Study of crack width assessment and propagation in RCC & masonry structures

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***Abstract*—The structures that are exhibiting rapid sign of distress requires immediate assistance in order to identify the underlying causes of their distress, constitute an accurate diagnosis, and determine the most appropriate approach for proper treatment and the rehabilitation of the structures. If not addressed properly these changes could cause distress. Both RCC and masonry construction will undoubtedly develop cracks over time. One of the specifications for structural concrete elements serviceability is the crack width calculation which results due to low tensile strength of concrete. When subjected to service loads. For concrete structure to resemble appealing and to last for a long time, controlling cracking is crucial. In this paper, the degradation of RCC and masonry structures is investigated experimentally. The crack measurement gauge is utilized in this empirical investigation to monitor the cracking in the structures. The degree of structural threat associated with a building can be established through the identification of such cracks. The cracks characteristics obtained from the experimental measurements utilized to manage with appropriate measures, the study provides a thorough examination of understanding, monitoring the cracks and estimating the equations from the same.**

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

I. Introduction

Engineering structures that are unsafe for maintenance as well as structures that are constantly loaded and exposed to fatigue stresses need to be remedied promptly. Inability to accomplish this will cause serious destruction to the environment. Due to reduced local stiffness and material discontinuities during the life expectancy as a result of micro cracks, reduced tensile strength, flexure, and shear, as well as other environmental factors, cracks typically appear at the microscopic level. The microscopic cracks expose the concrete to chlorides and other toxic chemicals, causing the concrete to deteriorate and corrosion of the reinforced bars. These are significant corrosion induced damages, reduction in the load bearing capability and section loss of reinforced concrete structures when there are cracks prevalent.

Early detection permits the use of preventative measures to stop further degradation of concrete due to environmental factors. Different methods can be used to identify structural cracks and non-structural cracks. Non-structural cracks having width of less than 3mm do not compromise the integrity of the structure. Visual inspection and surveying instruments can be utilised to gauge the structural surface conditions. One of the requirements for structural concrete elements serviceability is the calculation of crack width. In the present study, few RCC and masonry structures are selected and monitored for increase in crack width over a period of time. Base on the data collected, equations are formulated based on crack width and depth with respect to time.

II. Literature Survey

The literature review identifies numerous techniques and analyses for determining crack propagation in the structure. In order to gain more knowledge about the topic, researched papers regarding crack width propagation in masonry and RCC structures were acquired and examined.

S. M. Allam, M. S. Shoukry, G. E. Rashad and A. S. Hassa (2012) used building code and available equations to calculate the crack width in RC flexural members. Five RC rectangular models were studied as flexure-subject driven concrete members. The models account for a number of variables, including steel rebar arrangement, reinforcing steel ratio, and reinforcement grade. The results obtained by both methods were compared. It was concluded that most of the equations over-estimate effect of cover to the reinforcement and crack width depends on detailing and distribution of bars in structural members [1].

S.Y. Alam, A. Loukili, F. Grondin and E. Roziere (2015) used digital image correlation (DIC) and acoustic emission (AE) technique to study degradation and crack width determination in laboratory models. Three models of different sizes of proportionately equivalent beams to investigate the impact of structural measurements. It was concluded that DIC techniques gives precise measurement of cracks. Largely beams showed tensile micro-cracking while in other cases they showed tensile and shear micro-cracking [2].

T. A. Krakhmal'ny, S. I. Evtushenko and M. P. Krakhmal'naya (2016) studied the monitoring the bridges using remote system for crack opening. Remote system used the real time measurements and automatic process of data transmission via wireless connection. The technology authors are offering is built on crack width growth sensor, protected by patent [3].

A. Mohan and S. Poobal (2017) conducted a detailed literature survey to understand various methods and their effectiveness in crack measurement like image processing, optical fibres, etc. It was conclude that major techniques used for crack width determination were camera based image processing techniques [4].

N. Gehri, J. Mata-Falcon and W. Kaufmann (2020) used DIC techniques to study the kinematics of cracks in laboratory by measuring principal tensile strain. Crack width and slips were measured using DIC. It was concluded that the crack detection method fails if cracks are closely spaced. Algorithm presented by the authors works well with non-branching and well separated cracks. [5].

I. E. Bal, D. Dais, E. Smyrou and V. Sarhosis (2021) studied cracks in masonry structures using two distinct types of markers exposed to NIR (near- infrared) wavelength. The markers used are adhesive-backed retro reflective marker and the other marker is a paint made from infrared reflective pigments. It was concluded that painted markers perform better and this method is best used for use in heritage structure and for structures having acute foundation settlement [6].

P. Stalowska and C. Suchocki (2022) studied the non-destructive remote measuring technique using terrestrial laser scanning (TLS) for crack detection. Using this data, authors studied the limitations of TLS and developed a methodology for crack detection in building walls [7].

S. Khotiaintsev and V. Timofeyev (2022) studied the use of ordinary silica – core silica clad optical fibres in determination of structural cracks in ceramic bricks masonry. It was concluded that this method is simple and economical method and has wide application in permanent damage detection for structures in seismic zones [8].

Most of the above research uses techniques like DIC, AE and TLS for concrete and masonry structures. The equations used are based on principal tensile strain and shear using Eurocode and Egyptian code. In the present study, four different buildings in Goa are selected and crack width and depth is measured and monitored using steel crack gauges.

III. Methodology

When cracks are noticed in a structure, it is necessary to monitor about its size and growth so as to know whether it is active (growing) or passive (not becoming bigger over time). There is variety of gauges available in the market and a convenient tool can be selected in order to monitor the crack propagation as per the requirements of study. In order to determine the width of the crack, steel gauges as shown in Fig. 1 are used. The crack width can be approximately measured to be up to 0.3mm. The state of damage is assessed using steel ruler measurements at the start of the examination. After the steel gauge has been installed, a line is drawn across the gauge to show the crack width as and when it occurs. The line displaces the potential distance of the cracks expanding, which would demonstrate the movement which has been occurred up until the observation was made. The mark on the gauge indicates the installation date and a reference number. It will be necessary to observe this process over time, make estimations, and construct equations based on the findings.

The four cases selected in the present study are:

1. Case 1: 50 year old masonry building in Farmagudi Goa
2. Case 2: 25 years old RCC building in Old Goa
3. Case 3: 25 years old RCC building in Khorlim Goa.
4. Case 4: 25 years old load bearing structure in Pernem Goa.

These cases are discussed in detail along with the photographs taken at the site during measurements.

A. *Case study :1*

The RCC structure monitored for crack width is located in Farmagudi Goa (G+1) structure and is about 54 years old. Figure 1 shows the site measurements of crack width and depth taken at the Farmagudi site for a masonry building in the campus, each photograph shows crack width and depth measurement in every week. Table 1 shows the crack width and depth measured in each week at this site.

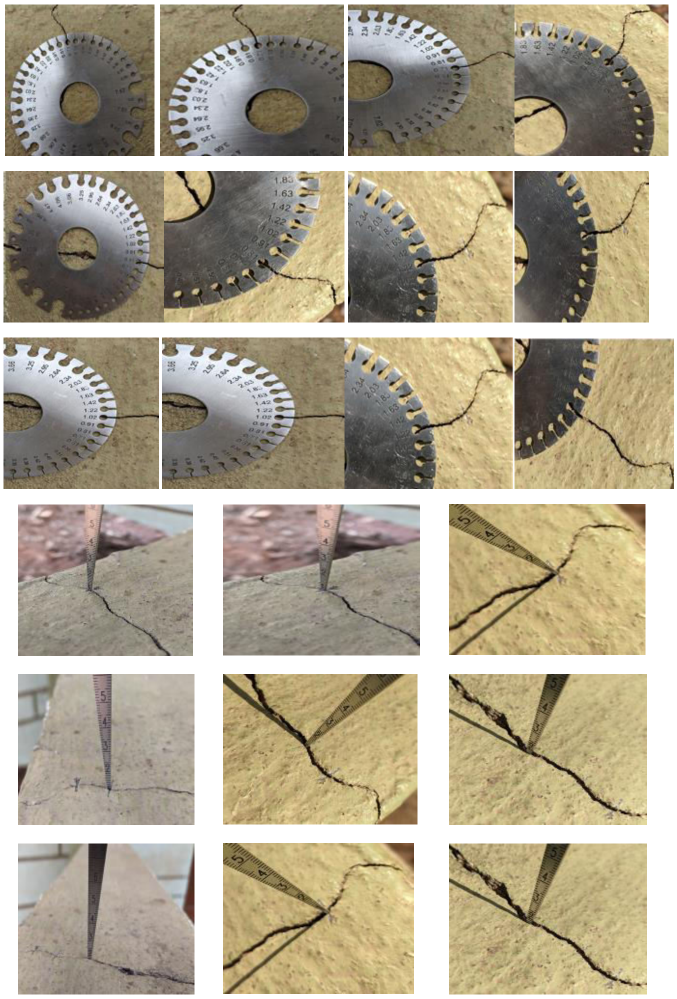

Fig. 1. Case study 1 displaying the measurement of the cracks in a structural component.

TABLE I. WIDTH AND DEPTH OBSERVATION OF CASE STUDY 1

Time (week)	*Width (mm)*			*Avg Width (mm)*	*Depth (mm)*			*Avg Depth (mm)*
1	0.71	0.81	1.02	0.85	0.5	0.5	1.4	0.8
2	0.71	0.81	1.02	0.85	0.5	0.5	1.4	0.8
3	0.72	0.85	1.05	0.88	0.5	0.7	1.4	0.866
4	0.72	0.85	1.05	0.88	0.5	0.7	1.4	0.866
5	0.75	0.91	1.22	0.96	0.5	0.8	1.4	0.9
6	0.75	0.91	1.22	0.96	0.5	0.8	1.4	0.9

7	0.81	0.91	1.22	0.98	0.5	0.8	1.4	0.9
8	0.81	0.91	1.22	0.98	0.5	0.8	1.4	0.9
9	0.81	1.22	1.22	1.08	0.5	0.8	1.4	0.9
10	0.81	1.22	1.22	1.08	0.5	0.8	1.4	0.9
11	0.81	1.42	1.22	1.15	0.5	0.8	1.4	0.9
12	0.81	1.42	1.42	1.22	0.5	0.8	1.4	0.9

The above results are plotted in Fig. 2 and trend line is plotted and equation of the same with R^2 value for each case noted. R^2 value of 0.90 and above is considered in the present analysis.

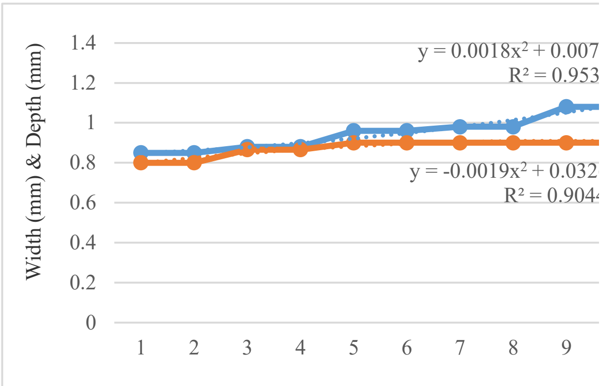

Fig. 2. Variation in width and depth with respect to time in Case study 1

Equation (1) and (2) show variation of crack width and depth with time respectively and the corresponding R^2 value. In these equations “t stands for time in weeks.

Equation developed for the crack width (w)

$$w = 0.0018t^2 +0.0078t+0.0386 \qquad (1)$$

$$R^2 = 0.9539$$

Equation developed for the crack depth (d)

$$d = -0.0019t^2 +0.0326t+0.7665 \qquad (2)$$

$$R^2 = 0.9044$$

B. Case study - 2

The building under consideration for this case study is located in Old Goa and is about 25 years old RCC G+5 building. Figure 3 shows the site measurements of crack width and depth taken at the Old Goa site for the G+5 building. Table 2 shows the crack width and depth measured in each week at this site.

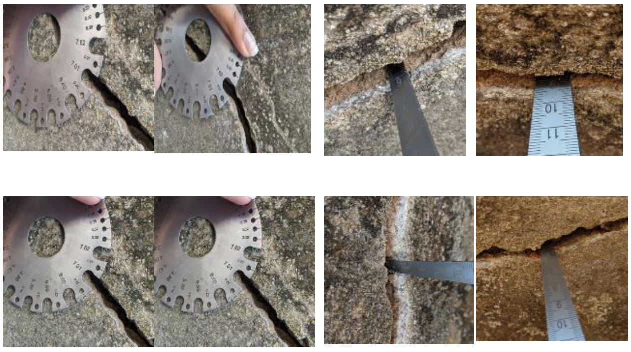

Fig. 3. Case study 2 displaying the measurement of the cracks in a structural component.

TABLE II. WIDTH AND DEPTH OBSERVATION OF CASE STUDY 2

Time weeks	*Width (mm)*			*Avg Width (mm)*	*Depth (mm)*			*Avg Depth (mm)*
1	7.01	7.01	6.40	6.81	6	6	5.5	5.83
2	7.01	7.01	6.40	6.81	6	6	5.5	5.83
3	7.05	7.05	6.6	6.9	6.9	6.9	5.5	6.43
4	7.3	7.3	6.6	7	6.9	6.9	6.5	6.7
5	7.62	7.62	7.01	7.41	9	9	7	8.33
6	7.62	7.62	7.01	7.41	12.5	9	7	9.5
7	7.65	7.62	7.04	7.48	12.5	9	7	9.5
8	7.8	7.8	7.01	7.5	12.5	9	7	9.5

The above results are plotted in Fig. 4 and trend line is plotted and equation of the same with R^2 value for each case noted. R^2 value of 0.90 and above is considered in the present analysis.

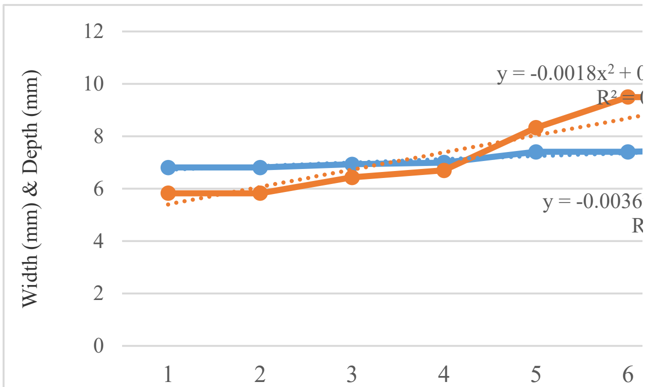

Fig. 4. Variation in width and depth with respect to time in Case study 2

Equation (3) and (4) shows the variation of crack width and depth with time respectively and the corresponding R^2 value. In these equations “t stands for time in weeks.

Equation developed for the crack width

$$w = -0.0018t^2 + 0.669t + 4.7357 \quad (3)$$

$$R^2 = 0.909$$

Equation developed for the crack depth

$$d = -0.0036t^2 + 0.1521t + 6.577 \quad (4)$$

$$R^2 = 0.9026$$

C. Case study : 3 of monitoring cracks

The building under consideration for this case study is located in Khorlim Goa and is about 25 years old RCC G+5 building. Figure 5 shows the site measurements of crack width and depth taken at the Khorlim Goa site for this building. Table 3 shows the crack width and depth measured in each week at this site.

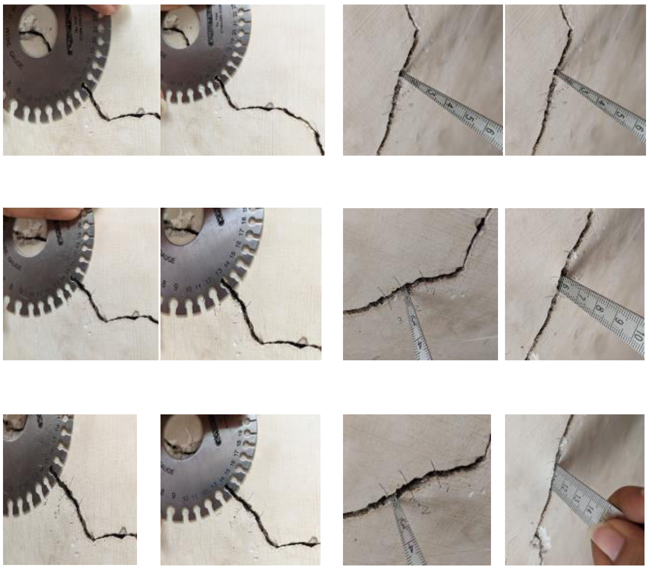

Fig. 5. Case study 3 displaying the measurement of the cracks in a structural component.

TABLE III. WIDTH AND DEPTH OBSERVATION OF CASE STUDY 3

Time week	***Width (mm)***			***Avg Width (mm)***	***Depth (mm)***			***Avg Depth (mm)***
1	1.63	1.83	1.83	1.76	3.6	1.4	1.1	2.03
2	1.63	1.83	1.83	1.76	3.6	1.4	1.1	2.03
3	1.88	1.88	1.83	1.86	3.6	2.8	1.9	2.76
4	1.88	1.88	1.83	1.86	3.6	4.8	1.9	3.43
5	1.88	1.95	1.89	1.9	10.5	5.5	1.9	6.0
6	1.88	1.95	1.89	1.91	11.3	5.9	1.9	6.1
7	2.03	2.28	1.89	2.06	11.3	5.9	1.9	6.36
8	2.03	2.28	1.89	2.06	11.3	6	1.9	6.4
9	2.34	2.34	2.34	2.34	11.3	6	1.9	6.4

The above results are plotted in Fig. 6 and trend line is plotted and equation of the same with R^2 value for each case noted. R^2 value of 0.96 and above is considered in the present analysis.

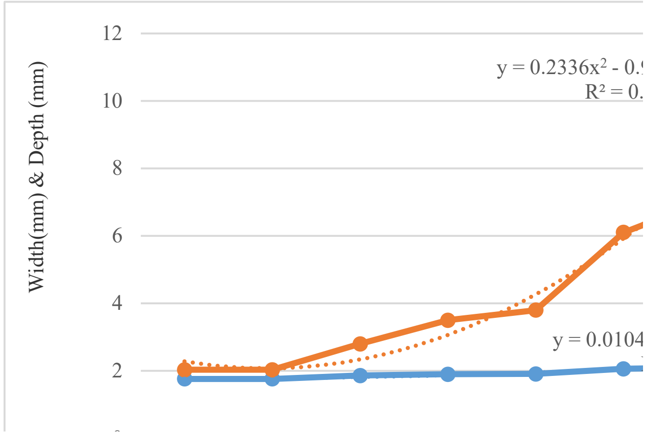

Fig. 6. Variation in width and depth with respect to time in Case study 3

Equation (5) and (6) shows the variation of crack width and depth with time respectively and the corresponding R^2 value. In these equations "t stands for time in weeks.

Equation developed for the crack width (w)

$$w = 0.233t^2 - 0.9064t + 2.9554 \quad (5)$$

$$R^2 = 0.9713$$

Equation developed for the crack depth (d)

$$d = 0.0104t^2 - 0.0179t + 1.7762 \quad (6)$$

$$R^2 = 0.9618$$

D. Case study : 4

The building under consideration for this case study is located in Pernem Goa and is about 25 years old load bearing masonry single storeyed building. Figure 7 shows the site measurements of crack width and depth taken at the Pernem Goa site for this building. Table 4 shows the crack width and depth measured in each week at this site.

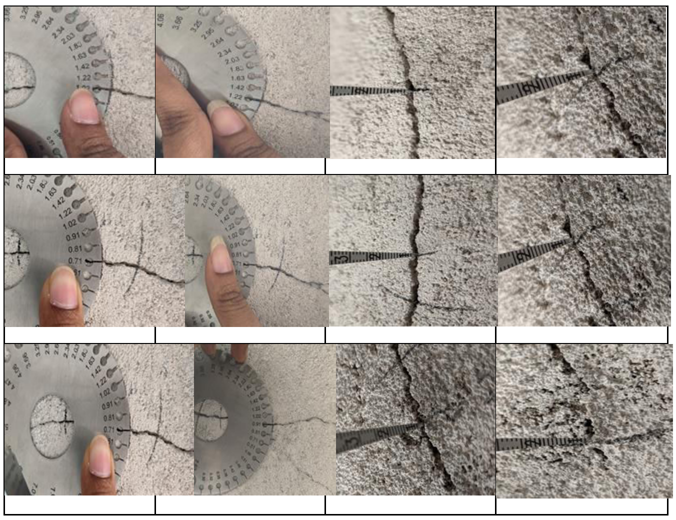

Fig. 7. Case study 4 displaying the measurement of the cracks in a structural component.

TABLE IV. WIDTH AND DEPTH OBSERVATION OF CASE STUDY 4

Time (weeks)	***Width (mm)***			***Avg Width (mm)***	***Depth (mm)***			***Avg Depth (mm)***
1	0.91	1.02	0.71	0.88	0	0.9	0	0.3
2	0.91	1.02	0.71	0.88	0	0.9	0	0.3
3	0.91	1.02	0.71	0.88	0.1	0.9	0	0.33
4	0.91	1.10	0.71	0.91	0.15	0.9	0	0.35
5	0.91	1.16	0.71	0.93	0.25	0.9	0	0.38
6	0.91	1.20	0.71	0.946	0.26	0.9	0	0.39
7	0.91	1.22	0.71	0.95	0.26	0.9	0	0.39
8	0.91	1.25	0.71	0.96	0.31	0.9	0	0.41

The above results are plotted in Fig. 8 and trend line is plotted and equation of the same with R^2 value for each case noted. R^2 value of 0.93 and above is observed in the present analysis.

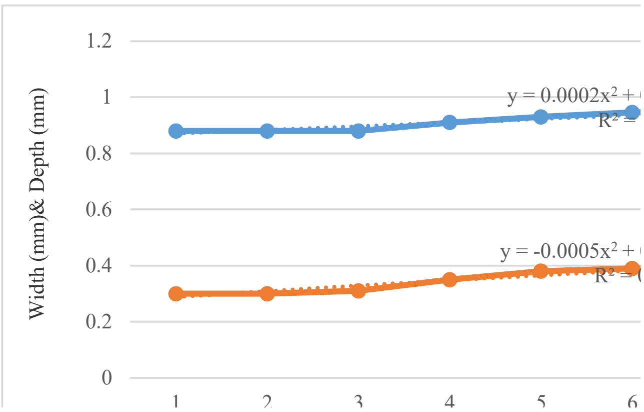

Fig. 8. Variation in width and depth with respect to time in Case study 4

Equation (7) and (8) shows the variation of crack width and depth with time respectively and the corresponding R^2 value. In these equations "t stands for time in weeks.

Equation developed for the crack width (w)

$$w = 0.0002t^2 - 0.0117t + 0.8594 \quad (7)$$

$$R^2 = 0.93$$

Equation developed for the crack depth (d)

$$d = -0.0005t^2 + 0.0226t + 0.2659 \quad (8)$$

$$R^2 = 0.93$$

IV. RESULTS AND DISCUSSION

It is seen from the above tables and figures that, in most of the cases, the crack depth increases faster as compared to width for masonry structures. The equations with higher R^2 indicate better correlation and acceptance of the equations developed. These equations will be very useful in studies on propagation of cracks in masonry and RCC structures. For more accuracy, further detailed studies can be taken up.

Considering the literature reviewed, it is observed that the crack propagation studies include the crack width, length, orientation and patterns of the cracks. Techniques such as image processing technique, DIC, Terrestrial laser scanning (TLS), AE etc. were used in order to find out the above data. In the present study, actual site crack measurement was done to understand the crack propagation with respect to time. This analysis of crack detection is useful for understanding the crack growth especially in RCC structures since these cracks may lead to further degradation of concrete due to corrosion of reinforcement due to ingress of moisture and carbon dioxide from environment. Different RCC and masonry structures can be observed and monitored over the period of time.

V. CONCLUSION

A manual methodology known as visual inspection has been used internationally to track the health of the RCC and masonry structures and trace the propagation of the cracks. The popular techniques for crack measurement are image processing technique, DIC, Terrestrial laser scanning (TLS) and AE. In this paper, a method for measuring cracks in RCC and masonry structures with a steel gauge is used to evaluate the viability of the approach as well as the measurement precision and accuracy. The data are collected with precision, it is possible to measure crack width to within 0.3mm. It gives preliminary idea about crack propagation in masonry and RCC structures

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