Challenge Journal of Concrete Research Letters

Case Study

Effectiveness of crack repairing measures in Tabuk City, Saudi Arabia

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ABSTRACT

Concrete cracking and defect patterns can often indicate its causes. In this research paper, detailed description of cracks types, causes, and proper solutions is identified. The main objective of the paper is to measure the response of specialists about the probability of certain cracks causes and solutions, and to evaluate the effect of using epoxy materials in repairing concrete cracks. The present study shows that about 50% of responders indicated that cracks due to steel corrosion represent between 10-20% of building cracks. And about 80% of the responders indicated that crack due to load increasing is rarely occurred in the site. The interviewed specialists ensured that using epoxy materials are effective in solving most cracks' problems. The experimental work results show that the flexural strength of epoxy repaired samples exceeded that of original samples. And the increase in flexural strength is inversely proportioned with sample depth.

ARTICLE INFO

Article history:
Received 28 May 2017
Revised 10 August 2017
Accepted 6 September 2017

Keywords:
Concrete cracking
Cracks solutions
Corrosion
Epoxy material
Flexural strength

1. Introduction

Some types of cracking indicate a structural issue, when others do not indicate any type of issue other than normal weathering. The age of the cracks should be determined before assuming any solution (Roger, 2014). There are many different causes of cracks, which can lead to different types of cracking patterns (Gwalior, 2004; Fowler, 2008). Each type of cracking pattern can be associated with a likely cause. Some cracks are a result of wear, while others are related to design or construction defects (Roberts, 2016). When a structure is overloaded to the extent not covered in safety factors, concrete may be damaged or fail. Overloading may be in shear, flexure, or tension, or may be a result of fatigue or cyclic loading. Each of these has a different cracking pattern to look for (Kashyzadeh and Kesheh, 2012).

Causes of cracks are different; some are related to corrosion in the reinforcing steel, others are occurred from freeze/thaw effects, others related to concrete shrinkage, and causes related to workmanship (Thagunna, 2014; Nama et al., 2015). Friedman conducted a study to identify the main causes of cracks in poured concrete and the proper methods to repair it (Friedman, 2007). Several studies searched for cracks solutions. The solutions varied from preventive to curative ones. Kishor and Namesh (2014) set different measures to control cracks in structure starting from identification and inspection.

Some studies tested the effect of adding repair materials to cracks. An old study showed that the flexural strength of cracked concrete specimens repaired by epoxy injections became larger than that of the original concrete specimen (Kleinschrodt, 1989). The study of Kunieda (2001) performed experimental work for evaluating flexural failure behavior of concrete beams repaired by crack injection techniques. Four samples were prepared at different sizes. The study results showed that flexural strength of repaired samples is larger than original sample. Another study was conducted to evaluate the performance of epoxy injection repair process by preparing test samples. The study found that using low viscosity epoxy is effective in sample with cracks width<1/16 inch. They found that medium viscosity epoxy is suitable for repairing cracked slabs (NAHB Research Center, 2002).

This study aims to measure specialist's response about crack's causes and solutions. And to test the effect of using epoxy materials in repairing cracks.

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ISSN: 2548-0928 / DOI: https://doi.org/10.20528/cjcrl.2017.03.003

2. Concrete Crack Causes

Cracks could cause major damage to any building. It is very important to study causes of such cracks and to know the ideal methods to deal with them. As known soil and footing settlement is the major cause of cracks in buildings. Other main causes of concrete cracking are described below:

1. Concrete reinforcement corrosion: concrete provides good protection to steel. This protection depends upon the quality of concrete, depth of concrete cover, and workmanship. When the reinforcement steel gets corroded, it increases in volume with setting up of internal stress in concrete. There are two major causes of corrosion in the reinforcing steel: chloride penetration and carbonation (Fig. 1).

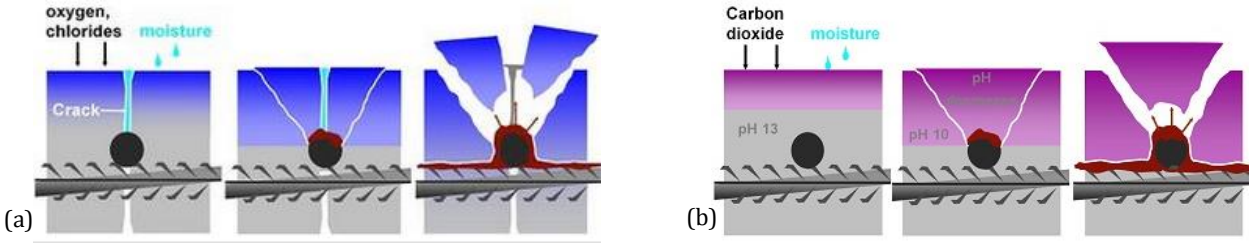

Fig. 1. (a) Corrosion due to chloride; (b) Corrosion due to carbonation.

2. Concrete shrinkage: Shrinkage in concrete could be either initial or plastic. Initial Shrinkage is normally occurs in all building materials or components that are cement based. Shrinkage of concrete and mortar occurs only at the time of manufacture, when the moisture used in the process of manufacture dries out. Plastic shrinkage occurred in freshly placed concrete. Sometimes cracks occur on the surface before concrete has set when there is relatively high amount of bleeding.
3. Concrete creep: This type of cracks normally occurred when buildings subjected to sustained load.
4. Vegetation Growth: Roots of a tree generally spread horizontally on all sides to the extent of height of the tree above the ground and when the trees are located in the vicinity of a wall, they can cause cracks in walls due to expensive action of roots growing under the foundation.
5. Sulphate attack: Soluble sulphates which are sometimes present in soil or ground water reacts with cement in the presence of moisture and form products which occupies much larger volume than the original constituents.
6. Alkali-aggregate reaction: Cement contains some alkalis. These alkalis react with certain siliceous mineral constituents of aggregate and cause expansion, cracking and disintegration of concrete.
7. Poor structural design/construction practices.

3. Study Analysis

The study aims to measure the response of specialists about the probability of certain cracks causes, and to identify the proper solutions for each cause from the responder's opinions based on a questionnaire distributed to them. The questionnaire was divided into two parts. The first part is related to different causes of building cracks. The second part introduces their opinions about the appropriate solutions for each cause. The questionnaires were distributed in the several engineering design and consultation offices in the city.

The following equation was used to estimate number of interviewed specialists (since standard deviation is not known).

$$N = p * q * (\frac{Z\frac{\alpha}{2}}{d})2\,, \qquad (1)$$

where: p is the proportion of interviewed specialists who suggested solving cracks with epoxy; q is the proportion of interviewed specialists who suggested solving cracks with other than epoxy.

To have the largest sample size; (p) is considered as 0.5. Confidence level is considered as 90% so Zα/2 equal to 1.645 and permitted error (d) as ±0.1, the sample size was found as 70 specialists.

4. Observations

The statistics from the observed data show their response about the cracks causes include: concrete shrinkage, steel corrosion, sulfate salts, increasing load, inadequate steel, defects in concrete, displacement in columns, stress on concrete, column overload, increasing in tile dimension, and bending strain. Their responses were measured on a subject scale with the probability of certain cracks causes' occurring. The study statistics and observations are shown in Table 1.

Table 1. Cracks due to concrete shrinkage.

Responders Answer	Occurrence Percentage
29%	Less than 10%
34 %	10 -20%
30%	20 – 50%
7 %	More than 50%

From Table 1, it is appeared that the opinions of responders varied about percentage of crack occurrence due to concrete shrinkage. This may indicate that such

crack appear in many concrete structures. Fig. 2 below show that about 50% of responders indicated that crack occurrence due to corrosion of steel represent between 10-20% of building cracks.

Table 2 below showed that about 80% of the responders indicate that cracks occurrence due to increasing load is rarely occurred in the site.

Fig. 3 below showed that the opinions of responders vary about percentage of crack occurrence due to inadequate steel. This may indicate that such crack appear in many concrete structures.

Table 3 below showed that interviewers respond were not clear regarding the presence of defective materials in concrete as a cause of cracks. This may indicate that such cause is related to the material used in concrete in each region.

The interviewers were asked about the best solution for the above mentioned cracks causes. Their response is restricted in using special epoxy materials to solve the cracks problems. They mentioned that method is widely used because it is cost-effective since it does not need to replace the existing structure. While they indicated several preventive solutions as summarized below (it is important to know that these are the opinions of the interviewed specialists).

1. Use sulfate-resistant cement with clean raw materials and clean water is the best solution to avoid cracks due to concrete sulfate salts.
2. Good compaction of concrete, concrete water treatment, and hydration for a period not less than 7 days is the best solution to avoid cracks due to concrete shrinkage.
3. Removing all impurities and clean the steel from rusting with isolate epoxy is the best solution for cracks due to steel corrosion.
4. Following design standards (loads, steel, and stirrups) is the best solution to avoid cracks due to design problem (increasing load or increasing slab dimension, column overload).

Table 2. Cracks due to increasing loads.

Responders Answer	Occurrence Percentage
41%	Less than 10%
39%	10 – 20%
14%	20 – 50%
6%	More than 50%

Table 3. Cracks due to the presence of defective materials in concrete.

Responders Answer	Occurrence percentage
38%	Less than 10%
33%	10 – 20%
26%	20 – 50%
3%	More than 50%

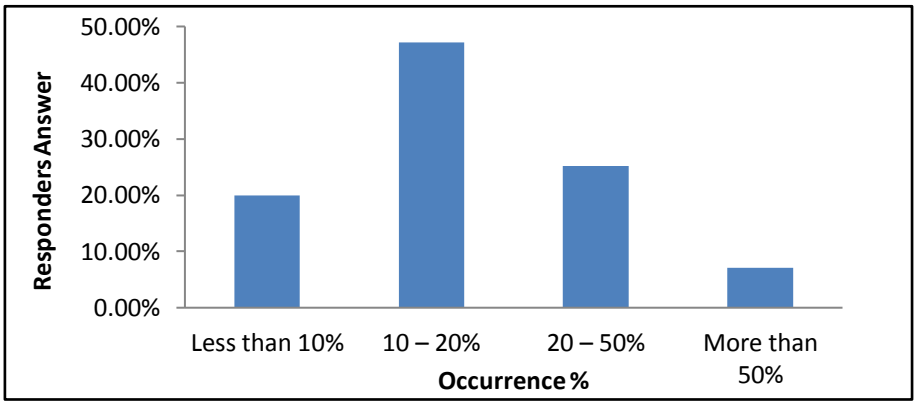

Fig. 2. Cracks due to steel corrosion.

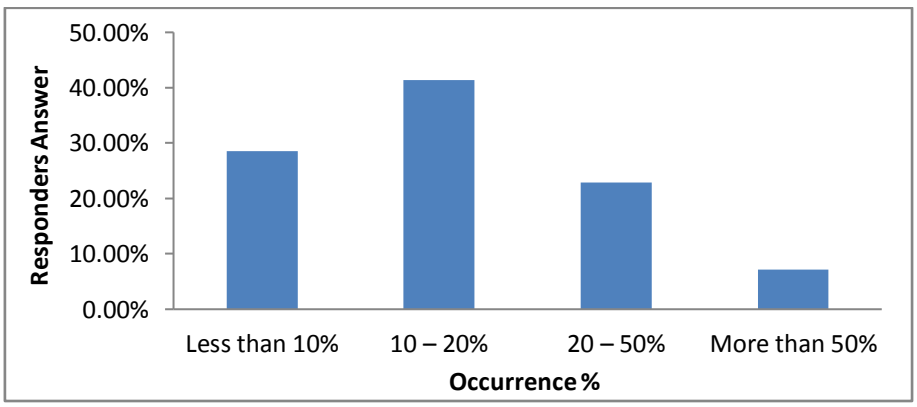

Fig. 3. Cracks due to increased shear stress (inadequate steel).

5. Experimental Work

Crack injection is a common technique for repairing damaged concrete structures. Several methods were used in testing and analyzing repair schemes. An ordinary concrete mixture was prepared with 0.45 water cement ratio and 15mm maximum aggregate size. Four concrete samples were prepared having 10cm and 20cm depth. A surface crack was made approximate 2mm width with 1/10 depth of each sample as shown in Fig. 4.

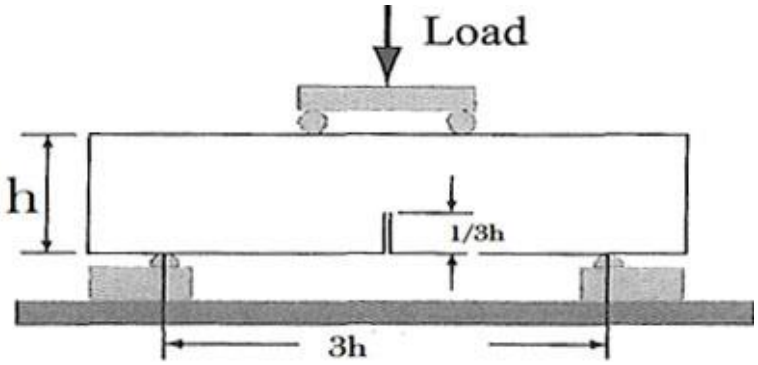

Fig. 4. Test setup for concrete samples.

Other two samples were cured using (Concure WB) crack repairing epoxy. This type of epoxy is based on a low viscosity wax emulsion. It applied to retain moisture in concrete for effective curing to reduce permeability, avoid surface cracks, reduce shrinkage, and improve durability. The use of Concure WB complies with BS 8110, ASTM C309 and ASSHTO M148. Concure WB was applied to the surface of the concrete samples immediately after de-molding. Samples were tested at 7 days concrete age. The test results of flexural strength are summarized in Table 4.

Table 4. Flexural strength test results (kg/cm2).

Increased Percentage	Repaired Samples	Original Samples	Sample Depth (cm)
3.6	98.5	95	10
1.3	101.8	100.5	20

It is appeared from table that the flexural strength of repaired samples exceeded that of original samples. It also appeared that the increase in flexural strength between original and repaired samples is inversely proportioned with sample depth. As discussed above, most of the experiments found that using epoxy injection is valuable in cracks curing. This conclusion is complying with other old studies' results, and with the responder's solution to repair cracks in building.

6. Conclusions

Building stability may be affected by serious types of cracks. Due to construction faults and other unavoidable reasons, different type of cracks starts to appear on various building. Some types of cracks need attention as they are structurally hazardous. In this paper, the response of specialists about the probability of certain types of cracks was measured. The study results showed that about 50% of responders indicated that cracks due to steel corrosion represent between 10-20% of building cracks. It is also appeared that about 80% of the responders indicate that crack due to load increasing is rarely occurred in the site.

Several solutions for cracks were suggested with different assumed preventative measures such as using sulfate-resistant cement, good compaction of concrete, steel cleaning, and following design standards. Such measures will help construction companies, consultant, and designers to avoid cracking problems. It is concluded that the causes of crack can be controlled if proper consideration is given to construction material and technique to be used. The experimental work on cracks was compatible with the study observations. It found that using epoxy is suitable for repairing cracked elements. And that the flexural strength of repaired samples exceeded that of original samples.

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