pti Technical Notes

1717 West Northern Avenue • Suite 114 • Phoenix Arizona 85021

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Wedge Forces on Post-Tensioning Strand Anchors

By Gregory P. Chacos[1]

1 - Introduction

This Technical Note discusses the forces that develop within anchorages of post-tensioned tendons. Of particular interest is the importance of wedge friction and its influence on the magnitude of radial tension developed in the anchors. The anchors considered are those used to confine wedges that hold seven-wire strand permanently, as with unbonded tendons, such as the example shown in Figure 1, or temporarily, as with bonded tendons. Also included are splicing devices which, like the anchors, can be made of steel or be ductile-iron castings.

This subject is discussed in some of the early literature about prestressed concrete (Leonhardt 1964), but is presented here in a simplified form, with particular reference to monostrand anchors, because it relates to some field problems that have been encountered by the author.

2 - Force Analysis

Figure 2 shows the resistance forces, C, generated in the anchor-pieces due to tendon force, T. The resultant forces, C, shown in the plane of the drawing, represent the pressure between the wedges and the anchor-piece. It will be shown in the following that the magnitude and orientation of the force, C, is a function of the geometry of the assembly and the friction coefficient between the wedge and anchor-piece.

Figure 3 illustrates the free-body diagram of the forces on two wedges holding a strand in a typical anchor assembly.

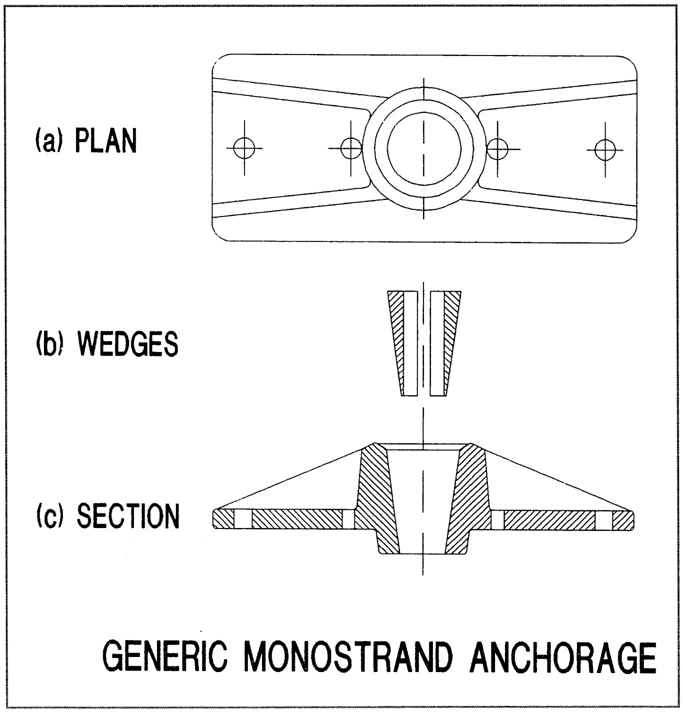


Figure 1

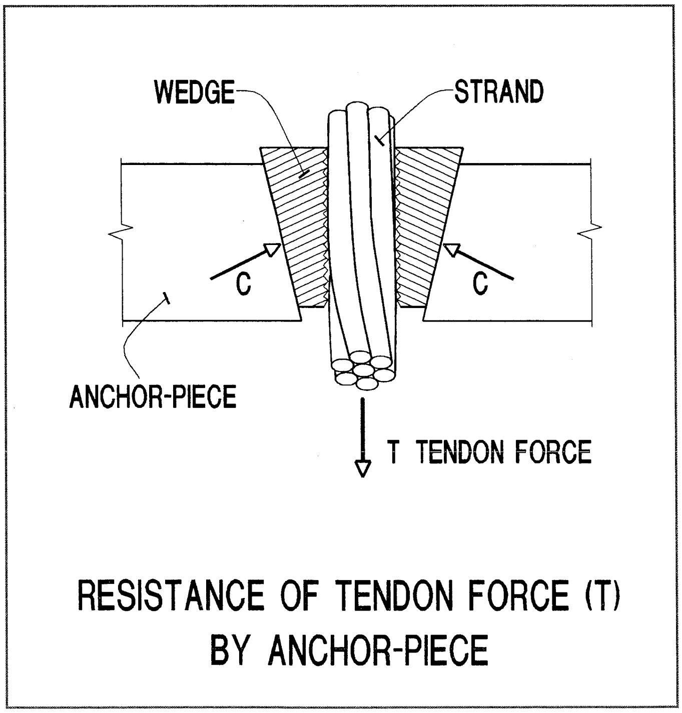
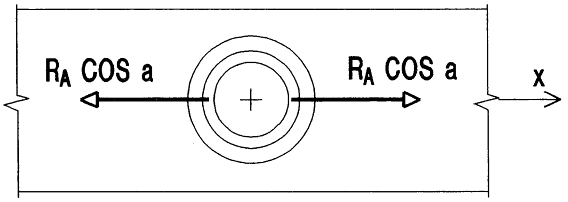
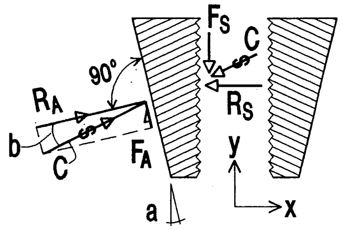


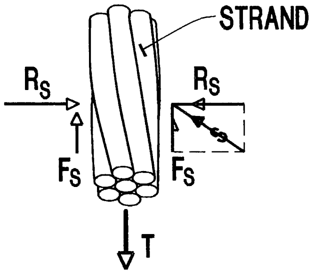
Figure 2



a) ANCHOR-PIECE PLAN



b) FORCE RESULTANTS ON WEDGE IN X-Y PLANE



c) FORCE COMPONENTS ON STRAND IN X-Y PLANE

RESOLUTION OF TENDON FORCE ON ANCHOR-PIECE COMPONENTS

Figure 3

Again, the forces shown are the resultants in the x-y plane, of the pressure between the interfaces of the components shown. The "friction" force Fs that keeps the strand from slipping through the wedges is actually a mechanical interlock caused by serration of the inner surface of wedges of the most common type. The wedges are confined within a cone-shaped recess in the anchor (Figure 2) and exert a radial force, RA, normal to the wedge-to-anchor surface, on the anchor. This force varies with the friction developed along the contact surface, and with the angle of the wedge, a, (usually 7 degrees).

For equilibrium within each wedge, the resultant of the radial and friction forces on the strand must equal the resultant of the radial and friction forces on the anchor. This leads to the following expressions.

From Figure 3,

$$T = 2\,FS \tag{2.1}$$

From Figure 4,

$$C = FS/[\sin(a+b)] = RA/\cos(b) \tag{2.2}$$

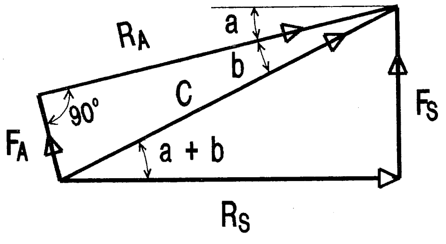
From expressions 1 and 2,

$$RA = T{*}\mathrm{Cos}b/[2{*}\mathrm{Sin}(a+b)] \tag{2.3}$$

where:
RA = radial force on anchor (normal to wedge)
a = wedge angle, commonly 7 degrees
b = friction angle at wedge-to-anchor surface (coefficient of friction)
T = strand tension at transfer (maximum on wedges)

3 . Coefficient of Friction

While the inner surface of a typical wedge has teeth machined into it, the outer surface may be smooth or rough, depending on the specifications to which it was manufactured. Some tendon fabricators use rough wedges for shop applied anchors to decrease the tendency of the wedges to shake loose during shipping, but this is not a universal practice. Most wedges are delivered to the tendon fabricator with an outer surface that is smooth, but not polished, and lightly oiled.



FORCE POLYGON OF ACTIONS ON WEDGE

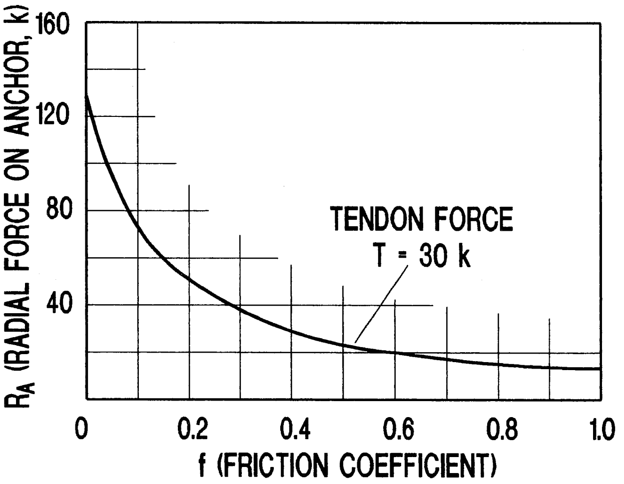
Figure 4

The most common anchor is a ductile-iron casting whose cone recess has an as-cast finish with a sandy texture. The cone is not a true surface of revolution, because of the shrinkage that occurs during cooling of the metal, so the wedges will not precisely fit the recess. This is not a problem, since the wedges deform and split to adapt themselves to the space available, but it complicates the ability to predict friction. The actual condition of the contact surfaces can vary from rough and rusted to smooth and heavily greased, so there can be a wide variation in friction.

Details of friction and lubrication are beyond the scope of this paper, but a review of technical references (Ganic, Hicks et al 1964, Gieck 1976) suggest the following values of coefficient of static friction:

Dry, pitted, rusted, old	1.0
Dry, lightly rusted, new	0.5
Lightly oiled, clean, new	0.3
Heavily greased, clean, new	0.1
Frictionless (theoretical only)	0.0

Figure 5 shows how the radial force on an anchor, RA, varies for a constant strand tension of T=30 kips (133.44 kN) (average for 1/2" diameter, 270 ksi strand at transfer) and various frictional values, f. For the usual conditions encountered with new material, the coefficient of friction should be between 0.2 and 0.4, resulting in radial force between 47 kips and 29 kips respectively (209.06 and 128.99 kN). It should be noticed that decreasing the coefficient of friction to 0.1 (feasible with heavy grease) increase the radial force to 68 kips (302.46 kN).



VARIATION OF RADIAL FORCE ON ANCHORAGE WITH TENDON FORCE
(1 k = 4.448 kN)

Figure 5

4 . Discussion

The phenomenon discussed here is a simplified version of what actually happens within an anchorage. It is difficult to predict the magnitude of the internal forces, but simple pull-through tests will show that lubrication and surface roughness play a significant role. Anchors that have a pronounced tubular configuration, such as those used for splicing, or the "donut" anchor collar, can be made to split if strand of sufficient strength is used. The stiffened-boss anchor casting is traditionally very sturdy and not prone to rupture from radial forces. However, new anchors developed for special conditions may not have the benefit of traditional proportions and may not have sufficient reserve strength to accommodate unusual stresses.

The actual magnitude of the radial force is of less significance than recognition that lubrication and surface smoothness have an influence on the stresses that develop in the anchor. This is not to say that it is necessary to demand that the surfaces be kept dry and free of oil and grease, but there is reason to take a cautious view of radically changing the customary procedures. Some tendon installers routinely check the cone recess with a greasy finger before placing an anchor on a strand, thereby applying some lubricant. This can give a uniformity of conditions that is desirable, and should not be dismissed as unacceptable just because it may result in higher than minimum radial forces.

Acknowledgment of this splitting phenomenon is of importance in development of new anchors and couplers, or in the modification of existing anchors and couplers to meet special circumstances. This is especially important during repairs and retrofitting when re-using old anchors. Pull-through tests should be conducted with lubricated wedge-to-anchor surfaces when developing new products, or modifying old ones, since this will develop the maximum radial forces.

Occasionally, specifications are found that require the cone recess to be greased or epoxy coated for protection from corrosion. Some anchors may not survive the increase in splitting force that this will cause, so care and awareness are required. Lift-off tests may seem to give erratic results with variations in anchor lubrication, but only in the force required to break the wedges loose and not in the sustained strand force measured thereafter.

Experience has shown that concrete encasement may not be sufficient to prevent splitting of marginal anchors, especially for anchors in slab edges. This being the case, it is prudent to have the anchors self contained as regards the radial forces.

5 . Conclusions

Designers, suppliers and installers of post-tensioning tendons should be aware that forces within the anchorages are influenced by the condition of the contact surfaces. Excessive use of lubricants on the wedges or in the cone recess may be detrimental to anchors and couplers and may cause problems where previous procedures did not. New or modified anchors and couplers should be designed for, or tested for, the forces that result from the lubrication of wedge-to-anchor surfaces.

6 - References

Leonhardt, Fritz, (1964), “Prestressed Concrete Design and Construction,” Wilhelm Ernst & Sohn, Second Edition, 1964, pp 100-103.

Ganic, Ejup N., and Hicks, Tyler G., (1991),”The McGraw-Hill Handbook of Essential Engineering Information and Data,” McGraw-Hill, Inc., 1991, pp 5.18-5.21.

Gieck, Kurt, (1976),”Engineering Formulas,” Second Edition, 1976, p Z16.

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[1] Gregory P. Chacos Inc.; 34 South Main Street, Chagrin Falls, Ohio 44022; Tel: (216) 247-1970; Fax: (216) 247-1680

Please contact the Institute or the editor, Dr. Bijan Aalami, for contributions, comments and suggestions for future issues.

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1717 WEST NORTHERN AVENUE, SUITE 114, PHOENIX, ARIZONA
(602) 870-7540 FAX (602) 870-7541

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