Measurement of Mid-span Deflections by using Digital Image Processing

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ABSTRACT

Nowadays, several measurement techniques and devices have been developed to measure the deformations on structural members, such as gages, low voltage displacement transducers (LVDT), strain gages and acoustic emissions (AE). With the recent developments, the photography is now in use of science to measure the deformations via the Digital Image Processing (DIP). This research aimed to determine and compare the mid-span deflections of wooden beams that are subjected to three-point bending load. The mid-span deflections of wooden frames are collected via the comparators and DIP. The behavior of the wooden beam is also compared with numerical results generated by using finite element method (FEM). It is observed that the DIP is considerable while measuring the deformations of structural members.

Keywords: digital image processing, wooden beam, three point bending load, mid-span deflection, FEM

1. INTRODUCTION

The Digital Image Processing (DIP) is a set of techniques ensuring the alteration of the quantitative values such as brightness, definition, contrast of an image in spatial area, the filtration of an image in the frequency area, and the formation of a new image with the alteration of its amplitude or phase values in order to understand, interpret, use, store and transfer well. The image information is converted into any requested format with the help of image processing techniques. These techniques can be exemplified as image conversion, repair, conditioning, fragmentation, compression, presentation, and detection [1-3].

2. METHODOLOGY

2.1 Digital Image Processing

To measure the displacement of a point image conversion [4], morphological opening and closure operations image area properties [5], and object capture techniques [6] are required while processing the images. The conversion of the colored sample image first to the gray scale then to the two-level values, which consisted of black and white values, is the first step of the process. At second step, the use morphological operations enable the clear appearance of the reference points,

which are necessary for the calculation of displacement. The centers of the fixed reference points are captured at third step by using the object capture technique; hence the coordinates of reference points can be determined. With the calculation of the distances of the center point values along the images, the displacement values can be calculated.

The proposed method for the calculation of displacements requires a total of 12 fixed reference points on the specimen, 3 for each top-right, top-left, bottom-right, and bottom-left corners, and a fixed point out of the sample (Figure 1). Thus, it fulfills the displacement calculation by determining the coordinate information of these points along the images. A three-step procedure is used to calculate the displacements:

- The determination of the coordinates of 12 fixed reference points on the specimen and one fixed reference point out of the specimen.
- The determination of vertical distance of the fixed point that is out of the specimen to the two horizontal lines in between fixed reference points on top left and right corners and bottom left and right corners, respectively.
- The calculation of displacement from the change of vertical distances for each image as the load incremented.
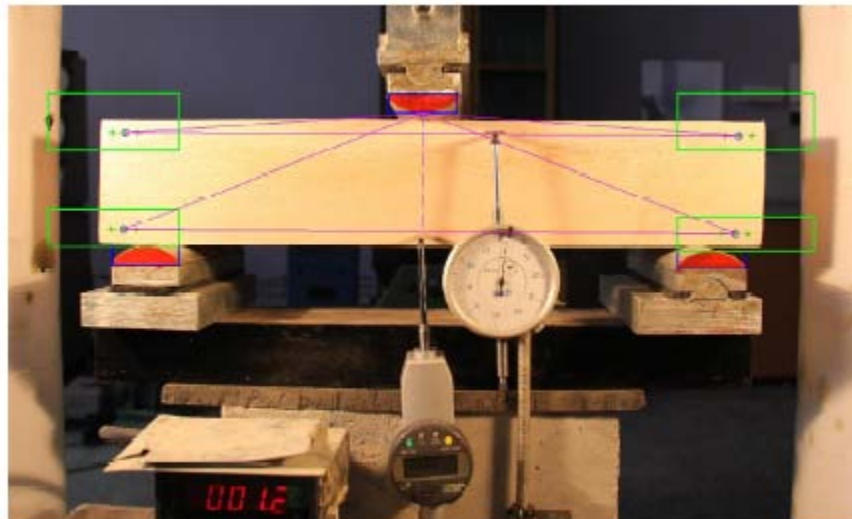

Figure 1 – Experimental setup and location of the fixed reference points

2.1.1. The determination of the fixed points on and out of the sample

A three-stage method is suggested for the determination of reference points.

<u>First step: The application of the color filter by using the point color</u>
Firstly, each frame information in the colored entry images which have the information of red, green and blue frames is normalized between 0 - 1. Then the filter below is applied on each frame:

$$\text{point}_{img} = (\text{Red} > 0.6) \text{ and } (\text{ Green} < 0.6) \text{ and } (\text{ Blue} < 0.6) \qquad (1)$$

The value 0.6 on the equation above has been determined by taking the common color value of the 12 fixed points on the sample into account. At the end of this color filter, all the other objects, except for the ones which have the colors of the fixed points, are eliminated. After the color filter application, the colored entry image turns into a two-level image consisting of black and white values.

Second step: The elimination of the artificial objects and the determination of the face area objects

In this step, a two-level operation is fulfilled. At the first level, the elimination of the artificial objects is ensured. And at the second level, the determination of the pier objects (face area objects) compressing the sample is done:

1. The elimination of the artificial objects:

There are many artificial objects together with the face area objects in the two-level image obtained. For the elimination of the artificial objects, two main morphological operations are fulfilled on the image: Opening and Closing. As the worn object pixels are cleared with the opening operation, there is a decrease in the count of pixels of the objects. Thus, the pixels around and not belonging to the object are eliminated. And in the closing operation, the object is expanded by using the determined structural element. In this way, with the association of the discrete parts of the object within a very close area, the integrity of the object is ensured (Figure 2).

2. The determination of the face area objects:

After the elimination of the artificial objects, there may still be some objects having the same color with the face area objects on the image. For the elimination of these objects which are thought to have different geometric shapes from the face area objects, the features below about the detected objects are used:

Area: The total numbers of pixels in the detected foreground object

Centre: The barycenter of the detected foreground object

Solidity: The ratio of the number of pixels of the detected foreground object in the convex hull to the number of pixels on the object.

Eccentricity: The similarity value of the object configuration to the line or the circle.

By checking whether the object features obtained independently are within the limits below mentioned, all the other objects except for the target face area object are eliminated.

$$250 > \text{Area} > 150 \tag{2}$$
$$1 > \text{Solidity} > 0.5 \tag{3}$$
$$1 > \text{Eccentricity} > 0.8 \tag{4}$$

The limit values used in these equations are the features belonging to the piers (face area objects) compressing the sample.

Third step: The detection of the fixed points

After the determination of the face area objects, the position information was on the 12 fixed points and the detection of the only fixed point out of the sample was tried. For this, 4 sections with certain proportions are taken from the bottom-right, bottom-left, top-right and top-left areas of the sample by taking the movement information of the face area objects along the video images into account. For the determination of the positions of the fixed points in these sections, the limit values below are used.

$$1 > \text{Solidity} > 0.8 \tag{5}$$
$$0.85 > \text{Eccentricity} > 0 \tag{6}$$

2.1.2 The calculation of the displacement value in the top and bottom parts of the sample

After the coordinate information of the 12 fixed points on the sample are obtained, the top and bottom displacement values in the current image are calculated as follows: The average

coordinate values of each three points in the top-left, top-right, bottom-left and bottom-right corners of the sample are respectively expressed as P_1, P_2, P_3, and P_4, and the point out of the sample is expressed as P_{out}.

$$a = \left\| P_2 - P_{out} \right\| \tag{7}$$

$$b = \left\| P_1 - P_{out} \right\| \tag{8}$$

$$c = \left\| P_1 - P_2 \right\| \tag{9}$$

$$\beta = a \cdot \cos(\frac{a^2 + c^2 - b^2}{2 \cdot b \cdot c}) \tag{10}$$

$$d = a \cdot \sin(\beta) \tag{11}$$

$$z = \sqrt{a^2 - d^2} \tag{12}$$

$$P_{right,top} = P_2 - \frac{z}{c} \cdot (P_2 - P_{1z}) \tag{13}$$

$P_{right,bottom}$ is also calculated with the same procedure. By using the $P_{right,top}$ and $P_{right,bottom}$ coordinates, displacements can be calculated with Eqn. 14 and Eqn. 15. All calculated displacements are in pixels and should be converted to a length unit. In this study, it has been observed that 1 cm length in the image is equal to 71.5912 pixels value.

$$Displacement_{top} = \left\| P_{out} - P_{right,top} \right\| \tag{14}$$

$$Displacement_{bottom} = \left\| P_{out} - P_{right,bottom} \right\| \tag{15}$$

2.2. Experimental Study

The wooden beams that are used in the experimental study were prepared from plane tree in dimensions of $100 \times 100 \times 500$ mm. Then, the fixed reference points that are used in the digital image processing are concretized on each specimen.

A digital comparator with 1% millimeter sensitivity and the manual comparator are used in the experimental setup (Figure 1). The measurements made by the load cell and the comparators are recorded with photographs, which are used in digital image processing, to conduct a comparison between the results of experimental study and digital image processing. For the determination of the displacements on the samples, the comparators are placed as follows:

1. The manual comparator was placed to measure the displacements on the top of the sample. This comparator was positioned 10 mm below the top of the sample and 50 mm rightward from the center of the sample (Figure 2).

2. The digital comparator was positioned at the bottom of the sample and 10 mm above the center

2.3. Finite Element Analysis

To conduct a numerical analysis, finite element method is used in this study. A 2D model is generated by using anisotropic material characteristics and plane stress elements. It is difficult to examine the mechanical features of wood since it is an anisotropic material [7-8]. The mechanical characteristics of same kind of wood can vary easily and can change with the water content of the wood. The material characteristics that are used in the model for each specimen are listed in Table 1.
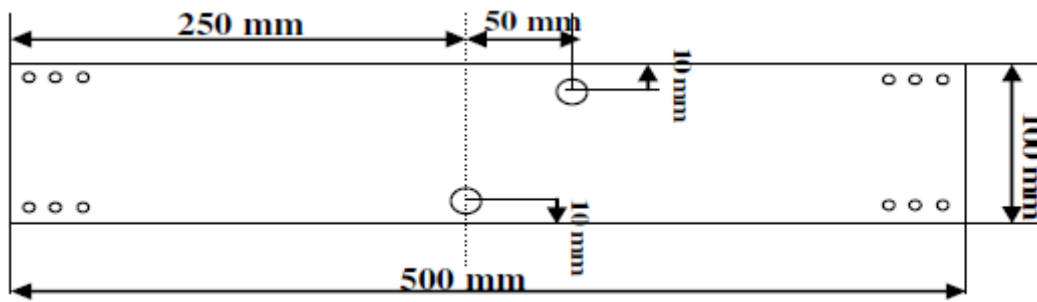
Figure 2 – Dimensions of the wooden beams

Table 1 – Material characteristics that is used in FEA

Modulus of Elasticity				Shear Modulus			
(MPa)	S1	S2	S3	(MPa)	S1	S2	S3
E_1	2000	2400	4000	f_{12}	300	360	600
E_2	200	240	400	f_{13}	300	360	600
E_3	200	240	400	f_{23}	75	90	150
Poisson's Ratio				Strength			
	S1	S2	S3	(MPa)	S1	S2	S3
v_{12}		0.05		C		-24	
v_{13}		0.05		T		16	
v_{23}		0.25					
Moisture Loss							
%	S1	S2	S3				
	12.5	18.9	22.8				

3. RESULTS

The measurements are made at point DC-DI for digital image processing (Figure 3). At this point the digital comparator is also used to measure the mid-span deflection of the beam. The displacement values are obtained by using digital image processing, digital comparator, and finite element analysis. The typical deformed shape of wooden beams is presented in Figure 4. It is observed that measurements are comparable with each other (Figure 5).
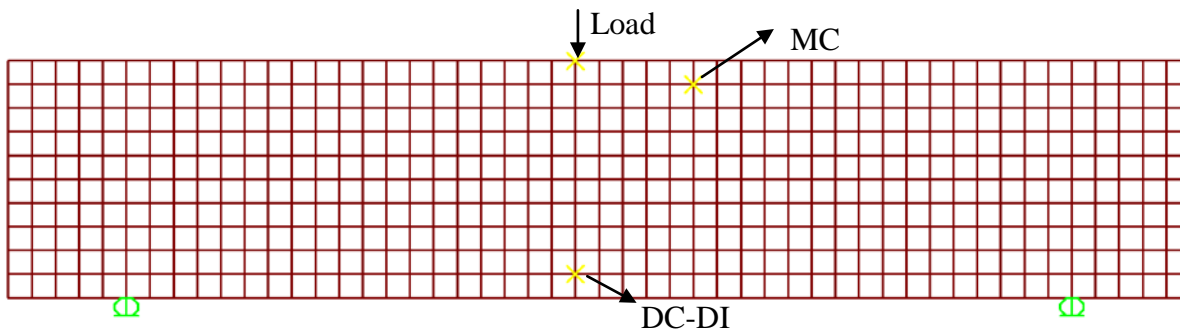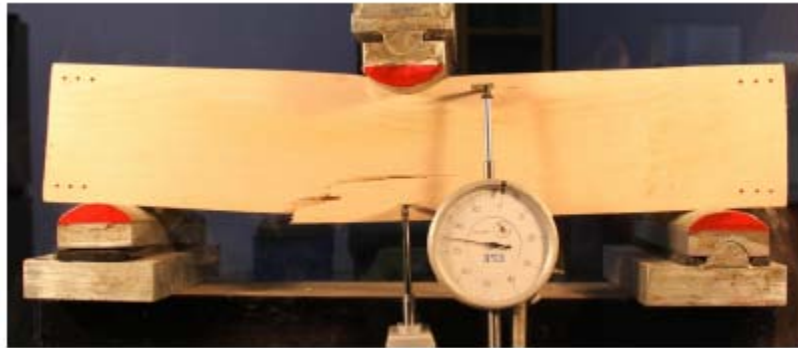

Figure 3 – Meshing profile of wooden beam

Figure 4 – The typical deformed shape of the wooden beams

To compare the results measurements are also made at point MC. At this point measurements are collected by using manual comparator. The load-displacement behavior at this point is compared with the results of finite element analysis (Figure 6). It is observed that measurements are comparable with each other at point MC too.
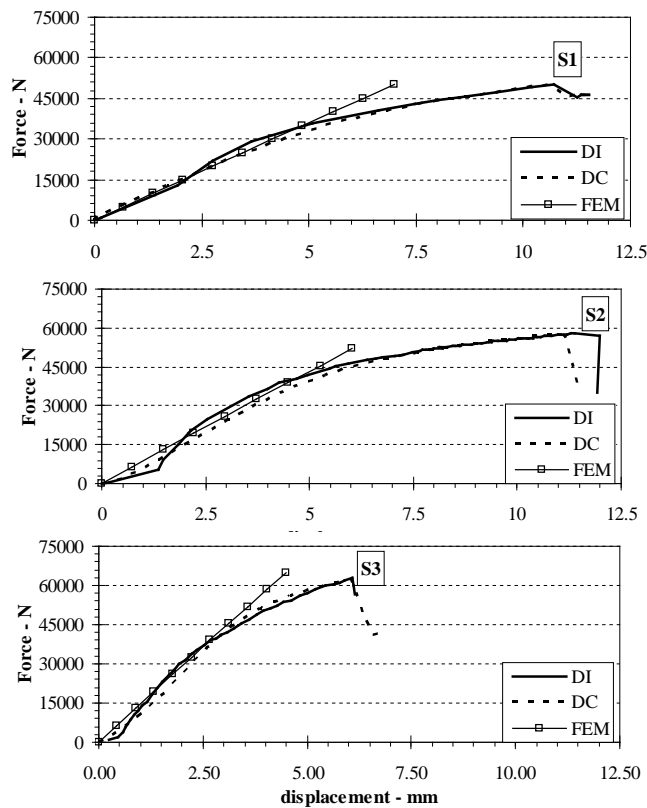

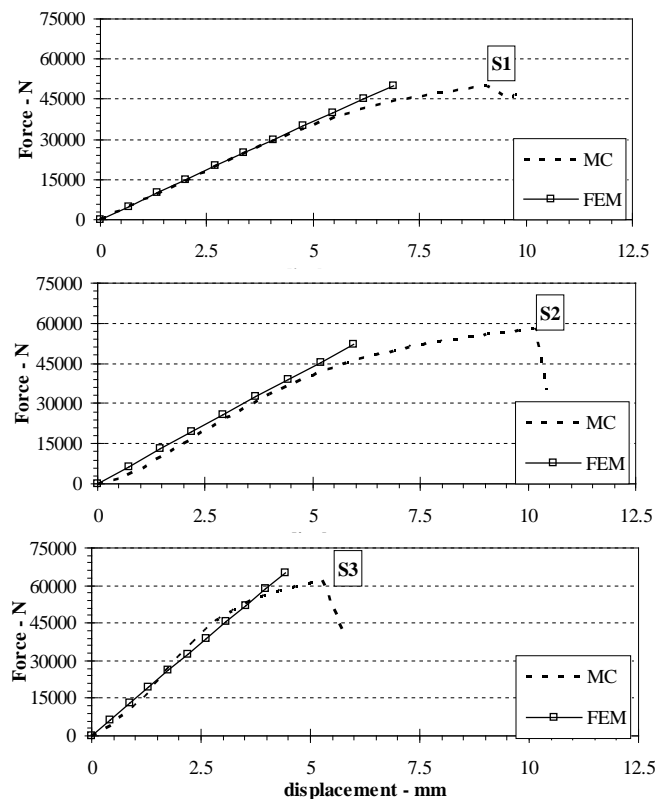**Figure 5 –** Load-deflection curve of wooden beams at point DC-DI

Figure 6 – Load-deflection curve of wooden beams at point MC

4. CONCLUSION

This research aimed to present the comparableness of measurements collected via digital image processing method. To present the comparableness, the mid-span deflections of wooden beams that are subjected to three-point bending load are collected via DIP and compared with the results from comparators. The behavior of the wooden beam is also compared with numerical results generated by using finite element method (FEM). The study presented that the measurement of displacements can be collected by using DIP method. The use of this method on site can be advantageous when it is tough to measure big-scale structures (i.e. dams).

5. REFERENCES

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