MESOSCALE SIMULATION OF TENSION STIFFENING EFFECT OF REINFORCED CONCRETE BY 3D DISCRETE MODEL

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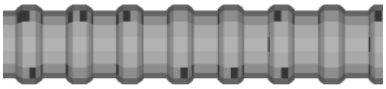
1. INTRODUCTION

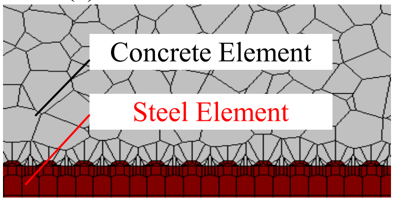
The behavior of the tension stiffening effect of reinforced concrete members can be defined by the capability of the concrete to develop tensile stress away from the crack section by the presence of bond between concrete and the reinforcement bar. Many simulations have been proposed on bond behavior at mesoscale where the crack from the bar is directly simulated, but still with some limitations, i.e. a 3-dimensional arrangement of steel reinforcement was not modeled. Our research group has used the RBSM to simulate the behavior of concrete by 3-dimensional models. However, the accuracy of RBSM in modeling the bond behavior has not been clarified yet. In this study, by modeling the tension stiffening effect of the reinforced concrete by a 3-dimensional RBSM is one way to study the bond behavior.

2. RIGID BODY SPRING MODEL

In RBSM, developed by Kawai (1978), a 3 dimensional reinforced concrete model is meshed into some rigid bodies. Each rigid body consists of 6 degree of freedoms at some points within its interior and connects with the other rigid bodies by 3 springs (see Fig.3). In order to prevent cracks propagated in a non-arbitrary direction, a random geometry, called Voronoi Diagram, is used for element meshing (see Fig. 1). To properly account for the interlock between reinforcement and concrete, a 3-dimensional arrangement of reinforcement bar is modeled. The constitutive models of a concrete element are shown in Fig.2. Moreover, the shear stress is assumed to decrease according to crack width. The actual stress-strain relationship of reinforcement bar is used to model the steel element. At steel-concrete interface, the normal spring is considered as the same as the concrete element, but the tensile strength of interface is assumed half times of the tensile strength of the concrete element.

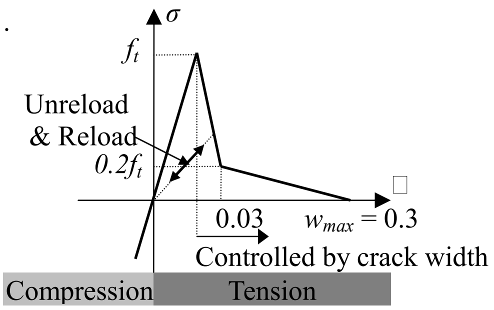


(a) Model of 3D Rebar

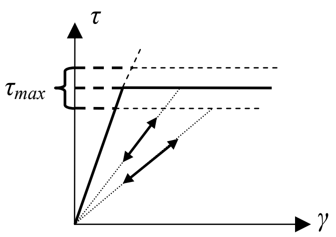


(b) Cross Section of Elements

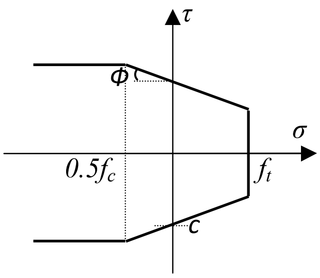
Fig.1 Mesh Arrangement of Concrete and Steel Reinforcement



(a) Normal Spring



(b) Shear Spring



(c) Failure Criterion

Fig.2 Constitutive Models of Concrete

3. ANALYSIS MODEL

Simulation is conducted for 1 specimen of normal concrete, done by Perera et.al (2011). The dimension of the model, the material properties of the reinforcement bar, and the material properties of the concrete are shown in Fig.3 and Table 1. The effect of shrinkage is not included in the simulation.

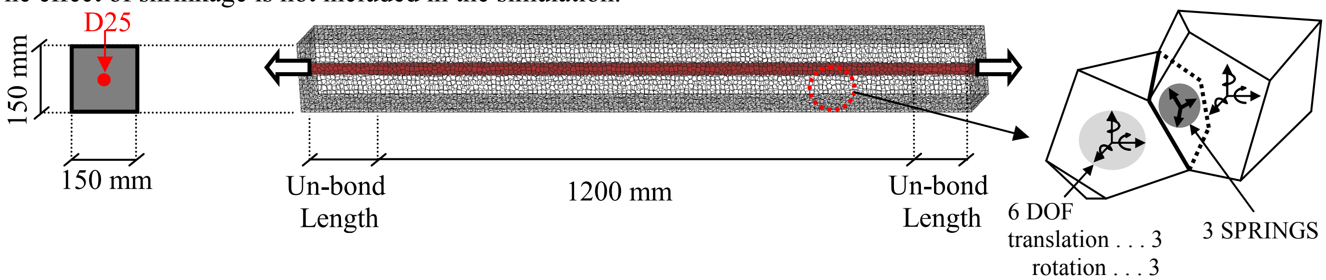


Fig.3 Analysis Model

Keywords: Rigid Body Spring Model, tension stiffening, average stress-strain concept, propagation of cracks
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Table.1 Description of Model

Model	Dimension			Concrete	Reinforcement Bar	
	Width	Height	Length	Compressive Strength f'_c	Modulus of Elasticity E_s	Yield Stress f_y
	mm	mm	mm	MPa	MPa	MPa
1	150	150	1200	40	202500	722

4. ANALYSIS RESULT

The simulation results are also shown in Fig.4. The results are compared with the experimental results, conducted by Perera et.al (2011). Based on the load-average strain relationship, the tensile stiffness of a reinforced concrete element is observed higher than that of a bare bar. Therefore, the tension stiffening effect of reinforced concrete can be simulated well by using RBSM, as the result of the presence of bond between reinforcement bar and concrete. The initial lateral cracks of simulation result are occurred when the axial load reaches 102kN. Therefore, the load is higher than that of experimental result, i.e. 60.5 kN, as the effect of shrinkage is not included in the simulation. Furthermore, the yielding point of the average stress-strain relationship of steel reinforcement, i.e. 680 MPa, is lower than that of the bare bar i.e. 722 MPa. It is well known that when a reinforcement bar at crack section yields, the stress of reinforcement bar between 2 cracks should be less than the yield strength of the bare-bar.

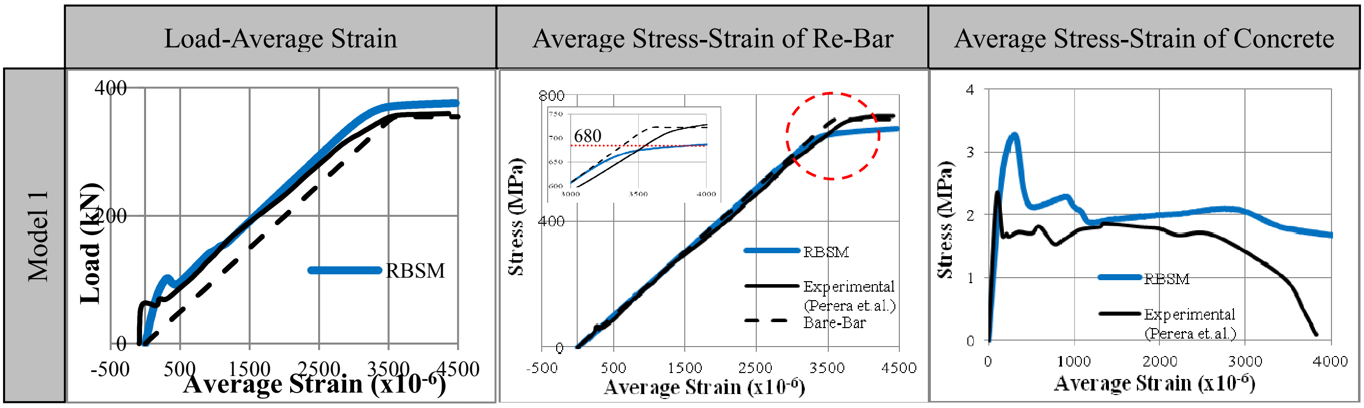

Fig.4 Load-Average Strain and Average Stress-Strain Relationship of Reinforcement Bar and Concrete

Moreover, it is revealed from the average stress-strain relationship of concrete that the concrete still can resist the tensile load in the post cracking range. Eventually, the load-average strain, the average stress-strain relationship of reinforcement bar and the average stress-strain relationship of concrete of simulation are roughly the same with those of experimental. The crack patterns of the simulation, compared with experimental result at final step of load, are shown in Fig.5. By 3D RBSM model, the crack propagation can be simulated gradually as the load increases. The crack spacing of transversal cracks is roughly the same with experimental.

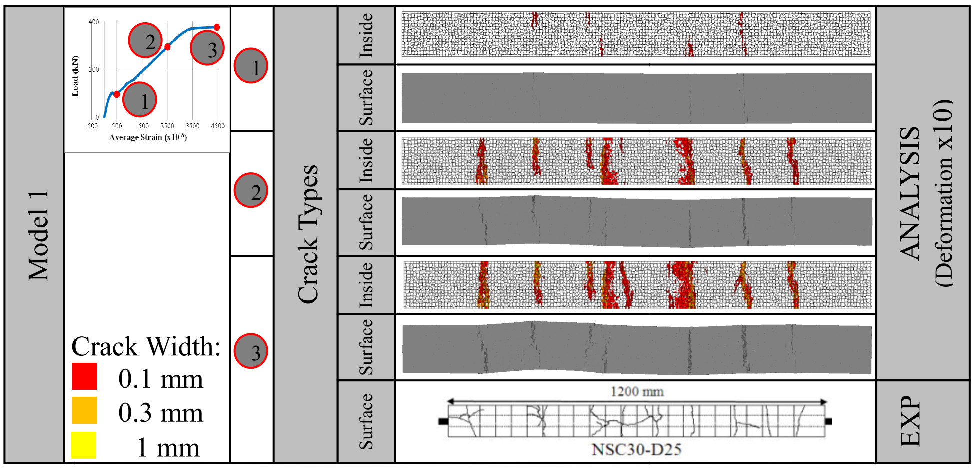

Fig.5 Crack Patterns

5. CONCLUSION

The tension stiffening effect of reinforced concrete can be simulated well by RBSM. More studies, for example by comparing the strain profile of reinforced concrete with experimental, need to be done.

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