Guided Wave Technique for Corrosion Detection in Reinforced Steel Bars

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ABSTRACT
Guided wave techniques are very promising for damage detection in pipe and plate like structures. Longitudinal guided waves are excited and recorded after transmission for corrosion detection in reinforcing steel bars. Apart from recording the amplitude of the transmitted guided waves or in other words, monitoring the attenuation of guided waves, differential time-of-flight is recorded with high temporal resolution using cross-correlation technique. It is found that corrosion can be detected from the TOF change as well. Feature extraction techniques are used from time-frequency representations.

INTRODUCTION
Oxidization of steel bars either in open environment or inside concrete causes corrosion. Any small damage (such as crack) in concrete can provide enough resource to corrode steel bars to its failure. In recent years researchers are making a lot of effort to develop a technique by utilizing guided acoustic waves to detect the corrosion of reinforcing steel bars in concrete. The feasibility of detecting interface degradation and separation of steel bars in concrete beams has been studied by Miller et al. (2013) using guided Lamb waves. Lamb waves can travel a long distance and distinctly identify any change in interface bonding. The majority of research related to longitudinal guided waves focuses on examining the amplitude of the waves propagating through a material. This research however, goes in a different direction. We investigate the change in the time-of-flight (TOF) of the waves with respect to the variation in corrosion in steel bars.

Experimental Setup
Two steel bar samples are corroded for different time durations using corrosive chemicals and then the experimental data obtained from these samples are compared with that from a non-corrosive sample. All three samples are of same length. For data acquisition, guided wave set up is established in transmission mode so that reflections and other shortcomings related to pulse echo method can be neglected at this time. Longitudinal guided waves are excited and studied in transmission for corrosion detection in steel bars. A chirp signal is excited from 50 kHz to 200 kHz in transmission.
Results and Discussion
The transient response of the excited chirp signal (50 KHz to 200 kHz) is recorded for non-corroded and corroded cases. To measure the change in time-of-flight due to corrosion in steel bars, a cross-correlation technique is adopted; it can provide the TOF change information with respect to the degree of corrosion.

In Figure 2, normalized time history, its Fast Fourier Transform (FFT) and Short Time Fourier Transform (STFT) are presented for the steel bar. FFT is useful to get an estimate about the frequency content in the entire signal whereas in STFT the time information within a small segment of the signal (window) is analyzed for its frequency content. The STFT thus presents a compromise between time and frequency resolutions. It provides a tool to choose the needed precision in either time or in frequency domains.

![Figure 2: (a) Transient signal for the non-corrosive sample, (b) Fast Fourier Transformation and (c) Short Time Fourier Transform (STFT) of the transient signal.](image)
The wide window size gives better frequency resolution at the cost of time resolution and vice versa. Corrosion causes surface roughness which is easily observed by naked eyes. In our case study, Non-corroded sample has length of 82 cm and diameter of 1.9 cm. In the first case, an effective length of 45 cm is corroded and the diameter is reduced to about 1.55 cm, 18% reduction with respect to original diameter. In the second case, an effective length of 45 cm is corroded and the diameter is reduced to about 1.25 cm, 35% reduction with respect to the original diameter. Due to corrosion the diameter of the effective length is reduced. Major changes that are observed in the propagating waves are in terms of the frequency shifts in the spectral plot as shown in Figures 3 and 4.

Figure 3: (a) Transient signal for first corrosive sample, (b) Fast Fourier Transformation and (c) Short Time Fourier Transform of the transient signal.
Similar to the results presented in Figure 3, in the third sample which is corroded for a longer period of time the diameter of the sample is reduced by 35%. Major changes that are observed in the propagating wave in terms of the frequency shifts are shown in Figure 4.

![Transient Signal](image-a)

![FFT](image-b)

![STFT](image-c)

Figure 4: (a) Transient signal for second corrosive sample, (b) Fast Fourier Transformation and (c) Short Time Fourier Transform of the transient signal.
From the above results, it is evident that as soon as corrosion process starts in steel bars significant shift in propagating wave frequencies is observed. For more careful study time-of-flight detection technique is used for the assessment of structural health reduction. In contrast to other procedures we do not correlate the measured signal pulse with the sent one to get the absolute TOF; instead of the absolute TOF a differential TOF, the difference in the TOF between two pulses is measured. Ideally both signals are the same except for a shift in time (TOF)$^2$, and some amplitude variations due to changes in the material on its propagation path.

In order to calculate the differential TOF, one part of the transient signal [presented in Figures 2(a), 3(a) and 4(a)] is selected from 342 $\mu$s to 375 $\mu$s for cross-correlation.

![Figure 5: Change in TOF due to different levels of corrosion in steel bars.](Image)

From the non-corroded sample to the first corroded sample 11.74 $\mu$s change in TOF is recorded and from the first corroded sample to the second corroded sample 10.12 $\mu$s time shift is recorded. Moreover, for better understanding of the recorded differential TOF, FFT of the selected part of the signal is also studied. Compared to the non-corroded sample in the first corrosion sample a significant frequency shift is observed (approximately 50 kHz). Whereas, between the first corrosion and the second corrosion samples instead of the frequency shift a significant drop in the amplitude of the propagating waves is observed.

**CONCLUSION**

The change in TOF due to corrosion in a steel bar is investigated experimentally. The transient signals for non-corroded and corroded cases are processed using Fast Fourier Transformation and Short Time Fourier Transform. The time-of-flight information is obtained by cross-correlation technique. It is demonstrated that the time-of-flight shows high sensitivity to different degrees of corrosion in steel bars. FFT and STFT show significant change in the amplitude of propagating waves that can also be caused by deterioration of bonding between the sensors and the specimens. The change in TOF is presented for one selected part of the propagating wave signal (time history) with a specific central frequency. The work is in progress for studying the TOF variations for different propagating wave modes due to various levels of corrosions.

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**REFERENCES**