Propagation of Crack in Cement Concrete Beam by Using Digital Image Correlation

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***Abstract*: Cracks induced by external excitation on a material that has defects may generate the stress concentration phenomenon. In the present project DIC technique is applied to the concrete member to measure surface displacements and strains. The technique is associated with the matlab programming in image processing. The measurement of the width of the localized zone on the surface of notched concrete beams under quasi-static three point bending helps in designing the structural components with high and low reinforcements as per the requirement thus providing safety for the structure and provides feasibility in designing slender sections. From the above experiment it is possible to define the zone where maximum strains are localized and consequently evaluate the flexural response of reinforced concrete beam and its size dependence. Thus the project helps in designing structures which satisfies serviceability, sustainability and durability conditions.**

***Keywords:* Digital image correlation, crack propagation, mat lab.**

1. INTRODUCTION

Cracks induced by external excitation on a material that has defects may generate the stress concentration phenomenon. The stress concentration behavior causes local buckling, which will induce the damage of the members made of this material. Thus, developing techniques to monitor the strain variation of a cracked member is an important study. The traditional technique (such as strain gauge) can only measure the average strain of a region. The strain variation within this region cannot be determined. Therefore, it cannot sufficiently reflect the mechanical behavior surrounding the crack. The Digital image correlation technique recently developed is an image identification technique to be applied for measuring the object deformation. This technique is capable of correlating the digital images of an object before and after deformation and further determining the displacement and strain field of an object based on the corresponding position on the image. Thus the project reinforces civil infrastructures industries and society.

The fracture process in reinforced concrete structures is complicated because it is associated with the development of both micro cracks and major cracks. The fracture behavior is also connected to other phenomena including strain localization and crack bridging and depends on the heterogeneity of concrete, the type of reinforcement, and the concrete and reinforcement properties. The present proposal helps in development of an industry, technology and provides quality education to the technical students and brings in innovative concepts that help the society. The proposal is an interdisciplinary project that helps mechanical and civil engineering students where software and digital Imaging act as aiding tool.

The purpose of this study is to investigate the crack propagation in reinforced concrete using Digital Image Correlation (DIC). DIC is a robust, non-contact and precise tool for fracture measurements. Digital images are taken at different loading stages and by comparing the images it is possible to infer the deformation of an object subjected to external loads. In this paper, the relationship between the fracture properties and the properties of the concrete and steel reinforcement is investigated experimentally. Tests were performed on small-scale reinforced concrete specimens in three point bending. By means of the DIC technique the visualization and quantification of the fracture properties of reinforced concrete could be determined. The DIC technique was found to be an effective mean to measure the crack opening displacements.

2. PRINCIPLE OF DIGITAL IMAGE CORRELATION

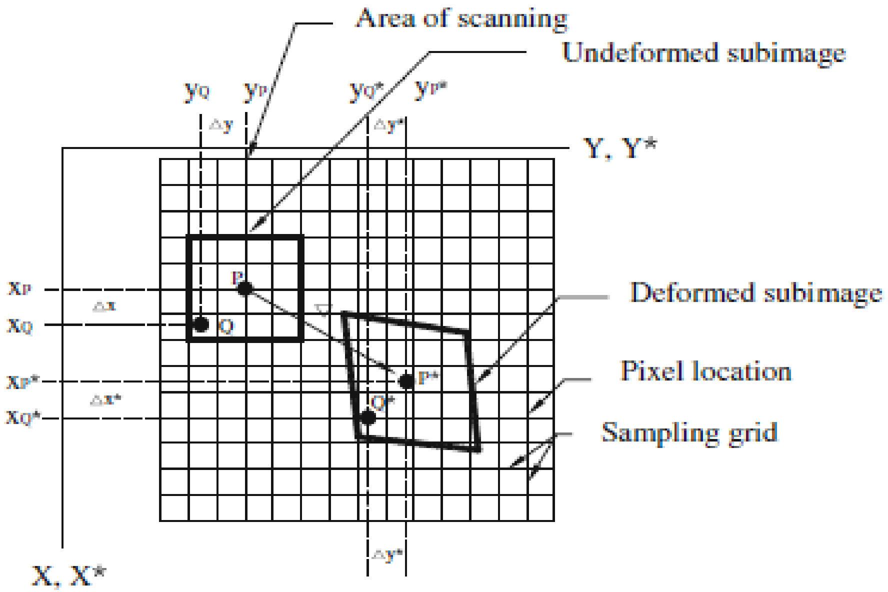
DIC is widely applied in the field of image identification technique by comparing the local correlation of two images; the relationship between deformed and un-deformed images can be identified. As shown in figure 1, the central point prior to deformation is point P; it is change to point P* after deformation. The functional relationship is expressed as (Shih et al 2008)

$x^* = x + u(x, y)$ (1a)

$y^* = y + v(x, y)$. (1b)

For un-deformed images, finite element method (FEM) is used to divide the images into several sub-images. Assuming the un-deformed sub-image is A, and the deformed sub-image is B, the correlation coefficient (Equation 2) (Chu et al 1985) is used to define the relationship between sub-images A and B. When sub-image B is exactly the same as sub-image A after deformation, the correlation coefficient will be equal to 1

$$\mathrm{COF} = \frac{\Sigma g_{ij}\widetilde{g_{ij}}}{\sqrt{\Sigma g_{ij}^2 \cdot \Sigma \widetilde{g_{ij}}^2}},$$



Similarly strains between two deformed points are computed.

3. MATERIAL AND SOFTWARE REQUIREMENT

2 test samples of Reinforced concrete beam to be designed and tested

Three point Bend Test machine

Camera body of Canon 7D body, 18MP 1.6X Crop sensor 8FPS HD vedio at 1080p

Camera lens of Canon EF 100 mm f/2.8l, 100 mm macro

LED source light

Test sample

System Configuration and Software Packages

System: Windows 7 and higher with 64 bit

Software package: MATLAB 2013

4. METHODOLOGY

- Preparation of the testing beam
- Testing of a concrete beam by three point bend testing machine
- Analysis of strain displacements using DIC

4.1 Preparation of the testing beam involves:

- Concrete Mix design
- Cube strength of the member
- Design and Casting of the beam
- V notch design

After mix design, the mix propotions are as follows:

Cement content = 392.32 kg/m³

Water content = 197.16 liters

FA =1151.207 kg/m³

CA =705.57 kg/m³

Two sample of test specimens are casted. Following are their structural details

Sample-1:

1. Beam Title: Beam-A, Beam-B, Beam-C

2. Number of beam casted: 3 numbers

2. Concrete grade: M25

3. Reinforcement details: Main reinforcement 2 of 12mm dia Hanger bars 2of 10mm dia Shear reinforcement 8mm dia 200c/c

4. Concrete slump while pouring 90mm

5. Compaction by using 16mm dia tamping rod and rubber mallet

6. Curing of beam in ponding condition up to 28 days

Sample-2:

1. Beam Title: Beam-D, Beam-E, Beam-F

2. Number of beam casted: 3 number2. Concrete grade: M25

3. Reinforcement details: Main reinforcement 2 of 10mm dia Hanger bars 2of 10mm dia Shear reinforcement 8mm dia 200c/c

4. Concrete slump while pouring 90mm

5. Compaction by using 16mm dia tamping rod and rubber mallet

6. Curing of beam in ponding condition up to 28 days

4.2 Testing of a concrete beam by three point bend testing machine:

A three-point flexural test was performed on a concrete specimen designed for a design load of 40 KN with loading rate of $1.6KNs^{-1}$. The sample size is 150 × 200 with an effective span of 1 m, the notch depth is 25 mm and width being 3 mm. The outer span is of the order of 1.2m**.** A camera body with lens placed on a tripod is used to capture consecutive image during the testing on the beam for the further analysis in matlab using DIC.

4.3 Analysis of strain displacements using DIC:

The Image processing and correlation is executed by Programming, correlating and data interpretation

4.3.1 Programming and Correlating:

Following are the set of programs that are coded and are executed in matlab pool for image processing and analyzing using DIC

- filelist_generator.m: It generates file name lists with max. 8 letters and '.jpg' at the end and creates a time_image list needed for merging stress and strain
- grid_generator.m : generates grid raster needed for the correlation code)
- large_displ.m : used when the displacement exceeds the correlation area
- automate_image.m : This function does all the hard correlation work
- displacement.m: This function will helps in analyzing your data
- RTCorrCode.m : "realtime"correlation code
- Multipeak_tracking.m : track multiple peaks along one axis

The above programmes are executed and results are interpreted in pictorial form

5. RESULTS

Displacement Result: Horizontal displacements and vertical displacements are recorded serperately from displacement.m function.

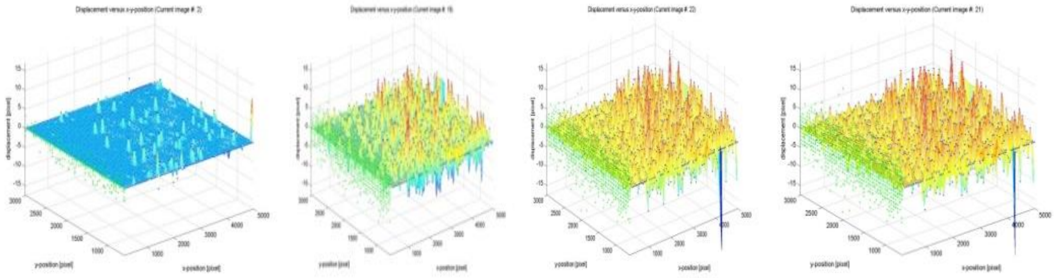


Fig.2 Horizontal displacement

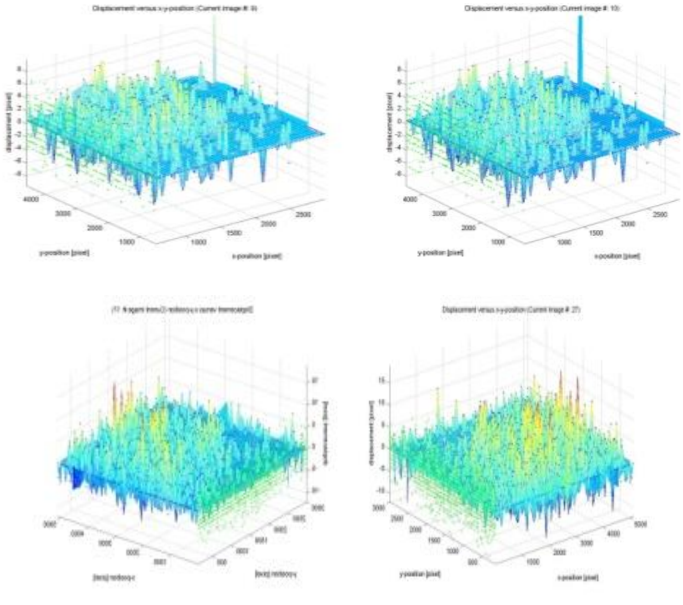


Fig.3 Vertical displacement

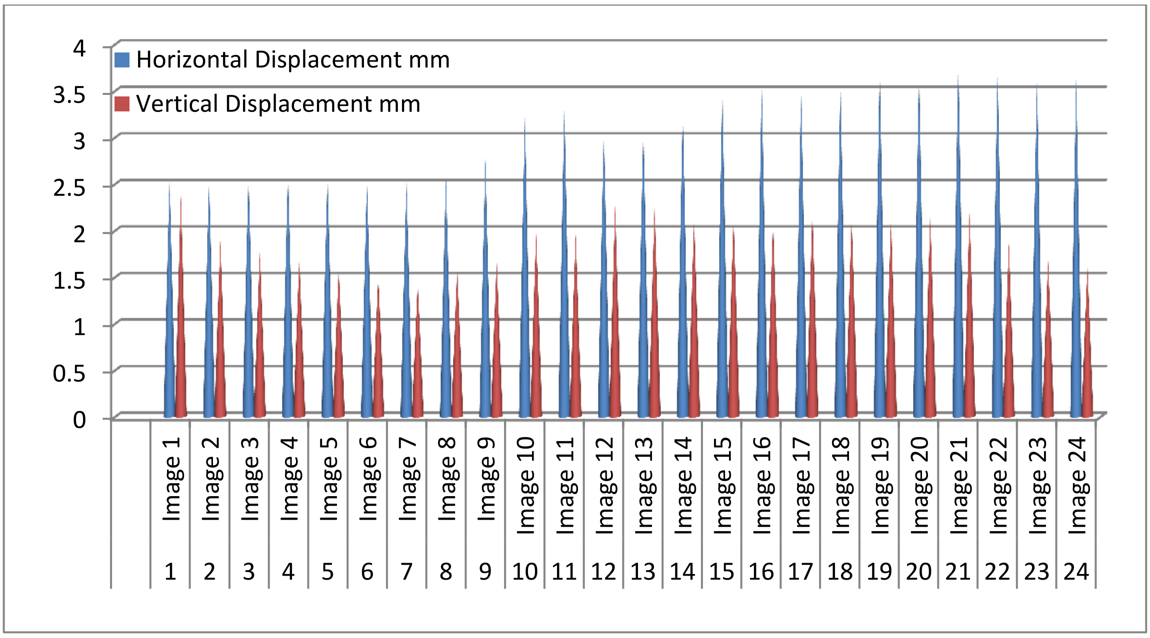
The results from DIC are interpreted as Grey scale. It is range of shades of grey without apparent color. Darkest shade is black which total absence of transmitted light/reflected light is. The highest possible shade is white. The total transmission or reflection of light at all visible wavelength. Intermediate shades of grey scale are represented by three primary colors (RGB) for transmitted light/equal amount of 3 primary pigments.RGB components are represented as decimal 0 to 255.

Cyan magenta and yellow are reflected light from RGB.CMY represent percentage from 0 to 100 (for each pixel)

Lightness of grey is inversely proportional to the number representing the amount of each pigment. Thus White signifies C=M=Y=0

Black signifies C=M=Y=100

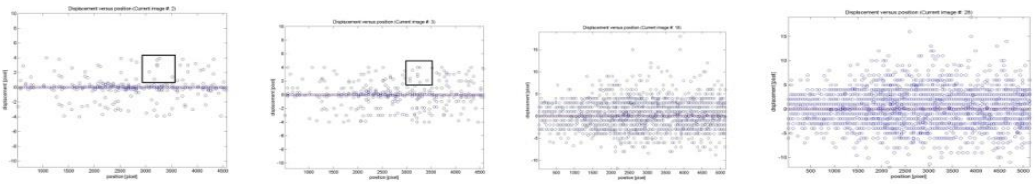
In the above horizontal and vertical displacement results Red signifies major displacements and Blue indicates lower scale displacements. From the results it is inferred that horizontal displacements are greater than vertical distance due to bending.



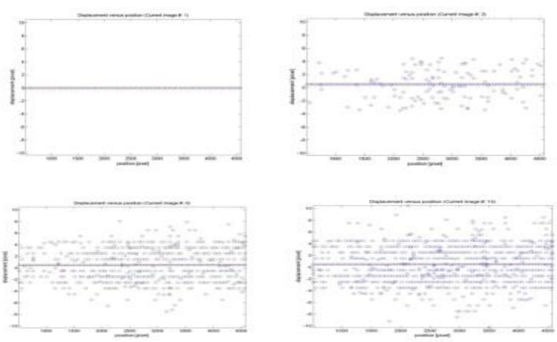
From the above graph it is inferred that horizontal displacement is 3.5 mm and vertical being 2.3 mm

Here Image no. refers to different loading as the pictures are taken with increasing loads.

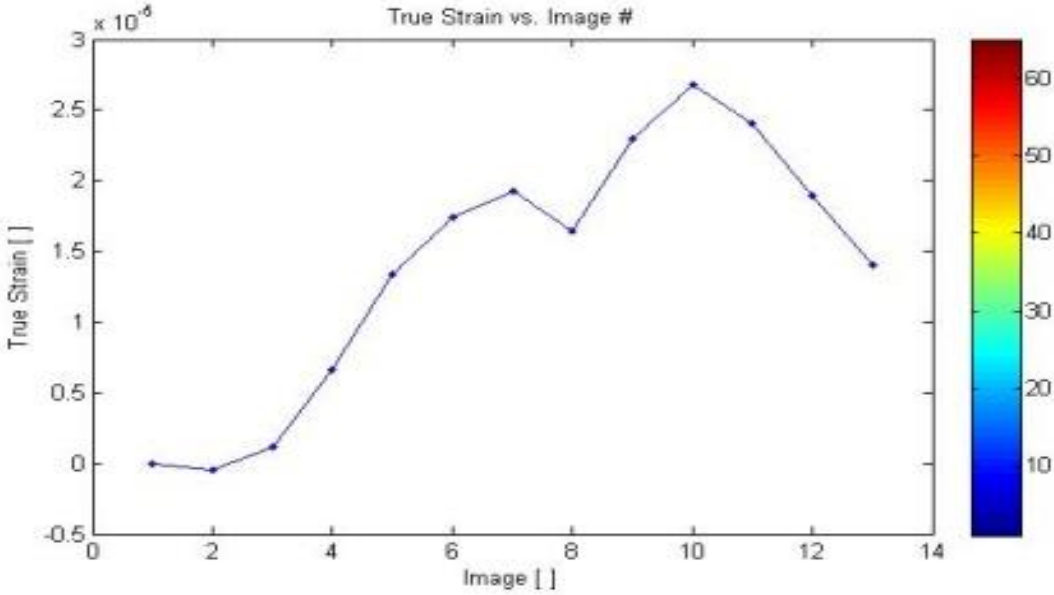
Strain Results:



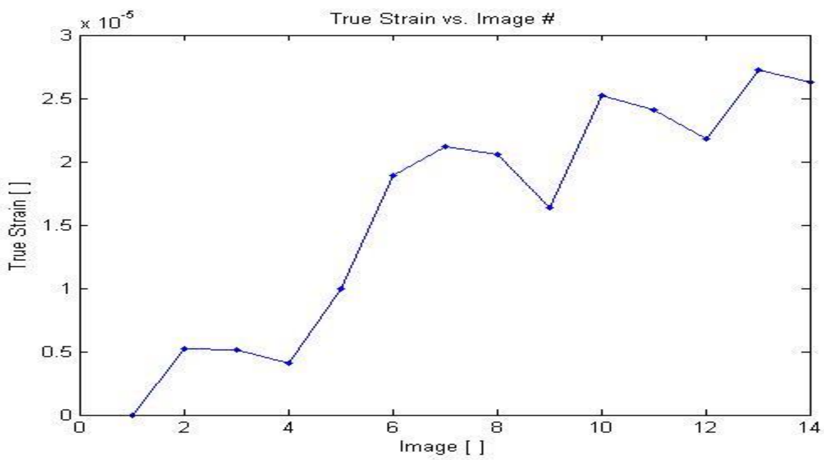
Horizontal strain:



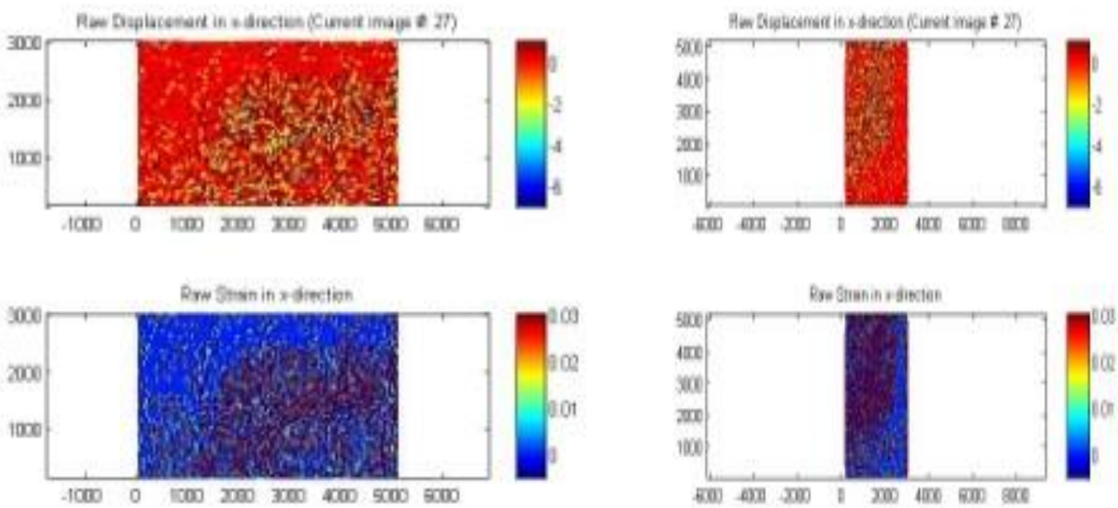
Vertical Strain:



Horizontal True strain:



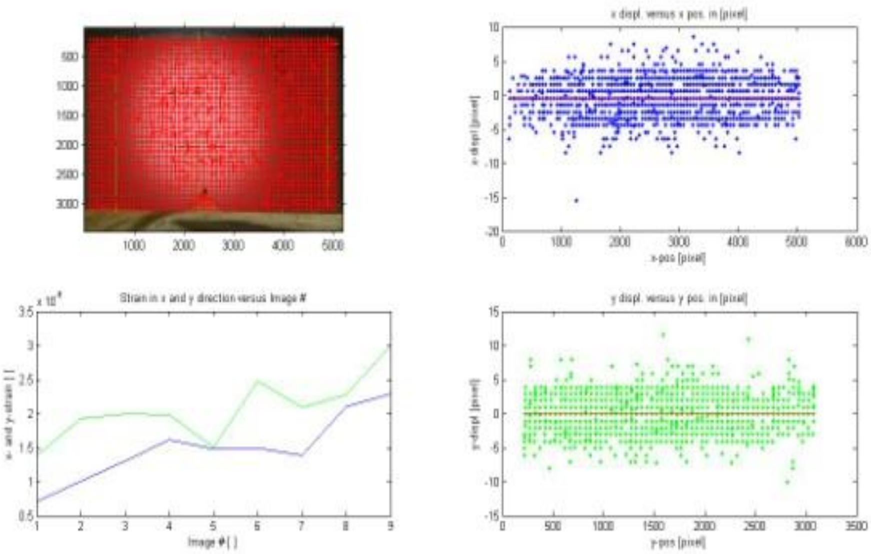
Vertical true Strain



Horizontal (L) and Vertical (R)raw displacement and strain:

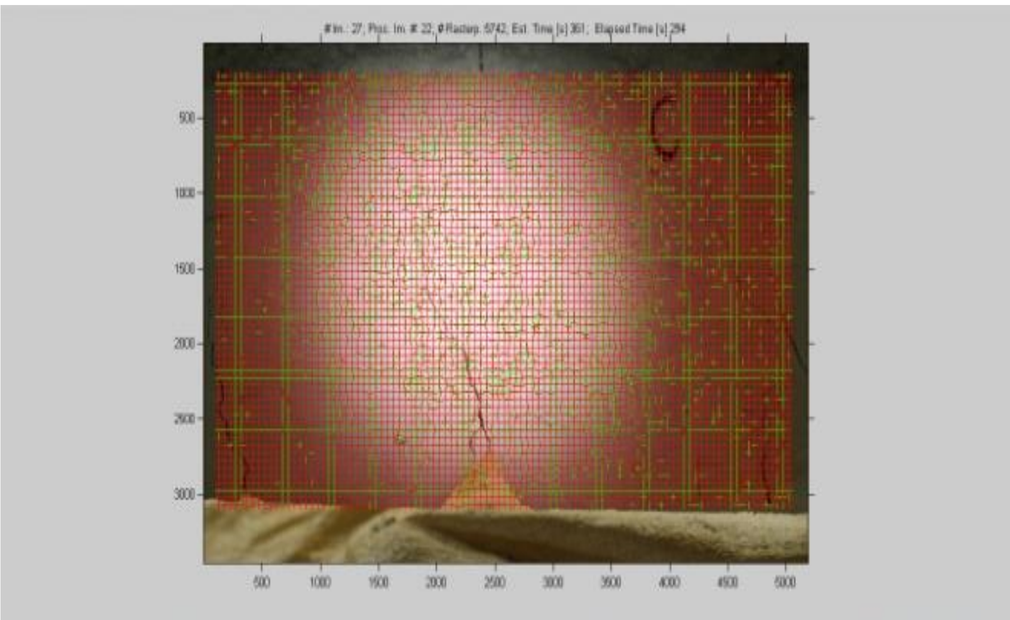
Strain is defined as change in length to original length. Any deformations constitute strain. Thus upon loading if the strain energy is exhausted deformation occur resulting strain. The tensile strain is looked after by steel whereas the compression strain is to be compensated with additional strain reinforcement.

Thus the software depicts compression strain and tension strain of an RCC beam as shown. The crack propagation, Crack density can be analyzed using the strain Plots. In the graph comprising Horizontal True strain V/s image no. the behavior of an RCC member as in steel can be depicted. Thus concluding that the typical behavior of an RCC member is as of steel. Raw displacements and strains are useful in redesigning and remodeling by tackling the structural deformation along the crack.



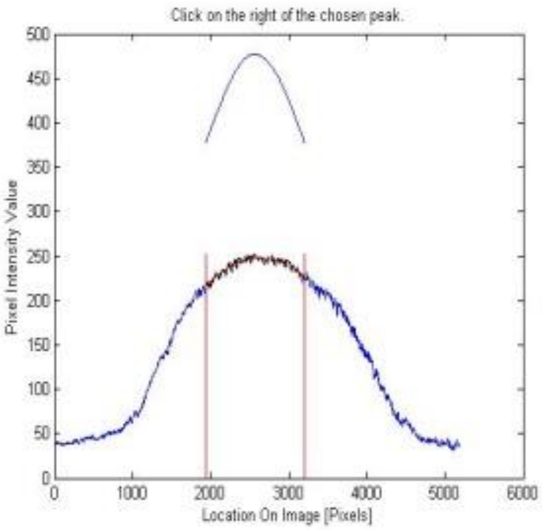
Relation between Horizontal displacements and strain with vertical displacement and strain

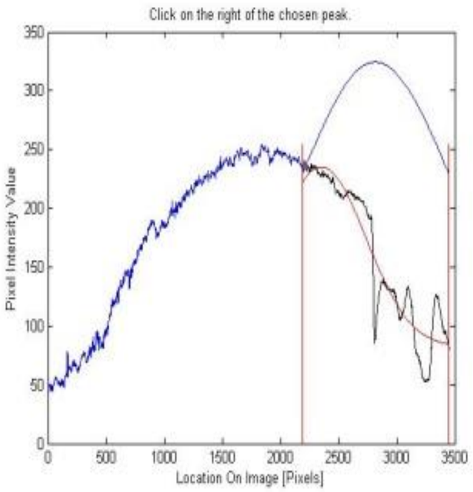
In the above fig A signifies Raster points. Raster points are the heart of correlation since the results depend on them and crack propagation are explained and crack density are depicted using them. The other figures pertaining to RT corr depicts the relation between H and V displacements and strains.



The result depicts mode of crack propagation with raster point equal to 5293 and no of frames per second equal to 0.071219. By marking the coordinated The crack length and mode of failure can be depicted.

Multi peak along the axis:





The displacements along any axis can be depicted by this programme helpful in analyzing and designing. The peak displacement are listed below for the set of images processed

Image No.	Horizontal displacement mm	Vertical displacement mm
1	2.2151	2.2313
2	2.2139	1.8128
3	2.2827	1.588
4	2.2755	1.595
5	2.2727	1.6012
6	2.295	1.5621
7	2.2833	1.6121
8	2.3113	1.5665
9	2.2631	1.6009
10	2.2971	1.573
11	2.2261	1.5286
12	2.2169	1.5732
13	2.2998	1.5151
14	2.2541	1.6051
15	2.2937	1.5269
16	2.2819	1.5223
17	2.2758	1.5674
18	2.2742	1.5677
19	2.2894	1.5691
20	2.2911	1.5686
21	2.2697	1.6051
22	2.2798	1.5921
23	2.2661	1.5244
24	2.2629	1.5293
25	2.2468	1.5527
26	2.2766	1.4934
27	2.2998	1.5134
28	2.3	1.5003

As per the processing and analyzing

Peak displacement along Horizontal =2.3 mm

Peak displacement along Vertical =1.5 mm

6. CONCLUDING REMARKS

When subject to gravitational pressure and external forces, the reinforced concrete structure will easily develop cracks due to thermal expansion and contraction, and uneven foundation subsidence. This causes water and moisture to penetrate the concrete leading to serious rust of the reinforcing steel bars to weaken the structure. Hence, monitoring cracks developed in reinforced concrete structure is an important link for diagnosing structural health.

In the present project results on strains and displacements are obtained.DIC can be used for static fracture analysis and dynamic fracture analysis. In the present project we have restricted our study to static fracture analysis.

Static Fracture Analysis

(i) Thus the DIC method detects and identifies early crack development since it monitors micro cracks in a structural member whereas the traditional method is incapable of doing so until the loading reaches a certain level that has already caused specimen cracking or rupturing.

(ii) Determines the tensile strain and compressive strain in the member at supports and mid-point of the section thus helping us in ductile detailing of an RCC member.

(iii) The failure mode for reinforcement concrete beam of various strength and steel bar reinforcement can be determined based on the displacement diagrams, strain diagrams and crack propagation.

(iv) Determines maximum load and measures crack length.

(v) Crack propagation characterizes material's resistance to fracture and prediction of crack growth is at heart of damage tolerance discipline. Thus the future inadequacy in serviceability can be determined.

(vi) The crack mouth opening displacement was extracted from DIC analysis and is used to compare the influence of different reinforced concrete beams parameters. It is found that concrete strength has a limited influence on crack opening, however, the bond stresses between reinforcement and concrete seemed to play a role in the observed crack propagation and crack bridging.

(vii) Study on crack initiation and crack growth can be obtained from Three point test and DIC analysis together

(viii) DIC analysis and three point bending test together states the serviceability of the member, Limit state of collapse and load at cracking point.

(ix) Structural deformations and local displacements with high accuracy for whole structure is obtained by use of raster points correlated with base image.

(x) DIC analysis provides an option to get interpolated strains. Thus the software not only determines the highest and lowest strains and displacements but also interpolates strains at any two pixel interval

(xi) Provides peak displacements at any distance from the crack tip which helps in redesigning and remodeling of the structure

(xii) Engineering Economy Environmental (EEE) traits achieved from Propagation of cracks obtained from DIC

a. Engineering: Satisfies Serviceability, Sustainability and Durability of the member by analyzing and redesigning the structure based on results from DIC

b. Economy : Reduction in overall cost of construction by designing slender section based on the results obtained from DIC analysis and structural deformation thus saving lots of material consumption used for design (steel and Concrete)

c. Environmental : Reduction in usage of concrete reduces emission of CO_2 produced during the production of cement

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