Bridge Maintenance, Safety, Management, Resilience and Sustainability – Biondini & Frangopol (Eds)
© 2012 Taylor & Francis Group, London, *ISBN 978-0-415-62124-3*

Strain measurement of bridge members using Strain Visualization Sticker

S. Umemoto & H. Ohata & N. Miyamoto & T. Okamoto
Keisoku Research Consultant Co Ltd., Hiroshima, Japan

T. Takaki & K. Fujii & I. Ishii
Hiroshima University, Hiroshima, Japan

ABSTRACT: Evaluation of stresses acting on bridge members is extremely important for assessing the safety of bridges. As a simple, economical strain measurement device, the authors propose a Strain Visualization Sticker which displays numerical characters and moiré fringe patterns corresponding to the strain without using conventional electrical elements such as amplifiers, strain gauges, or signal cables. Based on the principle of the Moiré fringe, the device displays a visible enlarged pattern showing the micro-displacement caused by strain, thereby providing strain information in characters which are visible to the naked eye. Precise values of strain can also be obtained from sticker images by image processing, and strain values can be measured remotely using a camera with a telescopic lens. A tensile test of a test specimen and bending test of a bridge member were carried out using the Strain Visualization Sticker. Accurate strain information was obtained non-contact in both tests. In the tensile test, error was less than 10 με, showing accuracy equal to that of the conventional strain gauge method, while error in the bending test was as small as 30 με. The visibility of strain information provided by the Strain Visualization Sticker was also investigated in the bending test, demonstrating that approximate strain information can be read with the unassisted eye. These results demonstrated that the Strain Visualization Sticker can provide an effective tool for evaluations of structural soundness.

1 INTRODUCTION

Rational, cost-effective maintenance and control of aging social infrastructure such as bridges and other structures has now become an important issue, heightening the need for efficient, effective techniques for investigating the soundness of structures. The main type of periodic inspection used in investigations of structural soundness is visual inspection of external appearance. If the stresses acting on structural members due to external forces could be determined at the same time during these routine inspections, this would provide useful information for assessing structural soundness.

Stress measurements of structural members are generally made using electrical sensors such as strain gauges. When electrical sensors are installed at a number of points, it is necessary to supply external power to each measurement point via the signal cable, or alternatively, to provide an internal power supply in the sensors. The measured data from the sensors must also be transmitted by a cable or wireless method. These requirements tend to increase the scale and cost of measurement systems.

In order to solve this problem, the authors propose a "Strain Visualization Sticker" which is capable of displaying characters corresponding to the amount of strain without using conventional electrical elements such as amplifiers, signal cables, and strain gauges.

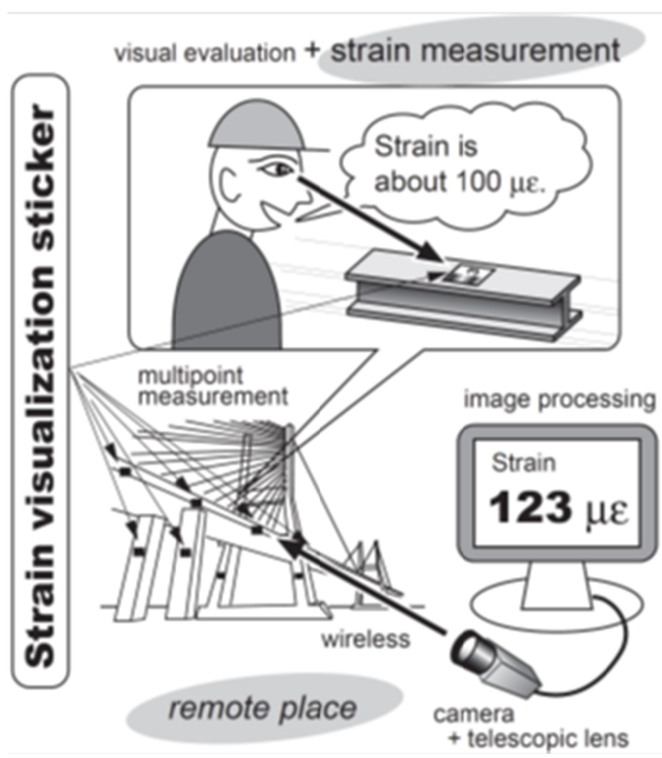


Figure 1. Concept of a proposed strain visualization sticker.

Figure 1 shows the concept of the proposed Strain Visualization Sticker. The sticker is easily attached to bridge members, and approximate strain information can be obtained from characters and patterns that can be read with the naked eye. Precise strain values can also be obtained from the sticker image by image processing, and remote measurement is possible using a camera with a telephoto lens. The Strain Visualization Sticker also has the advantages of a simple structure and low manufacturing cost, and thus is particularly well-suited to multi-point strain measurement.

Verification experiments were performed in order to confirm the performance of the developed Strain Visualization Sticker. This paper presents an outline of the experiments and the verification results.

2 STRAIN VISUALIZATION STICKER

2.1 *Structure of the Strain Visualization Sticker*

Figure 2 shows the structure of the Strain Visualization Sticker. The sticker comprises two film layers. Line gratings are printed on the back side of the top film and the front side of the bottom film. In order to obtain a clear Moiré fringe, the back side of the bottom film is painted white. The interface between the two films is filled with oil to prevent separation of the films. When applied to an object of measurement, the Strain Visualization Sticker displays the micro-displacement x of the object enlarged M times by the Moiré fringe, making it possible to determine the approximate strain ε by simple visual inspection. Assuming the distance between points where Strain Visualization Stickers are attached is the reference length L, strain ε is obtained as $\varepsilon = x/L$.

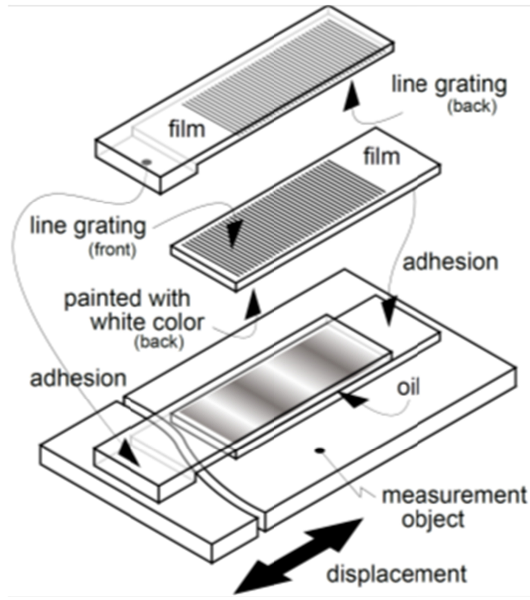


Figure 2. Structure of the strain visualization sticker.

2.2 *Developed Strain Visualization Sticker*

Figure 3 shows the appearance of the developed Strain Visualization Sticker. The dimensions of this device are length: 57 mm, width: 10 mm, and thickness: 0.44 mm. The film material is polyester. The line gratings are printed on the films using a photomask technique. The finest line which can be printed by this technique is 0.01 mm. The left side of the sticker displays a simple Moiré fringe for use in image processing, while the right side shows numerical characters, which make it possible to read the approximate measured strain with the unassisted eye. The magnification M of the Moiré fringe is x121, and its pitch p, △p, and repetition number n are 0.1 mm, 0.01 mm, and 12, respectively. Similarly, the magnification M of the numerical stripe is x501, and its pitch p, △p, and repetition number n are 0.1 mm, 0.01 mm, and 50, respectively.

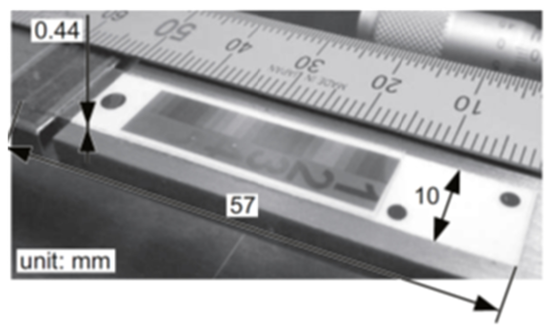


Figure 3. The developed strain visualization sticker.

3 TENSILE TEST

3.1 *Test piece*

The test piece for the tensile test (JIS Z2201 No. 14 test piece) is shown in Figure 4. For comparison purposes, a strain gauge was attached to the center of the test piece. The Strain Visualization Sticker was set on the flat bar so as to be positioned over the slit, and the flat bar was fixed to the test piece with screws so that the position of the slit coincided with that of the strain gauge.

3.2 *Outline of apparatus for tensile test*

As shown in Figure 5, the test piece was set in a compressive/tensile test device (rated capacity: 1000 kN), and a digital video camera for measurement of the Strain Visualization Sticker was set up squarely facing the sticker at a position 86.5 mm from the test piece. The digital video camera was a commercially-available product. The strain gauge was connected to a strain measurement device.

3.3 *Test method*

As the test method, loading and unloading were performed using loading steps of 0 kN, 20 kN, 50 kN, and 80 kN. At each loading step, strain was calculated by image processing from the photographed image of the Moiré fringe, and strain was also measured with the strain gauge using the strain measurement device.

3.4 *Result of tensile test*

The test results are shown in Figure 6. The relationship between tensile loading and strain is linear during both loading and unloading, and hysteresis does not occur. The difference between the measurements by the strain gauge and the Strain Visualization Sticker was <10 με. This result confirmed that non-contact strain measurement is possible with the Strain Visualization Sticker with substantially the same accuracy as with a conventional strain gauge.

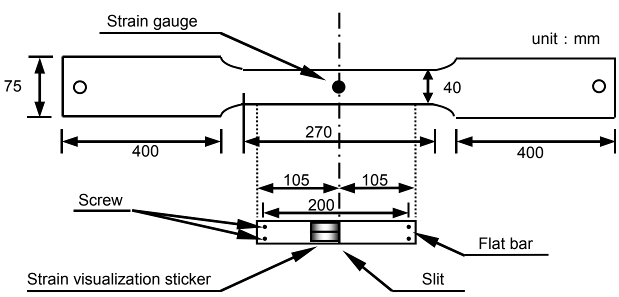


Figure 4. Test piece for tensile test.

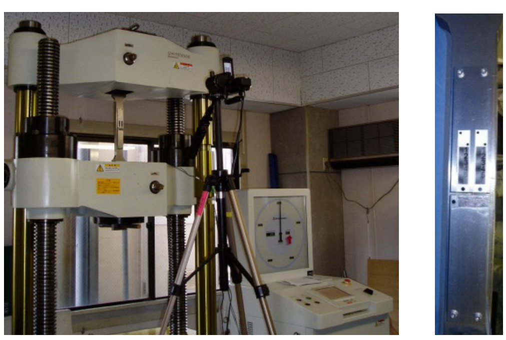


Figure 5. Outline of apparatus for tensile test.

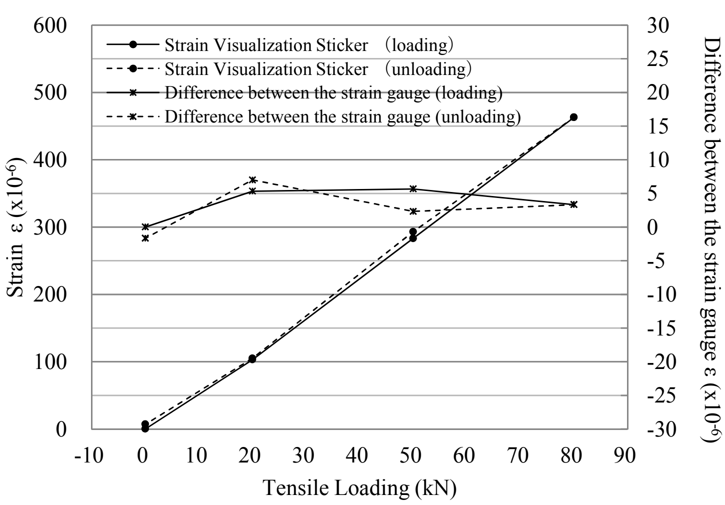


Figure 6. Result of tensile test.

4 BENDING TEST

4.1 *Strain Visualization Sticker*

In the bending test, in addition to the developed Strain Visualization Sticker (Sticker I), a newly conceived prototype sticker (Sticker II) which enables easier visualization of strain was also used. Figure 7 shows the appearances of the two devices. Sticker II has a structure in which the Moiré character gratings arranged in the form of a scale, making it possible to read the amount of change in strain directly from the device. The reference length L of both devices was 50 mm.

4.2 *Outline of apparatus for bending test*

The specimen used here was a steel I-beam having a width of 150 mm, height of 300 mm, and length of 4300 mm. Table 1 shows the sectional specifications of the specimen. Figure 8 shows an outline of the test apparatus. The distance between the supports is 4000 mm. Roller-type bridge bearings were used on both sides. Two-point loading was applied at loading points 500 mm from the specimen center on both sides of the center. A 750 kN jack was used. For measurement of the Strain Visualization Sticker, a digital video camera was set up directly under the center of the specimen approximately 30 cm from the specimen. The camera was positioned so as to squarely face the Strain Visualization Sticker. The two Strain Visualization Stickers (I, II) were arranged on the bottom flange at the center of the specimen, together with two uniaxial strain gauges used for comparison purposes. The sensor arrangement is shown in Figure 9.

Video images of the Strain Visualization Stickers were processed by a real-time image processing device, as shown in Figure 10, and strain was calculated in real time.

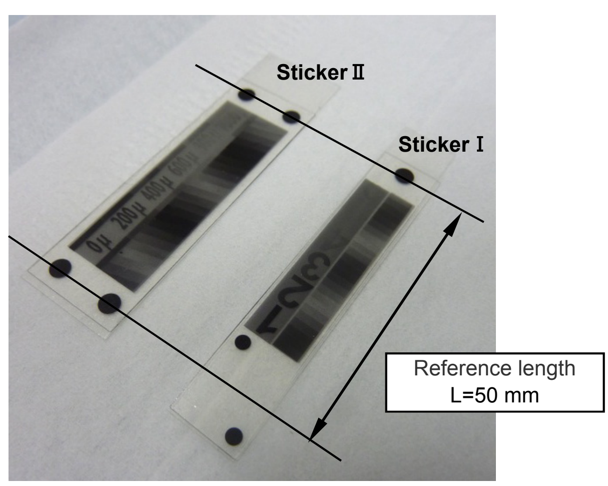
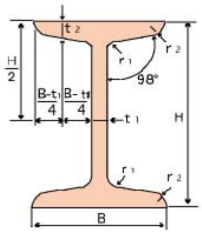


Figure 7. Strain Visualization Sticker for bending test.

Table 1. Sectional specifications.

Standard cross-sectional dimension				Cross-sectional area cm^2	Geometrical moment of inertia cm^4	Section modulus cm^3
H	B	t_1	t_2	A	I	Z
300	150	8	13	61.58	9480	632



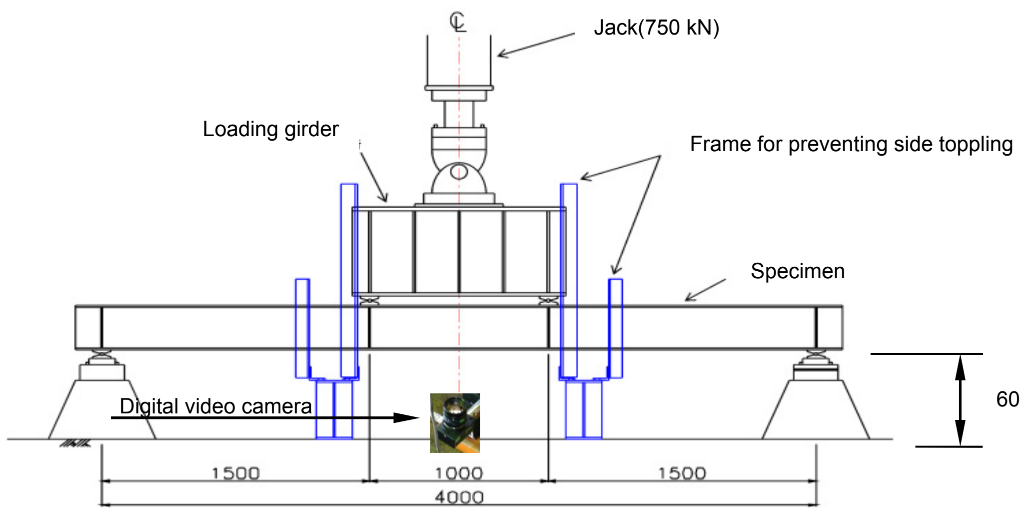


Figure 8. Outline of apparatus for bending test.

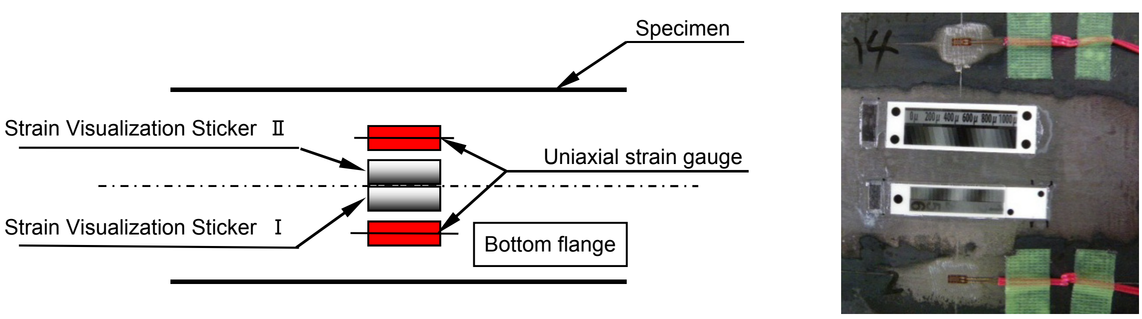


Figure 9. Sensor arrangement.

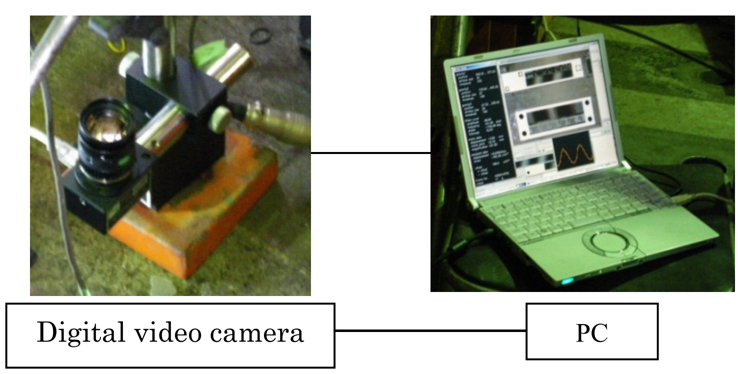


Figure 10. Real-time image processing device.

4.3 *Test method*

In this test, repeated loading was performed twice using the loading steps shown in Table 2. In each step, the strain values obtained from the Strain Visualization Stickers and strain gauge were recorded, and images of the Strain Visualization Stickers were recorded.

4.4 *Results of bending test*

4.4.1 *Comparison with strain gauge*

The relationship between loading and the strain obtained with the Strain Visualization Sticker is shown in Figure 11. The difference between the values obtained with the strain gauge and the Strain Visualization Sticker is also shown. The values of strain gauge are used average values. The relationship between loading and strain shows linearity during both loading and unloading. However, some hysteresis occurred. The difference between the strain gauge and the Strain Visualization Sticker was 30 με in the first test and 32 με in the second test.

4.4.2 *Nonlinearity*

Next, nonlinearity was calculated, assuming rated output (ε_{RO}) represents maximum generated strain and $\triangle\varepsilon_L$ is the maximum difference between the actual measured values and the strain obtained from a straight line joining 0 and the maximum generated strain. The average value of nonlinearity was 1.5% (RO = 845 με). Table 3 shows the calculated results.

4.4.3 *Visibility*

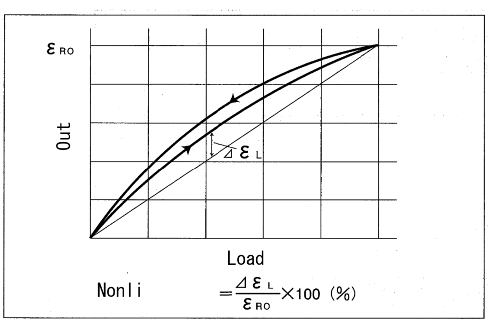
Figure 12 shows images of the Strain Visualization Stickers at steps of 200 με. Table 4 and Table 5 show the relationship between the generated strain and Moiré fringe (character grating) for Sticker I and Sticker II, respectively. With Sticker I, an increase of one number for roughly each 200 με step could be confirmed. With Sticker II, the scale increments (characters) disappear at roughly each 200 με step. The scale changes from 1000μ to 200μ, corresponding to increases in generated strain from 0με to 800 με, and thus provides a visualization of generated strains up to 800 με.

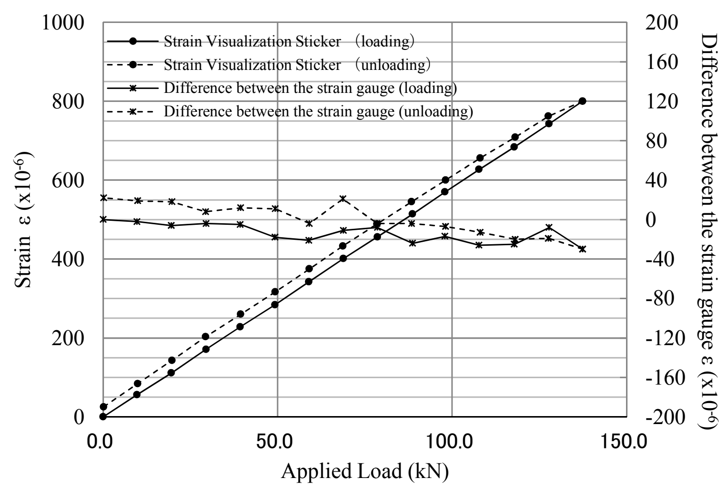
Table 2. Loading step.

Step	Load (kN)	Step	Load (kN)
1	0	9	80
2	10	10	90
3	20	11	100
4	30	12	110
5	40	13	120
6	50	14	130
7	60	15	140
8	70	16	150

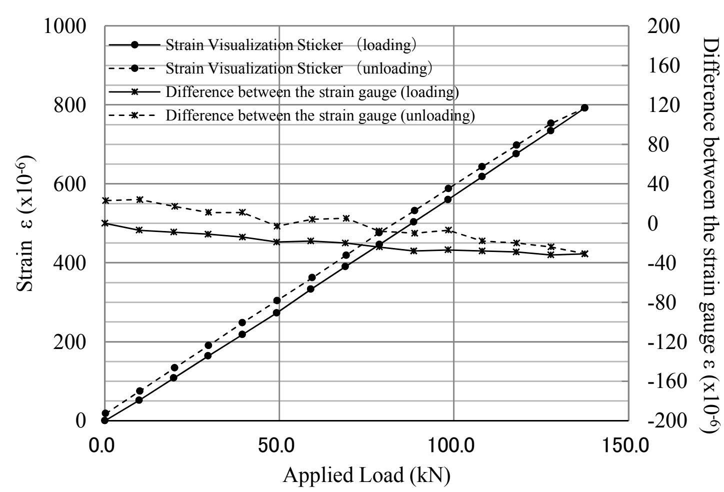
Table 3. Nonlinearity.

	ε_{RO}	$\triangle\varepsilon_L$	Nonlinearity
First test	842 με	13 με	1.5 %
Second test	847 με	13 με	1.5 %
Average	845 με	13 με	1.5 %





(a) First test



(b) Second test

Figure 11. Results of bending test.

0 με

200 με

400 με

600 με

800 με

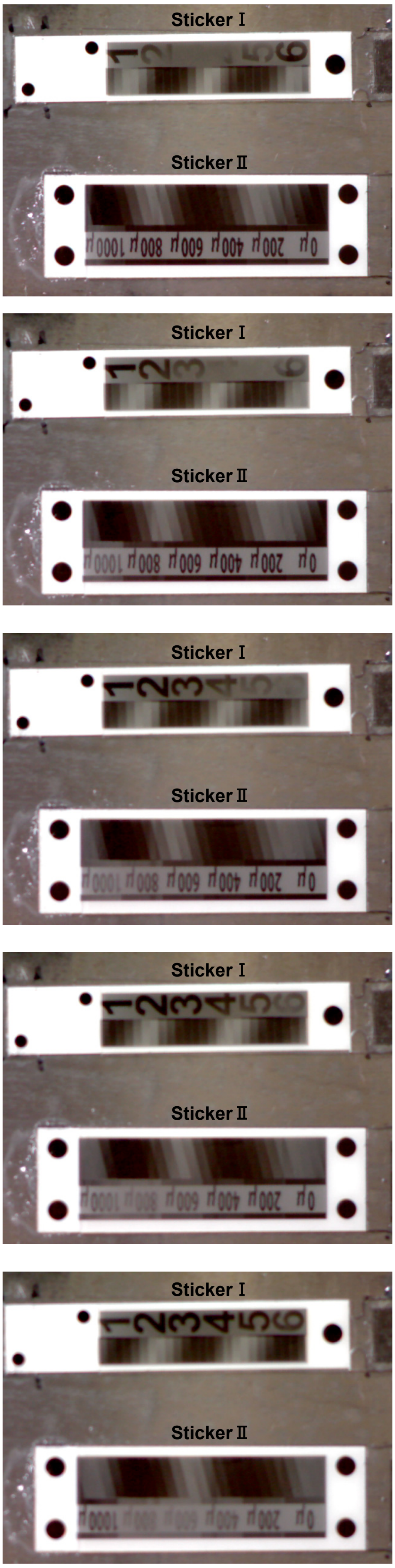


Figure 12. Change in character display with increasing strain.

Table 4. Change in character display with Sticker I.

Strain	Moiré character gratings					
0 με	1	2			5	6
200 με	1	2	3			6
400 με	1	2	3	4		
600 με	1	2	3	4	5	
800 με	1	2	3	4	5	6

Table 5. Change in character display with Sticker II.

Strain	Moiré character gratings					
0 με	1000μ	800μ	600μ	400μ	200μ	0μ
200 με	1000μ	800μ	600μ	400μ	200μ	0μ
400 με	1000μ	800μ	600μ	400μ	200μ	0μ
600 με	1000μ	800μ	600μ	400μ	200μ	0μ
800 με	1000μ	800μ	600μ	400μ	200μ	0μ

5 CONCLUSION

A “Strain Visualization Sticker” was proposed as a simple, inexpensive strain measurement device for bridges and other infrastructure. This device is based on the principle of the moiré fringe and displays numerical characters and moiré fringe patterns corresponding to the amount of strain. No electrical elements (amplifier, strain gauges, signal cables) are used. Tests to verify device performance confirmed that approximate strain information suitable for use in routine visual inspections can be visualized with the Strain Visualization Sticker. Precise strain values with substantially the same accuracy as with the conventional strain gauge can also be obtained by image processing of sticker images acquired by non-contact means. These results verified that the Strain Visualization Sticker can provide an effective tool for evaluations of structural soundness. In the future, the authors plan to improve the strain measurement accuracy and visibility of the Strain Visualization Sticker.

6 REFERENCES

Takaki, T. Omasa, Y. & Ishii, I. 2008. *Force Visualization Mechanism using moiré Fringe for Robot Grippers*, Proceedings of the 28th Annual Conference of the Robotics Society of Japan, 1K3-07, 2008. (in Japanese)

Takaki, T. Omasa, Y. Ishii, I. Kawahara, T. & Okajima, M. 2010. *Force Visualization Mechanism Using a moiré Fringe Applied to Endoscopic Surgical Instruments*, Proceedings of the 2010 IEEE International Conference on Robotics and Automation, pp. 3648-3653, 2010.