ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 8, NO. 5 (2007)
PAGES 563-572

ALGORITHMS FOR DETECTING HONEYCOMBS IN RC BEAMS

Z. Ismail* , D. Samugavelu and H. Abd Razak
Department of Civil Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ABSTRACT

While cracks and corrosion can be detected visually, honeycomb damage cannot be detected by observation with the naked eye. In this study methods of detecting and locating honeycomb damage using three operator algorithms were compared. Honeycomb blocks were prepared and placed at predetermined locations along reinforced concrete beams with 1200×75×125mm size. Honeycombs were located in the beam near one of the supports, in between mid span and support, at mid span, at symmetrical locations and randomly. A total of five damaged beams were prepared for the studies; with one beam prepared for the purpose of control. Modal testing method was used to detect the honeycombs. The test was done using a shaker to excite input to the beam. Eigenvalue data from the modal testing was used to detect the presence of honeycombs in the reinforced concrete beams. Eigenvector data from modal testing were used for detecting honeycomb locations. Eigenvector values were post-processed for detecting these locations. The best results were obtained using the Geometric Mean Operator.

Keywords: Honeycomb, RC beam, modal analysis, laplacian, simplified laplacian, geometric mean

1. INTRODUCTION

There are many types of damage that will cause a structure to fail or lose its optimum strength and may result in disastrous failures. This damage may be caused by cracking, surface deterioration, surface deposits, deformation, construction defects or construction features. Honeycombing is categorized under construction defect which occurs in concrete that is not correctly consolidated due to poor vibrations or poor design of formwork. This will segregate the course aggregates and fine aggregates with cement hence voids will occur. There are a few common in-situ testing techniques used to detect honeycombs in concrete such as hammer testing, shaker testing, ultrasonic pulse velocity testing and endoscope survey.

* Email-address of the corresponding author: zu_ismail@um.edu.my (Z. Ismail)

1.1 Detection Methods

Localized damage in a structure will reduce the stiffness and increase the damping in the structure. The damage will change the structures' dynamic properties. The changes are characterized by changes in eigenparameters (e.g., natural frequency, damping values and mode shapes) as described by Hammond [1], He [2], and e Silva [3]. The use of modal testing and analysis for damage detection and repair has been described by several workers like Avitable [4], Friswell and Penny [5], Holland [6], Hu et al. [7] and Nuno et al. [8]. Specific studies on crack damage have been done by workers like Cacciola et al. [9], Hjelmstad and Shin [10], Ismail [11] and Kim and Stubbs [12]. A localised change to EI will cause a localised change in the slope of the mode shape. The change in slope indicates the damage area and the bigger the change in slope the bigger the damage.

Yong and Hong [13] were among those who used frequency changes to identify damage in a structure. They stated that changes of the vibration data when processed could determine the location and magnitude of the damage. Ratcliffe [14] used a modified Laplacian Operator on mode shape data for detecting general damage in a beam. By using finite difference Laplacian function damage of about 10% could be located. Meanwhile for lower percentage of damage a modified Laplacian Operator was used.

Razak et al. [15] successfully showed that crack detection in a reinforced concrete beam could be done using a Simplified Laplacian Operator. They compared the use of Laplacian Operator and a Simplified Laplacian Operator and showed that the Simplified Laplacian Operator was a better algorithm to detect the damage. The higher frequency modes located the damage more clearly compared to the lower frequency modes.

Pandey et al. [16], Ismail and Razak [17], and Ismail et al. [18] used curvature mode shape for damage detection. While frequency changes alone were able to identify the presence of damage, they could not easily locate the damage. It was shown, however, that changes in curvature mode shape in the region of damage could be used to determine the damage location. It was also found that the bigger the damage in the structure the bigger the changes in curvature mode shape.

2. METHODOLOGY

Post-processing using an operator is one of the methods used to determine changes in mode shape slope. The common operator used is the Laplacian Operator, Simplified Laplacian Operator and Geometric Mean Operator.

2.1 Laplacian Operator (LO)

The Laplacian difference equation is commonly used to estimate the second difference of a discrete function, but it is applied to problems involving two dimensions. A beam can be analyzed as a one dimensional structure and for this case the one dimensional Laplacian of discrete mode shape is given by:

$$(LO)_i = (y_{i+1} + y_{i-1}) - 2y_i \tag{1}$$

2.2 Simplified Laplacian Operator (SLO)
The Simplified Laplacian is a modification of the Laplacian formula as shown in Eq. 1. The Simplified Laplacian Operator is given by;

$$(SLO)_i = y_{i+1} - y_i \tag{2}$$

2.3 Geometric Mean Operator (GMO)
Geometric mean operator was used in honeycomb location detection successfully as shown by Khezel [19], and Razak et al. [20]. The Geometric Mean Operator is given by:

$$(GMO)_i = ((y_i^2 - (y_{i-1} * y_{i+1}))^2 \tag{3}$$

3. EXPERIMENTAL PROCEDURE

3.1 Characteristics of Material
The dimensions of each of the beam were 1200x75x125mm. The beam was designed to a strength of 40 Mpa (grade 40). One sample was used as the control beam where there was no damage created during or after casting and testing was done. The other five beams were designed as damaged beams. Damage was created by locating honeycomb blocks in the beams. The size of honeycomb used was 100x50x75mm. Two reinforcement bars of 6mm diameter were placed in the beams.

3.2 Sample Preparation
The main material used in the concrete was cement, coarse aggregate, fine aggregate and water as guided by Teychenne [21]. Super plasticizer R100 was used as admixture in concrete. Since Ordinary Portland Cement (OPC) was the most common type of cement used in industry, OPC was used. Aggregate used was crushed granite rock. Coarse aggregate particles ranged from ½ inch to 6 inch. Fine aggregate particles ranged in size down to the No.100 sieve with from two to ten percent passing through this sieve and normally it is categorized as sand. The water used for mixing the concrete was restricted to water that was suitable for drinking purpose. Super plasticizer was used to increase the strength. Table 1 shows the proportions used for concrete.

Table 1. Mix proportions for concrete per m^3

Material	Measurement
Ordinary Portland Cement	480 kg
Coarse Aggregate	850 kg
Fine Aggregate	695.5 kg
Water Ratio (0.5)	212.4 kg

Super Plasticizer R1000	5L/100kg cement

The honeycombs were cast using 100x100x100 mould where plywood was used to spread the mould in half. Table 2 shows the material proportion for the honeycombs.

Table 2. Mix proportions for honeycomb per m^3

Material	**Measurement**
Ordinary Portland Cement	300 kg
Coarse Aggregate	1200 kg
Water Ratio	150 kg

3.3 Support of structure

Basically free supports and simple supports were used in this test for each beam sample. In most of the past research on structural modal testing free-free supports were used, but in this study roller supports were used as simply supported condition.

3.4 Modal Testing Setup

The general equipment used was a shaker, amplifier, signal source, a dual channel dynamic signal analyzer, a stationary reference force transducer, response transducer, blower and a microcomputer.

An electromagnetic shaker was used as the excitation input in the modal testing. In this test an electromagnetic shaker with power amplifier and signal source was used. This electromagnetic shaker was attached with an air blower every time it was used so that the shaker did not get heated up. The force was generated using alternating current that drove a magnetic coil. The test was done using single input function. This was very important to make sure the force was transmitted in line with the main axis of the load cell. A stringer was used to connect the load cell to the shaker for an axial force transmission. A piezoelectric transducer was used in the test. A signal generator was used for signal conditioning process. Conditioning operations was chosen according to the transducer type as well as on the recording and transmission system.

The beams were marked for testing. A total of fifty-two measurement points were marked on the beams. Figure 1 shows the location of honeycombs in the beams. The excitation was done at below surface at the centre of point 11 and point 37.

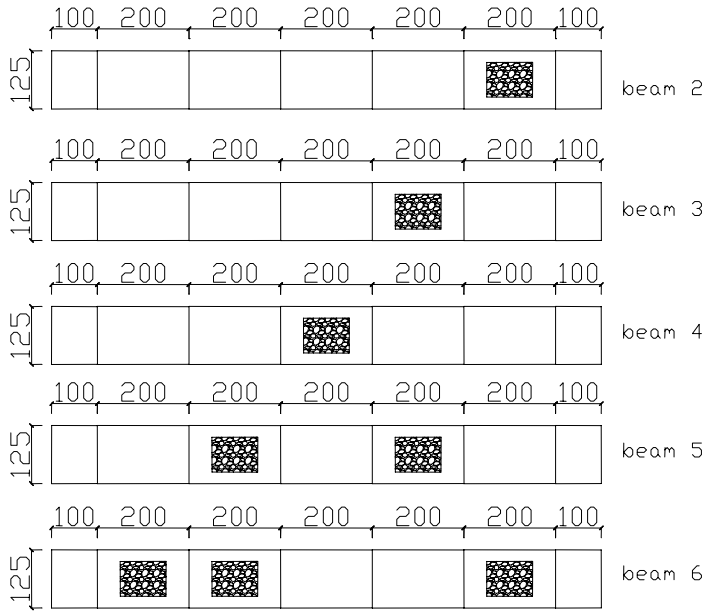

Figure 1. Location of honeycombs

3.5 Modal Analysis Setup

Modal analysis was done using the software Star and I-Cats. The data in FRF format from modal testing were used for modal analysis. Star software was used to transfer the raw data from modal testing to a global format that could be used in I-Cats software. I-Cats was then used to get the eigenvector (mode shape value) and eigenvalue (frequency). Eigenvalue was then used to present damage in the beam and mode shape value was post-processed to determine the location of damage.

4. RESULTS AND DISCUSSION

4.1 Frequency

Frequency was used to determine presence of damage in the beams. Frequency results for the control beam were compared with those of damaged beams. Table 3 and Table 4 show the frequencies obtained from modal analysis for the two cases of supports.

From Table 3, when honeycomb was located near the support (beam 2) the frequency decreased in 2nd, 3rd and 4th modes. The 1st mode showed a higher frequency compared to the control beam, but the percentage was only 0.07%. The maximum decrease was 1.10% for the 2nd mode.

Table 3. Natural frequency of beam on roller support

Beam/Mode	Beam1	Beam2	Beam3	Beam4	Beam5	Beam6
Mode1	359.5	359.8	360.8	359.0	366.5	362.4
Mode2	921.6	911.4	907.4	920.6	917.6	924.7
Mode3	1669.	1662.7	1652.7	1667.5	1669.8	1668.5
Mode4	2553.	2537.7	2520.7	2538.5	2541.3	2553.1

With the honeycomb between points 16 and 20 the presence of the honeycomb could be detected using 2nd, 3rd, and 4th modes. For 1st mode the increment was 0.38% compared to control. A maximum decrease of 1.53% was shown for 2nd mode. Beam 2 and beam 3 showed that the 2nd mode had most decrease in natural frequency. Honeycomb location for beam 4 was in the centre of the beam. The honeycomb location for beam 5 was similar to beam 3 but in beam 5 the honeycombs were on both sides.. The 2nd and 4th modes showed decreases compared to control. The 1st and 3rd modes showed increments. For beam 6 only the 3rd mode showed a decrease in frequency, while the others showed increases. Table 4 shows natural frequency of beams on free support. For beam 2, 1st, 2nd and 4th modes showed decreases compared to the control beam. Frequencies for all modes for beam 3 showed decreases. For beam 4 in the case of the 3rd mode there was no decrease and the 4th mode could not be detected.

Table 4. Natural frequency of beam on free support

Beam/Mode	Beam1	Beam2	Beam3	Beam4	Beam5	Beam6
Mode1	352.0	345.9	346.9	349.9	351.9	352.5
Mode2	921.8	909.5	901.1	916.4	912.0	920.2
Mode3	1654.8	1660.0	1642.2	1663.7	1658.9	1664.8
Mode4	2555.1	2534.5	2516.2	N/A	2567.1	2543.2

For beam 5 the 1st and 2nd modes showed decreases. The highest decrease was for the 2nd mode. For beam 6 the decrease was seen only for the 2nd and 4th modes.

4.2 Mode Shape

Figure 2 is plotted using eigenvector data for Beam 2 from modal analysis for roller support

for Mode 1. Similar plots were done for other beams, and for the case of free support, and for the other modes. All the plots showed that Beam 2, Beam 3, Beam 4, and Beam 5 had defects.

4.3 Laplacian Operator

From the derived data calculated using Laplacian Operator, graphs were plotted to determine the location of the honeycomb. The honeycomb in beam 2 was located between point 21 and 26.

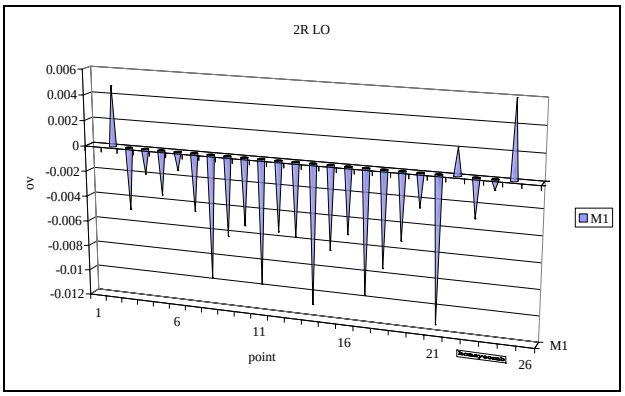

Figure 2. Laplacian operator Beam2 on roller support

Figure 3 could not detect the exact location of the honeycomb. Using Laplacian Operator, the 2nd mode for beam 2 on roller support did not show the location of the honeycomb.

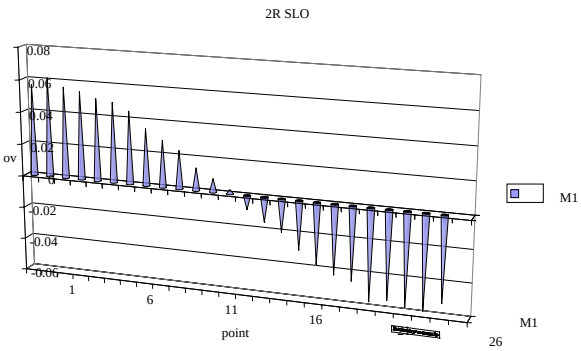

Figure 3. Simplified Laplacian operator Beam2 roller support

Comparing the results for the beam that was on roller support and those for free support showed that the results were almost the same. The results for the beam on free support were more sensitive and it was easier to determine the honeycomb location. Using Laplacian Operator produced poor results when the honeycomb was located symmetrical as found on

beam 5. Only one of the honeycomb locations could be detected for some of the modes.

4.4 Simplified Laplacian Operator

Using Simplified Laplacian Operator to detect the location of honeycombs for all the beams and for both types of supports was unsuccessful for all cases. Figure 3 shows a typical example showing the results using the Simplified Laplacian Operator.

4.5 Geometric Mean Operator

The Geometric Mean Operator ensures that the difference of y_m values is always positive. Figure 4 is a typical plot and shows that the honeycomb location near the support could be detected. The location of honeycomb in mid span could also be detected clearly. The honeycomb location could be detected for the 1st mode of roller support and free support even when the honeycomb was located near the support. When honeycomb was located in between point 16 and 21, 2nd mode on roller support showed a clear honeycomb location and 3rd mode when it was freely supported. When the honeycomb was located in mid span, high slopes were noticed for the first three modes. It was seen that the Geometric Mean Operator performed better in locating the honeycombs. The problem, however, was that it is very sensitive to noise.

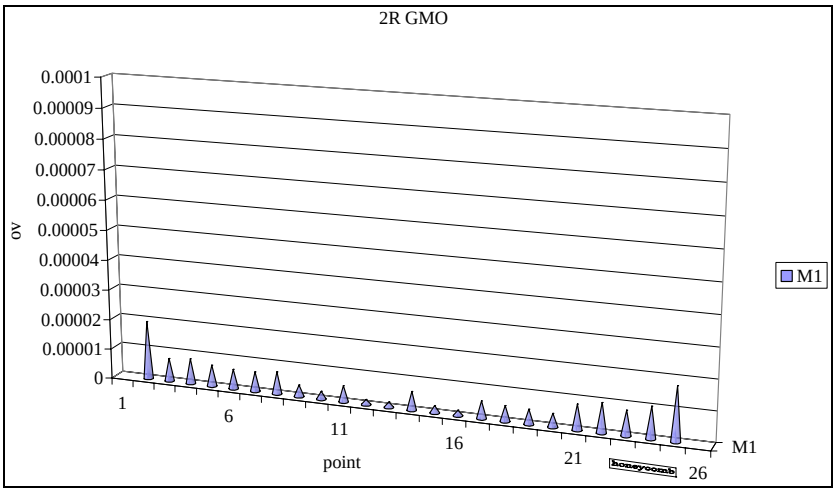

Figure 4. Geometric mean operator Beam2 roller support

5. CONCLUSIONS

Results obtained using natural frequencies were satisfactory. Although there was an indication of damage, the exact locations of the honeycombs, however, could not be confirmed. Mode shape could be used to determine the presence of honeycomb damage in a beam. Post processing was required to locate the honeycombs. The algorithms used to determine the honeycomb locations were the Laplacian Operator, Simplified Laplacian Operator and Geometric Mean Operator. The use of the Simplified Laplacian Operator was

not successful in determining the location of honeycombs. There was not much difference on the mode shape results for beams supported by rollers and those supported freely. However, the slopes for the freely supported beams were more sensitive. Using the Laplacian Operator and Geometric Mean Operator gave better results; and between the two approaches, the Geometric Mean Operator showed better detection. The size of honeycombs used in this study was the same for all the beams. For future work, different size of honeycombs could be used.

REFERENCES

1. Hammond, J.K., Fundamentals of Signal Processing, E Silva, J.M.M. and Nuno, M.M.M. ed, *NATO-Advanced Study Institute on Modal Analysis and Testing, Instituto Technico*, 1998, pp. 449-466.
2. He, J., Damage Detection and Evalution I, E Silva, J.M.M. and Nuno, M.M.M. ed, *NATO-Advanced Study Institute on Modal Analysis and Testing, Instituto Technico,* (1998) 325-344.
3. E Silva, J.M.M.: An overview of the fundamentals of Modal Analysis, e Silva, J.M.M. and Nuno, M.M.M. ed, *NATO-Advanced Study Institute on Modal Analysis and Testing, Instituto Technico*, 1998, pp. 1-34.
4. Avitabile, P. Experimental Modal Analysis, A Simple Non-Mathematical Presentation. Rev. 052700, *University of Massachusetts Lowell, Lowell, Massachusetts, USA*, 2001.
5. Friswell, M.I. and Penny, J.E.T. Is damage location using vibration measurements practical? *EUROMECH 365, Proc. Int. Workshop, DAMAS 97*, (1997).
6. Holland, R. Appraisal and Repair of Reinforced Concrete. *1st ed., Thomas Telford Ltd, London*, 1997.
7. Hu, N., Wang, X., Fukunaga, H., Yao, Z.H., Zhang, H.X. and Wu, Z.S. Damage assessment of using modal test data, *International Journal of Solids and Structures*, **38**(2001) 3111-3126.
8. Nuno, M.M.M., e Silva, J.M.M., Almas, E.A.M. and Sampaio:R.P.C. Damage detection in structures: from mode shape to frequency function methods, *Journal of Sound and Vibration*, No. 3, **17**(2003) 489-498.
9. Cacciola, P., Impollonia, N. and Muscolino, G. Crack detection and location in a damaged beam vibrating under white noise, *Computers and Structures*, **81**(2003) 1773-1782.
10. Hjelmstad, K.D. and Shin, S. Crack identification in a cantilever beam from modal response, *Journal of Sound and Vibration*, No. 5, **198**(1996) 527-545.
11. Ismail, Z. Damage detection in RC beams using Modal Analysis, PhD Thesis, University of Malaya, Dept. of Civil Engineering, Kuala Lumpur, Malaysia, 2005.
12. Kim, J.T. and Stubbs, N. Crack detection in beam-type structure using frequency data, *Journal of Sound and Vibration*, No. 1, **295**(2003) 145-160.
13. Yong, X. and Hong, H. Statistical damage identification of structure with frequency changes, *Journal of Sound and Vibration*, **263**(2002) 853-870
14. Ratcliffe, C.P. Damage detection using a modified Laplacian operator on modal shape

data, *Journal of Sound and Vibration*, No. 3, **204**(1997) 505-517.

15. Razak, H.A., Ismail, Z., Teng, S.L., and Rahman, A.G.A., Crack detection in a simply supported RC beam using simplified Laplacian, *Proc. 19th Int. Modal Analysis Conf.*, 2001, 1344-1350.
16. Pandey, A.K., Biswas, M., and Samman, M.M., Damage detection from changes in curvature mode shapes, *Journal of Sound and Vibration*, No. 2, **145**(1990) 321-332.
17. Ismail, Z., and Razak, H.A., Flexural stiffness of honeycombed beams using mode shape derivative, *Proc. 6th Int. Congress on Advances in Civ. Eng.. Istanbul*, 2004.
18. Ismail, Z., Razak, H.A., Rahman A.G.A., Flexural stiffness determination of cracked reinforced beam using mode shape derivative, *Proc. Int. Conf. on Concrete Engineering and Technology, Kuala Lumpur, Malaysia*, 2004.
19. Khezel, I.S., The effect of honeycomb on modal response of reinforced concrete beams, *Master Thesis, University of Malaya, Dept. of Civil Engineering, Kuala Lumpur, Malaysia*, 2002.
20. Razak, H.A., Ismail, Z., and Khazel, I.S., Effect of honeycombing on modal response of RC beams, *Proc. Malaysian Sci. and Tech. Congress, Melaka, Malaysia*, 2001, pp. 140-148.
21. Teychenne, D.C., Franklin, R.E., and Erntroy, H.C., Design of normal concrete mixes, Department of Environment., Her Majesty's Stationery Office, London, 1985.