DETECTION OF SPALLING USING VIBRATION DATA

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To my beloved mother and father

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ABSTRACT

This project presents a study in the effect of spalling to dynamic parameters such as natural frequencies and mode shapes. Numerical example of a slab will be used as an example in this study. The slab will be modelled using ANSYS 11.0 and various types of spalling are imposed. The changes of vibration parameters are monitored and compared. The sensitivity of modal parameters to spalling is determined using the flexibility method. Since frequency only can indicate the existence of damage, mode shapes are needed to determine the location and severity of damage. Therefore in this study flexibility method is employed. Based on the results it is found that by incorporating mode shapes using flexibility method, damage location and severity can be obtained.

ABSTRAK

Kertas ini membentangkan kajian tentang pengaruh spalling terhadap parameter dinamik seperti frekuensi semulajadi dan bentuk mod. Contoh berangka papak akan digunakan sebagai contoh dalam kajian ini. Papak akan dimodelkan dengan menggunakan ANSYS 11,0 dan pelbagai jenis spalling dikenakan. Laman parameter getaran dipantau dan dibandingkan. Kepekaan parameter modal untuk spalling ditentukan dengan menggunakan kaedah fleksibiliti. Sejak frekuensi hanya boleh menunjukkan adanya kerosakan, bentuk mod yang diperlukan untuk menentukan lokasi dan beratnya kerosakan. Oleh kerana itu dalam kaedah kajian fleksibiliti ini digunakan. Berdasarkan keputusan dijumpai bahawa dengan memasukkan mod bentuk menggunakan kaedah fleksibiliti, lokasi kerosakan dan tahap keparahan boleh diperolehi.

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LIST OF SYMBOLS

TITEL

[ ]	-	Matrix
{}	-	Vector
C	-	Damping of a particular degree of freedom
M	-	Mass of a particular degree-of—freedom, unless stated Otherwise
$\ddot{x}$	-	Acceleration of mass
$\dot{x}$	-	Velocity of the mass
x	-	Displacement
k	-	Stiffness
ω	-	Frequency (rad/s)
Φ	-	Mode shape
Ψ_{ni}	-	i_{th} entry of the n_{th} mode shape
C	-	Coefficient of new matrix
[A]	-	Damage mode shape
[B]	-	Undamaged mode shape
F	-	Flexibility number
ΔF	-	Difference in flexibility
E	-	Young's modulus of concrete
MAC	-	Modal Assurance Criterion

COMAC - Coordinate Modal Assurance Criterion.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

For safety reasons and because of the economic benefits that can result, quantitative and objective condition assessment for infrastructure protection has been a subject of strong research within the engineering community. To achieve this aim, methodologies of the ordinary inspections with fixed intervals or the continuous monitoring, which provide constant information on safety reliability or remaining lifetime of the structure, have been under development in recent years. Inspection of structural components for damage is essential to take decisions about their repair or retirement. Visual inspection is tedious and often does not yield a quantifiable result (Hjelmtad & Shin 1996). For some components visual inspection is virtually impossible. Methods which are based on pure signal processing have only a limited capability for the early detection of damage and often do not allow unique conclusions to be drawn on the sources of the damage (Fritzen *et al.* 1998).

The importance and difficulty of the damage detection problem has caused a great deal of research on the quantitative methods of damage detection based upon physical testing. Among those physical tests, the use of the modal tests has emerged as an effective tool to use in damage detection. The possibility of using measured vibration data to detect changes in structural systems due to damage has gained

increasing attention (Agbabian *et al.* 1991; Natke & Yao 1998). The modal analysis method, one of many non-destructive methods, is based on the fact that the change of structural properties causes a variation in the different modal parameters; namely natural frequencies, damping ratios and mode shapes.

The types of damage that normally exist in civil infrastructure are cracking, corrosion, spalling and deterioration of material properties. Buildings, in recent years, have increased in height, and high-strength concrete is now used in construction instead of ‘‘normal” strength concrete. Unlike typical concrete, high-strength concrete has the dense internal system of pore structures, which causes spalling in fires (Hertz 1992; Han 1998; Han *et al.* 2005; Pierre *et al.* 2001). The spalling can be defined as a phenomenon in which the surface of the concrete scales and then falls off from the structure along with explosion at elevated temperature. Ultimately, spalling in high-strength concrete can result in the collapse of the reinforced concrete (RC) structure. Many researchers have pointed out that the occurrence of spalling in RC structures using high-strength concrete must be prevented.

It is well known that spalling is prone to occur under certain conditions, such as low water to cement ratios, high moisture content and exposure to abrupt increases in temperature (Han 1998; Selih Jana *et al.* 1994; Sanjayan & Stocks 1993). For compressive members, spalling of concrete can reduce the effective cross section of the concrete, thereby reducing the ultimate compressive load. At this condition, it can reduce the effective cross-section and also expose the reinforcement thus increase the risk to corrosion.

1.2 Problem Statement

Since most of the concrete structures have been constructed with normal strength concrete the concern about spalling has been neglected and the investigation related to spalling has not been fully investigated. However, nowadays as many concrete structures tend to be high-rise buildings; high strength and high performance concrete have been used extensively. Though study about spalling becomes a major concern, investigation in this area is scarce.

1.3 Research Objective

The objectives of the study are:

1) To apply modal properties to detect spalling in reinforced concrete slab.
2) To demonstrate frequency and mode shape as an indicator to detect damage.
3) To investigates the sensitivity of Flexibility index in detecting spalling.

1.4 Research Scope

A global damage detection technique which is flexibility method will be emphasised on this study as a solutions in finding the existing, exact location and severity of spalling. The examples will be modelled in finite element analysis software (ANSYS) by modelling a concrete slab that has two span and three supports. The spalling will be model by giving the Young's Modulus (E) = 0, to the elements which are assuming to be spalled. The vibration parameters such as natural frequencies and modes are obtained from modal analysis of finite element model.

These parameters are then used to determine the damage location and severity based using Flexibility index. In this study, several spalling cases will be used to demonstrate the applicability of modal parameters in detecting spalling. Flexibility method employing mode shapes will be used to indicate the damage. The results for each case study are presented in flexibility bar charts that used to provide location and severity of damage information.

1.5 Significance of the study

Benefits proposed research:

1) The dynamic properties may indicate the present of damage.
2) Spalling can be detected based on the changes of modal properties.
3) Maintenance works can be done accordingly based on the location and severity of spalling. Hence, performance of the structure can be maintained all the time.