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DETECTION OF STRUCTURAL DAMAGE IN BEAM STRUCTURES BY CHANGES IN STRAINS

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ABSTRACT: In this paper the problem of using strain influence lines to detect and locate structural damages in beam structures is investigated. Imperfections in a structure are related to changes in the static response of the structure. Static methods are used as they are more precise than modal testing, and therefore more attractive than the dynamic methods. Furthermore, strain influence line can be obtained from measurements at only one point in the structure as well as deflection influence line. Using strain influence line instead deflection influence line has some advantages: (i) there is no need to derive measured function (the approximation errors are avoid), (ii) the deflection influence lines method gives values at a point while the strain energy method gives values within a segment. The difference in strain influence lines for damaged and intact beam has been used to locate the damage. The aim of this work is to find out a minimal number and the optimal location of the measurement points in the beam structure that can enable locating the damages reliably.

KEY WORDS: damage detection, strain influence lines

1. INTRODUCTION

The parameter identification of structures has become very important as researchers attempt to correlate changes in the test data to those in the structural properties. Using this approach, deterioration in cross-sectional properties of a number of important structures (such as aircraft, space stations, nuclear power plants, oil rigs, buildings and bridges) can be detected. The parameters identified can be used for the damage assessment of various structures in order to improve their reliability and performance. Imperfections in a structure are related to changes in the static and dynamic response of the structure. Static methods are used as they are more precise than the modal testing, and therefore more attractive than the dynamic methods. [3,5]

2. DESCRIPTION OF DAMAGE DETECTION METHOD

The strain influence line can be obtained from measurements or can be calculated, for which it is sufficient to take only one point in the structure.

Suppose we have two sets of the strain influence lines describing two states of a beam structure; the first state is intact and the second state is damaged. Damage is considered as a reduction in the bending stiffness.

$\varepsilon_{xx}(x)$ is the displacement influence line for the intact state,

$\varepsilon_{xx}^{*}(x)$ is the displacement influence line for the damaged state.

We assume that the system is geometrically and materially linear. Then, the strain can be written as

$$\varepsilon_{xx} = \frac{M}{EI} \cdot z\,, \qquad (1)$$

where *M* is bending moment, *EI* is bending stiffness and z is distance from the neutral axis to the measurement point (for example: the strain gauge).
If we assume that there is no change in the value of *z* for the two states of the structure then the changes in the strain influence line for statically determined systems can be caused by the changes in flexural stiffness (flexural stiffness has no influence on the flexural moments):

$$\frac{\varepsilon_{xx}}{\varepsilon_{xx}^{*}} = \frac{\frac{M}{EI}\cdot z}{\frac{M}{EI^{*}}\cdot z} = \frac{EI^{*}}{EI}\,. \qquad (2)$$

Comparison of the two sets of the strain influence lines gives the information about changes in the bend ing stiffness.
If the two sets are identical, there are no changes of bending stiffness in the structure.
A difference in the strain influence lines points to the changes in bending stiffness of the structure. The percentage of bending stiffness degradation can be derived using equation (*2*):

$$\Delta = \left(1 - \frac{\varepsilon_{xx}}{\varepsilon_{xx}^{*}}\right)\cdot 100 = \left(1 - \frac{EI^{*}}{EI}\right)\cdot 100 \quad [\%] \qquad (3)$$

3. DAMAGE DETECTION FOR A SIMPL Y SUPPORTED BEAM USING STRAIN INFLUENCE LINES

The analysis has been carried out for a simply supported beam with two damaged sections (Figure 1). The span length is *L=25 m*. The beam is numerically devided into *n=100* finite elements. The applied force is *F=100 kN*. The cross section area of the beam is $A=0,8567\ m^2$, second moment of area is $I=1,4\cdot 10^{-1}\ m^4$ and Young's modulus is $E=3,5\cdot 10^{7}\ kN/m^2$. The dam age has been simulated by reducing the bending stiffness of the finite elements as shown in figure 1.

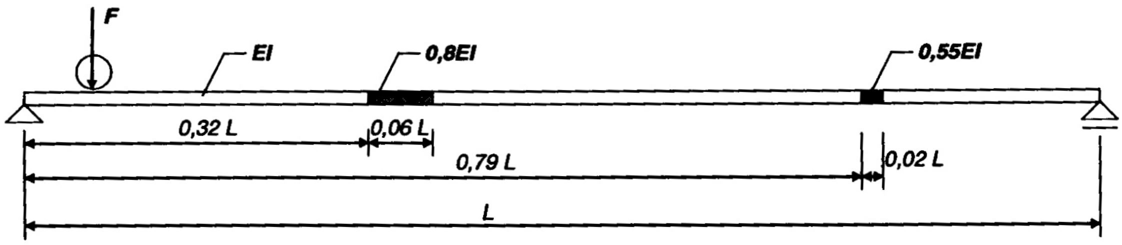

Fig. 1. Damaged model

The strain influence line is calculated for a mesh of *49* load positions (points) for both the intact and the damaged case. The load step (the length between two load positions) is *0,5 m*. The measurement point is in the middle of the span. Comparison of these two sets of values as well as stiffness degradation for each of these points is shown in figure *2*.
Give that the strain influence line is a discrete function, the bending stiffness change can be determined only at a point level.
From these resu lts we can see that the undamaged points are from *0-0.30L*, from *0.40L-0.78L* and from *0.82L-L*. As it can be seen from figure *2*, the damages are found at *0.32L, 0.34L, 0.36L*, *0.38L* and *0.8L*.

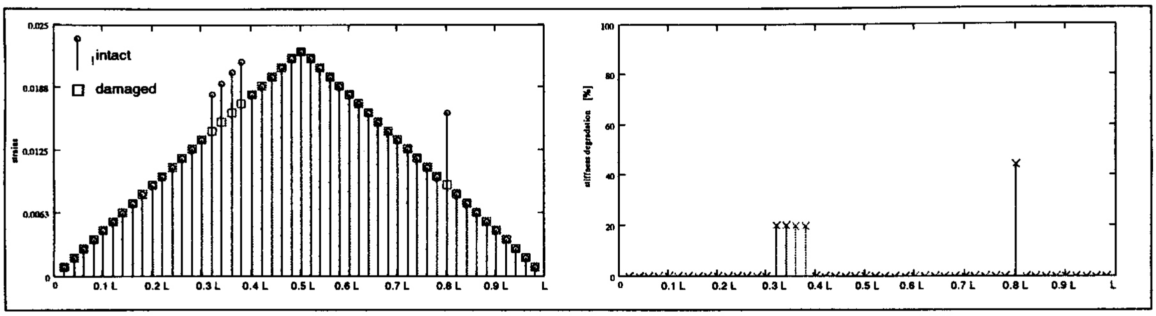

Fig. 2. Left: comparison of strain influence lines for intact and damaged case; right: stiffness degradation; (49 load points)

The stiffness degradation can be read from the right-hand diagram in figure 2 and is given in table 1:

Table 1. Calculated bending stiffness degradation

Point	*0.32L*	*0.34L*	*0.36L*	*0.38L*	*0.8L*
Bending stiffness dearadation	*20%*	19,9%	19,8%	19,7%	44,44 %

Although the bend ing stiffness degradation is determined pointwise, from figure 2 and table 1 we can conclude that damage is spread from *0.32L-0.38L*. The average bending stiffness degradation in this segment is *19,85%*. The length and the value of degradation are similar to prescribed damage. In the case of the second damage, the value of degradation is similar to prescribed bending stiffness degradation value, but there is no possibility to determine the length of the damaged section.

The second analysis has been done for a mesh with a double width. The load step is *1,0 m*. As can be seen from figure 3, both damages are detected. Although the wider mesh has an influence on segment length assessment (roughly from *0.32L-0.36L*) , the damage degradation assessment is accurate.

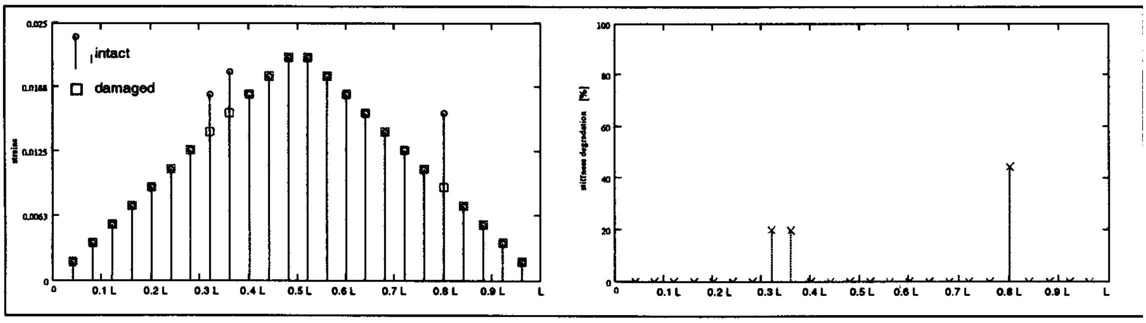

Fig. 3. Left: comparison of strain influence lines for intact and damaged case; right: stiffness degradation; (24 load points)

The third and fourth analysis have been done for even wider meshes (the load steps are 1,5 m and 2,5m). As can be seen from figures 4 and 5, damage can be detect jf a value of strain influence line is inside the damaged segment. Otherwise this method can neither detect nor locate the damage.

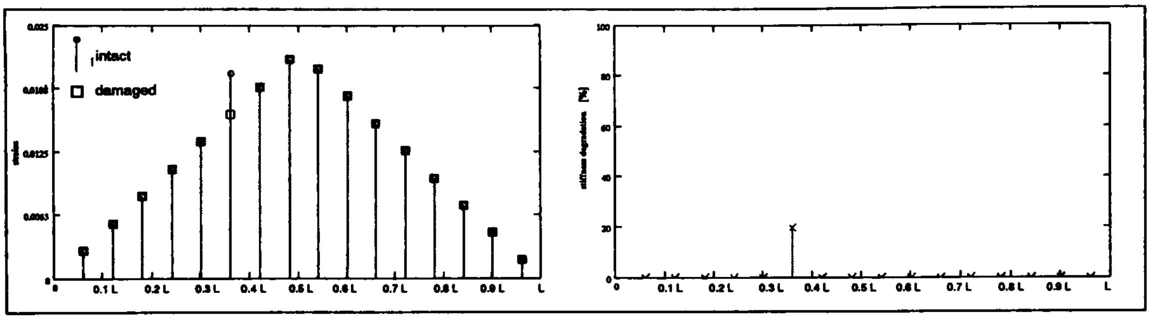

Fig. 4. Left: comparison of strain influence lines for intact and damaged case; right: stiffness degradation; (16 load points)

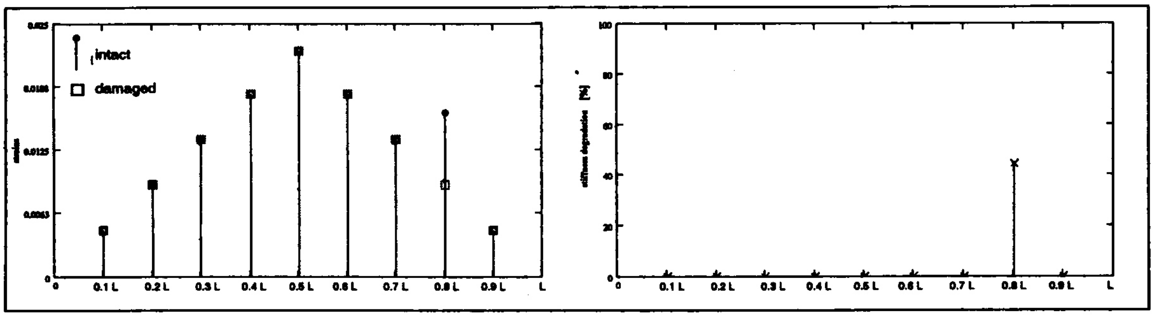

Fig. 5. Left: comparison of strain influence lines for intact and damaged case; right: stiffness degradation; (9 load points)

4. CONCLUSION

The strain influence line can be obtained from measurements or can be calculated, for which it is sufficient to take only one point in the structure. Minimal accuracy of measuring instrument which is needed is 1 %. Those two facts ensure simple on-site testing.

No need to differentiate the function provides a simple mathematical procedure for the location and evaluation of damages.

Because the procedure gives information about changes in bending stiffness at a point level the damage can be detected only if a value of strain influence line is inside the damaged segment. In other cases this method can neither detect nor locate the damage. It leads to conclusion that the damages shorter then the load step can remain undetected. Accuracy of the method can be increased by increasing the load point mesh.

5. REFERENCES

[1] KALAMKAROV, A, SAHA, G., ROKKAM, S., NEWHOOK, J., and GEORGIADES, A: Composites *Part B: Engineering,* Volume 36, Issue 5, Pages 455-467,2005: Strain and Deformation Monitoring in Infrastructure using Embedded Smart FRP Reinforcements

[2] MAASKANT, R., ALAVIE, T., MEASURES, R. M., TADROS, G., RIZKALLA S. H. and GUHA-THAKURTA, A: Cement and Concrete Composites, Volume 19, Issue 1, Pages 21-33,1997: Fiber-optic Bragg Grating Sensors for Bridge Monitoring

[3] OH, B. H., JUNG, B. S.: Journal of Structural Engineering, Vol 124, No 8, pp. 956-965, 1998: Structural Damage Assessment with Combined Data of Static and Modal Tests

[4] ŠTIMAC, I.: Disertacija, 2006, Split, Croatia: Damage Detection using Deflection Influence Lines (Croatian)

[5] YAM, L. H., LI, Y. Y., WONG, W. O.: Engineering Structures, Vol. 24, pp. 1465-1475, 2002.: Sensitivity Studies of Parameters for Damage Detection of Plate-Like Structures using Static and Dynamic Approach