PDHonline Course S132 (1 PDH)

Slab-on-Grade Reinforcing Design

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2020

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Materials:

The most common reinforcement associated with slabs-on-grade is welded wire fabric. However, this is not the only means of reinforcing slabs. In some cases deformed bars are used in order to assure that the reinforcement is placed at the correct depth within the slab and not damaged during placement. In either case when using deformed bars or welded wire fabric, it is essential that adequate support of the steel is provided.

Source: eHow.com

Welded Wire Fabric:

When using welded wire fabric, prefabricated sheets should be used in lieu of rolled fabric in order to help assure proper location of the steel within the concrete. In either case a minimum of one chair per 25 square feet of mesh should be used to adequately support the reinforcement above the sub-grade. The table provided in this slide lists common styles of welded wire fabric, including the "old" and "new" designations. Although the "new" designations are more than 20 years old, many engineers find this cross-reference helpful.

Common Styles of Welded Wire Fabric

Style Designation		Steel Area Sq. in. per ft.		Weight Lbs. per 100 SF
New Designation (by W-number)	Old Designation (by steel wire gauge)	Longitudinal	Transverse	
ROLLS				
6x6-W1.4xW1.4	6x6-10x10	.028	.028	21
6x6-W2.0xW2.0	6x6-8x8*	.040	.040	29
6x6-W2.9xW2.9	6x6-6x6	.058	.058	42
6x6-W4.0xW4.0	6x6-4x4	.080	.080	58
4x4-W1.4xW1.4	4x4-10x10	.042	.042	31
4x4-W2.0xW2.0	4x4-8x8*	.060	.060	43
4x4-W2.9xW2.9	4x4-6x6	.087	.087	62
4x4-W4.0xW4.0	4x4-4x4	.120	.120	85
SHEETS				
6x6-W2.9xW2.9	6x6-6x6	.058	.058	42
6x6-W4.0xW4.0	6x6-4x4	.080	.080	58
6x6-W5.5xW5.5	6x6-2x2**	.110	.110	80
4x4-W4.0xW4.0	4x4-4x4	.120	.120	85

* Exact W-Number size for 8 gauge is W2.1.
** Exact W-Number size for 2 gauge is W5.4

Deformed Bars:

The most common bar sizes encountered when using deformed reinforcement for typical lightly loaded slabs are #4 and #5 bars. However, it is recommended that #5 bars be used as a minimum as bars of smaller diameter are much more susceptible to damage due to foot traffic during the placing operation.

Source: John Rohrer Contracting Company

Post-Tensioning Tendons:

Post-tensioning is very popular for slab-on-grade construction in some areas of the country. This is especially true for super-flat industrial floors and areas susceptible to expansive soil. The most common post-tensioning material is half-inch diameter 270k prestressing strand. The strand is generally greased and encapsulated in an extruded plastic sheathing. Post-tensioning pre-compresses the concrete, which in turn helps to control shrinkage cracking allowing for greater distances between joints.

Source: Metzger Testing and Inspection

Fiber Reinforcement:

Synthetic fiberglass and steel fibers can also help to control plastic shrinkage cracking and limit the size of cracks when used according to the manufacturer's recommendations. However, currently there is no data indicating that the use of such fibers allows for an increase in joint spacing. In addition, currently ACI does not recognize fiber reinforcement as an acceptable substitute for conventional reinforcement. In addition, fiberglass fibers can sometimes protrude from the finish surface of the slab giving the concrete a "hairy" appearance.

Steel Fibers
Source: Concrete Construction

Subgrade Drag Procedure:

For most commercial and industrial floors, joint spacing is dictated by the location of columns or racks within the structure. This spacing may or may not coincide with the desired joint spacing of an unreinforced concrete slab. With some limitations, reinforcement for slabs can be sized using the Subgrade Drag Theory in order to increase the spacing of control or construction joints. The result is a lightly reinforced slab designed to offset the effects of temperature and shrinkage of the concrete.

ACI 360, "Design of Slabs-on-Grade", refers to this as a Type B slab. The Wire Reinforcing Institute recommends the use of the Subgrade Drag Theory for slabs up to 150 feet in length. However, with the relatively low percentage of steel provided by this method, it is recommended that only slabs whose joint spacing are within the range shown in Table 1 in the next slide should be reinforced using the Subgrade Drag Theory.

Longer strips of slabs than that indicated in the Table 1 can be placed, however, shrinkage cracks are more likely to occur. Additional reinforcing steel will help control the crack widths and supplement aggregate interlock, but random cracking is very likely to occur. Other calculation methods should be considered when determining reinforcing for joint spacing greater than that indicated in Table 1.

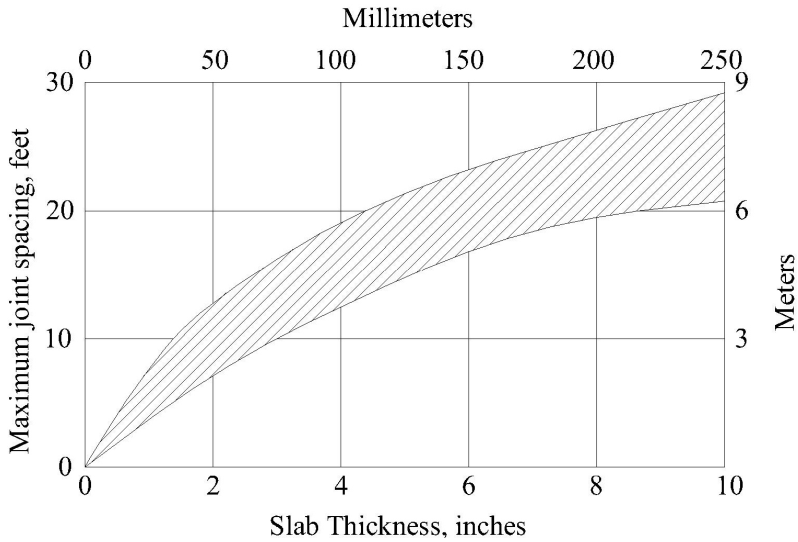


Table 1

The Subgrade Drag equation is frequently used to determine the amount of non-prestressed reinforcement required within the joint spacing distance L. This method does not apply to prestressing or the use of fibers.

The Subgrade Drag equation is as follows:

$$\mathbf{A_s = (FLW)/(2f_s)}$$

Where: **A_s** = cross-sectional area in square inches of steel per lineal foot of slab width

F = friction factor

L = distance in feet between joints

(the distance between the free ends of the slab that can move due to shrinkage contraction or thermal expansion).

W = dead weight of the slab (psf).

f_s = allowable working stress of the reinforcement (psi).

The 2 in the denominator is not a safety factor. It is based on the theory that the slab panel will move an equal distance from each end toward the center. This may not always be the situation (see the definition of L). F, the friction factor, can vary from 0.5 or greater. A value of 1.5 should be used as an average when accurate information is not available

Alternative Design Procedures:

There are two other rational procedures for selecting steel percentages for slabs-on-grade. One is based on temperature, and the other is based on the concrete-to-steel strength ratio. Both of these procedures will often produce slightly higher values than the Subgrade Drag procedure, however, these alternate methods do assure superior crack control. The Temperature method for determining reinforcement is:

$$A_s = (f_r(12)t)/(2(f_s - T\propto E_s)$$

Where:
- A_s = cross-sectional area in square inches of steel per lineal foot of slab width
- **t** = thickness of slab in inches
- f_r = tensile strength of concrete (psi) = 0.4 x Modulus of Rupture
- f_s = allowable working stress of the reinforcement (psi)
- **T =** range of temperature the slab is expected to be subjected to (F°)
- $\propto$ = thermal coefficient of concrete (in/in F°)
- E_s = modulus of elasticity of steel (psi)

The normal range of the coefficient of thermal expansion of concrete ($\propto$) is 5 to 7 x 10^{-6}. The modulus of elasticity (E_s) of reinforcing bars is generally taken as 29 x 10^6 psi. Interior floor slabs are usually not subjected to the same severe temperature gradients experienced by outside pavements. Therefore it is reasonable to design for the maximum temperature range that the slab will experience during its service life. However, even interior climate controlled spaces can experience temperature ranges of 40° to 60°F.

The second alternate procedure for determining reinforcement is the computation of the percent of steel necessary to complement the tensile strength of the concrete. The steel is calculated based on a value of 75% of the yield strength of the reinforcing, and the value of the tensile strength of the concrete, which is taken as 0.4 times the modulus of rupture (MOR). This method produces a significantly higher percentage of steel than the other two methods described. The modulus of rupture of concrete can be realistically taken as 7.5 $\sqrt{f'_c}$. This results in the following formula:

$$A_s = (36\sqrt{f'_c}t)/ f_s$$

Where:
- A_s = cross-sectional area in square inches of steel per lineal foot of slab width
- **t** = thickness of slab in inches
- f'_c = strength of concrete (psi)
- f_s = allowable working stress of the reinforcement (psi)

It is recommended that the merits of using the methods which require greater percentages of steel than that determined by the Subgrade Drag formula be considered, particularly for industrial floor applications where the control of random cracking is critical.

Steel Placement:

When the Subgrade Drag formula is used for steel design, the recommendation for concrete cover above the reinforcing is two inches below the top of the slab. However, it is reasonable to allow for an envelope of steel placement ranging from two inches below the top of the slab to the center of the slab. Placing the steel any lower than this limit could, however, adversely affect the performance of the slab.

For most conventional slab-on-grade design, the steel does not have to be discontinuous at the contraction or sawn control joints. However, in cold storage facilities it is recommended that the reinforcing be discontinuous at all control joints. In industrial facilities in areas subjected to random and repeated heavy forktruck wheel traffic it is also recommended that dowel baskets be used at the sawn control joint locations to help supplement the load transfer capability of the controlled crack location. This is particularly true if the slab is unreinforced and only capable of transferring vertical loads across the control joint via aggregate interlock.

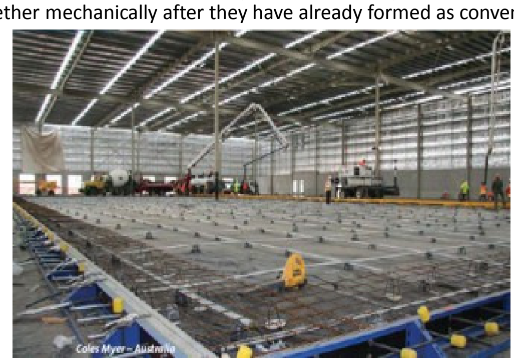
Dowel Basket
Source: Illinois DOT

Post-Tensioned Industrial Floors:

The advantages of post-tensioning for industrial floors are:

1. Less concrete, i.e. reduced slab thickness.
2. Reduction or elimination of random cracks.
3. Substantial reduction in joints, i.e. increased spacing of joints.

Post-tensioning is an active rather than passive form of reinforcing. In other words, post-tensioning pre-compresses the concrete to help prevent cracking from occurring rather than holding cracks together mechanically after they have already formed as conventional reinforcing does.



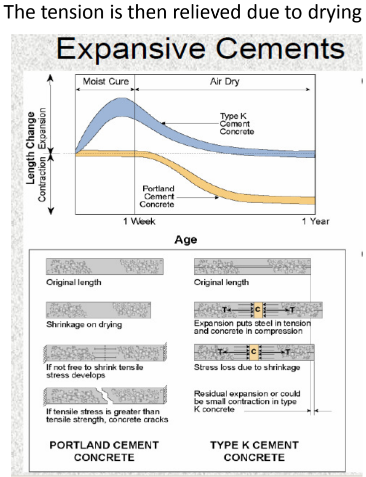
Source: VSL

Post-tensioned slabs are generally designed to have a residual pre-compression stress of 50 psi to 150 psi. This generally results in half-inch diameter 270k tendons spaced between 24 inches to 48 inches on center. Tendons are typically placed at the center of the slab to avoid any stresses that might be induced by the eccentricity of the strands relative to the concrete cross section. Post-tensioning tendons are usually seven-wire strand, with a cross-sectional area of 0.153 square inches. It is recommended that a continuous slip-sheet beneath the bottom of the slab and the subgrade be used to reduce drag as a result of movement of the slab due to the pre-compression induced by the post-tensioning force. Coefficients of friction can be kept at or below 0.5 with the use of either a single or double layer polyethylene slip-sheet membrane. When designing the thickness of a post-tensioned slab, it is recommended that standard PCA and WRI methods be used.

Source: JWK Inspections

Shrinkage Compensating Concrete Slabs:

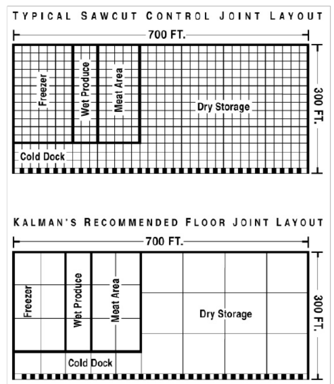
Shrinkage-compensating concrete (Type K cement) undergoes an early age expansion and then undergoes drying shrinkage similar to conventional concrete. However, the net result is the apparent lack of any shrinkage of the concrete once the material has cured. Bonded reinforcement is essential for this type of slab. The reinforcement is placed in tension during the initial concrete expansion. The tension is then relieved due to drying shrinkage and long term creep of the concrete.



Source: University of Berkeley, CA

The purpose of shrinkage-compensating concrete is to limit cracking and minimize joint spacing. Shrinkage compensating concrete permits slab panel sizes up to 15,000 square feet. More manageable sizes such as 50 x 50 feet (2,500 square feet) are more commonplace. Reinforcing steel for shrinkage compensating concrete ranges from 0.15 percent to 0.6 percent of the gross cross-sectional area of concrete, however, lower values have been known to perform successfully. In either case, the reinforcing should be placed in the upper third of the slab.

It is recommended that designers using this product familiarize themselves with ACI 223 "Standard Practice for the Use of Shrinkage-Compensating Concrete." It is also advisable to seek the assistance of a shrinkage compensating cement supplier and contractor familiar with this type of product prior to designing and detailing a project using Type K cement.



Source: Kalman Floor Company

Structurally Reinforced Slabs:

One additional use of reinforcing in slab-on-grades is to allow for a reduced slab thickness, even though as it is expected in the following example, hairline cracks due to loading will occur. The following example is taken from "Designing Floor Slabs-on-Grade," Boyd C. Ringo, Robert B. Anderson (Aberdeen Group, 1992).

Example:

Provide a maximum slab thickness of 8 inches. Strength will be provided with reinforcing steel selected to provide a safety factor of two.

- Actual moment = 5,700 ft. lb. per foot of slab width
- Concrete compressive strength - 4,000 psi
- MOR = 570
- Cracking moment; M_{cr} = ((bd^2)/6) x (MOR/12)
- M_{cr} = 6,080 ft.-lb. per foot of slab width
- Moment required for a safety factor of 2; 5,700 x 2 = 11,400 ft.-lb. per foot of slab width.
- One possible solution is the use of one layer of #6 bars. Table 2 provided in the next slide shows that the moment capacity per foot of width is 7.13 ft.-kips if the #6 bars are spaced at 12 inches. It is necessary to adjust this to a closer spacing since the 12-inch spacing does not provide enough moment capacity.
- Spacing = 12 (7.13/11.4) = 7.505 inches
- Use one layer of number six bars at 7½ inches one center

Slab Moment Capacities for One or Two Layers of Rebar at 12-Inch Spacing

Slab Thickness		8-in						10-in					
		#3	#4	#5	#6	#7	#8	#3	#4	#5	#6	#7	#8
Number of Layers	A_s (in^2)	0.11	0.20	0.31	0.44	0.60	0.79	0.11	0.20	0.31	0.44	0.60	0.79
	d_t (in)	0.38	0.50	0.63	0.75	0.88	1.00	0.38	0.50	0.63	0.75	0.88	1.00
ONE	d (in)	4.00	4.00	4.00	4.00	4.00	4.00	5.00	5.00	5.00	5.00	5.00	5.00
	resulting cover (in.)	3.63	3.50	3.38	3.25	3.13	3.00	4.63	4.50	4.38	4.25	4.13	4.00
	M_u (ft-k/ft)	1.78	3.24	5.02	7.13	9.72	12.80	2.23	4.05	6.28	8.91	12.15	16.00
	P (%)	0.11	0.21	0.32	0.46	0.62	0.82	0.09	0.17	0.26	0.37	0.50	0.66
	wgt (psf)	0.75	1.37	2.12	3.01	4.10	5.40	0.75	1.37	2.12	3.01	4.10	5.40
TWO	d (in)	6.38	6.25	6.13	6.00	5.88	5.75	8.38	8.25	8.13	8.00	7.88	7.75
	M_u (ft-k/ft)	2.84	5.06	7.69	10.69	14.28	18.40	3.73	6.68	10.20	14.26	19.14	24.80
	P (%)	0.23	0.42	0.65	0.92	1.25	1.65	0.18	0.33	0.52	0.73	1.00	1.32
	wgt (psf)	1.50	2.73	4.24	6.01	8.20	10.79	1.50	2.73	4.24	6.01	8.20	10.79

Notes:

1. f'c = 400 psi, cover=1.25 in, b=12in, Φ=0.90
2. Design Assumptions made in Table

	One Layer	Two Layers
d	t/2	t*(cover+d_t)
$J_m d$	0.9d	
M_u	$\Phi A_s f_y (j_m d)$	

3. Percentage of Reinforcement based on gross section b x t
4. Slab moment capacities (resistance) in foot-kips per foot of slab width, using either one or two layers of reinforcing bars.

TABLE 2

Unreinforced Slabs:

Unreinforced, plain concrete slabs (i.e. slabs without distributed steel or structural reinforcement) offer advantages of economy as well as ease and speed of construction. There are many similarities between an unreinforced road pavement and a plain concrete floor slab. As in pavement design, the factors involved in determining the required floor thickness of an unreinforced slab include:

1. Sub-grade and sub-base bearing support.
2. Strength of concrete.
3. Slab edge condition.
4. Location and frequency of imposed loads.
5. Magnitude of load.

Table 3 provided below is the suggested spacing for control joints in plain unreinforced slab-on-grade recommended by "Concrete Floors on Ground" published by the PCA (The Portland Cement Association).

Slab Thickness	Spacing (ft.)		
	< ¾” Aggregate	> ¾” Aggregate	Slump < 4”
5”	10	13	15
6”	12	15	18
7”	14	18	21
8”	16	20	24
9”	18	23	27
10”	20	25	30

TABLE 3