such design is shown in Fig. 12.8. Note that the tendon is located in the middle of a grade beam, in order to eliminate any flexural stresses caused by eccentricity. Note also that the grade beam and the column pier are placed together, to minimize the amount of dowels and keys that would otherwise be needed to transfer the outward forces from the column to the grade beam. As with any underground post-tensioning, protection of the anchors and the tendon ends is critical to the long-term durability of the system.

The concrete beams are located some distance below the top of the floor (usually 12 to 16 in) and are reinforced with a minimum of four bars, in addition to the post-tensioned tendon in the middle.

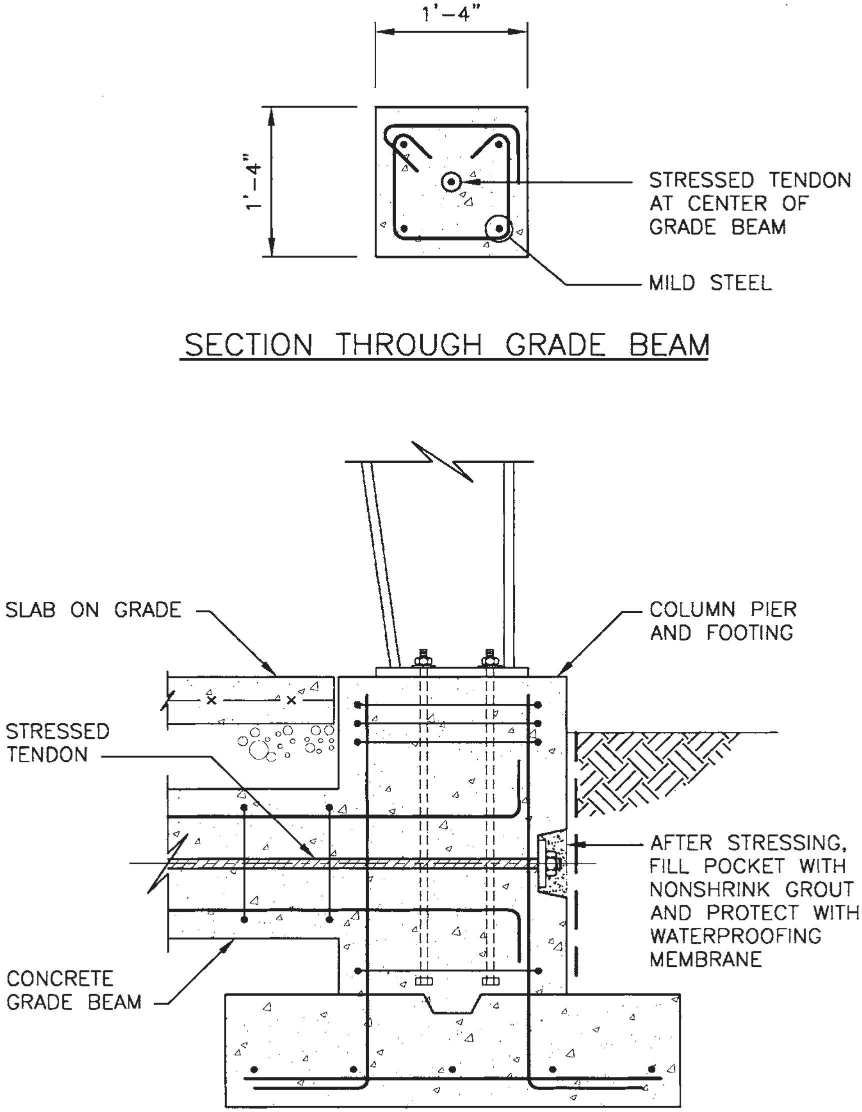

FIGURE 12.8 Post-tensioned tie rod encased in concrete beam.

The bars are ordinarily encased by two-piece stirrups. To protect these bars from corrosion, the concrete cover at the top and sides should be at least 2 in, and at the bottom, 3 in. A corrosion-resistant coating is also helpful. These "tie rods" can function not only in tension but also in compression, doubling as seismic foundation ties. The common grade beam sizes range from 14 × 14 to 24 × 24 in, as required by the column behavior. Stresses are low: a rod placed in a 16 × 16-grade beam and tensioned to the above-mentioned 36-kip force level applies a compressive stress of only 0.141 ksi.

Some engineers are concerned about potentially high upward pressures applied to grade beams that are framed into spread footings. As the footings settle slightly under load, they drag the ends of the grade beam with them, while the rest of the grade beam is supported by soil at the original elevation. To reduce these upward pressures and allow for some settlement under the grade beams, they can be placed on loose, locally uncompacted subgrade (or perhaps on a layer of biodegradable material, such as cardboard).

This rather sophisticated system has to compete with the cheapest tie-rod design, in which the rods are simply embedded in a thickened slab (Fig. 12.9). These embedded rods are typically not tensioned, and therefore subjected to the problems of slack and elongation mentioned above. But there is an even more serious potential danger—that of the rods being cut during future installation of underground piping and utilities. Both a sheath and a massive reinforced grade beam have a better chance of survival, since workers are trained to avoid cutting pipes and reinforced underground conduits. A thickened slab is not as alarming.

Tie rods are very effective in resisting the opposing column reactions, but unless the grade-beam design is used, they are not as effective in resisting reactions acting in the same direction, as from a wind load. Also, tie rods obviously cannot be used in buildings with deep trenches, large equipment pits, and similar discontinuities in the floor.

12.5.2 Hairpin Rebars

Hairpin rebars utilize the same principle as tie rods, but instead of connecting two opposite columns by a steel rod, the hairpin system relies on the floor slab to function as the tie. Concrete itself cannot resist much tension, of course, but steel reinforcement within the slab can. The function of hairpin bars is to transfer horizontal column reactions into slab reinforcing bars or welded wire fabric, essentially by lap splicing. The required area of slab reinforcement—and that of hairpin bars—is determined by dividing the horizontal column reaction by an allowable tensile stress of the reinforcement—24 ksi for grade 60 reinforcing bars and 20 ksi for welded wire fabric. The length of hairpin bars depends on the amount of slab reinforcement to be engaged. Hairpin bars are commonly hooked around the outer anchor bolts and extended into the slab at 45° (Fig. 12.10). Hairpins should be long enough for the assumed failure plane to intersect the desired number of slab rebars or wires and to allow for their proper development.

Hairpin rebars function best when embedded in slabs containing properly spliced deformed bar reinforcement, which is common in structural slabs but not in slabs-on-grade. Use of hairpins in slabs-on-grade raises several troubling questions about the slab's ability to transfer tension.

First, slabs-on-grade are frequently unreinforced or contain only short fiberglass or steel fibers clearly unsuitable for tension transfer. Second, even if slab is reinforced, it is often with welded wire

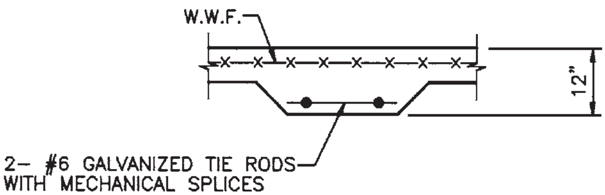

FIGURE 12.9 Tie rods in thickened slab.