Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 51(6) (2020)339-342
DOI: 10.22060/ceej.2018.14331.5625

Structural system identification of elevated steel water tank using ambient vibration test and validation of numerical model

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ABSTRACT: The present research aims to investigate the feasibility of using ambient vibration tests for system identification of elevated water tank. To this end, the elevated water tank located in Tarbiat Modares University (TMU) campus is utilized. The tank is instrumented with a sensitive velocimeter sensor and the ambient velocity of the tank is recorded for 30 minutes in three perpendicular axes. The amplitude of the velocity signal reaches to about 30 mm/s. Using the peak picking method, the fundamental frequency of the tank is determined about 1.9 Hz. Although, considering the non-perfect symmetry of the tank and the misaligned orientation of the sensor, the obtained values in two lateral directions differ 5%. Then, the numerical model of the tank is prepared in software and calibrated. In the primary modeling, the values of natural frequencies of the tank are in good agreement with the results of the ambient vibration data. It shows the calibration of the numerical model which can be used in the assessment of the seismic behavior of the elevated water tank.

Review History:

Received: 4/16/2018
Revised: 5/21/2018
Accepted: 6/20/2018
Available Online: 6/23/2018

Keywords:

System identification
Elevated water tank
Ambient vibration test
Peak picking method
Model calibration.

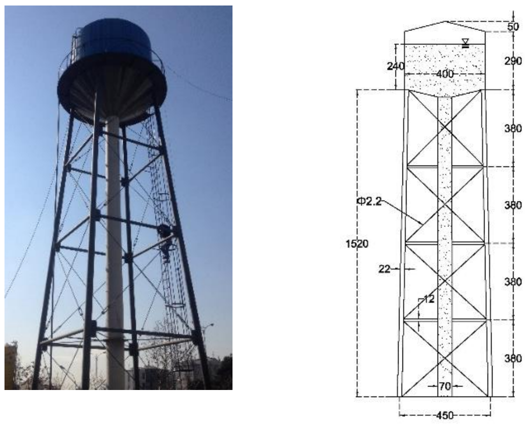
1. INTRODUCTION

Elevated water tanks are broadly used for water supply in industrial and residential areas. They are normally constructed from steel shell supported by a space steel frame. These structures which have a performance like inverted-pendulum systems, are usually idealized by single-degree-of freedom structures. Their seismic response has been previously investigated considering many affecting parameters including their flexibility, soil-structure and water-structure interactions [1-7].

System identification is a branch of engineering science in which the main properties of engineering systems are identified. In structural engineering, these main parameters are essentially the dynamic properties of civil structures such as natural frequencies and mode shapes [8]. Practically, the ambient vibration tests are utilized for the system identification of large full-scale structures considering the output-only algorithms [9]. In this paper, the system identification of an elevated steel water tank is done using the ambient vibration tests. Then its numerical model is constructed and validated using the obtained results.

2. THE SELECTED WATER TANK

The elevated steel water tank inside the Tarbiat Modares University campus is selected (Figure 1a). This elevated tank is located near Chamran highway. Its outer diameter is about 400 cm, and its height is 290 cm.



(a) (b)

Fig. 1. (a) The selected water tank, (b) the longitudinal section (all dimensions are in cm).

It is supported by a space frame with hollow circular sections with 4mm thickness. Its longitudinal section is shown in Figure 1b. All connections are rigid except the connection of the rod braces which are pinned. The main water pipe has a circular hollow section with the outer diameter of 70 cm and thickness of 3 mm.

3. Ambient vibration test

For the ambient vibration tests, a very sensitive seismic velocimeter is utilized. It has three input channels along the

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Fig. 2. The data acquisition system.

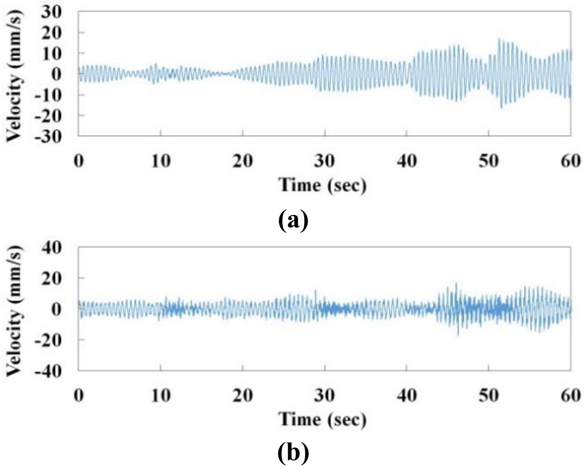

Fig. 3. A sample of the velocity data in (a) north-south, and (b) east-west direction.

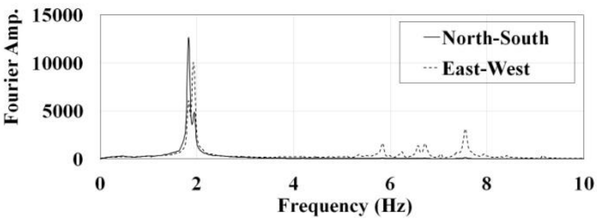

Fig. 4. The averaged Fourier curves in lateral directions.

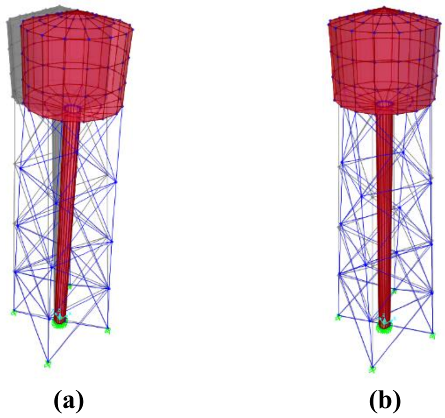

Fig. 5. The mode shapes of the elevated tank from numerical modeling. (a) 1st mode, (b) 2nd mode.

Cartesian coordinates. It is connected to a data-logger system that logs the velocity data with 24 bit A/D conversion. The data acquisition system is located beside the tank such that one of the channels is directed in north-south direction along the main axis of the space frame. It is shown in Figure 2.

The ambient vibration of the tank structure is because of the daily traffic of the near highway as well as wind blowing with the speed of 18 km/h. The total duration of data logging is about 30 minutes with the sampling rate of 200 sps. A high-pass filter the cut-off frequency of 0.1 Hz is applied to the data during the logging process.

4. THE RESULTS OF THE AMBIENT VIBRATION TEST

The ambient velocity data are acquired in the two lateral directions of the structure as well as the vertical one. A part of the sampled data in the two perpendicular directions are shown in Figure 3. The amplitude of the velocity may reach up to 30 mm/s which is considerable for civil engineering structures.

For extracting the dynamic properties of the tank, mainly the natural vibration frequencies, the peak-picking method is utilized. In this method, the Fourier transform of the recorded data is computed and the resulted peaks are designated as the natural frequencies of the system. For this purpose, first the full 1800 s recorded data are divided into the smaller sections of 81.92 sec with 2^{14}=16384 dada points using the Hanning moving window. The cover between the two adjacent windows is considered as half of the window. Hence the total record is divided into 22 smaller records. The Fourier transform of the smaller 22 records are averaged in the frequency domain, the resulted curves are shown in Figure 4. The main peak of the system in both lateral directions is located around 1.83 Hz, while the second peak which is very close to the first one is around 1.95 Hz. They can attributed to the fundamental vibration mode of the system in lateral directions. Although, considering the non-perfect symmetry of the tank and the misaligned orientation of the sensor, the obtained values in two lateral directions differ 5%. Higher peaks more than 5 Hz are observed only in east-west directions.

5. NUMERICAL MODELING AND VALIDATION

Base on the properties of the tank, it is numerically modeled using SAP2000 software. The tank itself is modeled using the linear shell elements. The results of the frequency extraction analysis are shown in Figure 5.

The first vibration mode of the system is two lateral direction is 2.05 Hz which is comparable with the results of the field tests. The higher system frequency is computed as 6.70

Hz which has a torsional mode shape. It is also comparable with the results of the field tests.

6. CONCLUSIONS

The present research aims to investigate the feasibility of using ambient vibration tests for system identification of elevated water tank. To this end, the elevated water tank located in TMU campus is utilized. The tank is instrumented with a sensitive velocimeter sensor and the ambient velocity of the tank is recorded for 30 minutes in three perpendicular axes. The amplitude of the velocity signal reaches to about 30 mm/s. Using the peak picking method, the fundamental frequency of the tank is determined about 1.9 Hz. Then, the numerical model of the tank is prepared in software and calibrated. In the primary modeling, the values of natural frequencies of the tank are in good agreement with the results of the ambient vibration data.

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HOW TO CITE THIS ARTICLE

M. Alembagheri, tank using ambient vibration test and validation of numerical model, Amirkabir J. Civil Eng., 51(6) (2020) 339-342.

DOI: 10.22060/ceej.2018.14331.5625