AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING

Newsletter

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Contents

President Message

Tommy Chan

Professor in Civil Engineering, Queensland University of Technology

Dear All,

Recently an article of one colleague of mine at QUT drew my attention. It is on the comparison of visual inspection and SHM as bridge condition assessment methods.[1] It can be found that there were not many papers on this topic in literature.

In the paper, the visual inspection and SHM were compared in terms of their functional performance, cost, and barriers (real and perceived) to implementation. I agree with the authors about the main limitations of visual inspection. The most significant shortcoming of the visual inspection is the reliance on the necessity for having a clear line of sight to conduct a condition assessment, which was generally admitted by many engineers. The second one should be the fact that the visual inspection based-assessments most often are subjective. Inappropriate and inadequate condition assessments are quite possible. Also detailed analyses for estimating the criticality and vulnerability of a member could only be conducted qualitatively and not quantitatively. The last limitation identified in this paper is about the inspection frequency. Although it can be adjusted according to the structural details and environmental conditions, yet no matter how frequent that visual inspection could be

[1] Agdas, D, Rice, J.A. Martinex, J.R. and Lasa, I.R. (2016) "Comparison of Visual Inspection and Structural –Health Monitoring as Bridge Condition Assessment Methods." *Journal of Performance of Constructed Facilities, ASCE,* 30(3): 04015049.

provided for a structure, it could not guarantee that there is nothing happening in-betweens. Regarding the limitations of SHM, the paper considered the complexity, maintenance and necessity of providing an automated data analysis of a SHM system. However, to me, I considered these as challenges for SHM researchers for further development rather than the limitations of SHM.

The paper also discussed the costs of inspection, compared with a SHM system using a case study of a bridge as a typical prestressed concrete girder bridge in a coastal region with 3 spans of 19.81 m. The bridge was assumed to have some known issues with corrosion of the prestressing tendons and has been identified scour-critical. It was concluded that the SHM installation costs would be around US$110,000 for a wired system and US$64,000 for the concrete girder bridge and the ongoing costs (data analysis and maintenance) for about US$12,000 per year for both systems. For the visual inspection, the total cost for a single routine inspection would be US$9,000. Although I consider the SHM system provided in the paper was more complicated than which it should be and all these were estimated in US settings, yet the figures could still help indicate that for a long run, the costs for SHM could be justified and also others costs, e.g. opportunity costs like traffic control during the installation of the SHM or during each routine inspection, were not included. Also, the level of detail and frequency of the visual inspection will be changed when the bridge problems are worsened. SHM could also help reduce the frequency and routine cost of visual inspection. All in all, I do not believe that SHM could replace visual inspection and the two methods could be complementary to each another, e.g. SHM can provide continuous monitoring of the structure, help assess damages for covered or inaccessible, minimise human errors, earlier identify damage and performance anomalies, and most importantly a SHM system can provide quantitative assessment of the condition of a structure.

The conclusion of the paper may provide asset owners some insights to consider:

Each method has its own strengths and limitations, making the case for and a hybrid/augmented system design for optimal functionality. Visual inspection has proven to be effective for general inspections. For smaller bridges with no known structural problems, this method can be sufficient in identifying preliminary issues. For larger structures and structural problems that require more in-depth understanding of their nature for effective maintenance, structural health monitoring may be more appropriate. Perhaps the best solution is an augmented, coupled visual inspection and structural health monitoring system.

I appreciate so much the effort which my colleague devoted to this topic and published this paper. Although he is working in the area of construction and project management and not in the area of SHM, yet the paper gives some visions to us on SHM. The paper also raised an issue about liability and responsibility of a SHM system. Although it is an important matter to be dealt with, yet as engineers, it is not an issue only related to a SHM system. We should be aware of it when we provide any of our service and to let the client know what we can do and what we cannot. We should always complete our task in a professional manner. For sure, SHM can help:

1. ensure safe structures - as early as during construction
2. plan rational and economic maintenance
3. achieve safe and economic operation
4. identify causes for unacceptable responses
5. verify design assumptions
6. provide information to improve future design.

We could set up a discussion web-forum for the above-mentioned points to have further discussions on visual inspection and SHM.

Below are the updates of the month.

ITRP Proposal Preparation

I am pleased to inform you that the *Call for Participation from Industry Partners* flyer for ANSHM ITTC has been produced.

It is the first fruit that we bear as the potential Chief Investigators (CIs) of this ARC ITTC. I am so pleased to see how well that we have been working with and I am very encouraged to see its final version produced on 25th May 2018.

As mentioned in the last monthly updates, in order to ensure to have a strong ITTC proposal for its success, we could not have that many Eligible Organizations (EOs) to be included in the proposal, so we could only have 11 EOs. The EOs are mainly the universities that ASNHM Executive Committee (EC) members and the active (those who frequently join ANSHM Annual Workshop) Advisory Board members affiliated with. At the moment, the CIs are using this flyer to approach the potential industry partners to invite their participations.

I am so pleased to see how the idea on this ITTC is so well received. On 24th May, even before the final version of the flyer is ready for its distribution, I approached two PIPs (potential industry partners) and received very good responses from both of them. One is prepared to contribute $20k to $30k per year and the other is prepared to contribute $50k per year.

According to our schedule, now we will approach our PIPs (potential industry partners) to introduce this ITTC and invite them for participation. We consider now is a golden period of the year as many PIPs will discuss internally their budget after the release of the Federal Budget and before the new financial year starting from 1 July 2018. Our timeline for working on this ARC ITTC proposal submission is listed as follows:

i. May and June – approach PIPs
ii. July
    i. Obtain some letters of support
    ii. Workshops to publicise the ITTC
iii. August - October
    i. ARC announces Rules
    ii. Proposal Preparation
iv. November
    i. Drafts for Review in early November
    ii. Submission in November

As mentioned in the last updates that for ANSHM members who are affiliated with other universities, you can participate this ITTC as non-CI. You can also join it as a CI, if you can secure cash contribution from the Industry Partners. Please contact me and let me know your plan. Please also email me if you would like to have a soft copy of the *Call for Participation from Industry Partners* flyer.

Technical Workshops

Yew-chin and Xinqun has been working hard for organising a technical workshop in Melbourne. The details are as follows:

Date: 16th July 2018 (9am – 5pm)

Venue: VicRoads Kew Theatrette – 60 Denmark Street, 3101 Kew

We are selecting the topics that are most interested by the VicRoads engineers and it is expected that a brochure will be ready for distribution soon.

ANSHM 10th Annual Workshop

We are still collecting views from the Advisory Board members and the Executive Committee members to find a best arrangement and a time slot of one and a half days that fit most of us for the 10th ANSHM Workshop. Originally we thought it will not be difficult to find a time slot during the period 27th Nov to 3rd Dec 2018 considering some of us may have to attend ACMSM25 in Brisbane from 4th to 7th December 2018 in which we ANSHM will also orgainise a special session. However it seems that it is not as easy as we thought to find such a time slot. Now we are extending the period to be from 27th Nov to 12th Dec to find a one and half day time slot for our 10th ANSHM Workshop. We will let you know the date once it is confirmed.

ANSHM Special Issues

ANSHM Second Special Issue in SHMIJ

The due date for the paper submission to this special issue has lapsed. By the time you read this update, the Editor-in-Charge of SHMIJ should have closed the on-line submission for this special issue. Xinqun, Andy and I have received 11 papers in total. The Editor-in-Charge has performed a pre-screening process for the submitted papers and few papers were rejected before sending them to us. We have invited many of us to be the reviewers of the papers, especially those who are authors of these submitted papers. Please accept the invitation and return the review report by the deadline. Please note that we have a tight schedule to follow in order to have this special issue to be published in September this year. Many thanks for those who have already accepted the invitation to be a reviewer. We will try our best to ensure that you do not have to review more than two papers.

ANSHM 3rd Special Issue in CSHM

For this special issue, currently there are still 2 papers under re-review. We are working to finalise this special issue as soon as possible, hopefully by June 2018.

ANSHM Special Sessions

ACMSM25

As mentioned earlier, we have received 7 abstracts for our ANSHM special session (SS03) in the 25th Australasian Conference on the Mechanics of Structures and Materials, 4th – 7th December 2018 in Brisbane (https://acmsm25.com.au/). We have already sent a message to the authors who have submitted an abstract to this special session. Please prepare the paper using the link provided in the message. The deadline for full paper submission is 1st July 2018.

7WCSCM

Regarding our Special session SS01: Recent Research Advances on Structural Control and Health Monitoring in Australia, the full paper submission has been closed and we have received more than 10 full papers.

IABMAS

IABMAS 2018 conference program is available. Seven oral presentations have been arranged on Tuesday 10th July 2018.

ANSHM Page (www.ANSHM.org.au)

As mentioned earlier that Hong Guan and her team are evaluating options of different web hosting providers for our ANSHM site and they have identified some commercial servers such as BlueHost, iPage, HostGator, GoDaddy, etc. Meanwhile we will still have the webpages hosted by QUT and if we receive any notice for migration, we should have no problem as QUT will provide us enough time for the migration.

SHMII-8 Follow Up Work

I have been advised that back in the early stages of the event, Brisbane Marketing had allocated some funding to assist with marketing expenses for the event. As we have met our delegate target we can claim these funds of $1,500. We now have the membership payments sorted with ISHMII, we will be working to finalise the accounts as soon as possible, hopefully by June, 2018. For your information, Saeed is working on the SHMII-8 Special Issue in CSHM.

In this issue, we have two interesting articles. Guan et al presented to use guided waves with nonlinear characteristics on an aluminium pipe to detect the existence of fatigue cracks and to assess its severity. Li et al. presented a bridge condition assessment approach under operational traffic loads.

With kind regards,

Tommy Chan

President, ANSHM

www.ANSHM.org.au

Fatigue crack detection in pipelines using nonlinear guided waves

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Abstract

Guided waves with nonlinear characteristics have been utilised on an aluminium pipe to detect the existence of fatigue cracks and to assess its severity. Surface-bonded piezoelectric transducers were adopted in the test, combined with a nonlinear signal collecting system. This report introduces the testing procedure and the proposed method can be used to detect fatigue cracks at the early stage including local material dislocation and crack initiation.

Introduction

With their advantages of long distance propagation and high sensitivity, guided waves are effective for pipeline inspection [1]. However, guided wave based methods using linear wave characteristics are limited by the excited wavelength being capable of detecting only gross damage. Guided wave based methods using nonlinear wave characteristics are therefore preferred for scenarios with microscale damage. These techniques focus on the nonlinear distortion of excited waves caused by the damage, including higher harmonic generation, mixed frequency responses, subharmonic generation, etc.
There are different types of nonlinearity in pipe structures such as material nonlinearity and contact acoustic nonlinearity (CAN), where the former is usually caused by the material dislocation while the latter is caused by the “breathing” behaviour of a microcrack. Liu et al. [2, 3] carried out analytical and numerical studies on the higher order interaction of different wave modes in weakly nonlinear hollow cylinders. Deng et al. [4] used circumferential guided waves to find the relation between nonlinearity parameter and the accumulated damage in a circular tube through experiments. Similarly, experiment test has focused on the thermal fatigue damage in an aluminium pipe with nonlinear guided wave detection [5]. In terms of CAN, however, limited studies are found in pipe structures, where the presence of flexural wave modes makes interpretation of the second harmonic wave more difficult. The objective of this report is to carry out experimental testing so as to investigate the second harmonic generation caused mainly by CAN and establish the relation between nonlinear parameter and the severity of fatigue crack.

Specimen preparation and signal collection

The specimen used in experiment is a 4 mm thick, 30 mm outer diameter and 1 m long aluminium pipe. A through-thickness notch 8 mm long and 2 mm wide was drilled in the middle of the pipe for fatigue crack initiation. Rectangular piezoelectric transducers 5 mm×10 mm and 5 mm×5 mm acting as actuator and receivers respectively were attached on the pipe in a line.

A signal generating and collecting system (see Figure 1) including Ritec RAM-5000 SNAP and an Agilent digital oscilloscope was used to generate and receive the signals. The system also contained a high-power low-pass filter which could suppress harmonics higher than 300 kHz from the source before the signal was input to the transducer. A 6-cycle tone burst signal at a central frequency of 300 kHz was generated and both the reflected and transmitted signals were monitored before and during the fatigue test.

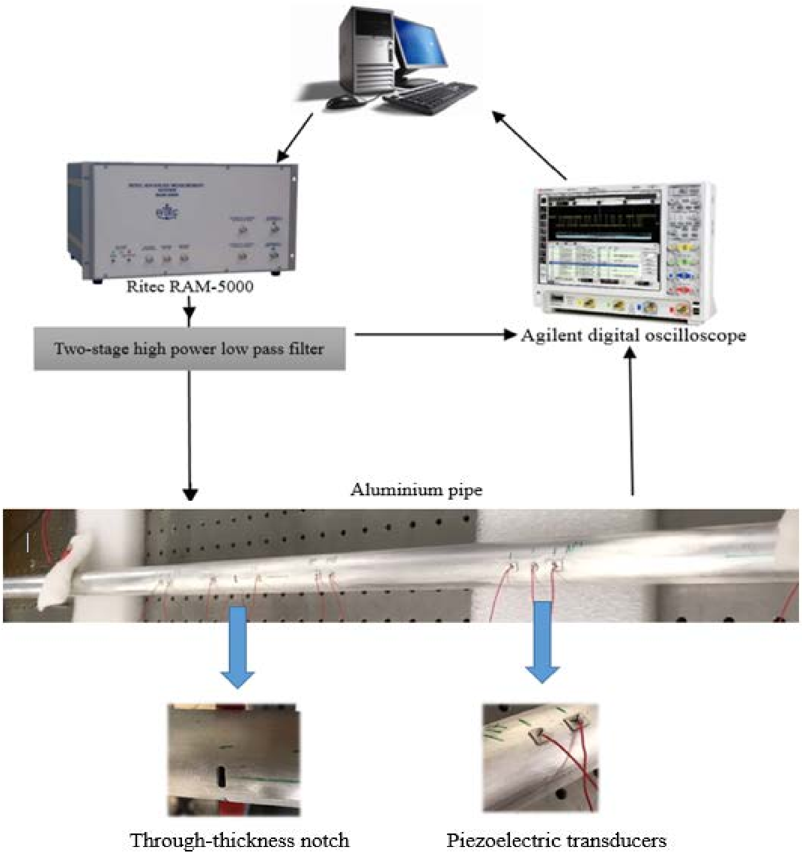

Figure 1 Signal collecting system with aluminium pipe specimen

Fatigue test on the aluminium pipe

To induce a microcrack, a steel frame was designed to hold the pipe and was combined with the fatigue machine. The pipe was therefore under three-point bending with a cyclic load in the middle, as in Figure 2. The cyclic load ranged from 0.2 kN to 2 kN with a 5 Hz load frequency. During the fatigue test, transmitted and reflected signals were continuously collected every 2000 cycles until 24000 cycles and then the collection interval was changed to 4000 cycles. The fatigue test was stopped at 42000 cycles when the nonlinearity in the received signals dropped to noise level. Signals were averaged 1024 times with a sampling frequency 200 MHz before recording.

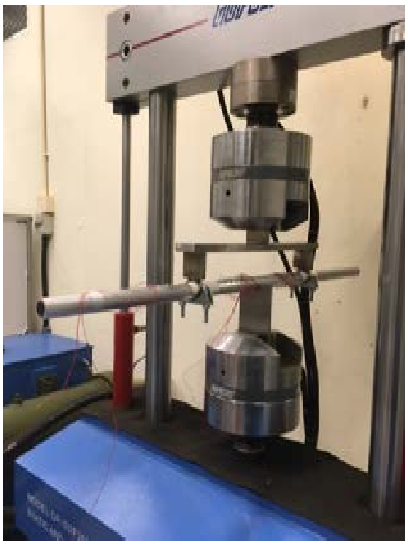

Figure 2 Steel frame combined with fatigue machine for three-point bending fatigue test

Results and discussion

A nonlinear index which is the integral of the amplitude profile of the wave at double frequency within a time period of interest divided by the integral of the amplitude profile of the wave at the fundamental frequency, is calculated to measure the nonlinearity in the structure. The nonlinear index for all the transmitted and reflected signals in terms of fatigue cycles is plotted in Figure 3. It can be seen that the nonlinear index increases gradually with the fatigue cycle until about 22000 cycles and then decreases to the same level as in the benchmark. The increase of nonlinear index indicates the material dislocation at the tips of the notch which is then evolved into microcrack as the fatigue cycle increases. It should be noticed that at the end of the fatigue crack, the crack length was about 1 mm, indicating that in practice the breathing behaviour exists at the early stage of the fatigue crack and it will then become an open crack immediately when the crack grows to a macro one and that is the reason for the drop of the nonlinear index after 22000 cycles.

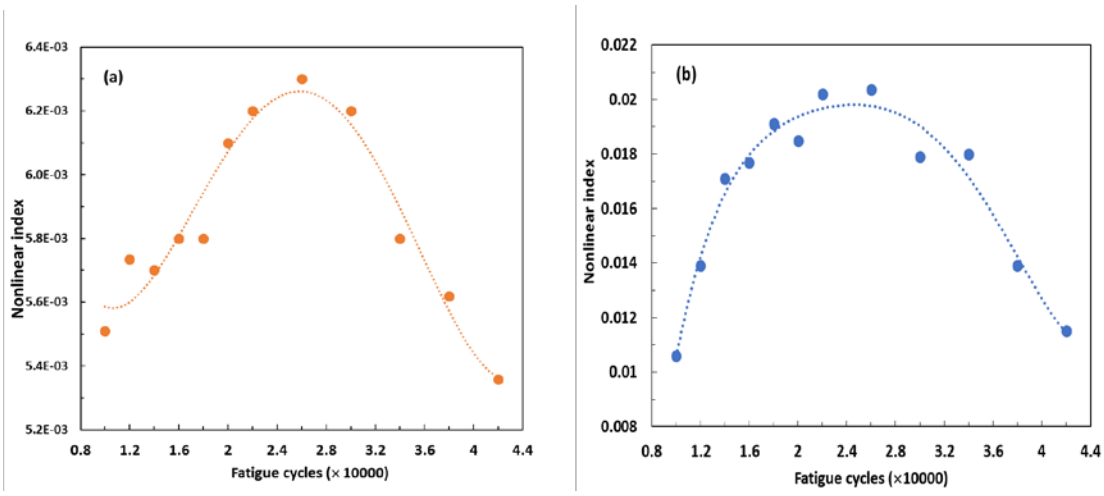

Figure 3 Nonlinear index vs fatigue cycles for (a) transmitted signals and (b) reflected signals

Conclusion

This report introduced an experiment testing on an aluminium pipe for fatigue crack detection using nonlinear guided waves. A proper nonlinear index was applied to assess the severity of the fatigue crack. From experimental analyses, it is found that the nonlinear index increases monotonously with the fatigue cycles at the early stage and then starts to decrease at specific fatigue cycle, indicating the nonlinearity only exits at the initiation of a fatigue crack before it becomes to a macro crack. This study provided a proper nonlinear index which can measure the material dislocation of the fatigue and the severity of the fatigue crack at its early stage.

Reference

[1] R. Guan, Y. Lu, W. Duan, and X. Wang, "Guided waves for damage identification in pipeline structures: A review," *Structural Control and Health Monitoring,* vol. 24, pp. e2007-e2007-17, 2017.

[2] Y. Liu, C. J. Lissenden, and J. L. Rose, "Higher order interaction of elastic waves in weakly nonlinear hollow circular cylinders. I. Analytical foundation," *Journal of Applied Physics,* vol. 115, pp. 214901-214901-11, 2014.

[3] Y. Liu, E. Khajeh, C. J. Lissenden, and J. L. Rose, "Higher order interaction of elastic waves in weakly nonlinear hollow circular cylinders. II. Physical interpretation and numerical results," *Journal of Applied Physics,* vol. 115, pp. 214902-214902-10, 2014.

[4] M. Deng, G. Gao, Y. Xiang, and M. Li, "Assessment of accumulated damage in circular tubes using nonlinear circumferential guided wave approach: A feasibility study," *Ultrasonics,* vol. 75, pp. 209-215, 2017.

[5] W. Li and Y. Cho, "Termal fatigue damage assessment in an isotropic pipe using nonlinear ultrasonic guided waves," *Experimental Mechanics,* vol. 54, pp. 1309-1318, 2014.

Bridge Condition Assessment under Operational Traffic Loads

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[b] Department of Mechanics, Taiyuan University of Science and Technology, Taiyuan, Shanxi 030024, China
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Operational traffic excitations are usually more significant than other excitation sources, such as ground motions, wind loading and temperature effect for short/medium span bridge structures. The response due to the moving vehicular loads is generally far larger than that under ambient vibrations especially for short- and medium-span concrete bridges. It is desirable to conduct the bridge condition assessment based only on the vibration responses of the bridge since the operational traffic excitations are difficult to measure. It is possible to analyse the bridge-vehicle interaction and obtain the responses from finite element analysis with sophisticated bridge and vehicle models [1]. Zhu and Law [2] conducted the simultaneous identification of bridge-vehicle interaction forces and structural damage iteratively. Later, structural condition assessment was performed in a three-span concrete bridge deck subject to a three-dimensional moving vehicle by identifying the interaction forces and system parameters simultaneously in an iterative manner [3]. A significant number of sensors was required to ensure that the identification equation for simultaneous identification of forces and system parameters is over-determined. This may limit the applications of those model based methods for real applications to bridge condition assessment.

In this study, a novel non-model based bridge condition assessment approach under operational traffic loads is developed based on the phase trajectory change of multi-type vibration measurements. A damage index [4] is defined by using the separation distance between the trajectories of undamaged and damaged structures to indicate the damage location. Experimental studies are performed to demonstrate the effectiveness and performance of using the proposed approach for damage detection in bridge structures subjected to moving loads.

In a general case, the location of the moving load can be expressed as the normalized location by $x'=x/L$, in which L is the length of the beam. The damage index is defined as the distance between the spatial coordinates of the normalized moving load locations from the undamaged and damaged phase trajectories

$$DI=\sqrt{\left(u_d^{x'}-u_0^{x'}\right)^2+\left(v_d^{x'}-v_0^{x'}\right)^2+\left(a_d^{x'}-a_0^{x'}\right)^2} \tag{1}$$

where $\left(u_d^{x'},v_d^{x'},a_d^{x'}\right)$ and $\left(u_0^{x'},v_0^{x'},a_0^{x'}\right)$ denote the spatial coordinates under the damaged and undamaged states, respectively.

A composite bridge model was constructed with a reinforced concrete slab placed on two steel girders, as shown in Figure 1. The slab and girder are linked together by using shear bolts. Figure 1 shows the experimental "bridge-vehicle" system. The vehicle model is simplified as a steel beam with two concrete blocks. The displacement and acceleration responses in the mid-span are used for the bridge condition assessment. The sampling rate is set as 2000 Hz. Minor structural damage in the composite bridge model is introduced by removing a few specific shear bolts to simulate the damage in the shear connection. This will create a little effect on the bridge global performance, and the limited local damage effect.

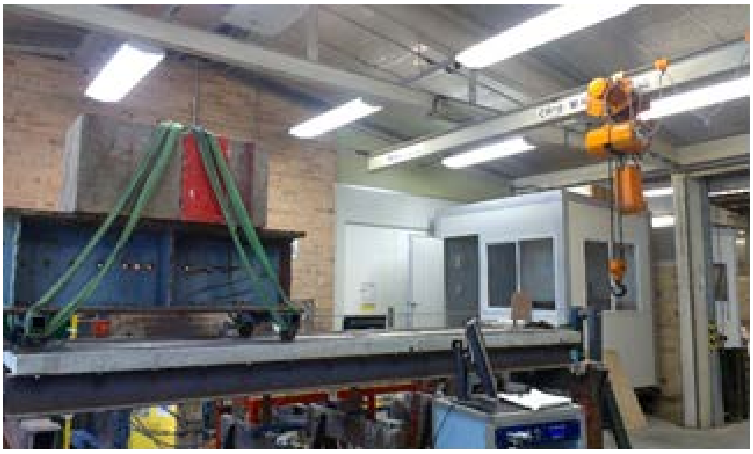

Figure 1 Bridge-vehicle system in the experimental study

A damage scenario and the associated removed shear connectors are shown in Table 1. The measurements from both the undamaged and damaged states of the bridge are taken. Figure 2 shows the comparison of the phase trajectories between the undamaged and damaged states. It is noted that clear difference can be observed from the undamaged and damaged phase trajectories in those two scenarios, indicating the sensitivity of the phase trajectory on changes of structural conditions. Since Damage Scenario 2 has more severe damages with more loosen bolts, the difference between the phase trajectories is more prominent than that in Scenario 1.

Table 1. Removed shear connectors in the experimental study

Damage Scenario		Removed shear connectors	Damage region
Scenario 1	damage 1	SC15 and SC15'	2.8m

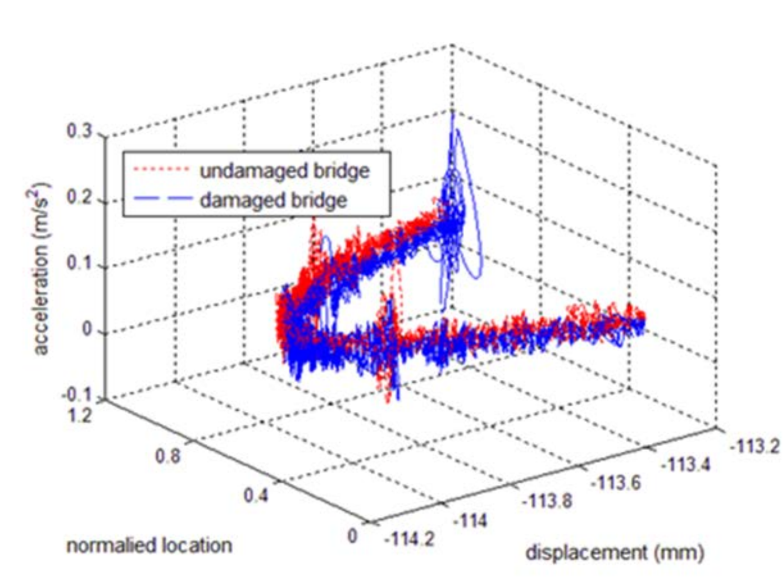

Figure 2. Phase trajectories between the undamaged and damage states

A two-dimensional phase trajectory with the measured displacement and acceleration responses is reconstructed and used to calculate the damage index. Eq. (1) is followed to calculate the damage index. A smooth processing scheme with 250 points is used to reduce the noise effect and improve the performance of damage detection. The condition assessment results are shown in Figure 3. With the axle distance of the front and rear axles of the vehicle equal to 1m, it can be observed from Figure 3 that only the front axle will pass along the region of removed shear connectors. The highest damage index indicates the location of damage when the front axle moves on the top of damage. It is roughly located at the normalized location 0.91, which matches well with the true introduced damaged location at 2.8m/3m=0.93, indicating that the damage can be identified effectively with the proposed approach. The other two peak damage index values at the normalized locations of 0.30 and 0.78 are corresponding to the instants when the front and rear axles impact the track at the central transverse plate.

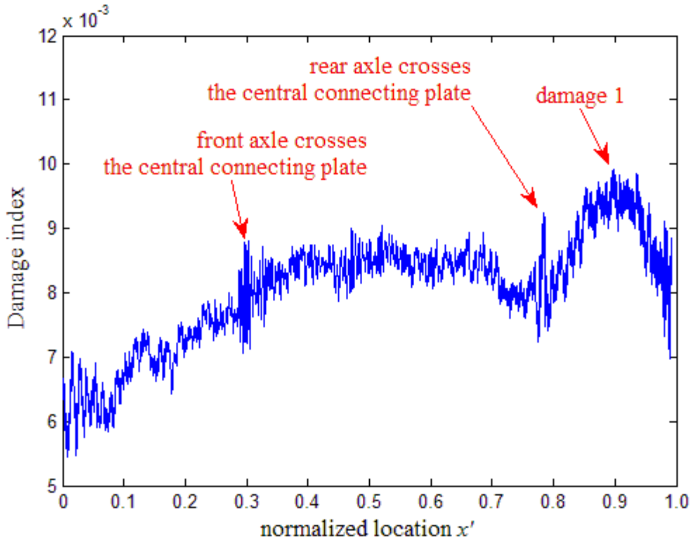

Figure 3. Bridge condition assessment results

The above results demonstrated that the proposed approach based on changes in phase trajectories is very sensitive to changes in structural conditions, even with only one displacement and one acceleration responses. Introduced structural damage by removing shear connectors in the present examples can be clearly identified, while such damages are difficult to be identified by using more traditional vibration-based parameters such as change in vibration frequencies.

Reference

[1] F.T.K. Au, Y.S. Cheng, Y.K. Cheung, Vibration analysis of bridges under moving vehicles and trains: an overview, Prog. Struct. Eng. Mat. 3 (2001) 299-304.
[2] X.Q. Zhu, S.S. Law, Damage detection in simply supported concrete bridge structure under moving vehicular loads, J. Vib. Acoust. ASME. 129 (2007) 58-65.
[3] S.S. Law, J. Li, Updating the reliability of a concrete bridge structure based on condition assessment with uncertainties, Eng. Struct. 32 (2010) 286-296.
[4] W. Zhang, J. Li, H. Hao, H.W. Ma, 2017, Damage detection in bridge structures under moving loads with phase trajectory change of multi-type vibration measurements, *Mechanical Systems and Signal Processing*, 87: 410-425.

Conference News

- Mini-symposium ***"Recent Research Advances on Structural Control and Health Monitoring in Australia"*** in the ***7th World Conference on Structural Control and Monitoring (7WCSCM)***, in Qingdao, China, 22-25 July 2018. Organized by Prof. Hong Hao, Dr. Kaiming Bi, and Dr. Jun Li. (http://smc.hit.edu.cn/wcscm2018/)
- ***"SS11 - Structural Health Monitoring for Infrastructure Asset Management"*** in the **9th International Conference on Bridge Maintenance, Safety and Management**, Melbourne, 9-13 July 2018. (http://iabmas2018.org)
- SS03 "Latest advances in Structural Health Monitoring in Australia" in the ***25th The Australasian Conference on the Mechanics of Structures and Materials (ACMSM25)***, 4-7 Dec 2018, Brisbane, Australia. Organized by Prof. Tommy Chan and Dr. Andy Nguyen. https://acmsm25.com.au/
- ***9th International Conference on Structural Health Monitoring of Intelligent Infrastructure,*** 4-7 Aug 2019, Missouri, US. https://shmii-9.mst.edu/
- ***2nd International Conference on Health Monitoring of Civil and Maritime Structures,*** 23-24 May 2019, Glasgow, U.K.

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