Crack width assessment and propagation in RCC and masonry structures – A review

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***Abstract*— The structures which are showing rapid signs of distress need immediate attention for ascertaining the causes of their distress and for proper diagnosis and selection of methodology for proper solution and rehabilitation of the structures. These changes cause distress if not taken proper care of. The presence of cracks is unavoidable in reinforced concrete structures as well as in masonry structures and it gives access to chlorides and other harmful agents to ingress into the concrete resulting in concrete degradation this includes corrosion of steel reinforcing bars. The presence of cracks accelerates the propagation of corrosion resulting in significant corrosion induced damage and loss of section and load carrying capacity of RCC structures. To investigate the detoriation of RCC and masonry an experimental study is conducted. One of the earliest signs of structural detoriation are cracks on concrete surface, which are crucial for maintenance since prolonged exposure could severely damage the environment. Manual inspection is the preferred technique for detection of cracks. In this research paper, the deformation and cracking on RCC and masonry structure, behavior of the crack is been monitored by the Glass Tell Tales or crack measurement gauge. The identification of such cracks enables the assessment of the degree of structural threat for buildings affected by earthquake or any other destructive phenomena to be determined. Then, the crack characteristics measured from the experimental measurement were compared and presented using the proposed technique. The paper a detailed review of understanding, monitoring the cracks and estimating the equations for the same so that the degradation of concrete can be easily detected and controlled to some extend with proper precautions.**

Keywords*— *Structural distress, cracks, crack measurement, structural repairs, crack propagation.

I. Introduction

The structures need immediate attention which are showing rapid signs of distress in engineering structures, which are precarious for the maintenance as well the constant loading, subjection of fatigue stress, will lead critical damage to the environment. Cracks which usually emerge at the microscopic scale reduces local stiffness and causes material discontinuities during its service life due to weaker tensile strength, flexure and shear as well as due to other various environmental factors.

The presence of cracks in reinforced concrete structures as well as in masonry structures are unavoidable and it gives exposure to chlorides and other harmful chemical agents to approach into the concrete, causing it to deteriorate and steel reinforcing bars to corrode. The presence of cracks encourage the propagation of corrosion prompting significant corrosion induced damage, loss of section and load carrying capacity of reinforced concrete structures. Early perception allows preventive measures to prevent destruction to the environment. Processing techniques can be used to detect cracks in the structures by crack detection process where in the crack are divided into structural and non-structural cracks. Usually, structural cracks wider than 6mm spread further into the concrete and at times even through the structural members. Whereas non-structural cracks does not affect the integrity of the structure and are usually less than 3mm in width. Surface condition of the structure can be evaluated by including visual examination and surveying tools. Crack detection techniques are self-operating and provides information regarding the type, width, length, orientation and crack pattern on the structural surface

II. Types of Cracks

A. Shrinkage Cracks

Concrete presents excellent performance of strength in compression. However, during its service life it easily cracks due to flexure, tension, and shear as well as due to the various environmental factors. Four forms of shrinkages can result in cracks in concrete and may appear in freshly laid and hardened concrete as shown in fig.1

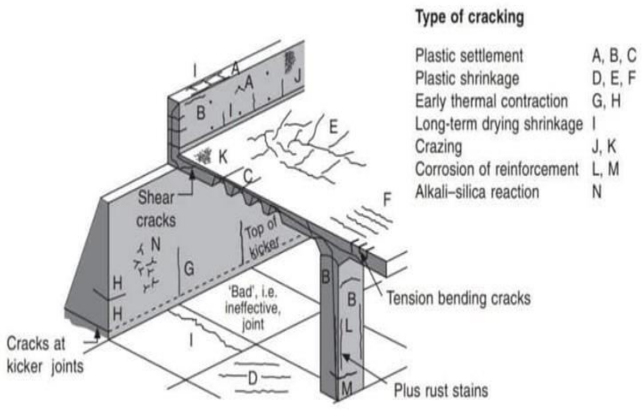

Fig. 1. Types of cracks in concrete.
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The plastic cracking typically arise within half an hour to 3 hours of placing and finishing due to evaporation of vapour in concrete, normally occurring due to high water: binder ratio, higher cement content, higher temperature and wind velocity. This can be managed by using lower water: binder ratio.

Autogenous Shrinkage occurs when water is withdrawn from capillary pores due to the hydration of unhydrated cement in hardened concrete. It occurs at higher temperature and with higher and finer cement contents. Drying shrinkage occurs when the concrete is left to dry in air with relatively a lower humidity in hardened concrete.

Carbonation shrinkage occurs in hardened concrete when atmospheric carbon dioxide seeps into concrete and interacts with calcium hydroxide to produce calcium carbonates. This further leads to the corrosion of steel and deterioration of concrete. Compressive and tensile strength of concrete increases due to Carbonation. The rate of carbonation depends on concentration of CO_2 in the atmosphere, concrete porousness and relative humidity. The extent of carbonation can be predicted with help of equation (1) as below:

$$x = k.\sqrt{t} \qquad (1)$$

Where "x" carbonation depth in mm, "k" is the coefficient of carbonation in $mm/years^{0.5}$ and "t" is the exposure time in years. k is the durability parameter which depends upon the environmental and concrete intrinsic dependent variables. Figure 2 demonstrates the relationship between carbonation depth and concrete's compressive strength. (Possan et al., 2021)

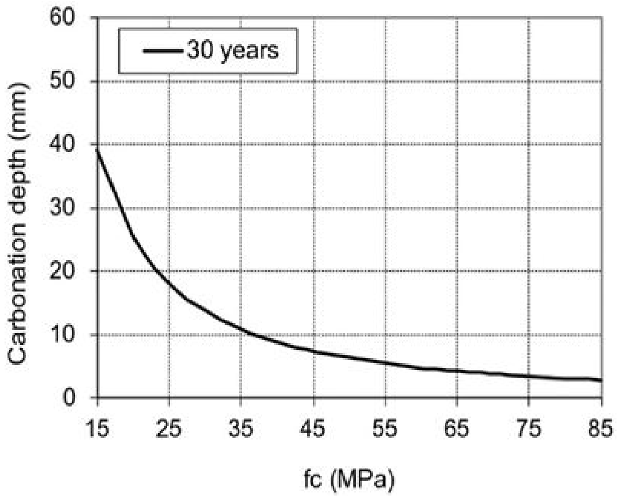

Fig. 2. Variation in Carbonation Depth with Concrete Compressive Strength (Possan et al., 2021).
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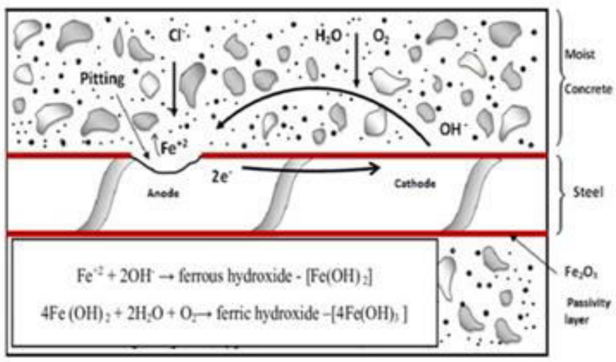
B. Chemical Reactions

Chloride attack is one of the most dominant characteristic while dealing with durability of concrete. It primitively causes corrosion of reinforcement. Chlorides are introduced into concrete by the use of admixtures, water, aggregate, and sometimes cement by diffusion from environment and attacks the reinforcements, if the concrete is permeable. If the passive layer is broken due to carbonation process the chloride and water can attack the reinforcement. (a)Process of Corrosion of Reinforcement and (b) Corrosion of Reinforcement and Spalling of Concrete due to Chloride Attack (see fig 3).



(a)

(b)

Fig. 3. (a) Process of Corrosion of Reinforcement and (b) Corrosion of Reinforcement and Spalling of Concrete due to Chloride Attack.
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Alkali-silica reaction (ASR) occurs between certain reactive silica minerals contained in the coarse or fine aggregates and alkalis like Na_2O and K_2O present in cement or other sources. Concrete may expand and crack in unusual ways as a result of this chemical process. To prevent this reaction in concrete, it is advised to use low alkali cements or mineral admixtures. Figure 4 shows the pattern cracking effect due to alkali silica reaction.

Fig. 4. The pattern cracking effect due to alkali silica reaction.

Alkali-carbonate reactions deteriorate similarly like ASR; however, Because ACR is unusual and generally unfavorable for use in concrete for other reasons, it is quite rare. This is due to the particular nature of the aggregates that are prone to this phenomenon. Petrographers may recognize the aggregates that are affected by ACR by their distinct texture. Compared to alkali carbonate reaction, the introduction of additional cementing materials fails to stop the harmful expansion caused by ACR. Concrete produced using ACR susceptible aggregates is not recommended. As mentioned earlier, once deleterious AAR extension results into severe cracking in a structure, the interior of the concrete is exhibit to the action of aggressive agents, and deterioration is enhanced, particularly when concrete is in exposed with salt water.

Sulphate attack is a chemical reaction between sulphates present in soil or ground water and concrete or mortar. Concrete is not severely attacked by the Solid sulphates but chemicals that are in solution enter porous concrete and reponding with hydrated cement products. It is observed that maximum damage is caused by sulphates of magnesium. The chemical reaction takes place between the calcium aluminate hydrates in the cement paste matrix and the sulphate, which further outcome in deterioration of concrete. Sulphate attack can cause concrete to expand, strength loss, cracking, and deteriorate as shown in figure 5 (a) & (b) shows the effect of sulphate attack on concrete.

(a)

(b)

Fig. 5. (a) & (b) shows the effect of sulphate attack on concrete.
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C. *Thermal shrinkage*

Like any other material Concrete shrinks or expands with temperature. The thermal expansion or contraction of concrete is of the order of 10 × 10−6/℃. The effects of temperature variation in slabs controlled by temperature reinforcement. In other structures, where continuity is unessential it is looked after by the expansion and contraction joints, like pre-stressed girders in bridges, concrete pavements etc. When the restraint to expansion and contraction, stresses develop and if tensile stresses surpass the tensile strength of the concrete, cracks develop. They can be surface cracks or internal cracks in the concrete. Cracks developed within the concrete have more unfavorable effect on the strength and durability of the concrete.

III. Literature Survey

The literature review lists a variety of methods and analysis for figuring out how a crack in a structure is propagating. Research articles on the issue of crack width propagation in RCC and masonry buildings were acquired and studied in order to learn more about this topic.

S. Kabir (2010) suggested imaging-based inspection procedure for crack detection in concrete. This study was put forward about the application of texture analysis approach grey level co-occurrence matrix (GLCM) and artificial neural network (ANN) to anticipate information regarding surface abrasion. Where examination were carried out on the CANMET blocks which were exposed to outdoor conditions and the slabs were kept indoor. Tested in laboratory and measurements were recorded at regular interval in order to estimate the amount of inner damage. [1].

P. wang and H. Huang (2010) proposed a mechanism to classify cracks based on their effectiveness and detect cracks using IP techniques. Depending on the image based cracks detection they are divided into four groups. They incorporate practical techniques, an integrated algorithm and morphological method. Using integrated algorithm shading correction was done. Implementing percolation method the uncertain cracks prediction was found. Using the morphological approach crack detection for the micro crack was done. It was concluded that Crack identification requires a lot of processing time, especially for large-scale concrete images where as Practical methods can produce outstanding results in a variety of concrete images [2].

B.Y. Lee, Y.Y. Kim, S.T. Yi and J. K. Kim (2013) studied about image processing technique where in digital image of concrete surface is proposed to analyse and detect cracks on the concrete surface. In the prefer technique, morphological analysis was performed to examine the shape and rectify the background's non-uniform brightness. For mentioned image processing methods, an algorithm was developed and various experiments and analytical studies were carried out to evaluate the algorithm's viability. It was concluded that the test results indicated accurate results and analysed using the recommended technique [3].

C. Giry, C.O. Leblond, F. Dufour and F. Ragueneau. (2013) investigated a reinforced concrete beam that was tested for four-point bending is examined. Beam behaviour is evaluated at various stages, from the global response to local information like cracking. The finite element analysis is then subjected to a post-treatment in order to characterise the cracking pattern. This article examines two distinct post-treatment techniques Continuous / discontinuous topological search and global/local crack opening. Results show that both approaches are capable to give reliable estimation of cracking [4].

S.Y.Alam, A. Loukili, F. Grondin and E. Roziere (2015) examined the influence of structural measurements using 3 different sizes of beams which were proportionally equivalent. DIC and AE techniques were utilised to evaluate the effect of structural dimension and studying the mechanisms of cracking. It was determine that DIC techniques provide accurate measurements. Most beams had tensile micro cracking and they displayed tensile and shear in other instances [5].

P. Chambel, R. Martins, and L. Reis (2016) studied how a specimen's fatigue crack spreads under mode I, II, or III of loading. For plane strain or stress state, stainless steel was developed. It was concluded that the JI values, which was calculated according to ASTM standards, were determined, are almost identical to the (a/w) ratios of 0.45 and 0.50. Crack growth rate for mode III was higher along specimens' external surfaces and in a 70° direction than it was in the middle portion [6].

A. mohan and S. poobal (2017) investigated around 50 research papers concerning to crack detection. Based IP techniques examination analysed data was collected regarding objective, error level, accuracy level etc. It was determined that camera-based IP approaches were the primary methods employed to determine crack width [7].

S. Wang and S. Hu. (2019) studied the fundamental hydraulic cracking technique to improve the tight hydrocarbon reservoir recovery process, which depends on the convergence of fractures. Utilising DIC methods, concrete beams with edge cracks and an active crack performed a three-point bending test. After interaction, a proposed enhanced restart cracking criterion is made. Predicted and experimental restart points for the tested beams are compared. A significant agreement is observed, demonstrating the reliability of this criterion. [8].

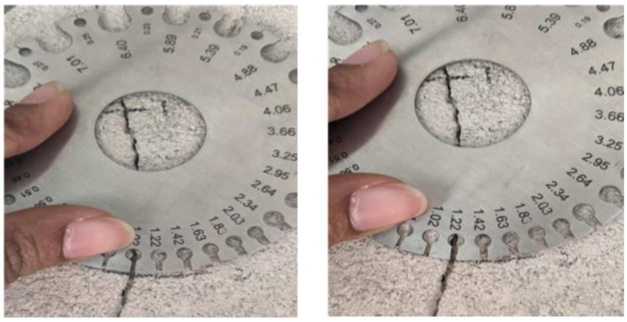
N. Gehri, J. M. Falcon and W. Kaufmann (2020) studied a fully automated method to identify cracks and study the kinematics using DIC approach. It is possible to extract significantly smaller cracks and their locations using the DIC principal tensile strain field. The optical result depends on the configuration of DIC and technique is restricted in case of closely spaced cracks. It was concluded that this method allows extremely precise measurements of kinematics and placement of cracks in large scale or even in complex project. [9].

A. Zaki, L. Murdiansyah', and Y. Jusman (2021) studied the magnitude of the challenges related to cracking in reinforced concrete structures. The cracking could cause harm and destroy RC structures, which need to be fixed or replaced. Early analysis will reduce damage and restore the expenses. As an outcome, the RC structure involves NDT, specifically visual examination method IP is then used in analysing the visual inspection image. The cracked structure is then follows by going through a rebound hammer technique and rebound index test to estimate its compressive strength [10].

The majority of the research mentioned above utilises DIC, AE, NDT and IP methodologies to concrete and masonry structures. The equations based on principal tensile strain and shear are developed in the above cases. In the current investigation detained literature survey is done and appropriated method is selected for the further studies.

IV. METHODOLOGY

When cracks are observed in a structure, monitoring its size and expansion is crucial to determine whether it is active (growing) or passive (not expanding over the period of time). Crack width is measured by means of a crack gauge. There are different types of gauges available and convenient gauge can be used for monitoring variations in crack width. If considerable care is practised, the cracks width can be measured approximately up to 0.5mm. It is essential to recall that steel rule measurements are subjective because it is not always possible to measure crack width from same location. For this reason, the state of the destruction is examined using steel ruler measures at the beginning of the inspection. The gauge includes markings for various width on it. By analysing the crack width to various sizes indicated on the gauge, one can estimate the size by measuring crack width. A standard steel gauge is applied to the cracks and measurements are noted done. This procedure is monitored over the period of time in order to estimate the propagation of the width. One of the experimental example is show below in figure 5 is a RCC structure monitored for crack width and depth with respect to time at Ponda site. Table 1 shows the crack width and depth measurements over the period of time.



(a)

(b)

Fig. 6. (a) & (b) displaying the measurement of cracks in a structural component over the period of time.

TABLE I. CRACK WIDTH AND DEPTH MEASURED OVER THE PERIOD OF TIME

Days	*Crack Width (mm)*	*Crack depth (mm)*
1	1.02	0.0
2	1.08	0.0
3	1.10	0.0
4	1.22	0.0

effectiveness. If considerable precautions are practised, the cracks width can be measured with approximation up to 0.5mm. It is necessary to recall that steel rule measurements are subjective because it is not always possible to measure crack width from same location. For this reason, the state of the destruction is examined using steel ruler measures at the beginning of the inspection. Finally, depending on visual inspection methods employed in each system, analysis were conducted.

V. DISCUSSION

This element provides the analysis of crack detection based on the literature used for the review This element offers an examination of crack detection based on the literature review, wherein it is divided into a number of factors for analysis, such as objective-based analysis, analysis of accuracy levels, analysis of errors and analysis based on image processing techniques. Depending on the parameter that contributes crack detection attainable, the objective can take several forms. The cracks length, depth, width, orientation and direction of propagation are couple of characteristics that makes this examination possible. Since surface estimates the cracks volume, numerous methods compromise crack detection by including crack detection as undesirable. In the further study in this topic different RCC and masonry structure will be taken into consideration and will be monitored over the period of time and based on the measurement estimation will be conducted and equations will be developed for the same.(see Fig. 7) showing objective based analysis bar char where in the x axis represent objective of cracks.

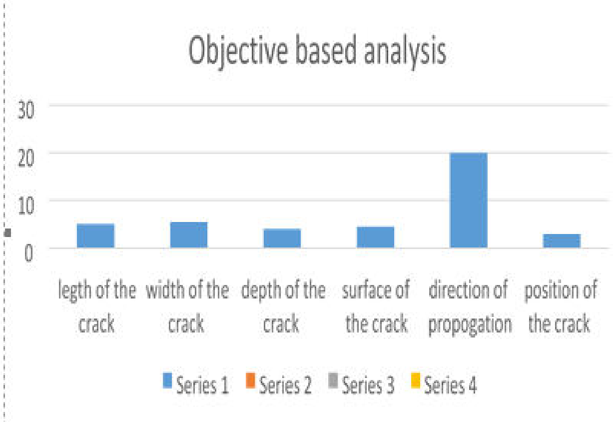


Fig. 7. Objective based analysis bar chart

VI. CONCLUSION

Several researched papers have been selected for investigation based on crack detection. Based on the reviewed papers five features have been concluded. The first constitutes of objective based study, where in parameters such as length, width and orientation of cracks are taken into account. After analysing the data sets are utilized for the techniques, it was observed that majority of the system use genuine sets of information for both conventional and

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