A COMPARISON OF MODAL FLEXIBILITY METHOD AND MODAL CURVATURE METHOD IN STRUCTURAL DAMAGE DETECTION

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ABSTRACT

Vibration based damage detection techniques examines the changes in dynamic properties of a structure such as frequency, mode shape and damping to indicate the presence of damage. This method is preferred for its ease of implementation, non-destructive nature and its ability to identify damage that is invisible to the surface. Two vibration based damage detection methods are used in this study, namely Modal Flexibility Method and Modal Curvature Method. Although there have been numerous publications on these two methods, there is lack of study on the direct comparison of the methods. Finite element modal analysis of a reinforced concrete slab and steel frame was carried out to obtain the dynamic responses that were used to calculate the Modal Flexibility and Modal Curvature. The structural models were simulated using four damage cases: damage at single location, damage at multiple locations, damage at support location and damage at different damage severities. The comparison of the sensitivity and reliability of Modal Flexibility and Modal Curvature were evaluated using the results of these four damage cases. The results show that the sensitivity and reliability of both methods are affected by the size of the damaged area, its location relative to the support location and the number of damaged segments.

ABSTRAK

Teknik pengesanan kerosakan struktur berdasarkan getaran dengan cara meneliti perubahan sifat dinamik struktur seperti frekuensi, bentuk mod dan redaman digunakan untuk memberi petunjuk kerosakan. Kaedah ini mudah, tidak merosakkan dan mampu mengenalpasti kerosakan yang tidak dapat dilihat di permukaaan struktur. Dua kaedah pengesanan kerosakan berdasarkan getaran digunakan dalam kajian ini, iaitu kaedah *Modal Flexibility* dan kaedah *Modal Curvature*. Walaupun terdapat pelbagai penerbitan berkenaan dua kaedah ini, namun kajian berdasarkan perbandingan secara langsung untuk dua kaedah ini adalah kurang. Kaedah analisis unsur terhingga struktur papak konkrit bertetulang dan kerangka keluli telah digunakan untuk mendapatkan reaksi dinamik struktur bagi mengira *Modal Flexibility* dan *Modal Curvature*. Model struktur tersebut disimulasi menggunakan empat kes kerosakan: kerosakan di satu lokasi, kerosakan di pelbagai lokasi, kerosakan di lokasi penyokong, dan kerosakan dengan tahap kerosakan yang berlainan. Perbandingan kepekaan dan kebolehpercayaan *Modal Flexibility* dan *Modal Curvature* dinilai menggunakan keputusan empat kes kerosakan tersebut. Keputusan kajian menunjukkan kepekaan dan kebolehpercayaan kedua-dua kaedah dipengaruhi oleh saiz keluasan kerosakan, lokasi kerosakan dibandingkan dengan lokasi penyokong dan jumlah segmen yang rosak.

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LIST OF SYMBOLS AND ABBREVIATIONS

[]	Matrix
{}	Vector
C	Coefficient of new matrix
[A]	Damaged mode shape
[B]	Undamaged mode shape
[F]	Modal Flexibility Matrix
[Ø]	Mass normalized modal vectors
[$1/\omega^2$]	Diagonal matrix containing reciprocal of the square of natural frequencies in ascending order
[K]	Stiffness
[M]	Mass matrices
λ_i	*i*th eigenvalue
φ_i	*i*th eigenvector
υ''(x)	Curvature at location
M(x)	Applied moment
E	Modulus of Elasticity
I	Moment of Inertia
$\bar{v}_{i,j}$	Modal Curvature
i	node number
j	mode number
h	structure length
[F]	Modal Frequency

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Recent devastating catastrophic natural disasters such as earthquake, tsunami and typhoon calls for a reliable damage evaluation technique or structural health monitoring technique of surviving structures to assess the extent the damaged state of the structure. Structural failure can lead to severe economic loss and loss of life, thus structural damage detection is of great interest to many researchers.

Damage can be defined as changes introduced into a system that adversely affects its current or future performance (Farrar & Worden, 2007). Damage can also be introduced by long-term degradation of the structure due to wear and tear, fatigue, cyclic loading, environmental effects, corrosion damage and other durability related damages. However, the term damage does not necessarily imply failure or total loss of the system functionality, but rather the systems is no longer operating in optimal manner or serves its intended purposes.

Structural health monitoring can be described as the process of monitoring the condition of a structure and detection of damage occurring in the structure over the time. (Catbas, Gul, & Burkett, 2008). Structural health monitoring (SHM) has been practiced in various industries including aerospace, manufacturing and more recently civil engineering infrastructure. SHM involves many challenges consisting of identifying the damage and its location, evaluating the severity of the damage, testing of the structure, data acquisition and interpretation, modelling and simulation, statistical analysis and ultimately estimating the remaining service life of the structure.

There are many methods in structural condition monitoring, which include visual inspection, localised experimental methods, and global experimental methods. Visual inspections are time consuming, subjective and require access to the damaged area, which limits this technique to the detection of damage that occurs or has spread to the surface of structural elements. Localised experimental methods are often referred to as non-destructive evaluation (or non-destructive testing) and include methods such as penetrant inspection, acoustic or ultrasonic methods, magnetic field inspection, eddy-currents methods and radiographic (X-ray) inspection (Doherty, 1987). These traditional monitoring techniques require access to the area to be tested and require prior knowledge of when and where the damage is likely to occur. Thus, these limitations call for need of more reliable non-destructive and global techniques for structure health diagnosis that examines the change of dynamic characteristics and its continuous development.

Global damage detection methods utilizes vibration based damage detection techniques to examine changes in the dynamic properties such as modal parameters, notably resonant frequencies, mode shapes, and modal damping, are a function of the physical properties of the structure (mass, damping, stiffness, and boundary conditions). Natural frequencies and mode shapes are known to be functions of its stiffness and mass distribution, variations in modal frequencies and mode shapes can be an effective indication of structural deterioration. Deterioration of a structure results in a reduction of its stiffness, which causes the change in its dynamics characteristics. Thus, damage state of a structure can be inferred from the changes in its vibration characteristics. Modal based method is gaining much popularity due to their ease of implementation. The modal-based methods are global in nature and can be used as a complement to local non-destructive techniques.

A vast amount of research has been conducted in the earlier mentioned areas to improve the methodology and applicability of SHM. Continuous health monitoring of structures will enable the early identification of distress and allow appropriate retrofitting to prevent potential sudden structural failures.

1.2 Problem Statement

Due to limitations of conventional non-destructive technique, a relatively new technique using vibration parameters and dynamic changes is developed. Vibration-based damage identification methods have some specific advantages over other methods that are used for structural damage identification: they are non-destructive and they are able to identify damage that is invisible at the surface.

In this study, two direct mode shape derive method is used, namely Modal Flexibility Method and Modal Curvature Method. Although there have been numerous publications on these two methods, there is still lack of study on the direct comparison of those methods.

1.3 Research Objectives

This study is carried out to understand the application of dynamic analysis for damage detection in structures. The main objectives are:

1. To demonstrate the application of modal parameters in vibration damage detection using Modal Flexibility and Modal Curvature Method

2. To compare the sensitivity and reliability of Modal Flexibility and Modal Curvature Method in damage detection using slab and frame structure models.

1.4 Scope and Limitations

In this study, only 2 modal parameters are used which are modal frequency and mode shape. The comparison on the sensitivity and reliability analysis is limited to Modal Flexibility Method and Modal Curvature Method. The analysis is limited to numerical work examples cited from previous study (Bakhary, 2007) using finite element analysis only.

1.5 Significance of the Study

Benefits of the research include

1. Dynamic properties can be used to indicate the presence of damage

2. Damage evaluation of a structure can be carried out using vibration based damage detection techniques such as Modal Flexibility and Modal Curvature Method

3. Structural health monitoring can be done in real-time and improve the overall performance and lifespan of a structure.