



## DETECTION AND QUANTIFICATION OF CRACKS IN REINFORCED CONCRETE BEAMS USING DIGITAL IMAGE PROCESSING TECHNIQUES

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### ABSTRACT

Recently, damage identification by nondestructive imaging has been widely used by capturing images for defected elements. This paper presents a digital image-based framework that developed to extract the properties of cracks in concrete beams. Algorithms of digital image processing are used to make computations on digital images of cracked elements to evaluate the presence of cracks in acceptable degree of accuracy. The output enhances graphical properties that can be used to identify cracks along with their structural reasons. As such, a database can be created for different types of cracks by representing them in numerical values. The research introduces a parameter, percent of area of the cracks with respect to total area of elements, which is used to predict the type of cracks in beam elements. The proposed research can be used to enhance decision making in cracked reinforced concrete beams.

**Key Words:** Crack detection, image processing, crack quantification, image-base analysis, cracking assessment.

### 1. Introduction

Concrete is a composite material that is made by binding aggregates together with a cementitious paste. While the independent response of a cement paste and aggregates to an

applied load is linear, the response of the composite concrete is highly nonlinear. This non-linearity can be attributed to the development of cracks throughout the concrete matrix as load is applied [1]. Concrete has a natural tendency to crack due to either internal or external factors, generally influenced by materials, design, construction, service loads and exposure conditions either individually or in combination. Cracks in concrete have many causes. They may affect appearance only, or they may indicate significant structural distress or a lack of durability. Cracks may represent the total extent of the damage, or they may point to problems of greater magnitude. Their significance depends on the type of structure [2]. The cracks in concrete can occur at any time starting from the casting time. Once the cracks have been developed in the concrete structure, it must be analyzed in order to determine whether they require repairing or structure has to be demolished. The proper repair of cracks depends on knowing the extent, causes and selecting the repair procedures that take these causes into consideration. Successful long-term repair procedures must attack the causes of the cracks as well as the cracks themselves [3]. Cracks in concrete occur mainly due to the low tensile strength and environmental sensations [1]. In construction practice, crack quantification is an important task in the process of conducting damages and preventing structural failure. However, cracks may appear due to structural and/or non-structural actions. For example, bond failure, shrinkage, settlement, drying shrinkage, thermal stresses, chemical reaction, corrosion of reinforcement, errors in design and detailing, overloading, and freezing and thawing [4-7]. These cases may affect the global or local structural integrity of the element. Hence, appearance of these cracks and their propagation in concrete indicates potential inceptions of declination of structural integrity [3].

Location and extent of cracking as well as information on the general condition of concrete in a structure can be determined by both direct and indirect observations, non-destructive testing, and destructive tests [8]. Conventional methods for measuring cracks include optical microscopy, scanning electron microscopy and radiography. These have been reviewed by Slate and Hover [9]. They are all destructive, requiring the drilling of cores from the concrete followed by sectioning of the specimens, and the results are two-dimensional. Recently, three-dimensional methods using computed tomography based on conventional X-ray or synchrotron radiation have been introduced. The true crack area can be measured, rather than its two-dimensional projection. However, the overall size of the specimen is limited to less than 100 mm (4 in.) in thickness for useful resolution. Moreover, these cannot be applied in the field [10]. By developing an automated system of crack detection it may help in securing the stability of the facility, and reducing the number of inspectors, inspection, time, maintenance cost. Moreover, the condition of the structural health can be judged objectively by acquiring and processing the acquired data. Different imaging technologies have been developed to detect structural damage in elements and components. Imaging devices including infrared, microwave, acoustic, X-ray imaging, and others are used to detect presence of structural damage including external or internal cracks [9]. Many approaches have been suggested to retrieve crack properties using image processing techniques. For example, Abdel-Qader et al. [11] compared the effectiveness of crack detection techniques such as Fast Haar Transform (FHT), fast fourier transform, Sobel,

and Canny. It was found that FHT was more reliable than the other three techniques. Abdel-Qader et al. [12] proposed a Principal Component Analysis (PCA) for pattern recognition (cracked or not cracked) based on distance measures. Whereas, Cheng et al. [13] proposed a crack detection method based on threshold operation using mean and standard deviation of gray-level image.

Several research efforts have proposed the use of image-based approaches for condition assessment and in particular crack detection. Image processing techniques provide important tools that prepare images for effective pattern recognition processing. Imaging has been widely used for damage identification by capturing anomalies on the surface or inside structural elements [14]. Zhu et al [15] deduced general automatic procedure in detecting cracks in concrete elements. Hagnauer et al [16] described the development and application of digital image processing techniques for analyzing the fracture behavior and environmental deterioration of specimens prepared from composite laminate materials. The digitized images were evaluated using pixel histograms generated through routines developed on a C-interpreter. White et al. [17] introduced a new technique for non-contact measurement of soil deformation in physical models and element tests. The system combines digital photography, close-range photogrammetry and image analysis by Particle Image Velocimetry (PIV) that allow soil displacements to be detected to a precision of 1/15000 of the field view. The three technologies have been combined to form a deformation measurement system for physical modeling and element testing. Many researchers have studied the automated concrete crack detecting method. Some researchers acquired the data from structures by using CCTV, laser scanner, and microwave [18]. Among them, the utilization of the image data acquisition is widely used. In this case, varieties of processing methods have been proposed: image processing using edge detection, histogram analysis, etc. All these methods are needed to detect defects automatically to reduce the effort of the human inspectors. So, variety of imaging technologies has been developed to detect structural damage. Also, detection of cracks with images of concrete surfaces has been explored by many researchers using a variety of methods. However, a comprehensive image-based damage framework is still lacking in the literature. Most introduced frameworks in literature included the following; Time-series monitoring of the inception or propagation of damage, detection of the boundary of damage at each image frame [19].

Image processing techniques could be used to retrieve image properties in an automated manner. Image processing techniques have been successfully utilized to detect cracks on concrete surfaces [20]. So, detection of cracks in concrete elements has been explored by many researchers using several methods. Limited research efforts explored the evaluation of crack appearance on concrete surface using image processing techniques. Therefore, comprehensive image-based damage quantification framework is still missing in the literature. This paper presents a framework that is capable to perform crack quantification using commercially available digital cameras. To detect the damage, an imaging device should be handled to capture the physical damage; hence the equipment may be expensive. To evaluate cracks in concrete

elements, the proposed research provides an image-based framework, whereby digital cameras provide the source images. The framework contains multiple image processing methods to get a digital geometric quantification of damage. Challenges of neutralizing non interesting portions in images are addressed. The proposed framework is considered an economic tool in evaluating damages in concrete beams.

## **2. Pre-Processing Data Acquisition**

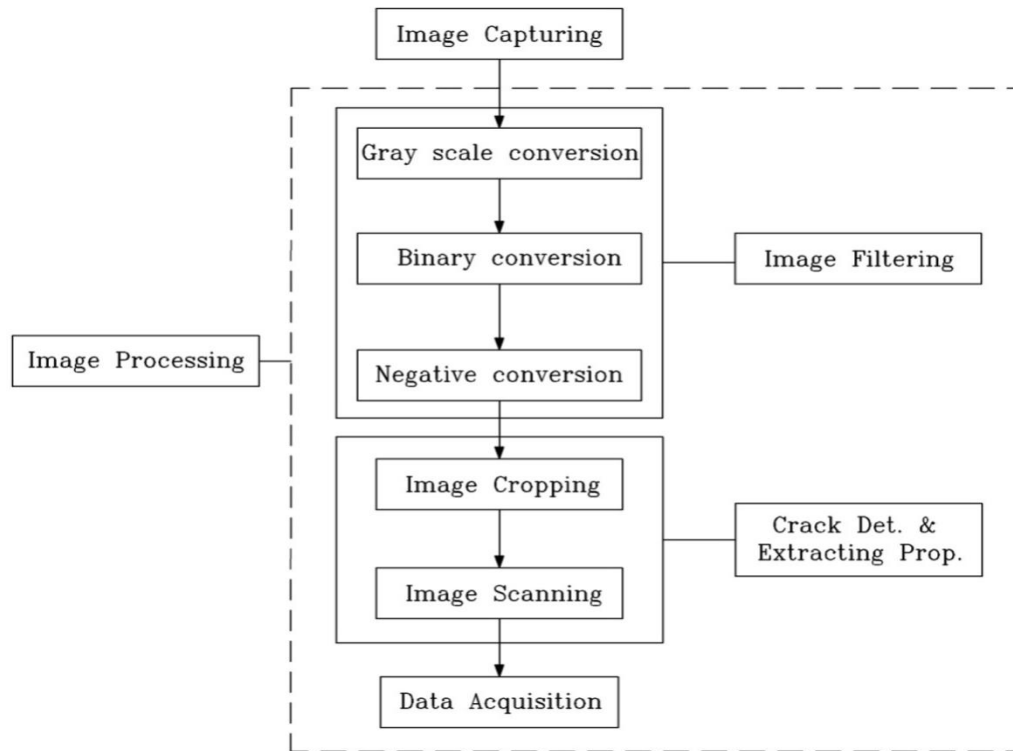
The research uses images of reinforced concrete pre-cracked simple beams with known reasons of cracking and failure modes. This data is found profusely in results of researches carried out in reinforced concrete labs for experimental programs that used beams as test specimens [6]. Specimens in those researches were used to observe different sorts of cracks in specimens that reached failure stages. Images for cracked beams were chosen after fulfilling the following criteria:

- Specimens are for reinforced concrete simple beams with rectangle cross section; where rectangle cross sections are more popular in use than others.
- Normal top and bottom reinforcement; no splices, studs, over or, under reinforced.
- Ordinary compressive strength of concrete (up to 300 N/mm<sup>2</sup>).
- Exclude deep or slender beam specimens from reviewing.
- Specimens Loaded till failure.

All collected data were just from images of specimens that reached failure stages and contains interesting types of cracks. The sort of crack is determined by reviewing the text in the research or lecture notes that state the type of failure and cracking observations, and geometrical characteristics are determined by inserting the image of the specimen through the image processing techniques proposed in this research.

## **3. Framework Components**

The proposed framework is capable to establish an image processing technique that can recognize and evaluate cracks in reinforced concrete simple beams, identify their types, and give recommendation for enhancement. The framework of the research consists of two main stages; Image Capturing and Image Processing as depicted in Figure 1.



**Figure 1: Framework Block Diagram**

#### 4. Image Capturing

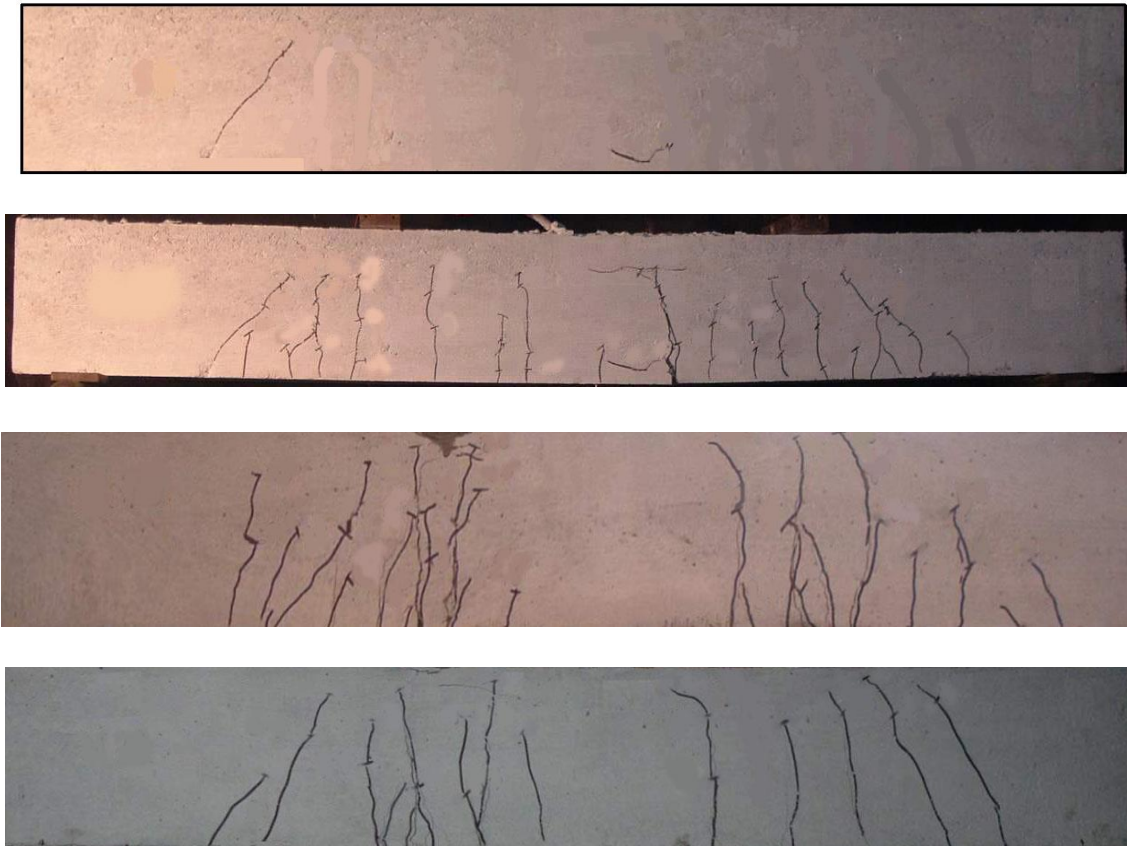
Whenever a non-expert determines the presence of negative observation on a concrete element, a two dimensional image for the element should be captured. The captured image should be saved in a digital format in which numerical processes could be applied. Also, high definition image capturing is essential, while ensuring all sharp boundaries appear in the digital image.

There are a variety of file formats for saving digital images. In this research, only JPEG file format is used. JPEG (Joint Photographic Experts Group) is the file format produced by the particular digital image camera used in the digital image acquisition for this research. The main advantage of using JPEG format is that it provides a wide range of colors. Also, JPEG files are stored in a compressed form. JPEG file format is the standard file format for most digital cameras because these files can easily be posted and transferred between Internet servers [21]. Figure 2 shows samples of captured images, showing how non-interesting backgrounds can be cropped from the images.

During an image capturing of the defected element the following points should be assured:

- Suitable distance and zoom in/out to include all element boundaries; all edges of the element should appear in the image file. No restriction of the edge orientation against horizontality or verticality. But it is not recommended to merge images.

- Illumination should be sufficient to recognize the defected element from the surrounding zone.
- The finer the cracks, the higher the resolution of capturing image are needed, i.e., there is no restriction to use a certain camera; choice of the suitable resolution depends on the negative observation obviousness.



**Figure 2: Sample of Captured Images**

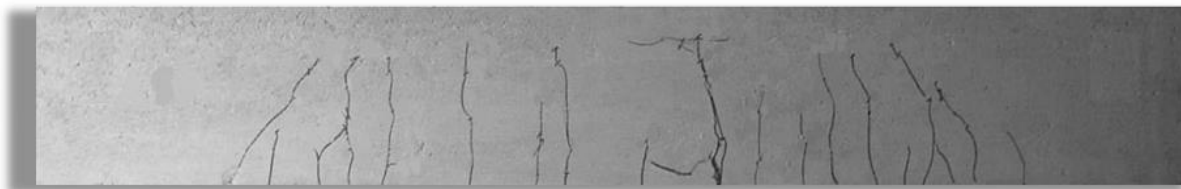
## **5. Image Processing**

The image processing procedure presented in this research offers a mean of cracks detection and quantification in simply supported beams. The basis of the method are using digital image processing, in which an image is captured and stored in terms of pixels. Pixels (picture elements) are small areas represents the picture. Then various geometrical calculations are computed on the pixel data. The two important things about the potential for this method are that the results can be quantified into measurable terms for more useful comparisons, evaluations, and decision making. The advantages don't promise only for the present research project, but also for concrete testing and behavior evaluation in general.

In this research several computer image Filtering algorithms were developed. The developed computer algorithms are divided according to their functions; into three sets. The first set is the image acquisition. An algorithm for scanning the image as RGB (Red-Green-Blue) colored file.

RGB is a filing system that stores the image in an m-by-n-by-3 matrix [22]. The accuracy of measuring characteristics by image processing depends on the image capture resolution, which depends on the specification of used camera, illumination, and distance between camera and concrete surface (the object). The second set is the crack filtering set. This set firstly converts the RGB image into a grayscale coloring system, in which the elements in the matrix are converted to gray level colors as shown in Figure 3, where levels range between 0 and 255 (computed through this equation;  $\text{gray level} = (R+G+B)/3$ ). Secondly, algorithms for filtering contain a sequence of processes that ends with clean image without any noise from spots or dirt could appear in the input image. Thirdly, the grayscale image is converted to a binary output image in which the elements of the matrix are limited to 0 or 1.

The third set is a computing tool that computes total area of cracks and uses it as quantification method to determine the extent of damage the beam was reached. It uses the binary image as an input and runs a sequence of steps that produce numerical data about the total cracked area, that it was used as a decision support for the feasibility of maintenance or rehabilitation.



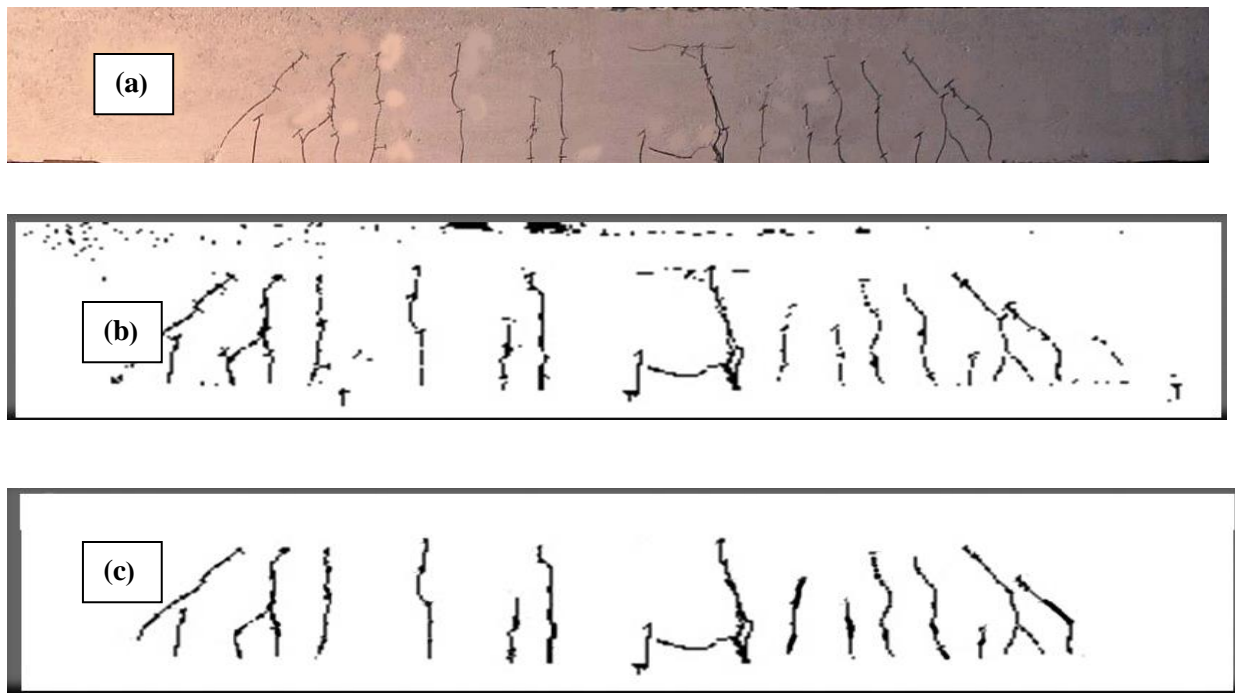
**Figure 3: Grayscale conversion of an image**

## **6. Image Filtering**

Most of images are captured from sites and defected buildings. It should be noted that from a practical point of view, the concrete surface of practical image capturing might contain pores or craters with gray levels that are similar to those observed in the cracks. Image imperfections need to be treated before further image analysis. The concrete surface may contain spots and/or stains that appear to have the same gray level as the cracks. Figure 3 shows an image after gray scale conversion. Image filter is applied on the enhanced grayscale image to increase visibility of cracks; because the original images are usually taken outdoors and may be not very clear. Image filtering increases the contrast of the image by mapping the intensity values by changing RGB image to grayscale then to a binary one [23].

Gray-level image is a process used to improve subtraction processing. Subtraction process generally removes the slight variation like irregularly illuminated condition, shadings, or dirt [24]. It is used to improve visualization of cracks on the noisy concrete surface by applying a median filter on a gray-level image. The steps of filtering in binary images are as follows: 1) Determine the connected components, 2) Compute the area of each component, and 3) Remove any objects significantly beyond the interested areas. Some objects connecting to the border are also removed using a filter designed to exclude all the objects that touch the image border.

Therefore, binary image is cleaned to identify cracks only and remove the surface imperfections. To do this, the binary images are opened using the original grayscale image as a reference; the remaining background was neutralized to a uniform color level. An image enhancer algorithm is applied to improve the quality of the crack image. Figure 4 provides a comparison between the original crack image, binary crack image, and binary crack image after filtration. It can be seen that the image after cleaning cracks is well visual than the original crack Image. The image is cleaned through a median filtering and extracting the borders of the image. Cleaning of the image is done using morphological filter that makes the lines smoother and removes small objects and spots.



**Figure 4: Comparison between original image (a), after binary conversion image (b), and filtered binary image (c)**

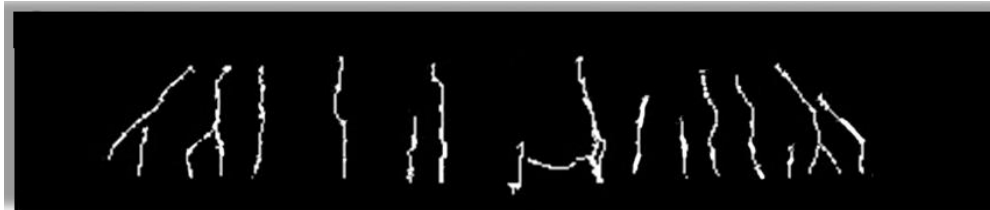
## **7. Crack Detection**

In this step, the crack detection identifies detects cracks shown on an image of a concrete surface in order to perform crack analysis. It is worth noting that the amount of illumination is used to insert the image into filters of grayscale analysis then into a binary one. This means that background brightness needs a treatment to uniform it. It is essential to normalize the brightness of the background, which makes it possible to improve the performance of proposed method. Cropping and scanning process are carried out analytically on images using algorithms; in which the image is scanned in order to detect the position of the simple beam in the image. The simple beam is defined by four points forming a rectangle. With respect to image cropping; the



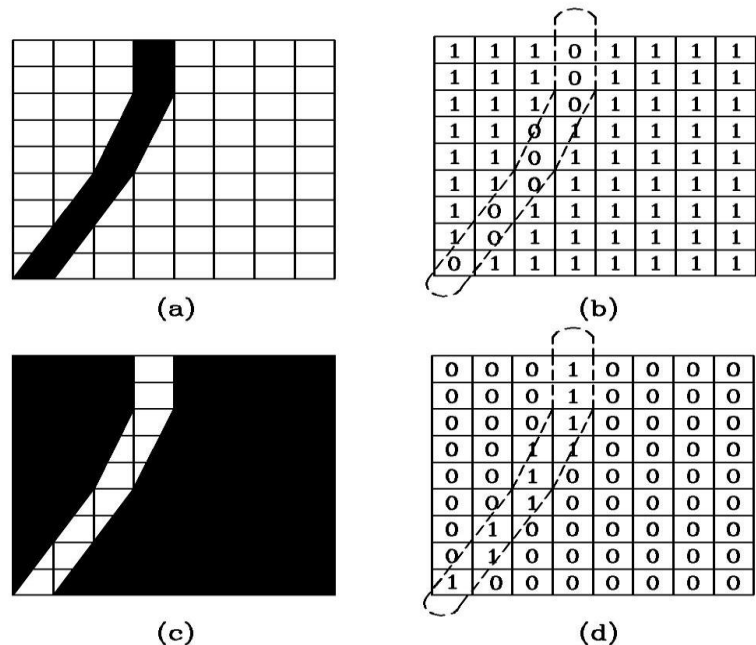
algorithm doesn't crop the image actually, it focuses the work only in the enclosed area in the formed rectangle.

Test results showed that the proposed detection algorithm can provide accurate crack detection on several types of crack images. The scanning is performed using Matlab image processing tool box [25]. The idea was to convert firstly the binary image into a negative as shown in Figure 5. The negative image is converted into a rectangle of black and white pixels and consequently into a matrix of zeros and ones. The black pixels are represented by zeros, the white pixels are ones. This means black background pixels are represented by zeros in a matrix, while crack pixels are represented by ones.



**Figure 5: Negative conversion of beam image**

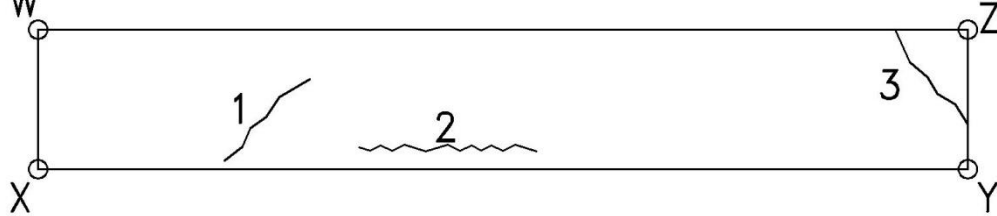
A matrix of zeros and ones is formed, making an ability to identify the location of ones through a field of zeros matrix. It makes it easier to perform mathematical operations like addition, or multiplication, etc. for the matrix of negative converted image than for the matrix of the original image. If the original image matrix was used; the crack pixels are presented by zeros and the background is presented in ones in a way that doesn't enable performing mathematical operations. Figure 6 shows a comparison between original binary image and negative binary as a result of matrixes' conversion.



**Figure6: Difference of converting (a) original image,(b)original representation matrix, (c) converted negative image, and (d) negative representation matrix**

## 8. Extracting Crack Property

As mentioned previously, one of the sets in the proposed image processing steps is working on a binary image to identify specific points on the beam and cracks. This research focuses on the simple beams which look like a rectangle shape. Therefore, whenever a binary image reaches the stage of extracting properties; the boundaries of the beam (a rectangle shape) are represented by four points. Figure 7 illustrates a beam that has four corners (W, X, Y, and Z) and three cracks 1, 2, and 3.



**Figure7: Simple beam contains three cracks**

In the filtering stage, the image is converted to a matrix of zeros and ones (i.e., the background is represented by zeros and cracks are represented by ones). Each location in this matrix represents an image pixel color. So, a detection of cracks begins in the area confined by the four points that represent the boundaries coordinates (W, X, Y, and Z). The detection takes place by scanning the matrix for digits of "ones" (white color pixels). The scanning for cracks ("one" values in matrix) begins from the top left corner of the rectangle (Point "W") then moves diagonally towards the right bottom point (Point "Y"). Any element in the matrix valued in "one" and forming with other elements a line shape, it was spotted.

A geometric property using image processing is Total Area of Cracks Percentage (TACP) against the total area of the beam. That is done using a scanning process for all white pixels enclosed in the rectangle that represents the simple beam. Scanning and counting activity is done using an algorithm used in extracting geometric properties. Using the total area percentage is performed to neutralize the following effects:

- Effect of mass size; it is known that simple beams (practically either in a lab or in field) are different in size, because span to depth ratio differs from place to place.
- Effect of image capturing circumstances; different capturing cameras, zoom magnification, and distances, etc. all affects beam size even for two similar beams.

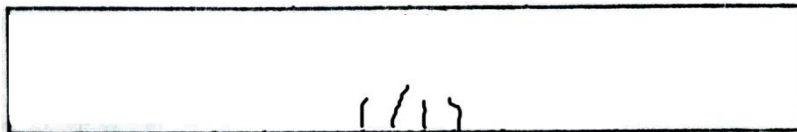
## 9. Case Examples

In this research, eight types of cracks are chosen to apply and verify the framework methodology considering different types, location, inclination, and shapes of cracks which may happen due to disasters (see Table 1). Figure 8 shows the type and shape of the considered types of cracks. Recently, most decision makers tend to evaluate cracking through the pattern or crack width [26]. This research proposes using TACP as an image processing outcome to be used in evaluating maintenance or rehabilitation of cracks. TACP value evaluates the tendency of the element and gives an idea about its mode (e.g., it reached failure state and need rehabilitation or it is still far from failure and needs maintenance only). This procedure supports decision maker to choose a successful long-term repair procedure.

Captured images for many cases were used to apply the framework methodology for beams reached failure mode due to cracking. Investigating the total area of cracks percentage (TACP), some values appeared to be frequent. Table 2 shows average of frequent values for TACP against crack types. These different values could assist in measuring the feasibility of choosing between maintenance or rehabilitation.

**Table 1: Cracks ID number against types of cracks**

| Crack ID | Crack Type   |
|----------|--|
| 1        | Cracks due to flexure in bottom chords                                     |
| 2        | Cracks due to tension shear  |
| 3        | Cracks due to diagonal shear   |
| 4        | Cracks due to bond slippage of reinforcement at the top chord near support |
| 5        | Cracks due to flexure in top chords over supports                          |
| 6        | Cracks due to concrete compression failure                                 |
| 7        | Cracks due to Bent bars corrosion  |
| 8        | Cracks due to bond slippage of reinforcement at the bottom chord           |



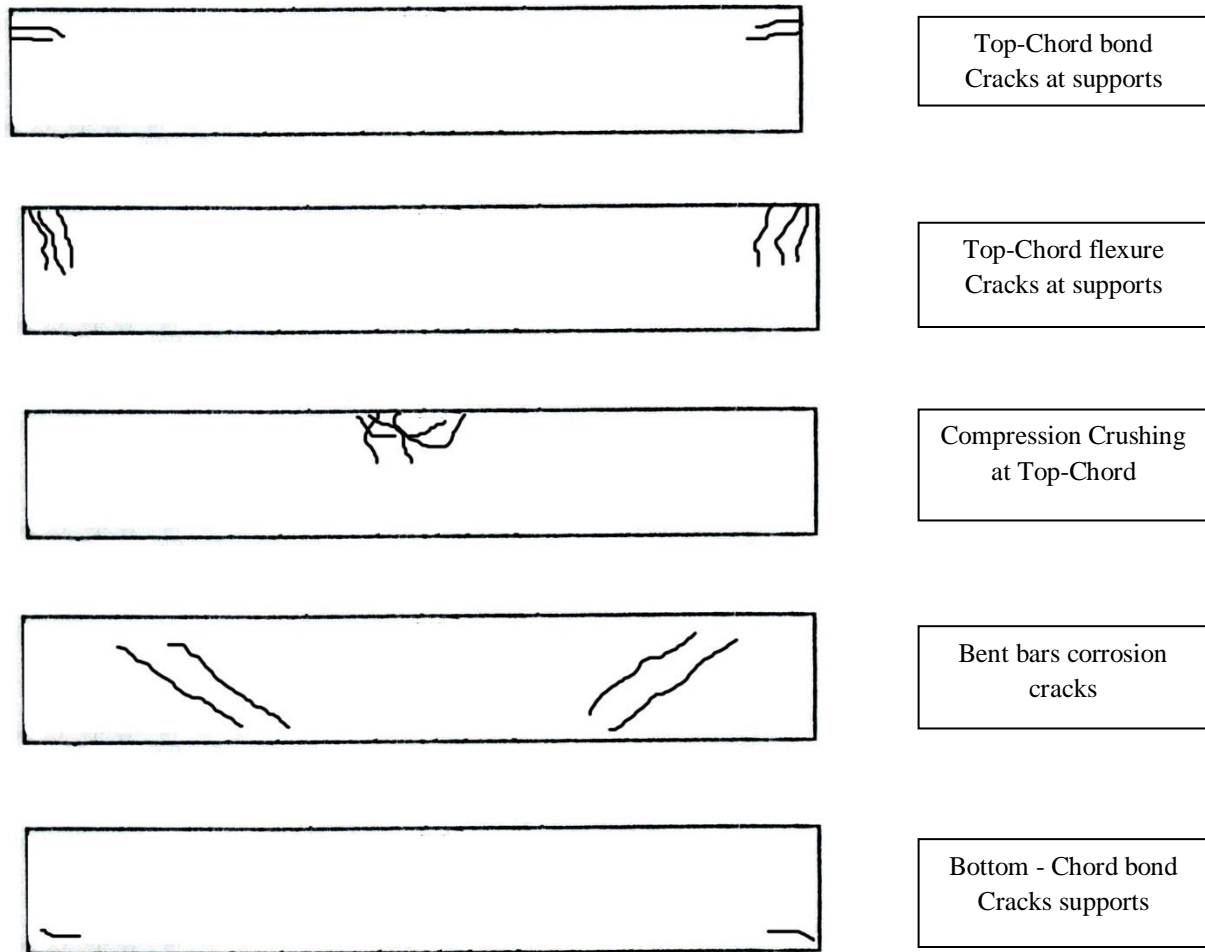
Flexure Cracks  
Bottom chord



Tension Shear Cracks



Shear Cracks



**Figure8: Types and shapes of cracking in R.C beams**

**Table 2: Average TACP at failure mode for different crack types**

| <b>Crack Type</b>                    | <b>TACP at failure mode</b> |
|--------------------------------------|-----------------------------|
| Bent bars corrosion cracks           | <b>0 – 0.2 %</b>            |
| Top-Chord bond Cracks at supports    |                             |
| Bottom - Chord bond Cracks           |                             |
| Top-Chord flexure Cracks at supports | <b>0.5 – 1.0 %</b>          |
| Compression Crushing at Top-chord    |                             |
| Flexure Cracks Bottom chord          | <b>1.0 – 2.0 %</b>          |
| Flexure - Shear Cracks               |                             |
| Diagonal - Shear Cracks              |                             |

## 10. Conclusion

This paper presented a digital image-based framework that develops to extract the properties of cracks in concrete beams. Algorithms of digital image processing were presented. The algorithms run a sequence of operations to produce numerical data concerning geometrical properties that present the total cracked area percentage (TACP), which is equivalent to ratio of cracked area to the total area. TACP can be used as a coefficient to estimate or evaluate the degree of damage in R.C beams. The TACP coefficient depends on extracting numerical data of areas of both cracks and the element itself. Crack pattern in concrete beams are exploited in this research to quantify the state of deterioration of the structure element and provide a decision support tool for choosing a proper action against cracking.

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