

Concrete in Practice

What, why & how?



CIP 19 - Curling of Concrete Slabs

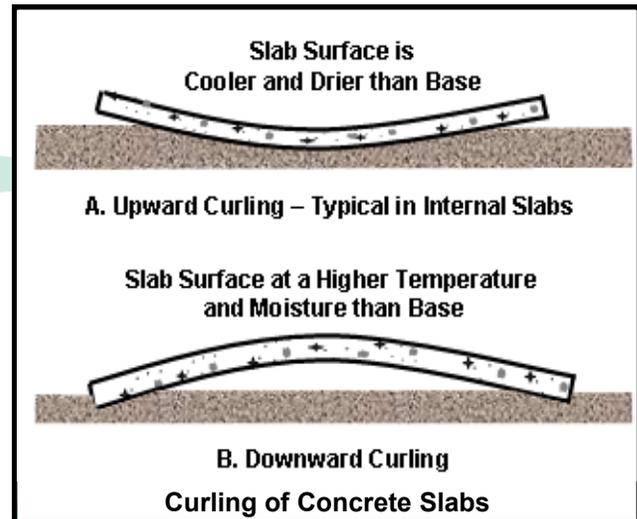
WHAT is Curling

Curling is the distortion of a slab panel into a curved shape by upward or downward bending of the edges and corners at joints or cracks. Curling is primarily due to differences in moisture and/or temperature between the top and bottom surfaces of a concrete slab. The distortion can lift the edges or the middle of the slab from the base, leaving an unsupported portion. The slab section can crack when loads exceeding its capacity are applied. Slab edges might chip off or spall due to traffic when they curl upwards. Curling is typically evident at an early age; however, its occurrence may occur over a period of time. The terms *curling* and *warping* are used interchangeably.

WHY do Concrete Slabs Curl

Differential changes of top and bottom slab surface dimensions results in curling. These volume changes are most often related to moisture and temperature gradients within the slab. When one surface of the slab changes size relative to the other, the slab will curl at its edges in the direction of relative shortening. The resultant curling is noticeable at the joints, edges, and corners. Drying shrinkage is the primary characteristic of concrete that impacts curling. Factors that increase drying shrinkage of concrete will tend to increase curling. Drying shrinkage of concrete increases with an increase in the water content and volume of paste in the concrete mixture. Aggregate type can also impact shrinkage.

The more common occurrence of curling is when the top surface of the slab dries and shrinks relative to the bottom. This causes an upward curling of the edges of a slab (Figure 1A). This is more commonly seen in interior floor slabs on ground. The top surface of the slab is exposed to a dry environment while the bottom is in contact with moist soil, causing the differential drying and shrinkage. During construction, excessive bleeding due to high water content in the concrete or water sprayed on the surface causes increased surface drying shrinkage relative to the bottom of the slab. This can be exacerbated with slabs placed directly on



a vapor retarder or with slab topping layers. Slabs placed on an absorptive subgrade will reduce bleeding and reduce the potential for curling.

Thin slabs and long joint spacing tend to increase curling. Thicker slabs will curl less as the weight of the slab counteracts the tendency to curl. In industrial floor slabs, close joint spacing that increase the number of joints is undesirable. Heavy forklifts and other traffic with hard wheels increase stress on the surface and damage joints with very marginal curling; or increase stress in unsupported portions of the slab to cause cracking in the slab panel. Joint spacing should be such that there is a balance between the potential for random cracks and increased curling at the joints.

Downward curling (Figure 1B) is typically caused by temperature differences between the top and bottom of the slab. This is more common in exterior slabs where variations in moisture and temperature gradients are dynamic. The top part of the slab exposed to the sun or higher ambient temperatures will expand relative to the bottom of the slab in contact with a cooler subgrade.

Temperature differential can cause upward curl when the slab surface temperature is cooler than the bottom and this will add to the upward curling caused by moisture differentials. This can occur on exterior slabs in cooler dry weather when the subgrade temperature is warm.

HOW to Minimize Slab Curling

The primary factors controlling dimensional changes of concrete that lead to curling are drying shrinkage, slab thickness and joint spacing, construction practices, moist or wet subgrades, and temperature gradients within the slab. Curling will diminish with age as differential moisture and temperature through the slab section diminish. The following practices will help to minimize the potential for curling:

1. Use the lowest practical mixing water content in concrete. Concrete slump has no bearing on curling; mixing water content does. Avoid placement delays that require jobsite adjustments.
2. Use the largest practical maximum size aggregate and/or the highest practical coarse aggregate content to minimize drying shrinkage.
3. Shrinkage reducing admixtures can be used in the concrete mixture to reduce shrinkage.
4. Some aggregates result in higher shrinkage that should be considered in the jointing plan.
5. Take precautions to avoid excessive bleeding. Place concrete on an absorptive subgrade to reduce bleeding and differential shrinkage. In dry conditions moisten the subgrade to avoid plastic shrinkage cracking.
6. Concrete placed on a vapor retarder or impermeable subgrade will increase bleeding. Vacuum dewatering techniques on freshly placed concrete can reduce water content to reduce curling.
7. Avoid requiring a higher than necessary cementitious materials content. This increases the paste volume and increases shrinkage.
8. A low w/cm concrete mixture does not result in lower shrinkage if the paste volume is high. Similarly, high compressive strength does not assure low shrinkage or curling.
9. Constructing a thicker slab will reduce curling.
10. Cure the slab after placement. Moist curing or a well applied high-solids curing compound will reduce rate of moisture loss and reduce the moisture differential.
11. To minimize curling, joint spacing should not exceed 24 times the thickness of the slab.
12. For thin toppings, clean the base slab to ensure bond and consider use of studs and wire around the edges and particularly in the slab corners.

13. Properly designed and placed reinforcement in the upper one-third of the slab perpendicular to the edges will reduce curling. Reinforcement should be placed for 10 feet from the slab edge or construction joint. Load transfer devices that minimize vertical movement should be used across construction joints.

14. Certain types of breathable sealers or coatings on slabs can work to minimize moisture differential and reduce curling.

For slab applications that cannot tolerate curling, alternative slab systems like shrinkage compensating concrete or post-tensioning can be considered. These options should be decided before the construction and could increase the initial cost of the project.

Some methods of remedying slab curling include sawing additional contraction joints, grinding slab joints where curling has occurred to restore serviceability, and injecting a grout under the curled slab to fill voids under the slab to restore support and prevent break-off of uplifted edges.

ACI 302.1R and 360R provides information on factors that cause curling and steps to take to reduce curling and warping of concrete slabs-on-ground.

References

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