

CURLING of Concrete Slabs

1 INTRODUCTION

The upward or downward movement of a concrete slab's corners or edges due to moisture and/or temperature differentials within the concrete is known as 'curling' or 'warping'. It may be evident in concrete elements other than slabs, eg wall panels. This Data Sheet is concerned only with curling in slabs, and particularly slabs on ground.

Curling typically occurs some months after concrete placement but can occur much earlier. The extent of movement is usually minimal (up to only a few millimeters) but may in severe cases be as much as 20–25 mm. In the worst cases, slab edges and corners may lift off the ground and stepping between adjacent panels may occur. The areas typically affected are those from 600 to 1500 mm from the free edges of the slab.

This Data Sheet outlines the mechanism of curling, identifies the factors influencing the risk of its occurrence and provides recommendations for its minimisation and rectification.

2 MECHANISM OF CURLING

Slabs curl due to moisture or temperature gradients between their top and bottom surfaces. The slab edges curl upwards when the top surface is either drier (shrinks more) or cooler (contracts more) than the bottom of the slab.

When greater moisture loss and shrinkage occur near the top and exposed concrete surface than the bottom of the slab the shrinkage gradient applies a curling moment to the slab. If the curling moment is greater than can be resisted by the weight of the slab plus any applied loads, the slab will deflect upwards or curl. **Figure 1.**



SLABS CURL due to moisture or temperature gradients between their top and bottom surfaces.

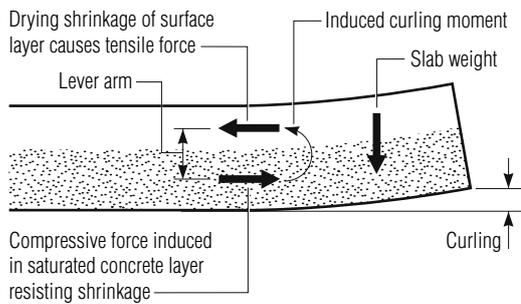


Figure 1: Curling of slabs due to differential drying shrinkage.

Suprenant¹ reports from tests on concrete specimens that 'moisture loss is significant only in the top 50 mm of the specimens or less, regardless of the specimen size'. Concrete beyond this point tends to remain at a high relative humidity (> 80%) and is therefore subjected to limited shrinkage. Thinner slabs and toppings, where drying affects a significant proportion of the thickness, and less weight or mass is available to resist the curling moments, can thus be particularly prone to curling.

Temperature variations cause changes in the volume of the concrete. When temperature gradients develop, the expansion and contraction cause curling moments. As the top surface heats up relative to the bottom, it expands and may cause downward curling; as it cools, it contracts and may cause upward curling.

3 FACTORS INFLUENCING CURLING

The factors influencing curling are those associated with the dimensional change of concrete. If moisture is lost uniformly from both the top and bottom surfaces of a slab, and the temperature is also uniform, then moisture/temperature gradients and hence curling will not develop. As this is difficult to achieve in practice, some of the factors that can influence differential shrinkage and temperature, and therefore assist to control or minimise curling are discussed below.

- **Concrete** Reducing drying shrinkage of concrete could have an impact on the differential shrinkage that may occur due to nonuniform drying. Concrete constituent materials, their proportions in the mix and the total water content of the concrete are some of factors that can affect drying shrinkage.
- **Slab thickness** Curling is reduced as the slab thickness increases. A 50% reduction in curling deflection has been recorded when the slab thickness was increased from 150 to 200 mm. Thin slabs, particularly toppings, are more susceptible to curling due to their lack of mass and the increased effects of drying shrinkage, ie the depth of drying generally represents a larger

percentage of the slab thickness (or concrete volume). For thin unbonded toppings, providing a minimum thickness to control curling is essential; ACI 302² recommends a minimum thickness of 75 mm for unbonded topping slabs, and if curling is an issue, the provision of additional joints. Note that thin unbonded toppings placed on plastic membranes are particularly at risk.

For bonded toppings the tendency to curl is resisted by the adhesion of the topping to the substrate. Adequate preparation and adhesion are therefore critical if delamination is to be avoided.

- **Slab stiffness** Thick slabs, or those stiffened by beams, eg a stiffened raft footing for a house, have a greater capacity to resist the induced curling moments. Thin slabs with no stiffening beams have less ability to resist curling, as demonstrated by the infill slab shown in **Figure 2**.



Figure 2: Curling of infill slab corner, lifting the brickwork bonded to it.

- **Reinforcement** ACI 302 (Section 11.11) suggests that one way to reduce slab curling is to provide a generous amount (approximately 1%) of reinforcement. Experiments indicate that this may result in a 60 to 80% reduction in the curling deflection. Reinforcement should be perpendicular to the slab edge and located in the top third of the slab as this is where the greatest shrinkage occurs. ACI 302 (Chapter 3) also states that 'the amount of reinforcement used in non-structural slabs is too small to have a significant influence on restraining movement resulting from volume changes'. Thus the normal reinforcing meshes (SL 62, 72 or 82) used in slabs will do little to reduce curling.

- **Post tensioning** Post tensioning can be used to induce moments within the slab that oppose the curling moments, and thereby reduce or even eliminate curling.
- **Subbase/subgrade** The material supporting the slab, either the subgrade or subbase, may influence curling. Wet subbases/subgrades provide moist environments which not only prevent drying, but may cause a slight expansion of the concrete, as concrete in wet environments tends to increase in volume, rather than shrink. The increased moisture gradient, ie expansion at the bottom and shrinkage at the top, will increase the induced curling moment and thus deflection. In areas subject to waterlogging, it is therefore recommended that the concrete is placed on a membrane.
- **Plastic membrane** The use of a vapour barrier, damp-proofing or other plastic membrane under the slab prevents drying from the base of the slab. This may increase the moisture gradient within the slab and therefore the potential for curling. In stiffened raft footings the dominant curling restraint is provided by the beams, hence the use of a membrane will have a little effect in this case.
- **Joint spacing** Smaller slab panels tend to reduce the extent of curling. As a guide, the joint spacing should be about 30 times the slab thickness. Attention should be given not only to the spacing, but also the detailing of joints as the ability to transfer loads across joints (dowels, ties or aggregate interlock) assists in minimising curling by restricting upward movement.
- **Curing** Curing is beneficial in maintaining moisture in the concrete and thus minimises or delays drying. The use of membrane-forming curing compounds results in a slow rate of moisture loss as they gradually degrade. This may provide sufficient time to allow some creep to occur, thereby reducing the maximum curling movement.
- **Weight of structure** If the weight of the structure supported by the slab edge/corner is adequate, then the moment resisting curling may be greater than the induced curling moment, thereby preventing curling of the slab. Referring to **Figure 2**, had the remainder of the structure been completed, the weight of the walls and roof would probably have been sufficient to prevent curling.

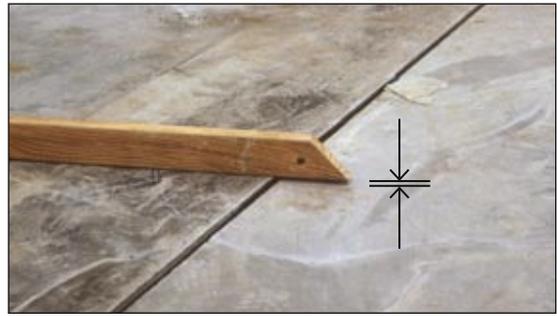


Figure 3: Curling of warehouse floor slab along edge (at joint)

- **Slab edge thickenings** ACI 360R³ states that thickened slab edges at construction joints can reduce curling and recommends that they be thickened by 50% with a gradual 1 in 20 slope. However, while edge thickenings may add some weight to the slab and locally reduce the effects of drying by providing a greater volume of concrete, Suprenant⁴ suggests that because the increase in weight may be small, their impact on curling is minimal.
- **Creep of concrete** The creep of concrete can be defined as the increase or decrease in the length of a concrete member when it is subjected to a sustained stress caused by some loading condition. As the change in length can be several times as large as that due to the initial loading (in this case the induced curling moment), over time the creep due to the weight of the concrete can considerably reduce the effect of the initial curling of the slab.
- **Environment** Environments which have low relative humidities promote increased drying and thus applied curling moments.

Where slabs have curled, consideration should be given to delaying the application of finishes and possible rectification works for as long as possible.

4 ASSESSING THE NEED FOR RECTIFICATION

Minimising curling becomes increasingly important with tighter tolerances on the surface finish of the concrete slab. While deformations from curling are usually within the allowable tolerances, for critical applications such as very flat warehouse floors, they may easily exceed the specified tolerances. Refer **Figure 3**.

In determining whether a curled slab requires rectification, assessment based on a number of parameters may be required:

- **Levelness and flatness** The concrete surface should be within the specified levelness and flatness tolerances. For the example in **Figure 2**,

if the curling had not been highlighted by the cracked brickwork joints, it would probably not have been evident as the extent of curling is within typical floor construction tolerances for residential buildings.

- **Stepping at joints** Curling of adjacent panels may result in stepping, ie a variation in the relative surface levels of adjacent panels at joints. This is particularly important for applications where it may be critical for the satisfactory operation of equipment. For residential pavements, an appropriate limit for the stepping between adjacent panels is 5 mm. For external pavements subject to repeated traffic loading stepping at joints may cause pumping of fine grained material through the joint leading to an erosion failure mechanism.
- **Support of slab** If the extent of movement due to curling is sufficient to lift the slab off the supporting ground, then movement of the slab under loading may be unacceptable. Suprenant and Malisch⁵ report that for industrial slabs subject to forklift loads, movements less than 0.25 mm indicates acceptable joint performance and tolerable curling. Movements between about 0.4 and 0.8 mm (or greater) are severe enough to cause deterioration three to four times faster than normal, and between these limits (0.25 to 0.4), the slab is in a grey area, where repairs may improve the floor's performance but not be cost-effective. Areas not subject to forklift traffic ie heavy loads, and those covered by carpet or tiles, may not need repair.

The long-term magnitude of curling will reduce as moisture and temperature gradients stabilise and concrete creep occurs. Curling may reduce to a tolerable level over time, possibly avoiding the need for repairs. If the construction schedule permits, this could be an available option and should be considered.

5 RECTIFICATION OF CURLING

It is important to establish whether or not the slab is still curling prior to carrying out repairs, as curling can continue for some months. Carrying out repairs while the slab is still curling may compound the problem. Also, the repair method may vary depending on whether the slab is dry, still drying, or has the potential for long-term cycles of wetting and drying.

While a number of options to repair the effects of curling are available, repairs should be carried out only if the curling affects the performance of the

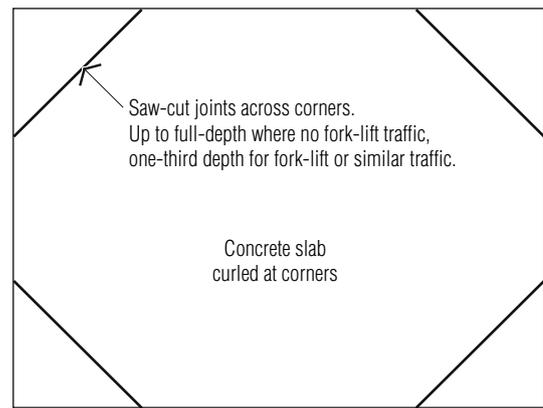


Figure 4: Diagonal saw cuts at curled corners of slab

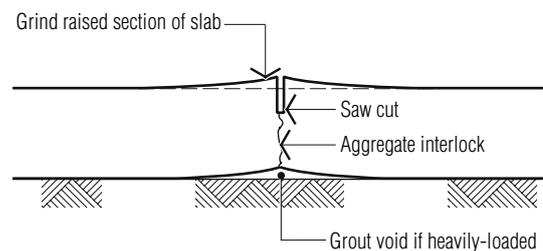


Figure 5: Repair of curled slab

slab in some way. The economic viability of repair must be based on the future expected performance of the floor. For residential and other lightly loaded slabs repairs may not be necessary.

Rectification generally involves correcting the effects of curling such as the loss of support, stepping at joints or surface levelness/flatness, rather than the curling itself.

- **Reinstating support for the slab** The two methods are:

- **Providing extra joints** The simplest way to reinstate adequate support for the slab is to cut extra joints across the corners of the slab as shown in **Figure 4**. For residential floors or floors with no heavy loading saw cuts may be full depth to ensure settlement of the slab. For light forklift traffic and loading, saw cuts are made to only one-third of the slab thickness to allow aggregate interlock and thus load transfer across the joint.
- **Grouting of void** The void beneath the slab is filled with either cement-, urethane- or epoxy-based grout, depending on the size of the gap. **Figure 5**.

- **Reducing stepping** The three methods are:

- Raise the lower slab by injecting grout beneath it.
- Grind the higher slab edge (150 to 200-mm-wide).
- Lower the upper slab by loading or ponding

with water (to increase surface moisture), and then provide mechanical connection across the joint. See 'Joints' below.

■ **Achieving levelness and flatness tolerances.**

Various methods are available:

→ **Grinding** Grinding the surface of the slab can be used to rectify local high spots caused by curling. Note that only those areas that require a flatter profile should be ground, and that grinding may not be an option for slabs with decorative finishes.

While minor grinding should not affect the performance of the slab, if more than a few millimeters are required to be removed, the minimum required slab thickness and cover to reinforcement should be provided, and any specified abrasion resistance of the surface complied with.

→ **Scabbling** Concrete at high areas can be removed by scabbling, and a cement or epoxy mortar topping provided to reinstate the slab surface. Note that any joints must be reinstated in the topping, and the reduced slab thickness checked for structural adequacy.

→ **Filling low areas** If the slab is to be provided with other floor finishes, filling low areas by increasing the bedding to tiles, or placing a topping beneath flat finishes such as vinyl sheeting or carpet may be an option.

■ **Joints** If curling has reduced the effectiveness of load transfer at joints, it may be necessary to 'stitch' the adjacent slabs together by installing dowels or transverse bars across the joint. This is typically required only in high traffic areas where differential movement is a problem, and where the slab thickness is at least 150 mm. Bars are installed by saw cutting a groove across the joint, installing the dowel/bar into the cut and using epoxy to bond the bar to the concrete. Details such as bar type, size and spacing, saw cut depth, etc will need to be determined for each specific case. Note that to reduce the saw cut width and epoxy required, flat steel bars rather than round or deformed bars could be used.

■ **Slab replacement** This should be considered as the last option to rectify curled slabs, particularly if decorative finishes have been provided. This is due to the difficulty of exactly matching the colour and/or finish of a new section of pavement with that of adjacent existing areas. Note that the causes of the curling should be identified prior to replacement to avoid a recurrence of the situation.

RECOMMENDATIONS TO MINIMISE CURLING

As prevention is always better than cure, the following are the basic aspects that should be considered to reduce differential shrinkage, and therefore curling:

- Use minimum total water content in the concrete.
- DO NOT add excess water on site.
- Avoid excessive bleeding.
- Use a mix with low-shrinkage characteristics.
- Use largest practical aggregate size
- Where possible, place concrete on lightly moistened, pervious subbase/subgrade that absorbs moisture from the bottom of the slab during initial set.
- Use a thicker slab (minimum 100 mm is usually recommended, use of 125 or 150 mm could be an advantage).
- Use adequate reinforcement in the top third of the slab.
- Ensure adequate spacing of control joints.
- Minimise the rate of evaporation by using evaporative retarders particularly in hot, windy or low humidity conditions.
- For industrial floor slabs, ensure the roof, and if possible walls (protection from wind) are completed prior to placing the slab to reduce rapid drying.
- Avoid delays in placement that may require water to retemper the mix.
- Take precautions when placing in hot weather conditions as cold overnight temperatures can result in large thermal gradients. Placing at lower temperatures can reduce thermal contraction from cooling.
- Commence curing as early as practicable – apply membrane-forming curing compounds as soon as the finishing operation is completed.
- Avoid rapid drying of surface after curing. Consider application of surface coating or sealer to provide more-uniform moisture conditions within the slab by reducing evaporation from the surface.
- Ensure adequate preparation for bonded toppings.
- Use post-tensioning as this can oppose the curling moment.

REFERENCES

- 1 Suprenant, B A *Why Slabs Curl Part I: A look at the curling mechanism and the effect of moisture and shrinkage gradients on the amount of curling* Concrete International, March 2002, pp 56–61.
- 2 ACI 302 *Guide for Concrete Floor and Slab Construction* ACI Manual of Concrete Practice, Part 2, American Concrete Institute, 2005.
- 3 ACI 360 Chapter 9 – *Reducing the Effects of Slab Shrinkage and Curling* ACI Manual of Concrete Practice, Part 5, American Concrete Institute, 2005.
- 4 Suprenant, B A *Why Slabs Curl Part II: Factors affecting the amount of curling* Concrete International, April 2002, pp 59–64.
- 5 Suprenant, B A and Malisch, R W *Repairing curled slabs*, Concrete Construction, May 1999, Vol. 9, pp 58–65.

FURTHER INFORMATION

Further information on good concreting practices can be downloaded from the Cement Concrete and Aggregates Australia website at www.concrete.net.au.

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