TECHNICAL NOTE 015

Cracks in Concrete – Is It a Design Issue Or Just 'Poor' Workmanship?

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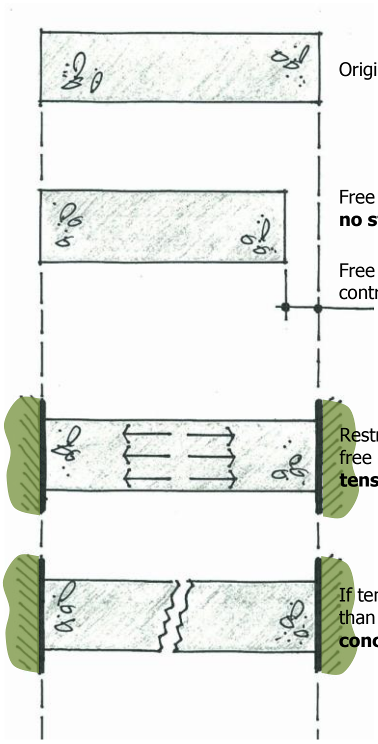
Keywords
Flexural Cracks, Early-Age Thermal Cracks, Drying Shrinkage Cracks, Plastic Shrinkage Cracks, Free / Restrained Contraction

Synopsis
Contrary to prestressed concrete, cracks in reinforced (or unreinforced) concrete are inescapable. It has been quite common to presume that cracks are formed as a result of 'poor' workmanship, and hence Contractors are required to come up with suitable remedial measures, and to bear the associated time and cost implications. Noting that workmanship could not possibly be the sole cause, this technical note attempts to explain the common types of cracks and their causes, with particular emphasis on those that are more design-oriented where Contractors have no practical input.

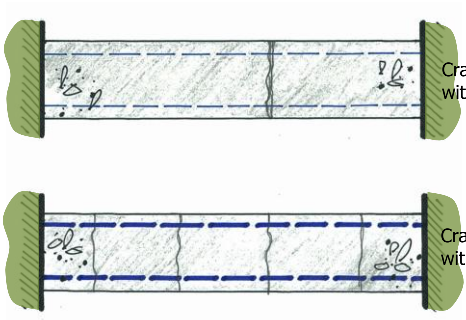
1.0 Introduction

Prior to discussing cracks in concrete, it is instructive to review the following behaviour.



Similar to most other materials, concrete will expand or contract in response to a temperature change, for example. In the context of this note, contraction (or shrinkage) of concrete is the prime concern. As long as contraction is free to take place, tensile stress will not develop in concrete elements. However, in reality, contraction movement will always be restrained in one way or another, causing the development of tensile stress. If the tensile stress is greater than the tensile strength, concrete cracks.

> **NB –**
> It must be noted that the provision of reinforcing bars (rebars) in concrete can only help control the crack spacing and width, but it will never eliminate cracks. If the rebars for some reasons were under-provided such that the tensile stress so developed in concrete could not be effectively redistributed, the resulting crack(s) would be more localised with large width.



2.0 Restraint

With regard to development of cracking, restraint to contraction movement can be grouped into two principle types: External Restraint and Internal Restraint. Estimating it wrong may result in wasteful over-provision of rebars, or under-provision leading to unacceptable cracking. Contraction movement could be caused by thermal effects, reduction in volume of hardened concrete (ie, shrinkage), etc.

2.1 External Restraint

External restraint to a newly cast concrete element can be subdivided into (i) Continuous Edge Restraint, (ii) End Restraint and (iii) Intermittent Restraint. In many cases, all three forms of restraint may act together. These are illustrated in the following figures.

[Source: Internet]

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In cut-&-cover tunnels, walls (new section) are usually cast onto the base slab (old section). This is a classic example of continuous edge restraint;

For slabs cast in hit-&-miss fashion, infill slab panels are subjected to end restraint.

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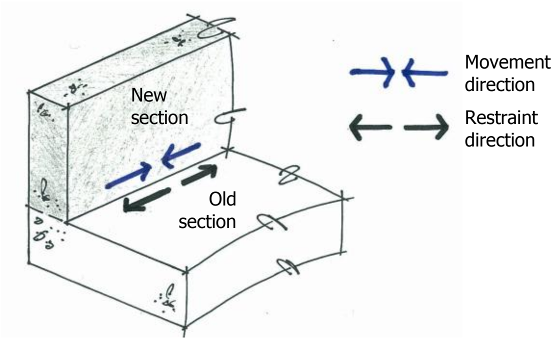
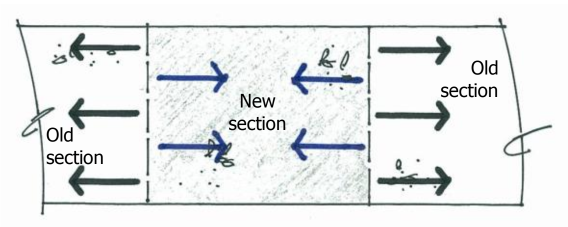
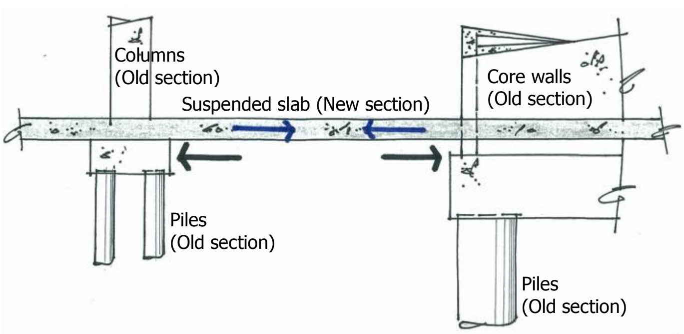
i) Continuous Edge Restraint
Walls (new section) cast onto rigid foundations, adjacent sections of slabs, or tunnel lining (old sections)



ii) End Restraint
Walls or slabs cast as infills



iii) Intermittent Restraint
Slabs cast on piles, suspended slabs cast on columns and/or core walls

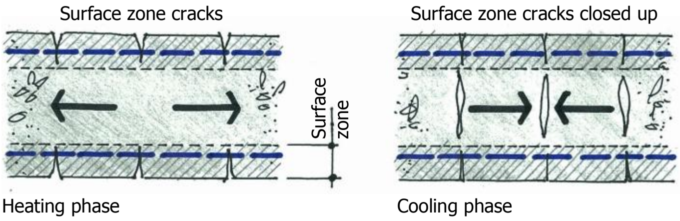


2.2 Internal Restraint

Change in temperature profile across a thick section can cause one part of the section to restrain the movement of another part of the same section.

For thick sections, the surface zone cools down more quickly than the core – this would be particularly so if formwork (or insulation) was removed too soon. The rapid cooling and contraction of the surface zone is restrained by the hot interior, and therefore the surface cracks. These surface cracks would be expected to close up as the core cools down.

By the time concrete has reached the ambient temperature from the peak, the surface cracks will have closed sufficiently to be able to transmit compressive stresses, and in extreme cases, internal cracks occurs as a result of tensile stresses developed in the core. That is, by this time, the core contraction is restrained by the surface zones working in compression.

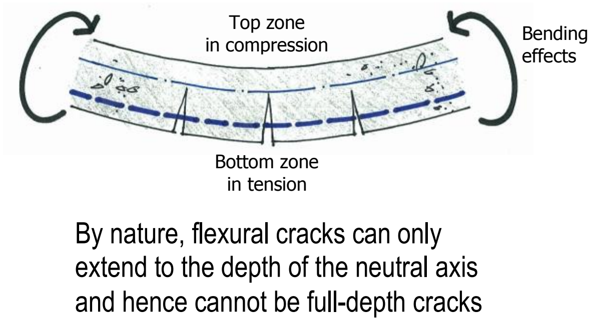


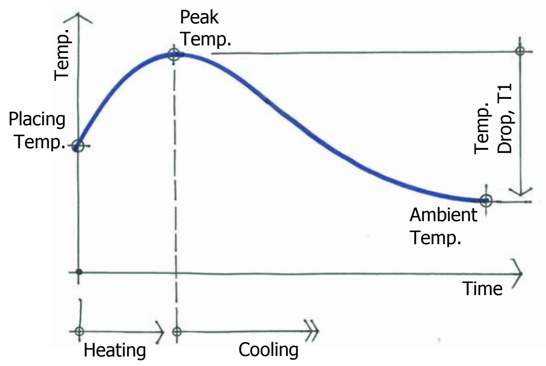
3.0 Types of Concrete Cracks

Generally speaking, cracks in concrete can be categorised into the following types:

i) Flexural Cracks (controlled by design);
ii) Early-Age Thermal Cracks (controlled by design);
iii) Drying Shrinkage Cracks (controlled by design & workmanship); and
iv) Plastics Shrinkage Cracks (controlled by workmanship)

The first two types of the cracks are very much design-oriented. If it is not a design-&-build type of contracts, Contractors basically have no influence at all in terms of adequate rebar provision for crack control. For drying shrinkage, their effects are first considered in design, and good workmanship during construction helps control cracking. Plastics shrinkage cracks cannot be controlled by provision of rebars at all, and can only be mitigated by good workmanship on site.





3.1 Flexural Cracks

For reinforced concrete members subjected to the SLS loads effects (ie, service loads), flexural cracks will form when the tensile stress owing to bending exceeds the tensile strength of hardened concrete. The cracks under service loads can only extend to the depth of the neutral axis, and thus will never be full-depth. In the context of flexural cracks in the SLS condition, concrete is mature.

The codified treatment is that reinforcing steel area (As) shall first be determined for the respective concrete members based on the ULS load effects (ie, strength design). The steel area so provided shall then be used for assessment of the SLS crack width. The assessment methodology is given in the following:

i) Cl. 7.2.3 of the Code of Practice for Structural Use of Concrete, Buildings Department; or
ii) Appendix B of BS 8007.

The ULS steel area might have to be further increased, if necessary, to meet the flexural crack width requirement, say 0.2mm.

The steel area so provided will then be used for further assessment of early-age thermal cracks and drying shrinkage cracks as explained below.

> **NB –**
> Flexural cracking is purely a design issue, and the responsibility of controlling flexural crack width rests with the Designer.
>
> As a Contractor, albeit we could take a view, we actually have no means to understand whether the rebar provision is adequate or not to control the flexural crack width under the serviceability limit state of any concrete members.

3.2 Early-Age Thermal Cracks

Early-age thermal cracking, happening usually in the first few days, is associated with the release of the heat hydration from the binder (ie, cementitious material) and is the result of either differential expansion within a concrete element during heat causing internal restraint, or by external restraint to contraction of a concrete member on cooling from a peak to the ambient temperature.

The temperature change in a concrete element during the early-age thermal cycle is the figure above.

The placing temperature of is usually kept to less than 25~30°C. After placing, the hydration process will cause concrete to heat up to a peak temperature (could be up to 85°C). During this period, concrete still behaves in a plastic manner and so the only result is an increase in volume. However, when it cools down from the peak to ambient temperature (T1), it has been hardened enough to go into tension and would crack if it is restrained. Thermal crack could be a full-depth crack.

The thermal crack width can be assessed using one of the following methods, based upon the steel area (As) mentioned in Section 3.1.

i) Cl. 7.2.4 of the Code of Practice for Structural Use of Concrete, Buildings Department;
ii) Appendix A of BS 8007; or
iii) CIRIA C660 Early-age thermal crack control in concrete

The steel area might have to be further increased, if necessary, to meet the thermal crack width requirement.

> **NB –**
> Early-age thermal cracking is primarily a design issue, and the responsibility of controlling early-age thermal crack width rests with the Designer.
>
> However, it should be noted that in addition to adequate rebar provision, control of thermal crack width also relies on a presumed temperature drop of concrete (from the Peak to Ambient temperature, T1). Therefore, if there is a requirement in the Specification prescribing control on the concrete placing temperature and peak temperature, Contractors have to ensure such compliance.

3.3 Drying Shrinkage Cracks

Drying shrinkage is caused by the reduction in concrete volume as a result of evaporation of free water. Concrete is usually mixed with more water than is needed to adequately hydrate the cement. The remaining water (known as free water) will evaporate, causing concrete to shrink. Restraint to shrinkage provided by the subgrade, reinforcement, or another part of the structure causes tensile stress to develop in the

Application of a full wet cure and soaker hoses prevent drying until concrete is strong enough to be able to resist shrinkage stresses.

[Source: Internet]

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Fog spraying increases the humidity of the air above concrete surface, slowing down the rate of evaporation.

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hardened concrete. Drying shrinkage crack could be a full-depth crack.

In many situations, drying shrinkage cracking is inevitable. Therefore, contraction (control) joints are routinely placed in concrete slab to predetermine the location of drying shrinkage cracks.

The assessment for drying shrinkage cracks is included in Appendix A.3 in BS 8007, and also in Cl. 4.6.2 in CIRIA C660 Early-age thermal crack control in concrete.

It states in Cl. 4.6.3 that *"… In general, when assessing the risk of early-age cracking, drying shrinkage may be ignored. …"* because the magnitude of early-age drying shrinkage is small.

NB –
Drying shrinkage cracking is a design issue. The Designer should have controlled the shrinkage (short- and long-term) effects by adequate rebar provision and predetermined contraction (control) joints.

From a Contractor's standpoint, several activities should be done to help mitigate drying shrinkage cracks, including:

i) Provide adequate construction joints;
ii) Saw contraction joints (if prescribed) to the proper depth and as soon as possible;
iii) Provide good curing to allow the concrete to gain sufficient tensile strength before significant shrinking forces develop.

3.4 Plastics Shrinkage Cracks

Plastic shrinkage cracks occur when the evaporation of moisture at the surface of concrete is greater than the availability of rising bleed water to replenish the surface moisture. If concrete has not achieved enough tensile strength when this occurs, the volume change (shrinkage) at the surface will cause cracking.

Plastic shrinkage cracking happens when concrete is in the plastic state (ie, still soft), which is normally within the first 24 hours after the cement begins to hydrate. Plastic shrinkage cracks are generally parallel to one another, do not generally extend to the free end of the concrete element, and can be of considerable depth.

Unlike the others, these cracks, formed in the plastic state of concrete, cannot be controlled by provision of rebars at all, and can only be mitigated by workmanship on site.

NB –
The key to controlling plastics shrinkage cracks is to find ways to reduce the rate of drying of the concrete, including:

i) Do not place the concrete in adverse conditions;
ii) Erect wind screens or use a water fog mist. (Note: A water fog mist is NOT the same as adding finish water.);
iii) Provide additional personnel to accelerate the finishing and curing operations;
iv) Properly use evaporation retardants, especially when finishing operations are lagging behind;
v) After the curing compound application, provide a water cure.

As mentioned at the outset of this note, some forms of concrete cracks are inevitable. Cracks in concrete elements could be a design issue and/or a matter of workmanship. If a significant amount of cracks appear, leading to substantial amount of remedial works with time and cost implications, please feel free to contact the Technical Department for advice.

NB –
Crack width calculations are not shown in this note. Please contact the Technical Department if support is required.

\- End -

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