MEC-E6007 – Mechanical Testing of Materials

LABORATORY EXERCISE 2 – DIGITAL IMAGE CORRELATION

Report

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OBJECTIVE

Measure strains and displacements of a loaded cantilever by using Digital Image Correlations (DIC).

BASIC INFORMATION

- Testing Method: Digital Image Correlation (DIC)
- Robust GOM System
- Pattern: printed and glued on stickers

INTRODUCTION IN DIC

DIC is a powerful optical measurement technique, which enables precise analysis of surface deformations and movements by evaluating sequences of digital images. This method is utilized across various fields such as materials science, mechanical engineering, biomechanics, and geosciences.

DIC operates by analyzing digital images of surfaces before and during deformation or movement by following various marked points, set on the surface. Before the measurement, the whole area of interest has to be captured in its initial state by taking images and analyzing the set-up pattern. During the process, the DIC software catches the deformation of the body and compares the pixel intensities between the reference and target images, calculating the displacement and deformation of the surface at sub-pixel levels. Through this, DIC can provide highly accurate 2D and 3D deformation measurements by only using two cameras and without destroying / damaging the object of interest.

Especially for material testing, DIC is becoming an important alternative to conversative testing methods. Mechanical properties, such as tensile strength, strains and fracture toughness can be easily measured, regardless of what material should be tested. Real-time data capture also provides rapid feedback for process control or experimental analysis.

PRECAUTIONS

To guarantee good testing results, some of these crucial considerations and potential sources of errors need to be considered:

- The quality and resolution of the reference and target images is critical for the accuracy of DIC analysis
- Before measurement, cameras must be calibrated the right way to ensure precise measurements
- Adequate contrast between reference and target images. Insufficient contrast can lead to measurement errors because the software can't catch displacement in the right way

- Constant illumination and a fixed position should be ensured. Changes during measurement can introduce errors in DIC analysis.
- Pattern size and shape should be tailored to object size
- Noise sources should be minimized, and additional filters applied before measurement

THEORY

To verify the measured deformations and strains, the results will be compared to Bernoulli beam theory.

The Bernoulli beam theory is a fundamental assumption in structural mechanics, stating that beams or cantilevers deform under bending but maintain their cross-sectional shape during this deformation. Concerning this theory, when a beam is subjected to bending, compressive and tensile stresses occur in its cross-section. The outer fibers of the beam are stretched (tensile stress) while the inner fibers are getting compressed (compressive stress). This results in the beam assuming a curved shape, with the maximum curvature occurring at the neutral axis.

By combining the Bernoulli beam theory with advanced measurement techniques like DIC, user can gain a better understanding of beam and cantilever behavior under deformation.

RESULTS AND INTERPRETATION

Experimental Setup

The experiment involved the application of stick-on DIC speckle pattern over a channel shaped cantilever beam to which weights are attached through a hanging plate as shown in Figure 1. Since the beam is fixed at one end, the clamped end, and the weights are added to the free end we would expect the displacements in the beam to be a sum of the bending and the torsional loading. As the hanging plate for holding the weights is offset from the center of the cross section of the beam the effect of torsion should be more dominant in the resulting displacement distribution. The loads were added in steps, the hanging plate for holding the additional loads was not considered as the deflections caused by it were zeroed. The weights were added in steps of 2.268 kg (5lbs), 1.824 kg, 1.848 kg. The resulting deflections were then recorded with the help of DIC set-up from Zeiss vendor. The experiment was repeated for unloading as well. To validate the results from the DIC measurements, the deflection data was also recorded with the help of four LVDTs attached to the beam.

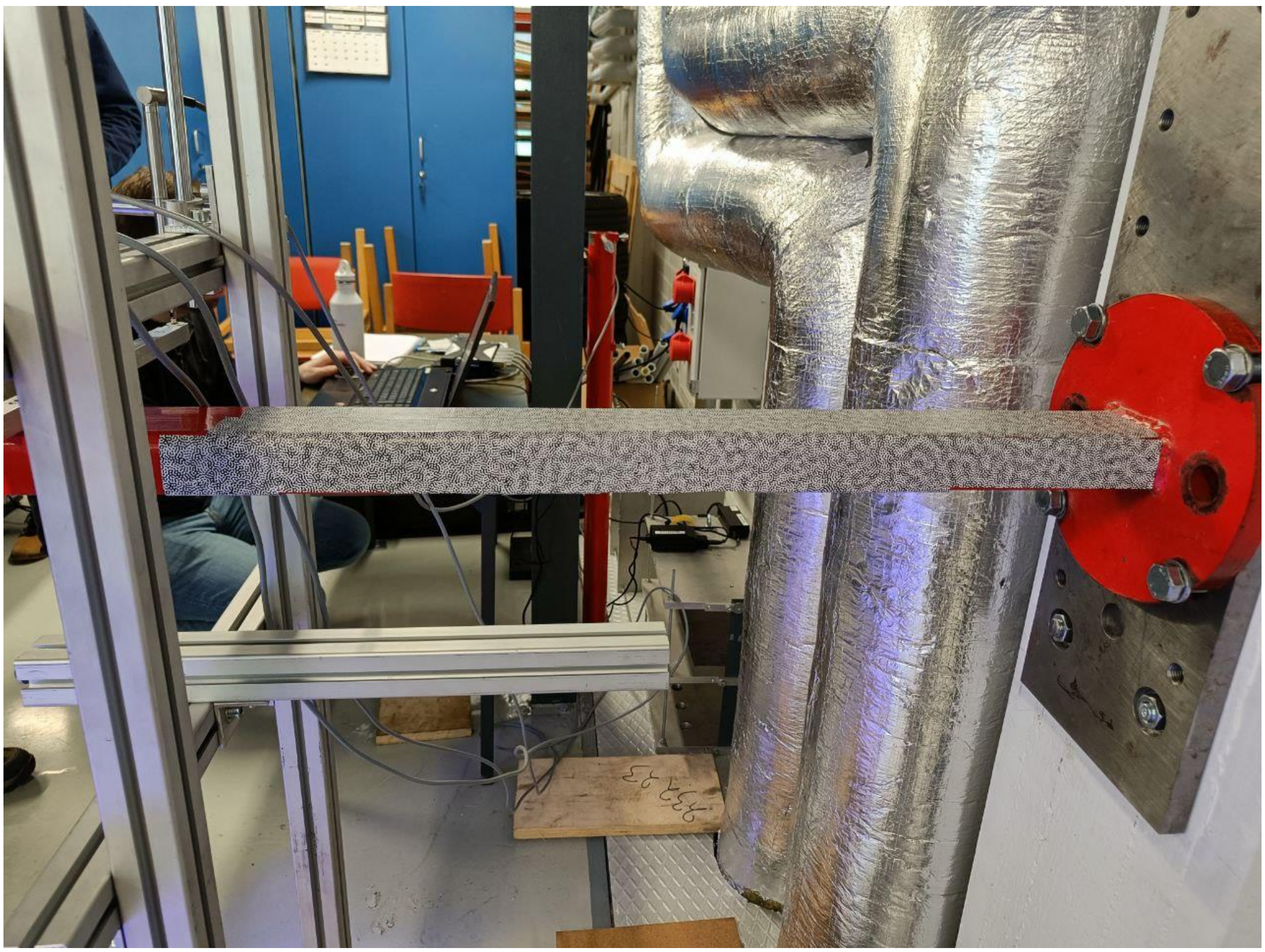

Figure 1: Side view of the beam

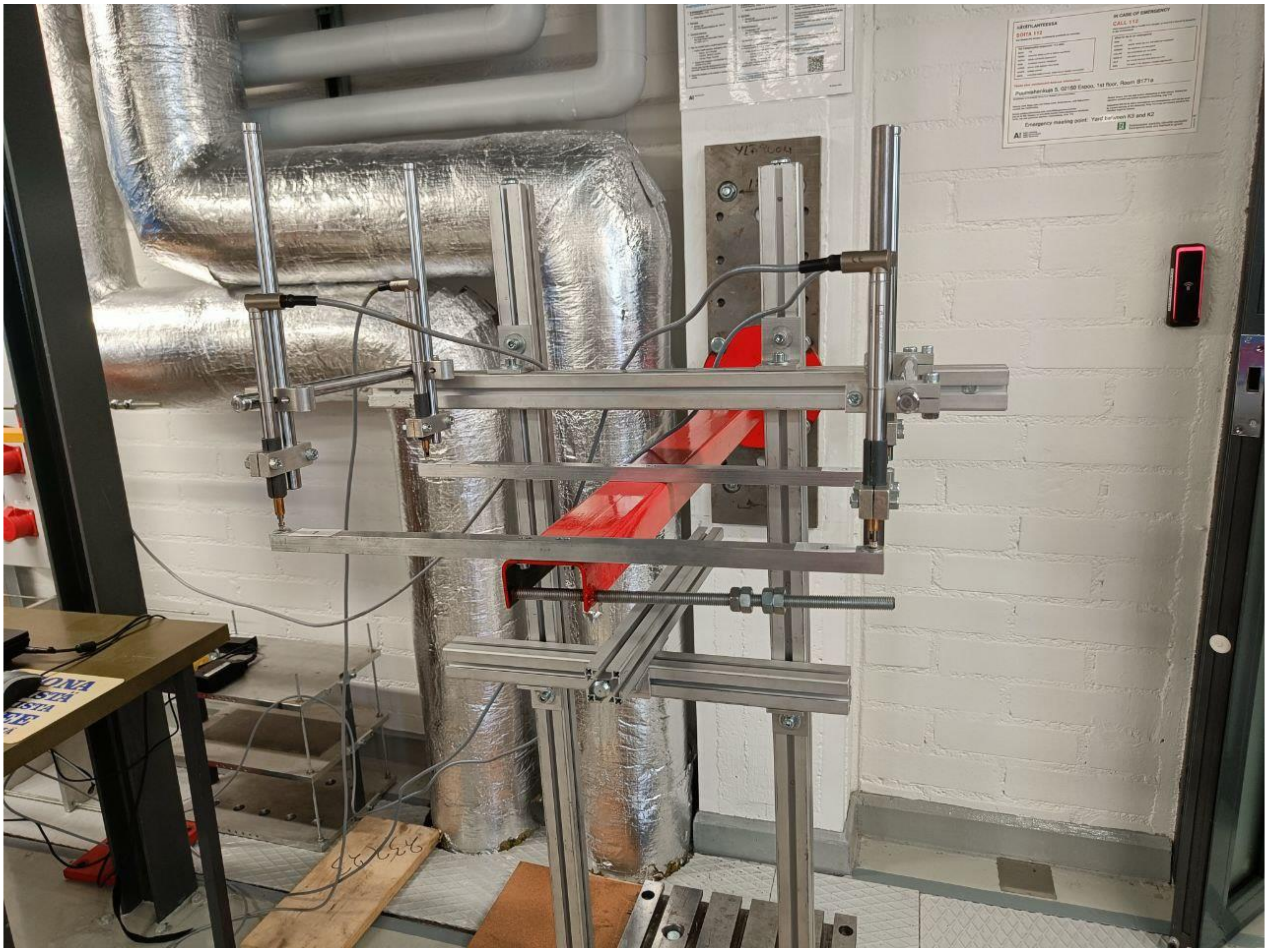

Figure 2: Front view of the beam

Discussion:

The series of images taken from the DIC set-up were then analyzed with Zeiss Inspect software provided by the vendor. The data was analyzed for strain and displacement distributions, but data from LVDTs shows only the transverse displacement, so the comparison to beam theory will only be made for this case. The results from the Zeiss Inspect software can be seen in Figure 3 to Figure 6. To compare the results, three collinear points were selected on the top surface of the beam and their transverse displacements were tracked across the 36 data frames.

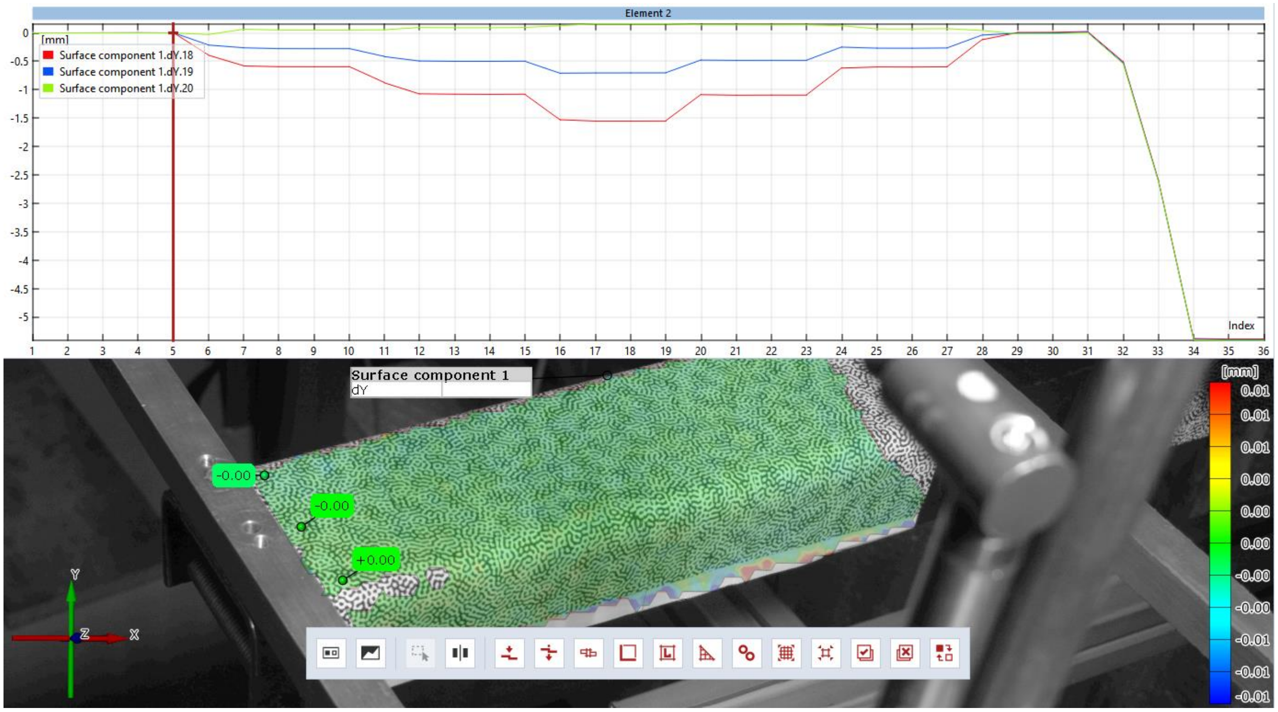

Figure 3: Pre Loading

As shown in Figure 3, the transverse displacement before the addition of any weight was zero. Next, a weight of 5 lb was added to the hanging plate and the displacement data was recorded as shown in Figure 4. From beam theory, we would expect to have zero displacement at the center of the beam cross section with values going from positive maximum at the end farthest away from the load and negative maximum at the end nearest to the load in a linear fashion. However, the DIC results for this loading step showed a negative displacement at the center of the beam. The same trend was observed in the next loading steps shown in Figures 5 to 8.

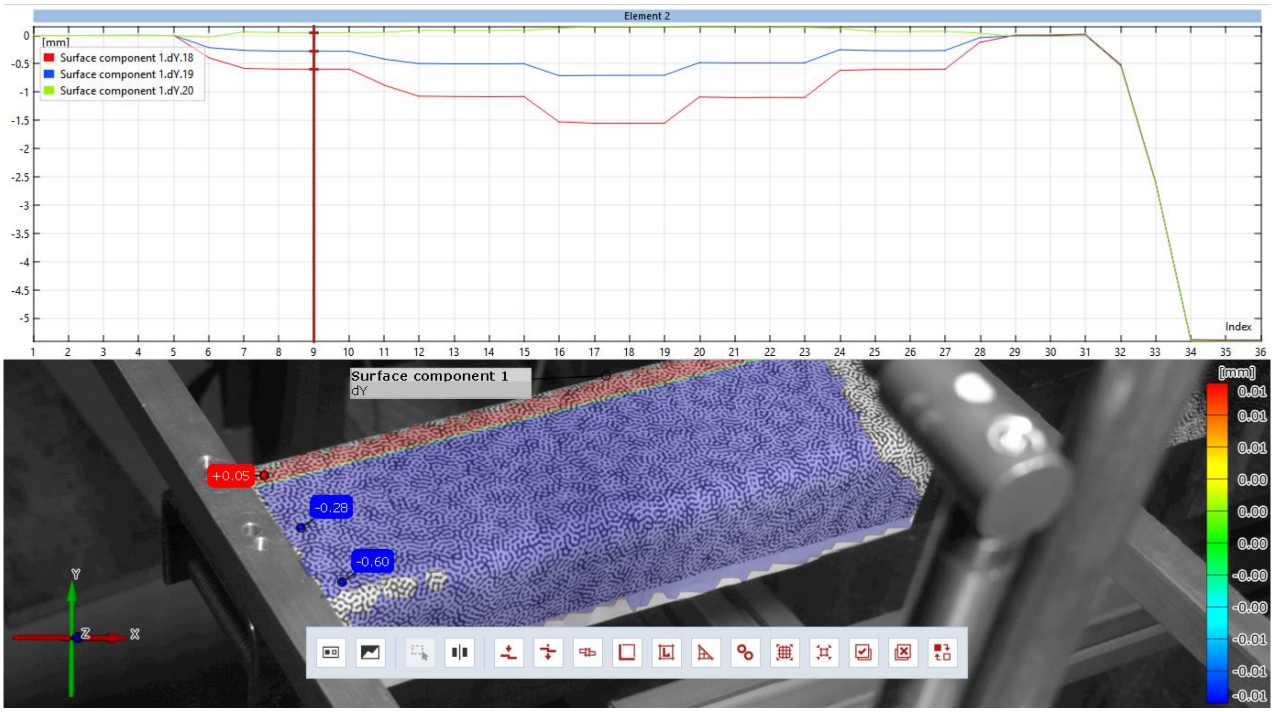

Figure 4: Loading step 1, weight added: 5 lb.

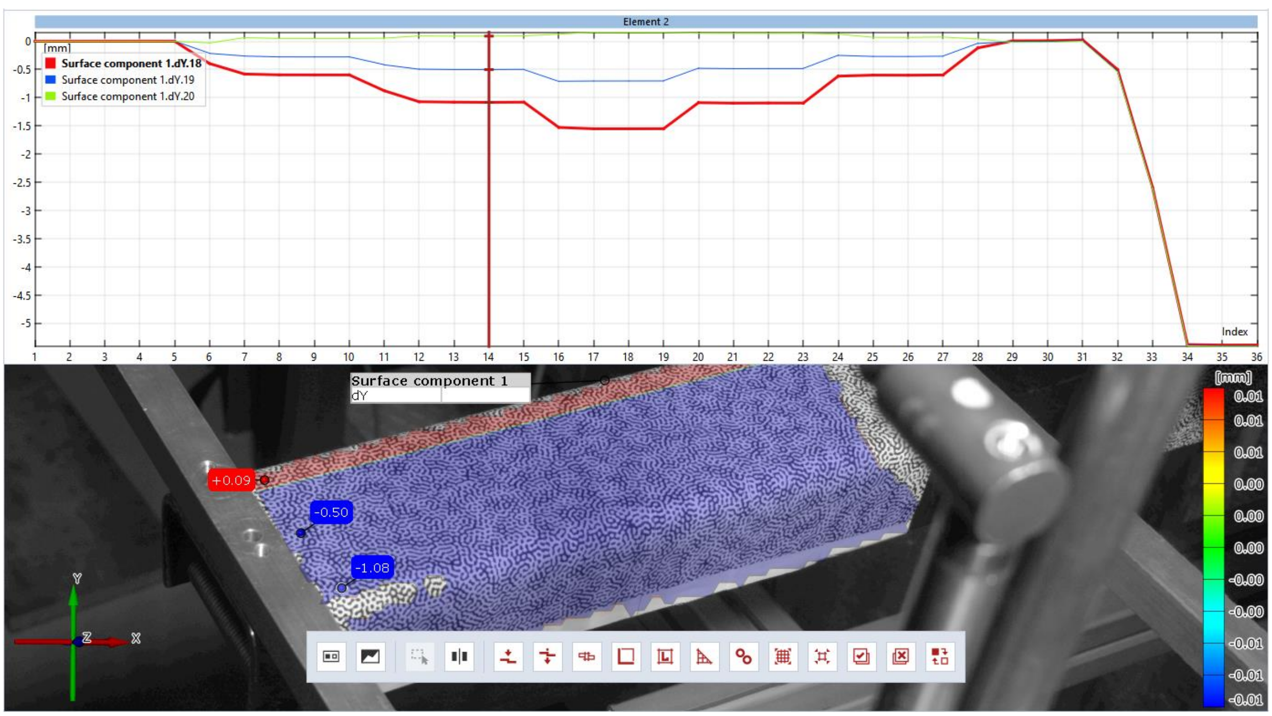

Figure 5: Loading step 2, weight added: 1.824 kg.

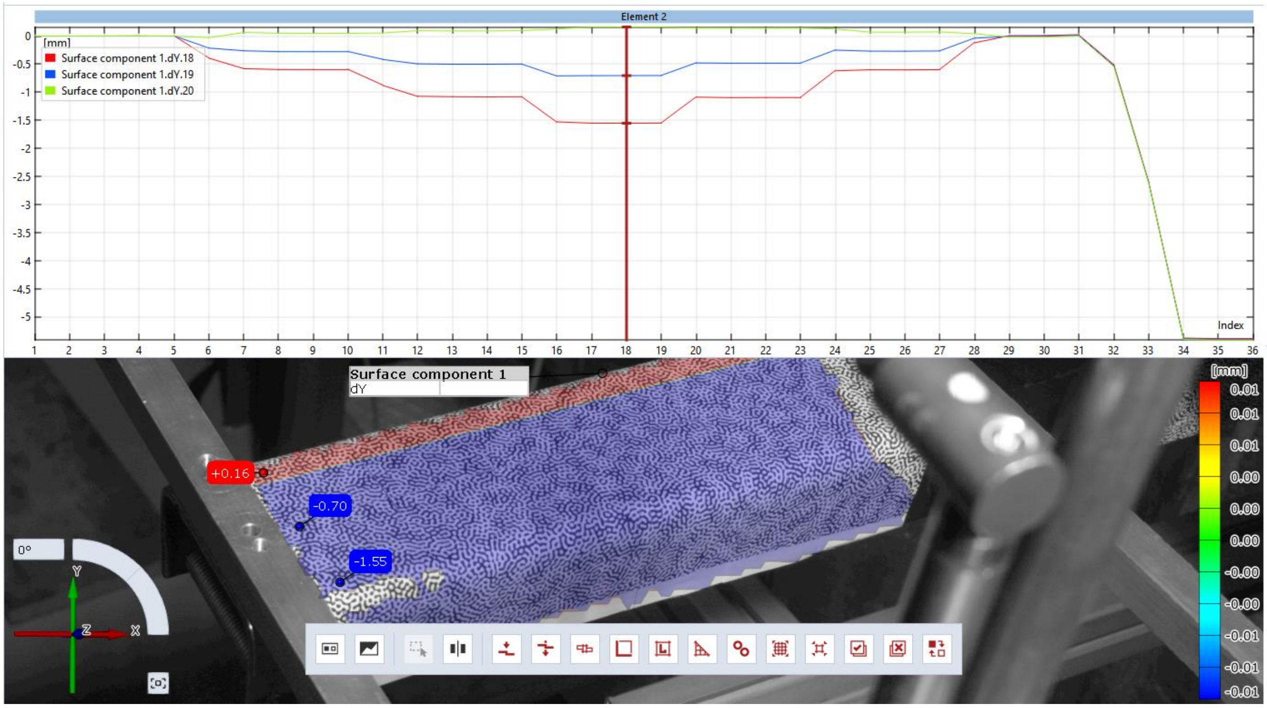

Figure 6: Loading step 3, weight added 1.828 kg.

Next, the displacement data was recorded for unloading these weights from the hanging plate. The results can be seen in Figure 7 to Figure 9. Figures 7 and 8 showed similar trends as explained for the loading steps, with decreasing magnitudes of displacements as expected. However, it can be seen from Figure 9 that the displacement profile underwent a sudden change upon the unloading of the final weight. The part of the beam nearest to the load moved slightly upwards, while the other end moved downwards, which is not consistent with the expected results from beam theory, according to which the displacements should return to zero completely after the removal of the load.

After the unloading step, the data showed a sudden increase in the displacement. The reasons for this have not been clear, however, it can be seen in Figure 10 to Figure 13, that the entire beam appeared to have moved downwards and this data was not considered for the analysis.

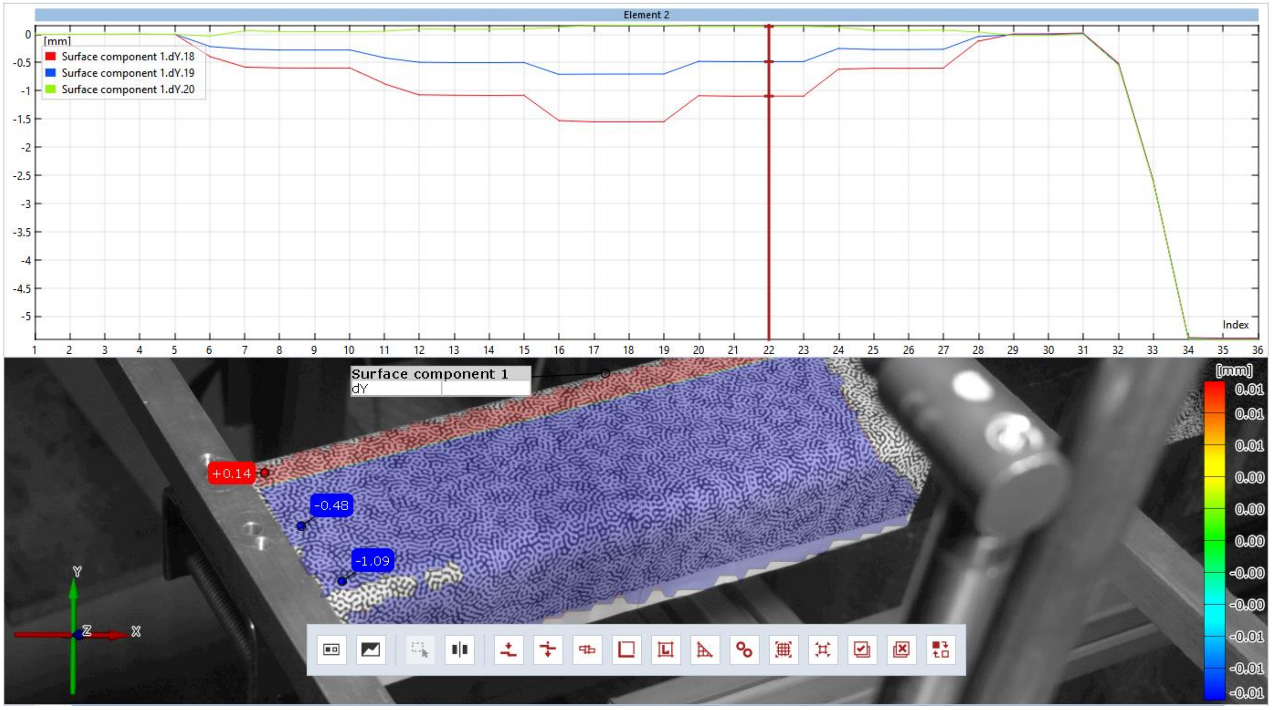

Figure 7: Unloading step 1, weight removed: 1.828 kg

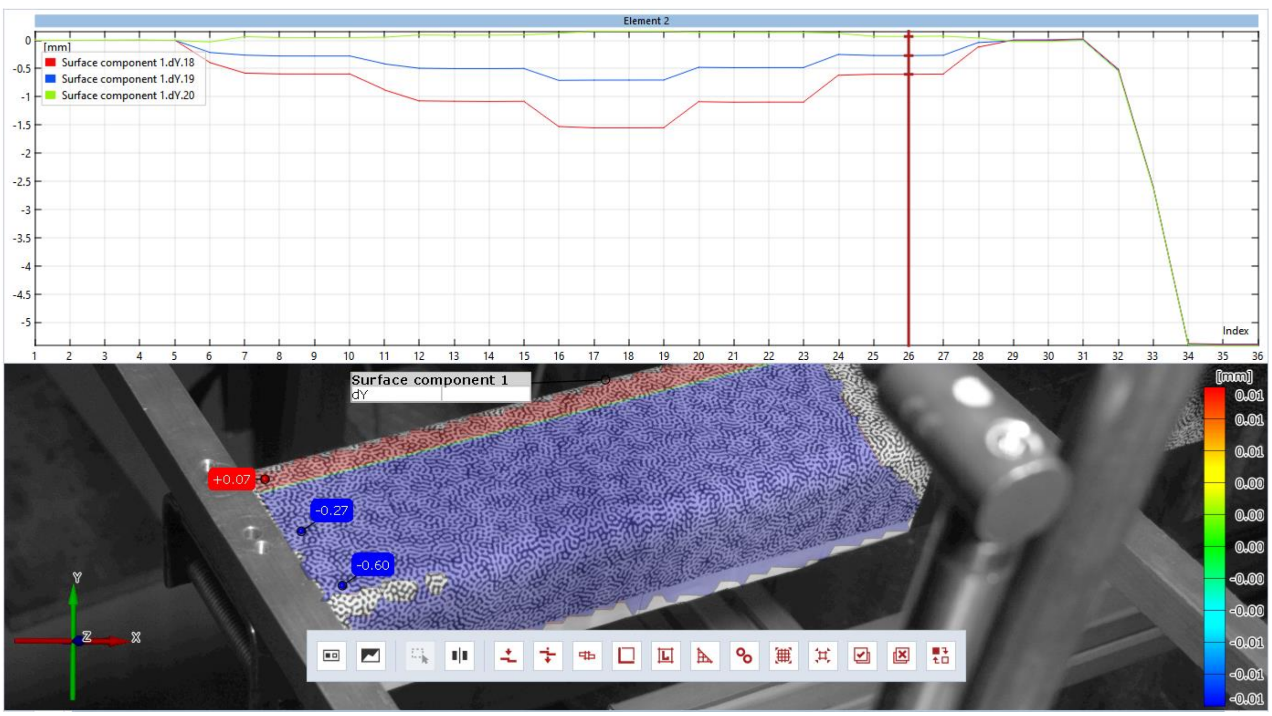

Figure 8: Unloading step 2, weight removed 1.824 kg

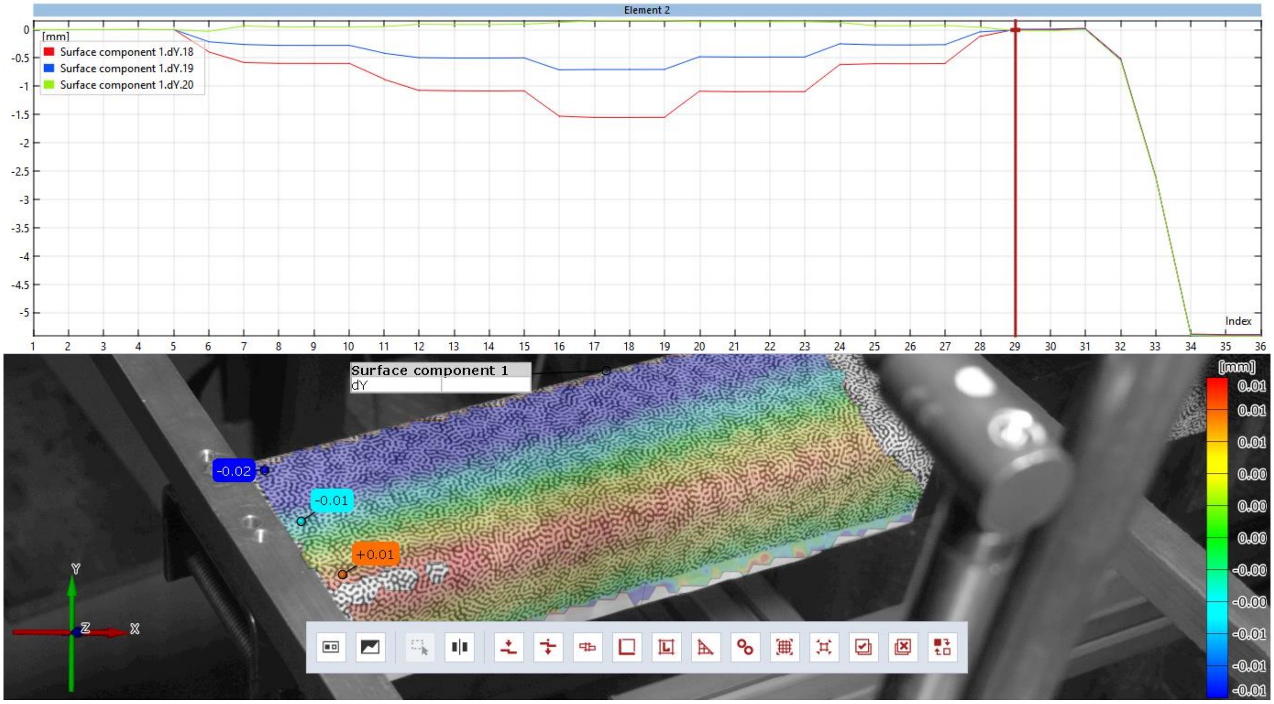

Figure 9: Unloading step 3, weight removed 2.27 kg (5 lb)

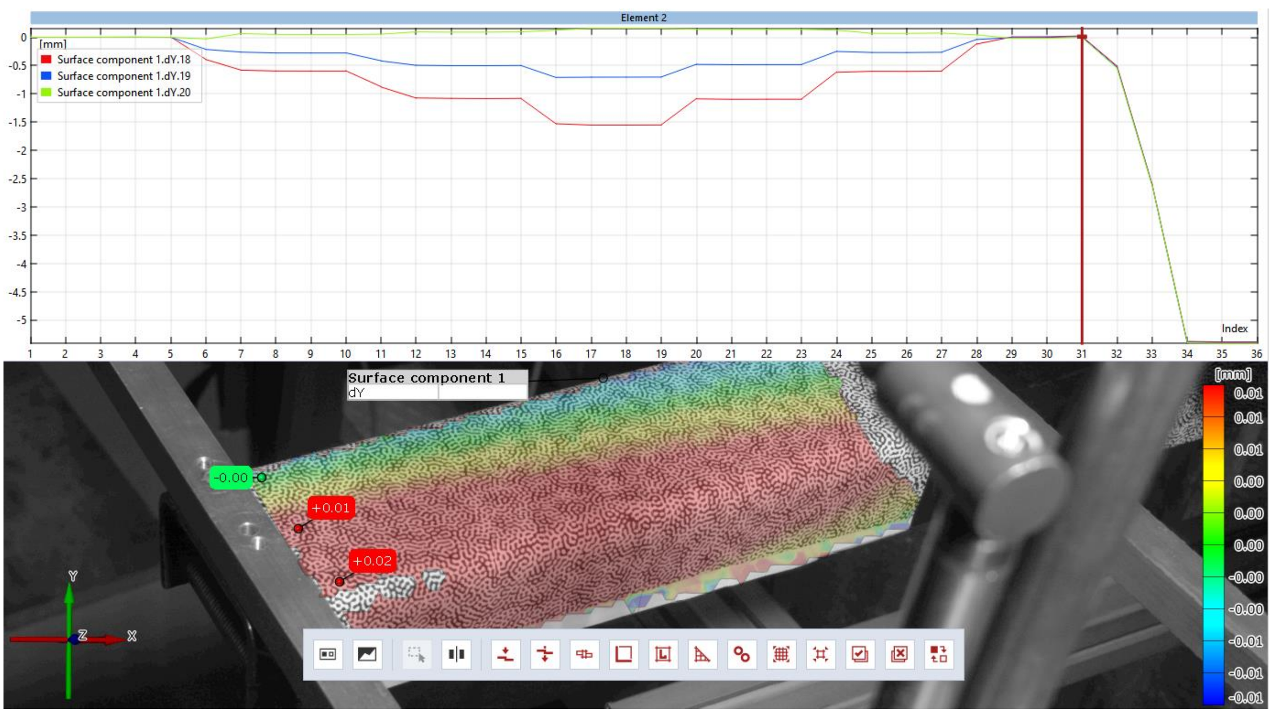

Figure 10: Post unloading

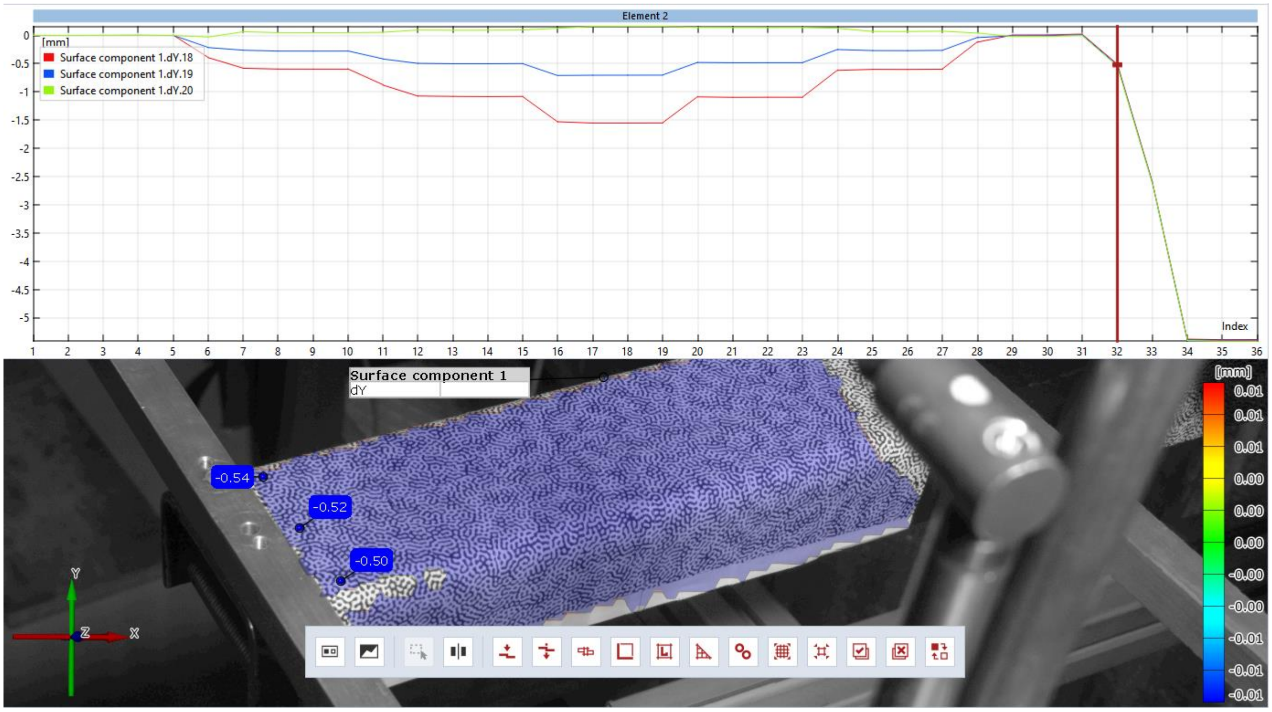

Figure 11: Post unloading

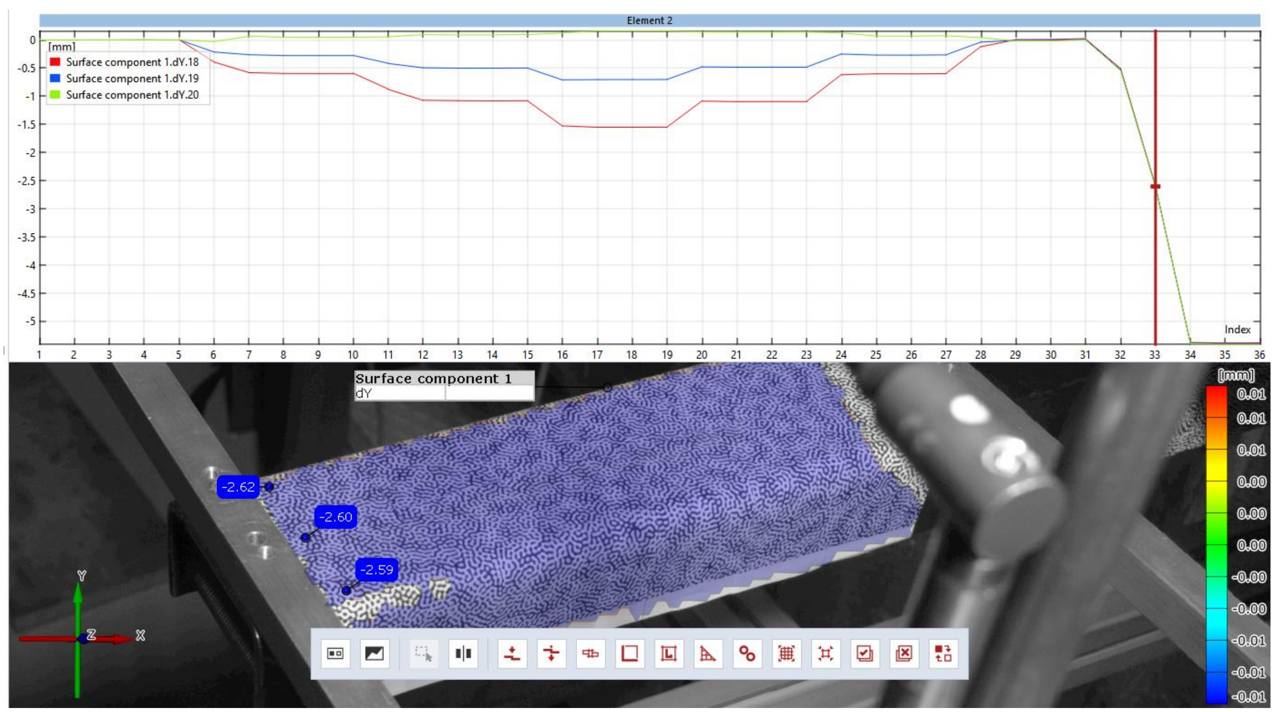

Figure 12: Post unloading

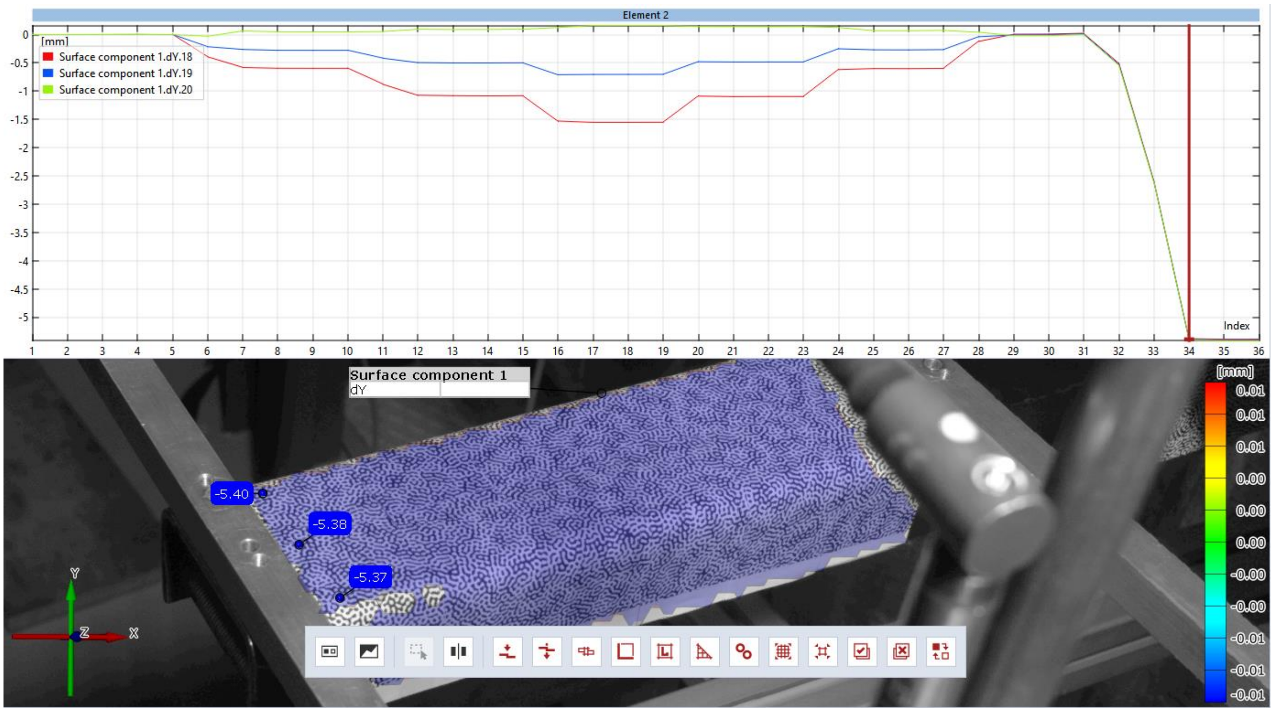

Figure 13: Post Unloading

CONCLUSION AND COMPARISON RESULTS-BEAM THEORY

For comparison with beam theory we utilize the formulae for angular deflection of a channel shaped beam which is given by:

$$\theta = \frac{TL}{G\sum(K1 + K2 + \alpha D^4)}$$

where K_1 and K_2 are given as :

$$K1 = ab^3\left[\frac{1}{3} - \frac{0.21b}{a}\left(a - \frac{b^4}{12a^4}\right)\right]$$

and K_2 is given as:

$$K2 = cd^3\left[\frac{1}{3} - \frac{0.105d}{c}\left(a - \frac{d^4}{192c^4}\right)\right]$$

Here a,b,c,d are the dimensions of the L shaped sections of the beam. As we can see, the beam theory overestimates the values as compared to the experimental results.

However, this difference can be attributed to the unknown values of critical dimensions such as the length of the moment arm and the material of the beam. For the analysis we assume the beam to be made of steel with elastic modulus of 210 GPa and Poisson ratio of 0.30.

Moreover, with the LVDTs, there is a source of error in the estimated values of the twist angle ϕ due to the unknown distance between them. Therefore, there is no reliable data either for the comparison of the measured results from DIC or from DIC itself as there is a possibility that the strains did not transfer effectively from beam to the stick-on pattern's glue.

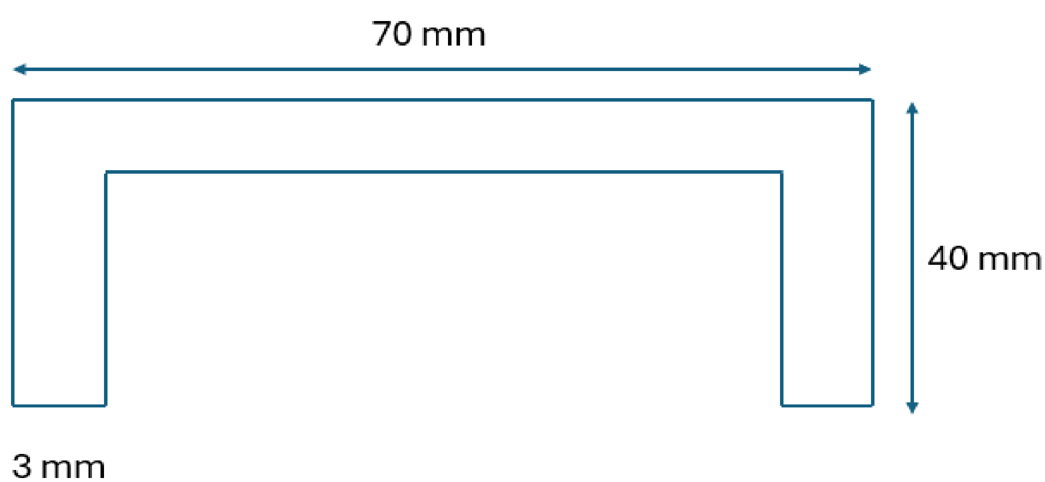

Figure 14: Beam cross section and dimensions, beam length = 100 cm .

Weights	Twist angle LVDT*	Twist Angle DIC	Twist angle Beam Theory*
2.27 kg	0.536°	-	2.51 °
2.27+1.824 = 4.094 kg	0.99°	-	4.54°
2.27+1.824+1.828= 5.922 kg	1.16°	0.0327°	6.33°
2.27+1.824 = 4.094 kg	0.87°	-	4.54°
2.27kg	0.524	-	2.51°

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*Due to missing dimensions of the distance between the LVDTs, the moment arm and the properties of the beam material, these values have been estimated.			

REFERENCES

1. International Digital Image Correlation Society, Jones, E.M.C. and Iadicola, M.A. (Eds.) (2018). A Good Practices Guide for Digital Image Correlation. DOI: 10.32720/idics/gpg.ed1
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