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Experimental evaluation of damage effect on dynamic characteristics of concrete encased composite column-beam connections

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ABSTRACT

A major defect in determining the structural response for concrete encased composite columns using finite element is due to the uncertainties and assumption associated with the modeling process. Therefore, experimental measurements should be performed in order to validate the numerical results as well as obtain the real structural response. This paper seeks to address an experimental study about the evaluation of damage effect on the dynamic vibration characteristics of concrete encased composite columns (CECC) considering different column-beam connection types using ambient vibration tests. In an attempt to do so, four half scale concrete encased composite column-steel beam were built and tested in the laboratory with different column-beam connection types abbreviated as CECC-A, CECC-B, CECC-C and CECC-D without any changes in geometrical configuration of specimens and test setup. Cyclic loading tests were conducted in order to assess the post damage condition, while ambient vibration test were performed to extract the experimental dynamic characteristics such as natural frequencies, mode shapes and damping ratios using Enhanced Frequency Domain Decomposition (EFDD) and Stochastic Subspace Identification (SSI) methods for both undamaged (intact) and damaged conditions. The natural frequencies have decreased distinctly and mode shapes were broken with damages. These tests revealed that ambient vibration tests are enough to identify the dynamic characteristics of engineering structures for different conditions. The maximum differences in natural frequencies were calculated between 21.72% and 39.96%. A good agreement was noted for undamaged condition, the mode shapes were identical and the Modal Assurance Criterion (MAC) had value of 1.0. In contrast, there was not a good agreement for post damage condition. The mode shapes were different and MAC values were close to zero. Lastly, as the experimental damping ratios were examined, the results supported the idea that there were some differences and the values did not correlate favorably. These results are the compatible with the literature, but it is thought that the differences typically indicate that higher excitation levels are required to accurately capture the damping ratios.

1. Introduction

The application of steel and concrete in the same section as structural elements which are also known as composite structural members goes to decades ago. Composite structural elements provide the combined behavior of two or more structural materials such

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as steel and concrete. Due to sufficient structural performances such as high stiffness, enough strength, good ductility and large energy absorption capacity, composite steel-concrete structural members are used in vertical and horizontal structural elements widely in recent years [19].

Concrete encased composite columns constructed from the encasing of I, H, pipe or tube steel profile in reinforced concrete columns are one of the best composite structural elements in vertical bearing systems. When the encased steel composite section is tube or circular hollow, it is named as concrete encased concrete filled steel tube section. The main advantages of these types of columns are, having high stiffness and enough strength with small cross section in comparison to other types. In addition, the fire resistance of these types of columns is higher than conventional steel and concrete columns, because the encased profile is fully covered with a concrete layer [36]. Another remarkable advantage which should not be ignored is the corrosion resistance of these columns. Using such types of columns is preferred in ashore areas. On the other hand, the big disadvantage of the concrete encased composite column is the difficulty associated with its construction.

Determination of structural response for concrete encased composite column using finite element analysis is very difficult because of many uncertainties and assumptions in the modeling process. Therefore, non-destructive experimental measurements should be performed to validate the numerical results and/or to obtain the real structural behavior. Ambient vibration based operational modal analyses method is one of the most efficient and useful tool which can be easily applied for these sort of structures.

Many numerical and experimental researches have been conducted in order to evaluate the structural performance of concrete encased composite columns. An and Han [5] studied the behavior of concrete-encased CFST columns under combined compression and bending. It is inferred that the column-beam connection zones show best performance in lateral dynamic loads such as earthquake, wave or wind. This phenomenon is studied by many researchers with respect to cyclic loading considering different types of connection details [8,10,15,16,24,28–30,34]. Ren et al. [26] conducted an experimental study to determine the performance of concrete encased concrete filled steel tube columns under compression and torsion at the same time. Chen et al. [9] presented a detailed study related to depth ratio of encased profile which is directly affecting the flexural ductility of the composite columns. A series of experimental tests were carried out for post fire behavior of composite structural elements to investigate the efficiency of exterior concrete cover [32,33]. Although a great deal of studies related to concrete encased composite columns, beams and connection types are available, there are no enough researches regarding evaluation of the dynamic characteristic of composite structures based on ambient vibration test results.

The rest of the paper is laid out as follows: Section 2 summarizes the basic formulation of ambient vibration test using Enhanced Frequency Domain Decomposition (EFDD) and Stochastic Subspace Identification methods (SSI) with Modal Assurance Criterion (MAC) value. Section 3 presents a brief test setup, column-beam connection type and loading protocol with its geometric configuration. Section 4 presents the modal characterization of the composite columns by means of experimental measurements. This section is also devoted to discussion and comparison of results. Finally, Section 5 draws the main conclusions of this study.

2. Formulation

2.1. Ambient vibration test

2.1.1. Enhanced frequency domain decomposition (EFDD) method

EFDD method is an extension of FDD technique. In this method, modes are simply picked locating the peaks in singular value decomposition plots calculated from the spectral density spectra of the responses. In EFDD, the single degree of freedom (SDOF) Power Spectral Density (PSD) function that is identified around a peak of resonance, is taken back to the time domain using the Inverse Discrete Fourier Transform. The natural frequency is obtained by determining the number of zero-crossing as a function of time, and the damping by the logarithmic decrement of the corresponding SDOF normalized auto correlation function [17]. In EFDD method, the relationship between the unknown input and the measured responses can be expressed as [7,17]:

$$[G_{yy}(\omega)] = [\overline{H}(\omega)][G_{xx}(\omega)][H(\omega)]^T \tag{1}$$

where G_{xx} is the $r \times r$ Power Spectral Density (PSD) matrix of the input of which r is the number of inputs, $G_{yy}$is the $m \times m$ PSD matrix of the responses of which m is the number of responses, $H(\omega)$ is the $m \times r$ Frequency Response Function (FRF) matrix, and $\overline{H}(\omega)$ and superscript T denotes complex conjugate and transpose, respectively. Solution of Eq. (1) is given in details in the literature [14,21,25,27].

2.1.2. Stochastic subspace identification (SSI) method

SSI is an output-only time domain method that directly works with time data, without the need to convert them to correlations or spectra. The model of vibration structures can be defined by a set of linear, constant coefficient and second-order differential equation [22]:

$$[M]\{\ddot{U}(t)\} + [C_2]\{\dot{U}(t)\} + [K]\{U(t)\} = \{F(t)\} = [B_2]\{u(t)\} \tag{2}$$

where $[M]$, $[C_2]$, $[K]$ are the mass, damping and stiffness matrices, $\{F(t)\}$ is the excitation force vector, and $\{U(t)\}$ is the displacement vector depending on time t. Observe that the force vector $\{F(t)\}$ is factorized into a matrix $[B_2]$, describing the inputs in space, and a vector $\{u(t)\}$. Solution of Eq. (2) is given in detail in the literature [11,18,35].