# Damage Severity Assessment of Timber Bridges using Frequency Response Functions and Artificial Neural Networks

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**Abstract** This paper presents a novel vibration-based technique that utilises changes in frequency response functions (FRFs) to assess advancement of damage in timber bridges. In the proposed method, damage patterns embedded in FRF data are extracted and analysed by using a combination of principal component analysis (PCA) and artificial neural network (ANN) techniques for estimation of severity levels of damage. To demonstrate the method, it is applied to a laboratory four-girder timber bridge, which is gradually inflicted with progressive damage at different locations and severities. To extract damage features in FRFs and to compress the large size of FRF data PCA techniques are adopted. PCA-compressed FRF data are then used as inputs to ANNs to identify severities of damage. The excellent severity predictions obtained from the ANNs show that FRF data can potentially be very good indicators for the assessment of damage advancements in timber bridges.

**Keywords** damage identification, timber, bridge, structural health monitoring, artificial neural network, frequency response function, principal component analysis

## 1. INTRODUCTION

In 2003, the Department of Transport and Regional Services (DoTaRS) estimated that there are 29,000 timber bridges in Australia, of which one third are older than 50 years. Due to the unknown health condition of Australia's aged timber bridge assets, it is crucial for road managers to have a reliable tool for monitoring and evaluating the integrity of their bridge assets in order to carry out timely maintenance and repair/replacement (McInnes 2005). This paper presents a novel vibration-based technique developed for the identification of damage severities in timber bridges.

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## 2. THE FOUR-GIRDER TIMBER BRIDGE

To validate the proposed damage severity identification method, it was applied to an experimental four-girder timber bridge structure built in a laboratory of the University of Technology Sydney. The bridge structure was inflicted with a total of 12 different progressive damage scenarios at four damage locations. The damage cases, which simulated pockets of rot, were located at either 1/8$^{th}$, 2/8$^{th}$, 4/8$^{th}$ (mid-span) or 6/8$^{th}$ of the span length. At each of these locations, three different damage severities were studied. All damage scenarios were inflicted in a progressive manner. To determine the dynamic characteristics of the laboratory bridge, experimental modal testing and analysis was performed.

## 3. DAMAGE SEVERITY ASSESSMENT UTILIZING RESIDUAL FRFS AND ANNS

### 3.1. Methodology

The proposed method for assessing the level of damage severity in a timber bridge is based on pattern changes in a structure's vibrational characteristics. FRF data, which are easily extracted from experimental modal testing and analysis, provide damage sensitive features for the detection algorithm. To enhance damage fingerprints embedded in FRF data, residual FRFs are derived and used as damage indicator in the proposed algorithm. The powerful pattern recognition abilities of ANNs are utilised to map changes in the residual FRFs to damage characteristics. In order to obtain suitable input data for network training, residual FRFs are compressed to a few principal components (PCs) adopting PCA techniques. The most dominant PCs are then used as inputs to ANNs to estimate the severity of damage.

### 3.2. Procedure and results of damage severity identification

The procedure of the proposed damage severity identification method can be described as follows. First, by means of experimental modal testing, excitation and response time history data are acquired. Second, FRF data are calculated by transforming and correlating the time history data of the impact force and response measurements into the frequency domain using FFT. Third, by summating the FRF data of all measurements of each girder, summation FRFs are obtained. Fourth, residual FRFs are determined by computing differences between the summation FRFs of the baseline/undamaged and the damaged structure. Fifth, by adopting PCA techniques, the residual FRFs are transferred into the principal component space and the most important PCs are identified. Finally, neural networks are trained with a small number of dominant PCs of residual FRFs to identify severities of accumulative damage at the different damage stages (one network is trained for each girder).

The damage severity results obtained from the proposed damage identification method were precise for all investigated damage cases. These promising outcomes are very encouraging and show the capabilities of the presented method. The results demonstrate that damage fingerprints in FRF data are very good indicators for quantitatively estimating damage typically found in timber bridges.

## 4. CONCLUSIONS

This paper presented a vibration-based damage detection method that uses damage fingerprints embedded in FRF data to estimate severity levels of progressive damage in a timber bridge. The damage detection results obtained with the proposed method were very promising with correct severity identifications for all investigated damage scenarios. These encouraging outcomes highlight the feasibility and effectiveness of the proposed method and show that directly measured FRF data in combination with PCA and ANN techniques provide robust and accurate means for damage detection in timber bridges.

## REFERENCES

McInnes, K. (2005), "Conserving historic timber bridges", National Trust of Australia (Victoria), 2.