AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING

Newsletter

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President Message

Tommy Chan

Professor in Civil Engineering, Queensland University of Technology

Dear All,

We had our 4th ANSHM Executive Committee meeting on 24 August 2021. Before the meeting started, we talked about our situations under Covid-19 recently. Some Executive Committee members in NSW and Victoria shared that they consider this time they are under larger work pressure during the lockdowns when compared to last year, especially due to the additional workload caused by remote teaching and at the same time the problems of shortage of teaching staff. However, they are still so keen to support ANSHM activities. I am heartened for their passions towards the organisation.

Recently, the most striking news for the engineering community in Australia is about the Skyview apartment complex in Castle Hill. A team of inspectors from NSW Fair Trading has reported "the existence of structural issues that would require specialist engineering advice" as the company seeks occupation certificates for two of its five towers (ABC News, 13 May 2021).

The construction of the other three towers is yet to be completed. Actually, it is the third in a row, after the issues of Masco Towers and Opal Towers (first mentioned in my monthly updates on 30 June 2019). In order to get buyers into their apartments, its developer has agreed to be liable for any structural defects in its new Skyview towers complex for 20 years, which is the first of its kind and it may become a new standard for new developments. The agreement states that the developer will source a structural engineer to monitor the buildings for 10 years and will fix any other defects that may become apparent after buyers settle (ABC News, 26 July 2021). Once again, we could confidently consider that SHM technologies together with the installation of SHM systems to building structures will not only ensure the quality of the construction but also cut down the monitoring costs for not only the first 10 years but also as long as the whole life of the structures. We believe that many developers are looking for innovative methods to assist them to ensure the quality and safety of their constructions and SHM technology should be one of them. I would like to re-state what I put down in my monthly updates commenting the issues of the Mascot Towers and Opal Towers on 30 June 2021:

It seems that the multi-million dollars loss of the builders, owners, insurers and government could be avoided or much reduced if some level of SHM systems could be implemented in the buildings as early as during construction and considered in the design.

Actually, the collapse of two buildings in the last two months, one in USA and the other in the Mainland China, should have already alerted the whole world that we should try our best to ensure the safety of our building structures. The first one is the collapse of Champlain Towers South, Surfside, Florida, United States, which happened on 24 June 2021, killing at least 98 people. There are various causes suggested about the collapse, which include corrosions due to the errors in the construction of the pool deck[1], excessive ingress of salt water (Newsweek, 27 June 2021), proper inspections were not performed during and after the construction (New Your Times, 4 July 2021), etc. Our Executive Committee member, Prof Hong Guan and her team, have efficiently prepared an article investigating the incident and highlighting the weak design points of the collapsed building by

[1] Morabito Consultants (October 8, 2018). Champlain Towers South Condominium Structural Field Survey Repor (https://www.townofsurfsidefl.gov/docs/default-source/default-document-library/town-clerk-documents/champlain-towers-south-public-records/8777-collins-ave---structural-field-survey-report.pdf?sfvrsn=882a1194_2)

simulation[2]. The second incident is the collapse of Siji Kaiyuan Hotel in Songling, Suzhou, Jiangsu, China on 12 July 2021, killing at least 17 people. A preliminary investigation found that the collapse was caused by the owner altering the structure of the building (BBC News, 14 July 2021). The causes of the second collapse incident are still under investigation, and we could not comment much on the incident at the moment. However, for the first collapse incident it is quite clear that a lot could be done properly to avoid the deaths of these 98 people, stopping the tragedies of the families of these people. The Structural Health Monitoring technologies will help avoid these to happen. We should advocate SHM to others to promote the technology to be implemented for the benefits of the country.

In the last monthly update, I am so pleased to announce that Bijan and I together with other researchers from the University of New South Wales, the University of Melbourne, Western University Sydney, QUT and 17 Industrial Partners, have been approved an award of $4.98 million to establish the the ARC Industry Transformation Research Hub (ITRH) for Resilient and Intelligent Infrastructure Systems (RIIS) in Urban, Resources and Energy Sectors. I am excited that Bijan and I could get involved in this Research Hub, as we consider that this Research Hub could help bring SHM in Australia to the next level and ANSHM could be integrated in the Hub. However, I will be happier if we could have a research hub or training centre led by ANSHM. In the next round (2022), the priorities of ITRP have been increased to 9 from 6 with 3 additional priorities being:

I. Defence
II. Recycle and Clean Energy
III. Space.

However, “infrastructure” is yet to be included. It is really a disadvantage to ANSHM, as most of our research studies are gearing towards monitoring infrastructure which will be welcomed by various road authorities. Because of the nature that they are government bodies that it is not easy to have cash contribution from them. Therefore, it would not be easy to have a good enough amount of cash-contribution to enhance the chance of success. Nevertheless, it could also be seen that there have been research hubs, training centres being awarded that they have components in SHM, although not directly on. All that it means that if we like to have an ANSHM led Research Hub or Training Centre, and “infrastructure” could not be included as a priority of the Industrial

[2] Xinzheng LU, Hong GUAN, Hailin SUN, Yi LI, Zhe ZHENG, Yifan FEI, Zhi YANG, Lingxiao ZUO (2021) "A preliminary analysis and discussion of the condominium building collapse in surfside, Florida, US, June 24, 2021", Front. Struct. Civ. Eng., https://journal.hep.com.cn/fsce/EN/10.1007/s11709-021-0766-0

Transformation Research Program, we really need to have some strategies to work that out. This should be an important task of our Research Collaboration Task Force.

Below are the updates of the month.

Research Collaboration

As mentioned above, Bijan and I will be heavily involved in the recently awarded ITRH for RIIS. Both of us will be the two Leaders as Chief Investigators to lead the Theme 4 of the Research Hub. The areas covered by the Theme 4 are as follows:

Theme 4 Infrastructure Health Monitoring and Predictive Maintenance

- Subtheme 4.1: Performance monitoring and health status evaluation
- Subtheme 4.2: Analytics for degradation prediction and remaining service life
- Subtheme 4.3: Optimised predictive maintenance and renewal decisions

We consider it would be a great opportunity for ANSHM to be evolved to the next stage by participating this Research Hub. Prof Bijan Samali devoted so much to ANSHM and considers that we should make use of the current strengths of ANSHM to generate various opportunities for us to collaborate and not limit to only the 4 universities involved in the Research Hub. He considers that the funding allocated to him should be used to generate research projects aligning with the needs of his Industry Partners with the support of ANSHM. This will become a win-win situation that we could have a platform of collaboration and the industry partners could have ANSHM helping them develop various SHM solutions to meet their needs. Through this platform,

- we could have many joint supervision research projects and PhD research projects;
- through the monthly, bimonthly or quarterly progress meets for these collaboration projects, the research staff and students could be trained and those ANSHM members participated could also be better weaved for the benefits of SHM research and development in Australia;
- Regarding our task of promoting SHM technologies, we could share the findings of this research platform through various ANSHM activities, e.g. Annual Workshops, Web Forums, Articles for Newsletter, information for monthly updates, SHM Specifications and so on.

Currently, the Research Collaboration Task Force subcommittee of the Executive Committee is formulating details about the criteria of participation of the research projects as well as the budget for the available fund. More details will be provided in due course.

ANSHM 13th Annual Workshop

On the day (30 Aug 2021) I prepared this update, there were 1,290 new COVID-19 local cases identified in the last 24 hours — a new high for any Australian state or territory, breaking yesterday originally highest record of 1035. Hence it seems that the situation is not any better than last month. However, the good news is that the vaccination rate is much better than any time before and yet we could not be certain if the borders could have open by December this year. Even our Prime Minister Scott Morrison is also not certain and could only challenge state premiers to open borders for Christmas if Australia reaches its COVID-19 vaccination targets by having 80% of adults fully vaccinated. In this regard, in the last Executive committee meeting we had a thorough discussion on this and had the following conclusions:

- 13th ANSHM workshop will be a virtual workshop hosted by ANSHM (UTS and USyd can participate the organising committee);
- UTS & USyd's co-host on ANSHM workshop (physical meeting) will be postponed to next year;
- The date of 13th ANSHM workshop is initiatively scheduled for two days during the week from Mon. 13th – Fri. 17th Dec 2021;

Prof Jianchun Li is seeking the views of the Executive Committee and the Advisory Board members for their preferences of the dates for the two-day 13th ANSHM Workshop. It is proposed that theme-based sections will be organised for its presentations and panel discussions to take advantage of online environment. More details will be provided in due course and will be very soon.

Publication generated from the 11th ANSHM Workshop

As mentioned before, this publication will be in the form of a monograph for the celebration of the ANSHM 10th Anniversary. The preparation for this publication is progressing well. Originally, we planned to have 11 chapters and so far 7 chapters have been received and reviewed. Many reviewers have completed their reviews and returned the reports. We would like to thank those reviewers for their prompt actions. For the other reviewers, it would be much appreciated if you could complete your review timely and return the review reports by the deadline stated in the invited messages and let us know if you find it difficult to complete that by the deadline. The coordinators of two other chapters have been granted for an extension of the submission and it is expected that they could send us their chapters by the extended deadline. The coordinators of another two chapters withdrew their proposed abstracts because of the unexpected workload due to Covid-19. It is understanding. In the last Executive Committee, Prof Hong Guan representing the editorial team of the monograph suggested to invite other proposed chapters for this monograph. However, we are also concerned about meeting the schedule required by the Publisher of this monograph. In this regard, we requested for an extension for the submission of the ready-to-print version and it was approved to extend the deadline of submission to 31 October 2021. Hence if anyone who is prepared to submit a chapter for this monograph, hopefully by mid-September, please send a message to Prof Hong Guan (h.guan@griffith.edu.au). We have already received one express of interest from the Executive Committee for a chapter.

Publication generated from the 12th ANSHM Workshop

Prof John Wilson and Prof Emad Gad, the Editors of the Australian Journal of Structural Engineering, have kindly agreed in principle to have the publication generated from the 12th ANSHM Workshop to be published as a special issue in the Journal. A/Prof Xinqun Zhu and myself will be the Guest Editors of the special issue, with the support of Lei Hou, Richard Yang and John Vazey. We will ensure a blind review process for all the submitted papers, where the authors do not know who the reviewers are.

The ANSHM Newsletter

I am so pleased to let you know that Dr Mehrisadat Makki Alamdari, an Editor of our ANSHM Newsletter, is expecting her baby boy in mid-October. Hence in the last Executive Committee meeting, we approved her a special leave for one year starting from 4th of October 2021. Dr Andy Nguyen, our External Affair Coordinator is happy to take up her role as an Editor of the ANSHM Newsletter during her leave of absence. The committee appreciates so much Andy for his being so willing to take up extra loads to help and give peace of mind to Mehri to waiting for the coming of her lovely and healthy baby.

A/Prof Jun Li is the Editor in charge of this issue. He expressed that after we identified the institutions with relatively less contributions to ANSHM newsletters, it makes the editors easier to invite researchers to contribute research articles. The Editorial team will continue to evaluate the process of inviting researchers to contribute research articles and see if it is necessary to formulate a 'Roster of Experts' for contributing articles to the Newsletter for the next two to three years.

In the next sections, we will have two articles from our members. The first article is by the researchers from the University of Adelaide and the Defence Science and Technology (DST) Group. Guided wave focusing on Lamb and Rayleigh wave modes has shown promising usage for damage detection. However, the actual boundary conditions in traditional Rayleigh wave experiments differ from those imposed for the theoretical derivation of Rayleigh waves. This article demonstrates the one-dimensional character of edge-guided wave modes could propagate for large distances without decay showing a great potential in damage detection. The second article is by the researchers from Deakin University, describing how the vibration based non-destructive testing technique is adopted for assessing the condition of in-service timber pole. Hilbert–Huang Transform (HHT) and Wavelet Packet Transform (WPT) are implemented to conduct time-frequency analysis during the process. The results of the study showed that HHT with WPT as pre-processor has a great potential for the condition assessment of utility timber poles.

Stay safe and healthy!

With Kind Regards,

Tommy Chan
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Research profile | **Research publications** | **Google Scholar citations**

Fundamental Edge Wave Mode for Structural Heath Monitoring

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Guided wave research has largely focused on Lamb and Rayleigh wave modes. The latter wave mode is generally considered be non-dispersive, and this property has made it very popular in nonlinear ultrasonics studies. The wide majority of Rayleigh wave experiments employ plane waves propagating along a specified direction. However, the actual boundary conditions in these experiments sometimes differ from those imposed for the theoretical derivation of Rayleigh waves (i.e. plane strain conditions). Therefore, one should expect some departures of the excited surface wave properties from the theoretically derived, which are often manifested in experiments by the presence of additional surface wave modes and other artefacts.

Waves can also be guided by the edge of a plate-like structure. Such edge-guided waves exhibit no geometrical spreading during propagation, and hence no geometrical attenuation, which makes them an attractive option for detecting and characterising damage (or inhomogeneities) located close to an edge. A proper theoretical description of symmetric edge waves propagating in plates of finite thickness has only recently been provided in a number of papers (see [1-3]). These edge waves have infinite number of wave modes, as in the case of Lamb waves. The fundamental mode, ES_0, is slightly dispersive and, generally, energy decaying. It does converge to the plane-stress analogue of the Rayleigh wave only for very thin plates, and for zero Poisson's ratio. The present efforts of our group are focused on understanding the propagation of edge waves, specifically ES_0, and its utilisation for NDT and SHM. In this short paper we will briefly summarise the main outcomes obtained over the past two years.

Introduction

Edge waves were first experimentally discovered by Shaw in 1956, who observed a coupling of the extensional modes of vibration in a circular disk with an unusual mode whose amplitude was large near the circular boundary of the disk and decreased rapidly toward the centre [4]. The coupling occurred at a frequency essentially independent of the radius of the plate, and far below the lowest frequency associated with real wave-numbers of the second and third branches for the propagating modes in an infinite plate, thereby ruling out those modes as a possible explanation for the edge-localised vibration. Gazis and Mindlin (1960) provided the initial theoretical description of the experimental observations and demonstrated that there exists an infinite spectrum of edge wave modes [5]. Following these works, there were several detailed theoretical and experimental studies focusing specifically on edge wave resonance, which is a special case of propagating edge waves with zero wavenumber [1].

Only recently, the properties of propagating edge waves have been investigated by representing the solution to the governing equations of elasticity as an infinite series of Lamb wave modes, which satisfy the homogeneous boundary conditions on the plate faces [2, 3]. Fig. 1b shows the real part of the dispersion curve of the resulting fundamental edge wave mode, along with the fundamental shear, SH_0, and symmetric Lamb wave modes, S_0, for the purposes of comparison. This plot employs a non-dimensional form of the conventional frequency-thickness parameter, defined by the relation $FTV = \omega 2h/c_2$, where ω is the circular frequency, h is the half plate thickness, c_2 is the shear wave speed. The plot serves to identify a suitable window for practical applications of the ES_0 mode that avoids coupling with the S_0 and SH_0 modes, thereby facilitating the interpretation of diagnostic signals from damage or inhomogeneities.

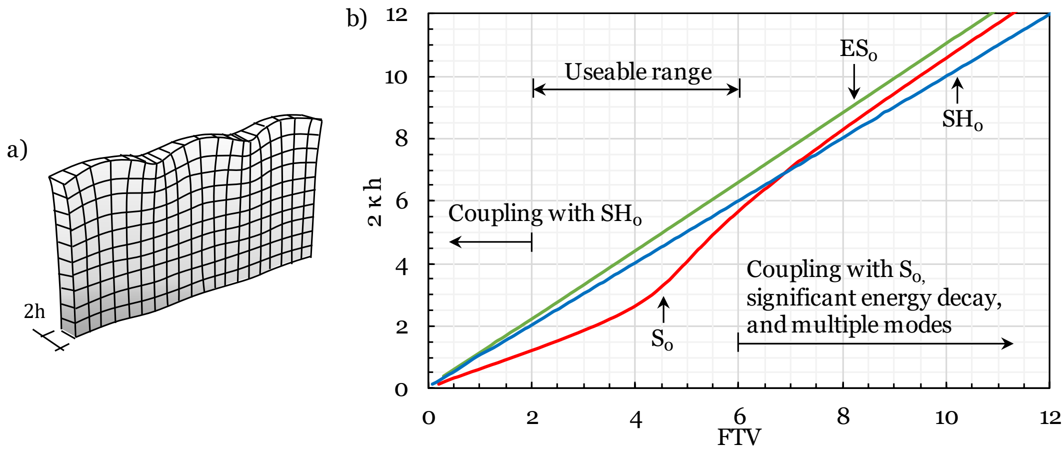

Fig. 1: a) Exaggerated defamations due to edge wave mode propagation in plate of thickness $2h$, and b) Dispersion curves for the ES_0, S_0, and SH_0 wave modes.

The decaying (imaginary) part of the dispersion curve has not been reported in the literature. Some theoretical results indicate that the decay is increasing with an increase of an increase of FTV as well as with an increase of Poisson's ratio, ν [1]. From a theoretical perspective, it is interesting to note that as $\nu \to 0$, the ES_0 mode converges to the plane stress analogue of the Rayleigh wave mode. However, a similar conclusion is not true for thick plates: the plane strain limit of Rayleigh waves is not achieved, and the wave speed of the ES_0 mode changes non-monotonically with the wave excitation frequency within the range of $0.9-1.0C'_R$ for ν = 0.3 (where C'_R is the plane stress Rayleigh wave speed).

Excitation of the Fundamental Mode of Edge Waves

Generation of the ES_0 mode has been first achieved by our group with the wedge excitation technique, Fig. 2b, and using a wedge made from ultrahigh molecular weight polyethylene, which was selected due to its low longitudinal wave speed and low attenuation characteristics. These characteristics help maximise the energy transfer into the edge wave mode from the PZT transducer. In laboratory studies sensing of the wave is typically achieved using a scanning laser vibrometer, Fig. 2a. Low-cost PZT sensors can also be utilised for practical applications.

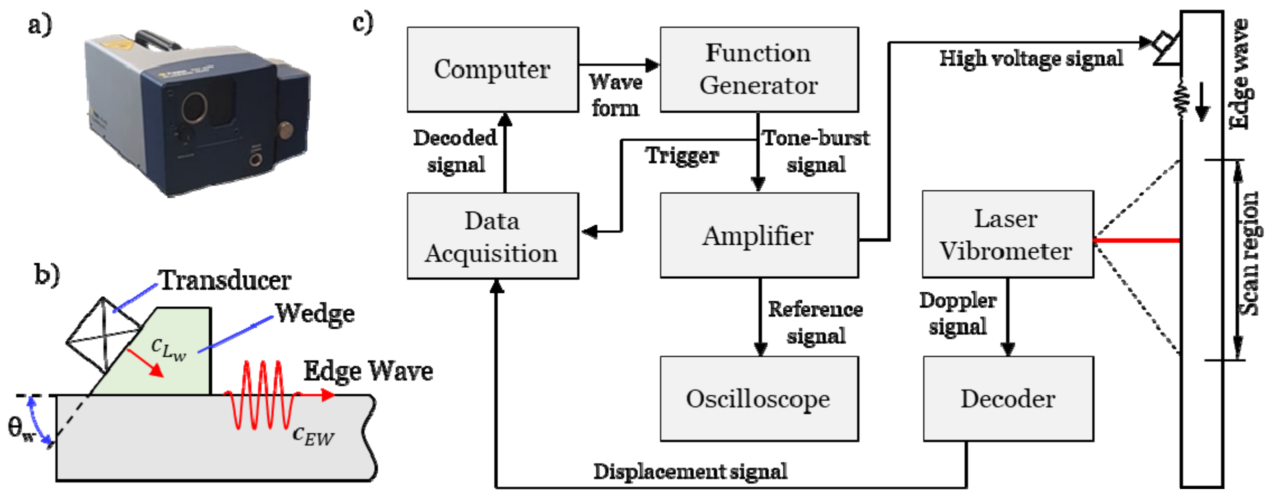

Fig. 2. a) Scanning laser vibrometer head, b) generation of an edge wave using a longitudinal transducer and an acoustic wedge, and c) schematic of typical signal flow and experimental setup

The properties of the fundamental edge wave mode have been investigated using the experimental setup shown in Fig. 2c. As noted earlier, it was found that a promising range of FTV for practical applications is between 2 < $\omega 2h/c_2$ < 6, where there is only a weak coupling of ES_0 with S_0 and SH_0, see Fig. 1b, as well as the absence of high-order wave modes and significant energy decay. Specifically, in our experiments the ES_0 excited at $\omega 2h/c_2 \approx$ 2.2 did not exhibit significant amplitude decay for laboratory-scale samples [6].

Applications of the Fundamental Mode of Edge Waves

In this section we briefly describe main outcomes of the application of ES_0 to NDT and nonlinear ultrasonics.

Detection of Edge Defects

As the name suggests, an edge wave propagates along an edge, which makes it very suitable for detecting edge defects. Fig. 3 shows the detection of a small crack-like edge defect 625mm from the probe location in a plate using ES_0 in the pulse-echo mode, where the travel time indicates the location relative to the probe, while the echo amplitude correlates with the crack size.

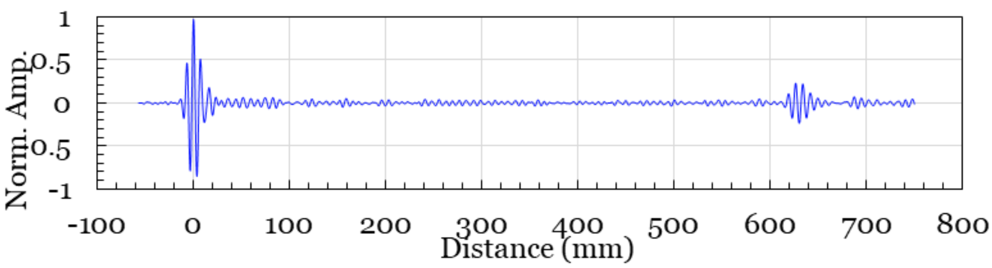

Fig. 3. Detection of a crack-like defect using the ES_0 mode.

Detection of Corrosion Damage

The ES_0 mode was also successfully applied to detect (distributed) corrosion damage using a base-line (free from damage) subtraction signal approach, as indicated in Fig. 4. Further details can be found in [7].

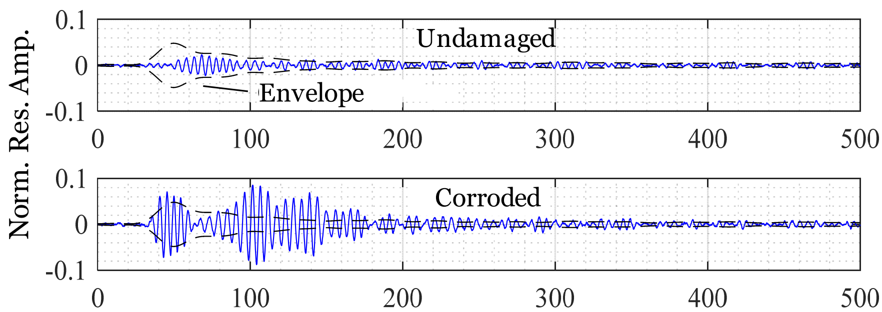

Fig. 4. Detection of distributed corrosion damage using the ES_0 mode and base-line subtraction.

Generation of Higher-Order and Mixed Harmonics for Evaluation of Material Nonlinearities and Distributed Damage

Examples of the utilisation of ES_0 mode for generation of higher order harmonics [8] and mixed harmonics [9] are given in Fig. 5 a) and b), respectively. It can be noted that the reliable detection up to fourth harmonics is possible with this wave mode due to very low frequency and spatial dispersions.

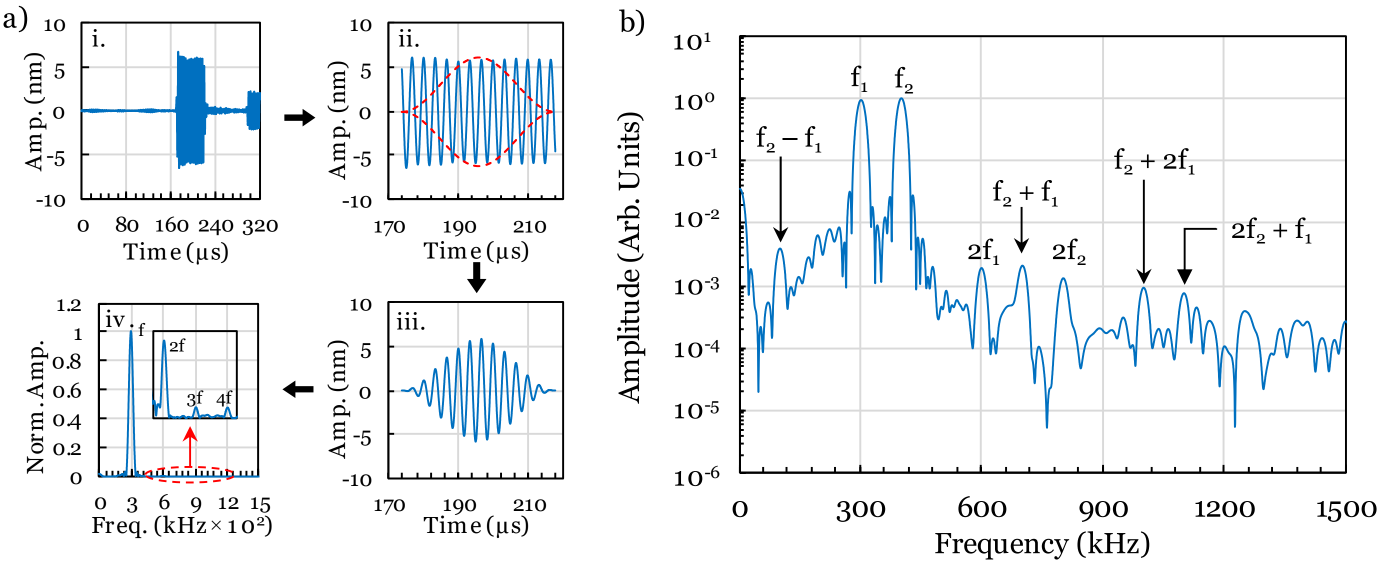

Fig. 5. a) The four main steps in data processing: i. Extraction of the raw displacement signal, ii. Isolation of the edge wave displacement, iii. Application of a Hann-window to the edge wave signal, iv. Results of the FFT, and b) FFT of a frequency-mixed edge wave where f_1 = 300kHz and f_2 = 450kHz (these figures adapted from [8] and [9] respectively).

Conclusion

The fundamental edge wave mode offers ample opportunities to develop effective defect and damage detection techniques. The one-dimensional character of edge-guided waves naturally avoids the spatial decay, and by judicious selection of the wave excitation frequency, the energy decay with propagation distance can be minimised, thereby facilitating the interpretation of diagnostic signals resulting from interaction with defects or inhomogeneities. Due to these unique properties, this wave mode can propagate for large distances without decay. In addition, its application for nonlinear ultrasonics studies (e.g. evaluation of material nonlinearities) demonstrates a great promise.

Acknowledgments

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An Improved Hilbert–Huang Transform for Vibration-Based Damage Detection of Utility Timber Poles

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Introduction

In this study, vibration based non-destructive testing (NDT) technique is adopted for assessing the condition of in-service timber pole. Timber is a natural material, and hence the captured broadband signal (induced from impact using modal hammer) is greatly affected by the uncertainty on wood properties, structure, and environment. Therefore, advanced signal processing technique is essential in order to extract features associated with the health condition of timber poles. In this study, Hilbert–Huang Transform (HHT) and Wavelet Packet Transform (WPT) are implemented to conduct time-frequency analysis on the acquired signal related to three in-service poles and three unserviceable poles. Firstly, mother wavelet is selected for WPT using maximum energy to Shannon entropy ratio. Then, the raw signal is divided into different frequency bands using WPT, followed by reconstructing the signal using wavelet coefficients in the dominant frequency bands. The reconstructed signal is then further decomposed into mono-component signals by Empirical Mode Decomposition (EMD), known as Intrinsic Mode Function (IMF). Dominant IMFs are selected using correlation coefficient method and instantaneous frequencies of those dominant IMFs are generated using HHT. Finally, the anomalies in the instantaneous frequency plots are efficiently utilised to determine vital features related to pole condition. The results of the study showed that HHT with WPT as pre-processor has a great potential for the condition assessment of utility timber poles.

Experimental test set-up

To validate the proposed method, vibration testing method using impact hammer was implemented on three serviceable/healthy and three unserviceable/unhealthy in-situ timber poles. Detail of the testing specimen is given in Tables 1 and 2. Since timber is an orthotropic material, its material properties vary in three different directions: longitudinal, radial, and circumferential. Subhani et al. [1] proposed an appropriate sensor set up for the non-destructive assessment of cylindrical type structures which has been utilised in this study in order to capture the three dimensional behaviour of timber pole. For field testing, an impact hammer, 12 accelerometers and a data acquisition system were employed. A total of 12 accelerometers were used and was connected to the pole by mechanically means. Figure 1a depicts the portable device used for the testing. Figures 1(c) and (d) demonstrate the experimental field set up for the vibration testing. Hammer impact was induced at a height of 1500 mm on the side of the pole with an angle of 45°. The sampling frequency was set to 100 kHz. Each pole was struck four times. Accelerometers were attached on the pole at 1200 mm and 900 mm from the ground level. Six accelerometers that are located at 1200 mm from the bottom of the pole are designated as layer 1 accelerometers and the other six accelerometers that are located at 900 mm from the bottom of the pole are designated as layer 2 accelerometers. For each accelerometer location, three positions along the circumference 0°, 90°, and 180° were taken into account. The accelerometer which is aligned with the impact line is named as 0° and the accelerometer opposite to 0° is called 180°. In the same way, the accelerometer which is located 90° around the circumference is called as 90°. Additionally, at each accelerometer position, the displacement was captured in two orthogonal directions, i.e., in the longitudinal (L), radial (R) for 0° and 180° and longitudinal (L) and circumferential (C) for 90°. The illustration of every accelerometer is named such a way that it represents the location and orientation of that particular accelerometer. For instance, a notation “A90C1” means the accelerometer belongs to layer 1 that is located at 1200 mm from the bottom of the pole and the position is 90° around the circumference; also, the displacement component is the circumferential one.

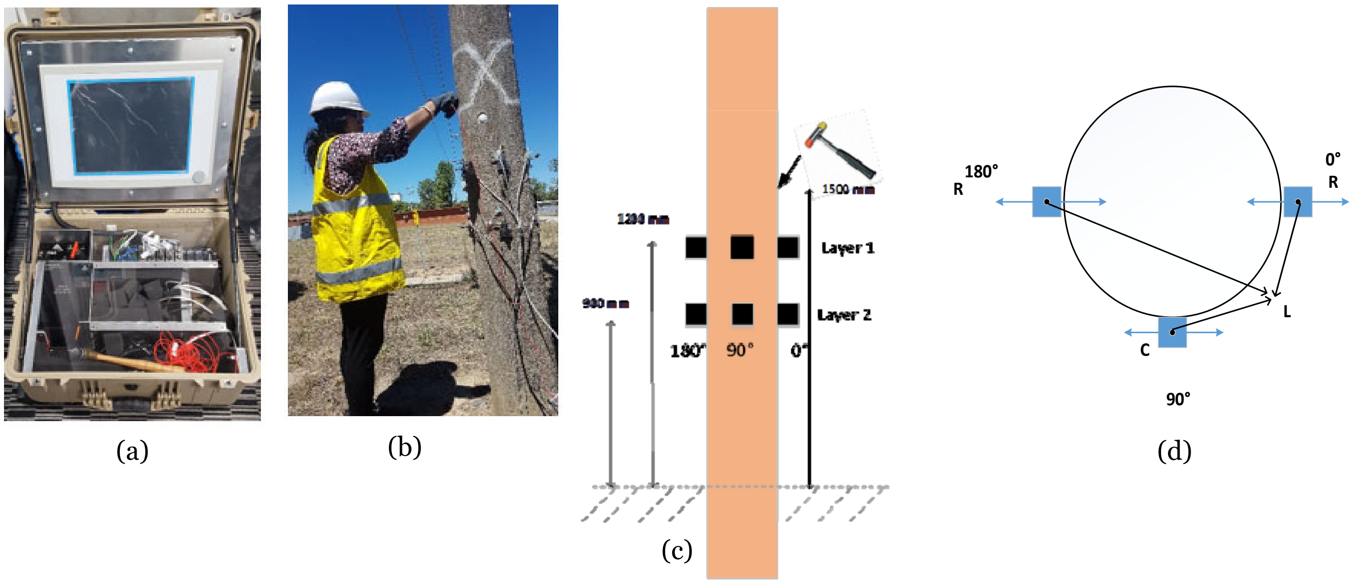


Figure 1. (a) Pole tester (b) Field testing (c) Schematic diagram of experimental test set up (d) Horizontal cross section

Table 1. Detail of three in-situ serviceable timber poles.

	Serviceable Pole 1	**Serviceable Pole 2**	**Serviceable Pole 3**
Timber species	White Stringybark	White Stringybark	White Stringybark
Timber type	Hardwood	Hardwood	Hardwood
Cross section	Circular	Circular	Circular
Strength class	3	3	3
Durability class	2	2	2
Condition of the pole	Serviceable/healthy	Serviceable/healthy	Serviceable/healthy
Diameter	870 mm	870 mm	980 mm
Above ground height	9114 mm	9144 mm	10000 mm
Location	Benalla, Victoria	Benalla, Victoria	Benalla, Victoria
Chemically treated timber	yes	yes	yes

Table 2. Detail of three unserviceable timber poles.

	Unserviceable Pole 1	**Unserviceable Pole 2**	**Unserviceable Pole 3**
Timber species	White Stringybark	White Stringybark	White Stringybark
Timber type	Hardwood	Hardwood	Hardwood
Cross section	Circular	Circular	Circular
Strength class	3	3	3
Durability class	2	2	2
Condition of the pole	Unserviceable/unhealthy	Unserviceable/unhealthy	Unserviceable/unhealthy
Diameter	890 mm	750 mm	1100 mm
Above ground height	9144 mm	9910 mm	15,240 mm
Location	Benalla, Victoria	Benalla, Victoria	Benalla, Victoria
Chemically treated timber	yes	yes	yes

Results and Discussions

Mother Wavelet Selection

Table 3 shows the sample results of 11 mother wavelet functions which have the highest energy to Shannon entropy value among 32 mother wavelets analysed for this study. From the analysis, it is found that bior5.5 wavelet has the maximum ratio of energy to Shannon entropy ($R(s)$) and that is why it is chosen as the best mother wavelet for our study.

Table 3. Results of 11 mother wavelet functions for 12 accelerometers.

Mother Wavelet	**A0L1**	**A0L2**	**A0R1**	**A0R2**	**A90L1**	**A90L2**	**A90C1**	**A90C2**	**A180L1**	**A180L2**	**A180R1**	**A180R2**
	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$	$R(s)$
db1	0.1581	0.1523	0.1612	0.1575	0.1588	0.1559	0.1480	0.1412	0.1571	0.1483	0.1516	0.1622
db4	0.1577	0.1542	0.1605	0.1577	0.1583	0.1567	0.1509	0.1404	0.1610	0.1490	0.1511	0.1590
db10	0.1586	0.1538	0.1612	0.1579	0.1586	0.1558	0.1504	0.1406	0.1601	0.1485	0.1510	0.1605
db15	0.1596	0.1530	0.1623	0.1581	0.1593	0.1564	0.1504	0.1409	0.1597	0.1487	0.1516	0.1613
db44	0.1578	0.1522	0.1615	0.1556	0.1584	0.1557	0.1508	0.1383	0.1596	0.1482	0.1519	0.1598
coif4	0.1585	0.1534	0.1625	0.1579	0.1594	0.1572	0.1513	0.1412	0.1598	0.1492	0.1525	0.1609
sym4	0.1585	0.1530	0.1626	0.1578	0.1598	0.1568	0.1506	0.1416	0.1591	0.1491	0.1520	0.1612
bior5.5	**0.1935**	**0.1848**	**0.1977**	**0.1758**	**0.1946**	**0.1908**	**0.1761**	**0.1575**	**0.1972**	**0.1766**	**0.1804**	**0.1976**
rbio6.8	0.1674	0.1617	0.1724	0.1629	0.1686	0.1662	0.1586	0.1459	0.1693	0.1564	0.1599	0.1705
dmey	0.1585	0.1525	0.1617	0.1574	0.1587	0.1564	0.1510	0.1404	0.1598	0.1483	0.1521	0.1604
fk22	0.1591	0.1535	0.1622	0.1582	0.1592	0.1572	0.1517	0.1407	0.1605	0.1489	0.1524	0.1609

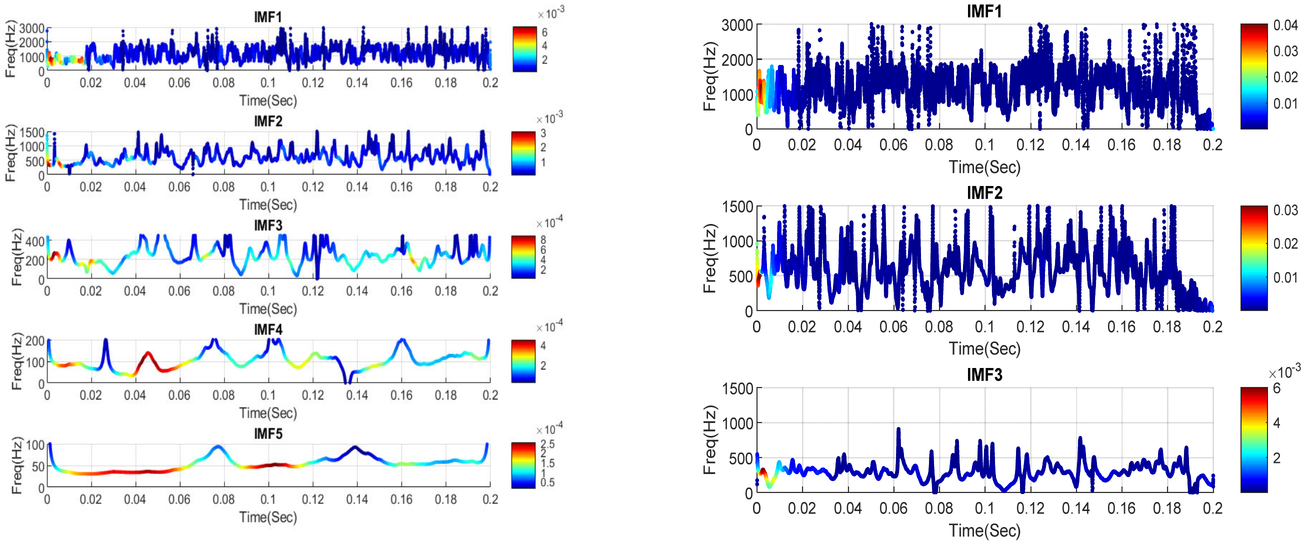
Instantaneous frequency analysis

In order to overcome the deficiencies of original HHT, improved HHT is employed for A90C1 sensor, Serviceable pole 1 and A0R2 sensor, Unserviceable pole 3. First, EMD is performed on the reconstructed signal of A90C1 sensor and A0R2 sensor that have been considered for the analysis. After decomposing this reconstructed signal through EMD, screening technique based on correlation coefficients value is applied to obtain the dominant IMFs. A threshold value of 0.1 is selected for the correlation coefficient in order to avoid accidental removing of some low amplitude but relevant IMFs. After applying improved HHT, 5 dominant IMFs are obtained for Serviceable pole 1 and 3 dominant IMFs are obtained for Unserviceable pole 3. Figure 2(a) and (b) demonstrate instantaneous frequencies of these dominant IMFs for Serviceable pole 1 and Unserviceable pole 3 using Improved HHT respectively. Figure 3 demonstrate the frequency range of dominant IMFs, average frequency of each dominant IMF and standard deviation for Serviceable Pole 1 and Unserviceable Pole 3, correspondingly, considering all the accelerometer data. Frequency range of dominant IMFs for Serviceable Pole 1 are found to be in a similar range with good consistency considering the variability and uncertainty can exist in any field testing (Figure 3). On the other hand, frequency ranges of dominant IMFs for the Unserviceable Pole 3 (from Figure 3) are found to be bigger than that of the serviceable pole case. Standard deviation values are also relatively high for the Unserviceable Pole 3.

One major finding from Figure 2 is that instantaneous amplitude of IMF1 is significantly higher than instantaneous amplitude of IMF1 for the serviceable pole case. This phenomenon is observed for sensors in the radial directions which contains highest energy since the hammer impact was made in the radial direction (horizontal).

Similarly, instantaneous amplitude of IMF1 for A0R2 are studied for all three serviceable poles and three unserviceable poles. Figure 4 illustrates the instantaneous amplitude of IMF1 for A0R2 considering all six poles used in this study. From this figure, it is clearly observed that instantaneous amplitudes of three unserviceable poles for A0R2 sensor are significantly higher than that of three serviceable poles. This finding is observed for all six poles and for all four repeats which reassures the accuracy and consistency of the study. Therefore, it can be concluded that instantaneous amplitude will increase according to the severity of damage.

Detail results and analysis of this study is reported in [2].



(a) (b)

Figure 2. Instantaneous frequencies of dominant IMFs using improved HHT (a) for A90C1 Serviceable Pole 1 and (b) for A0R2 Unserviceable Pole 3

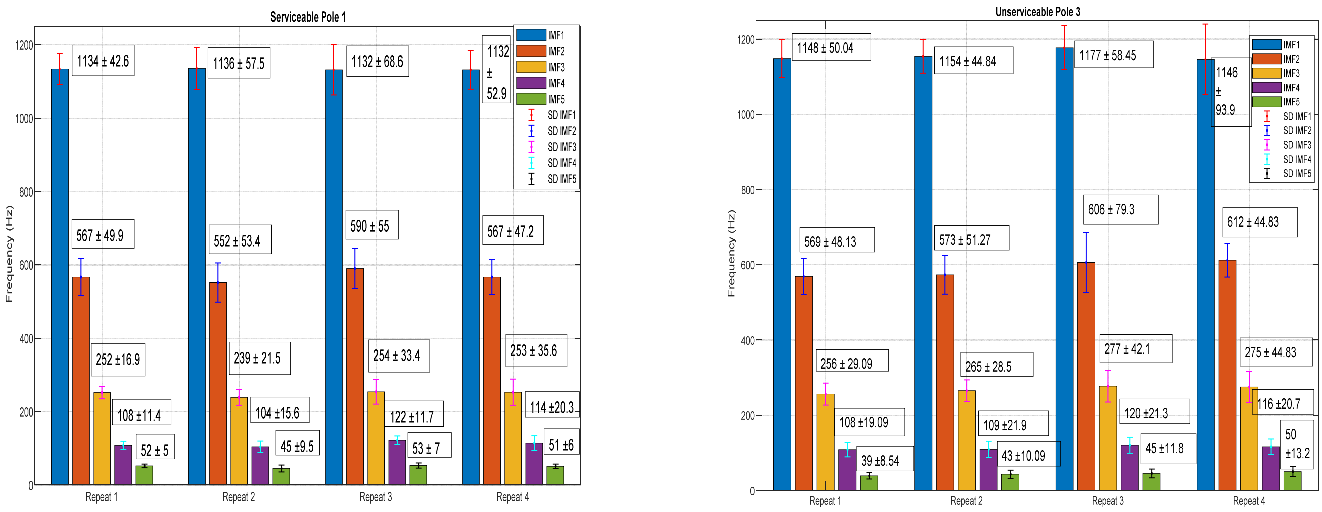


Figure 3: Bar chart showing frequency range of dominant IMFs, average frequency of each IMF and standard deviation for 12 accelerometers, Serviceable Pole 1 and Unserviceable pole 3.

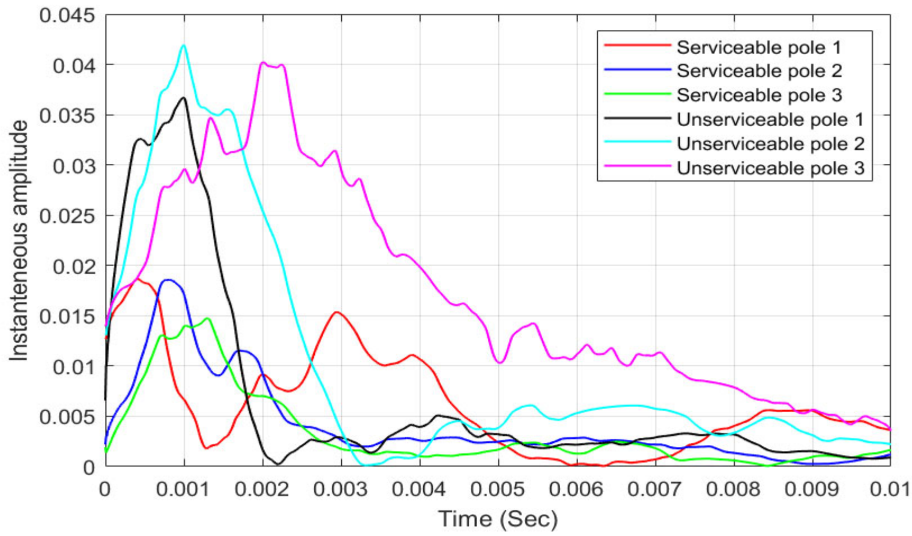


Figure 4. Instantaneous amplitude of IMF1 for A0R2 considering 3 serviceable poles and 3 unserviceable poles.

Conclusion

In this study, vibration-based NDT using HHT with WPT as pre-processor are adopted for determining features (natural frequencies) of timber poles with a view to assess its condition. Natural frequencies have been identified which is vital for the health state determination of timber poles. Additionally, from the comparison between serviceable and unserviceable pole, it is found that instantaneous amplitude of dominant IMFs rises according to the severity of damage. Since the condition of the pole vary with time, routine inspection is essential. If amplitude of instantaneous frequency and variations are increased with time, pole condition is referred to have deteriorated and sufficient measures should be undertaken accordingly.

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Conference News

- The Fifth Australasian Conference on Computational Mechanics (ACCM2021), Sydney, Australia, 13 - 15 December 2021, organised by Assoc. Prof. Sarah Zhang, Prof Yang Xiang, and Prof Richard Yang.

  Webpage: https://westernsydney.edu.au/accm2021

  Extended abstract submission due: 21 September 2021

- The 10th Australasian Congress on Applied Mechanics (ACAM10), 29 November - 1 December 2021, virtual congress, organised by Assoc. Prof. (Alex) Ching Tai Ng and Prof Andrei Kotousov.

  Webpage: https://acamconference.com.au/

  Extended abstract submission due: 6 September 2021

- Mini Symposium "Advances in Bridge Monitoring Strategies: Novel Technologies and Information Fusion" in the 11th International Conference on Bridge Maintenance, Safety and Management (IABMAS2022), Barcelona, Spain, from 11 July to 15 July 2022. Organised by Prof. Kim, Dr Makki Alamdari, Dr. Zhang and Dr. McGetrick.

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