone to occur after the operation is committed.

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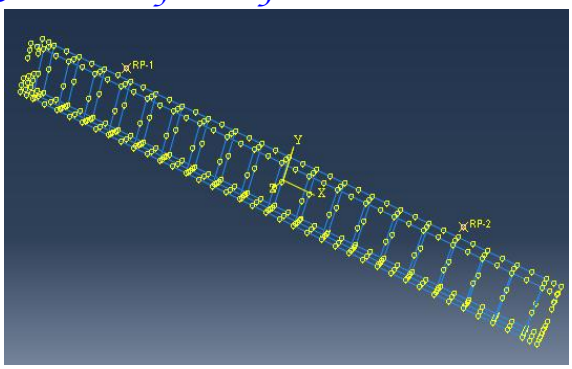


Figure 9: Steel skeleton mesh.

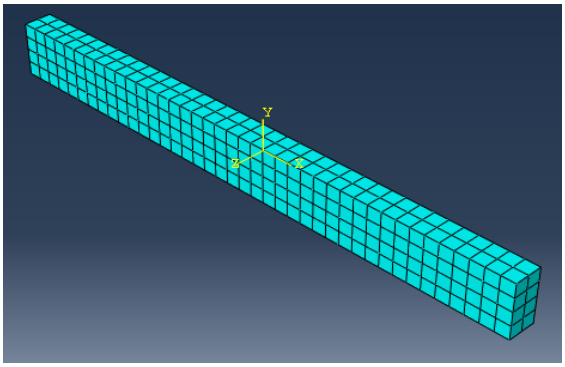
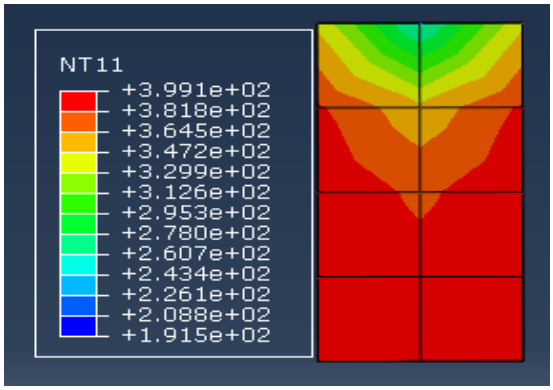


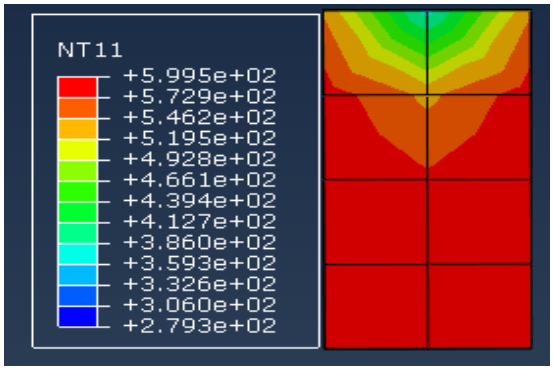
Figure 10: Concrete beam mesh.

2.4.4. Job submission and analysis

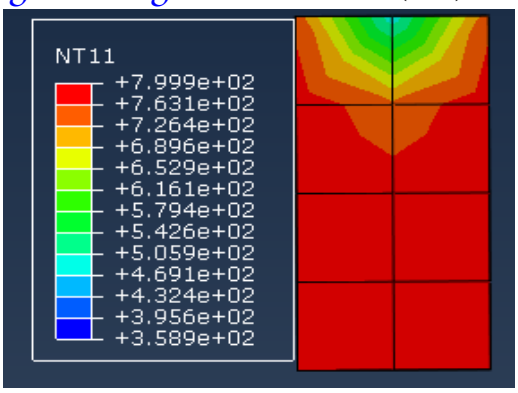
The previous thermal parameters have been set up before submitting the job for temperature field analysis, creating analytical assignments and submitting the final analysis results as shown in figure 11. Preserve analytical data to provide a predefined temperature field for mechanical analysis.



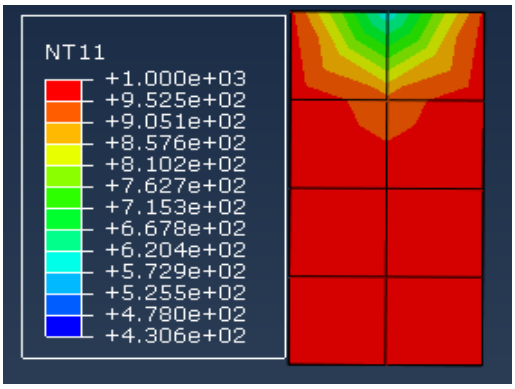
a）400℃



b）600℃



c）800℃



d）1000℃

Figure 11: distribution of temperature field.

3. Conclusion

Figure 11 shows the temperature distribution in the middle section of four different constant temperatures. As shown by the diagram, the simulated temperature field nephogram at different temperatures is similar, and the four models are left, right, and lower three surfaces under fire.

1) Different from the distribution of cloud load at constant temperature, constant load temperature distribution of cloud type U distribution, the outermost layer of the highest temperature and ambient temperature has been reached, from the outside to the inside temperature gradually decreased, the top surface temperature and a certain range below the lowest temperature;

2) This study will remain constant until the specified temperature is reached until loading is broken. During the constant temperature loading, the lower half of the beam cross section reaches a constant temperature due to the heat conduction of the beam. Because the upper section has only two sides heat conduction and the upper section does not heat transfer, the interface presents a V type distribution. Therefore, the temperature field distribution is different.

3) This research mainly analyse the temperature field of reinforced concrete beams, analysis respectively in accordance with the ISO834 standard heating curve of temperature rise to 400℃, 600℃, 800℃ and 1000℃, simulation of beam temperature field under different temperatures, to provide reference for future research.

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Acknowledgement

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References

[1] European Committee for Standardization, ENV 1994-1-2, Eurocode 4, Design of Composite and Concrete Structures, Part 1.2:Structural Fire Design[S]. 1994.
[2] T.T. LIE, E.M.A. Denham. NRC-CNRC Internal Report, 651, 1993.
[3] International Standard IS0834, Frie-Resistance Tests Elements of Building onsreetion, Amendment 1, Amendment 2[S],1980.
[4] M.S. Khan, J. Prasad, H. Abbasa, Construction and Building Materials, 24 (2010) 1869.
[5] M.B. Dwaikat, V.K.R Kodur. Journal of Structural Engineering, 135 (2009) 1408-1417.
[6] W.Y. Gao, J.G. Dai, J.G. Teng, G.M. Chen. Engineering Structures, 52 (2013) 488-501.
[7] J. Ožbolta, J. Bošnjaka, G. Periškića, A. Sharmaa. Engineering Structures, 58 (2014) 166-174.
[8] V.K.R. Kodur, P. Pakala, M.B. Dwaikat. Fire Safety Journal, 4(2010) 211-220.

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