Damage Pattern of Reinforced Concrete Beams Based on the Flexibility Matrix

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Abstract

In this study, the damage patterns of reinforced concrete beams based on the modal flexibility matrices are investigated and discussed. The study is carried out on the experimental modal data of four reinforced concrete beam specimens were gradually damaged until failure state. Two of the specimens were strengthened with externally bonded CFRP sheets when load reached approximately half of the predicted failure load. The damage patterns of the specimens are obtained by the changes of modal flexibility matrices before and after damage. To improve the damage patterns, a new method is proposed based on the flexibility matrices and the Ritz vectors. The consistency of the proposed damage pattern with experimental observations is discussed. The proposed method based on the Ritz vectors agrees well with the state of damage developments in the reinforced concrete beams. The loss of the stiffness along the length of beam specimens and the effectiveness of CFRP strengthening can be estimated by the proposed method.

Keywords: damage pattern, concrete beam, flexibility matrix, modal data.

1. INTRODUCTION

In the new industrial societies, there are increasing demands for infrastructures such as bridges. Over the years, these structures suffer severe strength and stiffness reduction due to deterioration, accidental loads, natural hazards and lack of repair. The damage affects the performance and the serviceability of the structures. Thus identifying the damage and maintaining the serviceability of the structures became conspicuous problem in structural engineering. For damage identification, numerous nondestructive damage detection (NDD) methods have been developed. Some of the NDD methods, such as ultrasonic, radiography, magnetic particle and dye penetrate apply to a specific portion of the structures [1]. The increased size and complexity of today's structures reduce the efficiency of these methods. Vibration based identifying methods are more efficient and aim at detecting, locating and quantify the damage of the entire structure. The vibration based methods utilize the dynamic response of the structure including changes in modal parameters (frequencies, mode shapes and damping ratios). Damage identification methods based on dynamic characteristics have attracted much attention in recent years. The attractiveness of these approaches can be attributed to the fact that dynamic characterization of the structure, in many cases, is easier to perform in the field than static characterization. The vibration based methods have been developed increasingly and there are a wide range of scientific literatures that dealing with this subject. From these scientific literatures, it is well recognized the methods that utilize the mode shapes are more efficient in damage identification. To show the damage localization and severity, the mode shapes must be analyzed and rearranged in appropriate form. For this purpose, the methods such as strain mode shapes, strain energy and flexibility matrices have been proposed.

There are many damage detection methods that were proposed based on the modal data. Betti [2] in 2005 points out that no single approach for all situations and with respect to linear or non-liniear, time domain or frequency domain and time varying or time-invariant, the appropriate method should be applied. According to Doebling et al. [3] the sensitivity of modal parameters (natural frequencies, damping ratios and mode shapes) to identify and locate the damage not equal to each other. An ideal robust damage detection scheme should be able to identify damage at a very early stage, locate the damage, provide some estimate of the extent or severity of the damage and predict the remaining useful life of the structural component in which damage has been identified [3]. Some of the damage detection methods were found not to be effective in locating the damage. Therefore, modifications on these methods should be proposed to overcome this problem.