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Post Tensioning Methods

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Abstract: *This review paper discusses post-tensioning, which is one of the major techniques in modern construction with respect to enhancing the performances of concrete structures by impounding compressive stress into the structure. It looks into the principles of post-tensioning, comparing this method with conventional reinforcement methods, and provides a discussion on its advantages - including reduced material usage, increased load-bearing capacity, and improved crack resistance. The paper also reviews applications in various segments of structural engineering, such as bridges, high-rise buildings, and parking garages. Case studies of real applications are also presented. It discusses the implications of post-tensioning on structural design, construction efficiency, and sustainability, aiming to provide valuable insights to engineers and architects in the field.*

Keywords: post-tensioning

I. INTRODUCTION

Post-tensioning has many potential advantages that include crack control, smaller and irregular cross-sections, and fast construction with minimal disturbance of traffic when combined with precast members. Though post-tensioning is not a new way of construction, it can still be developed with modernization of construction practices and available materials. It is better to consider the durability issues of the post-tensioning system and overall structure. In particular, chloride-induced corrosion from a marine environment or deicing salts is a very real concern for all types of bridges. Research in this area for post-tensioned bridges is limited in part due to the long-term nature of durability studies (Schokker 1999). The new post-tensioning materials and systems in recent years has made some of the durability research in this area obsolete. The current research focuses on evaluating the corrosion resistance performance of state-of-the-art, as well as potential, post-tensioning materials and construction practices. The experimental program includes both long-term exposure tests and electrically accelerated corrosion tests.

Concrete is strong in compression, but weak in tension. Therefore, it will crack in tension well before crushing in compression. To supplement the 1 relatively low tensile strength of concrete, steel is embedded in concrete to transfer tensile loads and control concrete cracking. The concrete and steel composite is reinforced concrete. Prestressed concrete is a form of reinforced concrete in which high strength steel reinforcement in the form of bars, wires or strands has been tensioned against the concrete. This tensioning, or stressing, operation results in a self-equilibrating system of internal stresses (tensile stresses in steel and compressive stresses in the concrete) which improves the response of the concrete to external loads (Collins and Mitchell). In order for prestressed concrete to crack, the tensile stresses must overcome not only the tensile capacity of the concrete, but the precompression of the concrete due to the prestressed steel as well. The ability of prestressed concrete to minimize or eliminate cracking and control deflections allow for to smaller concrete members than if using non-prestressed concrete.

II. PRINCIPLE OF POST TENSIONING

The purpose of prestressing is to put the concrete under compression in those areas in which load causes tensional stress. Applied tensile loads will have first to counteract the induced compression by prestressing before such loads can crack the concrete. Figure 1.1 (a) shows a simply reinforced concrete simple span beam and fixed cantilever beam cracked under applied load. Figure 1.1(b) shows the same unloaded beams with prestressing forces applied by stressing post-tensioning tendons. By placing the prestressing low in the simple-span beam and high in the cantilever beam, compression is induced in the tension zones; creating upward camber.

The function of prestressing is to place the concrete structure under compression in those regions where load causes tensile stress. Tension caused by applied loads will first have to cancel the compression induced by the prestressing before it can crack the concrete. Figure 1.1 (a) shows a plainly reinforced concrete simple span beam and fixed cantilever beam cracked under applied load. Figure 1.1(b) illustrates the prestress forces applied by the stressing post-tensioning tendons to the same beams, unloaded in this situation. By locating the prestress low in the simple span and high in the cantilever, compression is achieved in the tension zones; giving an upward camber to the beam.

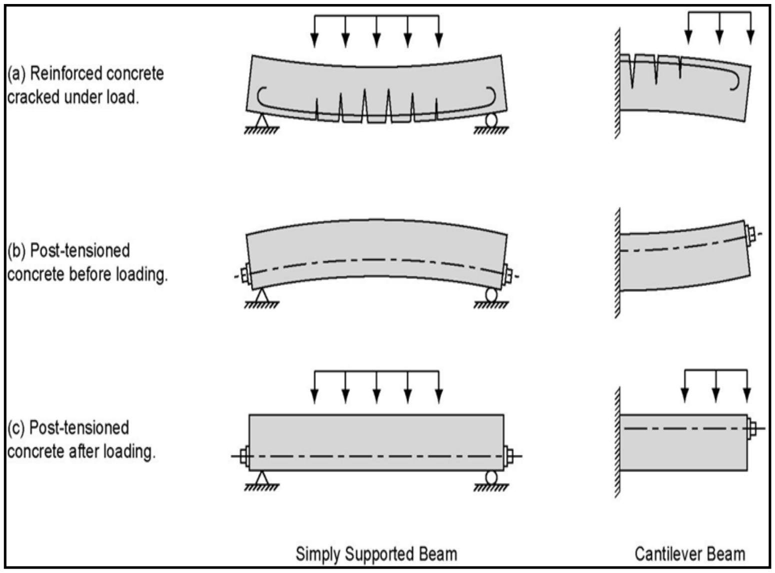

Figure 1.1 - Comparison of Reinforced and Prestressed Concrete Beams

III. BENEFITS OF POST TENSIONING

The tensile strength of concrete is only about 10% of its compressive strength. Thus, plain concrete members are bound to crack when loaded. Reinforcing steel can be embedded in the concrete members to accept tensile stresses which plain concrete cannot resist. Reinforcing is chosen considering the assumption that the zone of the concrete in tension has no tension and that it can withstand tensile stress only if it is developed by tension forces in the reinforcement bars. The reinforced concrete elements, obtained this way may crack but can still take design loads (Figure 1.2)

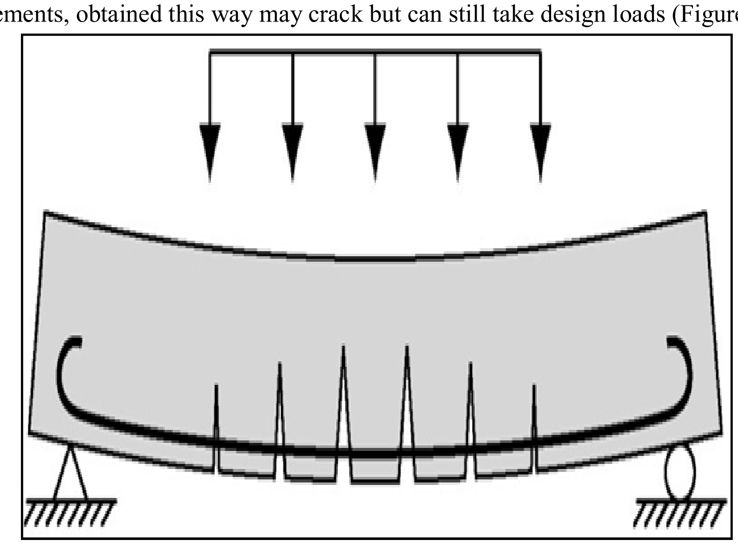

Figure 1.2 - Reinforced Concrete Beam Under Load

Although cracks occur in reinforced concrete, the cracks are normally very small and well distributed. Cracks in reinforced concrete can reduce long-term durability. Introducing a means of pre-compressing the tensile zones of concrete members to offset anticipated tensile stresses reduces or eliminates cracking to produce more durable concrete bridges.

Post Tensioning System :

Many proprietary post-tensioning systems are available. Several suppliers produce systems for tendons made of wires, strands or bars. The most common systems found in bridge construction are multi-strand systems for permanent post-tensioning tendons and bar systems for both temporary and permanent situations. Refer to manufacturers' and suppliers' literature for details of available systems. Key features of three common systems (multiple-strand and bar tendons) are illustrated in Figures 1.3, 1.4 and 1.5.

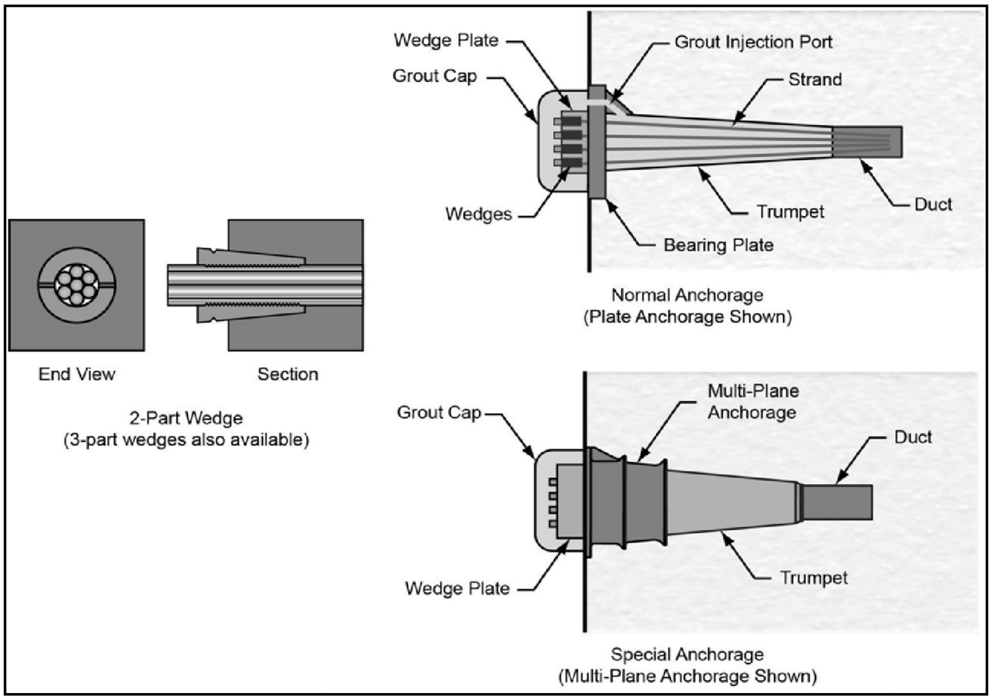

Figure 1.3 - Typical Post-Tensioning Anchorage Hardware for Strand Tendons

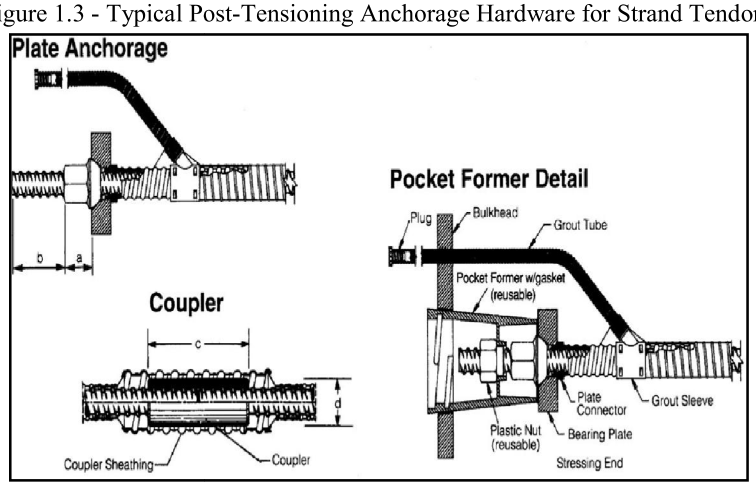

Figure 1.4 - Typical Post-Tensioning Bar System Hardware (Courtesy of Dywidag Systems International)

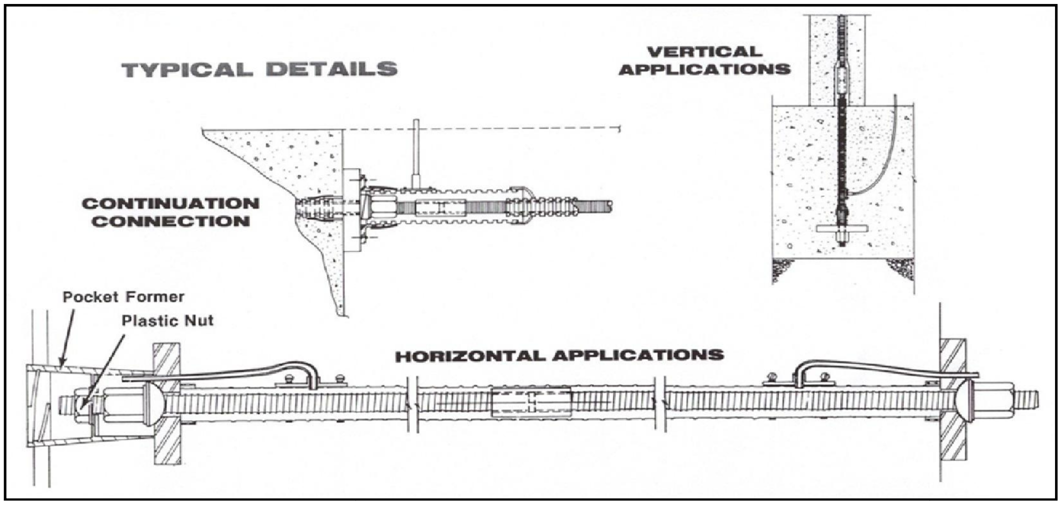

Figure 1.5 - Typical Post-Tensioning Bar System Hardware (Courtesy of Williams Form Engineering Corporation)

Ducts :

Originally, duct was mainly considered as a tool of creating a void through the concrete for the tendon, with little consideration given to the possible role of the duct as a barrier to corrosive agents (FHWA 2004). After finding cracks and voids in the grout, much importance has been given to the reliability of duct as a form of protecting the strand. Grout is injected into the duct after post-tensioning. Hence, the grout is not prestressed and may crack earlier than the surrounding prestressed concrete. Voids in grout can be caused by poor grouting procedures and/or accumulated bleed water. Proper grouting of the post-tensioning ducts is required for corrosion protection and bond transfer, but complete grouting is difficult because of poor visibility and access to all parts of the duct (Schokker 1999).

a)76 mm One-Way Ribbed

b)85 mm Two-Way Ribbed

Figure 1.6: GTI Plastic Ducts

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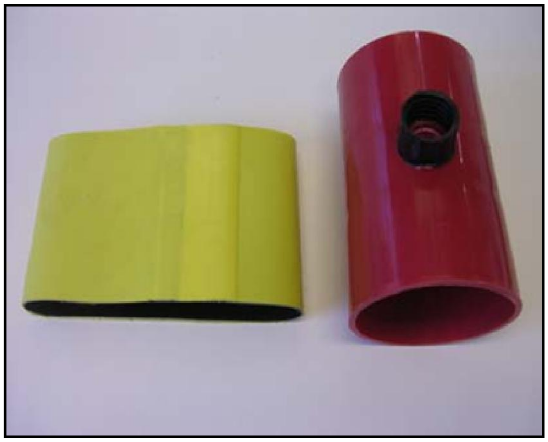
a)76 mm

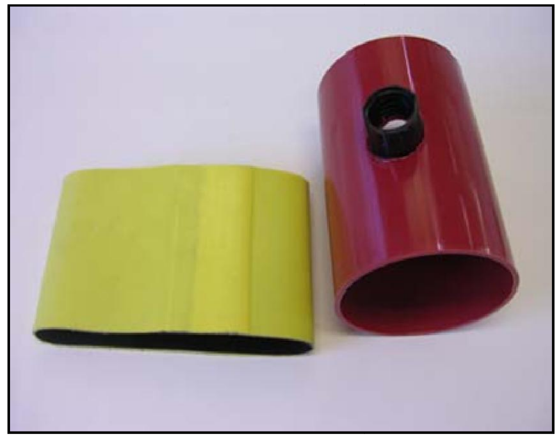
b)85 mm

Figure 1.7: GTI Slip-On Couplers with Heat Shrink Sleeves

Figure 1.8: Galvanized Steel Ducts

IV. TYPES OF BEARING PLATES

The specimen was originally intended for the VSL E5-3 bearing plate that is capable of holding three 0.5" strands. During the initial stages of the specimen's construction, VSL realized they would be unable to provide the E5-3 bearing plates because they are rarely available in the United States. The smallest bearing plate that VSL could procure for 0.5" strand was the EC5-7 by VSL that could hold seven 0.5" strands. Seal tendon with epoxy by plugging with the four extra holes found on the anchor heads. Anchor head epoxy was also the epoxy used to coat anchorage pocket before backfilling with mortar. Specimens were prepared using non-galvanized and hot-dip galvanized versions of the VSL EC5-7 bearing plates.

Acceptance of Post-Tensioning Systems :

Post-tensioning systems shall be approved in accordance with "Guide Specification for Grouted Post-Tensioning" (PTI/ASBI M50.3-12).

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For the acceptance and approval of a post-tensioning system, tests of all the components and results of post-tensioning system approval tests shall be conducted by an independent approved body or testing laboratory. Testing should be done before submitting Shop Drawings and other related documents to the Engineer for approval.

It is recommended that a system supplier provide full documentation including:

- Technical documents and drawings of general assembly of the system and details of components.
- Instructions and method statements for installation, stressing and grouting.
- A quality assurance plan covering production, shipping, handling, storage and installation of the system.
- Instructions for surveillance and maintenance of the system in service.

On site, the Contractor shall keep an accurate record of all documentation, test reports, shipping dockets, and approvals. Copies shall be available to the Inspector (CEI) for verification purposes.

Designing Post-Tensioned Slabs for Future Openings :

1. Locating post-tensioning tendons

For post-tensioned slabs and beams where tendon positions may not be easily visible, soft it marking can be used. Stainless steel staples are used before casting the slab to secure the ducts to the formwork. The position of the tendons is then very obvious upon striking the formwork when the staple lines have been linked by painted lines.

Alternately chalk lines may be marked over the top surface of slabs for aiding in the post tensioning tendon locating process. Such procedures shall enable locating openings to remain at some distance from the tendons.

2. Structural systems in post-tensioned concrete

a) Band Beam and Slab

The band beam and slab solution may be suitable for rectangular grids. This is the system commonly adopted for shopping centres and carparks as it offers economic advantages and relative insensitivity to floor height constraints. Normally band beams span in the long direction and impose the same constraints on hole placement as would a steel or reinforced concrete beam. However, small hydraulic type penetrations (approximately 150 mm diameter) can usually be accommodated without the need for remedial action. The slabs however, are usually quite lightly prestressed with tendons in one direction only at approximately 1500 mm centres. Reasonable size openings or large slots are therefore easy to accommodate without the need to cut post-tensioning tendons.

b) Flat Slabs and Flat Plates

For buildings that demand minimum floor to floor height and regular grids, the two-way post-tensioned flat slab is normally the most economical option. The standard construction method would focus the tendons into 'column strips' along the column grids at around 600 mm centers with tendons outside of the column strip at about 1400 mm centers.

Thus, small holes for services can be located without tendons needing to be cut. The system above can now be left in the centre panel as being traditionally reinforced and being designed as a `soft zone' to accommodate large openings. The cost penalty for the additional reinforcement required must be set against the perceived benefits.

c) Ribbed and Waffle Slab

The introduction of ribs spanning either one-way or two-way depending upon the aspect ratio of the grid may be dictated by larger grids or heavier loads.

Rib spacings for post-tensioned slabs are generally larger than for reinforced concrete, being typically 1.2 to 1.5 metres. Consequently small to moderate holes can easily be cut through the topping slab without disturbing the ribs. Indeed with tendons confined to the ribs their location is readily identifiable, assisting in the siting of the openings.

V. CONCLUSION

In conclusion it is worthy to reinforce a few key points.

There is a definite trend towards large spans in buildings due to the fact that there is now more emphasis on providing large uninterrupted floor space which can result in higher rental returns. Post-tensioning is an economical way of achieving these larger spans. For spans 7.5 metres and also over, post-tensioning will certainly be economic and, as the spans increase, so do the savings.

The most critical factor in slab system post-tensioning cost is the tendon
length. Other factors create a scatter of results leading to an upper and lower bound. Not withstanding this, it is always wise to solicit budget prices from a post-tensioning supplier. The dominant structural schemes that are provided are the flat plate, flat slab and banded slab, with the latter usually resulting in the most economical structure. However, other parameters such as floor to floor heights, services, etc., have to be considered in the choice of floor structure. For high rise construction and very repetitive floor plates, more specialized structural schemes is appropriate with emphasis on systems formwork.

Not infrequently is post-tensioning rejected in some types of building project because of an impression that flexibility is lacking. Tendons, however are spaced adequately far apart to allow reasonable size penetrations to be made later, without cutting through the tendons. If it is necessary to cut tendons, this can easily be done using well established methods.

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