# Vulnerability Assessment of Reinforced Concrete Component Building Structure using Crack Detection

Ganesh Ram Suwal, Roshan koju

**Abstract**— After the earthquake, immediate entry into damaged building is necessary for variety of reasons, including emergency search and rescue, building stabilization and repair, and salvage and retrieval of possessions. However, there are always risks associated with entering damaged buildings and often, further structural collapse produces additional victims. In this paper image-processing technique that automatically detects and analyses cracks in the digital image of concrete surfaces is proposed. The image-processing technique automates the measurement of crack characteristics including the width, length, orientation and crack pattern. On the basis of the nature, orientation and behaviour of the crack present on the concrete surface, the vulnerability assessment of a building is done. Various edge detector algorithms are used to find the cracks. Connected pixel labelling are used for details analysis of the crack. So the vulnerability assessment of a RCC building using crack detection is done. Algorithm was tested with Gorkha earthquake affected building's crack images. Results were compared with municipality's vulnerability decision and found highly accurate.

**Index Terms**— Crack Detection, Damage Grade, Image Processing, Post Earthquake Assessment, reinforeced concrete component.

## 1 Introduction

Concrete structures do not frequently fail due to lack of strength, rather due to inadequate durability or due to improper maintenance techniques. The most common cause of premature deterioration is attributed to the development of cracks. Cracking can occur in concrete structures for several reasons that can primarily be grouped into either mechanical loading or environmental effects. Mechanical loads induce strains that can exceed the strain capacity (or strength capacity) of concrete, thereby causing cracking. Concrete may be particularly susceptible to cracking that occurs at early-ages when concrete has a low tensile capacity [1].

If the loads are applied repeatedly or over a long period of time, fatigue and creep can affect the strain (or strength) development that can lead to failure or reduce stresses.

This "Crack can be treated as cancer in RCC structure. As cancer in its primary stage can be cured to a certain extent but becomes danger to life in later stage; same happens with cracks" [1]. Generally, cracks in building have following characteristics [2]:

1. Their Shape is thinner than the shape of textural patterns
2. Their brightness of a crack is darker than the background pixel.

The cracks in a structure typically develop at the location that has the highest stress and the weakest bond. Natural disaster is the one that come without notice. The natural disaster like earthquake, landslides, strong wind power, fire, heavy rainfall etc. may causes huge damage on building [1].

Nepal is highly earthquake prone country and there are large stock of vulnerable buildings exists in the country [3]. Many building were damaged due to last Gorkha earthquake. Some of the buildings were collapsed and some were very danger and risk to live human.

The risk level of a building can be analyzed on the basis of crack exists on a building. A high risk of a building gets damage even in moderate earthquake. Capital city Kathmandu valley has predicted to have more than 50% vulnerable building [3]. Quick damage inspection of buildings becomes the first essential action to be performed by the government to judge the safety of buildings and inform the habitants about the risk of damaged buildings. This paper presents the image processing as a tool to analyses the vulnerability of building.

The safety evaluation of buildings in the event of an earthquake is based on the procedures outlined is ATC-20 documents [4] which has outlined three procedural levels:

a. Rapid Evaluation – It is typically based on an exterior inspection of the structure only. The purpose of rapid evaluation is quickly identified apparently "Unsafe" or "Safe" building after as earthquake.

b. Detailed Evaluation – the detail evaluation is a throughout visual inspection of a structure inside and outside. The building cannot be determined as "Safe" or "unsafe" are further assessed in detailed and engineering evaluation

c. Engineering Evaluation – in this evaluation engineers/inspectors investigate the safety of a damaged structure from construction drawings and new structural calculations. In this evaluation severity and extent of damage to the structural and non-structural elements throughout a building is


- *Ganesh Ram suwal is masters graduate in compueter Engineering. He is author of book entitled "Data Structure and Algorithms for Computing". He has been lecturing in Khwopa Engineering college since last 9 years. His main research areas are image processing, big data analysis and artificial intelligence. E-mail: suwalganesh@gmail.com*
- *Roshan Koju is PhD research student at Pulchowk Campus, Tribhuvan University. He has published more than ten papers in national and international journals.. His interest areas are image processing, wireless communication and networking. E-mail: contactroshankoju@gmail.com*

observed, measured and recorded.

## 2 RELATED WORKS

Studying nature of crack through image processing has been carried out by other researchers as well. Moon and Kim [5] have used image processing and image classification techniques. They used subtraction and morphology operations to separate cracks from rest of image while used backpropagation of neural network for image classification. Their method was claimed to be 90% accurate.

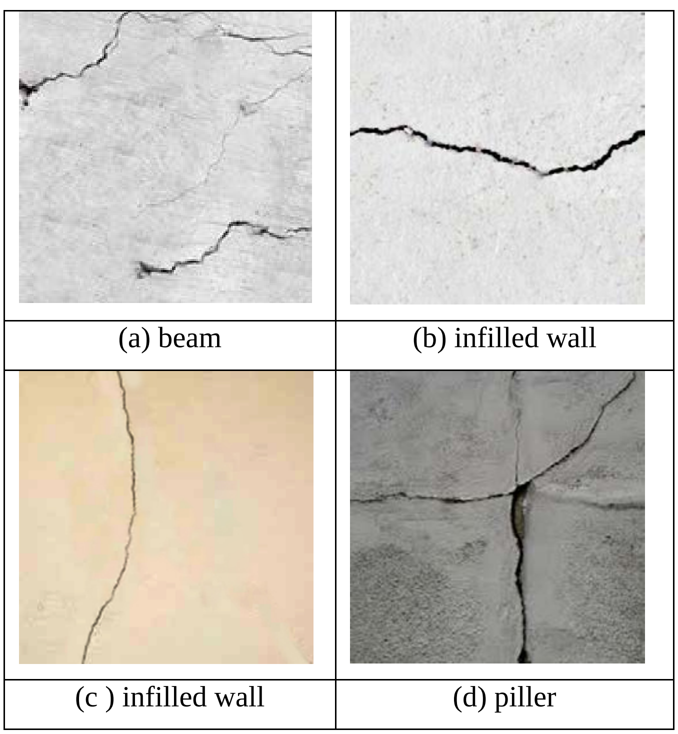
Similarly, Salman and Baporikar [6] developed crack detection technique using a robot. The method was restricted to bridge where robot navigate on bridge surface to collect crack images. They used morphological operations to determine cracks and its properties in image.

Balcones and et al [7], an adaptive road crack detection system by pavement classification is proposed. A vehicle equipped with line scan cameras is used to store the digital images that will be further processed to identify road cracks. The system performs well for road crack detection.

In Qader and et al [8], four edge-detection algorithms (fast Haar transform (FHT), fast Fourier transform (FFT), Sobel filtering, and Canny filtering) are applied to detect cracks in bridges. An efficiency comparison is provided, and it is concluded that FFT is more reliable than the three other methods.

## 3 METHODOLOGY

The image of a cracked area of building is captured. We captured four images from earthquake affected building. Captured crack images are shown in figure below:



| (a) beam | (b) infilled wall |
|---|---|
| (c ) infilled wall | (d) piller |

Fig 1. Captured cracks from (a) beam of hero honda show room sallaghari (b) infilled wall of Khwopa Engineering College, bhaktapur (c) infilled wall of Shanti Niketan School, chundevi (d) piller of Residential building of Chabahil:

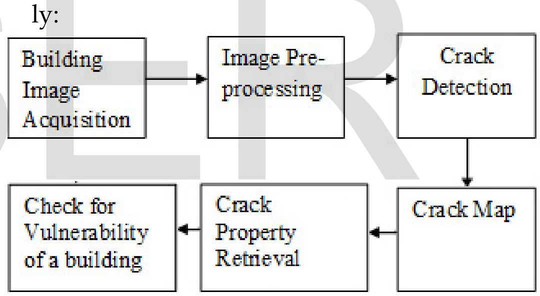
The images were of the size 256 * 256 in size and the resolution is 72 PPI (pixel per inch). The image is converted from RGB image to a grayscale image. The noise present in the image is removed by using various level of median filter like 3*3, 5*5 and 7*7. The Time Complexity, MSE (Mean Square Error) and PSNR (Peak Signal to Noise Ratio) were calculated. The algorithm which has low MSE, high PSNR and consume less time is selected for further processing. Mathematical relations for MSE and PSNR are as follows [9]:

$$MSE = \sum \frac{[W(u,v) - W'(u,v)]}{N^2} \quad (1)$$

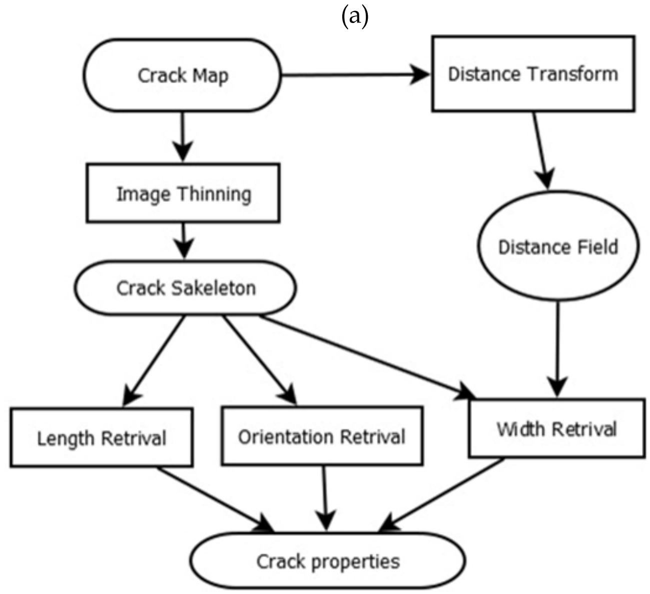
$$PSNR = 10log_{10} \frac{(255*255)}{MSE} \quad (2)$$

Various edge detector algorithms like Sobel, Prewitt and Robert edge detector algorithms were used to detect the crack present in an image thereafter.

Following block diagram explain these steps diagrammatically:




(a)




(b)

Fig 2. (a) & (b) Crack Properties Retrieval Overview

On the basis of these parameter the edge detector is selected and proceed for the further calculation. Connected pixel connectivity is used to calculate the connected component labeling. 4-pixel connectivity, 8-pixel connectivity and m-way pixel connectivity are used. The connected labeling component of a crack is analyzed.

On the basis of crack, labeling the number of crack is counted. Similarly, the nature, orientation and behavior of the crack is analyzed. Normally 0.06-inch width is the threshold value for the column, beam and slab of RCC building and 0.5 inches to 1-inch width is the threshold value for infilled wall [10].

The cracked is classified on the basis of the threshold Value. The major Crack and the minor crack is identified and counted. On the basis of number of major crack present in the building and the behavior of the crack the vulnerability of the building is tested. Hence, the vulnerability assessment of RCC building using Crack detection is tested.

Table 1: Damage Scale [11]

| Damage Rank | Remark |
|---|---|
| Rank 0: | No Damage |
| Rank 1: | Negligible Damage (Hair Line Crack in the wall) |
| Rank 2: | Slight Damage (Shear Crack in non-Structural Wall) |
| Rank 3: | Moderate Damage (Shear Cracks in structural Wall) |
| Rank 4: | Major Damage |
| Rank 5: | Collapse |

Based on above discussion, we formulated an algorithm for crack detection and analysis as follows:

Proposed Algorithm

1. Acquire an image of a RCC building having crack and remove the noise
2. Again the edge detection algorithm is applied to identify Crack in an image
3. If the crack is present in an image then generate the Crack MAP and Find its attribute
4. Classify the Crack and analyze the Crack (width, length, orientation and crack pattern)
5. Calculate the damage grade of a building
6. According to the damage grade level of a building, check for the Vulnerability of a building.

## 4 RESULTS AND DISCUSSION

Above algorithm is implemented in C#.net and tested with all four images shown in figure no. 1. In case of images with multiple cracks, they are numbered 1, 2, 3, 4 depending on their occurrence as algorithm scans image from left to right.

Edge detection algorithms resulted following statistics as shown in table 2.

Table 2. Result obtained from edge detection algorithm

| Image | Parameters | Sobel operator | Prewitt operator | Robert operator |
|---|---|---|---|---|
| (a) | MSE | 168.91 | 245.33 | 135.24 |
| | PSNR | 6.83 | 32.34 | 43.79 |
| | Time Required (Seconds) | 1.43 | 1.43 | 2.29 |
| (b) | MSE | 185.65 | 246.84 | 133.97 |
| | PSNR | 9.90 | 34.09 | 41.92 |
| | Time Required (Seconds) | 3.47 | 3.07 | 4.79 |
| (c) | MSE | 170.98 | 247.92 | 132.10 |
| | PSNR | 7.25 | 35.56 | 42.61 |
| | Time Required (Seconds) | 1.65 | 1.59 | 2.49 |
| (d) | MSE | 252.02 | 247.45 | 134.39 |
| | PSNR | 47.15 | 34.89 | 50.99 |
| | Time Required (Seconds) | 2.75 | 2.85 | 4.86 |

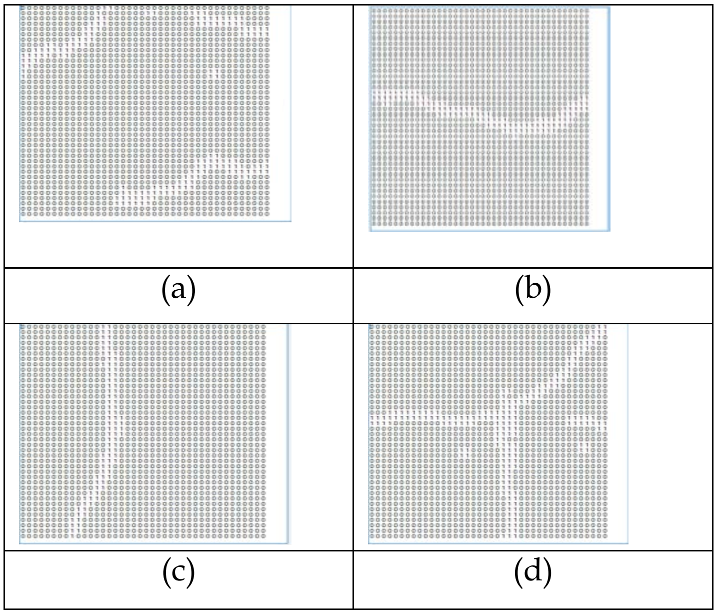
The image is resized into 40*40 of size and converted into a binary image. A binary image is one whose values is either 0's or 1's as shown in figure 3.

The m-way pixel connectivity algorithm is used to find the connected component labeling as shown in Figure 4.

After applying the connected component labeling the crack present in an image the orientation (Horizontal, Vertical) is calculated. Similarly, width and height of crack is calculated. Width and height are obtained in pixel. Those values are converted into inches for comparing threshold values. The threshold values for crack to be safe, it should be below 0.06 inch for beam and piller while it should be below 0.5 inches for infilled wall.

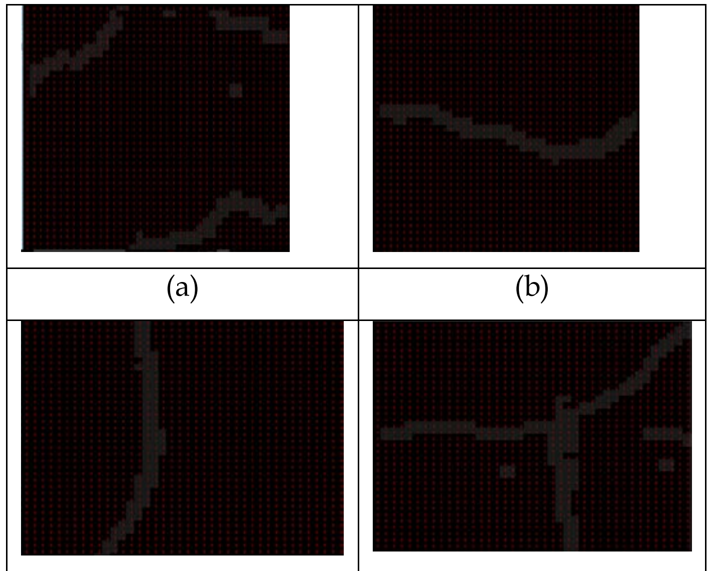
If crack width is greater than threshold, then it is labelled as major crack. If it is under threshold value, then it is marked as minor mark. Minor mark refers to safe crack while major mark means unsafe or vulnerable crack.

Table 4 shows all statistic parameters while table 5 compares algorithm's result with municipality's decision:



(a) (b) (c) (d)

Fig 3. Binary images of captured cracks from (a) beam of hero honda show room sallaghari (b) infilled wall of Khwopa Engineering College, bhaktapur (c) infilled wall of Shanti Niketan School, chundevi (d) piller of Residential building of Chabahil



(a) (b) (c) (d)

Fig 4. M-connected pixel of captured cracks from (a) beam of hero honda show room sallaghari (b) infilled wall of Khwopa Engineering College, bhaktapur (c) infilled wall of Shanti Niketan School, chundevi (d) Piller of residential building ofChabahil



| Image | Number of Crack Found | Crack Number | Height of Crack | height in inches | Threshold in inches | Width of Crack | width in inches | Threshold in inches | Orientation | Crack Type |
|---|---|---|---|---|---|---|---|---|---|---|
| A (Beam) | 5 | 1 | 10 | **0.138888889** | 0.06 | 10 | **0.13889** | 0.06 | Horizontal | **Major Crack** |
| | | 2 | 14 | **0.194444444** | 0.06 | 7 | **0.09722** | 0.06 | Vertical | **Major Crack** |
| | | 3 | 5 | **0.069444444** | 0.06 | 8 | **0.11111** | 0.06 | Horizontal | **Major Crack** |
| | | 4 | 2 | 0.027777778 | 0.06 | 2 | 0.02778 | 0.06 | Horizontal | **Minor Crack** |
| | | 5 | 1 | 0.013888889 | 0.06 | 2 | 0.02778 | 0.06 | Horizontal | **Minor Crack** |
| B (in-filled wall) | 1 | 1 | 9 | 0.125 | **1** | 15 | 0.20833 | **1** | Horizontal | **Minor Crack** |
| C (in-filled wall) | 1 | 1 | 40 | 0.555555556 | **1** | 3 | 0.04167 | **1** | Vertical | **Minor Crack** |
| D (Pil-ler) | 4 | 1 | 40 | **0.555555556** | 0.06 | 25 | **0.34722** | 0.06 | Vertical | **Major Crack** |
| | | 2 | 3 | **0.041666667** | 0.06 | 6 | **0.08333** | 0.06 | Horizontal | **Major Crack** |
| | | 3 | 2 | 0.027777778 | 0.06 | 2 | 0.02778 | 0.06 | Horizontal | **Minor Crack** |

ISSN 2229-5518

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 4 | 2 | 0.027777778 | 0.06 | 2 | 0.02778 | 0.06 | Horizontal | **Minor Crack** |

Following table discusses about vulnerability of building due to crack on the basis of above statistics we compared result with result of municipality's decision of vulnerability analysis:

Table 4: comparison of algorithm's result

| **Image** | **Algorithm's Decision** | **Municipality's Result** |
|---|---|---|
| A (Beam) | Structure is unsafe | RED STICKER |
| B (in-filled wall) | Structure is safe | GREEN STIKER |
| C (in-filled wall) | Structure is safe | GREEN STIKER |
| D (Piller) | Structure is unsafe | RED STICKER |

## 5. CONCLUSION

After earthquake entry into a building as soon as possible is necessary for variety of reasons. The manual processes are time consuming and difficult to judge. So a computerized system is developed for the quick analysis of building. The analysis of a building is done by taking an image of damage buildings. The acquired image is of 256 * 256 in dimension and 72 PPI in resolution. The Sobel, Prewitt and Robert edge detector are applied to identify the Crack in an image. The image is converted into a binary image. Connected Pixel connectivity is used to find the connected pixel labelling is calculated and crack map is generated. The Crack properties like nature (Major Crack and Minor Crack), Orientation (horizontal, vertical) and behavior of a crack is calculated and on the basis of these parameter the Vulnerability assessment is done. Result obtained in all four images are highly accurate.

## 6. REFERENCES

[1] K. Meraj, A.Sabih, "Causes and evaluation of Cracks in Concrete Structures", International Journal of technical research and Application, Vol.2, Issue 5, 2014, Pg 29-33

[2] H.John, "Crack Mapping for the Analysis of Complex Shear Wall Systems", The University of Illinois at Urbana-Champaig, September 10, 2010

[3] Hada Design Associates, "Post-Earthquake Assessment of Building after 2072 Earthquake of Shree Mahakaruna Sakyapa School Building", May 2015

[4] Z. Zhenhua, G. Stephanie & B. Ioannis, "Visual Recognition and assessment of Concrete crack properties" in Proceedings of the International Conference on Computing in Civil and Building Engineering, Georgia Institute of Technology, USA – 2010

[5] H.G. Moon and J.H. Kim, "INTELIGENT CRACK DETECTING ALGORITHM ON THE CONCRETE CRACK IMAGE USING NEURAL NETWORK", Department of Civil and Environmental Engineering, Yonsei University, Seoul, Korea, pg. 1461- pg.1467

[6] M.Salman and V Baporikar, "Review onImage Based Detection and Inspection of Cracks on Bridge Surface Using an Autonomous Robot",International Journal on Recent and Innovation Trends in Computing and Communication,ISSN: 2321-8169 Volume: 3 Issue:2 023– 027

[7] M Gavilán and et al, "Adaptive Road Crack Detection System by Pavement Classification. Sensors", 2011, 11, 9628–9657

[8] Q. Abdel, O. Abudayyeh, Kelly, "M.E. Analysis of edge-detection techniques for crack identification in bridges". Journal of Computer Civil Eng. 2003, 17, 255–263

[9] R.S. Adhikari, O.Moselhi and A. Bagchi, "Image based Retrival of Concrete Crack Properties"

[10] G. Biteli, R.Camassi, L.Gusella, A. Mognol, "IMAGE CHANGE DETECTION ON URBAN AREA: THE EARTHQUAKE CASE, DISTART", University of BOLOGNA, Viale Risorgimento,2 , 40136 Bologna, Italy