POST-TENSIONING IN GROUND-SUPPORTED SLABS

BY BIJAN AALAMI

C.1 OVERVIEW

The principal application of post-tensioned ground-supported slabs in the United States is for residential and light commercial buildings built on expansive soils (Fig. C.1-1), using variations of primarily unbonded and occasionally bonded post-tensioning systems (Fig. C.1-2 and C.1-3). The post-tensioning helps to reduce the damage caused by seasonal volumetric changes of the soil.

A second common application of post-tensioned ground-supported slab is for industrial buildings such as warehouses, where a large, jointless, and super-flat surface is required so that forklifts can maneuver safely when handling heavy loads and lifting them to multi-level storage stacks (Fig. C.1-4). In both of these applications, the primary function of the post-tensioning is to mitigate cracking of the slab under service load conditions. The strength limit state of the slab is generally not a design consideration.

A third major application of post-tensioned ground-supported slabs is for foundation mats. In this application, the post-tensioning is used to reduce the mat thickness and help distribute column and wall loads more uniformly. Figure C.1-5 shows the function of the profiled tendons in distribution of the loads.

The focus of this article is the function of the post-tensioning in ground-supported slabs of the first two types—namely, relatively thin slabs that are used in residential and light commercial buildings and super-flat industrial floors. These slabs are often as thin as 4 in. (100 mm); they are typically cast directly on the soil, usually with a moisture barrier and sometimes a layer of drain sand. It is rarely possible to construct a ground-supported slab within the tolerances that are used for elevated slabs. Unlike the flat and fairly rigid forms used for elevated slabs, the supporting ground may not provide a firm, smooth base for the concrete. The as-built slab may have variations in thickness. These variations are relatively more pronounced than in elevated slabs because ground-supported slabs are typically much thinner than elevated slabs. In addition, because the chairs that support the post-tensioning tendons in a ground-supported slab are not secured to a firm base, tendon heights within a slab can differ from their design values.

The construction realities of ground-supported slabs—which often include approximations in the values of the soil properties, inadequate preparation of foundation soil, and shortcomings in the design methods can lead to cracking and/or excessive deformation of the slab under service loads. These problems can, in turn, trigger an investigation into the cause of the perceived shortcomings. It is not uncommon for investigators to cite the variations in slab thickness, the location and profile of the post-tensioning tendons, and the unevenness in the slab base as contributing to the stresses that caused the cracking and/or excessive deformation. Consequently, the construction

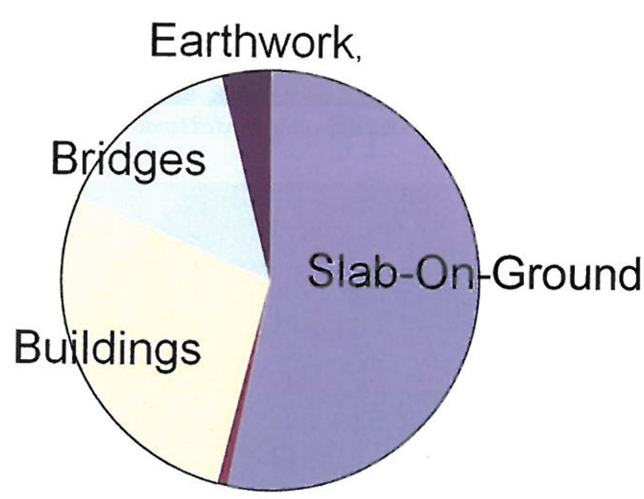

Fig. C.1-1—Representative distribution of post-tensioning tonnage in the United States.

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is considered deficient. One objective of this article is to show that minor deviations from the structural documents do not change the contribution of the post-tensioning in most common designs. As long as the slab remains ground-supported and is free to shorten during stressing, the post-tensioning force will result in a uniform precompression in the majority of the slab, regardless of the tendon position and profile, or variations in the slab thickness.

Fig. C.1-2—Ground-supported slab using unbonded tendons.

Fig. C.1-3—Ground-supported slab using bonded tendons.

Fig.—C.1-4 Industrial ground-supported slab.

While advanced design and investigation software (ADAPT 2014) can accurately predict the stresses in ground-supported slabs, some designers and investigators rely on the traditional beam formulas. When used incorrectly, these formulas can imply that construction, which actually conforms to the standard of practice, is defective. This article uses the traditional beam formulas as a means of highlighting their proper application when calculating stresses in ground-supported slabs.

The increased availability and use of commercial software in structural engineering design is reducing the emphasis on a designer's knowledge of structural engineering formulas and the procedures to calculate deformations and stresses. The emphasis is instead shifting to the designer's ability to evaluate the results of a software-generated analysis/design report and determine whether

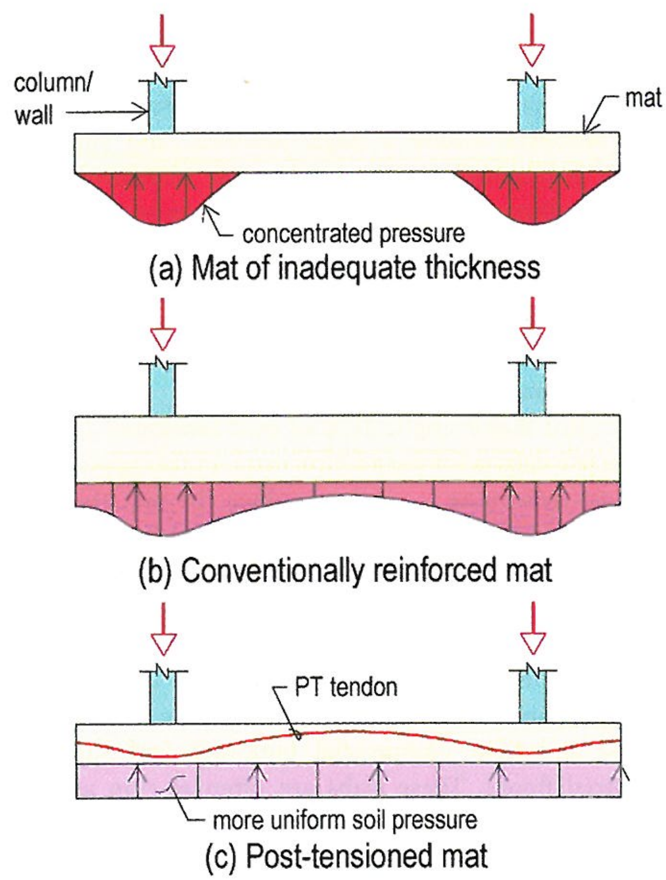

Fig. C.1-5—Mat (raft) foundation. A thin mat can result in an unacceptably high soil pressure (Part a). Increasing the mat thickness will distribute the load more uniformly and thus reduce the soil pressure (Part b). Alternatively, profiled post-tensioning tendons can be used to distribute the loads more uniformly without increasing the mat thickness (Part c). (Aalami 2014) the structure's predicted response is reasonable. A key component in the validation of software-generated solutions is the engineering judgment of the designer, who must be able to visualize the anticipated response of the structure and approximate values of the results. To this end, the next objective of this article is to provide the background to the response of ground-supported slabs under different loading scenarios and conditions. These include tendons not being at the centroid of a slab; tendons having unintentional profile, friction, shrinkage, creep, variations in slab thickness; and concentrated loads.

C.2 ENGINEERS' BENDING STRESS ASSUMPTIONS

It is common in engineering practice to use the Euler-Bernoulli beam equation when calculating axial and bending stresses in beam/slab type members at regions away from the point of application of any loads or discontinuities. The key assumption of this equation is that plane sections of the member remain plane under a bending moment.

For elastic linear material, commonly assumed, the moment M in the member is given by

$$M = \frac{EI}{R} \qquad \text{(Exp. C.2-1)}$$

where E is the modulus of elasticity of the member; I is the second moment of area of a member's cross section about its centroidal axis; and R is the change in radius of curvature in the member.

A slab that is cast over a non-level surface, having an initial curvature $(1/Ro)$, will not be subject to a bending moment, arising from the initial curvature of its support. However, changes in the loading or support conditions, such as a change in the profile of the soil, can cause a change in the slab curvature and a bending moment. For small displacements, the moment can be calculated from the slab displacement w according to the well-known equation

$$M = EI\left(\frac{d^2w}{dx^2}\right) \qquad \text{(Exp. C.2-2)}$$

where w is the out-of-plane displacement of the slab.

Note that the rigidity of most PT foundations is such that the foundation does not strictly follow the soil profile; therefore, gaps between the foundation and soil are created by soil movement.

At regions away from discontinuities and points of applied loading, the distribution of stress in a member having linear elastic material properties is

$$f = \frac{Mc}{I} \qquad \text{(Exp. C.2-3)}$$

where c is the distance from the member's centroidal axis; and f is the stress at distance c from the centroidal axis.

C.3 STRESSES UNDER DIFFERENT LOAD APPLICATIONS

Figure C.3-1 shows the ground-supported slab that we will investigate under different prestressing and support conditions. The slab is assumed to be long enough to have distinct boundary and interior regions. Points A and C represent points at the slab edge, where the tendon anchorages are located. Point B represents a point away from the slab edge.

When a ground-supported slab is cast, the weight of the wet concrete is transferred directly to the ground. The slab assumes the profile of its support so the curvature in the slab will initially be the same as that of the supporting soil. As long as the slab remains in contact with the soil, bending stresses will only be generated in the slab if there is a *change* in the profile of the soil support. Ignoring temporarily the effects of shrinkage, creep, temperature, and settlement, there will be neither bending nor axial stresses in the slab prior to the application of post-tensioning.

Consider the case of a slab on rigid ground support without any restraint to shrinkage or expansion; in effect, the slab is on roller support. The slab is loaded at its centroid by an externally applied force P (Fig. C.3-2(a-i)); the force is intended to simulate the application of post-tensioning through an anchorage assembly. At a Point B away from the slab edge, the entire axial force P will be available, with the stress distributed uniformly over the slab thickness (Fig. C.3-2(a-ii)).

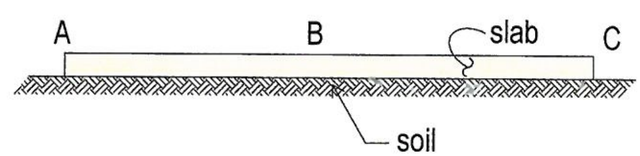

Fig. C.3-1—Configuration of a typical ground-supported slab. Points A and C represent the end conditions, where the post-tensioning anchorages are located. Point B represents the interior condition, away from the anchorages.

In Fig. C.3-2(b-i), the end forces *P* are applied with an eccentricity *e* to the centroid of the slab. The eccentric force is equivalent to a moment *Pe* and an axial force *P* at the slab edge. The moment component will result in an adjustment in the soil pressure over a short length from the end of the slab. The mechanism for the neutralization of the moment at the slab ends is discussed later. At regions away from the slab edge, on the premise that the slab keeps its contact with the soil support and the profile of soil support away from the ends is not changed, no moment will be generated from the eccentric application of the forces *P*. The distribution of stress in the slab at regions away from the ends will be uniform compression (Fig. C.3-2(b-ii)).

At this point, it is beneficial to review the distribution of force and stress in the preceding example because it covers several of the concepts in the stress distribution of ground-supported slabs.

Figure C.3-3(a)a shows the distribution of stress for the slab segment on frictionless support with concentric end loads *P* that is illustrated in Fig. C.3-2(a). The force diagram of the same slab segment is shown in part (b) of the figure. The weight of the slab *W* results in the soil reaction (S = *W*). The force *P* of the severed tendon at Point B results in a uniform precompression *f* on the cut face of the slab. For the eccentric tendon of the same scenario, provided the eccentricity does not uplift the slab edge, the stress distribution will be as shown in part (c). From the force diagram of the eccentric tendon shown in part (d).

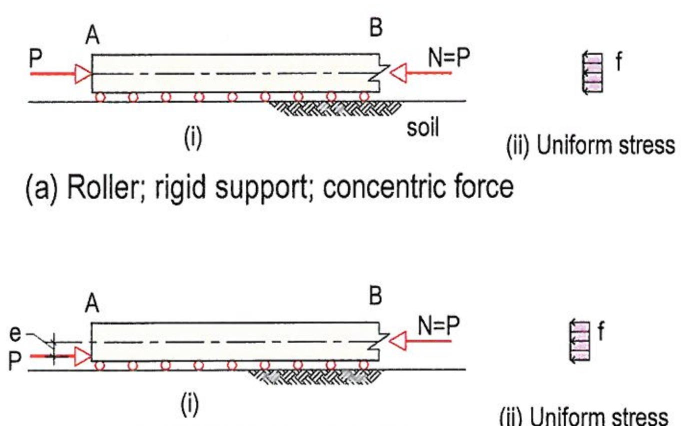

Fig. C.3-2—Partial view of slab on frictionless rigid support. Concentric (part a) or eccentric (part b) application of forces at the slab edges result in uniform precompression in the slab at regions away from the slab ends (Point B). N is the demand force at Section B. f is the compressive stress over the section.

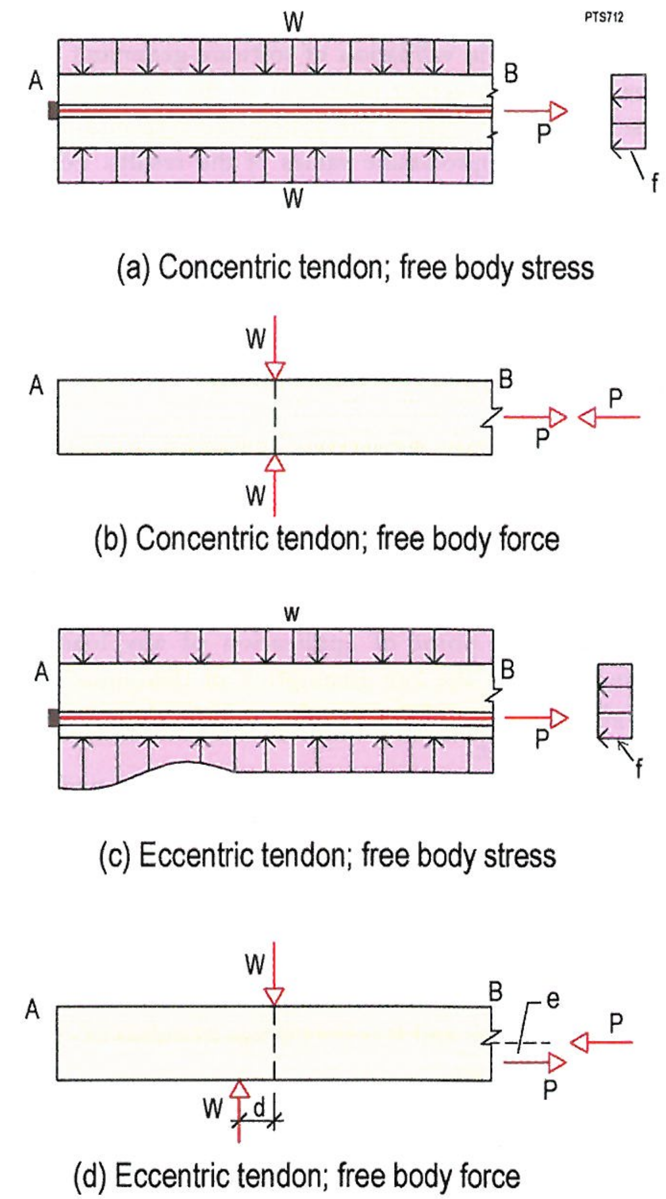

Fig. C.3-3—Partial view of ground-supported slab on frictionless support; free body stress and force diagrams. For the concentric tendon (part a), the unit weight of the slab w *is balanced by a distribution of stress on the soil equal and opposite of the applied weight* s = w. *The tension of the cut tendon as* B *is counteracted by a uniform distribution of stress* f *on the cut section. The sum of the uniform precompression* f *equals the tendon force* P. *Part (b) shows the resultant of forces from the stresses acting on the slab segment. The total weight of the slab* W *is collinear with the total soil reaction* S = W. *The moment at the slab end due to the eccentric tendon in part (c), changes the distribution of soil reaction, resulting in an offset* d *between the resultant of the slab weight* W *and the total reaction from the soils (part d). The moment* Wd *is equal to the moment at slab edge* Pe. *Likewise, the distribution of uniform stress f on the section will add up to a concentrated force* P *that forms a couple with the tendon force* P *at section* B.

$$Wd = Pe \qquad \text{(Exp. 3.2-1)}$$

The force P acting on the cross section of the slab at Point B is concentric and results in a uniform precompression.

Figure C.3-4(a) is a partial view of a slab on ground with friction. The slab is subjected to an eccentric axial force P from post-tensioning at its ends. Friction (F) between the slab and the underlain soil over the distance AB dissipates a portion of the axial compression P in the slab (part b). The net force N at Section B is ($P - F$). Bending stresses of the Bernoulli-Euler beam equation (Exp. C.2-3) are not generated because the slab retains its contact with the soil. The friction forces are not deemed to change the soil profile; the slab simply slides over the soil. The axial force N results in a uniform compression f.

$$N = P - F \qquad \text{(Exp. C.3.3-1)}$$
$$f = N/A \qquad \text{(Exp. C.3.3-2)}$$

where A is the cross-sectional area of member at Section B; F is the friction between the soil and the slab; and N is the force demand at Section B.

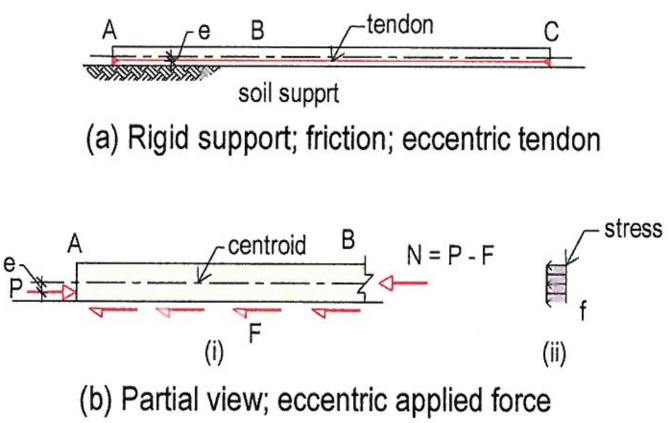

Fig. C.3-4—Ground-supported slab on soil with friction; distribution of stress away from the slab edge. Friction F results in a reduction of precompression force in the slab from P at slab edge to (P-F) at Point B (part b). However because there is no change in slab curvature, no moment will be generated at Point B. The resultant of the force at Point B will (N) distributes into a uniform stress (f). The equilibrium of the system is established in a similar manner to the previous condition through changes in the otherwise uniform soil pressure.

C.4 STRESSES NEAR SLAB BOUNDARIES

Stresses near the slab boundaries must be investigated separately from those in the interior region of the slab. Two cases are considered: one for the anchorage being located below the slab centroid, and one for the anchorage being above the slab centroid. Figure C.4-1a shows a post-tensioned ground-supported slab with tendons anchored below the slab centroid. If the force P is large enough, it will cause the slab ends to curl, as shown in part (b) of the figure. Part (c) shows the forces acting on the slab if the soil is assumed to provide rigid support. The concentrated force R generated at the edge of the slab will be counteracted by the weight of the slab. At distance a from the slab edge, both the moment and the shear in the slab will be zero (parts (d) and (e) of the figure). Beyond distance a, the distribution of stress in the slab will be a uniform compression (part (f)). Whether or not the slab edges will actually curl as shown in the figure, and the length over which the slab will separate from the soil depend on the stiffness of the soil k, the force P, the eccentricity e, and the structural properties of the slab.

When the tendons are anchored above the slab centroid, the slab will tend to curl up (Fig. C.4-2(b)). If the moment Pe caused by the eccentricity of the force is large enough, the slab ends will lift off the ground. However, the self-weight of the slab will counteract the moment and re-establish the slab's contact with the soil at a distance a. If the support is assumed to be completely rigid, the force distribution in the slab can be idealized as shown in part (c) of the figure. The moment and shear at distance a from the slab edge will be zero (parts (d) and (e)). As a result, the distribution of stresses over the concrete section at the regions to the right of distance a will be a uniform compression, as long as the slab remains in contact with the soil in this region. For static equilibrium of the system, the force couple (P and the stress distribution f) shown at Point B in part (f) of the figure will have to be equal to the moment from the force R and the weight of the slab to the left of it.

C.5 SLAB ON FLEXIBLE SUPPORTS

Strictly speaking, soil is not rigid. The initial deformation of the soil due to the weight of the wet concrete will not cause bending stresses in the slab because the change in soil profile takes place before concrete hardens.

However, an eccentric force applied at the slab edge after the concrete hardens will create a local bending moment as discussed in Section C.4. The change in the

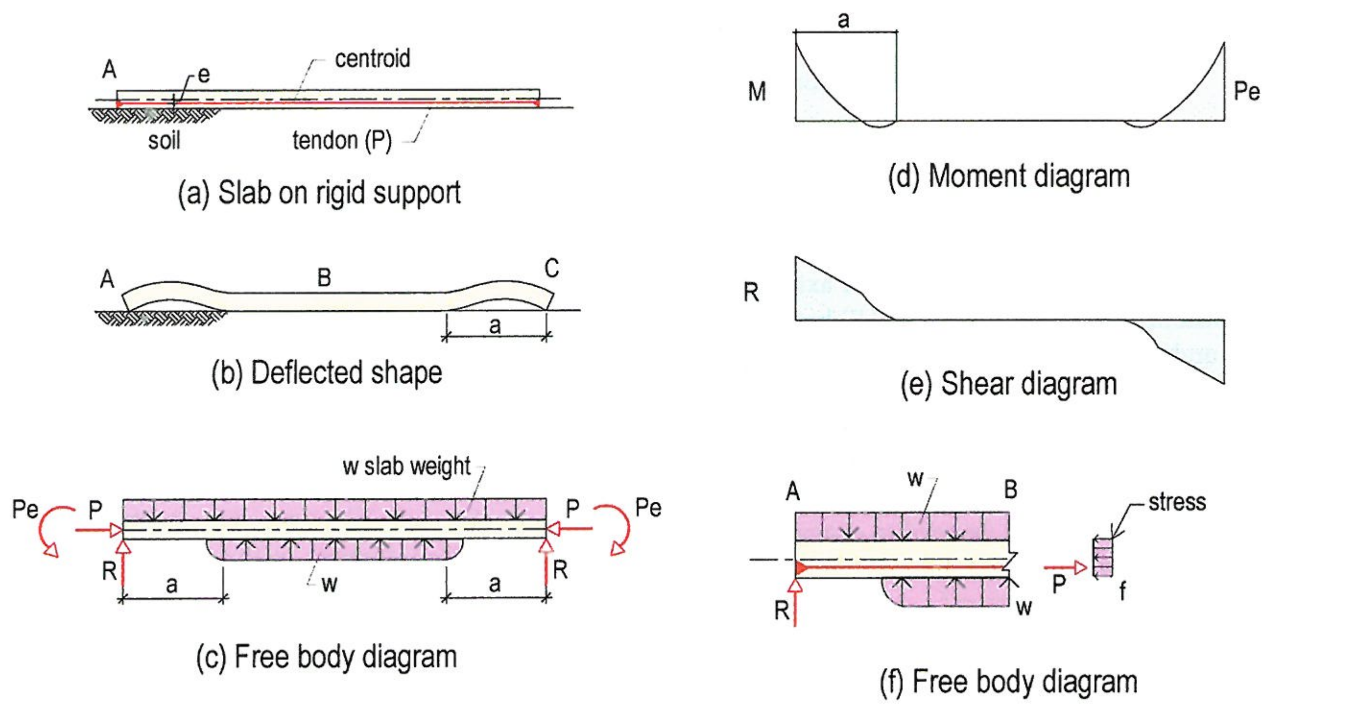

Fig. C.4-1—Distribution of stress in ground-supported rigid slab for tendon anchored below the slab's centroid. The rigid soil results in a concentrated support reaction R *at the slab edges. At a distance* B *farther away from the slab edge, the soil pressure* s *equals the slab weight* w *immediately above it. The forces shown in part (f) of the figure are in static equilibrium, with the stress on Section B being a uniform compression f.*

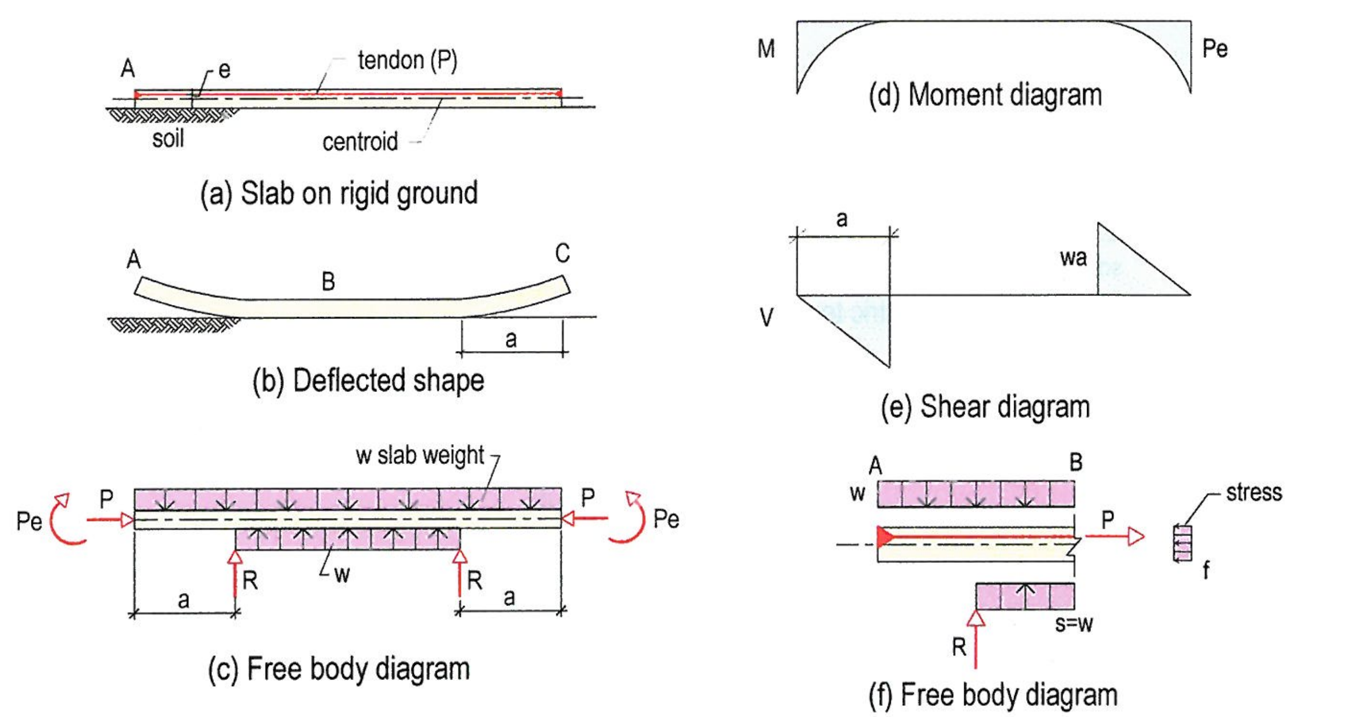

Fig. C.4-2—Distribution of stress in ground-supported slab for tendon above the slab's centroidal axis. If the force P *and the eccentricity* e *are large enough, the slab ends will lift off the supporting soil. The rigid soil results in a concentrated reaction* R *at the point the slab re-establishes contact with the soil. At Point B (further away from the slab edge than* a*), the soil pressure equals the slab weight immediately above it. The moment generated over the distance a is resisted by the offset of force at Section B. The force in the slab section at B is uniform compression.*

stress distribution at the soil-slab interface will be more gradual than the idealizations shown previously, because the soil is flexible. Figure C.5-1(a) shows the stress distribution of Fig. 4.1(c) modified for a flexible soil support. Figure C.5-1(b) shows Fig. 4.2(c) modified for a flexible soil support.

C.6 FRICTION AND DISTRIBUTION OF STRESS

Invariably, compression due to a force applied at the slab edge will be resisted by friction at the soil/slab interface. In theory, if a slab is very long, at a distance far enough from the slab end (distance L shown in Fig. C.6-1), friction fully exhausts the influence of the applied force—irrespective of whether the force is from a post-tensioning tendon or an externally applied force. Although the friction reduces the axial force in the slab, the distribution of precompression over the slab's section remains uniform.

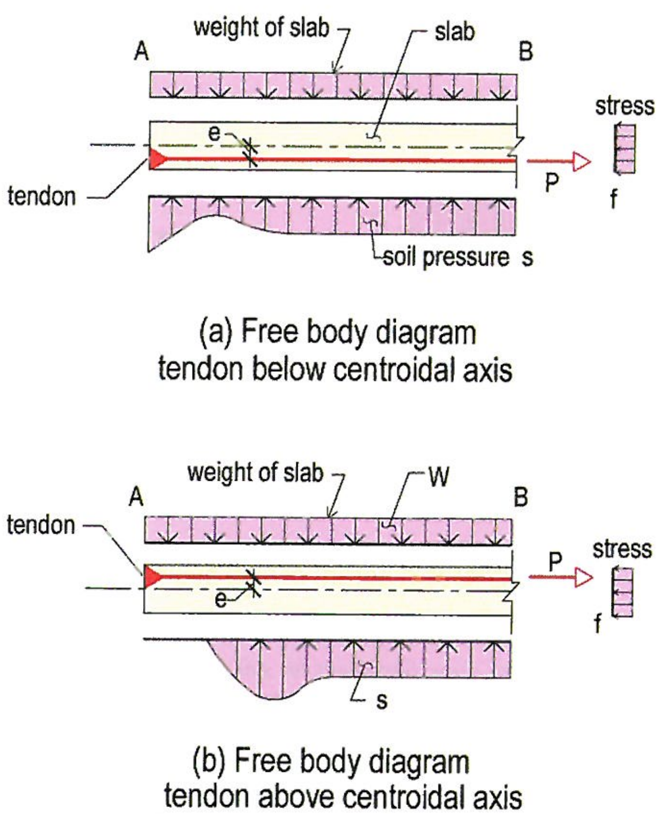

Fig C.5-1—Post-tensioned slab on flexible ground. The moment generated by the eccentric force P *at the slab edge changes the soil pressure below the slab, as illustrated in the figures. At regions away from the slab edge, the distribution of soil pressure remains unchanged. The axial force results in a uniform precompression in the slab.*

Because friction does not result in a change of the slab curvature, at Section B, the distribution of the stress from the balance of compression will be uniform. This is explained in the following.

In Fig. C.6-1, the net force at Section B is the difference between the applied force P at the slab edge and the friction force F, accumulated from the slab edge to Section B. Because friction does not result in a change of the slab curvature, at Section B, the distribution of the stress from the balance of compression will be uniform.

Figure C.6.2(c) shows the force diagram of a segment of a ground-supported slab with friction, where the friction has not fully exhausted the precompression from the axial force P. The actions in the slab at the Section B are the shear force V, axial force N, and moment M. The governing force relationships are

$$N = P - F \qquad \text{(Exp. 6.2-1)}$$

The net axial force N at Section B results in a uniform compressive stress f (part b-ii).

$$V = W - S \qquad \text{(Exp. 6.2-2)}$$

where W is the total weight of the slab segment; and S is the total reaction of the soil on the slab segment.

Taking moments about a point at Section B gives

$$Fh/2 + S(x/2 - d) = Wx/2 \qquad \text{(Exp. 6.2-3)}$$

C.7 EFFECTS OF SHRINKAGE

A post-tensioned ground-supported slab continues to shrink after application of the post-tensioning force—initially at a higher rate, and then at a reduced rate with time. This shrinkage is due both to loss of water through evaporation and to the chemical action between the cement and the mix water. Friction at the slab-soil interface will resist the slab shortening caused by shrinkage as shown in Fig. C.6.7-1(a); the friction will be balanced by internal tensile force N in the slab. If the precompression from the post-tensioning is not enough to counteract the tensile stresses, there can be cracking through the depth of the slab.

The shrinkage will result in a modification of the soil pressure s from the slab weight w as idealized in part

(b) of the figure. As with the friction generated from the externally applied load (Section C.6), the moment in the slab from the friction force F is balanced by the change in distribution of soil pressure s. It is important to note that shrinkage will not result in bending stresses in the slab—because the slab remains in contact with the soil, and the profile of the soil is assumed unchanged. No moment at the slab sections is generated.

In the preceding discussion, it is assumed that the shrinkage strain will be uniform through the depth of the slab. In practice, the shrinkage will be greater on the top surface of the slab due to evaporation. This can result in curling of the slab at its edges, somewhat like the slab response shown in Fig. C.4-2. However, away from the

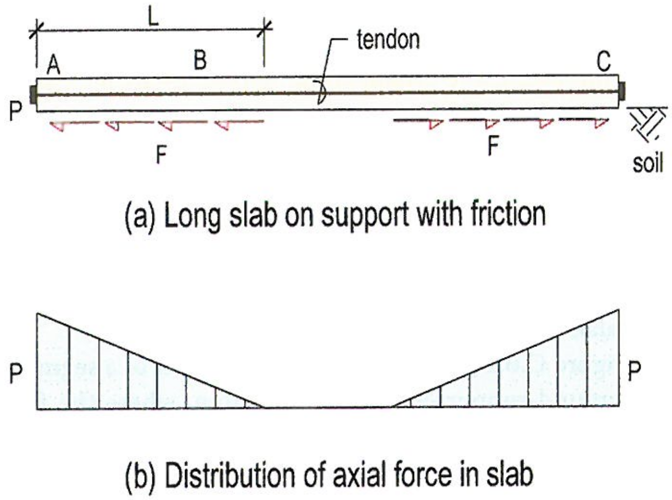

Fig. C.6-1—Axially loaded ground-supported slab with friction. Friction F reduces the precompression in the slab. If the slab is long enough, at a distance L from the stressing end, the axial precompression will be completely dissipated.

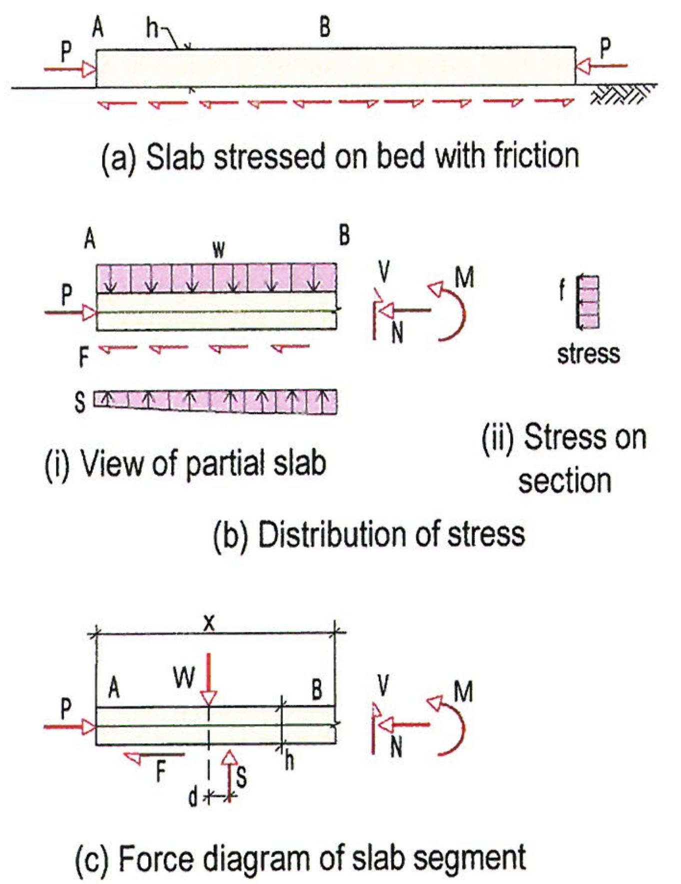

Fig. C.6-2—Force diagram of axially loaded slab supported on ground with friction.The axial compression in slab N is reduced by the friction force F. The moment caused by the axial force P and the friction force F is counteracted by a shift d in the centroid of the soil pressure S. The demand moment M shown at section B will be zero.

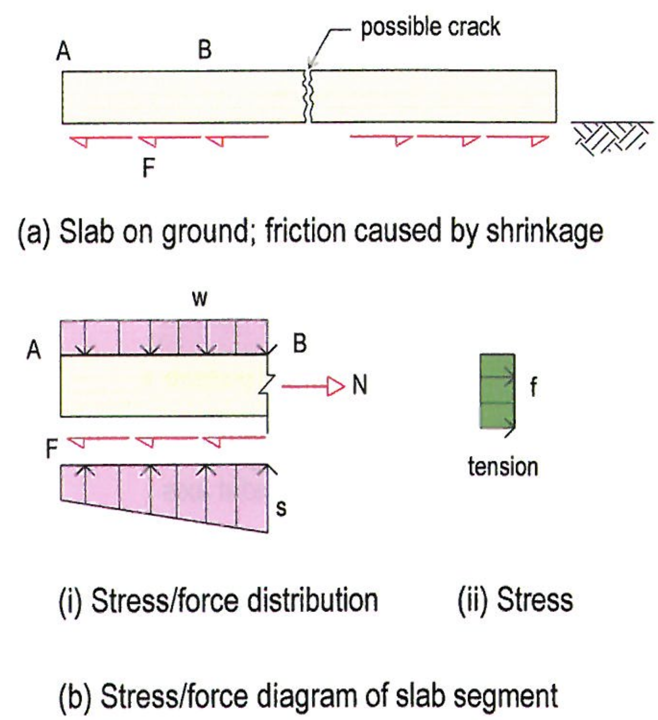

Fig. C.7-1—Force and stresses from shrinkage and friction on ground-supported slabs. Shrinkage for slab on a rough surface will be resisted by a friction force F at the slab-soil interface; an equivalent tensile force N develops in the slab because the shrinkage is restrained. The tensile force will result in a uniform tensile stress on the slab section because the curvature of the ground support remains unchanged. Because forces F and N are not collinear, there will be a moment which for equilibrium of the system results in a change in the otherwise uniform distribution of soil pressure s in part (b) (i) of the figure. Cracking through the depth of the slab can occur if the tensile stress f from friction is greater than the sum of the tensile strength of the concrete and compressive stresses from other sources.

slab edges, the slab will remain in contact with the soil, and there will be no moment in the slab.

C.8 EFFECTS OF CREEP

When an unrestrained member is subjected to an axial compressive load, there will be an immediate elastic shortening, as shown in Fig. C.8-1(a). The member will also continue to shorten with time under the load. This additional shortening, referred to as creep, can be two to three times the initial shortening. If the axial force in the slab is from post-tensioning, the creep shortening reduces the precompression in the slab because there is a corresponding decrease in the tendon's elongation. The decrease in precompression due to creep is typically around 4% of the initial precompression in the slab.

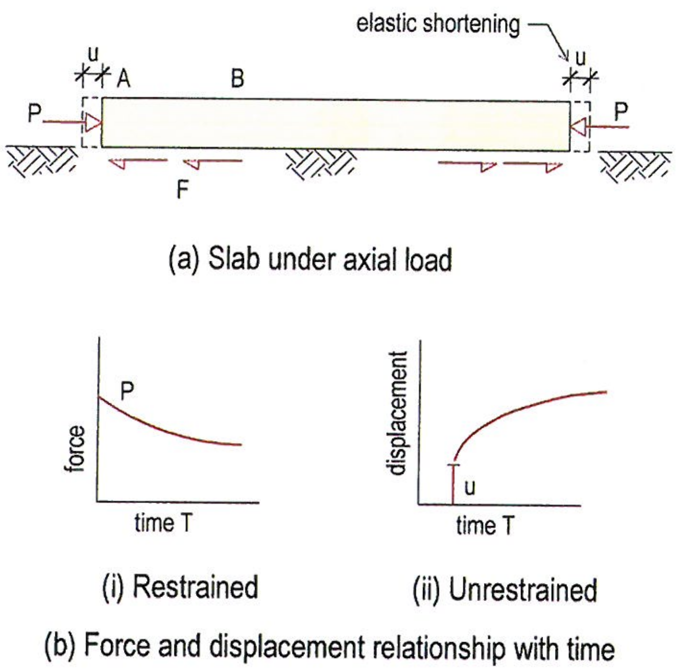

Fig. C.8-1—Creep in axially loaded ground-supported slab. Under an axial load, the slab will continue to shorten due to creep of the concrete.

The design of a post-tensioned ground-supported slab must account for creep, as well as shrinkage and friction. While each of these phenomena will generally have some impact on the slab's response to the other two, in common engineering practice they are accounted for separately and the effects are superimposed. Creep does not alter the distribution of the precompression from post-tensioning because the slab retains its contact with the supporting soil and the supporting soil does not change its profile (curvature).

C.9 CHANGE IN TENDON PROFILE ALONG THE MEMBER LENGTH

Figure C.9-1 shows a schematic of a two-span elevated slab with the typical profile of a post-tensioning tendon. Common North American engineering practice is to specify a tendon force and profile that will balance 75 to 80% of the self-weight of the slab. As long as the uplift from the post-tensioning does not exceed the weight of the slab, the slab will not separate from the forms. The stressing will cause the slab to shorten and will change the distribution of the stress applied to the form, but will not generate any bending moment in the slab because the slab will remain supported over its length, and the forms are assumed rigid enough not to deform at stressing. Because there is no bending moment, the slab will be subject to a uniform compressive stress from the post-tensioning. Likewise, a change in the tendon profile along the length in a ground-supported slab, whether by design or unintentional, is unlikely to overcome the slab's self-weight. As long as the slab remains in contact with the supporting soil, and the supporting soil does not deform as a result of deviations in tendon profile, there will be no bending moment in the slab and the distribution of the precompression from the post-tensioning will be uniform.

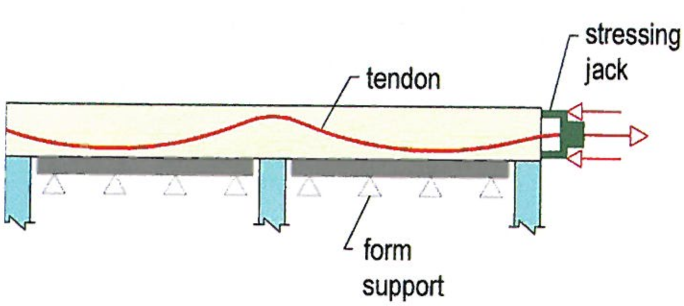

Fig. C.9-1—Slab on support with profiled tendon.

C.10 RIBBED SLABS

In some parts of the United States, it is common practice to divide a ground-supported slab into roughly square segments with intersecting ribs. Figure C.10-1 shows two examples of such slabs—one with a drain sand layer above the moisture barrier. The tendons that align with the ribs are generally anchored at the middepth of the slab and then profiled to run along the bottom of the rib, as shown in Fig. C.10-2(a).

Before the tendons are stressed, the soil pressure will be equal and opposite to the weight *w* of the slab. When the tendons are stressed, the up and down forces caused by the tendon profile will modify the distribution of soil pressure as idealized in part (c) of the figure. In the idealization shown, the tendon profile is assumed to be made up of parabolic segments. Segment AC will create a downward force that will increase the soil pressure. This is followed by a reduction in soil pressure from the upward force of the tendon over Segment CD. There is no change in the soil pressure between the inflection points at the bottom of the slab (Point D); between these inflection points, the tendon is laid straight. The straight portion of tendon beyond the inflexion point D does not change the soil pressure.

(a) Slab with drain sand over moisture barrier.

(b) Ribbed slab ready to receive concrete.

Fig. C.10-1—Ground-supported slabs with interior beams.

At Section B, the moment generated by the couple P is balanced by the moment created by the variations in soil pressure between A and D. Because there is no change

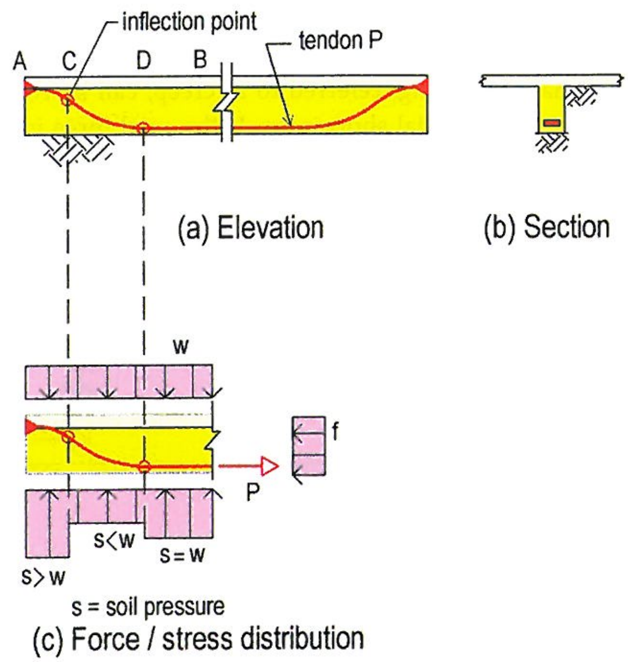

Fig. C.10-2—Ribbed ground-supported slab. The tendon profile and force result in a modification of the otherwise uniform soil pressure s. *The resulting nonuniform soil pressure will balance the moment from tendon profile, leading to a uniform compression stress* f *on the ribbed slab section at B.*

Fig. C.10-3—Ground-supported waffle slab construction. (courtesy CONCO) in the member's curvature at Point B, there will be no moment at this section. The force on the concrete section acts at the centroid of the section, resulting in a uniform distribution of compression.

A variation of the ribbed slab construction is the waffle slab shown in Fig. C.10-3, where the tendons in both directions are straight and placed at the middepth of the topping slab. In this configuration, too, the tendons result in a uniform compression in the slab away from the anchors.

C.11 UNINTENDED VARIATIONS IN SLAB THICKNESS

Investigation of an allegedly defective ground-supported slab will often include measuring the slab thickness at various locations and comparing the measurements to the design values. Due to the rough and irregular nature of the soil support in typical building construction (Fig. C.11-1), along with the fact that slab is relatively thin, there may be relatively significant variations in the slab's thickness. A change in thickness from the value shown on the structural drawings will cause the tendons to have an eccentricity that is different from what is specified by design. However, as discussed in Section C.4, the distribution of the precompression in the slab is not a function of the tendon eccentricity; the precompression will be uniform away from the slab edges.

In other words, local variations in slab thickness do not change the function of prestressing in resulting to a uniform precompression. The magnitude of the uniform precompression will depend on the slab thickness.

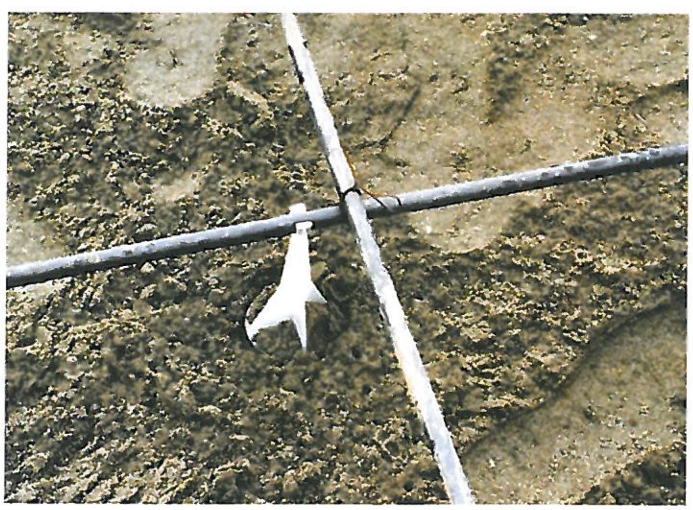

Fig. C.11-1—Close view of a ground-supported slab in building construction ready to receive concrete.

C.12 CONCENTRATED LOADS

Industrial slabs in warehouses and factories are typically subjected to concentrated loads from forklift wheels and storage rack supports (Fig. C.12-1). These slabs must be designed to avoid large tensile stresses at the bottom of the slab under these loads. Often these slabs are post-tensioned because the precompression provided by post-tensioning helps to offset the tensile stresses from the applied loads (Fig. C.12-2).

The concentrated load will result in a local bending moment in the slab; the bending moment will be reflected in a local change in the slab's curvature and bending stresses that are superimposed on the uniform precompression from the tendons. The assumption of uniform precompression is based on the premise that the change in the slab's

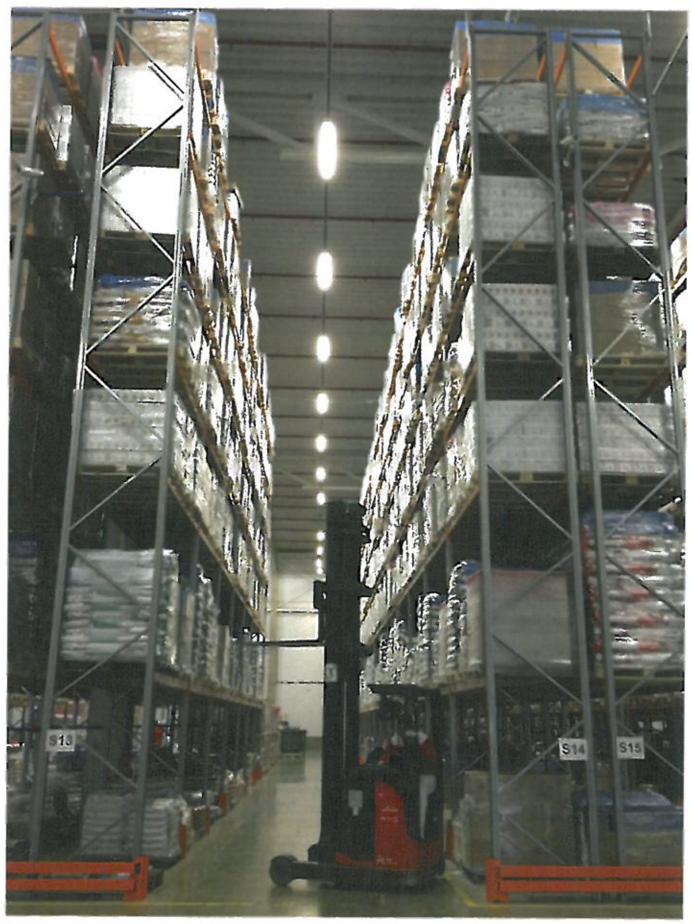

Fig. C.12-1—Post-tensioned ground-supported slab in warehouse. (Moscow P823) The slab is subject to concentrated loads from the legs of storage stacks and the wheels of forklift trucks. The post-tensioning provides a uniform precompression that helps to mitigate cracking under these loads.

radius of curvature R below the concentrated load is strictly the result of, and restricted to, the added load.

Although the position of the tendon plays an important role when designing for safety, ground-supported slabs are typically only designed for service conditions. When designing to control service stresses and prevent cracking, there is no advantage to placing the post-tensioning tendons below the slab centroid. A straight tendon will provide uniform precompression under the concentrated load, regardless of its position in the slab. Thus, the common practice of placing the tendon at the slab centroid, without any profile, is appropriate, as it provides good cover over the tendons. The increase in soil pressure under the applied load (part (a)) results in local bending of the slab and associated bending stresses (part (b)-(i)). However, the post-tensioning results in a uniform compressive stress across the section, irrespective of the tendon's position in slab (part (b)-(ii)).

C.13 CONCLUDING REMARKS

This article reviews the distribution of stresses in post-tensioned, ground-supported slabs for common scenarios, including eccentric tendons, friction, shrinkage, creep, the addition of ribs, changes in slab thickness, and concentrated loads. It is shown that for the conditions considered, the post-tensioning results in uniform compression at locations away from the slab edges. The compression offsets the tensile stresses caused by other effects, thus reducing the potential for crack formation.

Commercially available software can calculate stresses in ground-supported slabs using a three-dimensional representation of the slab and its support. However, this article demonstrates that the engineer's common beam formula, based on the Euler-Bernoulli assumption of plane sections remaining plane, can be used to determine the distribution of stresses resulting from post-tensioning.

By providing the background to the distribution of stresses in ground-supported slabs under various loading and support conditions, the article will help design engineers evaluate the solutions from commercially available software.

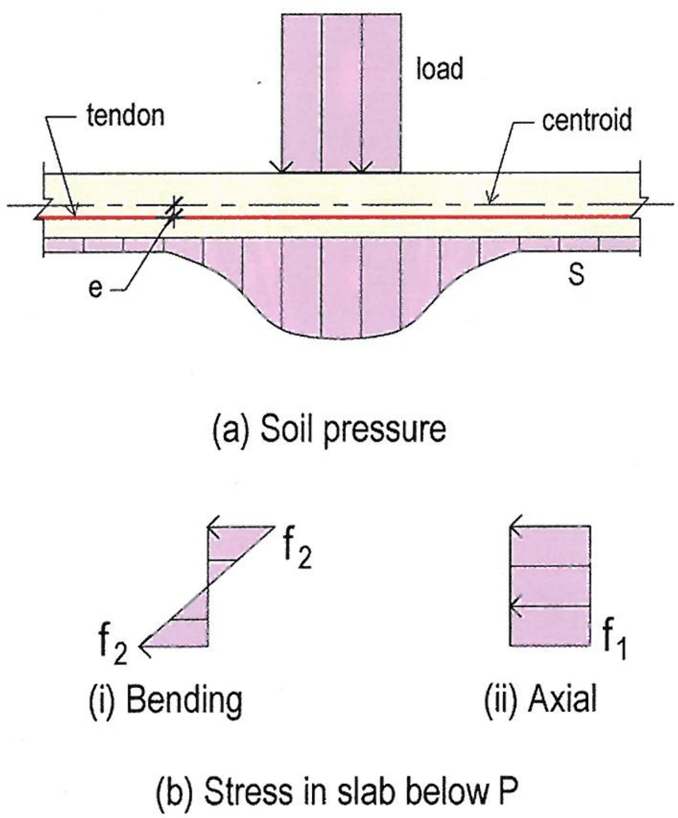

Fig. C.12-2—Distribution of stress in ground-supported slab under a concentrated load.

C.14 REFERENCES

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Bijan Aalami *is Professor Emeritus, San Francisco State University; Principal, ADAPT Corporation. He has been involved in the design and observation of post-tensioned projects in more than 35 countries for the past 30 years. He is a PTI Lifetime Member, Legend, and Fellow.*