

Displacement Measurement of Bending Tests Using Digital Image Analysis Method

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Abstract—Over the last few years due to sharp increase in experimental investigations in the field of structural engineering, the necessity for reliable and precise deformation measurement is felt more than ever. The most common experimental test in the field of structural engineering is bending test in which beam's deformation is evaluated in order to calculate other structural parameters. One of the most usual techniques for obtaining beam's deformation is utilizing Linear Variable Differential Transformer (LVDT) sensors. However, non-mechanical procedures for displacement measurement have shown much interest between researchers. Photogrammetry, Digital Image Correlation (DIC) method and Particle Image Velocimetry (PIV) are some of the new image-based methods for displacement measurement. Due to the advantages of PIV method in the field of experimental fluid mechanics and Geotechnics, the current study has been focused on the performance of PIV method for displacement measurement of bending test in structural engineering. To reach the aforementioned goal, one steel I-beam was subjected to four-point flexural loading and the load-displacement curve was plotted using PIV method. The experimental results obtained from the PIV method showed excellent agreement with LVDT's data. It is concluded that due to the lower cost and potential of obtaining whole displacement field on common bending tests, PIV method could be widely used as an alternative to conventional measurement techniques in structural engineering.

Index Terms— Bending test, digital image correlation (DIC), displacement measurement, linear variable differential transformer (LVDT), particle image velocimetry (PIV).

I. INTRODUCTION

Over the last few years due to extreme increase in experimental investigations in the field of structural engineering, the necessity for accurate deformation measurement is felt more than ever. It is obvious that further calculations could be seriously affected by accuracy of the evaluated displacement fields. Bending test is the most common test in the field of structural engineering in which beam's deformation should be evaluated in order to calculate any other structural parameters. Utilizing Linear Variable Differential Transformer (LVDT) is a primitive technique for obtaining deformation of bending tests. Although there are certain benefits of LVDTs such as high accuracy and simple installation, there are also some disadvantages such as high cost, inability to obtain the whole displacement field and extra charges for data acquisition.

Photogrammetry is another technique which is applied to

obtain displacement in the field of structural engineering. Photogrammetry is the process of obtaining accurate measurements from physical objects using photography. Few investigations have been conducted using this technique in the field of structural engineering [1]. In summary the technique operates by monitoring colored targets which are placed at selected locations on the field surface using specially designed cameras. The accuracy of the system is mainly dependent on the camera hardware, scale of the object and geometry of the survey [2].

A. Digital Image Correlation (DIC) method

Another recent method for obtaining displacement fields is Digital Image Correlation (DIC) method. In general, DIC is an image analysis procedure which uses the mathematical correlation functions to analyze digital images of a field undergoing deformation. This technique offers the advantage of obtaining continuous measurements of the whole displacement field. Few studies have been carried out using this technique [3], [4]. In order to obtain the displacement field, surface preparation consisting of creating a random sprayed-on speckle pattern, should be done. After the surface preparation, digital images should be recorded during deformation of the object. Finally the correlation between the deformed images and the undeformed reference image will be used to obtain a two-dimensional displacement field [3]. The accuracy of this technique is based on the camera resolution. Based on experimental investigation, an image displacement accuracy of approximately 0.01-0.005 pixels can be expected [3]-[5].

B. Particle Image Velocimetry (PIV)

Particle Image Velocimetry (PIV) is originally a velocity-measuring technique developed in the field of experimental fluid mechanics [6]. The technique was originally implemented using double-flash photography of a seeded flow and the resulting photographs were divided into a grid of test patches. For PIV analysis, the displacement vector of each patch during the interval between the flashes is found by locating the peak of the autocorrelation function of each patch. The peak in the autocorrelation function indicates that the two images of each seeding particle overlying each other, so the correlation offset is equal to the displacement vector [7]. A modified approach was used to implement PIV in geotechnical testing by White et al, 2003. Although fluid requires seeding with particle to create features upon which image analysis can be operate, natural sand which is used in geotechnical tests, has its own texture in the form of different-colored grains and the light and shadow formed between adjacent grains when illuminated [7]. According to White's investigations, the modified PIV technique offers an order-of-magnitude increase in accuracy, precision, and

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measurement array size compared with previous image-based methods of displacement measurement. An image displacement resolution of 0.005 pixels can be expected from the PIV technique [7].

The advantages of PIV method in the field of experimental fluid mechanics and geotechnical tests and also due to importance of the bending test in the field of structural engineering, have led the current study to evaluate the performance of PIV method for displacement measurement of bending test by means of experimental investigations.

II. EXPERIMENTAL PROCEDURE

A. Test Setup

In order to evaluate the displacement field using PIV method, one steel I-beam was subjected to four-point flexural test. The yielding stress of the steel was equal to 240 MPa according to the manufacturer's catalog. The steel I-beam dimensions and the test setup are shown in Fig. 1.

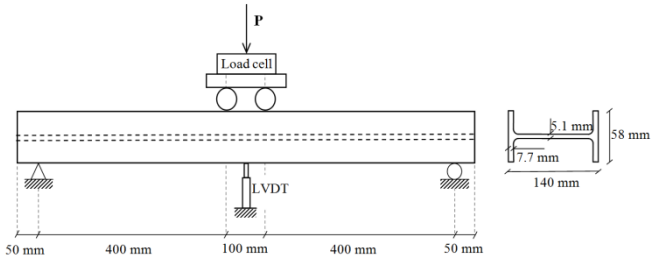


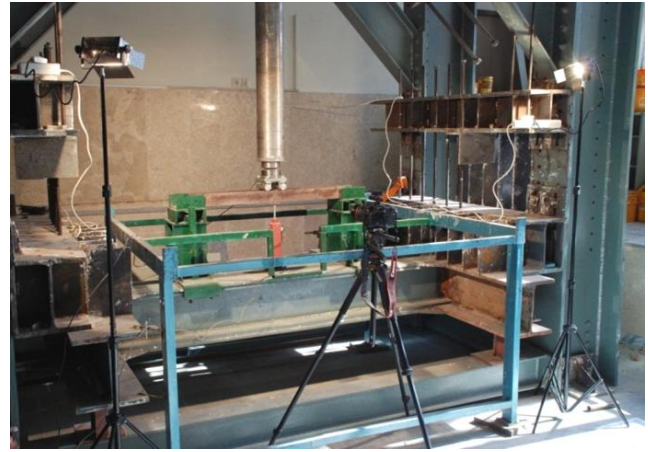
Fig. 1. Dimensions of steel I-beam specimen and loading arrangement

As it was mentioned earlier, it is necessary for the images to have a texture to create features upon which image processing can operate. Thus, since the steel I-beam originally does not show a suitable texture, natural colored sand between sieve no. 50 and 100 was stuck to the beam's face using suitable two-component epoxy adhesive.

The beam was subjected to four-point flexural loading in elastic zone, using a 2000 kN displacement control hydraulic jack. A Linear Variable Differential Transformer (LVDT) having a resolution of 0.1 mm was mounted at the mid-span of the specimen for plotting the load-displacement curves. The camera was placed perpendicular to the beam face at a distance equal to 1.0 m. In order to eliminate any probable parasitic lights, the specimen was illuminated using two white light projectors. Digital images were taken using a remote control at regular intervals and a digital data logger was used to monitor the load cell, LVDT and image numbers. Test setup and the camera view are shown in Fig. 2.

B. Image Analysis Using Particle Image Velocimetry (PIV)

Digital images were taken of the deformed steel I-beam using Nikon D80 digital camera with resolution 10.0 megapixel (3872×2592 pixels) during the loading procedure. The images then were processed using GeoPIV8 software, developed at Cambridge University [8], and load-displacement curves were plotted. In order to investigate the impact of camera resolution on displacement accuracy, the test was repeated using Canon 5D Mark II digital camera with resolution 21.0 megapixel (5616×3744 pixels) and the results were compared.



(a)



(b)

Fig. 2. (a) Test setup; (b) camera view

III. RESULTS AND DISCUSSION

The load-displacement curves for the steel I-beam which were obtained from the PIV method using 10.0 megapixel and 21.0 megapixel cameras are shown in Figs 3 and 4, respectively. In order to evaluate the PIV results, load-displacement curves obtained from the LVDT have also been plotted in Figs 3 and 4.

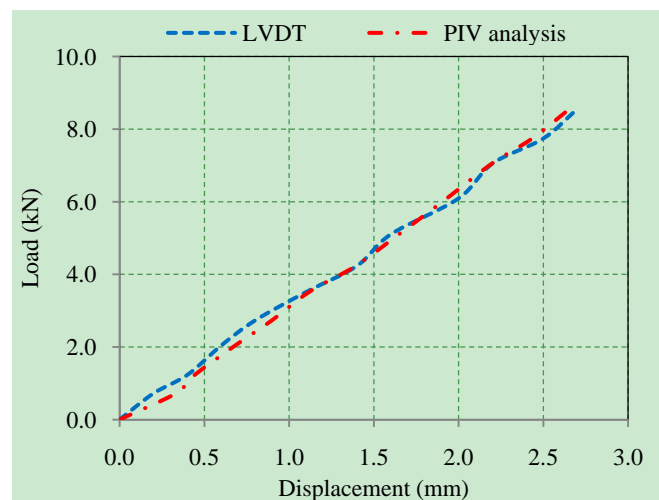


Fig. 3. Load-displacement curves for tested steel I-beam using LVDT and 10.0 megapixel camera.

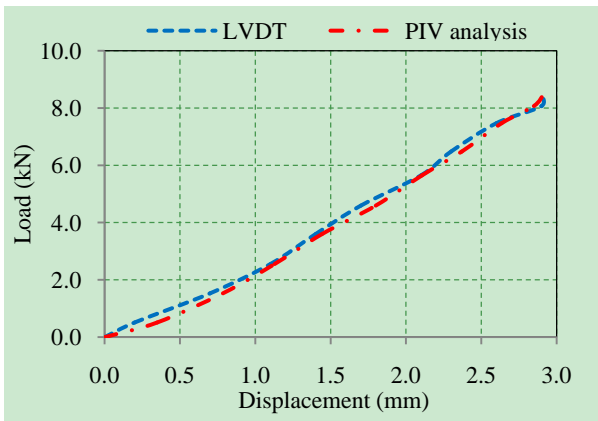


Fig. 4. Load-displacement curves for tested steel-I beam using LVDT and 21.0 megapixel camera.

As it is shown in Figs 3 and 4, the load-displacement curves for the test beam obtained from the image analysis method, very well match the load-displacement curves obtained from LVDT's data. In addition, as it is obvious in Figs. 3 and 4, using 10.0 megapixel or 21.0 megapixel camera does not affect the image analysis results. Moreover, displacement field can be also obtained from PIV method. For this purpose, the PIV analysis was undertaken using patches of 128×128 pixels, spaced at 64 pixels centers. Mesh generation and displacement vectors for the central zone of the tested steel-I beam are shown in Figs. 5 and 6, respectively.

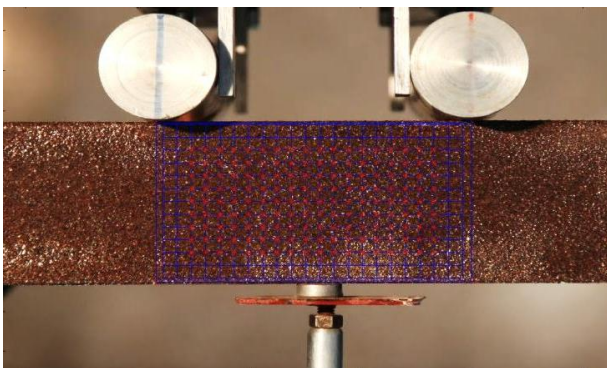


Fig. 5. Mesh generation for the test beam

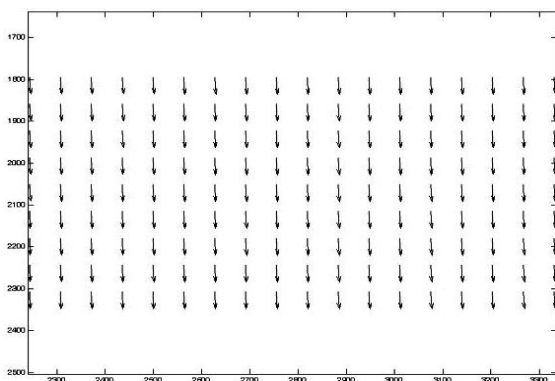


Fig. 6. Displacement vectors obtained from PIV analysis (magnification factor = 5)

IV. CONCLUSIONS

In this paper, an experimental study was conducted on the performance of Particle Image Velocimetry (PIV) method for displacement measurement of bending tests. Based on the experimental results of the current study, the following conclusions are drawn:

- 1) Displacement obtained from the image analysis method extremely matches LVDT's data; hence, load-displacement curves can be easily drawn for bending tests using PIV method.
- 2) Camera resolution has no significant effect on displacement data obtained from the image analysis method, although high camera resolution increases the resolution and accuracy of the displacement field.
- 3) Due to the lower cost and potential of obtaining the whole displacement field on common structural tests, PIV method can be widely used as an alternative to conventional measurement techniques.

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