CHAPTER 1 INTRODUCTION

1.1 GENERAL

Most civil engineering buildings and structures such as highway, railway bridges, water, gas, petroleum pipeline, electrical transmission towers, and offshore structural foundations are unavoidably experiencing deterioration and damage during operation. Many structures are now decaying because of age, deterioration, misuse, lack of repair, and in some cases, because they were not designed for load alteration. Structural damage causes weakening of the structure that negatively affects its performance, and it becomes crucial to appraise it in order to prevent potential catastrophic failure.

Current damage identification methods are either visual or localized experimental methods such as acoustic or ultrasonic methods, magnet field methods, radio-graphs, eddy-current methods and thermal field methods. All these require the vicinity of damage to be known in advance and the portion of the structure being inspected to be readily accessible. Subjected to these limitations, these identification methods can only detect damages on or near the surface of the structure. Moreover, the increase of size and complexity in today's structures also reduce the efficiency of these methods. To overcome these shortcomings, a damage identification method, which examines changes in the vibration characteristics of a structure is developed to provide a global way of evaluating the structural state of health. The underlying concept is that modal parameters namely natural frequencies, mode shapes and modal damping, are functions of the physical properties of the structure, which is mass, damping and stiffness. Thus any changes in physical properties will cause changes in modal properties.

In the past two decades, damage identification and health monitoring of structures, based on changes in their measured dynamic properties have become a popular topic in many researches. In 1993, a system of classification for damage identification methods, as presented by Rytter [37], defines four levels of damage identification:

Level 1 Determination of the presence of damage in the structure.
Level 2 Determination of the geometric location of the damage.
Level 3 Quantification of the severity of the damage.
Level 4 Prediction of the remaining service life of the structure.

Many practical theories which emphasized on Level 1, Level 2 and Level 3 have been developed to evaluate the state of the structure and to predict the damage location. Boltezar [7] and Nandwana [8] adopt an equivalent linear spring with its stiffness k to model a crack at a particular location of the structure. The value of k is assumed constant for all vibration modes and the intersection point of the stiffness at various natural frequencies ω_i along the axial direction of the beam would give the probable crack location. In another research, Narayana [5] directly used changes in natural frequencies to detect the crack location in a cantilever beam. The percentage change in natural frequencies of any vibration mode is dependent on the crack location and is a useful parameter to predict the location. Kim [10] formulated a crack location model and crack size by relating fractional changes in modal energy to changes in natural frequencies. The error index, $0 \leq e_{ij} < \infty$, is introduced as an indicator to locate the crack location. Yong Xia [39], on the other hand, proposed an index referred to as the probability of damage existence (PDE) in which the PDE is then estimated based on the probability of density functions of the stiffness at two states, namely the intact state and damage state. The value of PDE is 0 to 1, where the value close to 1 indicates the damage zone. Pandey [12] also presented a new parameter called the mode shape curvature as a possible parameter for identifying and locating damage in a structure. The analytical results from a vibrating cantilever and a simply supported analytical beam were used as examples in the study to illustrate the absolute changes in the mode shape curvatures, which are localized in the damage region. It was found that the change in mode shape curvature was proportional to the degree of severity. Meanwhile, Ratcliffe [13] adopted the same approach and applied a finite difference approximation of Laplace's differential operator to the mode shape. This operator, known as the Laplacian operator, successfully identified the location of the damage at lower modes with a high degree of severity.

In vibration testing or modal testing, the boundary condition is one of the major and influencing factors affecting the dynamic properties of a structure. Theoretically, boundary conditions are normally defined as either free or fully restrained in the modal testing [20]. Many researchers simulate the free condition by suspending the structure using very low stiffness materials or use a cantilevered beam, thus making the assumptions and equations used in modal analysis exact. However, these boundary conditions do not resemble the supports in actual structures. Therefore, it is imperative to investigate the effect of boundary conditions on damage identification techniques in order to evaluate its applicability to actual structures.

1.2 OBJECTIVE OF RESEARCH

The primary objective of this research is to identify damage in a homogeneous steel beam and to evaluate the effect of boundary conditions on frequency based and mode shape based damage identification techniques. Natural frequencies and mode shapes are used to ascertain the presence of damage, locate and obtain severity of the damage caused by a single crack. Subsequently, the damage identification technique was used for a dual crack damage scenario to verify its applicability. Finally a finite element (FE) model was prepared and model updating was performed so as to obtain agreement with results from experimental modal analysis. A new damage identification technique is proposed by utilizing results from both the experimental and FE modal model.

1.3 SCOPE OF WORK

In this study, two uniform straight beams were used as test specimens, and the beams were tested on different boundary conditions namely the free-free, spring and fixed roller supported. Subsequently, single saw cut and dual saw cut were introduced to each beam to stimulate an open crack at the soffit of the beams. The depth of cut was increased in order to give different levels of severity of damage on the beam.

Modal testing was conducted on intact and damaged beams, and the response data for the first six flexural modes and the first five torsional modes were acquired using the transfer function technique. The measured natural frequencies, mode shapes and modal damping were used to investigate the effect of boundary conditions. Subsequently, the frequency based and mode shape based damage identification techniques were implemented to evaluate the structural state. The change in natural frequencies, curvature mode shapes, modal assurance criterion (MAC) and coordinate modal assurance criterion (COMAC) as damage indicators were used to evaluate and identify the crack location. A new algorithm for damage identification was proposed, which combined the Laplacian operator (LO) with the geometry mean operator (GMO). Finally, the analytical models of the free-free and fixed roller supported beams using finite element (FE) modeling were prepared. The modal data for the updated finite element model were combined with the experimental results to prodive a new damage identification method.