LITERATURE SURVEY ON ANCHORAGE ZONE DESIGN OF POST TENSION CONCRETE GIRDERS

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Abstract—The anchorage zone of post-tensioned members can be divided into local and general zone. Many researchers investigated the effect of various parameters of anchorage zone and the accuracy as well as the improvement in the analysis and the design methods. In this article, the survey of literatures is established in order to study the post-tensioning anchorage zone in theoretical and experimental aspects based on previous works. Based upon the investigation results that showing the effect of various parameters on behavior and performance in local and general zones, there also remain some unclear aspects of anchorage zone in post-tensioning member, especially stress distribution in the interface between local and general zone and it can be recommended to more research in future.

Keywords—anchorage zone; local zone; general zone; confined reinforcement; bursting force; spalling force

I. INTRODUCTION

In general, concrete materials have a shortcoming with low tensile strength in spite that it can withstand high compressive stress. In order to overcome this deficiency, there are two methods, namely, pre-tensioning and post-tensioning that use prestressed concrete beams. Figure 1 shows the principle of prestressed concrete beam. Whether pre-tensioning or post-tensioning, the purpose of creating a pre-stress is to reduce the tensile stress of the concrete material occurring in the in-service structure. In this work, the main focus is laid on the post-tensioning. The post-tensioning induces the tensile prestress in the concrete by applying the tension on the tendon after pouring concrete and hardening it. One end of tendon is anchored on the concrete while other end is stretched by the device such as the jack as shown in Figure 1.

When the tensile load is transferred into the bearing plate through the wedge, very high local stress happens at the bottom of bearing plate, which is finally transmitted into the whole structure. The zone where local post-tensioning force is transferred from the anchorage device to the whole structure is referred to the anchorage zone. As compared with other parts of structure, anchorage zone is subjected to very high stress.

The compressive stress that is higher than the uniaxial compressive strength is acted near the anchorage device while high tensile stress happens away the anchorage device, leading to the division of anchorage zone into local and general zone.

The local zone is referred to the concrete zone where surrounds the anchorage device. Since the local zone under high stress plays a role of transferring the post-tensioning force into the general zone, it should withstand high compressive stress occurring in the in-service structure. The compressive stress in the local zone is closely related with the detailed geometry of anchorage device. There have been published some specifications for determining the length of anchorage device and the dimensions of bearing plate.

The main factor concerning with the determination of strength inside the local zone are the bearing stress ahead of the anchorage device and the stress at the concrete surrounding it. The representative failure mode in the local zone is the compressive failure of concrete.
The general zone is defined as the region of the structure behind the anchorage device. The general zone has a local feature where the ordinary beam theory is disturbed by the introduction of the concentrated tendon force. The general zone plays a role of final transferring the post-tensioning force into the whole structure. The general zone suffers from the bursting stress induced by the lateral spreading of post-tensioning force and the spalling stress due to the constraint of displacement continuity. The bursting stress is the tensile one acting perpendicular to the longitudinal direction of the tendon while the spalling stress is the one acting parallel to the anchorage plate. The most common method used for evaluating the strength of general zone is the strut-an-tie model (STM) and the finite element method (FEM). Most of the failures in the anchorage zone are caused at the time of the initial application of the post-tensioning force, or shortly thereafter. At that time, the post-tensioning force reaches to maximum and at the same time, the strength of the concrete becomes minimum. The failure mechanisms occurring in such case contain the excessive cracking and the unstable cracking.

Once the excessive cracking, where can be observed in either the local zone or the general zone, happens, it reduces the tensile strength of concrete significantly. One of the most common and simple methods to prevent the increase of tensile strength caused by the excessive cracking is to use the passive reinforcement.

If sufficient passive reinforcement is added near the zone where the cracking happens, the opening and progression of the cracks will be stopped. Even though the structure is uncracked after the tendons have been stressed, cracking may still happen at a later stage, due to creep of the concrete or external causes such as temperature effects. The unstable failure of the anchorage zone occurs when the tendon force the internal force are not in equilibrium. First of all, cracking of concrete due to tension will occur in the local zone if the concrete strength or the local confinement is not sufficient. Also, insufficient reinforcement in the general zone will lead to the cracking of concrete. Sometimes, failure will be induced at the interface between the local zone and the general zone if the compressive strength of concrete in the general zone is not sufficient. Due to the importance of anchorage zone, there have been published one of Design Specifications of Anchorage Zone, American Association of State Highway Transport Officials (AASHTO) and Load and Resistance Factor Design (LRFD) in 1994. Nevertheless, this specification does not provide the detailed and sufficient guidance for designing the anchorage zone in the post-tensioning. From above considerations, this work is aimed to give the survey of previous literatures relating with the evaluation of strength of anchorage zone in the post-tensioning as well as the design specifications and to draw some of conclusions to be seemed interesting.

II. LITERATURE SURVEY

Gergely [1, 2] presented the preparation of 25 tests on anchorage zones, where specimens have rectangular and “I” beam sections with different reinforcement patterns. Analytical study by
using finite differences was performed. It was concluded from the study that the performance of “I” sections is better if the force goes through the flange. The tensile zone was large for concentric loaded sections whilst the stress peaks were higher for eccentric loaded sections. With low eccentricities, the bursting stress under the load is highest, while the spalling stress at the mid height of the section is highest with high eccentricities. The elastic analysis was invalid in a cracked section because reinforcement cannot be utilized before cracking.

Iyengar [3] and Breen [4] presented experimental investigation of 24 specimens with the lightweight concrete on the anchorage zone. It was concluded that the lightweight concrete is of less resistance than normal concrete and they recommended to use larger bearing plates or increase the thickness of the section in order to adjust for the lower strength. The post-tensioning duct reduced the ultimate strength. Moreover, the more rigid plate was, the better the performance of the specimen was.

Breen [5] performed the experiment for fifteen “I” section specimens, leading to the conclusion that the cracking load has little affected by concrete compressive strength. Increasing the percentage of web reinforcement did not affect the cracking load and also was not greatly affected by the size of the bearing plate. Very long spirals were effective in delaying the first cracking load. Transverse post-tensioning was very effective in controlling and preventing tendon path cracks and formation of cracks along the tendon axis could be accelerated by anchorages with stiff transitional cones radial forces due to tendon curvature.

Stone [6] investigated several large thin-webbed box girders, with post-tensioned anchorage zones designed in accordance with AASHTO and American Concrete Institute (ACI) requirements, where have experienced large cracks along the tendon path in the anchorage zones at the design stressing load. Linear elastic three dimensional finite element method was used for the design of post-tensioning anchorage zone. The study investigated effects of several factors on cracking load and showed from the study that the cracking load does not remains at same level by increasing cover but the change is not significant. The thickness was found as one of the important factors because the cracking load also increases significantly when the thickness increases. The cracking load decreases if the angle of inclination and eccentric effect increases. Cracking load slightly increases when the size of bearing area plate increases. Spiral reinforcement is of better performance than orthogonal one for controlling of cracking width as well as the increase of cracking load and ultimate load.

Yong [7] studied the effect of shear forces on the stress in the anchorage zone by using FEM analytically and performed the experiment for 15 specimens of “I” sections with concentric and eccentric anchorage having the same set of three end block lengths. The results indicated that a lateral shear force on a beam causes a significant reduction in the value of the lateral tensile strain but has relatively little effect on the transverse tensile strains. If lateral active reinforcement is used to control lateral bursting strains, special attention needs to be paid to potentially high transverse strains in thin web members. Peak lateral bursting strains do not occur at the same location as peak lateral bursting stresses.

Burdet [8] performed analytical and experimental study on behavior and design of anchorage zone by combination of FEM with STM. More than 60 specimens were prepared for experimental program. It was concluded that the cracking loads computed based on the elastic stresses and the split cylinder strength of the concrete are slightly smaller than the actual cracking loads, possibly because of the detrimental effect of the transverse compression. The ultimate capacity of anchorage zones can be conservatively predicted using the STM. This investigation clearly indicates the critical nature of the compressive struts in anchorage zones. This differs from many other D-region applications in which the struts are not as critical.

Burgoyne [9] presented an experimental study on the behavior of strip-loaded reinforced concrete prisms and compared with literature on the subject. The experimental program consists of seven types of specimens with different formation of steel reinforcement. As a result, bursting strain reading from test is close agreement with linear elastic FEM predictions at low loads. The design
method of reinforcement generally is very conservative and produces a lot of conjunction in anchorage zone.

Yun [10] estimated the ultimate strength of post-tensioned beams up to anchorage failure using approximate stress analysis/design method such as the AASHTO and LRFD, where AASHTO bearing strength equation and Non-linear STM was used. The study showed that the approximate method overestimated the ultimate strength of post-tensioned beams. The bursting force calculated in general zone depends on reinforcement bars and their stress. If the bursting force is located away from loading plate, the anchorage zone is subjected to a large ultimate load. The use of bearing strength equation is important if spiral reinforcing bars ahead of anchorage plate exist in structural member. The STM used in the critical section concept is appropriate for a lower bound design based on the theory of plasticity and this method is used for the analysis/design with complicated geometrical anchorage configuration.

Bonetti [11] studied the ultimate bearing strength (UBS) of the local zone analytically by using FEM. The test program was divided into two main categories, namely, the investigation of the ultimate bearing of plain concrete blocks and of the reinforced concrete blocks. For plain concrete blocks, the study concluded that when A/Ab, where A is the supporting area and Ab, the plate area and aspect ratio L/w increases, the UBS also increases and the plate shape has negligible influence on the UBS if A/Ab ratio lies between 2 and 16. Normal weight concrete shows better agreement of UBS than light weight concrete. Increasing concrete compressive strength produce decreases of UBS especially for A/Ab >6 and the duct size does not affect significantly the UBS. For reinforced concrete blocks, UBS increases with an increase in the mechanical reinforcing ratio. However, results from this research suggest that for values of mechanical reinforcing ratio >0.5, no further benefit is achieved with additional increase of the reinforcing ratio.

Johnson [12] performed analytical and experimental study to determine the feasibility of reduction of the mild steel reinforcement by adding fibers to the general zone and to evaluate the impacts of doing so because large amounts of mild steel reinforcement are placed in this area of the bridge girder in order to resist these highly tensile stresses and this causes congestion in the area of the steel and poses difficulty during concrete placement. Finite element method was used. The conclusion from the study indicated that the maximum reduction of mild steel reinforcement, with the addition of 0.50% steel fiber, is 65% in the general zone and the addition of steel fiber to the general zone in amounts above 0.50% can cause an increase in stresses.

Anil [13] presented experimental investigation for 14 specimens with two different anchoring arrangements. They used semi-empirical equation that was proposed for calculating the analytical capacities of the specimens in [14]. The study showed that the strength was increased significantly at anchorage specimens compared with the specimens without anchorages. The number of anchorages had positive effect on the strength but contribution was decreased proportionally with the increase in the number of anchorages. The strengths of specimens were strengthened with two-row staggered anchorages less than specimens that were strengthened with one row of anchorages. The mechanical anchorages were significantly better than the CFRP anchorages in bonding and anchorages made a positive effect on the load–displacement behavior of the test specimens including failure modes in all specimens. A semi-empirical equation that was proposed in [14] was used for calculating the analytical capacities of the specimens. The equation was successful for calculating the capacities of the specimens without anchorages but was not sufficient for calculating the specimens with anchorages. This should be expected because of the lack of variables in the equation related to anchorages.

Christodoulides [15] investigated on the stress distribution in the end anchorages of post tensioned concrete beams using three dimensional problem. The distribution of principal stresses was recorded, as it is considered that failure will be governed by the maximum principle tension. It was concluded from the study that the maximum shear stress and the absolute maximum principal stress occur immediately under and on the center line of the loading steel cubes, i.e., anchorages. The position and the magnitude of the principal tensile stresses obtained explain the anchorage failures.
The actual distribution of stress in end block of post tensioned beams is a three dimensional one. The experimental investigation of the problem indicates the importance of the point and also the affection of cable ducts cast in the concrete on the distribution of the stresses.

Chouragade [16] conducted an analytical study on three dimensional stress analysis of anchorage zone in pre-stressed post-tensioned concrete beam using finite element software ANSYS. A case study is performed in which the loaded area ratio is varied for beam subjected to concentric loading and eccentric loading and various stress distribution are obtained. They modeled the anchorage zone as a cubical block with circular shape anchorage place. From the study, the author concluded that there is a reduction of stresses with introduction of eccentric loads that directly affects the bursting tensile forces. Hence it was recommended to consider the analysis of spalling zone as well as anchorage zone for pre-stressed post-tensioned concrete beams subjected to eccentric loading.

Hou [17] studied the most accepted STM in practical design for post-tensioning of anchorage zone subjected to centric or eccentric based on experimental investigations and FEM simulations, to improve the models in accuracy, economy and efficiency. Conclusion was drawn that the investigations using the linear FEM is effective to determine principle stress in post tensioning anchorage zone and the STM can be configured with Mörsch model for the centric anchorage zone based on the FEM results. Also the research showed that the modified STM configuration method is more accurate and easy to handle for civil engineers for large eccentric condition.

III. CONCLUSION

This study investigates the various literatures indicating the importance and the effect of some parameters on post-tensioned anchorage zone. The following conclusions and findings can be drawn from this study:

- The number of anchorages had positive effect on the strength but its contribution was decreased proportionally with the increase in the number of anchorages.
- Spiral reinforcement gives better performance than orthogonal one for controlling cracking width and for the increase of cracking load and ultimate load.
- The maximum reduction of mild steel reinforcement, with the addition of 0.50% steel fiber, is 65% in the general zone and the addition of steel fiber to the general zone in amounts above 0.50% can cause an increase in stresses
- For large eccentric condition, the modified STM configuration method is more accurate and easy to handle for civil engineers.
- Performance of “I”-type sections is better than rectangular sections if the force goes through the flange.
- The maximum shear stress and the absolute maximum principal stress occur immediately under and on the center line of the loading steel cubes, i.e, anchorages.
- When the thickness of section increases, the cracking load also increases significantly and the cracking load decreases if the angle of inclination and eccentric effect increase.
- The experimental investigation of the problem indicates that the cable ducts cast in the concrete will affect the distribution of the stresses.
- The linear FEM is common effective to determine principle stress in post tensioning anchorage zone.
- In general, all design methods of reinforcement is very conservative and produces a lot of conjunction in anchorage zone.
- The lightweight concrete has less resistance than normal concrete. In order to adjust for the lower strength, use of larger bearing plates or increase of the thickness of the section is recommended.

Recommendation

Future study could contain the behavior and stress distribution in the interface between local and general zone because of the lack of researches available related to this aspect.
REFERENCES


