論 文

[2109] Crack Surface Asperity on Stress Transfer Mechanism.

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1.Introduction.

The so-called "Contact density model" based on the idealization of crack surface developed by B. Li and K. Maekawa[1] is path dependent model which can be well applied to normal concrete subjected to monotonic, non-monotonic and reversed cyclic loading paths. However, in concrete with different shape of crack surface from that of normal concrete e.g.. high-strength or light weight concrete, the applicability is still questionable. We carried out stress transfer experiment on high strength and light weight concrete and applied the model to these concrete in order to clarify applicable range of the model. Loading paths which are concerned in this report are crack width constant monotonic loading paths.

2. Experiment.

The stress transfer experiment was done on concrete blocks of 30 x 15 x 60 cm in dimension. Details of the experiment can be found in [1]. Compressive strengths of tested concrete are 30 MPa and 100 MPa for light weight and high strength concrete respectively. Maximum size of aggregate used in both concretes is 15 mm. We employed crack width constant monotonic loading paths of 0.25, 0.5 mm constant crack openings for light weight concrete and 0.5, 0.7 mm crack openings for high strength one. Fig 1 shows experimental results along with corresponding analytical ones compared with previous results of normal concrete done by B. Li and K. Maekawa [1].

We can clearly see from the figures that though the model is very well applied to normal concrete in Fig 1(c), it is definitely inapplicable to high strength and light weight concretes [Fig 1(a) and (b)]. The model gives unusually high stiffness compared to those from the experiment. Especially, note that shear stiffness of high strength concrete with 100 MPa compressive strength is less than the stiffness of normal concrete of just 23.8 MPa in the strength.

3. Differences between high strength/light weight concretes and normal concrete concerning stress transfer behavior.

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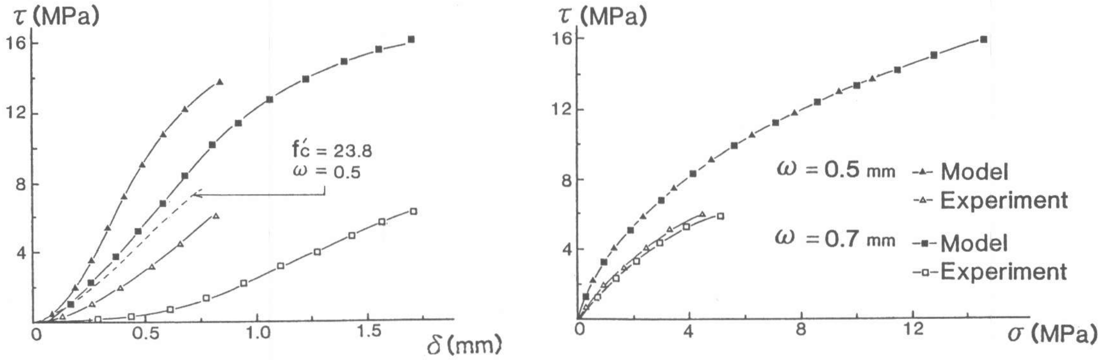
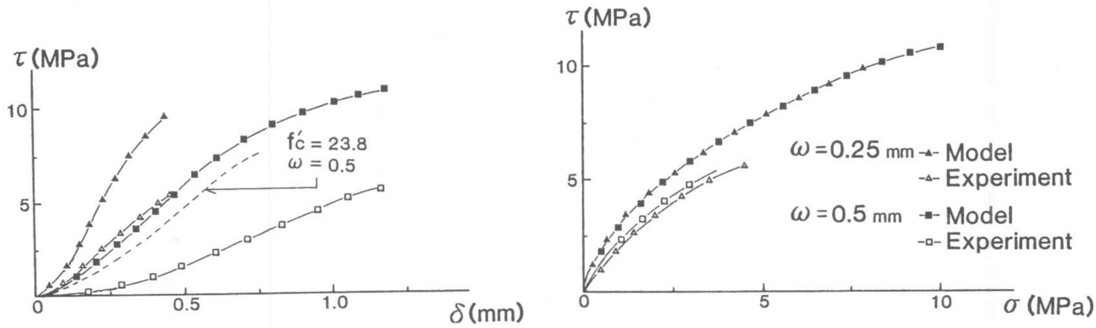
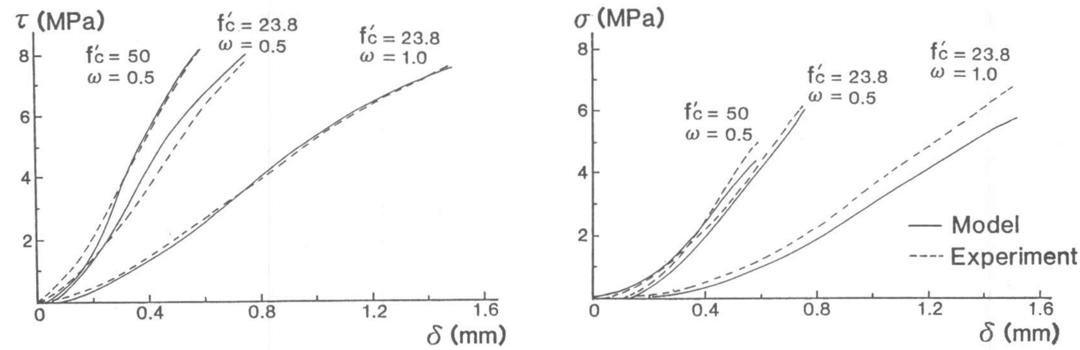


(a) high strength concrete fc = 100 MPa.



(b) light weight concrete fc = 30 MPa.



(c) normal concrete

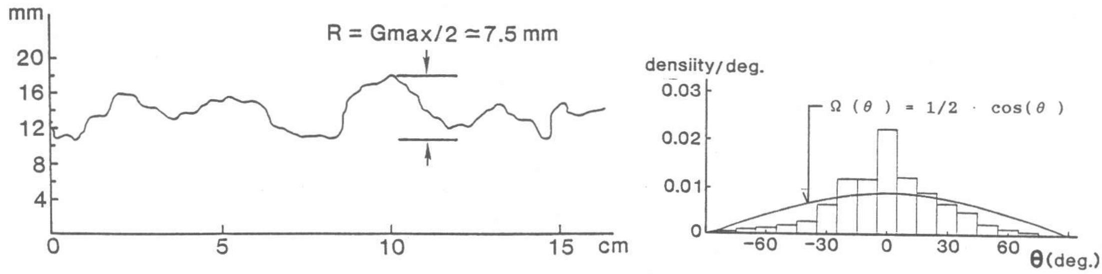
Fig 1 Experimental and Analytical results of various concretes.

In order to understand why the model which can be successfully applied to normal concrete yields insufficient results when applied to high strength/light weight concretes, we should take a closer look into basic assumptions on which the model bases and figure out if the assumptions change in cases of high strength/light weight concretes. Following are the forementioned assumptions

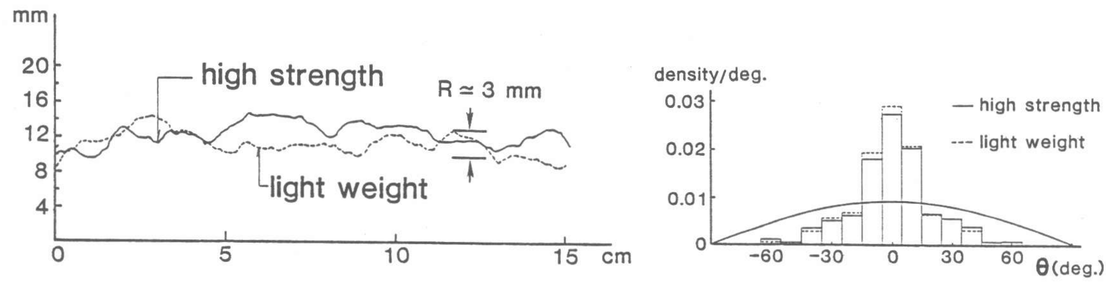
(1). Contact density function $\Omega(\theta)$ A crack plane is composed of stochastically distributing contact area with different inclinations denoted by a "contact density function $\Omega(\theta)$"[1]. For normal concrete, this function is assumed as

$$\Omega(\theta) = 1/2 \cdot \cos(\theta) \quad (1)$$

This representative function can be verified by measuring configuration of a crack surface and determining distribution of planes of various angles constituting the crack surface. Fig 2(a) shows an example of a normal concrete crack surface and its directional distribution along with the assumed contact density function $\Omega(\theta)$. Also shown in Fig 2(b) are examples of high strength concrete crack surface and a light weight concrete crack surface accompanied by their measured directional distributions.



(a) normal concrete.

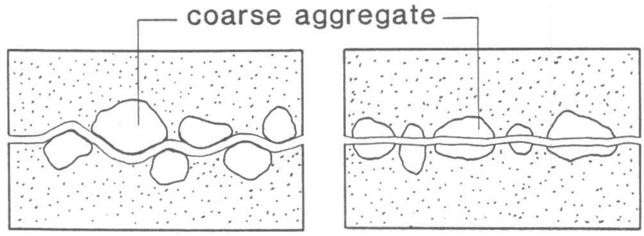


(b) high strength/light weight concretes.

Fig 2 Concrete crack surfaces and directional distributions.

We can see that the crack surfaces of high strength/light weight concretes are relatively flatter than that of normal concrete. In high strength concrete, this may be explained by the fact that the strength of mortar and bond between mortar and coarse aggregate are so high that coarse aggregates tend to break when subjected to splitting force rather than to get loose from mortar as those in normal concrete [Fig 3].

The situation is the same in case of light weight concrete. However, this time, the strength of coarse aggregates is relatively low compared with that of mortar. We can confirm this flatterness of crack surface by comparing the directional distribution of normal concrete to those of high strength and light weight concrete. From the distributions we can see that, in high strength/light weight concretes, the density concentrates in the region of -20° to +20° more than in normal concrete and the contact density function $\Omega(\theta)$ of $1/2 \cdot \cos(\theta)$ for normal concrete can not be appropriately applied to high strength/light weight concretes.



(a) normal concrete. (b) high strength/light weight concretes.

Fig 3 Crack forming.

(2). Effective contact area coefficient $K(\omega)$ Contact area decreases with the increase of crack opening and will be zero if crack width is large enough compared with the maximum roughness of a crack surface. There exists a relationship between the K coefficient and crack opening. The maximum roughness of normal concrete ,R ,was found to be about one half of maximum size of coarse aggregates ,Gmax ,and the relationship between K and ω was established for normal concrete[1] as

$$K(\omega) = 1-\exp(1-R/\omega) \geqq 0 \qquad (2)$$

However, one half of the maximum size of coarse aggregates can no more be regarded as the maximum roughness of crack surface in high strength/light weight concretes [Fig 2(a),(b)] because of the breaking of coarse aggregates. In this case, we may estimate from Fig 2(b) that the maximum roughness of the concretes is about 3 mm.

(3). Normality of contact force. A contact force on a plane is assumed to be perpendicular to the plane. This assumption is ideal because, strictly speaking, there must be frictional force on the plane causing the resultant contact force to deviate from normal line of the plane. However, at the same time, the plane deforms due to contact reaction. This deformation may be caused by mortar plastic deformation around coarse aggregates. The deformation tilts the resultant force to coincide with the normal line of the plane before being deformed. Hence, the normality of the contact force can be assumed.

The difference in normality assumption between normal concrete and high strength/light weight can not be directly proved. For the time being, we will assume that this assumption holds in the three kinds of concrete.

4. Application of the model to high strength/light weight concretes.

The difference in geometries of crack surface $\Omega(\theta)$ and $K(\omega)$ is the cause which made the model inapplicable to high strength/light weight concretes. In order to make the model more applicable we will change the assumptions on the geometries of crack surface accordingly.

Firstly, we have to use more realistic and more appropriate contact density function $\Omega(\theta)$ for high strength/light weight concretes. We have chosen the truncated normal distribution function [Fig 4] as more correct $\Omega(\theta)$. The function is

$$\Omega(\theta) = A \cdot \exp^{-(\theta^2 \cdot B)} \qquad (3)$$

for θ as degree, $A = 0.0133$, $B = 0.000556$ for θ as radian, $A = 0.769$, $B = 1.825$

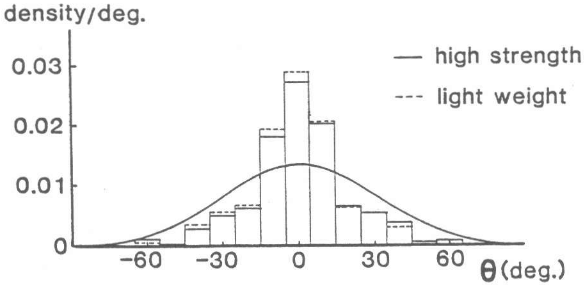
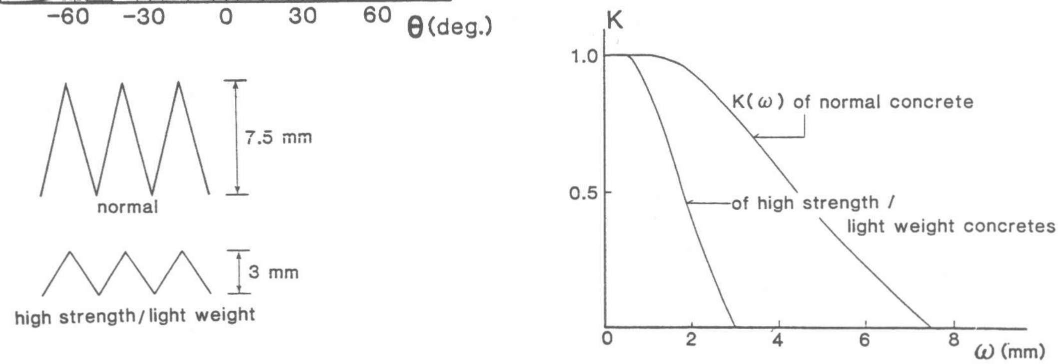


Fig 4 Contact density function for high strength/light weight concretes.



(a) maximum roughness.

(b) K(ω) relationship.

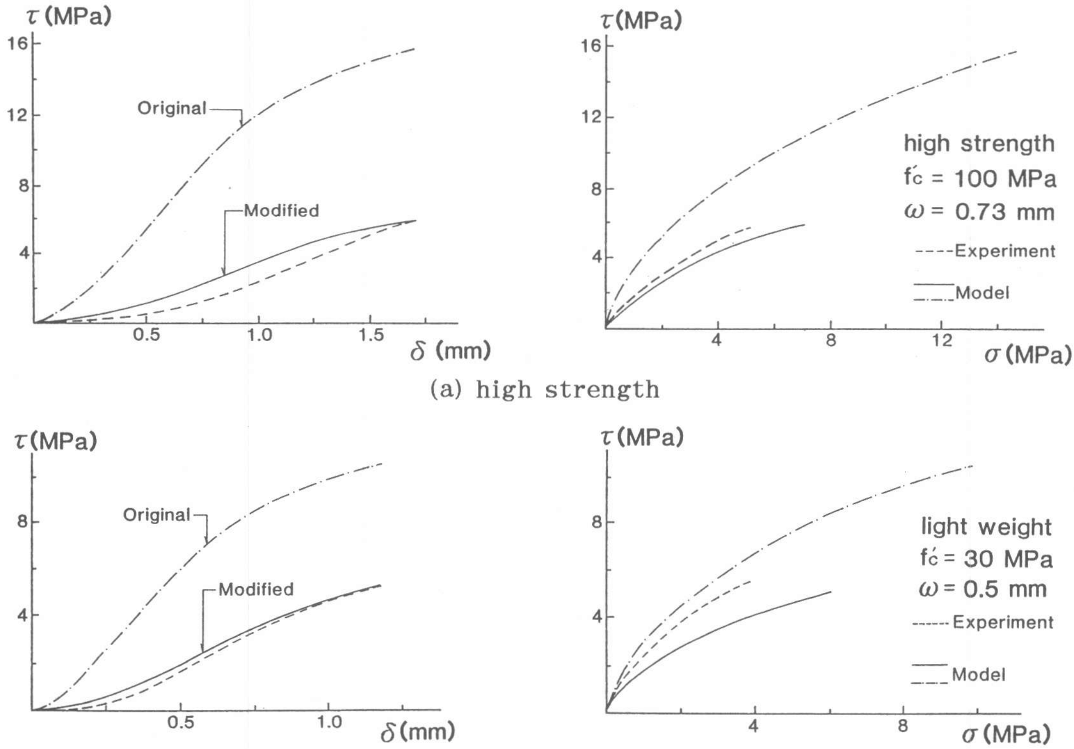
Fig 5 Effective contact coefficient

Secondly, significance of the effective contact coefficient $K(\omega)$ must be considered. In normal concrete, crack opening concerned in stress transfer problem is usually much smaller than the maximum roughness or one half of the maximum size of coarse aggregates. Therefore, $K(\omega)$ is not so sensitive to changing in crack opening in normal concrete. Nevertheless, in high strength/light weight concretes, crack surface is flatter and the maximum roughness is much smaller than that in normal concrete. So, $K(\omega)$ become much sensitive to changing in crack opening ω [Fig 5].

We tried to apply the contact density model to high strength/light weight concretes using the modified contact density function $\Omega(\theta)$. For $K(\omega)$, we had tried a wide range of $K(\omega)$ in order to match the experimental results.

Fig 6 shows the outcome of the matching between analytical results and experimental ones in high strength concrete of $\omega = 0.73$ mm and in light weight concrete of $\omega = 0.5$ mm.

The outcome of matching suggests that changing of $\Omega(\theta)$ to a more realistic one and giving more consideration to $K(\omega)$ reasonably improve the applicability of the model to predict stress transfer behavior of high strength/light weight concretes. However, judging from the figures we can see that the modification of these two parameters alone is not enough to



(a) high strength

(b) light weight

Fig 6 Modified model prediction.

adjust the analytical results. The normality assumption should also be modified to make the contact density model perfectly applicable to the concretes under the constant crack width monotonic loading paths. The modification of normality assumption has to do with frictional effect on a crack surface as reported in [2].

CONCLUSION.

The original contact density model which is well applied to stress transfer problems of normal concrete subjected to monotonic, non-monotonic and reversed cyclic loading paths was found to be imperfect when applied to high strength/light weight concretes even under monotonic loading paths with constant crack width. It was found that the three assumptions of the original model need to be modified to more realistic ones for further applications of the model.

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