Manitoba Ready Mix Concrete Association
Technical Update

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What you should know about the Causes of Cracking of Concrete

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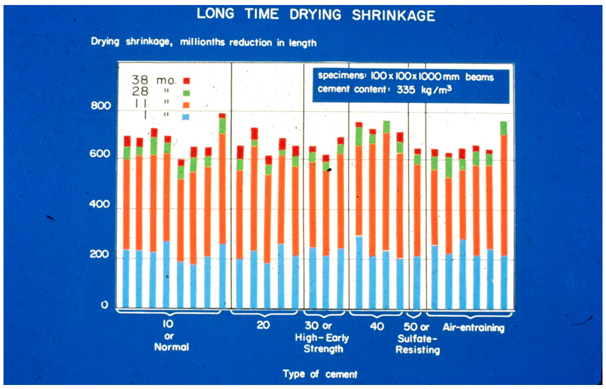
Concrete cracks, usually for predictable reasons. Cracking in some concrete, such as in a structural beam under load, is expected and usually acceptable. Other cracks can cause early failure and must be controlled or prevented. The concrete supplier, the contractor and the design engineer each have a role to play in minimizing the cracking and keeping it within acceptable limits.



Drying shrinkage: Virtually all concrete undergoes volume change as it dries; it's called drying shrinkage. Keep the concrete saturated and it will not shrink but will, in fact, expand slightly . Most projects can keep concrete formed, wet or sealed with curing compound for only a week or less. Therefore for all intents and purposes, all concrete shrinks. As soon as it starts to dry, it starts to shrink, even within hours. As the chart above shows, only about one-third of the shrinkage occurs in the first month; it takes a year or more before it is virtually at a stable dimension. It doesn't matter if it's air-entrained or not.

The more water in the mix, the more it will shrink. That's why adding excess water on site can create a problem. That's also why it's most desirable to use water-reducing admixtures in most mixes. We can minimize drying shrinkage even more by the use of high range water-reducers (super plasticizers) since we can get very workable concrete with a minimum amount of water.

Cement content or supplementary cementing materials such as flyash or admixtures have a very limited effect on shrinkage; it's the water content that's the critical aspect of a mix. The aggregate size and combined gradation can reduce the water demand. The larger the maximum size of aggregate, the lower the water demand but it is seldom economical to insist on larger sized aggregates simply to minimize shrinkage. A fine aggregate mix, such as commonly used for a floor topping or bridge deck overlays, will demand more water per cubic metre simply because there is more surface area on the many particles which must be coated with the water/cementitious paste.

In general, aggregate types with a high modulus of elasticity and low absorption will produce a low-shrinkage concrete. Quartz, limestone, dolomite, granite, feldspar and some basalts can generally be classified as low shrinkage types.

Since drying shrinkage and the resulting tension cracking is totally predictable, both the contractor and the design engineer must prepare for this in both flatwork and walls. The most economical way is to provide control joints which force the unsightly cracks into aesthetically pleasing and maintainable straight lines.

Chamfer strips can form such stress-relieving joints in walls. On flatwork, sawcuts are the most economical way to accomplish this but some walls are sawed also. But they must be spaced no further apart than 25 times the slab or wall thickness - or in Imperial units, no further apart in feet than twice the thickness in inches. They must also be deep enough - 1/4 of the wall or slab depth. And the third crucial thing is timing: the cuts must be made before the concrete starts to shrink and pull itself apart. Depending on ambient conditions, this can be only a few hours later - certainly within 16 hours. As a result, joint cutting is often done by a late evening crew. The advent of early-entry saws such as the Soff-Cut makes early cutting much easier.

If any of these three rules is broken, random cracking as pictured above is likely to occur. That slab had already shrunk and cracked hours before the saw cut was made. Too late! Now you have both the joint and the crack and the slivers where they meet are likely to spall out over time.

Placing reinforcement in a slab or wall does not prevent this type of cracking. Rebar may, of course, be necessary in walls designed to withstand lateral loads but is seldom required in floors or pavements. In non-structural cases, all rebar does is permit the joints to be spaced further apart or, if enough steel is used (0.6% or more of the cross-section), be eliminated altogether. That's why, when used in a slab, rebar is commonly located in a non-structural location at mid-depth. Such steel is stressed only after the concrete cracks. If the sawcut joints are close enough together as discussed above, no steel at all is needed in slabs on grade or pavement, even when the slab is built on Manitoba's expansive clay subgrades.

Plastic shrinkage: Even before the concrete starts this long-term drying shrinkage, there is a risk, especially in cool weather, of small, shallow shrinkage cracks appearing on open flatwork such as floors, decks, curbs or pavements. These are only a few millimetres deep and appear even before the concrete sets. Often aligned perpendicular to the wind direction, these cracks are caused by plastic shrinkage and occur when the concrete has yet to set and the evaporation rate from the concrete surface is faster than the rate at which the bleed water can escape from within.

Evaporation is affected primarily by the temperature *difference* between the concrete and the air, with wind and humidity also being important. [See #7 *Temperature* in this series at www.mrmca.com].] For a given wind/humidity combination, the greater the difference in temperature, the more likely plastic shrinkage will occur so cool weather construction with heated concrete poses a greater risk for this problem than mid summer.

The contractor must be aware of this risk and prepare accordingly with such strategies as early morning placement when winds are usually low and humidity high, wind-breaks if feasible, or the spraying of a fine mist upwind to raise the local relative humidity. Such misting is mandatory when silica fume is specified since such mixes self-dessicate, resulting in a very high risk of plastic shrinkage during placement.

Floor finishers now commonly make use of mono-molecular films such as Confilm, Sure Film or Eucobar. Products of this type are designed for use between the stages of bull-floating, floating and trowelling on a polished floor surface. They must be applied quickly with a long wand immediately behind the bull-floating and often again later after the power floating operation to be effective. Being only one molecule thick, they slow down evaporation and then dissipate once the trowel blade hits. Originally developed to minimum loss of precious water by evaporation from reservoirs in the US south-west, they have proven their worth in slowing evaporation of bleed water from concrete during placement. They are not curing compounds or sealers however.

Unless some other method of curing has been specified, after finishing all exposed concrete must be sprayed with liquid membrane forming curing compounds meeting ASTM C309. This will not only assist in developing the compressive strength of the mix in place but will also reduce the risk of rapid development of drying shrinkage stresses which would lead to early cracking. Good curing also permits a somewhat greater spacing of control joints since the tensile strength of the concrete is well developed before the drying shrinkage stresses occur. Better curing means fewer random cracks.

Other sources of cracking: Typically, each type of cracking has a signature pattern that helps identify its source. Pictured here is a Montreal freeway barrier suffering from the expansive forces of alkali-aggregate reaction, too common in aggregates in that region but fortunately very rare in Manitoba.

Occasionally some local aggregate sources do contain certain dolomitic limestones that eventually crack and shatter in a signature crack pattern in a phenomenon known as D'cracking when both moisture and frost are available - such as pavement or retaining walls.

Mass concrete pours can suffer random cracking (at right) from high temperature differentials between the inner core and edges of the pour. For mass pours, specify a high flyash or slag content in the mix, (30% or more), a low concrete temperature and a week or more of insulation of all forms and exposed surfaces until the core and surfaces both cool close to ambient temperatures.

Expansive corrosion of steel rebar with insufficient depth of quality concrete protecting it from water or chloride exposure leads to cracking of the concrete. Casting two dissimilar metals like steel and aluminum too close together also likely leads to corrosion and cracks. With salt as an electrolyte, that makes a battery, resulting in corrosion and cracking. Above is shown a double whammy on a Winnipeg bridge barrier!

Transverse cracks in newly constructed bridge decks are commonly observed above the reinforcing steel and are usually full depth. The cracks are typically 1m to 3 m apart. Research in the US determined that the most important construction-related factors affecting transverse cracking involve weather and curing. The mixes that performed best in lab tests had essentially no slump and required excessive compaction to consolidate, a situation likely problematic in the field. The studies found that longitudinal tensile stresses in the concrete deck caused transverse deck cracking. Shrinkage stresses are generally higher in a steel-girder bridge than a concrete-girder bridge with larger girders at a narrow spacing providing the highest restraint stresses leading to such cracks.

References: Specification for Concrete Cracking; Concrete International, September 2007, pp 50-54:
ACI 224 Control of Cracking in Concrete Structures; ACI International
Robbins, M.E., Predicting Temperature Rise and Thermal Cracking in Concrete; PCA R&D 3030
Transverse Cracking in Newly Constructed Bridge Decks; NCHRP Report 380; 1996

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