ABSTRACT
論文の内容の要旨

Microscopic Mechanism and Influencing Factors on Cracking Resistance of Chemically Prestressed Concrete Member
(ケミカルプレストレスト部材のひび割れ抵抗性の微視的機構と影響因子)

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Cracking, once taking place in reinforced concrete (RC), can downgrade its structural performance, deteriorate its durability and damage its appearance. In the view point of durability, cracking can substantially accelerate the ingress of the deteriorating substances and, as the result, shorten the service life of structure. Performance based design requires that the cracking of RC structure should be controlled under limits. To control cracking of concrete structure, expansive additive has been extensively exploited. Adding a suitable amount of expansive additive to concrete in RC to induce prestress and create a so-called 'chemically prestressed concrete (CPC)' is a well-known method to inhibit cracking. In practice, CPC is current considered as same as the prestressed concrete and thus only the effect of prestress is taken into account for its cracking resistance, although there have been some research showing more ductile tensile properties of restrained expansive concrete. Besides there have been various structural properties of CPC which is still unexplainable by mechanical prestress. One good example is the capability of CPC to reduce crack width and number of flexural crack at the same time. Consequently, the deeper understanding on the mechanisms is indeed to develop more rational guideline for application of CPC. It is therefore an aim of this study to investigate all basic properties and mechanisms of CPC related to its cracking resistance as an important steps to the more rational guideline for designing CPC.

Usually, crack width has been regarded as the most important parameter in cracking problem because the width of crack controls the penetration rate of the deteriorating substances. The crack width of RC can be simply considered as the difference of elongation of rebar and the surrounding concrete in a cracked portion. In the other words, the width of crack can thus be determined if (1) average strain of concrete; (2) average strain of reinforcing bar; and (3) length of cracked portion or crack spacing are known. The deeper investigation on each of these parameters is conducted in this dissertation.

The investigation on deformability of restrained expansive mortar, that is, ductile nature of expansive mortar or concrete when external confining forced is provided were conducted by producing the specimen of which bonding between reinforcing bars and surrounding concrete is eliminated. With this special type of specimens, it is thus possible to remove reinforcing bar before loading the specimen in flexure and to separately the

rebound strain (elastically returning strain from effect of prestress) and the pure material deformation.

The rebound strain can be measured during the removal of restraint from externally restrained expansive mortar. The true value of rebound strain is less than the calculated value. This fact implies that there should be a visco-plastic strain during prestressing process. During the flexural loading, the tensile stress-strain relationship is measured at bottom fiber of flexural specimens during loading after the rebar is removed. The nonlinearity of restrained expansive concrete is confirmed. The levels of restraint affects the peak strain at 7 days but the effect becomes negligible at 28 days.

After the specimens fails, a residual strain which can represent the plasticity of restrained expansive mortar could be observed in the constant moment span except at the location of crack.

This residual strain is a large component of surface concrete strain. It was found that the residual strain of restrained expansive mortar is approximately 5 times larger than that of normal mortar at 7 days and 3 times at 28 days. It was additionally observed that ages and curing condition can significantly affect this residual strain. However, the restraining ratios from 1.3% to 3% give almost same residual strain. This plasticity might be result of the initial dispersion of micro-defect caused by expansion of expansive agent in the surrounding cement paste matrix.

Another experiment was conducted to observe this plasticity in the case where the reinforcement is provided at the middle of specimens. The results shows that, with the presence of reinforcing bar, chemically prestressed mortar (CPM) and CPC can distribute the damage over wider area and the damage is not localized at only the cracking location. This performance can be referred to as the ‘Anti-Localization’ of CPC. The curvature was another crucial factor that can raise the residual strain of both RC and CPC. In addition to residual strain, the plasticity before cracking of CPC and CPM where also experimentally manifested. The nonlinearity and plasticity of expansive mortar approve that the strain of restrained expansive concrete in CPC should not be neglected in the estimation of crack width of CPC.

Only the stress-strain relationship of concrete and rebar is still not sufficient to accurately estimate the crack width of CPC. The mechanisms explaining how rebar and concrete in CPC share the cross sectional force is another important issue from the view point of cracking problem. As the preliminary investigation on both bond and crack spacing, the experimental study on the tension stiffening effect of CPC was selected. The outstanding tension stiffening performance of CPC could be perceived. At least two marvelous behaviors of CPC are noticeable. Firstly, there is no abrupt reduction of tension stiffening effect after cracking in CPC during crack development region. This indicates that the stress redistribution due to cracking is less and thus concrete can carry more stress in CPC. The other one is that the degradation of tension stiffening effect during the stabilized cracking region is trifling. These two observations are strong evidence that the damage of restrained expansive concrete in CPC is slower and smaller than the damage of RC at the same average strain.

The direct inspection on local bond distribution was done by monitoring the strain distribution of rebar in RC and CPC as an attempt to clarify how CPC develops such outstanding tension stiffening effect of CPC. The direct observation agrees well with that the bond stress around ends is higher in CPC and the elongation of rebar in CPC is thus shortened because the expansive concrete can resist more average stress. The effect of cross sectional area (or cover depth) significantly affects the bonding characteristics of CPC.

However, the bonding characteristics of CPC can not explain how CPC can develop longer crack spacing because the better bond characteristics should induce more cracking and generally result in larger number of cracks. The observation on internal damage of both RC and CPC is conduced to elucidate the longer crack spacing of CPC. The special specimens into which red ink can be injected during loading were produced and the specimen was cut by diamond saw to observe the internal damage at the end of loading.

The observation specifies the ability of CPC to prevent the internal crack to propagate to surface although there is no clear difference in shape and direction of internal crack between RC and CPC. Besides, the level of internal damage of RC and CPC at yielding of reinforcing bar is very similar. However, the observation on occurrence of splitting crack shows another meaningful behavior of CPC. It was noticed that, although the splitting cracks take place at higher load in CPC, the growth of splitting crack is very fast once it forms. This may denote the dissimilar process of internal damage between RC and CPC. In the other words, although the final damage at yielding is same but the CPC is more likely to resist damage until subjected to a certain level of load. Although the overall mechanisms could not be comprehended in this study, the ability of CPC to prevent the propagation to surface of internal crack can partly explain the longer crack spacing length of CPC which is confirmed once again in this experimental investigation.

The performance of CPC under long-term drying has been in doubt for a long time. It is generally believed that the performance of CPC should become almost same with RC when it is subjected to long-term drying. In this study, the cracking characteristics of CPC under long term drying are also experimentally inspected. It is proved that CPC is capable to control the maximum crack width even after being subjected to drying condition for a long time while the maximum crack width of RC always increase if it is subjected to drying condition.

According to the aforementioned findings, it is apparent that the smaller crack width of CPC can not be appropriately estimated by the present standard guideline which taking into account only the effect of prestress. The smaller average strain of rebar which is caused by better bonding characteristics, the larger strain of restrained expansive concrete which resulted from its nonlinear behaviors and more stress transferred from rebar should be taken in to the account. The normal assumption that the strain of concrete is negligible is not apposite in the case of CPC. However, it is important to note here that the properties of CPC are very sensitive to restraining condition, environmental condition, and loading condition. The fact that CPC can not guarantee better performance than RC in all conditions should be kept in mind when one is considering to apply CPC.