Research Article

Sealant Delamination Detection of Structural Sealant Glazing Systems Based on Driving-Point Accelerance

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The structural sealant glazing system is widely used in glass curtain wall worldwide. However, due to the aging of the sealants, cracking may form along the sides of the glass. If the panel of curtain wall arises, delamination may occur and induce failure or loss of the system. In order to detect the delamination of the sealant, in this paper, a new vibration-based damage identification method is proposed by using the difference between the predamage and postdamage driving-point accelerance (DA). This detection method would require only one acceleration sensor on a glass panel and a rubber hammer, which operates very conveniently. When the rubber hammer taps the glass panel near the acceleration sensor, the glass curtain wall panel would generate acceleration response which can be measured by the acceleration sensor. The measured acceleration responses will be used to calculate the DA and lead to a new delamination index, called relative accumulative difference of DA, which will give indications on the potential delamination of the sealant. In addition, the influence of the acceleration sensor installation position was analysed by the finite element method, and the optimal sensor location was determined to be at the intersection of the long-side quarter and the short-side quarter. Nine cases on various delamination severities were identified by the new method, as well as the natural frequency reduction and modal assurance criterion. The laboratory experiments showed that the relative accumulative difference of DA is extremely sensitive to sealant delamination. Even if delamination severity was only 6.39%, the relative accumulative difference of DA would be larger than 18%. As the delamination of the sealant progresses, the relative accumulative difference of DA increases, resulting in an effective detection method for sealant delamination of the structural sealant glazing system. The fundamental frequency reduction is suitable to identify relatively large delamination, and the modal assurance criterion of higher modes is also sensitive to sealant delamination.

1. Introduction

The structural sealant glazing system (SSGS) is widely used in the high-rise buildings and commercial structures since it provides a beautiful appearance for the building. However, due to the aging and fatigue in the service life, the structural sealant may delaminate and fall off resulting in damages in the supporting system of SSGS [1]. To avoid the detachment of the glass curtain wall panel, it is of great importance to detect the sealant delamination and repair it timely [2–5].

To detect the sealant delamination, there are two types of methods available, including static-based and vibration-based method. The static-based detection method is used relatively earlier, which includes appearance visual inspection, knock detection, cutting and drawing method, shore hardness method, suction lifter, air bag, and pulse echo ultrasonic testing [6–10]. The visual and knock methods are simple but can only be used as the preliminary testing of the delamination of structural sealant, whose accuracy depends on the experiences of the inspectors [11]. Cutting and drawing method is to bring the cut part of the sample back to

the laboratory for testing. This method would induce damage to the structure which is a destructive testing method. Shore hardness method detects the degree of hardening of structural sealant, which needs to be combined with other methods together to identify damages [12]. Air bag method needs the displacement measuring equipment to detect. Suction lifter method belongs to outdoor detection, which is usually used to detect the adhesion of the glass curtain wall just for double glazing [13]. Recently, Hong et al. [14–16] used the thermal wave and ultrasonic wave to detect structural sealant damage directly and visually. Static-based detection method usually requires location where workers can reach, and the testing labor is huge.

For the vibration-based method, which was firstly developed in bridge engineering, delamination is detected by measuring the changes in dynamic characteristics or dynamic response of the system, such as natural frequency, mode shapes, mode shape curvature, waveform chain code, and signature assurance criteria [17–24]. Memari et al. [25] developed kinematic-based models to predict earthquake-induced failure of the SSGS. Puga et al. [26] studied the glass failure mechanisms of glass panels with different thicknesses, as well as assessed their probability of failure by estimating fragility curves. Carolina et al. [27] analysed the cyclic response of a glass curtain wall for seismic performance assessment. Xu et al. [28] used the dynamic response parameters and dynamic characteristics parameters as the input of artificial neural network to identify debonding situation, which can be used as the damage monitoring of several important unit of SSGS. Liu et al. [29, 30] detected natural frequency reduction of the glass curtain wall and related that to the weakening of the boundary conditions. Miao et al. [31] provided a relationship between the ratio of the main peak frequency of the fast Fourier transform to the total power of the signal and damage length of the SSGS. Fang and Luo [32] identified the damage of perimeter sealant by the change in mode shape curvature.

Although delamination of the structural sealant can be identified using the change of predamage and postdamage dynamic characteristics, there are dozens of taps in experimental modal analysis which spend long time to get mode shapes of only one unit of SSGS. For a glass curtain wall building, it usually contains hundreds of independent units, and different parts of the glass curtain wall have different degrees of aging and delamination. It is a tedious work to detect the safety of glass curtain wall. Detecting the delamination fast is a challenge in practical detection. Recently, Huang et al. [33–35] validated in experiments that the change of the fundamental natural frequency can be used to detect damage of the structural sealant and proposed the first peak of acceleration Fourier spectrum as the approximate fundamental frequency to significantly reduce the test time. It is well known that fundamental frequency reflects the overall characters of structures, and it is suitable to identify relatively large delamination; however, local small damage is not easy to be identified [36].

In this paper, a new vibration-based method is developed to identify the delamination of sealants of the SSGS quickly during manual inspection process, even if in the case of small

delamination. In this method, a new delamination index is established by using driving-point accelerance (DA) to identify the sealant delamination and approximately estimate the severity of damage. Only one acceleration sensor on a glass panel and a rubber hammer are required and only one driving point should be tapped to measure DA, so the operation of this method is very simple and fast. To improve the effect of sealants delamination on the DA, the optimal sensor location was analysed by the finite element method, and the effect of tapping point from the sensor on the DA was investigated by experiments. Then, nine different delamination cases were carried out in the laboratory to verify the rationality and accuracy of the proposed method. Because each glass panel only needs to be tapped one point, it is very suitable to detect the delamination of SSGS with thousands of units for its less detection time.

2. Delamination Index Based on Driving-Point Accelerance

When the sealants of the SSGS is delamination, the boundary conditions of the curtain wall are changed, which cause the corresponding change of dynamic characteristics and dynamic response of the system. DA, which is sensitive to the change of boundary conditions, is used for the delamination of sealants.

Considering the impact hammer load applied to a specific degree of freedom (DOF), the forced vibration equation of an n -degree-of-freedom system is [37]

$$[m]\{a\} + [c]\{v\} + [k]\{u\} = \{f\}p(t), \quad (1)$$

where $[m]$ is the mass matrix, $[k]$ is coefficient matrix stiffness, and $[c]$ is damping matrix of the glass panel; $p(t)$ is the time history of the hammer load, $\{u\}$, $\{v\}$, and $\{a\}$ are the displacement, velocity, and acceleration vectors; and $\{f\}$ is the force attribution vector. The load are applied to the r th DOF; then, the element of $\{f\}$ is

$$f_k = \begin{cases} 1, & k = r, \\ 0, & k \neq r. \end{cases} \quad (2)$$

Let the first n natural frequencies and associated mode shapes be ω_j and $\{\varphi_j\}$ ($j = 1, 2, \dots, n$). The driving-point accelerance (DA), which is the acceleration frequency response function (FRF) of the r th DOF, can be expressed as follows:

$$H_r(\theta) = \frac{A_r(\theta)}{P(\theta)} = - \sum_{j=1}^n \frac{\varphi_{rj}^2 \theta^2}{-\theta^2 m_j + i\theta c_j + k_j}, \quad (3)$$

where $i = \sqrt{-1}$, $P(\theta)$ and $A_r(\theta)$ are the Fourier transforms of $p(t)$ and $a_r(t)$, respectively; $a_r(t)$ is the acceleration time history of the r th DOF; $m_j = \{\varphi_j\}^T [m] \{\varphi_j\}$ is the modal mass; $c_j = \{\varphi_j\}^T [c] \{\varphi_j\}$ is the modal damping coefficient; and $k_j = \{\varphi_j\}^T [k] \{\varphi_j\}$ is the modal stiffness coefficient; and φ_{rj} is the r th element of $\{\varphi_j\}$.

Once the sealants have some delamination, the dynamic characteristics of panel will be changed, leading to the corresponding change of DA generated by the hammer load.

FIGURE 1: Model of a panel. (a) Sketch of sensor locations; (b) finite element model.

Therefore, based on the relative changing of predamage and postdamage of DA, the delamination index, called relative accumulation difference (E_a) of DA, is proposed to detect the delamination as follow:

$$E_a = \frac{\int_0^\infty ||H_r^d(\theta)| - |H_r^u(\theta)|| d\theta}{\int_0^\infty |H_r^u(\theta)| d\theta} \times 100\%, \quad (4)$$

where the superscript u and d denote the undamaged and damaged case, respectively. In the practical test, the signals of acceleration and load are discrete signals so that DA is calculated by the discrete Fourier transform (DFT).

From equation (3), it can be seen that the location of acceleration sensor significantly affects DA. Thus, the hammer impact location must be optimized for less error because the theoretical tap location is occupied by the sensor. Therefore, first, investigate the optimized location of acceleration sensor and the effect of the error of hammer impact location and then investigate the accuracy of the delamination index, E_a .

3. Optimization of Acceleration Sensor Location

In order to optimize the sensor location, numerical analysis was performed using ANSYS on a typical panel, as shown in Figure 1(a), to obtain the mode shapes and frequency responses. The size of the unit was 1585 mm in height, 985 mm in width, and 6 mm in thickness. As shown in Figure 1(b), the panel was divided by shell element into 128 elements

with Young's modulus $7.2 \times 10^4 \text{ MPa}$, density 2000 kg/m^3 , and Poisson ratio 0.2. The panel was attached to the support frame by sealant with width $w_s = 10 \text{ mm}$ and thickness $h_s = 15 \text{ mm}$. Boundary condition was assumed to be simply supported in the X and Y directions, and there was the spring bearing in the Z direction to simulate the effect of sealants. Given Young's modulus E_s of sealant is 0.8 MPa , the spring stiffness of sealant per meter was estimated as $k_s = E_s w_s / h_s = 533.3 \text{ kN/m}$.

Locations A, B, and C (the three locations are representative relatively) in Figure 1(a) were selected as sensor locations to compare the difference of DA with varying sensor locations. Location A is the intersection of the quarter of long-side and short-side; location B is the center of the panel; location C is the intersection between the midpoint of the long-side direction and the quarter of the short side. Figure 2 shows the first 10 modes of vibration from the modal analysis. The DA of the three locations A, B, and C are shown in Figure 3. It can be seen that the DA of location A had six resonance peaks between the frequency range of 0 to 105 Hz, however, that of locations B and C only had three peaks. Comparing with the mode analysis results, it can be seen that the eighth (95.982 Hz) and ninth (103.05 Hz) mode shapes did not appear as resonance peaks of the DA of location A in the first ten natural frequency range, and the resonance peaks of third and fourth and sixth and seventh modes were very close and merge to one. However, only the responses of the first (19.120 Hz), fourth (55.099 Hz), and eighth (95.982 Hz) mode shapes were excited to lead three resonance peaks in the DA of location B. The responses of

FIGURE 2: The first 10 mode shapes and corresponding natural frequencies: (a) the 1st mode (19.120 Hz); (b) the 2nd mode (32.937 Hz); (c) the 3rd mode (55.019 Hz); (d) the 4th mode (55.099 Hz); (e) the 5th mode (64.120 Hz); (f) the 6th mode (80.449 Hz); (g) the 7th mode (80.749 Hz); (h) the 8th mode (95.982 Hz); (i) the 9th mode (103.05 Hz); (j) the 10th mode (104.06 Hz).

FIGURE 3: DA at various locations: (a) location A; (b) location B; (c) location C.

the first (19.120 Hz), fourth (55.099 Hz), and seventh (80.749 Hz) mode shapes were excited to lead three resonance peaks in the DA of location C. Since the acceleration sensor should be installed at a location where the most numbers of DA natural mode shapes are obtained, location A is a relative optimal location to install the acceleration sensor. The DA at location A was used to identify the sealant delamination in the further experiments.

4. Error Analysis of Hammer Impact Location

4.1. Sample Preparation. The experimental panel was attached to the square steel pipe frame by the sealant, as shown in Figures 4(a) and 4(b). The panel was double glazing comprised of two panels of 6 mm tempered glass and a gap with 12 mm, and the size of the panel also was 1585 mm in height and 985 mm in width. The sealant and the unit should be constructed for three months before test. This was an indoor experiment to research the index itself, so the changes of the external factor were very small that the temperature effect was not considered.

4.2. Experimental Equipment. The type of equipment used in the experiment is shown in Table 1. The equipment was connected together, as shown in Figure 5.

The acceleration sensor was installed at location A using the hot melt adhesive to ensure a proper bonding between glass and sensor. The sampling frequency of test was 2048 Hz. Although the DA calculation requires the impact hammer tapping position and the sensor position to coincide, in the actual test, the impact hammer can only tap the locations near the sensor instead, which would induce systematic errors. At the same time, the arbitrary tapping by operators at the aim point might vary a little bit every time while tapping, which would cause the random error. Figure 6 shows the difference of DA between two times taps for the same aim point. The E_a between the first and second tap is 2.84%, which was denoted that the random error was very small and can be ignored.

An impact hammer generated impacts on several tapping positions, as shown in Figure 7. The tapping locations were designed to be close to the acceleration sensor (location A, in Figure 7) in the four directions. In each direction, there were six tapping points. The first five

FIGURE 4: Experimental sample. (a) Overall sample; (b) local details.

TABLE 1: Equipment and type.

Experiment	Type
Impact hammer	DYTRAN-5800B4
Sensor	DYTRAN-3097A2
Data acquisition instrument	COINV-3018A
Computer	Lenovo-X201 tablet

FIGURE 5: Experiment equipment.

points have an interval of 10 mm in between, and the sixth point has an interval of 50 mm away from the fifth point. The exact solution was specified as the result of the DA of sensor location A for the four directions. The result is shown in Figure 8. It can be seen that the E_a along the long-side direction is smaller than the short-side direction due to the fact that the long-side direction is far from the boundary and the short-side boundary is relatively close, which has more influence on the E_a . When the excitation point of the impact hammer is controlled within 3 cm of the distance from the acceleration sensor and is along the long-side direction, the error E_a is lower than 5%.

5. Delamination Detection

5.1. Experimental Setup. To validate that the developed technique can detect delamination for the SSGS, nine cases, as shown in Figure 9, were tested. The delamination of the sealant was simulated by cutting. The severity of delamination to the sealant is defined as the ratio between

FIGURE 6: Difference of DA between two times taps for the same aim point.

the failure length l_d and the total length l_t of the sealant, that is,

$$d = \frac{l_d}{l_t}. \quad (5)$$

The severity of structural sealant delamination in each case is shown in Table 2.

To potentially detect the severity and delamination locations, two acceleration sensors were installed at location A and location D, respectively, which are the intersection of the quarter. Then, the location A or D was used as the driving point to illustrate the effect of delamination location on the delamination index. The sampling frequency of the test is 2048 Hz, and then the glass panel was tapped by the impact hammer in the vicinity of the acceleration sensor away from the constraint direction (within 3 cm) to control detection error from hammer locations.

FIGURE 7: Hammer impact locations: (a) tapping locations (unit: mm) and details of point A (unit: mm); (b) photo of the experimental setup.

FIGURE 8: E_a of various points.

5.2. Experimental Results. For a distributed parameter system, there are infinite number of the natural frequencies and associated mode shapes. However, relatively few modes can provide sufficiently accurate results in engineering applications. Therefore, through the structural modal parameters to identify the delamination, only a few modes are needed to be considered. The DAs of the nine cases of driving point A are shown in Figure 10. In each case, the hammer is tapped for three times. The two lines in Figure 10(a) almost coincide

for the undamaged case (case 1) DA of arbitrary two test. In Figures 10(b)–10(i), the dashed line is the average DA of the three tests of delaminated case, also shown in solid lines, are the DA of the undamaged case. It can be seen that the differences of DA between damaged cases and undamaged case is more significant with the increasing severity of damage. The DA of case 2 and case 3 is almost the same as that of the case when the frequency is lower than 60 Hz. It means that the effect of the tiny damage on response of low-

FIGURE 9: Perimeter sealant failure illustration of different cases: (a) Case 1; (b) Case 2; (c) Case 3; (d) Case 4; (e) Case 5; (f) Case 6; (g) Case 7; (h) Case 8; (i) Case 9.

TABLE 2: Delamination level.

Case	1	2	3	4	5	6	7	8	9
Delamination severity (%)	0	6.39	12.78	19.16	25.55	31.94	38.33	48.61	58.89

FIGURE 10: Continued.

FIGURE 10: Comparison of DA of driving point A under different cases, (a) 1 vs. 1; (b) 1 vs. 2; (c) 1 vs. 3; (d) 1 vs. 4; (e) 1 vs. 5; (f) 1 vs. 6; (g) 1 vs. 7; (h) 1 vs. 8; (i) 1 vs. 9.

FIGURE 11: Continued.

FIGURE 11: Comparison of DA of driving point D under different cases, (a) 1 vs. 1; (b) 1 vs. 2; (c) 1 vs. 3; (d) 1 vs. 4; (e) 1 vs. 5; (f) 1 vs. 6; (g) 1 vs. 7; (h) 1 vs. 8; (i) 1 vs. 9.

FIGURE 12: E_a for various cases: (a) driving point A; (b) driving point D.

order vibration modes is small since the low-order modal reacts to the overall macroscopic property and is not sensitive to the local damage. When the frequency is higher than 60 Hz, the difference of DA between the damaged and undamaged case is significant, even though the damage is small. It is because the higher mode reflects the local information so that it is sensitive to the local damage. Therefore, when using the E_a algorithm, the analysis frequency should reach the modal order that can fully reflect the structural dynamic response. The interval of frequency for calculating the E_a is specified between 0 Hz to 128 Hz in the test. The DAs of the nine cases of driving point D are shown in Figure 11, which has similar responses as in Figure 10.

It was tapped three times under every case. According to the experimental data, the results of E_a for various cases are listed in Figure 12.

Figure 12 shows the value of E_a is positively correlated with the severity of delamination, that is, E_a increases with the increase of the severity. In the test, the results of tapings for the

same case are all smaller than 5%, which means that the random error of hammer taping location will have a slight effect.

5.3. Discussion. The average value of E_a of three taps are shown in Table 3. The fundamental frequency reduction [38] E_{ω_1} and modal assurance criterion (MAC) [18] are also listed in Table 3 for comparison. The E_{ω_1} can be calculated by

$$E_{\omega_1} = \left| \frac{\omega_1^u - \omega_1^d}{\omega_1^u} \right| \times 100\%, \quad (6)$$

where ω_1^u is the undamaged fundamental frequency of the SSGS and ω_1^d is the fundamental frequency of damaged SSGS. The i th predamage mode shape is $\{\phi_i^u\}$, and the i th postdamage one is $\{\phi_i^d\}$; then, MAC of $\{\phi_i^u\}$ and $\{\phi_i^d\}$ is

$$\text{MAC}(\{\phi_i^u\}, \{\phi_i^d\}) = \frac{\left(|\{\phi_i^u\}^T \cdot \{\phi_i^d\}|^2 \right)}{\left(\{\phi_i^u\}^T \cdot \{\phi_i^u\} \cdot \{\phi_i^d\}^T \cdot \{\phi_i^d\} \right)}. \quad (7)$$

TABLE 3: E_a , $E_{\omega 1}$, and MAC.

Case	1	2	3	4	5	6	7	8	9
Delamination severity (%)	0	6.39	12.78	19.16	25.55	31.94	38.33	48.61	58.89
$E_a/\%$ (driving point A)	3.60	18.10	29.50	43.74	45.03	48.25	63.38	63.96	72.52
$E_a/\%$ (driving point D)	3.87	18.02	27.12	42.24	46.03	48.05	49.14	55.68	56.29
$E_{\omega 1}/\%$	0	0.13	0.79	1.67	2.64	2.69	6.94	18.13	20.33
1st order	1	0.98	0.97	0.97	0.97	0.77	0.16	0.35	0.12
MAC	1	0.99	0.99	0.98	0.98	0.39	0.45	0.32	0.27
2nd order	1	0.99	0.99	0.98	0.98	0.39	0.45	0.32	0.27
3rd order	1	0.91	0.87	0.44	0.36	0.43	0.36	0.19	0.18

FIGURE 13: Driving points in experimental modal analysis (unit: mm).

For each case, the natural frequency and mode shapes are obtained by experimental modal analysis. In the modal experiment, the glass panel is divided into 32 cells and 45 tap points, as shown in Figure 13. The eigensystem realization algorithm (ERA) [39, 40] is used to identify the natural frequencies and mode shapes. The identified fundamental frequencies are shown in Figure 14. The identified first mode shapes were shown in Figure 15.

In Figure 15, colors represent the relative amplitude of the mode shapes with colors from purple to green showing the decrease of the amplitude. A block is installed at the bottom of the glass curtain wall panel. While the block helped supporting the vertical gravity of the panel, and it also

restricted the horizontal displacement. Therefore, the mode shape of case 1 is unsymmetrical and the mode amplitude of the top was larger than that of the bottom. The block also effectively restricted all of other cases which cause the mode amplitude of bottom was relative less. It can be seen that the differences of mode shapes between case 1, case 2, and case 3 were small. For case 4 and case 5, the change in the mode shapes was obvious, but the MAC of the first mode shape was still almost unchanged. In fact, MAC of the first two modes was larger than 0.95 until the delamination severity is 25.55% (case 5). The low sensitivity of fundamental frequency and mode shape shifts to delamination required either in very precise measurements or more serious

FIGURE 14: The change of fundamental frequency.

FIGURE 15: First mode shapes for various cases: (a) Case 1; (b) Case 2; (c) Case 3; (d) Case 4; (e) Case 5; (f) Case 6; (g) Case 7; (h) Case 8; (i) Case 9.

damages [17, 35]. However, the MAC of the 3rd mode was 0.91 for case 2, which was relative sensitive. In addition, it can be seen from Figure 15 that the change of fundamental frequency is small until case 6, that is, the fundamental frequency reduction E_{ω_1} is less than 5% until the delamination severity is around 32%.

From Figures 10 and 11, together with Table 3, it can be seen that the E_a leads to increase with the increase of damage severity. For case 2, the delamination severity is only 6.39%, and the E_a is 18.10% and 18.02% for driving points A and D, respectively. When comparing the E_a of location A and location D in Table 3, it is clear that the E_a is very sensitive to delamination, even though delamination is small and the distance between the driving points and the delamination will also change the detected E_a . The difference between the E_a of driving points A and D increases as the damage severity

increases. Especially, for case 7 to 9, the E_a of location A and location D are significantly different. The comparisons between the E_a of location A and location D indicates that even if the E_a is very sensitive to both delamination severity and locations, it is more sensitive to severity than to locations. In addition, even if the relative location between the driving point and delamination location is very far, the changes of E_a is significant for small delamination. The high sensitivity of DA is a result of that fact that the higher natural frequencies and mode shapes are more sensitive to small and local delamination. The DA includes more than 10 mode shapes responses in the test; therefore, the small delamination would induce significant changes of DA. For practical applications, if both delamination location and severity are needed, two or more DA locations may be required and other damage index may be needed to be developed in

addition to E_a for the accurate measurements on both parameters.

According to the results of test, when the E_a is larger than 10%, the existence of sealants delamination can be identified with confidence. In practical application, the measured natural frequency will change because of the environmental influence [41]. It is difficult to work out damage identification when the damage index is less than 5%. Therefore, E_{ω_1} and MAC of the lower mode shapes are only suitable for damage identification of large delamination. To get higher modal shape, it needs relative long time to finish much more point taps. However, only one point is required to measure DA. Therefore, it is more convenient for engineering applications to detect the damages by DA.

6. Conclusions

Based on the difference of predamage and postdamage DA, a new delamination index, which calculates the relative accumulation difference of predamage and postdamage DA, is proposed to identify the delamination of the sealant in SSGS. Theoretical and experimental results show that

- (1) To measure DA, only one acceleration sensor and a rubber hammer are required, so the test operation is extremely simple. The relative accumulative difference of DA increases with the increase of the delamination of the sealant. The relative accumulation difference of DA is very sensitive to delamination because it includes much information of higher modes; thus, it is applicable to identify the delamination of sealant in SSGS. It can be seen that the sealants have delamination when the E_a is larger than 10%.
- (2) The location of acceleration sensor installment will influence the value of DA. Usually, the relative optimal place to install the sensor is at the intersection of the long side and the quarter of the short side of the glass panel where it would cause symmetric and antisymmetric mode shapes. To decrease the effect of the error of hammer impact location, the impact hammer taps in the direction of the long side, and the tapping point should be controlled within 3 cm far from the sensor.
- (3) The fundamental frequency reduction is suitable to identify relatively large delamination. The MAC of higher mode shape is sensitive to local damage and can be used to delamination identification of SSGS, but it will spend relative long time.

In the future, more research studies are needed to analyse the performance of this method with the changes of temperatures, detect small delamination using the relative accumulation difference of DA under different sizes of panels and different damage sites, combine other damage index to identify the damage locations, and perform actual field testing.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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