Pre-Estimation of Concrete Cracking

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Abstract— **In this paper we are going to model early age concrete cracking. These accounts for hydration of cement in the constitutive modelling at macro-level of material description and assume cracks as geometrical discontinuities and for the heterogeneous nature of concrete conditioning. Cracking can be the result of one or a combination of factors such as drying shrinkage, thermal contraction, restraint (external or internal) to shortening, subgrade settlement, and applied loads. Cracking cannot be prevented but it can be significantly reduced or controlled when the causes are taken into account and preventative steps are taken. We also recall the thermodynamic framework of concrete framework allows to identify the hydration degree and the affinity as internal state variable and conjugated forces, respectively, from mass conservation considerations and thermodynamics of porous media, direct at the macro-level of material description. We thus model concrete cracking and thus we can guess the crack patterns, crack width and placing by just a few parameters.**

I. INTRODUCTION

A common adage is that there are two guarantees with concrete. One, it will get hard and two, it will crack. Cracking is a frequent cause of complaints in the concrete industry. The Concrete Foundations Association has produced a new flyer to help contractors educate their customers about the causes of cracks and when they should be a concern. A more detailed explanation of cracking is presented in this article.

Cracking can be the result of one or a combination of factors such as drying shrinkage, thermal contraction, restraint (external or internal) to shortening, subgrade settlement, and applied loads. Cracking can not be prevented but it can be significantly reduced or controlled when the causes are taken into account and preventative steps are taken.

Another problem associated with cracking is public perception. Cracks can be unsightly but many consumers feel that if a crack develops in their wall or floor that the product has failed. In the case of a wall, if a crack is not structural, is not too wide (the acceptable crack of a crack depends on who you ask and ranges from 1/16” to 1/4”) and is not leaking water, it should be considered acceptable. It is in the best interest of you, the wall contractor, to educate your customers that the wall will crack and when it should be a concern to them.

Cracks that occur before hardening usually are the result of settlement within the concrete mass, or shrinkage of the surface (plastic-shrinkage cracks) caused by loss of water while the concrete is still plastic.

Settlement cracks may develop over embedded items, such as reinforcing steel, or adjacent to forms or hardened concrete as the concrete settles or subsides. Settlement cracking results from insufficient consolidation (vibration), high slumps (overly wet concrete), or a lack of adequate cover over embedded items.

Plastic-shrinkage cracks are most common in slabs and are relatively short cracks that may occur before final finishing on days when wind, a low humidity, and a high temperature occur. Surface moisture evaporates faster than it can be replaced by rising bleed water, causing the surface to shrink more than the interior concrete. As the interior concrete restrains shrinkage of the surface concrete, stresses can develop that exceed the concrete's tensile strength, resulting in surface cracks. Plastic-shrinkage cracks are of varying lengths spaced from a few centimeters (inches) up to 3 m (10 ft) apart and often penetrate to mid-depth of a slab.

Cracks that occur after hardening usually are the result of drying shrinkage, thermal contraction, or subgrade settlement. While drying, hardened concrete will shrink about 1/16 in. in 10 ft of length. One method to accommodate this shrinkage and control the location of cracks is to place construction joints at regular intervals. For example, joints can be constructed to force cracks to occur in places where they are inconspicuous or predictable. Horizontal reinforcement steel can be installed to reduce the number of cracks or prevent those that do occur from opening too wide.

The major factor influencing the drying shrinkage properties of concrete is the total water content of the concrete. As the water content increases, the amount of shrinkage increases proportionally. Large increases in the sand content and significant reductions in the size of the coarse aggregate increase shrinkage because total water is increased and because smaller size coarse aggregates provide less internal restraint to shrinkage. Use of high-shrinkage aggregates and calcium chloride admixtures also increases shrinkage. Within the range of practical concrete mixes – 470 to 750 lb/yd3 (5- to 8-bag mixes) cement content – increases in cement content have little to no effect on shrinkage as long as the water content is not increased significantly. Concrete has a coefficient of thermal expansion and contraction of about 5.5 x 10-6 per °F. Concrete placed during hot midday temperatures will contract as it cools during the night. A 40°F drop in temperature between day and night-not uncommon in some areas-would cause about 0.03 in. of contraction in a 10-

ft length of concrete, sufficient to cause cracking if the concrete is restrained. Thermal expansion can also cause cracking.

Structural cracks in residential foundations usually result from settlement or horizontal loading. Most (but not all) structural cracks resulting from applied loads are nearly horizontal (parallel to the floor) and occur 16" to 48" from the top of the wall. They are much more prevalent concrete block construction. They can be brought about by hydrostatic pressure or heavy equipment next to the foundation.

Diagonal cracks that extend nearly the full height of the wall are often an indication of settlement. In either of the above conditions, an engineer should be consulted. Diagonal cracks emanating from the corner of windows and other openings are called reentrant cracks and are usually the result of stress build-up at the corner. Diagonal reinforcement at the corner of openings can reduce the instance of crack formation and will keep the cracks narrow.

Hydration of cement is a highly exothermic and thermally activated reaction. The exothermic nature of the chemical reactions leads to heat generation, which, in the hours after pouring, may result in high temperature rises of up to 50° C massive structures. The temperature evolution influences the kinetics of the hydration: the higher the temperature the faster occurs the reaction. As the rate of hydration slows down the temperature decreases resulting in a thermal shrinkage, which induces stresses of thermal origin. Moreover, the hydration of cement is at the base of the ageing phenomenon, which -at a macro-level of material description. Furthermore, this change concentration of the hardened cement gel is accompanied by a volume which results in a chemical shrinkage, coupled with a capillary shrinkage related to the formation of menisci due to water consumption hydration. Finally, the shrinkage (if restrained) gradients induce a severe state of stresses, which might be of the strength beyond the strength developed.

Aim:

This research focuses on studying the thermo chemical properties of concrete and estimating the probable time estimated for cracking of the structures. We study the early age cracking of concrete.

Objective:

The aim of this research was achieved through the following objectives:
1) To Study the physical and chemical properties of concrete before and after casting.
2) To study and improve the key role of chemical properties of concrete and its impacts on the structure.

PROBABLISTIC MODELLING OF CRACKING OF CONCRETE

It is generally admitted, that the cracking of hardened concrete is strongly influenced by the heterogeneity of the matter: the tensile strength of concrete is mainly related to that of the hardened cement paste, which intern is governed by the presence of voids, micro cracks etc. created during the concrete hardening by non-uniform shrinkage of thermal and origin at the scale of the heterogeneous material, i.e. at the scale of the concrete aggregates. This heterogeneity of the matter constituting concrete can be considered to be at the basis of apparent size effects ,governing the overall cracking behaviour at the macroscopic scale of material description. This has led to the development of the probabilistic modelling of concrete cracking over the last decade (Rossi and Wu 1992), which accounts for the heterogeneity of hardened concrete by random distribution functions of the mechanical properties of the material (Young's modulus, tensile strength) with experimentally determined standard deviation and mean values which depend upon the volume ratio of coarsest grain to test specimen size (Vg/Vt) for a given apparent compressive strength fc. Since the heterogeneity of the hardened concrete, as modelled by relations (35), results from void and micro-crack creation induced by non uniform shrinkage of thermal and capillary origin during hardening, by chemo-mechanical couplings. The previous expression assumes a homogenety of maturing material properties with respect to the hardened one, and is widely used in the experimental determination of apparent material characteristics of maturing concrete. Note however ,in the framework of the probabilistic modelling, this heterogeneity of the hydrating matter constituting concrete, i.e. the cement paste. This needs still to be confirmed, proposed modelling is just a first attempt to model size maturing concrete. Finally, the probabilistic modelling of early age concrete cracking can be readily used in finite element application within an explicit approach with special contact elements that interface the solid elements. The Young's modulus and the tensile resistance are distribution of all mesh elements, by replacing in the experimentally determined random distribution function (3 5) the volume of the test specimen by the volume of each singular solid finite element. This is consistent with physical evidence: the smaller the scale of observation (respectively the modelling scale) with respect to that of the structure, the larger the fluctuation of the local mechanical characteristics, and thus the (modelled) heterogeneity of the matter. This renders the numerical results mesh-independent in the case of maturing concrete, the (randomly distributed) Young's modulus and the tensile strength in the mesh are updated in each time step on account of the hydration degree locally developed. A crack opens according to crack criterion (33). With crack opening the local tensile strength is set to zero (local irreversible fragile tensile behaviour): the strength is not recovered when the crack recloses. Massive concrete elements are prone to early age thermal cracking due to the heat of hydration. The service life of the element can be severely reduced by the presence of thermal cracks. It is thus extremely important to control the early age thermal cracking. A three-dimensional finite element simulation procedure, based on a the degree of hydration as a fundamental parameter, is developed. By means of experimental research the relation between thermal and mechanical properties of the hardening concrete and the degree of hydration has been studied in detail. Thermal and mechanical properties can be modelled by means of simple relationships. A fundamental influence of the degree of hydration on the basic creep of the hardening concrete has also been found, as well as on the fracture energy. In a staggered thermal cracking analysis, first the temperature fields are calculated, after which the mechanical simulation is executed. The time dependent material behaviour is implemented by means of a degree of hydration based Kelvin chain. The cracking behaviour is simulated using a smeared cracking concept with non-linear softening, using material properties also depending on the degree of hydration. The results of the model are verified experimentally.

At what width does a crack in concrete become a problem? That question often arises, but unfortunately there is no definite answer. It can vary from one project to the next. The answer may also change with the person's perspective: What is acceptable to the contractor, engineer, or architect may not be acceptable to the owner, who must live with the crack day after day. Even the American Concrete Institute has no standards or recommendations that give a "yes" or "no" answer as to what cracks need repair based on width and other factors. In general, cracks wider than a credit card and running through the depth of the concrete are structural in nature and could be a sign of more serious problems (see Concrete Crack Repair Evaluation). These cracks -- no matter what the width -- are rarely acceptable. Consult an engineer or concrete repair professional to determine the cause of the crack and to recommend the best repair solution. For hairline or non-structural cracks in concrete, the answer as to what's acceptable is less clear. The width at which they became a problem requiring repair often depends on the following factors:

- Is the crack static or is it gradually becoming wider? If you notice movement of the crack, it may continue to widen if the crack isn't repaired and could indicate a structural problem.
- If the crack is in a horizontal surface, such as a floor or slab, is it wide enough to present a tripping hazard?
- In foundation walls or slabs, is the crack wide enough to allow moisture seepage? (See Foundation and Basement Crack Repair.)
- Does the crack trap dirt and present a maintenance or sanitation issue?
- Is the crack an eye sore and located in a high-visibility area?

Be aware that if you decide to repair the crack, the repair itself is likely to be visible unless you cover it with an overlay. However, it's often possible to disguise or accentuate a crack through saw cutting, staining and other techniques.

Factors affecting the creep and relaxation properties

Creep of the concrete depends on many factors, intrinsic and external, and the intrinsic factors represent the material characteristic which are dictated by the concrete mixture, and the external ones are those, which can vary after casting, such as the temperature and moisture conditions, age of loading, load duration, type of loading (tension or compression), level of loading etc.. Creep of hardening concrete is an even more complicated issue due to the effect of varying temperature and humidity content. In many investigations, the influence of the following factors on the creep/relaxation properties of the early age concrete is investigated:

- Age of loading
- Water/binder ratio
- The linearity of applied stress and induced strain under different load/strength ratio
- The temperature history prior to loading and the temperature development during and after loading

High creep at early loading age, the influence of the temperature and humidity content on the creep and creep under tensile stress are some of the most relevant aspects for cracking risk assessment in young concrete. A relatively small numbers of tests that investigated these aspects were reported in literatures. And within the present study, the focus is mainly on the influence of the following three factors on the creep property of early age concrete:

- Type of load (tension or compression)
- Replacement of amount of cement with mineral additives, such as FA and BFS.

Methodology:

In order to improve the durability of our built infrastructure, concrete temperature control and chloride ingress must be considered before the concrete is placed. If cracking occurs, or very permeable concrete is placed, repairs can be very expensive and may delay the project completion. Engineers, contractors, and material suppliers all have equal roles in building a durable structure. They need a tool that can help quantify the concrete performance before placement, so that the concrete may be optimized for durability.

***Casestudy*:**

Cracking of concrete structures during the hardening phase often seriously compromises not only structure integrity, but also durability and long-term service life. The problem arises from the fact that concrete experiences complex chemical and physical changes and interacts with its environment at early ages. During the hardening process (first 1-2 weeks), volumetric changes due to thermal dilation and autogenous deformation occur simultaneously in the concrete structures. Thermal dilation is caused by the temperature changes due to heat of hydration. Autogenous deformation is a result of continuing water consumption in the hydration reactions, leading to self-desiccation (unlike drying shrinkage, which is due to water loss from the concrete). The mechanical properties such as elastic modulus and tensile strength are developed quickly during the hardening phase. Consequently, self-induced stresses will be generated in structural members subjected to restrained conditions. Cracking of young concrete is mainly caused by restrained thermal deformation and autogenous shrinkage, which may induce a severe state of stress beyond the material strength development.

High-strength concretes (HSC) and high-performance concretes (HPC) with low water/binder ratio are increasingly used for structures where their superior mechanical properties and durability performance provide an override advantage. However, the increased use of such concretes was accompanied by concern regarding their early age cracking sensitivity. In these concretes considerable deformation due to combination of autogenous shrinkage and thermal dilation can develop and lead to early sensitivity to cracking in restrained conditions. The cracking of early age concrete increases the permeability and permits ingress of external harmful agents into the concrete more easily, such as penetration of chlorides, carbonation, damage due to freezing, and sulphate attack etc..

The pozzolanic (e.g. fly ash, silica fume) and cementitious materials (e.g. ground blast-furnace slag) are used extensively as mineral additives in production of high-strength and highperformance concretes in the last decades due to significant cost and energy savings. A pozzolan is defined as a siliceous or siliceous and aluminous material which in it self possesses little or no cementing property but will in a finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. The reaction between a pozzolan and calcium hydroxide is called the pozzolanic reaction. The engineering benefits, likely to be derived from the use of mineral additives in concrete, include improved resistance to thermal cracking because of lower heat of hydration, enhancement of ultimate strength and impermeability due to pore refinement, and (as a result of reduced alkalinity) a better durability to chemical attacks such as by sulfate water and alkali-aggregate expansion.

Traditionally, the risk of cracking in early age concrete structures were evaluated based on temperature criteria. A temperature criterion can be applied by limiting the maximum temperature difference between newly cast concrete and old concrete or ambient environment. Temperature criteria are often unreliable as they reflect only a fraction of the influencing factors, and an important reason for this uncertainty is that the zero-stress temperature is usually different over the cross-section of a member. Especially for large massive structures where stresses are built up during the heating period the temperature criteria have shown some limitations, and therefore a more accurate analysis of the stress development at early age is needed. (Springenschmidt, R. et al., 1994)

Early age cracking has been subject of extensive research in last decades. In recent years, more realistic insights have been gained through various research efforts in related fields, as for example, thermal cracking in concrete at early age by RILEM proceeding 25 and early age cracking in cementitious systems by RILEM technical committee TC 181-EAS. On the other hand, the even-growing number of application of high-strength concrete and massive concrete structures makes essential to establish comprehensive methodology to prevent cracking of early age concrete.

The amount of stress generated by thermal dilation and autogenous shrinkage in a given time interval depends on the degree of restraint which is imposed by the surrounding structures, the development of mechanical properties, especially elastic modulus and tensile strength, and the creep/relaxation properties of the concrete at early age. Making reliable cracking risk assessment involves experimental testing and advanced modeling of the time and temperature dependent behavior of the properties mentioned above, the restraint conditions of the structure as well as the external environmental conditions. The cracking risk at given time is determined by comparing the (measured or calculated) maximum tensile stress or strains in concrete structure to the tensile strength or ultimate tensile strain of concrete at that time.

Advanced testing methods combined with suitable modeling of material properties and accurate numerical analysis techniques are necessary for solid understanding and effective control of early age cracking.

During the hardening phase, the hydration reaction is constantly progressing and accompanied by volume changes due to thermal dilation and autogenous shrinkage, as well as the development of mechanical properties due to the changes in microstructure. Although all the processes occur simultaneously and are affected by diverse interacting factor, the determining material properties can still be identified, if carefully performed experiments are used in conjunction with appropriate analytical models.

The following material properties are main factors which influence the sensitivity of concrete to cracking at early age, and are required for a full evaluation of cracking risk in hardening concrete structures: • The temperature sensitivity (activation energy) • Heat of hydration • Coefficient of Thermal Expansion (CTE) • Autogenous Deformation (AD) • Mechanical properties (E-modulus, compressive strength, tensile strength) • Creep/relaxation properties
• Restraint Stress development in a TSTM (the test result is the net effect of the properties listed above)

All above listed material properties are determined by tests performed in the present study, and the test methods and procedures are described in detail in the following sections. In addition, a field test of a “double-wall” structure was carried out in 2004 by the Norwegian Public Road Administration (SVV), and this wall is comparable to the walls in the Bjørvika submerged tunnel which is under construction in Norway. The test data of material properties is used directly as input for temperature and stress calculations of the wall. The calculations were first compared to the stress development in the TSTM, and then the material models are applied in 3-D numerical analysis of the field test to predict temperature, strain and stress development in real concrete structures.

***Conclusions*:**

The modelling of early age concrete cracking gives direct access to crack-patterns, crack-width and crack-spacing induced by thermo-chemomechanical couplings with a minimum of material parameters of clear physical significance and accessible by standard material tests.for the thermal problem needs a calorimetric test result is needed, order to determine the of hydration, while for the mechanical problem using the probabilistic modelling of concrete cracking, the compressive strength hardened concrete and the size of the aggregate is required. Finally, by assuming that the hydration affinity does not depend on the strain, effects were eliminated in the modelling. the physio-chemical phenomena may be at the origin of a stress thermodynamic imbalance, which gives rise to creep effects. Cracks can also be caused by freezing and thawing of saturated concrete, alkali- aggregate reactivity, sulfate attack, or corrosion of reinforcing steel. However, cracks from these sources may not appear for years. Proper mix design and selection of suitable concrete materials can significantly reduce or eliminate the formation of cracks and deterioration related to freezing and thawing, alkali-aggregate reactivity, sulfate attack, or steel corrosion.

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