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Commentaries

Bond Constitution Laws between Concrete and Reinforcement and their Applications

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Keywords: bond stress, slip, research survey, finite element analysis (FEA), tension-stiffening

The transmission of internal force between concrete and reinforcement and their displacement gap are called as bond stress and slip, respectively. The bond constitutive laws are defined as the relationship between bond stress and slip (τ-s relation). There are lots of proposed types of bond constitutive laws, so it is necessary that the laws should be selected carefully to adopt in finite element analysis (FEA). The Japan Concrete Institute had organized the Technical Committee for bond problems to clarify the information about bond constitutive laws and propose the appropriate applications of the bond constitutive laws. Some of committee activities such as meso-scale analysis, review works for previous papers and analysis results for tension-stiffening effect are introduced.

Studies began as early as the 1980s to determine the bond behavior through direct modeling analysis of mechanical mating between lugs of a reinforcing bar and concrete, which is the essence of the bond between a deformed reinforcing bar and concrete. According to the analysis, the τ-s relation is not regarded as a constitutive law, and the bond phenomenon is reproduced as a result of the propagation of fracture of concrete peripheral to the reinforcing bar, such as the internal cracks occurring from the front end of a lug and the plasticizing of concrete at the front side of the lug. Consequently, it is expected that the analytical results give a macroscopic bond model.

The review works for the previous 345 papers which were published in US, Germany, Australia and Japan from the late 19th century show us that;

Bond problems were recognized at the same time as the invention of reinforced concrete systems in the late 19th century. The world's first RC design provisions in 1904 describe an equation for the estimation of bond stress and the allowable bond strength of flexural beams.

It is commonly thought that bond tests were also conducted in the late 19th century. Basic experimental methods including the pull-out test and the uniaxial tension test.

The bond-related studies had dealt with flexural reinforcements and lapped splices in flexural beams by the 1960s. Studies of tension stiffening in RC plates began in the 1970s.

The bond splitting problem has been recognized since the 1970s. The ring-tension model is proposed to investigate the mechanism of bond splitting.

Second-order differential equations were first applied to bond problems in 1933. The pace of the analytical studies of bond problems began to accelerate after Gallus Rehm's research in 1961.

FEA of RC structures was started by D. Ngo in 1967; the use of the bond link element was started in the same study.

Engineers and researchers often use the bond link elements in FEA to express the bond slip between reinforcing bar and concrete. On the other hand, the bond behavior is indirectly expressed by the tension stiffening model of concrete in case of smeared crack model. The tension stiffening model is boldly modeled of tensile stress of concrete transmitted by the bond. If the bond link elements and tension stiffening model are simultaneously used, it is anxious that the effect of bond is double counted. The "double counted effect" is investigated by the FEA using both bond link elements for discrete reinforcing bar and tension stiffening model for concrete. The results lead that "double count" of tension stiffening effect does not occur. In case of smeared model, all elements for concrete show the same strain, so that bond link does not work. The use of combination of smeared concrete element, discrete bar element and tension stiffening model is effective only for expressing the large scale of slip such as slip out of bar from concrete.

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Construction records

Construction of a central pillar by slipform construction in the Tokyo Sky Tree

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Keywords: Tokyo Sky Tree, Central pillar, Slipform construction, High strength concrete

The world's tallest free-standing broadcasting tower, 634m-high Tokyo Sky Tree®, has appeared in Tokyo in 2012. The first observatory deck is located 350m above ground and the second one is further up at 450m. In the center of the tower stands a cylindrical "central pillar" of 8m in diameter and 375m in height. The central pillar structure is similar to traditional towers in Japan, "five-story pagoda temples". It works as a vibration controlling system and makes the tower more resistant to earthquakes and strong wind. We built a 375m steel-reinforced concrete central pillar at the core of the tower's steel frame by slipform construction.

Slipform construction is a method of efficiently constructing towering structures in a short period of time, which at the same time achieves safety and high precision, by continuously placing concrete into a formwork that is raised progressively upward with jacks.

In this construction method, we made sure that slipform equipment had the following features: (a) Capability to handle a lot of materials, (b) Increased efficiency of work, (c) Accuracy management using laser beams, and (d) Anti-earthquake procedures. Moreover, an early earthquake warning system, a thunder alarm system, and a weather bulletin system were installed in the control room.

The concrete used to build the central pillar is high strength concrete with design strength 54MPa and 60cm slump flow to cope with a high-density bar arrangement. Furthermore, under concrete temperature of 10℃, slump flow holds more than 55cm two hours after mixing and compressive strength reaches 0.1MPa 6.5 hours after mixing. We developed this high strength concrete which appropriately combined an air-entraining and high-range water reducing agent and a hardening accelerator (Photo1). We measured the temperature of concrete cast in the formwork. We then estimated compressive strength of early age concrete using the relation between accumulated temperature and compressive strength, and indicated the rise of slipform equipment.

The appearance of the central pillar is shown in Photo 2. This is a view from the 250m point in height. We have improved the method continuously. The project has been completed by cooperation of design, construction, and research sections.

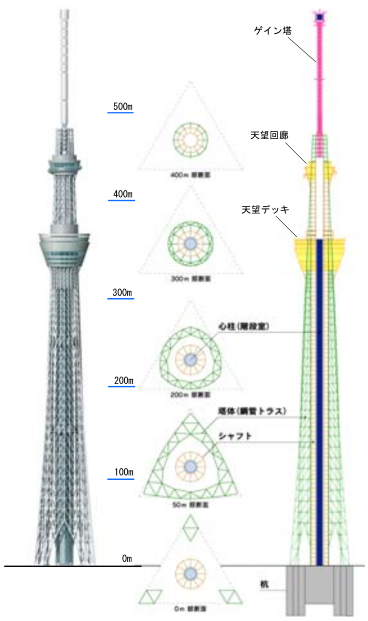

Fig.1 Cross Section of Tokyo Sky Tree

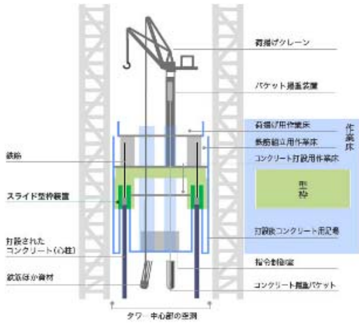

Fig.2 Slipform equipment

Photo2 View of central pillar

Slumpflow 2 hours after mixing

Strength 6.5 hours after mixing

Photo1 Concrete under 10℃

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Construction records

Maintenance and Retrofit for Reinforced Concrete Structure of Tokaido Shinkansen

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Keywords: Tokaido Shinkansen, reinforced concrete structure, cantilever, steel plate pasting, maintenance and retrofit

Tokaido Shinkansen opened in 1964, and its reinforced concrete structure has maintained properly. One of the maintenance is surface coating to stop carbonation, but a part of coating cracked and carbonation has progressed again because of repeated train loads. The countermeasure for carbonation has been developed to maintain reinforced concrete structure. In this paper, we report “Cross Section Restoration Method (steel sheet pasting)”, a new maintenance and retrofit.

Covering the surface of reinforced concrete with a steel sheet stops carbonation certainly and retrofits the cantilever of viaduct that is weakened by the corrosion of steel bar. But boring for anchor bolt has a bad influence on the concrete structure and a heavy sheet of steel has an inefficiency installation work.

“Cross Section Restoration Method” has 3 points for improvement. First is a development of mechanical coupler that loses the weight of steel sheet and the number of anchor bolts. Second is the structural type holds the load of noise barrier widely. Last is the structural type that prevents the fall of steel sheet and noise barrier.

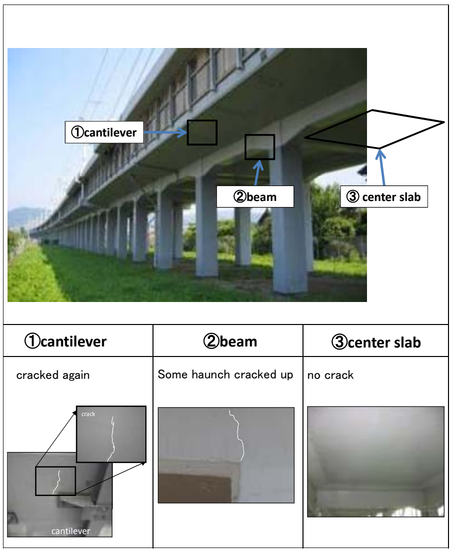

Fig.1 crack condition

The 3-dimensional FEM analysis indicates that cracks never occur in the condition of maximum wind speed 70m/s and the internal stress disperses along the track direction.

The loading test with an actual size cantilever model shows that the steel sheet and the reinforced concrete move together under the condition of 10.0kN/m^2.

An efficiency installation work and no bad influence on the reinforced concrete structure are confirmed in the installation test with the viaduct of Tokaido Shinkansen.

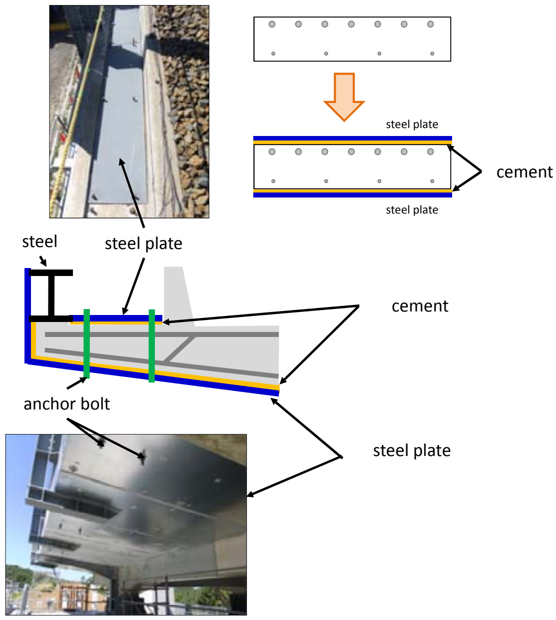

Fig.2 structure type

Fig.3 a completed noise barrier

Fig.4 installed condition of steel plate