

Curling of Concrete Slabs on Grade

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This Update reviews the causes of curling in on-grade concrete slabs and discusses methods of repair for various environmental conditions.

Concrete slabs on grade tend to curl up at joints and around the perimeter, sometimes causing the slab to lose contact with the subbase material. In industrial buildings such as factories and warehouses, concrete floors must remain smooth and flat to enable forklifts, high-reach stackers and other specialized equipment to operate safely and with precision. At a joint where curling has occurred, crossing the step in

elevation is often enough to cause the forks of a forklift truck to scrape the surface of the floor. In addition, edges of the slab may spall or fracture if subgrade support has eroded. As a result, floors may deteriorate rapidly, causing safety problems and requiring repairs.

Curling is most noticeable at construction joints, but it can also occur at cracks and saw-cut joints (Figure 1). At slab corners, the upward curl can be as much as 25 mm, but most slabs that have the curl repaired have edges that have risen 5 to 10 mm from the original plane.¹ At construction joints that have no provision for load transfer, curling generally results in a loss of subbase contact over about 20% of the slab length between joints (Figure 2), twice the amount lost at saw-cut or doweled joints.

Cause

The basic cause of curling is differential shrinkage that occurs in a slab as the exposed top surface shrinks and the core does not. This shrinkage is usually due to drying, but can also be caused by carbonation of the surface concrete, or, in cement-rich high-strength concrete mixes, by the internal desiccation (autogenous shrinkage) that occurs as the cement paste hydrates.

Concrete, like many construction materials, is not dimensionally stable when subjected to changes in moisture content. As new slabs dry from the surface down, the moisture gradient through the slab leads to differential shrinkage. Carbonation adds to surface shrinkage, but may be reduced by

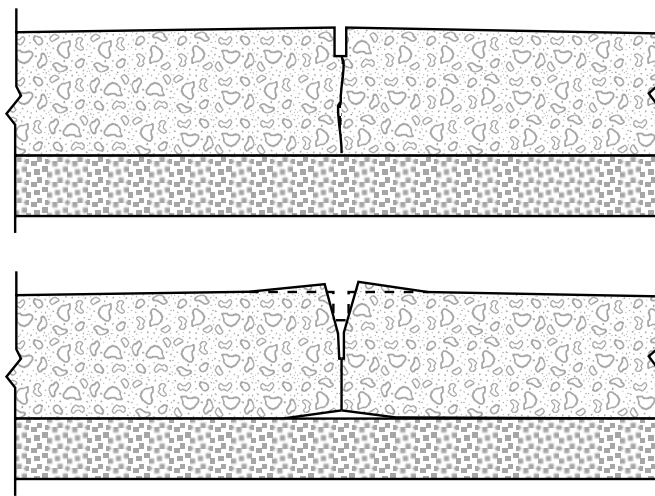


Figure 1. Curling at a sawcut joint

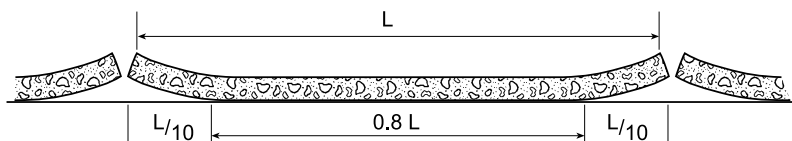


Figure 2. Slab edge curling resulting in a 20% loss of subbase contact

the use of surface coatings, sealers and waxes.² If the finishing techniques used cause the cement paste and fine aggregate to be concentrated at the surface, differential shrinkage can be aggravated. Heat produced as fresh concrete hardens can also exacerbate differential shrinkage in cement-rich mixes. Bonded or monolithic concrete toppings are prone to curling as they cure and shrink relative to the base slab, both in new construction and at repair locations.

Factors

The factors that affect the amount of curling in a slab are those that determine the relative humidity and moisture gradient within the slab. These include the subbase material, concrete mix characteristics, handling of the concrete and in-service conditions after construction.

Subbase

Generally, a slab subbase consists of one of three materials: 20 mm clear crushed stone, graded crushed stone with limited fine material, or pit-run gravel. All three materials permit drainage of excess mix water from the concrete. Clear crushed stone acts as a capillary barrier, but graded crushed stone and pit-run gravel permit capillary movement of ground water up to the lower slab surface. Because of this movement of ground water, it has become common to lay an impermeable polyethylene barrier sheet on the subbase before placing the concrete slab. While the poly sheet may prevent water from entering the underside of the slab, it also prevents excess mix water from draining from the new concrete, which exacerbates the curling. Even when workers perforate the barrier to encourage drainage, the poly sheet decreases friction between the subbase and the slab, and the overall shrinkage of the slab tends to increase.

Concrete Mix

Concrete mix characteristics such as water-cement (w/c) ratio, cement type, aggregate type, admixture types, cement content and mix temperature affect the shrinkage rate of concrete.

W/C ratio. Concrete mixes with a high cement content and a very low water/cement (w/c) ratio (less than 0.30) are likely to develop significant autogenous shrinkage.³ Mixes with too high a w/c ratio contain an excessive amount of free water, which increases the porosity and results in high overall shrinkage.

Cement type. The use of cement (such as Type 30) that has inherently high shrinkage characteristics can increase overall shrinkage by 25%.²

Aggregate. Contamination of the aggregate or the use of aggregate that is susceptible to expansion and shrinkage can cause serious shrinkage problems in all concrete mixes. It is important to incorporate the maximum coarse aggregate content possible in order to keep the cement paste portion of the mix to the minimum, while maintaining acceptable workability for ease of placement.

Other mix characteristics. Cement-rich concrete mixes have high shrinkage rates, and the use of a high-slump mix can increase shrinkage by 10%. In rich mixes, the heat produced when cement hydrates also increases curling because of the temperature difference between the surface and the core of the slab. The slab surface shrinks as it cools and sets, while the interior remains warm and expanded. High concrete mix temperatures during winter construction work can also increase this effect. In addition, some water-reducing admixtures actually increase shrinkage.

Handling

Rapid evaporation from the surface of fluid mixes encourages differential shrinkage. Over-finishing of the slab surface by repeated trowelling to produce a dense abrasion-resistant surface can cause cement paste to rise and larger aggregate particles to sink, which results in curling because of the higher shrinkage rate at the surface. Improper curing intensifies differential shrinkage if the surface is allowed to dry too quickly. When sawcutting of joints is delayed, cracking and subsequent debonding occurs at the bottom of the sawcut (Figure 3).⁴

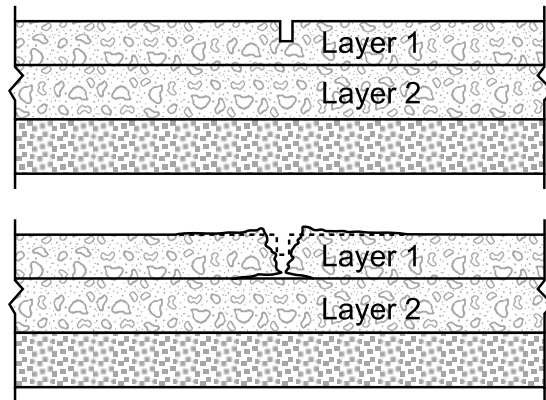


Figure 3. Cracking and subsequent debonding at sawcut joints due to delayed cutting

In-service Conditions

The very dry interior environments that result from the cold winters in most of Canada worsen the moisture gradient in newly constructed slabs, and encourage curling. Radiant heaters over loading dock doors also rapidly dry slab surfaces, especially during the first winter, and exacerbate any tendency to curl.

Prevention of Curling

Although it is possible to repair curling in most slabs, prevention is preferable.⁴ By reducing and controlling shrinkage, slab curling can be minimized. Good mix proportioning, placing and handling, especially curing, and the use of shrinkage-reducing or shrinkage-compensating admixtures can also help.

Concrete Mix

Control of shrinkage and curling is affected by the water content, temperature, cement type and content, and aggregate in the concrete mix. The water content of the fresh concrete should be decreased as much as the desired workability will allow. The use of a low w/c ratio, high-range water-reducing admixtures, largest-sized aggregate possible, and maximum volume of graded coarse aggregate possible per unit volume of concrete keeps water content low. The maximum temperature of the concrete mix should be controlled during placement, preferably to less than 10°C. If occupancy requirements permit, the mix design should be based on 60- or 90-day strength, to reduce amount of cement paste in the mix.

Part of the Portland cement can be replaced with blast furnace slag or fly ash, to reduce heat generation from cement hydration. Routinely, a 25% replacement rate has been used, but in hot weather or in tropical areas, up to 50% has been replaced. Use of aggregate with inherently high shrinkage should be avoided.

Handling

Proper handling is key to decreasing curling in concrete slabs. Avoiding the use of a polyethylene sheet over the subbase can help reduce shrinkage and curling. Every effort should be made to avoid placing high-quality slabs on grade before the building roof is in place. It is also preferable that the walls be constructed as well, to provide shelter for the slab from the drying effects of wind. Excessive finishing or any procedure that will depress coarse aggregate and produce a concentration of cement paste and fines at the surface should be avoided. The concrete should be properly cured before it is allowed to dry out.

Controlling Curling

Because some curling of the slab is unavoidable, proper use of saw-cut joints can help to decrease the need for repair. Saw-cut joints should be spaced according to guidelines from the Cement Association of Canada (formerly the Portland Cement Association), and should have a depth of at least one-quarter of the slab thickness.⁵ “Soft-cut” saws can be used as soon as workers can access the floor slab, and the joints produced by them appear to provide contact and shear transfer across the cracks occurring at the bottom of the slab.

Many engineers believe that reinforcement of the upper layer of a slab can oppose curling, but the amount of reinforcement required to restrain curling renders this option uneconomical. In addition, concrete placement by laser screed machine has made preplaced reinforcing mats undesirable.

Preventing Damage to Curled Slabs

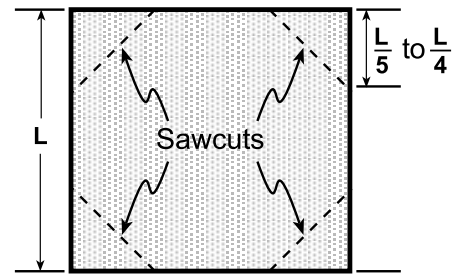
Where a slab has curled, with even as much as a 7-mm difference in elevation at a joint, repairs can be avoided with good forklift truck operation. Using pallets properly, keeping forks high enough above the floor, restricting truck speed and limiting loads can all help maintain a slab in reasonable condition. Skidding pallets across a curled slab can spall joint edges with the slightest difference in elevation, causing unsightly gouges at the joints if any nail heads are protruding.

Loss of sub-grade support causes slab movement as a forklift passes over the joint, with the result that edges start to chip and deteriorate, followed by cracking parallel to the joint. This kind of deterioration usually requires repair.

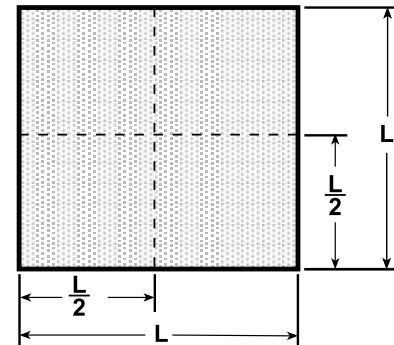
Repair

The decision to repair a floor slab is based on the future expected performance of the floor and the cost effectiveness of the repair. The age of the slab and the measured movement of the slab joint edge as a forklift truck passes over the edge indicate whether a repair is appropriate. Movement less than 2.5 mm is considered acceptable, and over 5 mm severe and needing repair. Between 2.5 and 5 mm is a “gray” area.¹ Repairs to a slab with movement of 2.5-5 mm may improve floor performance, but not be cost effective, and without repair the floor may deteriorate, but still be acceptable.

Repairing the slab while it is still curling can compound the problem. A slab’s moisture environment changes from saturation as fresh concrete, to controlled drying in service. After the slab has become stable with respect to its moisture cycle (typically after two heating seasons), movement can be measured, and a repair technique can be selected. A variety of techniques are used to deal with or repair curled slabs: waiting, ponding of the surface, installation of more joints, grinding, grouting and grinding, patching, and installation of dowels.



Diagonal cuts at curled corners



Cuts at panel centerline

Figure 4. Installation of additional joints through diagonal and centreline cuts¹

Waiting. As the slab dries and the moisture content becomes more uniform, curling is often reduced without intervention. Creep of the slab under self-weight also reduces the amount of curl. Measuring and monitoring the slab movements help determine whether any repairs are needed.

Ponding. Wetting the top of the slab temporarily reduces or reverses the amount of curl. Sometimes more joints are cut while the slab is level after ponding.

Cutting more joints. Cutting additional joints at slab corners or panel centrelines (Figure 4) after the first heating season can reduce curl by up to 50%. This repair is not suitable for floors with forklift traffic.

Grinding. After the second heating season, edges and corners can be ground to a distance of 60-180 cm from the curled edges. Because grinding makes the slab thinner, this repair may not be suitable for areas with forklift traffic.

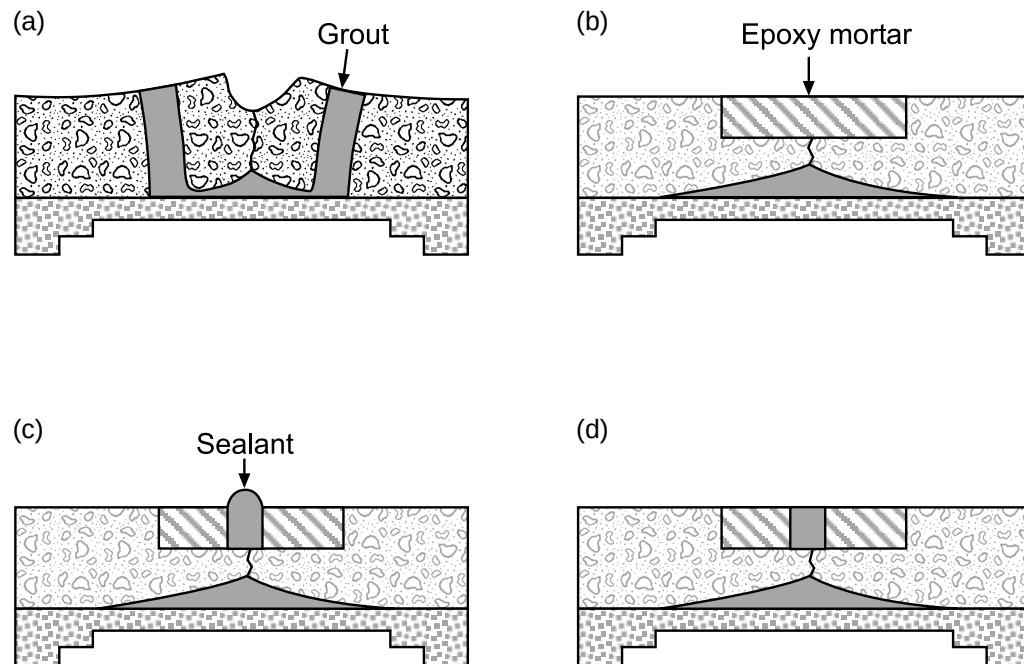


Figure 5. Sequence in repair of curled joint¹

- (a) grouting of void
- (b) sawcutting and filling with mortar
- (c) recutting and filling of joint
- (d) resulting smooth flat joint

Grouting and grinding. Grouting and grinding is typically used on floors subjected to frequent or heavy forklift traffic. Holes are drilled at elevated edges and corners, and under-slab voids are filled with grout. After the grout hardens, the curled edges are ground to the desired floor profile.

Patching. Voids under the slab are grouted as above, and the curled area is repaired by sawcutting around the area to be patched, chipping out concrete below the desired profile, and patching to the required elevation (Figure 5). This partial depth patching with grouting is suitable for areas with forklift traffic.

Installation of dowels. Dowels can be used alone or in combination with other procedures to improve load transfer and minimize differential movement. Because of the cost, they are best used in high traffic areas of slabs at least 150 cm thick, where soft subgrade soil makes grouting unsatisfactory.

Summary

Concrete slabs on grade tend to curl up at joints and around the perimeter, causing problems in industrial and commercial buildings. As a result, floors may deteriorate rapidly, causing safety problems and requiring repairs. Although it is possible to repair most slabs, curling can be minimized by careful control of concrete mix composition and handling. The repair options available depend on the service conditions and the severity of the problem.

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