EVALUATION OF EFFECT OF HEAT CONDUCTION OF REBAR BY USING RBSM-TRUSS NETWORK MODEL

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ABSTRACT

The explosive behavior of RC members due to thermal stress and vapor pressure under high temperature was investigated numerically using a developed method. RBSM-TRUSS Network model was adopted as an analytical method, in which 3-dimensional Rigid Body Spring Method (RBSM) based on dynamic equation of motion as structural analysis and truss network model as mass transfer analysis were integrated. Moreover, the effect of rebar such as heat conduction and thermal expansion was modeled. Two RC members were simulated and it was shown that rebar with small cover influence to damage accumulation and explosive behaviour.

1. INTRODUCTION

Behavior of concrete structure under high temperature are time and heat dependent combination problem of material, structure and mass transfer. The fireproof performance has been evaluated by experimentally and analytically [1] [2]. An advantage of analytical methods is to evaluate the effect of several factors on fireproof with low cost and short time. Therefore, it is desirable to enhance the performance of analytical methods in order to solve mechanical behavior from cracking to explosive behavior, considering realistic structural conditions such as arrangement of rebar, member shape and boundary condition.

A numerical method to simulate explosion spalling behaviour of concrete subjected to high temperature has been developed by authors [3]. However, the applicability was limited to concrete only and it could not simulate RC members considering the effect of rebar .

In this study, in order to simulate RC members under high temperature, the rebar is modeled by beam element as structural member and is modeled by a part of truss network as heat conduction field. Then, the effect on damage accumulation and explosive behaviour of the rebar is simulated.

2. ANALYTICAL METHOD

2.1. 3-Dimensional RBSM

3-dimentional RBSM is used as structural analysis, which represents a continuum material as an assemblage of rigid particle elements interconnected. Each rigid particle has three translation and three rotational degrees of freedom defined at nuclei. The interface between two particles consists of several springs as shown in Figure 1. That is, a boundary surface is divided by triangles with the center of gravity point and vertices of the surface, and individual one normal and two tangential springs are set at the integral point.

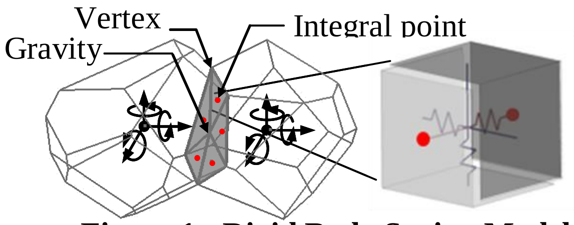
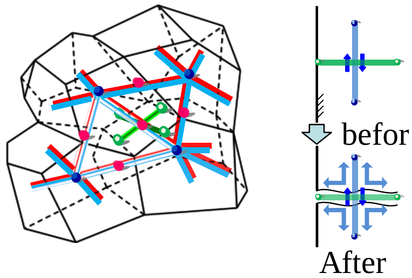


Figure 1 : Rigid Body Spring Model



(a) Truss for bulk concrete (b) Truss for crack

Figure 2 : Truss network model

2.2. Truss network model

3-dimentional truss network model integrated with RBSM is applied to both heat conduction analysis and vapor pressure analysis. Truss elements are arranged between nuclei and the intermediate points of particle boundary, and by the truss element on the particle boundary as shown in Figure 2(a). The truss which is connected between each particle is assumed to have the corresponding to the area of particle boundary surface which provide mass transport in bulk concrete. On the other hand, the area of the truss on particle boundary is decided by crack width which provide mass transport through crack. Then, a simplified 1-dimensional diffusion equation using truss element is employed to carry the potential flow, in which the conductivity is changed dependent on the location such as in bulk concrete or crack.

2.3. Concrete material models

The concrete material models are provided into normal and shear springs. In normal spring, tensile and compressive behavior are modeled, in which the tensile of concrete up to the tensile strength is modeled by using a linear elastic, and 1/4 model considering fracture energy is modeled after cracking as shown in Figure 3. In shear spring, mohr-coulomb type criterion is assumed [4].

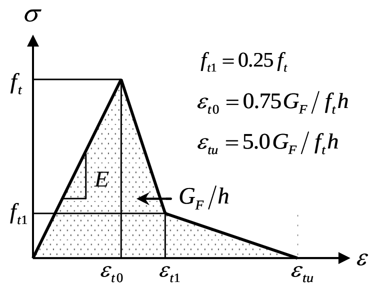


Figure 3: Stress-strain relationship

2.4. Modeling of rebar

Each reinforcement element is represented by a series of regular beam elements. The beam nodes are attached to the concrete particles without regard

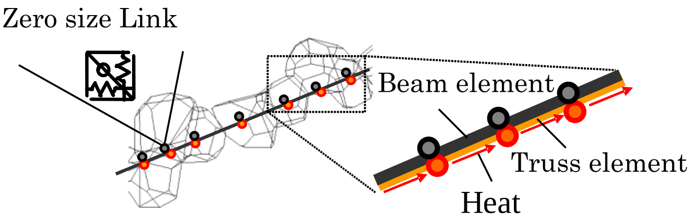


Figure 4: Modeling of rebar

to the concrete mesh design through zero-size link element as shown in Figure 4 . The stress strain relationship of reinforcement is modeled by bi-linear model.

In the conventional truss network model, the mass transfer between concrete elements and through crack was considered, and the heat conduction of rebar was not taken into account. In this paper, the heat conduction of rebar is expressed by superposing truss network on the beam element of rebar. The effect of rebar on both structure and heat conduction can be considered by simple one dimensional element, in which information of temperature obtained from truss network is delivered to beam element at common element nodes.

2.5. Effect on thermal expansion of rebar

In the axis direction, the thermal expansion strain ($\alpha\ \Delta T$) is considered by internal strain of beam element. In the radius direction, the expansion strain work as compelling action to concrete. The action is considered as compelling displacement radiately. The compelling displacement is induced by the following equation,

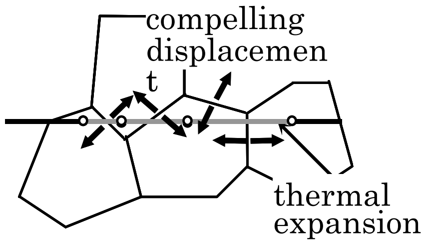


Figure 5: Thermal expansion

$$U = R\alpha\Delta T \tag{1}$$

where U is compelling displacement, R is the radius of rebar, α is thermal expansion coefficient of re-bar, and ΔT is temperature increment. In this study, thermal expansive coefficient of rebar is set to 1.0×10^{5} as same as concrete.

The compelling displacement is translated to the displacement in the direction of normal springs at adjacent points as shown in Figure 5 and the internal strain is introduced in the springs, which is calculated by dividing the displacement depending on the thermal expansion by the normal spring length.

3. OUTLINE OF ANALYSIS

Figure 6 shows the analytical flow in the method. The method are combined with the heat conduction analysis, the vapor pressure transfer analysis and the structural analysis. First, the heat conduction analysis is performed by truss network model, in which the temperature dependent parameters of specific heat $c(T)$ and heat conductivity $\lambda(T)$ are defined by the temperature in previous of step [5]. Then, the temperature distribution obtained from the heat conduction analysis is used to estimate the saturated vapor pressure p* and the thermal expansive strain $\Delta\varepsilon_n$.

In the vapor pressure transfer analysis, the production of vapor pressure is calculated by considering the estimated saturated vapor pressure and relative humidity obtained in previous step. The distribution of vapor pressure is calculated by solving moisture transfer equation. The estimated vapor pressure is applied to structural analysis and the relative humidity is renewed for next step.

The structural analysis is performed by considering the thermal stress and the vapor pressure. The thermal stress of concrete is considered by the initial strain problem using the thermal expansion strain. The thermal stress of rebar is considered by the initial strain problem in longitudinal direction and by the compelling displacement in radius direction. The vapor pressure is considered by initial stress problem, which is applied to normal spring in RBSM. The dynamic analysis is performed by solving the equation of motion in order to simulate the explosion spalling behavior. The equation of motion is solved by Newmark's β method implicitly. The value of β is 0.25. The structural analysis provides the cracking and the explosion spalling behavior. Moreover, the effect of cracks is considered in the vapor pressure transfer analysis, in which larger parameters are set.

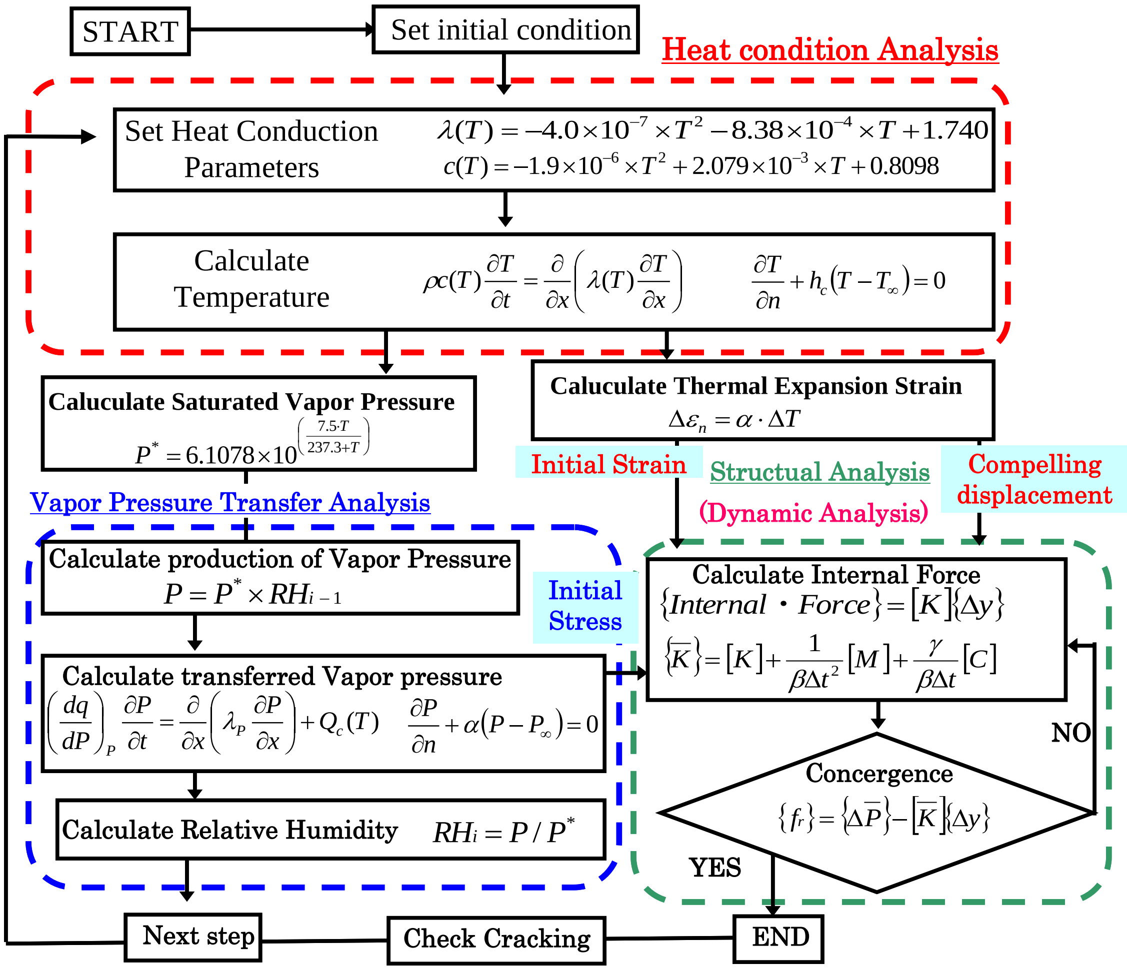


Figure 6: Analytical Flow

4. EVALUATION OF EFFECT OF REBAR

4.1. Simulation of corner effect

It is known that a section shape influence to damage of concrete by heating. For example, damage generate at the corner which is called as "corner effect". In this section, rebar is arranged at the corner with small cover thickness and influence on the corner effect of rebar is evaluated.

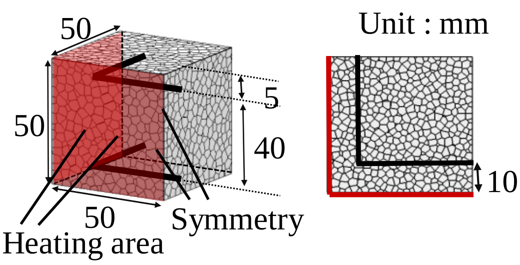


Figure 7: Analytical Model

Figure 7 shows the analytical model and boundary condition. The analytical model is modeled by a part of member which is square cross section and web reinforcements are arranged at 10mm depth from heating surface. The analysis performed by 1/4 model (50 × 50 × 50mm) considering the symmetry of the heating condition. The specimen is divided by Voronoi particles and the element size was set about 2mm . The top and bottom surfaces are fixed as the structural boundary conditions. The heating area is surface sides and heating is given according to the RABT curve. Moreover, no rebar specimen is analyzed to compare the results of specimen with rebars.

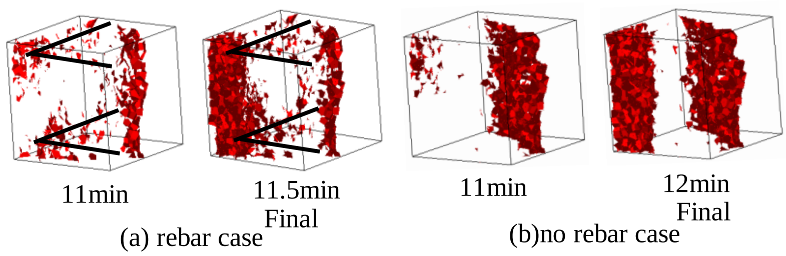


Figure 8 : Cracking behavior

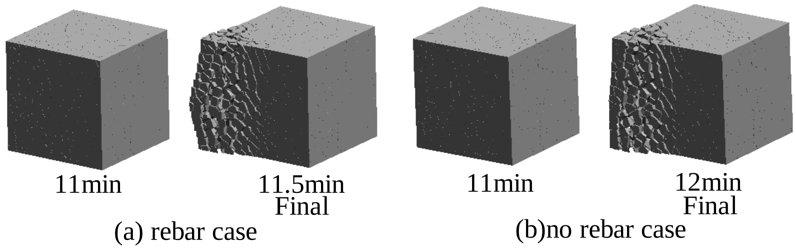


Figure 9 : Deformation behavior

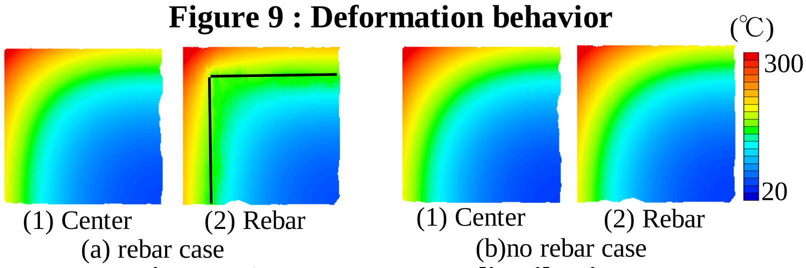


Figure 10: Temperature distribution

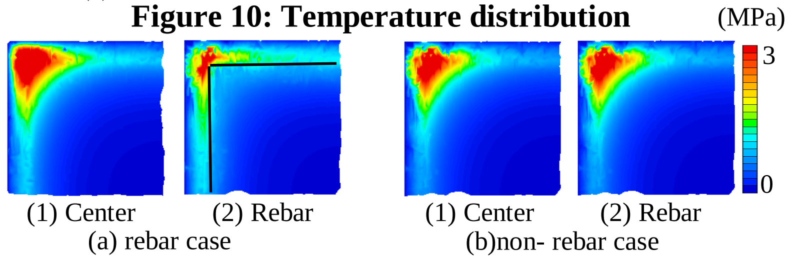


Figure 11: Vapor pressure distribution

Figure 8 shows the cracking behavior at 11 minutes and final stage that explosion spalling occur. At 11 minutes, occurrence of crack around rebar and at coner is observed in the rebar case. On the other hand, crack only occur at corner in the no rebar case. Figure 9 shows the deformation behavior at the same times. At the final stage, deformation behavior is different between the rebar case and the no rebar case. In the no rebar case, deformation occur uniformly from bottom to top at corner. In the rebar case, deformation at center section is larger than other parts. The reason is discussed as below by temperature and vapor pressure distribution. Figure 10 shows temperature distribution at 11 minutes on the sections at rebar and center section. It is observed that the temperature distribusion are different in the rebar case at each section. At center section temperature distribute similar with no rebar case. On the other hand, at rebar section, the temperature distribute along rebar and high temperature area become smaller than center section. The reason is that heat conducts to other parts rapidly by heat conduction of rebar and temperature is dispersed along rebar. Figure 11 shows vapor pressure distribution at the same times and sections. In the rebar case, vapor pressure distribution is influenced by temperature distribution at the corner of rebar section, and high vapor pressure area become smaller than that of center section. By above reason, deformation at center is larger than rebar section.

4.2. Simulation of spalling of RC slab

The effect of the cover thickness of rebar is evaluated using RC slab. The analytical model and the boundary condition are shown in Figure 12. The analysis is performed by 1/4 model (200×50×200 mm) considering the symmetry of the heating condition. The specimen is divided by Voronoi particles, and the mean element size is about 3mm near the heating area. Outer surfaces are fixed as the structural boundary conditions. In order to evaluate the influence of the depth from the surface of rebar, depth of the rebar is set as 5mm and 10mm. Six rebars are arranged as shown in Figure 12. Moreover, no rebar specimen is analyzed to compare the results of specimen with rebars. Heating was given according to the RABT curve .

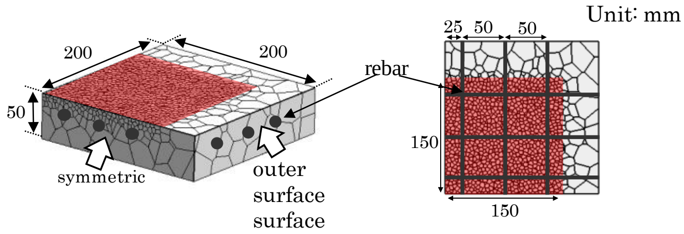


Figure 12: Analytical model

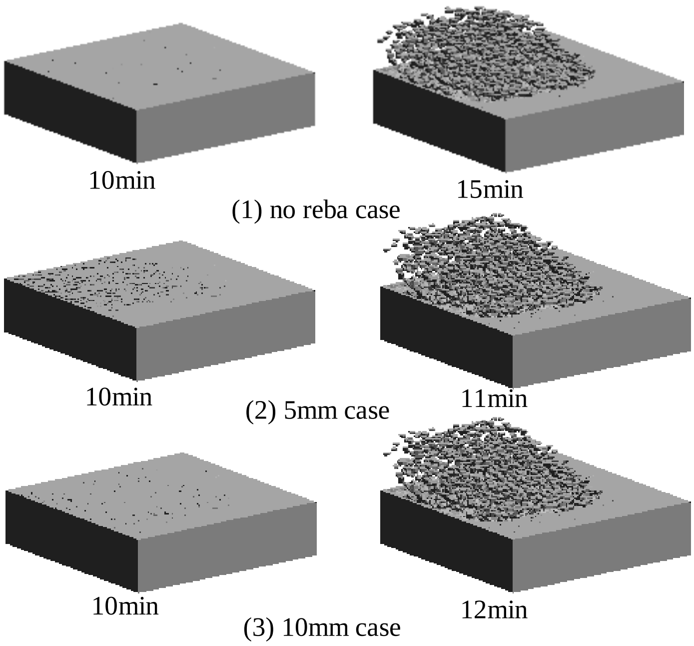


Figure 13 : Deformation behavior

Figure 13 shows the deformation behavior at 10 minutes and final stage that explosion spalling behavior occur. At 10 minutes, it is observed that surface crack occurrence and damage accumulate earlier when rebar is arranged with small cover thickness. The explosion spalling occur in all cases. The behaviors are almost same, but the occurrence time is different. Figure 14 shows temperature distribution at 10 minutes on surface and in cross section. In all cases, the difference is much small. Figure 15 shows cracking behavior at 10 minutes in the area of 5mm depth from surface, 10mm depth from 5mm depth and 15mm depth from 10mm depth. In the no rebar specimen, a few cracks occur in surface area. In the case of 5mm cover thickness, many cracks occur to 10mm depth. The rebar affect crack behavior obviously. In the case of 10mm cover thickness, although the cracks in surface area are not so many, many cracks occur about 10mm depth near the rebars. This is effect of thermal expansion of rebar.

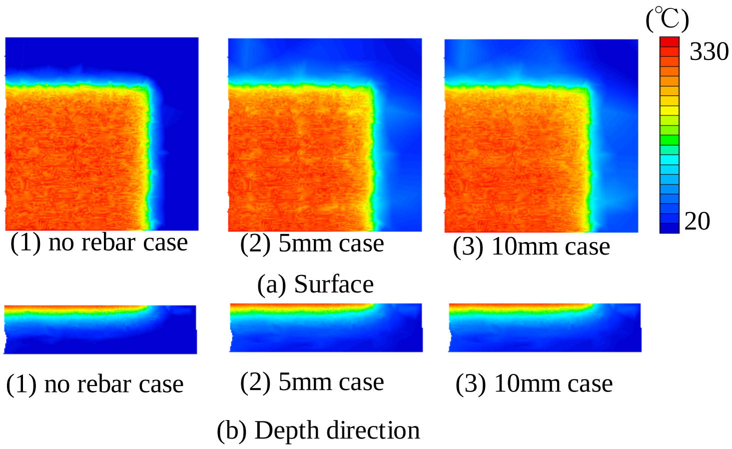


Figure 14: Temperature distribution

Moreover, the cracks under 10mm depth are larger than the case of 5mm depth due to the effect of thermal expansion of rebar.

5. CONCLUSIONS

(1)The analytical method to simulate the effect of rebar under high temperature was developed. In the method, rebar is modeled by beam element as structural element and by truss element as heat conduction field.

(2) The cracking behavior is influenced by rebar, because temperature distribution is varied by heat conduction of rebar

(3)The spalling occur earlier for existing of rebars and smaller thickness, in which thermal expansion of rebar influence to damage accumulation.

rebar.

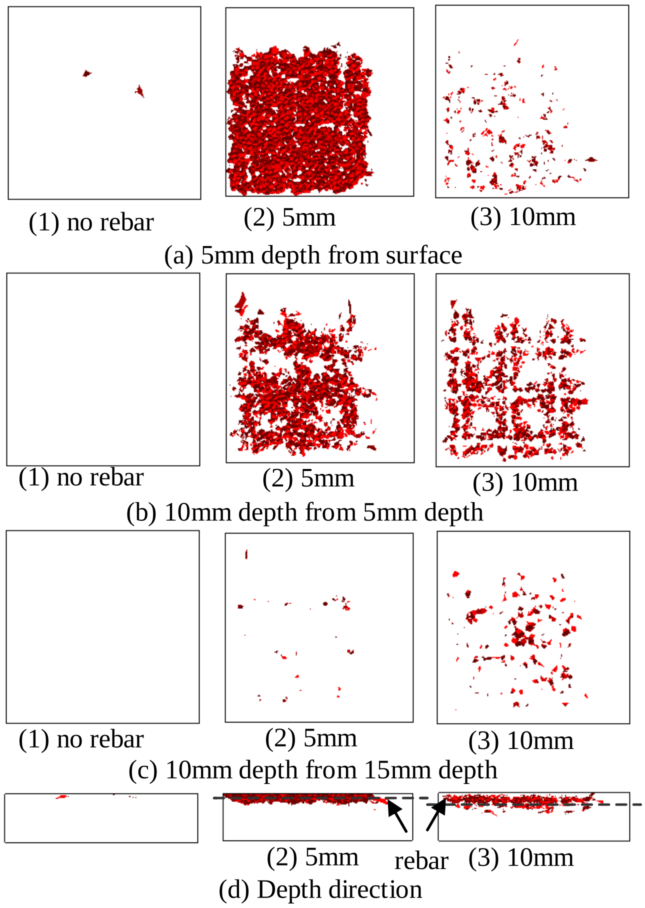


Figure 15: Cracking behavior

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