When things get hot – placing concrete in large pours

In past issues we have looked at various forms of cracking. We will continue this theme by exploring cracking attributable to the heat generated during the cement hydration process. The subject is complex, and therefore with the space limitations of this article we will look only at:

- developing some initial understanding of the issues;
- determining when designers and builders should think carefully about this subject;
- the types of cracks that can form;
- design and construction strategies to remove, or reduce the incidence of this type of cracking.

For those wanting a more detailed discussion on this subject, I recommend CIRIA Report 91 "Early-age thermal crack control in concrete" available from the CCANZ Library.

Heat of Hydration

The mixing of cement with water starts a chemical reaction that gives off heat. The amount of heat generated is influenced by several factors, including:

- the amount of cement used;
- whether supplementary cementitious materials are used;
- the type of cement, for example, High, Early or General Purpose cement;
- the properties of aggregates;
- the placing temperature of the concrete;
- the ambient temperature;
- the type of formwork, and when it is stripped.

Table 1 provides an indication of the temperature rises above mean ambient for various cement contents, section thickness and formwork types. The table specifically relates to an assumed concrete placing temperature of 20^{o}C and a mean ambient temperature of 15^{o}C. Higher placement and ambient temperatures will increase the rate of hydration, and higher temperature rises above ambient will occur. The table also assumes that the formwork remains in place until after the peak temperature has been reached. For a 500mm thick section the peak temperature will typically be reached between 20-48 hours.

If it is considered desirable to reduce the temperature build-up in the concrete, there are several mix design related options that could be explored. In these instances it is worth discussing the options with CCANZ and your local ready mix company to assist in evaluating both the technical and economic implications of the options. Options which may be considered include:

- using supplementary cementitious materials such as granulated ground blast furnace slag, silica fume, or fly ash;
- using larger aggregates;
- using water reducing admixtures;
- lowering the placement temperature.

Heat of Hydration Cracks

Cracking associated with hydration heat, can be roughly split into two categories:

- cracks that are due to the development of a large thermal gradient through the member (internal restraint);
- cracks which develop due to external restraint from free contraction as the member cools.

Table 1: Range of temperature rises above mean ambient temperature (C) for concretes

Section thickness (mm)	*Steel formwork Cement content (kg/m^3)*				*18-mm plywood formwork Cement content (kg/m^3)*			
	220	*290*	*360*	*400*	*220*	*290*	*360*	*400*
<300	5-7	7-10	9-13	10-15	10-14	14-19	18-26	21-31
500	9-13	13-17	16-23	19-27	15-19	20-27	27-36	31-43
700	13-17	18-24	23-33	27-39	18-23	25-32	34-43	40-49
>1000	18-23	24-32	33-43	39-49	22-27	31-37	42-48	47-56

Figure 1: Continuous edge restraint of wall cast on base

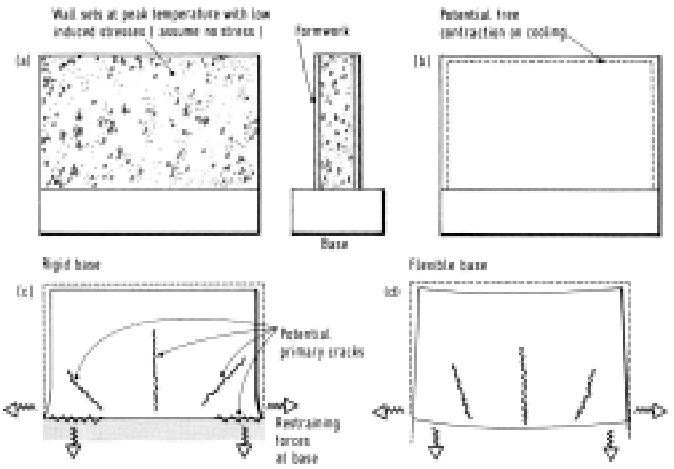

Figure 2: Restraint for various slab or wall pour sequences

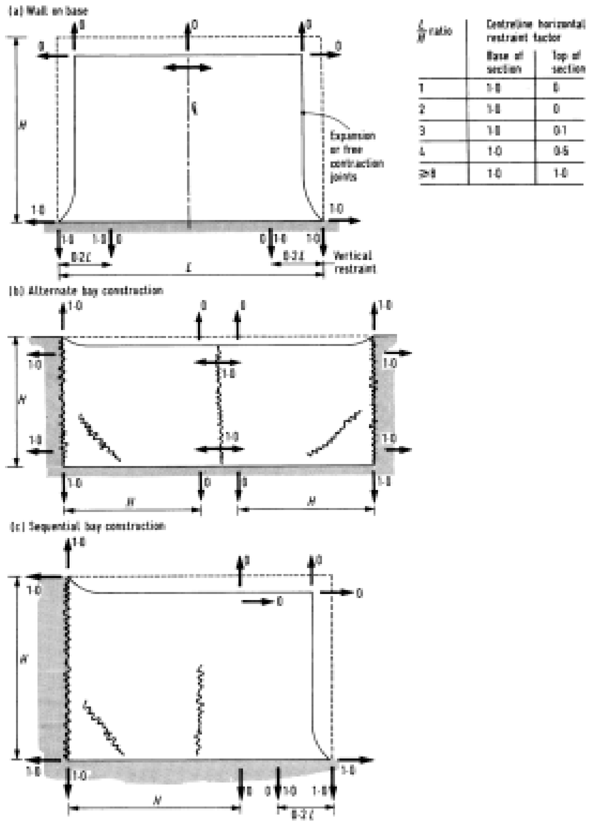

Figure 3: End restraint factors in walls or slabs

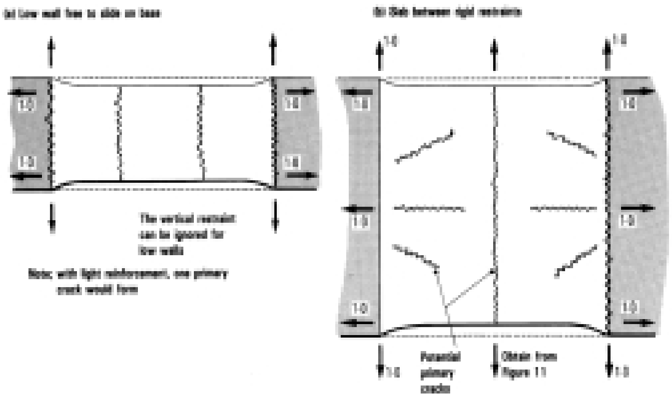

Table 2: Summary of strategies to prevent or control early-age thermal cracking

Mix Design			
Factor	*Most heat*	*Least heat*	*Comments*
Cementitious materials	HE GP	GP/Pfa GP/GGBFS GP/Silica fume	Cement type has a significant influence on the heat generated. Cement selection will depend upon economic risk and consequence consideration.
Admixtures	None	Water reducers Superplasticisers	Modest reduction in heat achieved as a cementitious material remover.
Aggregate size	Small diameter	Large diameter	Consider implications of aggregate size on placing around reinforcing.
Construction Technique			
Factor	*Greater risk of cracking*	*Lower risk*	*Comments*
Placing temperature	High	Low	Is cooling the concrete before placing feasible and economic?
Ambient temperature	High	Low	Little or no control over this
Cooling of placed concrete (a) Cooling pipes (b) Surface cooling			Effective, but expensive. Should only be used in sections under about 500 mm thick
Formwork material (a) Section thickness under about 500 mm (b) Large isolated sections	(a) Insulated plywood (b) Steel GRP	(a) GRP steel (b) plywood insulated	The aim is to minimise the thermal gradients across the section
Formwork striking times (a) Section thickness under about 500 mm (b) Large isolated sections	(a) Long period (b) Short period	(a) Short period (b) Long period	Also keep the upper surface insulated
Reducing restraint (a) Construction sequence (b) Movement joints	(a) Alternate bay Long period between successive lifts (b) None Partial movement joints	(a) Sequential construction or short infill bays Short period between lifts Slipforming (b) Full movement joints	Sequence of casting is not significant if the joints are full movement joints
Control of crack widths with reinforcement	Large dia. bars at wide spacings	Small dia. bars at close spacings	

Internal Restraint

The usual rule of thumb used to prevent the first type of cracking is to ensure that the temperature difference through the member is less than 20^{o}C. Temperature differences larger than this can occur in large members such as raft foundations, or potentially when the formwork is removed early. It is suggested that this issue should be carefully considered when the member thickness is greater than 500mm.

In the mid eighties, I was involved in the construction of a 1m thick basement slab. The most economical solution was to use an untanked basement with appropriate reinforcement. Without tanking, it was important that the concrete was crack free to prevent leakage. The specification called for the slab top to be insulated, however for the first pour it was decided to monitor the concrete temperature using thermo-couples and apply the insulation only if necessary. At 3:00am we were applying the insulation. The experience illustrated two things. Firstly that very high temperatures could be developed in a 1m thickness of concrete (in excess of 50^{o}C from memory), and how effective the insulation was. Upon its application the temperature quickly normalised throughout its thickness.

External Restraint

As concrete cools it contracts. If this contraction is prevented by external restraints it can crack. Figures 1, 2 and 3 illustrate typical crack patterns that can develop if the induced tensile strains in the concrete exceed the materials tensile capacity.

The key to the prevention of this cracking lies in ensuring that the coefficient of expansion x temperature drop x restraint factor is less than the tensile strain capacity. Therefore reducing the thermal movement or the restraint, or increasing the tensile strain capacity reduces or prevents early age thermal cracking. If it is not possible to prevent early age thermal cracking, the crack widths can be controlled by reinforcement.

Table 2 provides a summary of factors that help prevent or control early age thermal cracking. C