

Design of Slab-on-Grade/Ground (SOG) Construction

Fine Print: The information below is not a research paper and no references are provided; it is a compendium of material gathered during my years of practice. The information provided is generally correct, and the reader is invited to research the contents for verification. Any comments or criticisms are invited.

General

SOG construction consists of placing a concrete slab on the existing native soil. The existing native soil may consist of a layer of engineered fill to bring the slab to proper elevation. The existing native soil, in many instances, is considered the sub-base.

On top of the sub-base, the base course is compacted. This provides additional bearing support and a generally flat surface.

On the flat base course, a concrete slab is constructed. The thickness of the concrete slab depends on the type of loading and the quality of the native soil on which the construction is founded. To prevent moisture from 'wicking' up through the concrete from the native soil, often a vapour retarder is installed between the base course and the concrete slab.

You can never guarantee cracking will not occur, but you can, however, minimise it with care. For proper construction, it is necessary to specify the proper base and sub-base, concrete mix design, provide control joints, and provide a manner of curing.

Concrete is a brittle material and to minimise random cracking, if the minimum dimension of the slab is greater than 5m, it is also necessary to provide proper control joints. The use of control joints should always be considered as part of the SOG construction.

For high quality or special purpose SOG construction, review of the Work should be considered as part of the project.

In many locales, there are specialty designers and contractors that work with SOG construction.

SOG construction is one of the most trouble prone and litigious elements of concrete work; care and diligence is essential.

There are several good publications for SOG construction. These should be reviewed prior to commencing a significant SOG project.

Design

Most SOG construction is subject to minimal, static loading and these are generally infrequent. If frequent and moving loads are encountered, then the SOG should be constructed as a pavement. This is considered as a sub-set of SOG structures. Pavement design includes consideration of both flexural stresses encountered and repetitive loading. If high loads and/or patterned loads are involved, then special consideration should be made to accommodate them.

The effect of a pattern point load may influence stresses in the concrete slab at point load locations adjacent to the load under consideration. This additional loading should be considered in the slab design. The design can include for point loading, line loading and wheel loading.

SOG construction can be designed based on a "drag formula" which tries to accommodate the shrinkage of the concrete and restraint of the granular base material.

SOG construction can also be designed by limiting the flexural tensile stresses generated by loading to a portion of the concrete modulus of rupture for flexure. The flexural stresses can be determined by elastic solutions or FEM studies.

The design may include for granular base materials as well as the sub-base. These can contribute to the modulus of subgrade reaction which is one of the 'key' soil parameters for SOG design. A multiple layered approach can be used; this is normally reserved for high quality, or special purpose SOG construction. Examples of this type of construction could be large cargo terminal buildings, airport runways, high speed highways, etc.

When designing for flexural tensile stresses, it is necessary to consider the probability of loading as well as fatigue issues.

Before designing the slab, determine the end use from the owner. Carefully document what the purpose of the slab is, and what loads it is required to resist. Loading may be in the form of point loads, line loads, uniform loading on various areas, and loading from equipment used on the slab. Record the frequency and magnitude of loading. Determine if there are racking loads, with isles between the racks and determine if there are pathways with forklift traffic. Loads can be static or dynamic. Determine if there is a high repetition of loading that the slab needs to be designed for fatigue loading. Heavy point loads from racking and forklift traffic often govern the design of the slab. Make sure the client is advised of the loading parameters the slab has been designed for 'in writing'. This may eliminate some future dialogue about the capacity of the slab. Also determine if there may be future loads that should be considered during the initial design.

Base and Sub-base

The sub-base can be proof rolled to check for uniformity of bearing materials. Soft areas can be excavated and or scarified and re-compacted with engineered fill. The more uniform the base and sub-base, the better the SOG construction.

The base should be a uniformly graded quality granular material that readily compacts. It provides a bearing surface for the concrete SOG over. There is research by both the American Concrete Institute (ACI) and the Portland Cement Association (PCA) that the effect of compacted granular base is minimal. To a lesser extent, it helps transfer loading from the concrete slab to the sub-base below. In addition, it can provide a smooth hard surface on which to construct the SOG.

The base aggregate under the slab should be carefully specified. A uniform degree of compaction with no soft spots and a relatively smooth surface is needed. A non uniform surface provides projections that can restrain a slab and promote cracking.

Vapour Retarder

To minimise moisture entering the SOG from the sub-base and granular base material below, it is common practice to place a polyethylene vapour barrier between the slab and base. To minimise curling of the slab, it is also practice, in some locales, to place 50mm or so of sand material between the polyethylene and the slab. This permits water from the concrete mix to seep into the sand layer and provides a more uniform moisture content throughout the concrete slab.

Concrete

Concrete testing can be predicated on using the compressive strength of concrete or, more correctly, the flexural tensile strength based on 'beam tests'.

The mix design must be carefully selected. A low slump concrete should be used to minimise shrinkage. a 75mm maximum slump is often specified. Note the use of the word 'maximum' and not just a 75mm slump. In some locales, a 100mm slump satisfies a 75mm specified slump. A superplasticiser can be utilised to achieve workable mix when a low slump is specified.

Consideration of a large proportion by weight of flyash should be made. This has the effect of

reducing shrinkage, but causes a slower strength gain. Large amounts of flyash may have an effect on the finishing of the concrete surface.

If the slab is exposed to freeze-thaw conditions, the concrete strength, water:cement ratio, and air content should be carefully considered.

If the slab is exposed to deicing chemicals, there are additional considerations for the concrete design, such as strength, water:cement ratio, curing and sealing should be carefully considered.

If the slab is exposed to sulphates, there are additional considerations for the concrete design, such as sulphate resistant cement, strength, water:cement ratio, curing and sealing should be carefully considered.

If the slab is exposed to sulphates and chlorides, there are additional considerations for the concrete design, such as strength, water:cement ratio, curing and sealing should be carefully considered. Sulphate resistant cement is contraindicated for chloride resistance and a fly ash mix using 25% or 30% by weight of flyash.

The temperature differential between the top of the slab and the bottom of the slab should be minimised. This can be challenging when slabs are cast in sub-zero weather. Procedures for hot and cold weather concreting are applicable for SOG construction due to the general thinness of the elements involved.

Slab Thickness

The slab thickness is determined by the design loading and the quality of the base and sub-base materials below. Soil properties can be determined by a qualified geotechnical consultant. Refer to information contained under the heading 'Design'. There are some excellent resources and design aides available for determining the thickness of a concrete slab.

You should try to use a 125mm slab thickness minimum. Many codes require the concrete thickness to be three times the maximum aggregate size. This permits the use of 40mm aggregate to minimise shrinkage.

If the slab is used for supporting loads in the same fashion as a strip or spread footing, then some codes require a minimum thickness of 200mm.

Reinforcing

It is common to place reinforcing steel in the upper one-quarter of the slab thickness. This is somewhat contrary to flexural mechanics. Maximum flexural moments occur at the bottom fibre of the slab. In addition, tractions produced by the base material on the bottom of the slab, tend to increase the bottom fibre tension and put the top fibres of the slab in compression. The reason for placing the steel in the top is to minimise cracking on the top surface which is subject to 'wear and tear'. Cracking of the top surface is not aesthetically pleasing because it is visible. Cracking of the underside is not so noticeable.

Reinforcing is often placed in a single layer near the top of the slab. It is common to place the reinforcing to provide a concrete cover equal to the depth of the sawcut.

Cracks on the top become accentuated with time due to objects moving over the top surface.

Although some jurisdictions permit reinforcing steel to be placed at five times the slab thickness, a spacing of three times the slab thickness should be considered.

The effect of reinforcing in small amounts is somewhat nebulous and its main function is to hold the concrete sections together to help develop the aggregate interlock at the fractured surface. For improperly timed, sawcut joints, is also helps distribute cracking a little better and minimises crack widths.

It is common to provide 0.2% of the concrete area as reinforcing steel area. This proportion can be increased to 0.5% or 0.6% to largely 'eliminate' visible cracking. The cracks still occur, but they are much more frequent and have a greatly reduced crack width.

Control Joints and Sawcutting

Unreinforced, or minimally reinforced, slabs usually have control joints located at 35x to 40x the slab thickness, but not greater than 5m or so. This is recommended by the ACI SOG committee.

If the structure is unheated, then the sawcuts should be at a closer spacing.

It should be noted that the time for sawcutting is critical. This is more important for a thin slab. A thin slab reacts to changes in temperature, and humidity.

The sawcuts should be made with an "early entry" saw, or 'Soff-Cut' saw, that permits sawcutting within two to four hours of the completion of the floor finishing. Sawcut timing is critical. Without an early entry saw, sawcutting should commence within 6 to 8 hours after finishing. CSA A23 stipulates that sawcutting should commence as soon as possible. Concrete should have sufficient strength to prevent the aggregate from ravelling behind the saw blade. If too much time passes, sawcutting is superfluous and the location of the microcracking has determined where the cracks will form. In this instance, the location of the sawcuts will not make any difference.

The depth of sawcut should be a minimum of one-quarter of the slab thickness.

The sawcutting pattern should correspond with any interior columns.

The sawcutting pattern should not cause an angle between the adjacent panel of less than 40°.

The sawcut should continue if it terminates at the edge of the adjacent panel.

For irregular shapes, the sawcutting pattern can be shown on the construction documents.

In addition to sawcutting, construction joints should be located at approximately every twenty metres.

Projections or re-entrant corners in the slab that will restrain movement should be detailed so they are isolated.

After the initial shrinkage has occurred, sawcuts should be filled with a caulk material that adheres to the concrete sawcut face and provides support for the concrete adjacent to the sawcut. This can be a polyurethane material that has a hardness to prevent the ingress of particles. For heavier loaded slabs, the caulk hardness should be increased.

Slab Flatness

Because of new equipment used for material handling and storage, slabs may require a degree of 'flatness' today that was not required several decades ago. It is not uncommon to have storage racks that tower 40' or 50' above the finished floor level. To safely store and recover items stored at such heights there is a need for slabs to be extremely flat. Once the need for a flat slab has been determined, it is a matter of determining how flat. This information can often be provided by the equipment supplier. Alternatively, the client may be able to provide it or the degree of flatness can be

determined from guidelines for the use. There are a couple of methodologies for specifying and checking the flatness of the slab to be constructed. The 'Face', Ff/FI, method is used in North America and the Free Movement Classification, FM, is used in Europe. Examples of the Face 'flatness' are as follows:

20/15	Mechanical Rooms, Parking Structures, Etc.
25/20	Carpeted Areas of Commercial Office Buildings
35/25	Typical Warehouse for Moderate/Heavy Random Traffic, Factory, Etc.
45/35	Considered 'Flat' for Typical Warehouse with Air Pallet Use, Ice Rinks, Etc.
65/40	Considered 'Very Flat'
100/50	Considered 'Super Flat'

Alternatively, with the Free Movement Classification:

The maximum vertical deviation over 600mm shall not exceed:

2.5mm for quality FM1,
3.5mm for quality FM2, and
5.0mm for quality FM3.

and, the maximum vertical deviation over 3.000m shall not exceed:

3.0mm for quality FM1,
6.0mm for quality FM2, and
8.0mm for quality FM3.

The degree of flatness required should be determined with some care because the cost increases significantly with each improvement. The cost also increases in a similar manner for remediation of a non-conforming slab.

Curing

Concrete curing prevents water within the concrete from leaving by evaporation and encapsulates the concrete to keep the water within the concrete itself. The curing 'envelope' can also prevent water loss from exposure to sunlight and effects of wind. Proper curing of concrete is essential for concrete to develop its specified strength and enhances the long term durability. This is achieved during the initial strength gain of the concrete surface.

The common means of curing can be achieved by the means of chemical surface coatings that prevent evaporation. This curing agent should be applied immediately after finishing. Some curing agents are coloured white to clearly show that they have been uniformly applied, and the white colour has the effect of reflecting sunlight to minimise evaporation due the surface heat. Usually a good curing compound will have a high solids PVC content. Due to their poor track record, polyvinyl acetate (PVA) products should be avoided. In addition, there are other methods:

- The concrete surface can be flooded to provide a layer of water that precludes evaporation;
- The concrete surface can be misted. This has a similar method of protection as flooding;
- Special care should be made for SOG's cast in the open air to prevent undue evaporation by exposure to direct sunlight and any wind. Additional care should be taken for thin slabs.
- Burlap fabric can be applied and this surface wetted down. This prevents evaporation; and
- For beam and columns, the formwork can be left in place. The formwork should be loosened once the concrete has achieved sufficient strength to prevent damage, and then left in place. The formwork can be wetted down periodically. Failure to loosen initially it may cause excessive damage to the concrete surface and/or the formwork if they are loosened at a later date. For flatwork, tarps or insulated tarps can be applied. These methods help minimise water loss due to evaporation.

Curing should be maintained for the initial strength gain, and preferably longer. If maintained longer, no harm will come to the new concrete and the concrete qualities may be enhanced.

With cold weather concreting, it is essential that the concrete not freeze. There are anecdotes of concrete freezing and hydrating to proper strength after thawing, but it's best 'not to go there'. Once the cement gel has started to form, the fresh concrete can be severely and irreparably damaged.

Cold weather protection can be considered as part of the curing process. Formwork is generally enclosed in a heated environment; this may be the construction area or local to the formwork. Heat is applied to keep the plastic concrete from freezing. For flatwork this is achieved by added heat and the use of insulated tarps. Care to provide proper ventilation of the fuel fired heating units to prevent a build-up of CO₂. The latter reacts with the water in the concrete to produce a mild acid that can cause 'dusting' of the surface.

Heat should not be sufficient to desiccate the concrete surface and application should be maintained for the initial strength gain, and preferably longer.

Sealers

A concrete sealer is necessary to protect the concrete from deterioration. There is disagreement within the engineering community that these are even required; this engineer's opinion is that they are. The deterioration is normally due to exposure to chloride or sulphide chemicals. These are present in de-icing chemicals that are used to thaw water that has frozen on the concrete surface.

Salt damage is most commonly due to exposure to de-icing salts. However, any chemical containing chlorides, including sodium chloride, potassium chloride, calcium chloride etc. found in "safe de-icing chemicals," fertilizers, ocean water, etc. present a danger to the concrete. All are mildly acidic, and attack the cement gel that bonds the concrete.

There are several types of concrete sealer and you must choose between surficial and penetrating sealers. Both types penetrate the concrete surface slightly with the penetrating sealers going deeper. Sealers generally fall into the following chemical groups: silicate, siliconate, silane, and silane/siloxane products. Most sealers reduce moisture penetration by 90% or more. Reducing surface water penetration freeze-thaw deterioration is reduced. This helps prevent damage caused by vegetation, etc. and reduces staining and discolouration. The silicates and siliconates are low VOC, and the writer is unaware of any respiratory contraindications.

Silicates

This is considered as a surficial sealer. Silicates, in the form of sodium or lithium silicate are used. Chemically they are both similar. They react chemically with the concrete to form a calcium silicate hydrate (CSH) and are also known as densifiers. The CSH forms in the concrete voids; the density of the concrete increases slightly and the size of the voids decrease. Sodium silicate has a long history, and was originally known as 'water glass'. It was used to coat egg shells and increase the useful life of eggs. Silicates do not suffer from UV degradation.

Some of the advantages of using a densifier are:

- it can increase the surficial strength of the concrete, and marginally reduce wear;
- it marginally reduces dusting of the concrete surface by providing a harder and more durable surface;
- it marginally reduces curling of the concrete slab by allowing moisture to pass unimpeded; and
- it does not alter the appearance of the concrete.

The reader is invited to review the use of silicates and determine if they are suitable to purpose.

Siliconates

This is considered a surficial sealer. They have the advantage of not discolouring the concrete

surface or leaving a surficial film. Like silicate sealers, they chemically react with the concrete to produce a hydrophobic barrier; they do not suffer from UV degradation.

The reader is invited to review the use of siliconates and determine if they are suitable to purpose.

Silanes

Silanes are silicon chemicals that can react with inorganic substrates such as glass to form stable covalent chemical bonds. Depending on the process, they can be hydrophobic or hydrophilic. Silane, itself, is a flammable, poisonous gas, and irritant. They are also used as 'coupling agents' to improve the adhesion of some caulking and adhesive materials. Silane is rendered less harmful by suspending it in a water or solvent based solution. Care must be used in its application and MSDS sheets should be referenced for all products using the material.

Silanes have a relatively small molecule size and are able to penetrate concrete surfaces to a depth sufficient for protection. They can be used on concrete surfaced that are subject to abrasion due to this deeper penetration. To form a chemical bond, Silanes rely on the high alkalinity (or pH) value of the concrete to act as a catalyst. They perform very well on most concrete, but perform better on recently cast concrete. They reduce the absorption of surface water and, in the process, reduce deterioration caused by water absorption or reduce moisture transmission through concrete pores/voids. This can include cracking, spalling, pitting, freeze-thaw damage, and efflorescence. In addition, mold and mildew growth can be inhibited, reducing stains caused by these processes. You want to select a 'high solids' product. A good product will have a life expectancy of between 5 and 10 years, before re-application. They can be applied by roller or by spray. Two coats are generally recommended with the second coat applied at 'right angles' to the first.

In order to prevent de-icing and chloride damage it is best to use a silane sealer or a blended water based silane/siloxane sealer. If you are looking for the much desired water bead effect choose a silane/siloxane blend.

Both water based and solvent based silanes are available. The solvent based sealants have slightly better penetration, but are not as VOC friendly. Water based products generally have a lower VOC content and are easier and safer to apply. They are less flammable and have fewer fumes.

If the existing surface has already been treated with a siloxane sealant, then in all likelihood, a solvent based product is prescribed. If a water based solution is applied and it 'beads' on the surface, then a solvent based product should be used. Also if you want to apply a different sealer over, such as an acrylic one, then you want to consider using solvent based. In all matters, such as this, the material supplier and/or the technical data sheets should be consulted. If the surface is to receive a finish or a covering requiring an adhesive, the supplier should be consulted.

Unless formulated properly, they can discolour the substrate they are being applied to.

The reader is invited to review the use of silanes and determine if they are suitable to purpose.

Siloxanes

Siloxanes or silane/siloxane based sealers are similar to silane sealers. Manufacturers have learned that by using a blend, the overall product is improved. The addition of silane is generally used to improve the characteristics of siloxane sealers. The molecule size of siloxanes, compared to silanes is much larger. This reduces the depth of penetration and abrasion resistance. Because of this, siloxanes are often used for vertical surfaces where abrasion is not normally part of the environment. They perform well on concrete, brick, or CMU surfaces. The use, application and durability is similar to silane sealers.

Unless formulated properly, they can discolour the substrate they are being applied to.

The reader is invited to review the use of siloxanes and silane/siloxane blends and determine if they are suitable to purpose.

Slopes

Exterior concrete surfaces should be sloped to permit drainage. This gives the surface better utility and safety. A flat surface that is relatively smooth may present a 'slipping' hazard. Sloping the surface also marginally improves the longevity by reducing the water contact. Precipitation does not remain on the surface and the growth of mold or mildew is reduced. Small cracks are not allowed to remain with water and in cold environments this can reduce freeze-thaw damage. A distinctive slope may be beneficial for any 'Stormwater Run-Off Calculations' if site drainage is an issue.'

The slope should be significant to promote drainage. An absolute minimum slope of 1% should be considered, and a slope of 1-1/2% to provide good drainage would be a better choice. Drainage can be to the exterior edges with suitable swales to remove the water flow. Alternately, a more complicated series of interior drains with catchbasins and piping can be incorporated. The latter has to be properly designed allowing for storm conditions, cleaning, freeze-thaw, etc.

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