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RESEARCH ARTICLE OPEN ACCESS

Preventing failures of concrete in regions of hot weather

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ABSTRACT
Failures of concrete usually form as cracks. Cracks are commonly found in concrete structures and are undesirable features that may be brought about by environmental causes, workmanship, natural causes as well as age of the concrete element. It is therefore essential that causes and consequences of cracking are well understood so that suitable remedial measures can be adopted. This study is set to determine the likely causes of cracks in concrete structures especially in hot countries. The area of study was selected within Kuwait. Survey questionnaires will be used to collect data on causes and methods used for treatment of cracks. The survey is closely followed by an analysis of the data collected to reveal major causes of the cracks in Kuwait. This paper finally gives recommendations to be taken to prevent such cracks based on findings from the survey questionnaire.

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I. INTRODUCTION

In a concrete structure, cracking is a common indicator of defects in the structure. Cracking presents itself as the first sign of distress in a concrete structure. Cracking can take place both in hardened and fresh concrete. Cracks in concrete may correlate with the extent of damage in concrete and hence may hint to problems of greater magnitude in concrete.

Cracks in a concrete structure may be broadly categorized as either structural cracks or superficial cracks. Superficial cracks only affect the appearance of the structure while structural cracks have a significant negative impact on the durability of the structure. It is also important to note that cracking in concrete can occur at different stages i.e. before hardening and in hardened concrete. In plastic state, cracks in concrete can occur due to drying shrinkage as moisture is lost from the concrete during hot weather. Bleeding and segregation during placing of concrete may also cause cracks in plastic concrete. Cracks in plastic concrete usually appears between one and six hours after placing of concrete. In hardened state, cracks in concrete may be caused by settlement of foundation soils as well as a result of thermal contraction which causes thermal stresses (Banerjee et al., 2004).

It is important to evaluate cracks in buildings and structures since these cracks may affect the structural integrity, aesthetic appeal and long-term durability. The primary concern with regard to cracking in concrete can only be established by thoroughly evaluating the cracks. Evaluation of surface cracks is usually done during visual inspection of a structure. The width of the crack can be measured using a gauge. To provide a true picture of the extent of cracking, the depth of cracks also has to be taken into account. Crack depth measurement has been proven to be important since deep cracks can cause corrosive agents to easily reach reinforcement in concrete which causes them to be quickly corroded over time. Moreover, the effectiveness of crack repair methods depends on the accurate prediction of crack depths. Many different methods can be employed to asses both the extent and depth of cracking.

This paper presents issues regarding concrete durability, hot weather concreting, types, causes and methods of treating concrete cracks. Data on likely causes of concrete cracks are obtained through use of questionnaires distributed in Kuwait.

II. METHODOLOGY

2.1 Area of study

The study will be conducted to investigate the causes of cracking in Kuwait which is a hot weather country.

2.2 Questionnaires and Interviews

Questionnaires on likely causes of cracking of concrete in Kuwait will be prepared to be filled out by engineers in Kuwait. Agencies that constructed the building, i.e. the contractor will also be issued with questionnaires wherever possible. This information will be vital in deducing the major causes of cracking.

2.3 Analysis of questionnaire data.

Responses captured in the questionnaire filled out by construction professional will finally be analyzed to ascertain the major types and causes of cracking in Kuwait. Finally, recommendations on measures to be taken to prevent such cracks will also made as well as remedial actions to be undertaken to mend the cracks.

III. TYPES OF CRACKS

Concrete structures in hot and arid weather characteristic of Middle East countries tend to deteriorate more rapidly thus exhibiting greater problems with cracking than those in temperate regions of the world. (Al-Samarai, 2015)

Extreme environmental conditions in Kuwait namely high ambient temperatures, salt laden dust and low relative humidity have exposed concrete to durability problems in the form of cracks. Durability as used in the context of concrete implies that structures made of concrete should maintain a satisfactory performance with very minimal maintenance over its design service life.

It is through avoiding the degradation threatening the concrete structure due to the type and aggressiveness of the environment and also by selection of optimal material composition and structural detailing to resist the anticipated degradation on the structure during its design life that concrete structures can last without showing any sign of distress (Schafer, 2011)

Cracking in concrete can occur at different stages i.e. before hardening and in hardened concrete. In plastic state, cracks in concrete can occur for instance as moisture is lost from the concrete during hot weather i.e. drying shrinkage. In hardened state, cracks in concrete may result from settlement of foundation soils, application of excessive external loads, design and detailing errors as well as a due to thermal contraction which causes thermal stresses.

Cracks are linear fractures in concrete arising whenever tensile stresses subjected to concrete elements exceed their tensile strength. Concrete cracks takes two forms explained below.

Structural cracks – These are cracks resulting from application of excessive loads onto the concrete structure which results in tensile stresses exceeding the capacity of the concrete member. By excessive loads we mean loading application exceeding the design loads guaranteeing the serviceability check.

Non-structural cracks – These are superficial cracks which are inherent to concrete. There exists three main types of this cracks which are discussed overleaf.

3.1 Non-structural cracks

3.1.1 Plastic cracks - These type of cracks develop on fresh concrete usually between 1 and 8 hours on placing of concrete. They are further categorized as either plastic shrinkage cracks or plastic settlement cracks.

❖ ***Plastic shrinkage cracks –*** Concrete heavier and coarser particles tend to settle more than their finer counterparts thus grout which is a mix of water and cement will manifest on the concrete surface. This means that if environmental conditions namely temperature, air relative humidity and wind speed are favorable in the context that they lead to increased loss of water from the concrete surface, only the upper surface of the placed concrete will lose water through evaporation and hence volumetric strain. While this is happening, the concrete below which is not shrinking tends to restrain this layer from contracting thus inducing tensile stresses at the bottom of the outer concrete resulting in plastic shrinkage cracks as the outer concrete is still in plastic state and hasn't developed sufficient strength to withstand such stresses.

Figure 1: *Plastic shrinkage cracks.*

Remedial measures for plastic shrinkage cracks

Complete prevention of loss of water from concrete after casting through any of the following methods

- ✓ Frequent curing or covering the placed fresh concrete with polythene sheets between finishing operations.
- ✓ Erection of windbreaks to curb high velocity winds .This also implies that flat concrete works can be scheduled to start once wind breaks in the form of walls have been constructed.

✓ Provision of fog sprays to minimize surface evaporation by saturating the air above concrete.

❖ ***Plastic settlement cracks –*** While the concrete is bleeding after being placed, the heavier concrete fraction namely aggregates and cement moves downwards under gravity thus sedimentation. The implication is formation of a weak layer of concrete near the surface .In the event of presence of obstructions in the form of reinforcing bars, ducts or changes in the concrete section e.g. at junction of beam and slab casted monolithically, the settlement process in a concrete element becomes uneven. Consequently the concrete breaks back at the restraint leading to formation of cracks over it. The cracks assume a tapered profile where it is wide at the surface and extends downwards to the reinforcement or any other restraining element. This type of cracks appear at the surface mimicking the layout of the obstruction.

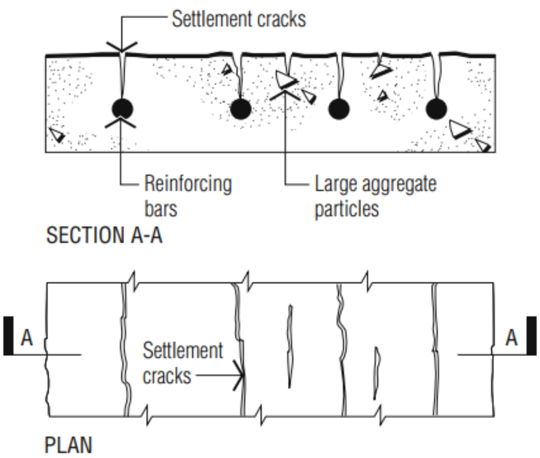

Figure 2: *Settlement cracking.*

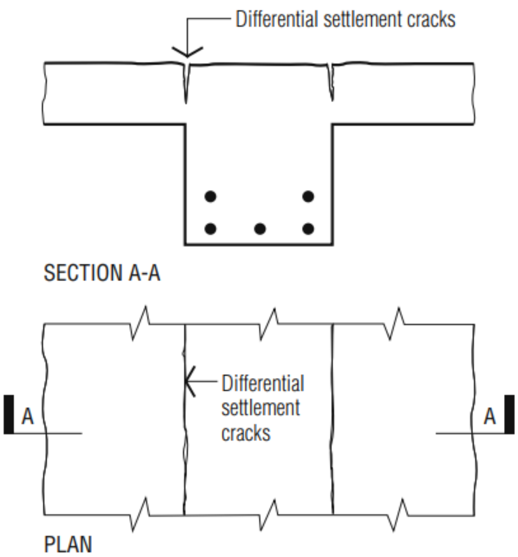

Figure 3: *Differential settlement cracking.*

By exposing the reinforcement, plastic settlement cracks poses a great risk of corrosion of steel and consequent durability issues in structures.

Remedial measures for plastic settlement cracks

✓ Provide a large cover to compression (top) steel

✓ Design concrete mixes having low bleeding characteristics. This might call for use of air-entraining admixtures .Air bubbles in fresh concrete mix keeps solids particles in suspended state thus minimizing sedimentation while at the same time reducing movement of water as is the case during bleeding.

Treatment of plastic settlement cracks.

Despite plastic settlement cracks not going through the full depth of the section, they usually pose the challenge of exposing the reinforcement to corrosion which can affect the structural integrity. Therefore such cracks should be sealed by adopting any of the following approaches

✓ Concrete re-vibration at the earliest opportunity before initial setting that is if such cracks are noticeable in newly placed concrete. However, this calls for proper timing to ensure that concrete can re-liquefy under the action of a poker vibrator.

✓ The need to treat plastic settlement cracks in hardened concrete will depend on a number of factors like exposure condition and size of cracks. If need be, they can be sealed with a resin injection

3.1.2 Early-age thermal cracks – There are two major challenges encountered during concreting in hot areas i.e. high environmental temperature and high temperature of concrete.

Hydration of cement is more rapid whenever the temperature of concrete is greater than normal. This coupled with low relative humidity of the air as is often the case in hot areas results in rapid evaporation of mix water especially at the surface of concrete hence development of plastic shrinkage cracks already discussed in the previous section.

Thermal cracking especially in mass concrete structures arise due to restraint of contraction of concrete following a spike in heat of hydration of cement. This is the case whenever no mechanism is provided to shield the freshly placed concrete mass from the atmosphere. Since there is rapid evolution of heat of hydration of cement, there develops a temperature gradient within the concrete mass since the inner concrete remains hot as the surface concrete losses heat to the environment. From the foregoing it is clear that tensile stresses will be induced on the surface concrete and compressive stresses on the inner concrete. This may result in surface cracks. During the cooling phase, the surface concrete contracts hence sealing off any tensile cracks developed during the heating phase. However, the outer concrete is restraining the interior concrete from contracting more .Doing so, large tensile stresses are induced onto interior concrete. It is the tensile stresses due to cooling restraint that bring about thermal cracking of mass concrete structures.

Remedial measures for of thermal cracks

✓ Temperature of fresh concrete can lowered by influencing temperature of its constituent components before or during mixing. For instance mixing water can be stored in tanks painted all white or buried underground. Aggregate stockpiles intended to be utilized in the job mix can be stored in a shade or lightly sprinkled with water so that heat is lost through evaporation. The objective of this approaches are to lower the concrete peak temperature such that the temperature gradient between the environment and concrete during cooling is reduced.

✓ The entire surface of concrete can be insulated from the atmosphere using any suitable form so that expansion and contraction of concrete takes places freely without any restraint arising from temperature gradient

✓ Scheduling of concrete mixing and placing works. It might call for concrete works to be undertaken at night or during times when air temperature has significantly dropped in an attempt to produce concrete having ideal temperature.

✓ Choice of formwork- For thin concrete elements usually those less than 500mm thick, metallic formworks can be adopted as they can quickly dissipate the heat at the concrete surface meaning the heat at the interior won't peak. This way, detrimental temperature differentials will not occur.

✓ Portland cement that generates low heat of hydration can be specified for concrete mixes.

3.1.3 Drying shrinkage cracks – Drying shrinkage cracks manifest themselves in hardened concrete. Not all the water in concrete mix are utilized by cement hydration process. Some fraction of mix water are only meant to provide the workability requirement of concrete. During curing and hardening of concrete, the excess water is lost to the environment resulting in shrinking of concrete. As the concrete is shrinking, elements within the concrete like reinforcement bars, restrain the concrete from shrinking leading to creation of tensile stresses in concrete which produce drying shrinkage cracks. Tensile cracks develop if the resulting tensile stress is greater than the tensile strength of concrete.

Drying shrinkage cracks can also occur if there is external restraint to shrinking either by another structure or subgrade as shown below.

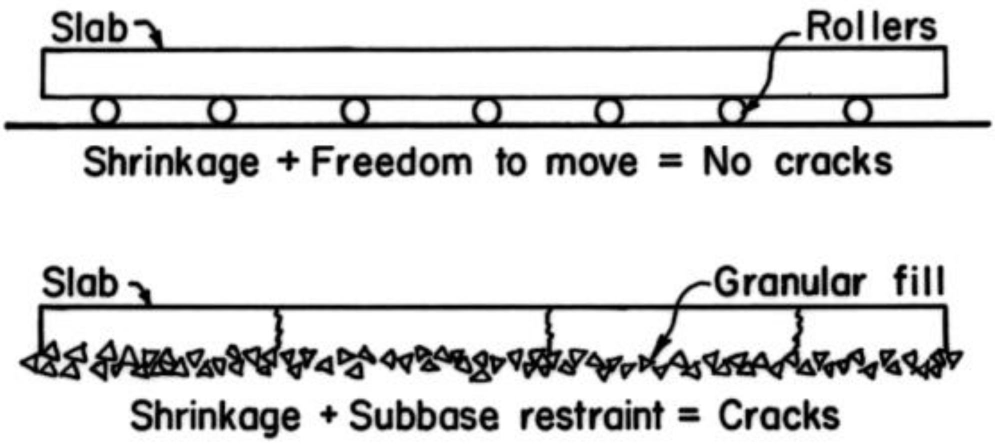

Figure 4: *Movement joints and how they prevent drying shrinkage cracks*

Remedial measures for drying shrinkage cracks.

✓ Use of shrinkage reducing admixtures

✓ Tensile strength of concrete can be increased through adequate curing

✓ Concrete mix design review to ensure that the lowest possible water content for workability is used. Increasing the size of coarse aggregates in the mix can lower water demands of a concrete mix at the same time provide internal restraint to volumetric change.

✓ Provision of movement joints to eliminate external restraints.

3.2 Other causes of cracks in concrete

a) Structural design and detailing errors.

It is a common practice that design of concrete structures be informed by the nature and amount of loads the structure will be exposed to. Concrete is poor in withstanding tensile stresses and this calls for its reinforcement with steel as the latter has high tensile stress capacity. From the foregoing, design discrepancy with regards to steel reinforcement areas provided and foundation design results in a serious serviceability problem in the form of cracking. It is worth noting at this point that poor foundation design may result in differential settlement whose end result is cracks.

b) Poor construction practices

Some of the practices which result in cracking of concrete structures include

- ✓ A high water content in an attempt to increase concrete workability. Not only does this practice lower the concrete strength but also increases its settlement. The implication is increased drying shrinkage plastic settlement cracking.
- ✓ Using large cement content in concrete mixes to compensate for high amounts of water added to attain the desired workability. This is majorly the case with mass concrete structures where the heat generated by cement hydration is quickly dissipated at the surface while the internal temperature drops slowly. This implies the cooler surface will be contracting much faster unlike the inner concrete which is contracting slowly and offering restraint to contraction of the cooler concrete leading to creation of tensile stresses which result in thermal cracks at the concrete surface due to the large temperature differences at the section.
- ✓ Lack of or inadequate curing .Failure to cure fresh concrete few hours after it has been placed results in development of plastic shrinkage cracks. In the long term, the hardened concrete will be found to have low strength as it lost a lot of water which is essential for hydration meaning strength gain did not proceed to completion.

c) Chemical reactions

This involves reaction between the alkali component of cement and active silica contained in aggregates which produces an alkali- silica gel which has a tendency to increase in volume by absorbing water thereby putting pressure on the surrounding concrete consequently, tensile stresses increases beyond the capacity of concrete leading to crack development.

d) Corrosion of steel reinforcement

Reinforcement steel which is usually embedded in the alkaline concrete is usually stable since the later usually forms a passive protective coating around steel. However, this passive protection is lost through carbonation. This is where carbon (IV) oxide dissolves in atmospheric water to form carbonic acid and finds its way through the concrete cover thus neutralizing the alkaline environment. Since the reinforcement has lost the protective layer, corrosion begins. The resulting by-products i.e. rust occupy a larger volume than steel .Tensile stresses brought about by expansion leads to cracks. At higher temperatures, carbonation proceeds at a much faster rate (Al-Samarai-2015)

IV. METHODS OF CRACK REPAIR

Epoxy injection – This method is suitable for repair of fine cracks up to 0.05mm.However, this method is not applicable for repair of leaking cracks as epoxy is not effective on wet surfaces. It involves the use of low viscosity epoxy grouts. The crack to repair is first cleaned and sealed to prevent leaking of the epoxy before gelling. The epoxy is then injected under pressure to penetrate the crack. Once the epoxy has cured, the seal is removed using any appropriate means.

Routing and sealing-This treatment method is suitable for both narrow and wide cracks especially in flat concrete members like slabs and beams. Routing refers to the process in which the existing crack is widened using a saw or any other suitable tool. The groove is then cleaned and sealant applied. The sealant material can take any form from epoxies to polymer mortars. It is however advised that grouts made of cement should be avoided due to their high likelihood of cracking. It is widely employed in repair of cracks in water retaining structures.

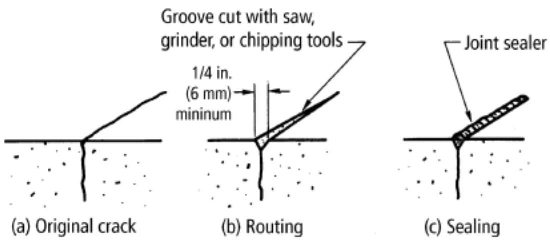

Figure 5: *Crack repair by routing and sealing.*

Near surface reinforcing (NSR) and pinning – This is where additional tensile reinforcement is added across the plane of a crack. First, a slot about 3mm wide is cut using a saw across the crack. It should be ensured that the depth of the slot is deeper than the diameter of the bar to be used. Once the slot is made, an epoxy resin is introduced followed by the reinforcing bar .The former acts as a bonding medium between the reinforcing bar and the concrete

Gravity filling – Resins and monomers are used to seal cracks whose surface widths ranges from 0.03mm to 2mm.The surface is thoroughly cleaned and let dry. Resins and monomers are then poured and spread on the surface where they can fill any existing crack by gravity

Drypacking – This method is suitable for repair of dormant cracks using hand. Mortar having a low water-cement ratio is hand placed into a crack and tamped. Because of the low water content, the mortar will experience little shrinkage hence durability

Provision of additional reinforcement – In this technique, cracks are first sealed followed by drilling of holes which intersect the crack at approximately 90^0 .The crack and the hole is then filled with injected low viscosity epoxy and reinforcement placed into the drilled hole. The reinforcement provided should extend at least 0.5m either side of the crack. Epoxy serves to bond the bar to the crack wall and the cracked concrete into one monolithic form.

Drilling and Plugging – This method is applicable for repair of vertical cracks running in straight lines. Holes having diameter range of 50-75mm are first drilled along the crack center. A key is then formed by passing down grout which helps prevent leakages. The method is often applied in repair of vertical cracks in retaining walls.

V. DATA ANALYSIS, DISCUSSION AND CONCLUSION.

Data Analysis and discussion

This chapter presents the results of a questionnaire entitled "Causes of concrete cracking in hot Countries-Kuwait," The survey was sent out to and filled by specialists involved in construction within Kuwait. It was intended to utilize the results in focusing the research on the durability of concrete structures, especially in hot countries.

A total of 75 responses have been received from participants in Kuwait. The respondents included consultants, material engineers, structural engineers, contractors, and researchers. Surveying professionals from a wide range of job descriptions ensured that the results captured an accurate view and opinions of the wider construction industry stakeholders.

The questionnaire listed 10 possible causes of cracking in concrete. All the questions required the participant to rate the likely causes of concrete cracks they have encountered during their engineering practice in Kuwait on a 5-point scale, where a 1 would be the least likely cause and 5 as the most likely cause.

The results of each question are presented as an average to the replies of the respondents. Tabulated below, are the questionnaire questions and their corresponding average responses.

Table 1:*Results of questions 1-10 regarding the causes of cracks in hot countries, the case of Kuwait.*

No.	Question	Average rating.
1	Plastic shrinkage cracking	3.29
2	Plastic settlement cracking	3.23
3	Drying shrinkage	3.6
4	Thermal stress	3.87
5	Structural design and detailing errors	3.4
6	Corrosion of steel reinforcement	3.32
7	Poor construction practices	3.69
8	Chemical reactions	3.15
9	Construction overloads especially in precast members	3.24
10	Externally applied loads	3.43

Through a questionnaire on the likely causes of cracking in concrete in hot countries, the case of Kuwait, the opinion of industry professionals engaged at all stages right from design to execution has been determined. The following conclusions are made based on the results.

- There have been various categories of cracks in concrete structures in Kuwait since all the varying causes of cracking as surveyed ranked above 3.0, which implies that all the stated possible reasons may have in one way or another contributed to cracking of concrete.
- Thermal stress was considered as the significant cause attributed to the cracking of concrete structures within Kuwait. It was ranked 3.87.
- On the other hand, chemical reactions were considered the least significant contributing factor to cracks encountered by industry specialists. It ranked 3.15.

VI. CONCLUSION

This paper sought to establish the causes of cracks in hot countries, a case of Kuwait. It consists of five sections. The first part offered a basic introduction about the broad classification of cracks in concrete and their effects on structural integrity and durability. The second section described how questionnaires would be utilized to collect data from construction industry professionals regarding the causes of concrete cracking in Kuwait. A detailed description of the types, potential causes, and preventive measures of cracks was provided in the third part. Section four of this study focused on the various techniques that can be used to cure concrete cracks. Analysis of questionnaire data was carried out in part five to ascertain the major causes of cracks in concrete structures in Kuwait. The results revealed that cracks attributed to all the possible reasons stated above had been observed in Kuwait. However, thermal stress-related cracks accounted for the bulk of cracks observed by the respondents. Proper consideration should be given to the major causes of cracking at the initial phase of design and construction to mitigate against cracking of structures at an early age and during service.

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