A SunCam online continuing education course

Concrete Slabs-on-Grade:
From the Ground Up

by

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Course Outline:

SLABS-ON-GRADE: INTRODUCTION

Knowing the nature of concrete slabs-on-grade means knowing more than what its 28-day compressive strength should be. Mainly, slabs are a convenient barrier between the dirt and the first floor of a building. Problems in slabs are often a result of poor soil conditions beneath the slab, or cracking of the concrete due to concrete shrinkage. So, while knowledge of strength is important, it is just the beginning.

There are numerous resources available for gaining insight into slabs-on grade. These include industry guides, provisions, codes and articles, proprietary literature, and other educational material. With an interest in promoting the wise use and high performance of concrete, the American Concrete Institute (ACI) has produced a family of guides on concrete design and construction. Three that are excellent resources for designing and specifying concrete slab-on grade are:

1) "ACI 301 – Specifications for Structural Concrete"
2) "ACI 302.1 – Guide for Concrete Floor and Slab Construction", and
3) "ACI 360 – Design of Slabs-On-Ground"

Therein, most of the characteristics and behavior of concrete slabs con be found. This course highlights some of the more salient topics on slabs on grade to practicing engineers.

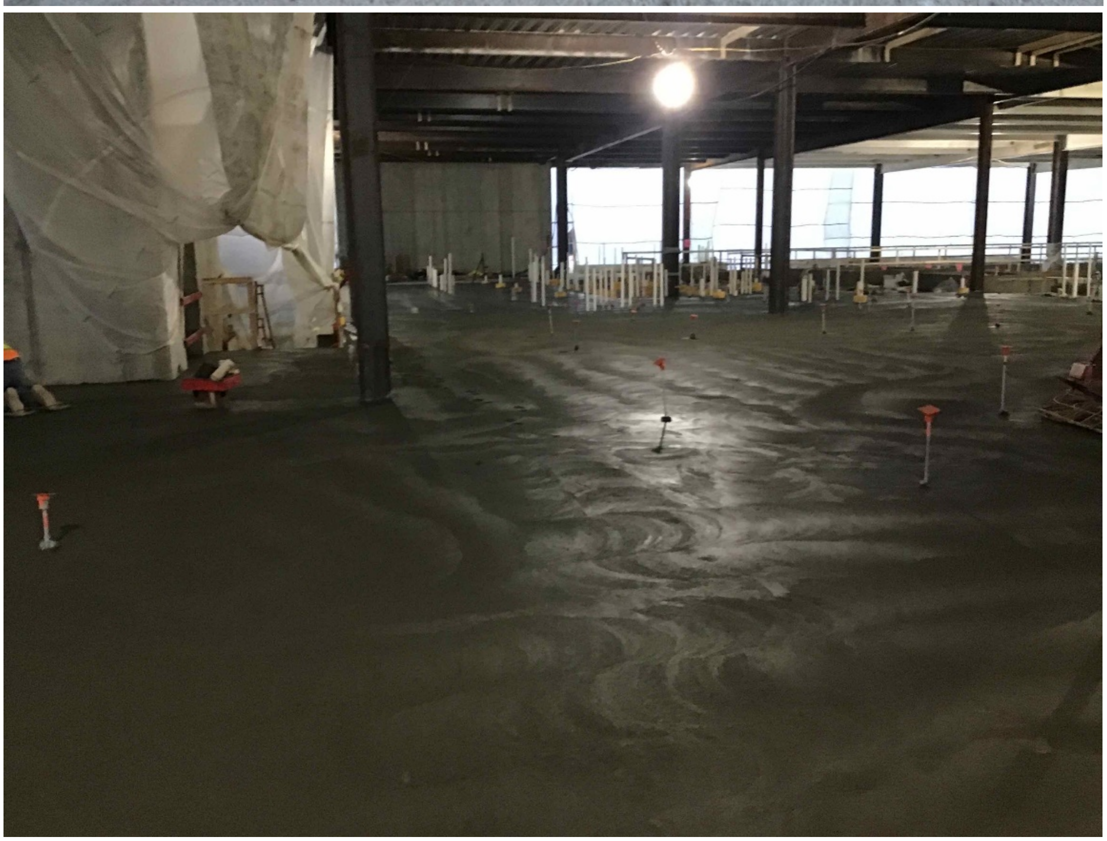

Fig. 1 –Slabs-on-grade (including previous page) – Top to bottom: Crack in new slab, Bird on broom-finished sidewalk, Troweled concrete slab prior to sawcuts

Fig. 2 – Slab-on-grade being poured for a freezer warehouse, with optional reinforcing

Types of Slabs

Slabs-on-grade, or slabs-on ground, are areas of concrete poured on the ground for things such as pavement, parking lots, and building floors. See Figs. 1 and 2. This course will focus mainly on interior slabs-on-grade for typical buildings. A future course will then move to more specific options and design methods for industrial facilities. Slabs for interior spaces are used to provide a solid surface on which to perform the activities of the building on the ground floor. Removing the performance of the slab from the list of potential problems for an owner is a priority. The goal should be for the slab design to meet the required performance, but not more than necessary, so that the most economical solution is achieved.

There are many types of slabs to consider, as noted in Fig. 3. Slabs can be broken down into several categories:

1) Unreinforced slabs
2) Slabs with fiber reinforcing
3) Slabs with steel bar or wire reinforcing (rebar or welded wire fabric)
4) Slabs with specialized reinforcing and/or cement for a specific crack-prevention strategy such as:
    a. Shrinkage compensating concrete
    b. Post-tensioned concrete
5) Structural slabs, which support building loads above them, or are supported in the final service condition by some other means than the ground directly

Note that this course addresses slabs-on-grade that are supported by the subgrade only. Some slabs-on-grade are poured on rigid insulation in freezers. Also, for some poor soils the ground is too loose to build on, but some of these can stiffened by the use of rammed aggregate piers, which are closely spaced columns of gravel and rock that are pounded down to put the ground in a more dense, compressive state.

Slabs on sites with poor soils that are prone to undue settlement or heave are designed to span as structural slabs between load-bearing structural components in the soil matrix. These are not explored in detail in this course. Some examples:

1) For sites with anticipated settlement issues, structural slabs may be poured on formwork that spans between steel, concrete or wood piles bearing on stable soils below. The ground can settle while the slab stays supported and in place.
2) For sites cases with extremely expansive clays, structural slabs may be poured on crushable, wax-impregnated void forms that hold up to the weight and activity of concrete pours, but degrade from moisture over time. If the soil heaves, it crushes the void forms. The concrete slab ends up spanning structurally between concrete piers or caissons, which are concrete columns poured into holes in the ground, and extend to more stable soils deep in the soil profile.

Table 2.1—General comparison of slab types

Slab type	Advantages	Disadvantages
Unreinforced concrete	• Simple to construct • Generally costs less to install than slabs designed by other methods	• Requires relatively closely spaced sawcut contraction joints • More opportunity for slab curl and joint deterioration • Large number of joints to maintain • Positive load transfer may be required at joints • Flatness and levelness may decrease over time
Reinforced with deformed bars or welded wire reinforcement sheets for crack width control	• Sawcut contraction joint spacing may be further apart than an unreinforced slab • Reinforcement is used to limit crack width • May reduce the long-term loss of flatness and levelness if reinforcement is continuous through the joints	• May have higher cost than an unreinforced slab • Reinforcement can actually increase the number of random cracks, particularly at wider joint spacings • More opportunity for slab curl and joint deterioration • Positive load transfer may be required at joints
Continuously reinforced	• Sawcut contract joints can be eliminated where sufficient reinforcement is used • Eliminates sawcut contraction joint maintenance. Curling is reduced to heavy reinforcement and elimination of joints • Changes to flatness and levelness are minimized	• Requires relatively heavy (at least 0.5%) continuous reinforcement placed near the top of the slab • Typically produces numerous, closely spaced, fine cracks (approximately 3 to 6 ft [0.9 to 1.8 m]) throughout slab
Shrinkage-compensating concrete	• Allows construction joint spacings of 40 to 150 ft (12 to 46 m). Sawcut contraction joints are normally not required • Reduces joint maintenance due to increased spacing of the joints reducing the total amount of joints and negligible curl at the joints • Increases surface durability and abrasion resistance (ACI 223, Section 2.5.7—Durability)	• Requires reinforcement to develop shrinkage compensation • Window of finishability is reduced • Allowance should be made for concrete to expand before drying shrinkage begins. Joints should be detailed for expansion • Contractor should have experience with this type of concrete
Post-tensioned	• Construction or sawcut contraction joint spacings 100 to 500 ft (30 to 150 m) • Most shrinkage cracks can be avoided • Eliminates sawcut contraction joints and their maintenance • Negligible slab curl if tendons are draped near joint ends • Improved long-term flatness and levelness • Decreased slab thickness or increased load capacity • Resilience against overloading • Advantages in poor soil conditions	• More demanding installation • Contractor should have experience with post-tensioning or employ a consultant with experience with post-tensioning • Inspection essential to ensure proper placement and stressing of tendons • Uneconomical for small areas • Need to detail floor penetrations and perimeter for movement • Impact of cutting tendons should be evaluated for post-construction penetrations
Steel fiber-reinforced concrete	• Increased resistance to impact and fatigue loadings when compared to slabs reinforced with bars or mesh • Simple to construct	• Concrete containing steel fibers may require adjustments to standard concrete mixing, placement, and finishing procedures • Some fibers will be exposed on the surface of the slab • Floors subjected to wet conditions may not be suitable candidates for steel fiber because fibers close to the surface and in water-permeable cracks will rust
Polymeric fiber-reinforced concrete	• Helps reduce plastic shrinkage cracking • Simple to construct • High-volume macropolymeric fibers provide increased resistance to impact and fatigue loadings, similar to steel fiber • Polymeric fibers do not corrode	• Micropolymeric fibers do not help in controlling drying shrinkage cracks • Joint spacing for micropolymeric fiber-reinforced slabs are the same as unreinforced slabs
Structural slabs reinforced for building code requirements	• Slabs can carry structural loads such as mezzanines • Sawcut contraction joints can be reduced or eliminated where sufficient reinforcement is used	• Slab design should comply with ACI 318 • Slab may have numerous fine or hairline cracks if reinforcement stresses are sufficiently low

Fig. 3 - Types of slab (ACI 301)

Subgrade, Sub-base, and Vapor Barrier

1) A typical slab profile is shown in Fig. 4. A base and subbase are not always required, but a subbase is typically present. The thickness of the layers are dependent on the characteristics of the in situ soil, the slab design parameters, and recommendations from the geotechnical engineer. These layers can help serve as capillary breaks to limit the seepage of water to the concrete, and they can aid in the distribution of load below the slab by increasing the stiffness and strength of the soil profile, as well as making it more uniform in its support. On muddy sites, wheeled traffic causes ruts, and it is difficult for machinery or workers to move around. Cement or lime is often mixed in with the subgrade to stabilize it during construction.

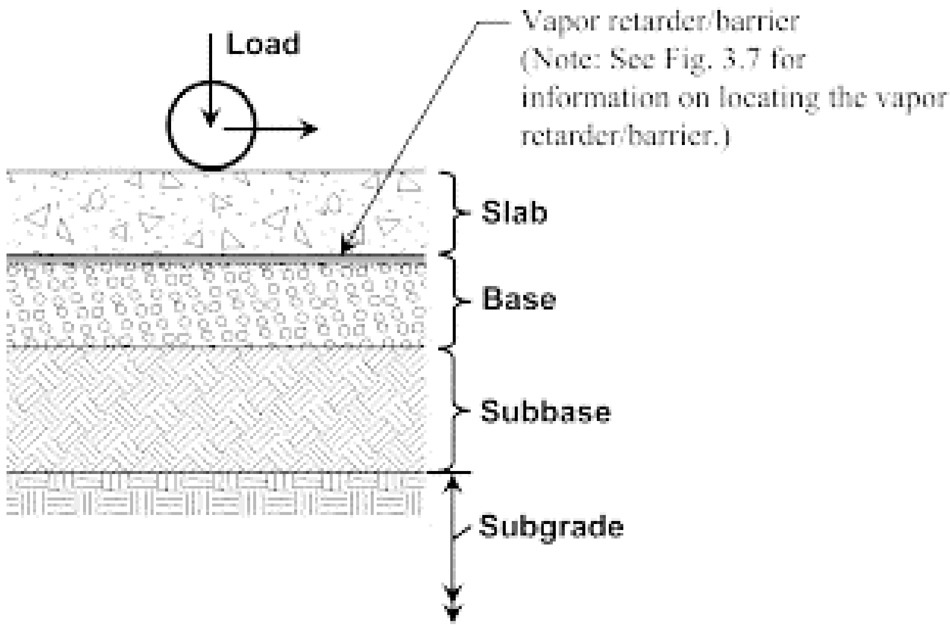

Fig. 4 – Slab-on-grade profile with soil– ACI 360

2) Establish an understanding of the proposed building requirements for the geotechnical engineer:
   a. Loads on Floor slab on grade, examples:
      i. Design uniform load (pounds per square foot)
      ii. Concentrated and Line loads (kips, kips per foot)
   b. Limit on total settlement or heave of foundations and slab

c. Limit on differential settlement or heave for building slab, example: 1/2 inches in 30 feet
d. Minimum stiffness of soil subgrade (known by subgrade modulus or coefficient of subgrade, kips per cubic inch)
e. Any required deep excavations

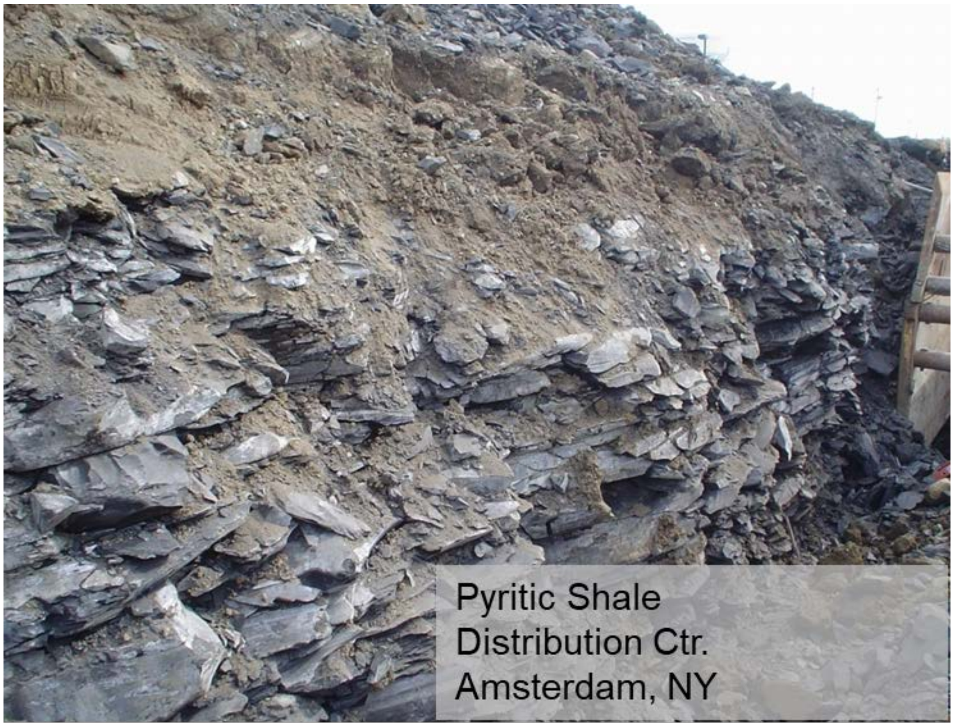

Fig. 5 - Removal of expansive shale in preparation for foundations and slab-on-grade

3) Establish with the geotechnical engineer and civil engineer the soil profile and characteristics at the proposed site.
   a. Soil suitability for short and long term loading
   b. Water table elevations – Seasonal and historic highs (see Fig. 6)
   c. Uniformity of soils across site (e.g., occasional rock outcroppings)
   d. Presence of organics, debris, etc.
   e. Presence of larger size rocks that may impact compaction or local uniformity of soil

f. Grading
    i. Site soil slopes; retaining walls required
    ii. Presence of unsuitable soil and what to replace it with
    iii. Cut vs. fill locations and anticipated settlements
    iv. Site vs. off-site spoils and fill – related costs
    v. Identify any surcharge requirements and duration
g. Compaction requirements for in-situ soil, fill, and sub-base
h. Sub-base type and thickness
i. Subgrade risks (Karst formations, Peat layers, etc.)
j. Any local knowledge that would be advantageous to know such as local issues with slabs in the region
k. Site soil remediation or stabilization recommendations (e.g., mixing lime or cement into the top layer of soil)
l. Construction issues – wheels rutting in the mud, etc.
m. Rock excavation required – what, where, how, and minimum thickness of fill above
n. Required minimum depth of bottom of footing for frost depth penetration
o. Expansive soils
p. Dessicant or collapsible soils
q. Utilities – old & new
r. Existing or abandoned buildings or foundations on site
s. Deep foundation solutions
t. Cost vs. risk studies if remedial action required
u. Settlement expectations (magnitude and expected timing of settlement to occur)
v. Seismicity & liquefaction – mitigation, shear wave testing
w. Corrosivity of soil with respect to metal pipe in ground and cements used in concrete.
x. Drain tile recommendations, especially for soils with rock and potentially percolating ground water

Fig. 6- Site groundwater – before and after de-watering – 2,700 gpm constant flow. High water table forced the owner's design team to use a mat foundation 5 feet thick to counteract the hydraulic pressure beneath the waterproofed basement.

4) Issues with site soils that have the potential to affect the slab-on-grade are extremely important to identify and discuss with the Architect, Contractor and Owner. Some examples of issues at buildings the author has been called to observe and address:
    a. Soils corroded underground fire loop piping around and below a distribution center over 1 million square feet in size. Massive amounts of water poured into the soil with each breach. This increase in moisture content lead to the activation of expansive clays in the soil matrix, and heaved the slab throughout the building. Being an industrial facility, the movement of the slab at slab joints is an on-going disruption for the operation of forklifts and pallet jacks.
    b. At a very large distribution center in an otherwise dry climate, rain water from heavy periodic thunderstorms seeped under a building over several decades. Soils have a compaction or settlement level that depends on moisture. The site soils on this site were very dry, and classified as dessicant or collapsible soils, meaning that the natural compacted state of the deeper soils was fairly loose. At original construction, these soils were only compacted at a shallow depth. So, with the historical lack of moisture in the deeper soils, the potential was always there for them to settle more with added moisture. With the introduction of rain water through a considerable depth of the soil profile, the soils settled. As a result of non-uniform, differential settlement, the slab experienced significant distress. Slab joints opened up and adjacent edges of concrete joints lifted or sank relative to one another up to 2 inches (Fig. 7), which was too much for materials handling equipment to handle. The problem worsened as storm drains cracked and the corners of the building settled, allowing rain to pond and pour over the shallow parapets instead of reaching the roof drains.

Fig. 7 - Slab distress at settling soil

5) Once the geotechnical report has been reviewed, the building owner should be made aware of any risks associated with the site soils. If the building owner will inherit the building pad from a developer, it is imperative to understand the recommendations in the geotechnical report versus how the developer chose to act on those recommendations.
6) Use a well-graded and well-drained gravel base and sub-base. Proof-roll with a truck so construction vehicles will produce an imprint of 3/4" maximum, or an amount recommended by the geotechnical engineer. Sand and stone are also used, depending on availability.
7) The stability and performance of the soil will depend on its level of compaction or consolidation either as an in situ material or through the use of compaction equipment such as vibratory or sheepsfoot rollers (Fig. 8). The geotechnical engineer will recommend optimal moisture contents for the soils in order to

achieve their maximum density. Required compaction efforts can be defined by test methods such as the ASTM D698 Proctor test or ASTM D1557 Modified Proctor test. The compaction of the soil profile below the slab will be important for two main reasons:

a. Settlement – Movement of the slab due to long-term settlement of the slab under the weight of the building and existing or new soil profile can impact the performance of the building. Examples:
    i. If a building column settles due to the weight of the overlying building and the soil between the columns settles less, the slab may "hog", or have a slight convex curvature near the area where the slab dips down as it rides with the column and footing. A crack may develop in, say, ceramic floor tile that an owner will have concerns about. Also, building components such as steel stud walls with brittle finishes (gyp board and tile) that are attached to both the slab below and structure above without a slip joint may undergo distress and buckling as the wall will be squeezed between the two rigid building elements.
    ii. Columns may be supported on well-compacted soil at deeper elevation for something such as frost protection during construction or so the footing is low enough for underground pipes to run over them. If the backfill above these footings is poor, or is looser around, say, a mass amount of pipes or conduit, the soil may settle unevenly, resulting in distress similar to that described above. Note that low strength flowable concrete fill (compressive strength less than 500 psi for future removal) can be used where compaction efforts fail.

b. Stiffness – The immediate or short-term reaction of the soil to loading is also important. The ability of the soil to receive loading from the slab and distribute it into the ground will depend on its stiffness and ability to respond elastically and without failure. Consider an abrupt discontinuity in the slab, such as a crack, joint, or slab edge. If heavy equipment with wheels passes over the discontinuity, the slab will have a concentrated load at its edge. If the ground supporting the slab is very soft and springy, it will subside in response to the load being transferred from the slab. The slab, which is very stiff and brittle, will need to "span" to engage a greater area of soil to resist the load. This will impose bending stresses in the slab, and there is clearly a greater risk that the slab will develop a failure crack in bending than if the soil were stiff.

Fig. 8 - Sheepsfoot roller (By Jwh at Wikipedia Luxembourg, CC BY-SA 3.0 lu, https://commons.wikimedia.org/w/index.php?curid=67442554)

8) IBC 2018 Section 1907 states that a vapor barrier is required below slabs by default, but may be excluded in certain cases. The vapor barrier (Fig. 9) is meant to be a permanent barrier to prevent moisture from migrating from the subgrade into the slab. Without a properly installed vapor barrier, moisture can penetrate through the concrete and rise to the top surface of the concrete.

   Moisture content below the slab will vary, but undue moisture in the slab is undesirable for a variety of reasons. One of the main ones is that floor coverings such as resilient tile will have adhesives that are very sensitive to moisture and moisture vapor. Warranties are generally are part of the flooring installation. Vapor transmission limits required for these warranties can be very difficult to achieve, especially on fast moving projects, where there is little time for the slab to dry out. See Fig. 10 for a flowchart from ACI 360.

Fig. 9 - Vapor barrier

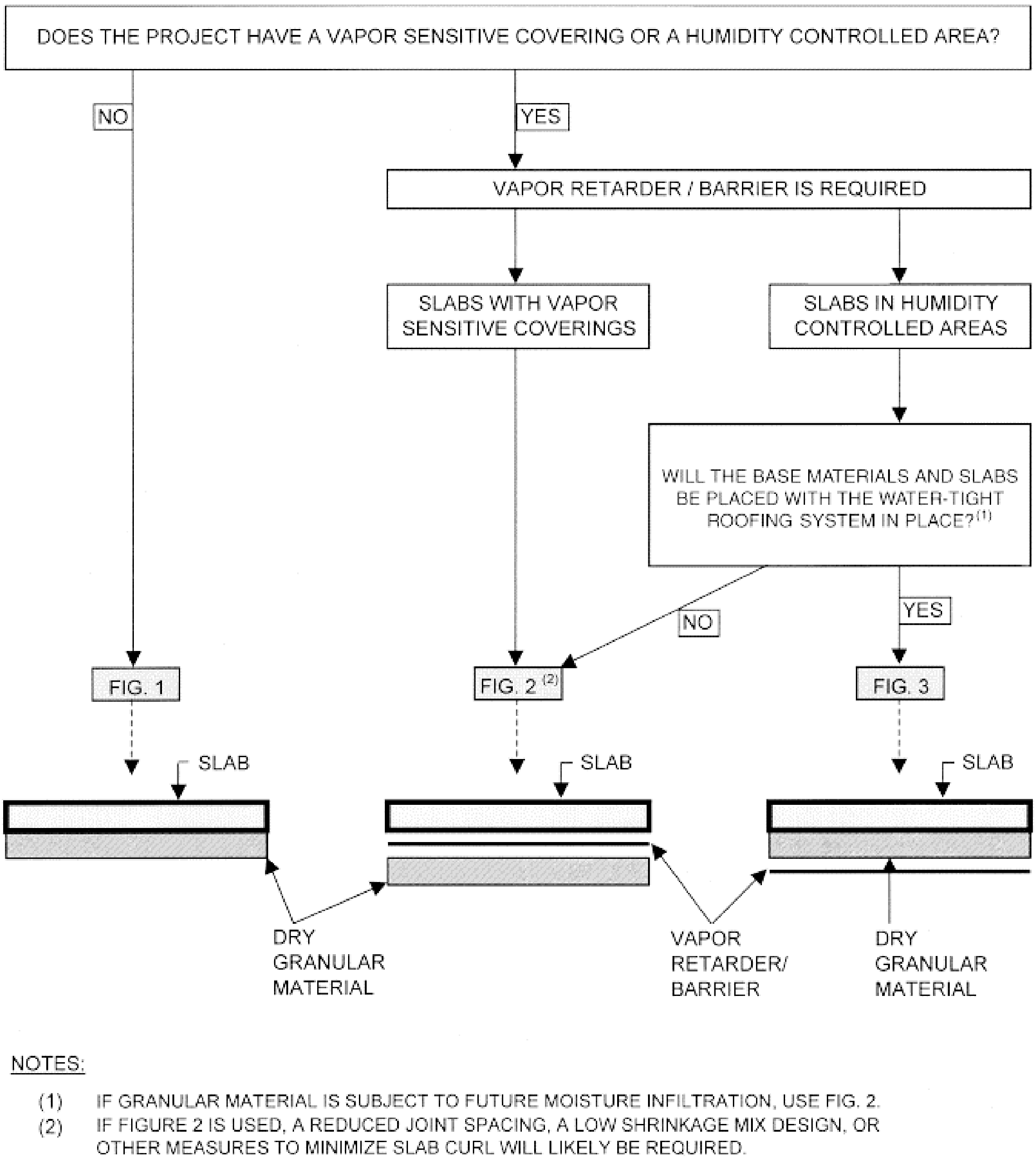

Fig. 10 - Placement of vapor barrier – (ACI 360)

9) Note that if the water table is high enough, water may cause hydraulic pressure under the slab, and either lift the slab, or cause shallow flooding of the floor. The impact of this needs to be addressed in pre-construction. Waterproofing the

underside of the slab may be necessary, but the water pressure also needs to be addressed.

10) If concrete shrinkage can be adequately controlled and its magnitude minimized, it may be desirable to use an additional thin polyurethane sheet above the vapor barrier (say 6 mil) to provide reduced friction between the slab and soil, allowing for shrinkage to occur with minimal restraint. Two sheets can be used if no vapor barrier is present.
11) Membranes may be required for other purposes, such as the mitigation of methane vapor from being transmitted into the building.
12) The information from the geotechnical report should provide most, if not all, of the subgrade information necessary for slab-on-grade design.

Concrete Properties and Behavior

1) Plain concrete is strong when in a uniform state of compression (squeezing forces), and relatively weak in tension (pulling forces).
2) Concrete will crack if the tensile stresses in the concrete exceed the tensile strength. Cracks will weaken the concrete section and tend to propagate if the tension field is not relieved by the crack (see Fig. 11).

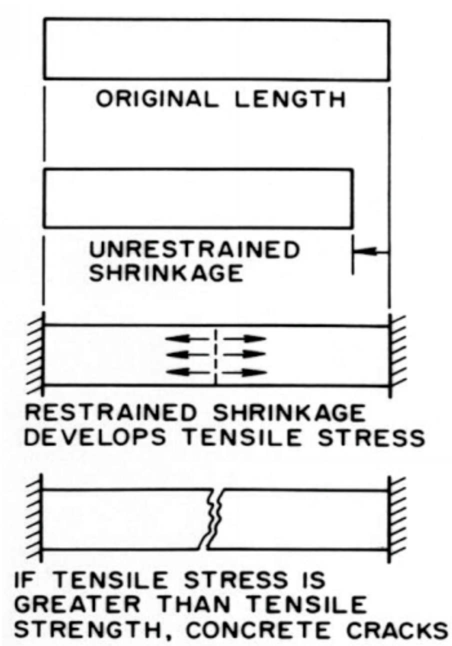

Fig. 11 - United States Nuclear Regulatory Commission: "Non Structural Cracks in Concrete"; https://www.nrc.gov/docs/ML1215/ML12153A412.pdf

3) Concrete is a stiff but relatively brittle material, so if ductility in the slab is required after cracking (post-crack strength), steel or synthetic reinforcing may be desired (discussed later).
4) Concrete needs water for mixing and workability and the water hydrates the cement so it can become fluid, mix with the aggregate, and harden into its final solid state (see Fig. 12). The water reacts chemically with components of cement such as calcium, silicon, and aluminum to form cement paste, or binder, which coats the fine and coarse aggregate (sand and rock) to “glue” the concrete mix together.
5) One of the tests done on concrete is slump testing, or how much wet concrete will flatten out when released from a cone-shaped form. The amount it settles is the measure of slump, usually in inches, so a larger slump means more fluidity. It is a rough approximation of workability and consistency. The concrete specifier should allow the concrete supplier some flexibility in the range of slump specified because the optimal mix of ingredients in the concrete may dictate a higher or lower slump.

Fig. 12 - Wet concrete being placed – [mardoqueo sagastume / CC BY (https://creativecommons.org/licenses/by/3.0)]

6) Generally, the concrete is poured and raked into place at roughly the finished depth. Consolidating the concrete with a mechanical vibrator is usually the next step. Vibrating the concrete helps prevent honeycombing (Fig. 13) by mixing the

cement paste into pockets of uncoated aggregate and removing trapped air. The concrete becomes liquefied and it flows together while air bubbles escape though the surface. This is most important at joints and around steel reinforcing to make sure the concrete fully forms onto and around edges and embedded objects.

Fig. 13 - Honeycombing –Poorly vibrated concrete

7) Then the excess concrete is brought to level by a process called screeding or strikeoff. The tools for this involve some kind of straight edge, or screed that pull back and move side-to-side slightly to make sure the concrete surface is uniform and flat. Two powered screeds are shown below (Figs. 15 to 16)

Fig. 15 - Lightweight ride-on laser screed (https://www.somero.com/products/ride-on-screeds/s-485-laser-screed-model/)

Fig. 16 - Telescopic boom laser screed - https://www.somero.com/products/boomed-screeds/s-15r/

8) After screeding, finishing the surface is done with several methods, or a combination of them. Floating with a bullfloat or highway straightedge evens out the surface (Fig. 17), getting rid of local bumps and pits by pulling them across

the top of the concrete. Large aggregate particles are also pushed down below the surface.

9) Where finer, more flat, and smoother surfaces are desired, troweling is done next. Interior slabs are often finished with the use of a power trowel (Fig. 18), which can be hand-held or riding. The trowel floats on blades that spin around. This action further embeds aggregates and evens out the surface while densifying the paste at the surface for better durability.

Fig. 17 - Floating the concrete (United States Nuclear Regulatory Commission)

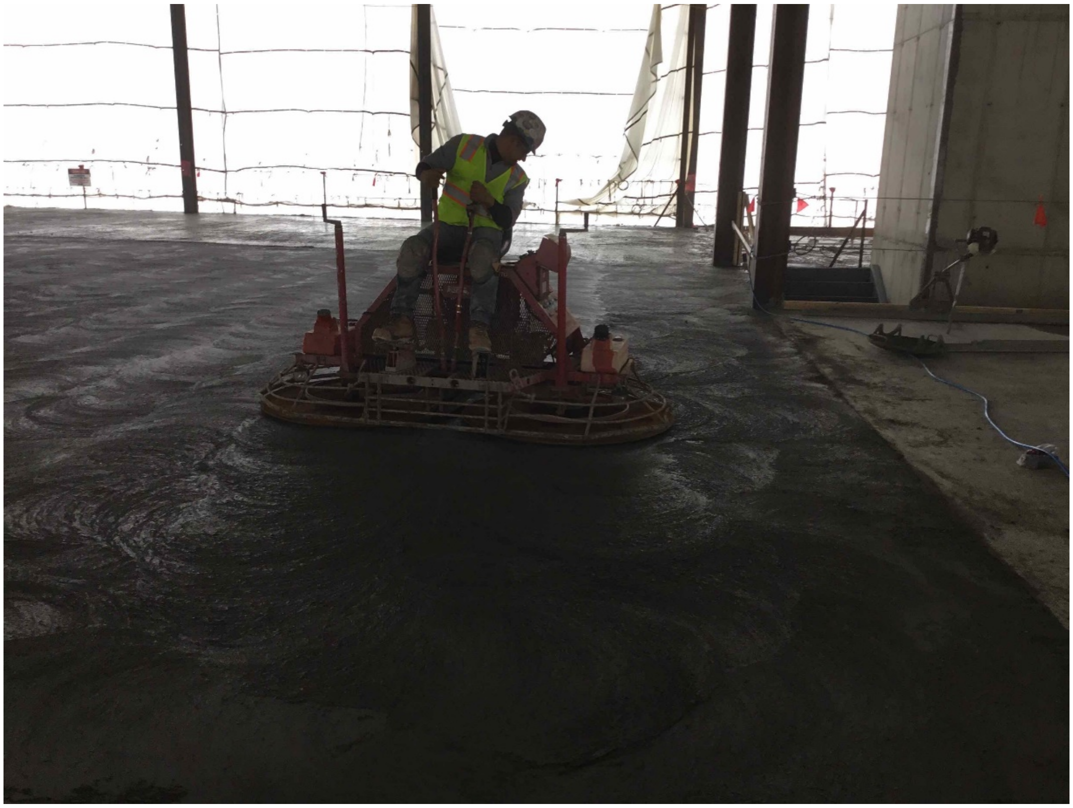

Fig. 18 - Riding power trowel with steel blades

10) Concrete shrinks in various ways in early phases. Even though shrinkage of typical concrete is small, on the order of 0.04 to 0.08% with respect to volume, the relative brittleness of concrete means that cracks can develop in concrete with conditions sufficient to produce them. There are several types of shrinkage to note.
    a. Plastic shrinkage – Early in concrete pours, slab surfaces are susceptible to wind, low humidity, and high temperatures. These all have a tendency to of dry out the surface of a slab before it develops any kind of strength, or when the concrete is still plastic in nature. Cracks that develop at this time are called plastic shrinkage cracks, and can be mitigated by any combination of means to prevent rapid moisture loss (fogging, plastic sheets, shading, wind breaks, etc.)
    b. Autogenous shrinkage – Happens early in concrete curing, when water is used up for the hyrdration of cement. More common in mixes of low water/cement ratios, the capillaries or conduits naturally created for water to migrate to the hydrating cement will become drier, and surface tension

within the very small voids will cause shrinkage and sometimes cracking. Again, moisture loss prevention is the key to avoiding this type of shrinkage.

c. Temperature shrinkage – The concrete slab will naturally undergo a volume change with varying temperatures. Concrete in the early phase will be warmer as the cement hydrates. After this, the air and ground will influence the concrete temperature. The change temperature during the construction phase, as well as the final in-service temperature of the concrete should be considered, especially if there will be extreme differences.
d. Drying shrinkage – After curing, and similar to autogenous shrinkage, in the process of drying out, the cement paste will shrink in volume as it loses water. In this case, the surface tension in the capillaries is a result of evaporation of the mixing water, or that available to give the concrete its workability. This type of shrinkage is significantly more prevalent than the autogenous variety. The concrete mass will tend to shrink towards its center of mass. Also, the concrete may lose water non-uniformly at its defining surfaces. Sides exposed to air will dry out faster. Sides exposed to soil will dry more slowly, Sides exposed to vapor barriers or plastic sheets will dry very slowly near those surfaces. For slabs-on-grade, the top surface exposed to air will dry much more quickly than the bottom, which is generally in contact with gravel or a vapor barrier. If the air is very dry or hot, or if there is a significant wind, the drying action of the top surface will occur at an increased rate. Once again, moisture loss prevention is the remedy.

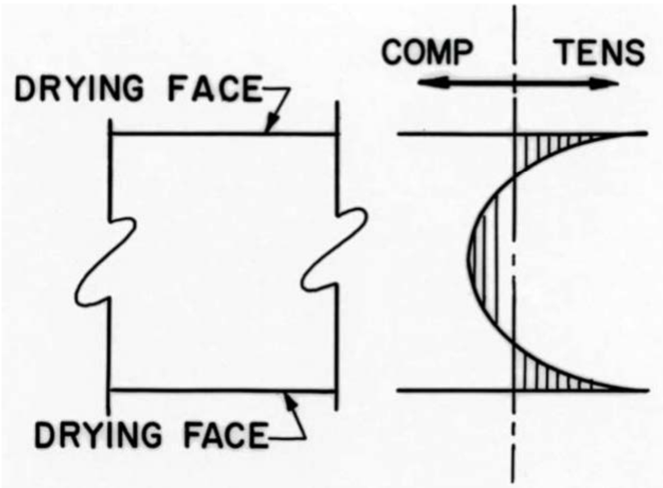

Fig. 19 - Stresses in a slab with a top and bottom drying face – (United States Nuclear Regulatory Commission)

11) For slabs-on-grade, there will be combination of a faster drying top surface and some amount of friction at the bottom of the slab. Also, imperfections in the subgrade such as random pieces of gravel sitting proud of others, will restrain the concrete as it shrinks. Due to its own weight, the slab will not lift up over these imperfections as the concrete mass shrinks in local areas, and the concrete will be in a state of tension (Fig. 20). As stated so elegantly in ACI 360, "...shrinkage will vary with the depth, causing the as-cast shape to be distorted and reduced in volume. Resistance to formation of this distorted shape…may cause the concrete to crack."

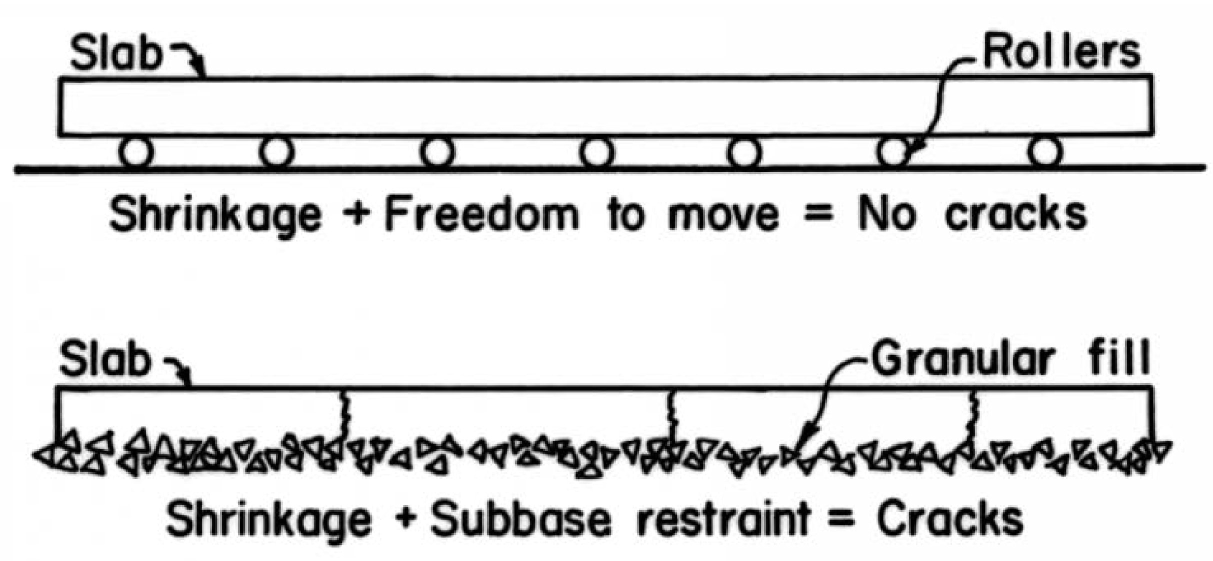

Fig. 20 - Cracking due to restraint of a shrinking slab (United States Nuclear Regulatory Commission)

12) Assuming favorable conditions, there will be a period of time before the tension is sufficient to cause cracking. Eventually, however, concrete will crack at weak planes. The remedy is to induce weak planes before this cracking happens naturally. This is done by introducing a straight line discontinuity into the top surface of the concrete, by one of the methods below. The challenge is to wait until the concrete is strong enough to walk on and cut without the concrete raveling or bunching up at the cut, and also keeping the aggregate from being displaced.
    a. Sawcutting - Shallow cuts with a circular saw blade (see Figs. 21, 22). These can be done when the concrete is still wet or at a later time when concrete is drier. Later cuts risk cracks happening before cutting, and cracks running ahead of the cut due to crack propagation in a slab that is just about to crack.
    b. Tooling - By pulling a tool that has a shallow ridge across the concrete surface and neatly gouges it (see Fig. 23), or
    c. Inserts - The use of continuous linear inserts pushed into the surface during finishing. Due to their irregularity in placement and difficulty for working around for final finishing, these are not recommended by the author unless the uniformity of the finished slab is unimportant.

Fig. 21 - Sawcutting a concrete slab (Source: http://www.navy.mil/view_image.asp?id=24454; Author: Mark H. Overstreet)

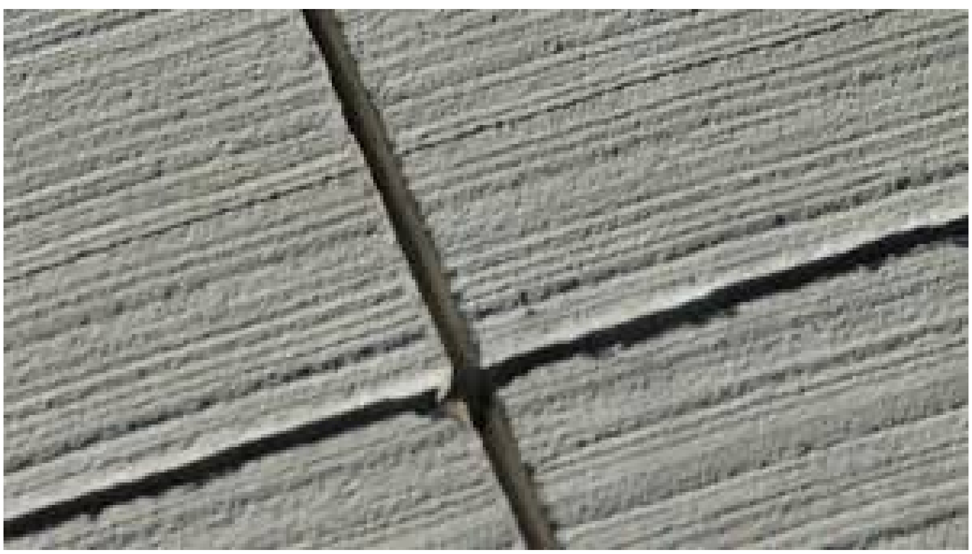

Fig. 22 - Typical final sawcut in concrete slab (http://www.chicagolandconcrete.com - Chicagoland Concrete, Inc.,)

Fig. 23 - Tooling joints in a concrete slab – (Source: https://www.dvidshub.net/image/664009/dirt-boys-pave-eielson-streets; Author: Staff Sgt. Jim Araos)

13) Meanwhile, the concrete has a finite time to dry, and has only developed a portion of its final tensile strength. If the timing is right, the moment when the concrete tends to crack is beyond the time of the sawcut. With the sawcut in place (see Fig. 24, roughly 1/4 the depth of the slab), the weak planes thereby created are where the concrete cracks though its section, and nowhere else. The resulting crack is called a sawcut joint or tooled joint, and the generic term is a **control joint**. If appearances are important, control joints should be extended to concrete edges, or the concrete will develop random cracks from the end of the joint to the edge on its own.
14) Note that, by design, two slabs separated by a control joint are designed to move freely from one another in the horizontal direction for shrinkage. There may be increases in temperature or moisture from other sources which cause the slabs to expand, but generally, interior slabs have a small gap between them at control joints.

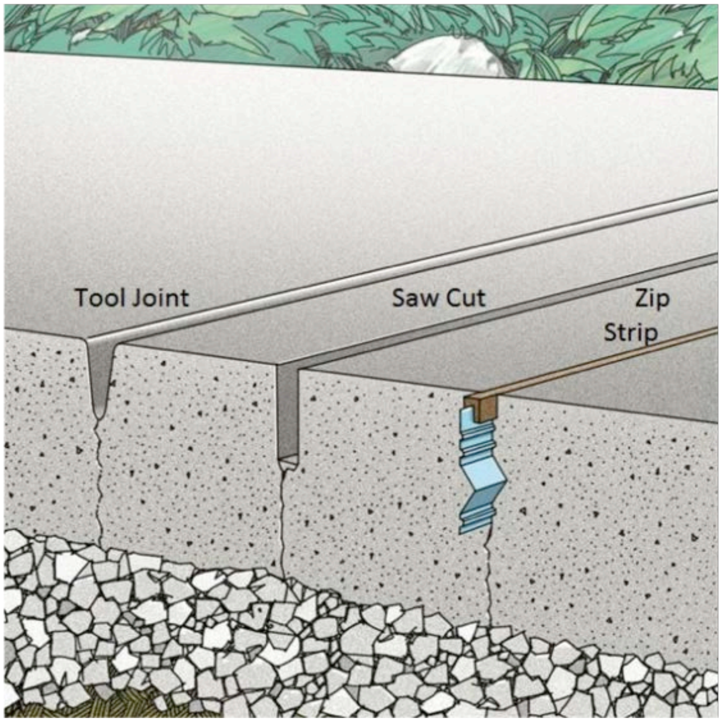

Fig. 24 - Typical sawcut and tooled joint in concrete slab (https://blog.strongholdfloors.com/epoxy-floor-coatings-what-about-the-cracks-what-if-i-have-a-joint-part-2)

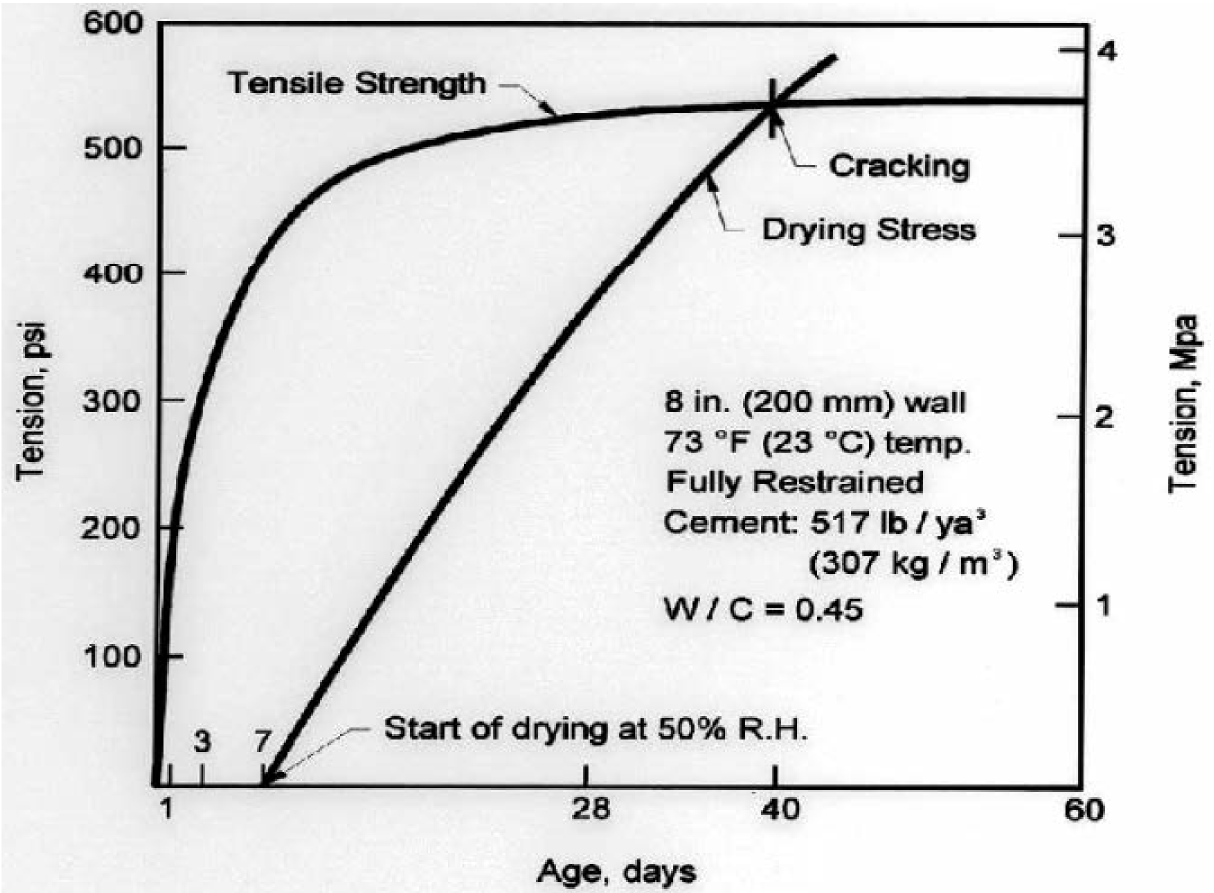

Fig. 25 - Relationship between tensile strength and drying stress over time (United States Nuclear Regulatory Commission)

15) The spacing of these control joints is guided by experience. ACI recommends 24 to 36 times the thickness of the slab. Sawcuts are performed in the two orthogonal directions, creating a patchwork of sawcut panels (see Fig. 26). Generally, even divisions are made between columns. It is recommended aspect ratios of panel size is 1.5:1 maximum. (see Fig. 27) Panels of greater aspect ratios tend to form unwanted cracks across the panel width at the midpoint of the longer panel dimension.

Fig. 26 - Typical control joint patterns in a concrete slab

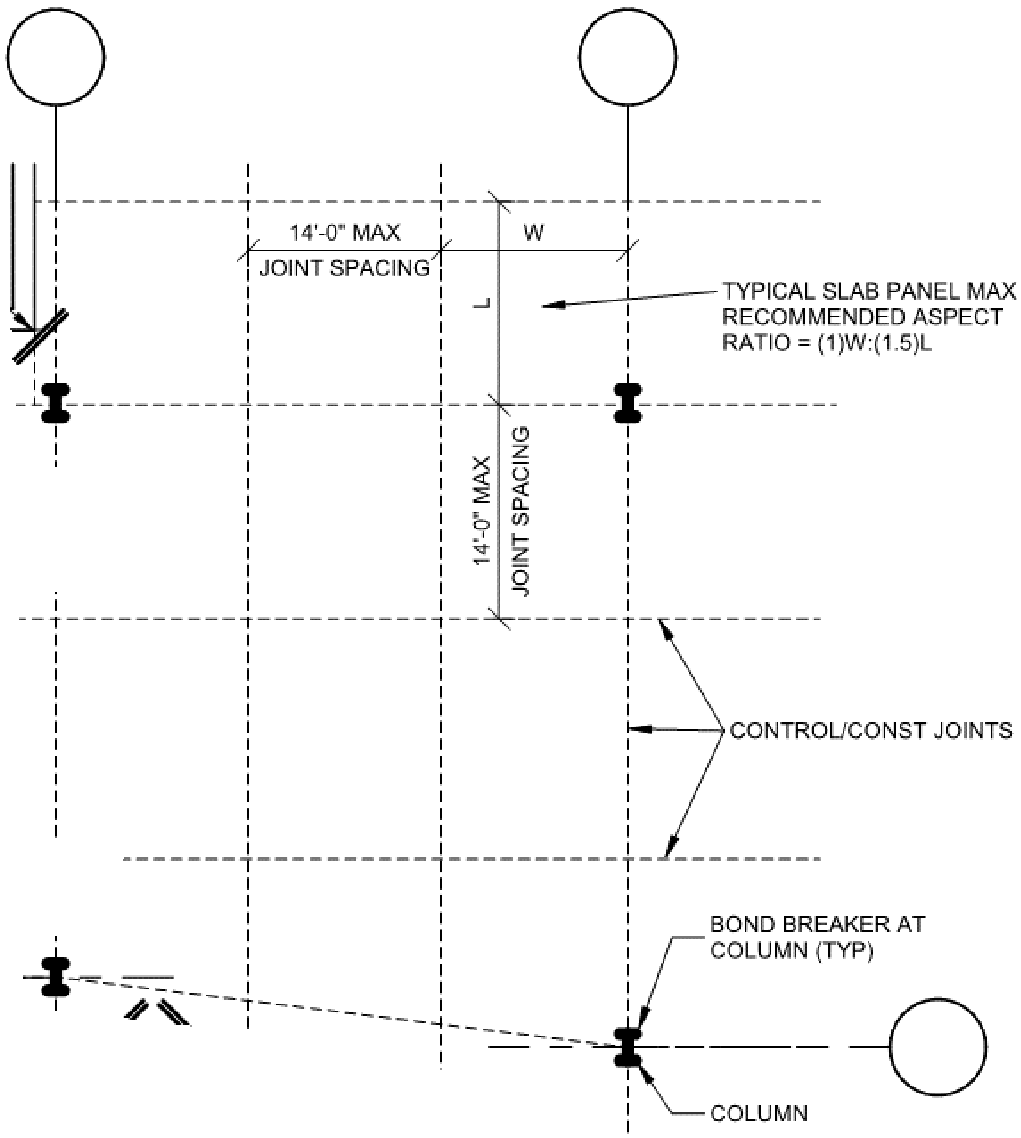

Fig. 27 - Typical guidelines for control joints

16) During construction or in service, integrity across the joint is desirable for things such as wheeled traffic crossing the joint. The integrity of the control joint for vertical load transfer is generally dependent on aggregate interlock, see Fig. 28. If the crack is small enough, aggregate interlock can be counted on due to the jagged nature of the crack below the shallow depth cut or tooled joint. Per TR34, it is recommended that the effectiveness of aggregate interlock be limited to 15% of fully intact slabs. This only holds for joints that open up less than 0.06 inches. This is roughly equivalent to a shrinkage gap from concrete panels 15'-0" wide

with 0.06% shrinkage and a reduction in width to account for restraint of the subgrade. ACI 360 has more strict advice, noting that the threshold for joint gap size for aggregate interlock is 0.035”. For typical buildings, with minimal shrinkage, the aggregate interlock is sufficient to provide load transfer across the joint. For warehouses, a high volume of materials handling traffic needs to be considered against the long-term durability of joints.

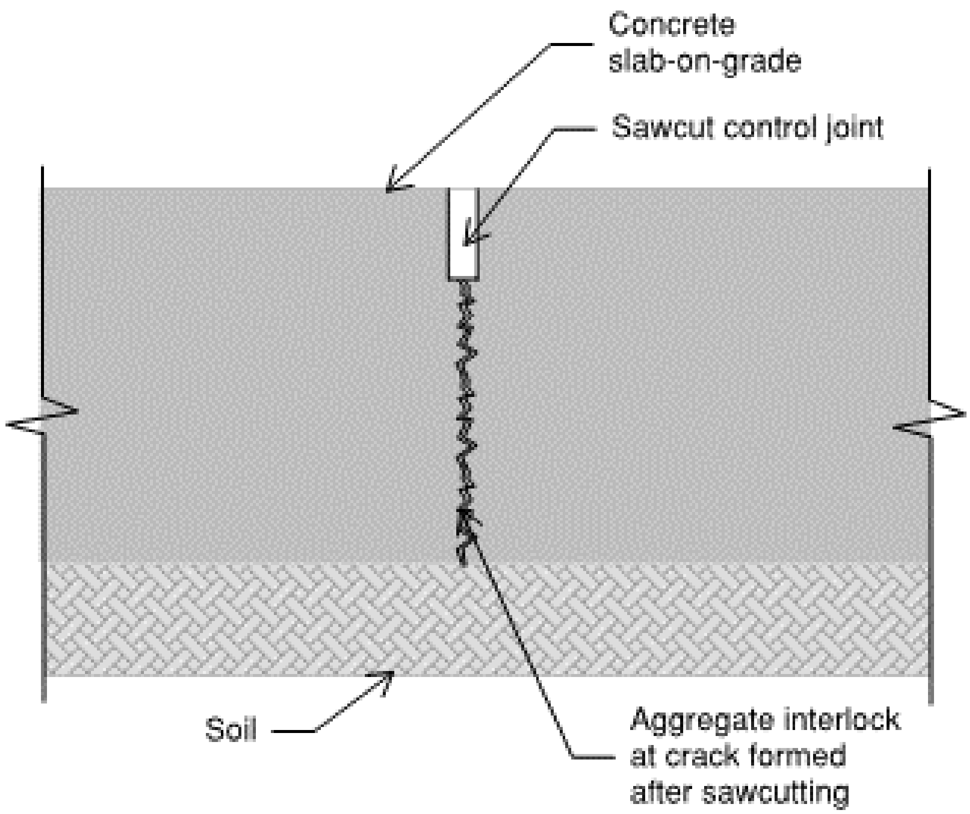

Fig. 28 – Aggregate interlock

17) Because there are various practical limitations on the area of slab that can be poured within a given working day, it is necessary to stop concrete pours at convenient boundaries within the overall area of concrete pours. These boundaries are called bulkheads or ***construction joints***.
The first pour is stopped at a vertical plane and the second pour is poured against the vertical face of the first concrete pour.

The treatment of these joints depends somewhat on the projected end use of the facility. A construction joint detail is presented in Fig. 29. If two slabs are simply poured side-by-side at different times with a vertical plane between them, the slab alone does not have any means of load transfer from one slab to the other across the joint, as described above. These joints are designed for free movement horizontally. If there is vertical movement due to differential settlement, or one slab moves more than the other, one slab may sit proud of the other. Hence, construction joints are almost always detailed with load transfer elements. Some of the more common ones in buildings with or without constant wheeled traffic are:

a. Keyways, typically formed by chamfered forms. Joints will open up under shrinkage, making for a loss of contact at the keyway and vertical movement may result. If keyways are used alone without sufficient reinforcing to restrain movement (0.5% steel by area across joint), an extremely costly endeavor for unreinforced slabs, these are not recommended by the author.
b. Rigid steel dowels across a joint. Typical sizes are ½" in diameter and 2'-0" in length. Dowels are centered on the joint, and one end may be greased.
c. Square plate dowels or diamond dowels. These are steel plates as shown in Fig. 30 that are laid flat and oriented at 45 degrees to the joint. A sample installation for standard buildings is 1/4" thick x 4-1/2" x 4-1/2", with a 2'-0" on-center spacing, and centered in the slab. There is a unique method of placing these. A rigid plastic housing of adequate strength is first nailed onto initial concrete edge form and gets included in the first concrete pour. The dowel is then slipped into the housing for the second pour. This means that the contractor does not need to provide holes in the formwork to accommodate a plate dowel placed in the first pour. Another advantage of these dowels is the allowance for shrinkage movement in two directions. The plastic housing is designed with an allowance for movement parallel to the joint, and naturally the dowel slips out of the housing is there is movement perpendicular to the joint. As mentioned, concrete panels shrink toward their center of mass, so near the corners, the slab is moving diagonally. This leads to a component of movement both parallel and perpendicular to the slab joint.

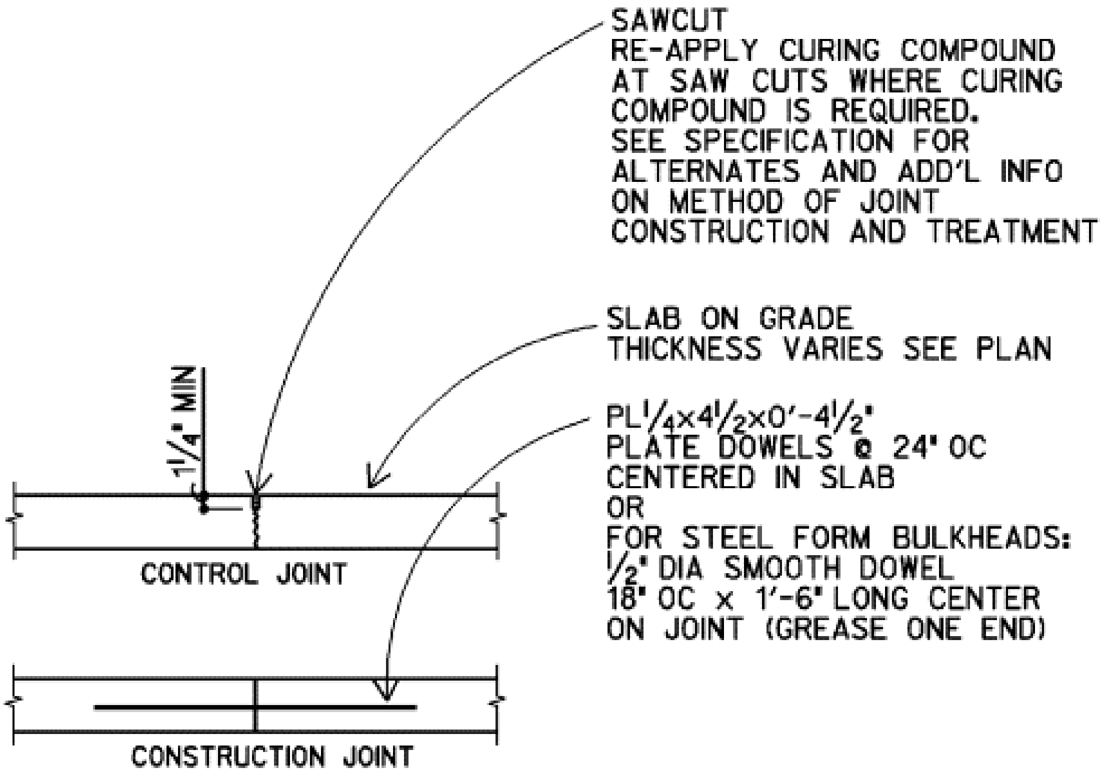

Fig. 29 - Typical details for control and construction joints in a concrete slab

Fig. 30a – Insert at edge of construction joint set into first concrete pour, with second concrete pour to follow

Fig. 30b - Square dowel to be placed at a construction joint placed in insert that was set into first concrete pour, with second concrete pour to follow (https://www.pna-inc.com/products-designs/diamond-dowel-system)

18) Crack widths are somewhat predictable, but there may be some that open up more than others due to variable conditions. These are called dominant joints, and can result when shrinkage is less than predicted, or joints are spaced more closely than necessary.
19) Crack filling of joints is not usually required in typical slabs. In warehouses, it very well may be good practice. This is discussed in a future course.
20) If concrete is left to crack on its own, the size, location, spacing, direction, crack width and shapes of these cracks will be fairly random (Fig. 31). Owners may question the quality of the concrete or the expertise used to design, place and cure it. Also, it is more difficult to fill and repair a randomly wandering crack that is not straight.

Fig. 31 - Typical random crack in concrete slab

21) There will be many building components that will make the use of control joints difficult to employ with complete regularity. Objects such as building columns will project through the plane of the slab, and with enough lateral movement of the slab due to drying shrinkage or temperature effects, the restraint can induce cracking at the margin of the object. The joints that provide relief at these objects are called **isolation joints**, with an intentional gap and a compressible filler material, an example of which is shown in Fig. 32. Re-entrant corners will exist where floor areas follow building geometry and at transitions between adjacent areas that require discontinuities in the slab. Special details may be required.

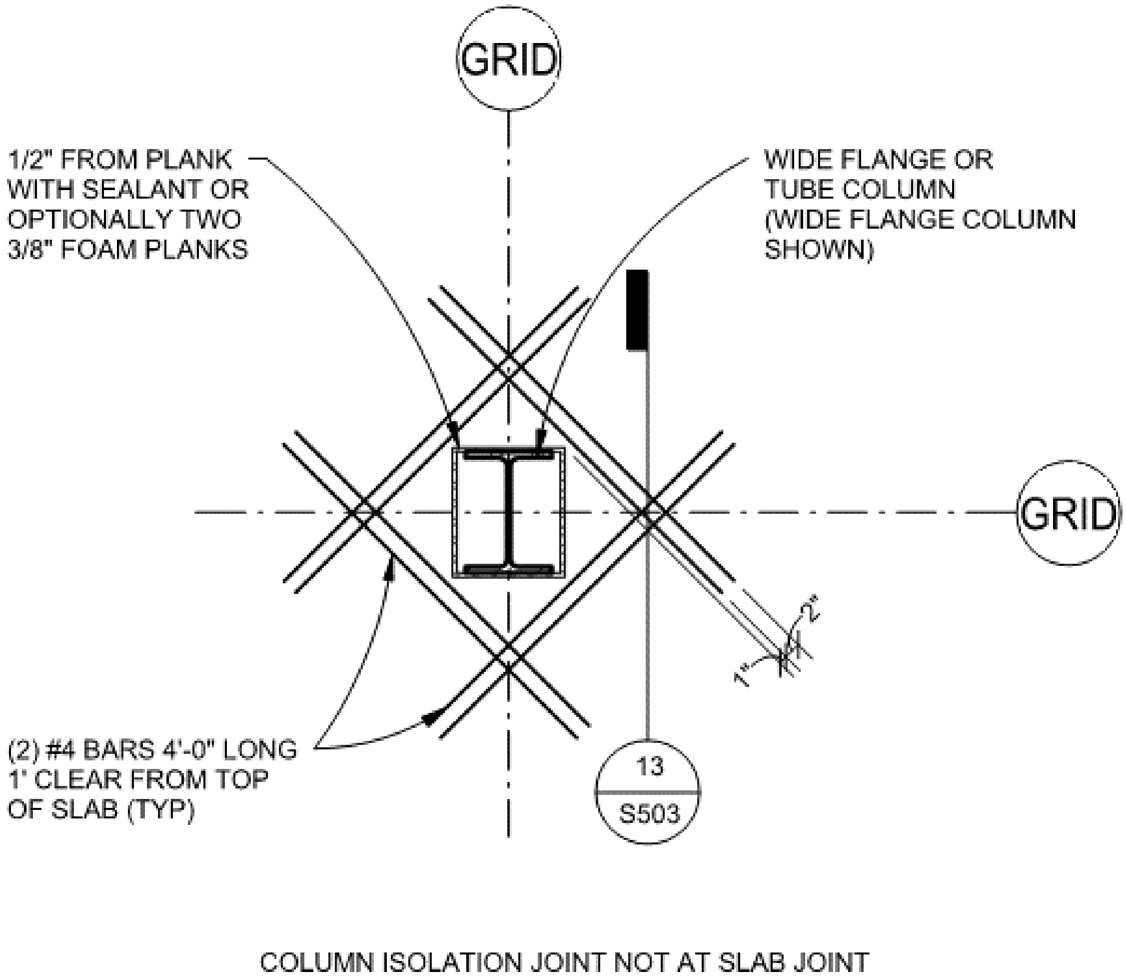

Fig.32 - Details for typical concrete slab conditions at column penetration

22) Note that the strategy of using control joints to mitigate cracking in concrete does not guarantee that slabs will not crack in undesirable or random locations. A rough approximation for use in setting expectations is that about 3% of concrete panels will develop shrinkage cracks between control joints (per ACI 360). This can be reduced if the concrete contractor demonstrates greater expertise and

experience and if an increased level of care and oversight is used. For example, aggregate at the bottom of a stockpile pile may contain mud that gets into a mix. When an area of mud dries, it has significant shrinkage, shown by the maze of and cracks with curled edges at its surface that resembles so many wood shavings. This same mud mixed into concrete can influence the shrinkage of the concrete. Good oversight prevents this and other ways unwanted shrinkage results.

23) There are other methods of controlling cracks and their sizes, which will be discussed later. Some strategies allow for the elimination of control joints between construction joints. These are strategies that require a good plan and the control of many variables, from subgrade preparation, to mix design, to execution, and including what is and is not allowed, what to do when things go wrong, and what needs to be documented by whom to aid in the assessment of failure should it occur. If there are questions about these strategies, a smaller area test slab pour within the footprint of the building can always be done prior to construction. If successful, it can be considered the building's first pour. The standard practice is to provide control joints, and that is the method of design described here.

24) Besides cracking, the tendency of slabs to dry out on top before the bottom can cause a common phenomenon known as curling. Also, concrete that is allowed to cure in a more moist condition such as the bottom half of a slab will exhibit decreased final shrinkage. Differential drying shrinkage, or the shortening of the top relative to the base will result in an upwardly concave curvature that tends to lift the slab at its sawcut edges. If greatly exaggerated, the shape of the slab panel would resemble a rectangular dinner plate. The lifting action is countered by the weight of the slab. This is shown in Fig. 33.

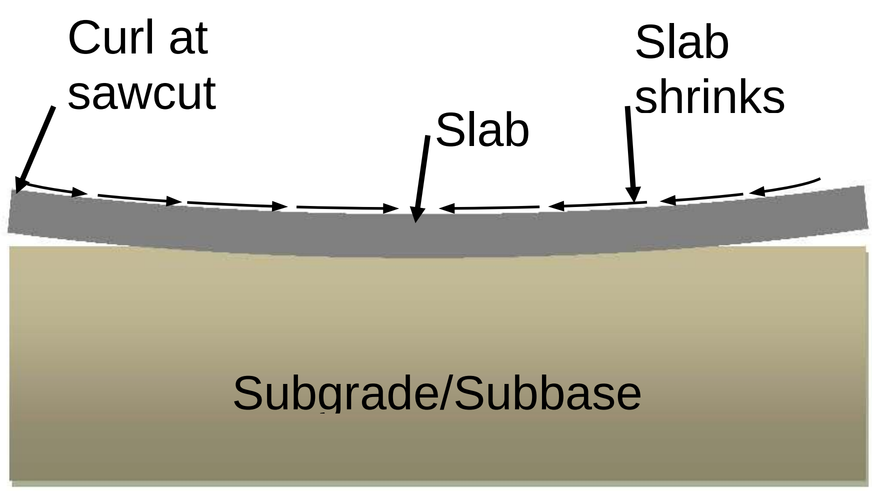

Fig. 33 - Curling of slab panels

25) Concrete mix designs:

a. Cement is the dry powdered substance that is mixed with water to activate its binding and hardening properties when hydrated. For typical concrete mixes, the amount of cement in a mix determines the final strength of concrete. Because the minimum strength needed for slabs to achieve adequate durability and load resistance generally is in the 3,000 to 3,500 psi range, a minimal practical strength should be specified, but not greater. Cement is easily the most costly ingredient in concrete. Also, the higher the cement content in the mix, the greater the final shrinkage.

b. Provide the minimum amount of water to achieve workability and surface finishing, but not more than necessary. The cement paste is the mixture of cement and water that surrounds the aggregate. The cement paste binds the aggregate together. To get the mix to flow, spread and flatten out as it is poured, the amount of water in cement paste will be more than that required to activate the cement particles for strength. Thus, there will be much of this "mixing water" that will evaporate from the concrete. Water in excess of the amount for workability will promote an additional increase in shrinkage and also lower the strength and surface durability because it will leave voids where the minute water particles evaporate from. Note that the measurement of water/cement ratio is generally used in a specifications. Because the cement content in slabs is minimized, reducing the water/cement ratio should not be the primary goal. Reducing the total volume of water per cubic yard should be the goal. (Harrison)
c. Aggregates are the rock and sand particles in concrete mixes. Rock and stone are the coarse aggregates (e.g., river rock or pea gravel), and sand-sized particles are the fine aggregates. Use well-blended sizes of fine and coarse aggregates to maximize the volume occupied by these aggregates in concrete. Gradation is the term for the blend of aggregate sizes by volume. In a well-blended gradation, the smaller particles will fit in the spaces between the larger particles. The more the aggregates are packed together, the less voids that the cement paste will occupy. When cement paste loses its water content, it is the main cause of shrinkage. So, minimizing cement paste volume is advantageous. Use aggregates that are as stiff as possible to restrain the cement paste shrinkage, and that have minimal or negligible shrinkage of their own (e.g., quartz). Per Harrison and also Ytterberg, "Unrestrained paste will shrink roughly four to five times more than the concrete made with the paste". ACI 302 goes into detail about proportioning the various sizes of aggregate sizes to achieve well-graded blends.
d. Per unit volume, the larger the maximum aggregate size as a ratio of its size to the slab thickness, the less amount of cement paste required to coat the aggregate. Thus, using the maximum aggregate size possible relative to the slab thickness will also reduce shrinkage. (Harrison). A maximum aggregate size of 1/3 the slab thickness is a good goal. For example, a 1-1/2" maximum aggregate size is a good choice for a 4" slab.

e. There are substances other than Portland cement that can serve as additional cementitious binders in concrete. These are called supplementary cementitious materials. Generally they are added for their beneficial properties and perhaps for lower costs. Their use should be limited to the amounts that have been proven beneficial by research. They include:
    i. Fly Ash – This is a by-product of coal production, and is a substance that reacts with calcium hydroxide in concrete. The reaction forms cementitious compounds that occur after the initial cement reactions, causing a slight delay in concrete strength gain with some fly ashes. The resulting binder in the concrete is generally more fully reacted, and therefore less permeable, and with less free calcium hydroxide to bind with more harmful reactive substances, such as sulfates. As coal production wanes, some fly ash is being reclaimed from man-made ponds where excess fly ash was deposited. There are different classes of fly ash, with different effects on concrete. Not all fly ash should be used in concrete.
    ii. Ground, Granulated Blast Furnace Slag (GGBFS) – This is a by-product of blast furnaces.
    iii. Silica Fume – An airborne by-product produced by furnaces involved in silicon or silicon-type substances.

f. Concrete admixtures may be added to the concrete. These are generally proprietary products that have been introduced to the concrete industry, and may serve to improve various aspects of the concrete. They include:
    i. Air-entrainment admixtures – These help to add very small air bubbles to concrete to help with freeze-thaw durability. As the water in concrete freezes, the air bubbles provide additional space to expand into. Also, a certain percentage of air is generally specified for lightweight concrete. Air-entraining does decrease the strength of concrete slightly.
    ii. Water-Reducing Admixtures – These are generally used to reduce w/cm ratio and improve workability and fluidity of fresh concrete. Thus, less water may be required to get the concrete to be workable.
    iii. Shrinkage-Reducing Admixtures – These reduce the impact of drying shrinkage in concrete due to the loss of water. As concrete dries, surface tension is created in the pores, resulting in a

tendency to pull the concrete together, hence a reduction in volume. The SRA's reduce this surface tension in the pores, and serve to decrease the shrinkage of concrete.

iv. Accelerating Admixtures – These speed up the set time of concrete, especially where cold weather slows the set time down. Care should be taken to review the chloride content in accelerators to prevent undue shrinkage of concrete and corrosion of metals.

v. Retarding Admixtures - These slow down the set time of concrete, especially where hot weather speeds the set time up.

vi. Corrosion Inhibiting Admixtures – These slow down the rate of corrosion of steel reinforcing in concrete.

g. Fiber Reinforced Concrete - One method of enhancing the integrity of concrete is the use of fibers. Generally speaking, the fibers have a very high aspect ratio of length-to-width) and are 2 inches or less in length. Fibers typically are added at the job site at during the final revolutions of a truck's drum. Fibers end up randomly oriented in the concrete, except at the margins, where finishing and forms naturally leave them parallel to the surface, nut randomly oriented in-plane. Over-dosing or under-mixing can cause them to bunch up and to lack enough concrete coating. Fibers can generally be seen below the thin upper paste surfaces of concrete, so expectations need to be managed. Dosages very greatly, as do material properties. ACI 544 provides information on fibers in concrete. There are three main kinds of fibers noted below, but many proprietary fibers are available, and the technology is ever-changing, so this should not be considered an exhaustive list.

i. Microfiber – Typically polypropylene, these are very thin fibers common in concrete applications such as residential driveways to prevent plastic shrinkage cracks at the surface during the finishing phases of concrete placement. Because of its relatively lower density than cement and aggregates, water slowly migrates to the surface after placement. This is known as bleeding, and the water that reaches the surface is known as bleed water. During highly evaporative conditions, concrete without microfiber can release bleed water inconsistently across the surface, leaving some areas wet longer than others. Concrete shrinks at the surface as it dries, and in dry conditions, this inconsistency across the surface can lead to differential shrinkage, and eventually cracking and tearing of the concrete between wetter and drier areas. Microfibers aid in promoting consistent bleeding, resulting in less plastic shrinkage cracking. These types of fibers do not contribute significantly to final sectional strength under design event loading, as they do not reliably enhance post-crack residual strength.

ii. Macrofiber (Fig. 34) – These fibers are thicker, wider, and longer than microfiber, and are also made from synthetic polypropylene materials. With typical widths of about 1/8", and with lengths in the range of 2", macrofibers have enough integrity (stiffness and strength, along with adequate bonding to cement paste) to mimic the traits of light reinforcing. Macrofibers are often used in slabs to replace shrinkage and temperature reinforcing. The real benefit of these types of fibers is in post-crack, or residual strength. The fibers will bridge across smaller sized cracks and help maintain some measure of tensile strength even in the presence of random cracks. Suppliers and specifiers will point to evidence that macrofibers can be used to spread out control joints and to limit curling due to microcracking. The idea is that concrete with macrofiber has a significant amount of non-visible cracks that tend to relieve the slab from tensile stresses. The stiffness of the fibers, coupled with the high incidence and close spacing of cracks keeps the cracks very small. The post-crack residual strength serves to provide long-term durability and reserve strength. It should be noted that macrofiber will not be nearly as effective at large cracks that arise. The author has specified macrofiber for slabs-on-grade in many buildings, with excellent results in relation to crack control, but this is not a crack prevention measure. Obviously there is a cost trade-off to plain concrete, and some fibers will be visible at the surface.

iii. Steel fiber – Steel fibers tend to be shorter in length compared to macrofiber, and generally resemble deformed wire, or wire with headed or deformed ends. Individual steel fibers have the benefit of the stiffness and strength of steel, and serve the same post-crack purpose as macrofiber. Suppliers will have data on this, but some steel fibers provide better load transfer at joints than plain concrete. Price should be studied, as well as appearance. It should be noted that steel fibers are not a viable substitute for steel reinforcing in concrete components supporting building loads (i.e., structures requiring ACI 318 design).

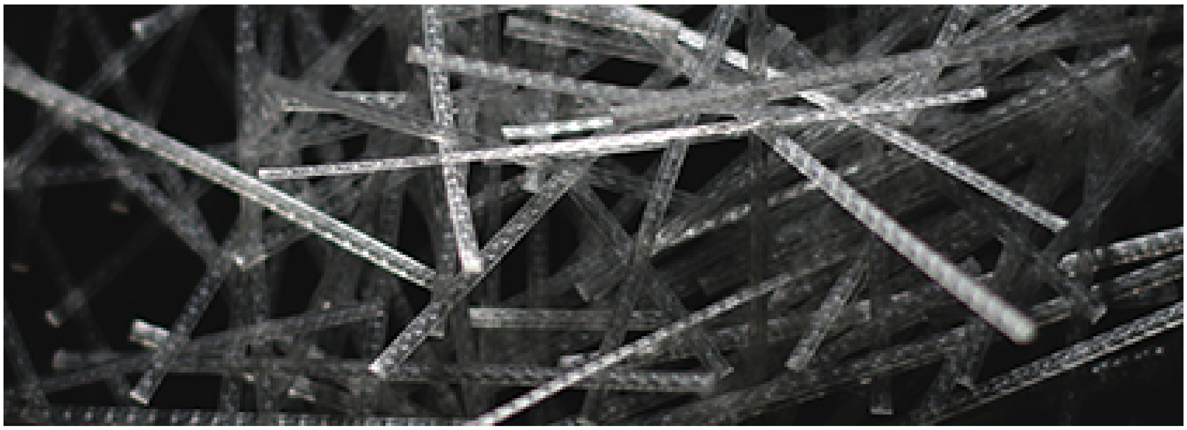

Fig. 34 - Macrofibers (https://www.euclidchemical.com/products/concrete-fibers/synthetic-macrofibers)

26) Outside of reinforcing included in the concrete mix, steel reinforcing may also be used to mitigate the effects of post-crack behavior.

   a. Deformed steel reinforcing bars, or rebar, may be used to control crack sizes. Welded wire mesh or fabric is also used. This is a grid of pre-welded wire that is laid in overlapping mats. The purpose of either method of steel reinforcing is to provide a stiff and strong ductile element in the poured concrete to help keep cracks that develop to a smaller size. Reinforcing will not prevent cracks, as the behavior at incipient cracking is dominated by the relative stiffness and strength properties of the concrete section. To properly restrain the crack sizes to sizes that can be largely ignored in slab design, the proportion of steel in the overall section of concrete needs to be roughly 0.5%, which will have a big impact on material and labor costs. Lesser amounts may be used, but generally should be kept below the 0.1% range, where there is some certainty that the concrete will control the shrinkage and cracking behavior. Reinforcing amounts of 0.1% or less may help control shrinkage and joint performance, but conclusive research would need to be found to support this claim. ACI 360 mentions the use of the "enhanced aggregate interlock" method using about 0.1% reinforcing. Steel amounts between 0.1% and 0.5% may cause random cracking as the level of restraint made by the steel governs more by degrees, but without effectively restraining the concrete cracks. (Holland, *World of Concrete*). Crack width reduction for various reinforcing amounts are shown in Fig. 35.

Table 5.3—Reduction in strain due to reinforcing concrete

Steel ratio, %	Concrete stress, psi (tension)	Steel stress, psi (compression)	Restrained shrinkage strain	Reduction in unrestrained shrinkage strain, %
0.1	14	14,078	0.000485	2.91
0.2	27	13,679	0.000472	5.66
0.3	40	13,303	0.000459	8.26
0.4	52	12,946	0.000446	10.71
0.5	63	12,609	0.000435	13.04
0.6	74	12,288	0.000424	15.25
0.7	84	11,983	0.000413	17.36
0.8	94	11,694	0.000403	19.35
0.9	103	11,417	0.000394	21.26
1.0	112	11,154	0.000385	23.08
3.0	229	7632	0.000263	47.37

Note: 1 psi = 0.00690 MPa.

Fig. 35 - Effects of reinforcing on restraining shrinkage (ACI 360)

b. A note on welded wire fabric (WWF). The American Concrete Institute (ACI) states that in order for the steel in the concrete slab on grade to properly serve its purpose it must be placed in the top half of the concrete slab (ACI 360). It is very difficult to place 6"x 6" or 4" x 4" WWF consistently in the top half of a concrete slab. The WWF mats can sag between supports, and get pushed down onto the ground when laborers walk on the mats, and they generally do not rebound. For correct, reliable, and consistent placement, labor cost may be significantly increased. As an alternative, stiffer steel reinforcing bars can be used at a wider spacing of 16" or more to allow for footfalls between bars and lifting onto chairs.

27) When finishing operations have been completed, it is desirable to slow the evaporation of water from concrete to allow the hydration process to continue to help bring the concrete to full strength, and prevent differential shrinkage between the top and bottom of the slab. The ambient conditions of temperature (both hot and cold), relative humidity of the air, rain, snow, wind, sun, and other effects may have an impact the time-dependent maturity of concrete. So, protecting the slab is ideal for concrete to perform optimally in service. The process of controlling the moisture and temperature of concrete is called curing. Based on ACI 301 recommendations, the minimum level of care for curing concrete is to protect the surface for a duration of 7 days, while keeping the surrounding temperature above 40 degrees Fahrenheit. Curing can be done in a number of ways. Some of the most widely used are:

   a. Covering the concrete in burlap and/or plastic with water added to the surface. The concrete needs to be wetted every so often. The materials need to be pinned down if wind is present.
   b. Applying curing compounds to the surface. These are proprietary products that are sprayed on to form a continuous and uniform membrane over the surface of the concrete. Some notes on the use of these products:
      i. Curing method should be based upon the purpose of the concrete, any subsequent treatment/coating/finish it will receive, and the environment in which the work is being done.
      ii. Liquid membrane-forming curing compounds must conform to ASTM C 309.
      iii. Follow manufacturers recommendations regarding:
         1. Timing of application to the concrete surface after finishing.
         2. Not applying to concrete that is still bleeding or has a visible water sheen on the surface.
         3. Ensuring visual inspection of coverage.
         4. If a single coat is not adequate, multiple coats, applied at right angles, may be required for even coverage.
         5. Concrete contractor will need to review if the concrete will be painted, or covered with vinyl or ceramic tile, in which case a liquid compound that is non-reactive with the paint or adhesives must be used, or use a compound that is easily brushed or washed off by the concrete contractor.

6. On floors, the surface should be protected from the other trades with scuff-proof paper as recommended after the application of the curing compound

c. To help keep concrete warm in cold and perhaps freezing temperatures, insulating blankets can be used to keep the concrete at a temperature adequate for continued maturity. Concrete will produce its own heat from the hydration process, so it is a matter of controlling the loss of this heat. Keeping blankets from blowing away is a major concern.

Concrete Slab Finishes and Flatness

1) Final floor finishes will generally be decided upon between the owner and architect. The engineer will need to find out what the floor finishes are to know if special precautions need to be taken to make sure the finished concrete, subgrade, and vapor barrier are compatible with the floor finishes. Besides moisture vapor concerns, floor flatness and levelness is another issue that needs review. To address this topic, ACI maintains the document ACI 117 – “Specifications for Tolerances for Concrete Construction and Materials and Commentary”. Guidance is provided therein for specifying standardized flatness and levelness criteria for various types of floors. For example, for proper installation, ceramic tile will need a certain flatness. The larger the tile, the more strict the flatness criteria will need to be. Flatness and levelness criteria is generally provided by the tile supplier. Today’s industry standard of measurement is ASTM E-1155, which calls for the determination of F-numbers: F_F = Floor Flatness, F_L = Floor Levelness. Flatness describes the waviness of a slab. Levelness describes the variation of slope of a slab. Typical criteria for a building slab is shown in Fig. 36.

   Note that floor flatness and levelness is measured within the first 72 hours. So, slab behavior such as curling may have an impact on floor finish install several months down the road. Grinding of local high spots of the slab or filling local low spots with cementitious self-leveling underlayment materials may be required, and often at considerable expense. All the more reason to control curling from the onset of design.

SLAB-ON-GRADE TOLERANCES TABLE

Occupancy	F_F (Flatness)	F_L (Levelness)
Non-critical areas such as mechanical rooms and surfaces to have thick set tile:	20	15
Carpeted areas:	25	20
Thin-set flooring:	35	25
Large Format Tile (as identified by TCNA)	50	25

Fig. 36 - Typical floor flatness and levelness specifications for concrete slabs

2) Regarding floor finishes, it is worth noting that there will always be a chance that the floor finishes will be affected by cracks or joints. With vinyl tile, cracks and joints may be reflected through over time due to service life traffic (e.g., due to equipment for materials handling and maintenance). Even very slight movements from temperature or moisture changes can cause ceramic tile to crack. Because the discontinuity will generally be very obvious, the author recommends avoiding the placement of construction joints parallel to long open areas with vinyl tile, such as main traffic aisles in retail stores. The discontinuities will clearly in reflective surfaces of well-lit areas.
3) For exposed concrete slabs, special floor treatments may be desired to provide enhanced durability or protection from chemicals. Commercial sealers are available that can provide this protection. Polished concrete needs a special system of chemical products that work with the sanding and polishing techniques.

Typical Slab Design Considerations

Minimum Slab Thickness

IBC 2018 Section 1907 states that slabs on grade are to be a minimum of 3-1/2" thick. A typical slab-on-grade thickness is 4". Anchorages for frames for handrails, half-walls, or overhanging desks or countertops require a certain thickness of that order, and things like conduits may be placed within the depth of the slab. Also, historically, 4" is a fair minimum practical thickness that can be used with a mat of conventional #3 or #4 reinforcing or welded wire mesh when reinforcing has been used, and allowances for the proper clear cover to the subgrade or exposed top are made.

Types of loading on slabs

In a typical building with interior spaces, the slab-on-grade is not a highly engineered or even critically examined structural component. In fact, the service load demand of a slab is likely far below its capacity to resist it. For normal occupancies, such as offices, stores, schools, hotels, and apartment buildings, the application of heavy or high impact loading is not common. In service, the loading might be light duty shelving or small equipment. From ACI 360, "…cracking, joint instability, and surface character problems are considered to be serviceability issues and are not relevant to the general integrity of the building structure." The largest loads these slabs would typically see are from construction equipment at original build or during remodels, or during materials handling with slow-moving walk-behind pallet jacks. So, for all practical purposes, plain concrete without steel reinforcing is well-suited to handle standard loading.

Of course, there may be areas of a typical buildings that include a warehouse space with storage racking. Depending on the height of racking, the slab thickness may need to be increased or steel reinforcing may be required. Course II on warehouse facilities would apply. Other loads may include such things as non-load bearing masonry partitions. Additional special or unusual loading may be encountered depending on building use. Fitness clubs may have areas designated for weightlifting, and therefore weight dropping. Impact loading from this type of activity can be quite severe. When these or other special loads are encountered, the slab should be adequately designed to handle them so the owner does not have major repair or replacement issues.

Other than for lateral design, there isn't a life safety issue with a slab-on-grade design for typical buildings. Unless specifically required, these slabs aren't supporting any load-bearing building elements. So, the concrete building code (ACI 318 in the United States) does not apply. The owner conveys the projected use, and the design is carried out by an engineer as a due diligence exercise. If the slab did carry building loads, it would be considered a foundation, and subject to the requisite code-driven loading and strength requirements for its design and construction.

Design of Slabs for Lateral resistance or stability against sliding

Another type of loading that needs consideration is for lateral stability of building components. Sometimes, shear walls or other lateral components tie into slabs-on-grade to engage the friction of the slab with the ground as a resisting component against sliding. Also, in a similar manner, the tops of retaining walls may engage slabs for their frictional resistance against movement. Furthermore, walls at truck dock areas are built with a drop in elevation so that the truck bed is even with the facility's slab. To reduce the vertically unbraced height of the wall, the slab again may be used as a horizontal resisting element to brace the wall. All of these examples would tend to fall under ACI 318 requirements, or those requiring design under the more critical lens of the structural building code.

Design of Slab for Strength against Loading

(Note: For a more in-depth look at the strength and durability design on concrete slabs on grade, See Course II.)

Use of Steel Reinforcing in Slabs-on-Grade

Historically, it has been a common standard practice for engineers to specify a nominal amount of slab reinforcing for slabs-on-grade. Some notes on this:

- In slabs on grade, reinforcing is generally not needed for strength unless there's crane traffic or other significant loading that would need to rely on reinforcing to resist it. However, it's not until the slab cracks that the reinforcing will do its job, so if the slab cracks, it may need to be replaced.
- No amount of reinforcing will keep the slab from cracking. The crack width may be reduced with reinforcing, but will likely still be of a size that will reflect through brittle finishes. At slabs-on grade, control joints and good concrete design and execution are acceptable methods to help with this.
- At slab joints, a nominal amount of reinforcing such as #3 bars at 16" on center may be too much (0.2% by area) such that the cracks may actually happen outside the sawcut because reinforcing is too strong across the joint. So, cutting half the bars at the joints in this case might be a good practice.
- Again, many buildings have designated areas for warehouse-type use with storage racking, forklifts, and pallet jacks. Retail stores are increasingly undertaking more storage within same building as the store, and the storage racks may even be located on the sales floor. Depending on the severity of loading and the amount and type of lift traffic on the slab, these slabs will need to be reviewed closely. For example, for storage racks in seismic zones, uplift and shear at base plate anchors need to be checked, and often controls the slab thickness design.

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