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# Ambient vibration based seismic evaluation of isolated Gülburnu highway bridge

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ABSTRACT

This paper describes ambient vibration based seismic evaluation procedure of an isolated highway bridge. The procedure includes finite element modeling, ambient vibration testing, finite element model updating and time history analysis. Gülburnu Highway Bridge located on the Giresun–Espiye state highway is selected as a case study. Three dimensional finite element model of the bridge is created by SAP2000 software to determine the dynamic characteristics analytically. Since input force is not measured, Operational Modal Analysis is applied to identify dynamic characteristics. Enhanced Frequency Domain Decomposition and Stochastic Subspace Identification methods are used to obtain experimental dynamic characteristics. Analytical and experimental dynamic characteristic are compared with each other and finite element model of the bridge is updated by changing of material properties to reduce the differences between the results. Analytical model of the bridge after model updating is analyzed using 1992 Erzincan earthquake record to determine the seismic behavior. EW, NS and UP components of the ground motion are applied to the bridge at the longitudinal, transverse and vertical directions, respectively. It is demonstrated that the ambient vibration measurements are enough to identify the most significant modes of highway bridges. Maximum differences between the natural frequencies are reduced averagely from 9% to 2% by model updating. It is seen from the earthquake analyses that friction pendulum isolators are very effective in reducing the displacements and internal forces.



## 1. Introduction

Finite element analyses of important engineering structures such as highway bridges are performed in the design phase by experienced engineers to determine the structural behavior. However, material properties, boundary conditions and section properties accepted in the analyses can be changed by some reasons such as workers' mistakes while construction, different load cases to be exposed to the structure in the course of time which is not considered in the design, the difficulty in defining the exact material properties and the difficulty in matching the true connection behavior. So, performance of such bridge has to be controlled with the help of field testing or experimental measurements.

It is generally known that natural frequencies and mode shapes obtained from field testing do not coincide with those of the analytical model. The problem of how to modify the analytical model from the dynamic measurements is known as the model updating in structural dynamics [1]. The main purpose of the model updating procedure is to minimize the differences between the analytically and experimentally determined dynamic characteristics by changing some uncertainty parameters such as material properties or boundary conditions.

In the literature, there are some studies related to finite element modeling and experimental measurements of highway bridges. Bayraktar et al. [2] determined the dynamic characteristics of Kömürhan Highway Bridge located on Elazığ–Malatya highway in Turkey using finite element analyses and ambient vibration tests. Whelan et al. [3] studied on real time wireless vibration monitoring of a bridge with single span integral abutment using operational modal analysis in service condition. Liu et al. [4] investigated finite element analyses, field measurements using ambient vibration tests and seismic evaluation of a three-span highway bridge subjected to a virtual ground motion. Kwasniewski et al. [5] presented an experimental study for a preselected typical highway bridge. Static and dynamic field tests were performed on a two-lane concrete highway bridge. During the tests, one or two fully loaded trucks crossed over the bridge, which was instrumented with strain gauges, accelerometers, and displacement transducers. Feng et al. [6] applied a neural network based system identification technique to a highway bridge using

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experimental measurements under ambient vibrations such as traffic loads. Brownjohn et al. [7] studied on assessment of highway bridge upgrading by dynamic testing and finite element model updating. Zhao and DeWolf [8] performed the dynamic monitoring of steel girder highway bridge using modal flexibility approach. It can be seen from the literature that there is no enough studies about finite element analyses, experimental measurements and seismic evaluation of base isolated and post-tensioned segmental highway bridges constructed with balanced cantilever method.

The objective of this study is to investigate seismic evaluation of a base isolated and post-tensioned segmental highway bridge constructed with balanced cantilever method using operational modal testing in service condition. Gülburnu Highway Bridge is chosen as an application. Three dimensional finite element model of the bridge is created by using SAP2000. Ambient vibration tests are performed and experimental dynamic characteristics are extracted using Enhanced Frequency Domain Decomposition and Stochastic Subspace Identification methods. Finite element model of the bridge is updated by changing of material properties to eliminate the differences between analytical and experimental dynamic characteristics. Seismic behavior of the bridge is determined using 1992 Erzincan earthquake ground motion records after model updating.

**Table 1**
Classification of some relevant output-only identification algorithms [10].

| | Method | Characteristics |
|---|---|---|
| Frequency domain | Peak Picking (PP) | Classical SDOF method |
| | Frequency Domain Decomposition (FDD) | MDOF method; application of SVD to reduce noise |
| | Enhanced Frequency Domain Decomposition (EFDD) | MDOF method; application of SVD to reduce noise |
| | Polimax | MDOF method |
| Time domain | Random Decrement (RD) | Operates on time domain series, leading to a free decay curve analysis |
| | Recussive Techniques (ARMA) | Time series modeling using recursive algorithms |
| | Maximum Likelihood Methods | Stochastic methods based on the minimization of a covariance matrix |
| | Stochastic Subspace Identification Methods (SSI-DATA) | Stochastic methods based on the project of state vector on a vector of past realizations |

**Table 2**
Comparison of advantages and disadvantages of the EFDD and SSI methods.

| **Parameters** | **Enhanced Frequency Domain Decomposition (EFDD)** | **Stochastic Subspace Identification (SSI)** |
|---|---|---|
| Transform tool | FFT | FFT |
| Computation time | Very fast | Slow |
| Analysis domain | Frequency | Time |
| *Modal parameters* | | |
| Stabilization diagram | No | Yes |
| Natural frequencies | Good | Very good |
| Mode shapes | Good | Good |
| Damping ratios | Unreliable | Reliable |

## 2. Formulation

Ambient excitation does not lend itself to Frequency Response Functions (FRFs) or Impulse Response Functions (IRFs) calculations because the input force is not measured in an ambient vibration test. Therefore, a modal identification procedure will need to base itself on output-only data [9]. There have been several modal parameter identification techniques available which are developed by improvements in computing capacity and signal processing techniques. These techniques include the Enhanced Frequency Domain Decomposition (EFDD) method from the Power Spectral Densities (PSDs), Auto Regressive Moving Average (ARMA) model based on discrete-time data, natural excitation technique (NExT), Stochastic Subspace Identification methods (SSI) and maximum likelihood frequency domain methods. Classification of some relevant output-only identification algorithms is given Table 1.

**Fig. 1.** Some views of Gülburnu Highway Bridge.

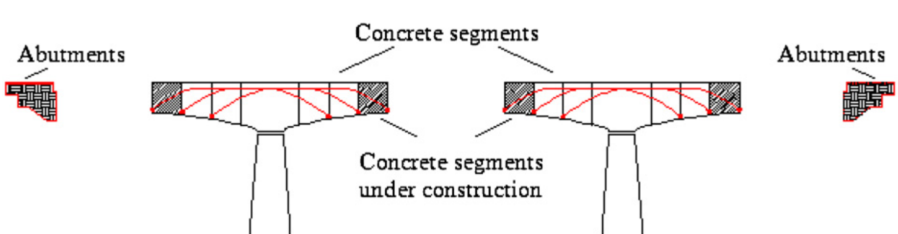


**Fig. 2.** Schematic drawing of balanced cantilever construction.