Comparisons of Three Different Sensors in Different Ambient Vibration Measurements

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***Abstract*—The accuracy of the vibration measurements is directly related to testing equipment. There are some reasons that affect the performance of instruments like sensitivity, internal noise level, temperature, pressure etc. The influence of instruments should be considered in vibration recordings. There are too many products on the market. For the researchers, the main struggle is to decide which sensors or digitizers or their combinations should be used for the defined study aim or the equipment which they have is suitable or not for their purpose of the study. There are limited studies in this field in the literature. In this study, three different sensors were compared in the frequency domain, a seismometer and two different accelerometers. The seismometer is Guralp CMG-6TD (G6), one of the accelerometers is Guralp CMG-5TCDE (G5) and the other one is TDG Sensebox-7021 (TDG). The measurements were conducted in a four-story, residential reinforced concrete (RC) frame building. G6 and G5, G5 and TDG were compared to each other in two different measurements. As a result of this study, in all comparisons, the first mode's frequencies were very close to each other and the frequency spectrums which established by means of the compared instruments were quite similar to each other.**

***Index Terms*—ambient vibrations, building frequency, sensors, operational modal analysis**

I. Introduction

Ambient vibration records are used for both determining dynamic characteristics of structures and site effect estimation. In ambient vibration test, the structural response is subjected to the ambient noise present in the environment [1] [2]. Ambient noise, which occurs in a wide range of frequencies, can be caused by microtremors, wind, traffic etc. It is believed that forced vibration tests provide more accurate results compared to the ambient vibration test due to the larger amplitudes of vibrations [3].

The most widely used technique in site effect estimation is the H/V ratio technique proposed by [4]. The H/V ratio technique is commonly used in micro-zonation projects to identify site effects, the technique is considered as giving a good estimation of the fundamental resonance frequency by many authors [5], [6], [7], [8]. Although, Mucciarelli [7] and Guillier, Atakan et al. [9] were conducted tests with different seismological equipment in order to reveal the influence of equipment on the results of H/V spectral ratios, there are limited studies about the effect of instruments on the ambient vibration measurements. Guillier, Atakan et al. [9] have tested and compared a total of 12 digitizers and 18 sensors (accelerometers and seismometers) and resulted that digitizers are generally accurate whereas the sensor influence is more complex and can cause some troubles.

The accuracy of the vibration measurements is directly related to testing equipment. There are some reasons that affect the performance of instruments like sensitivity, internal noise level, temperature, pressure etc. The influence of instruments should be considered in vibration recordings. There are too many products in the market. For the researchers, the main struggle is to decide which sensors or digitizers or their combinations should be used for the defined study aim or the equipment which they have is suitable or not for their purpose of the study.

In this study, three different sensors were compared in the frequency domain, a seismometer and two different accelerometers. The seismometer is Guralp CMG-6TD (G6), one of the accelerometers is Guralp CMG-5TCDE (G5) and the other one is TDG Sensebox-7021 (TDG). The measurements were conducted in a four-story, residential reinforced concrete (RC) frame building. G6 and G5, G5 and TDG were compared to each other in two different measurements. The aim of the study is firstly to establish that whether these three sensors can be used for determining the dynamic characteristics of reinforced concrete (RC) buildings which their fundamental frequencies around five hertz or not. The second purpose is to state the advantages and the disadvantages of the investigated instruments compared to each other.

II. Study Area

The measurements were carried out in a four-story, residential RC frame building which is located in Eskisehir, Turkey. The investigated building shown in Figure 1 which the seismic loads are jointly resisted by frames and structural walls. There are only one structural wall along longitudinal direction and four structural walls along transverse direction of the building. The floor area of the building is 400 m2 and story heights are 2.83 m.

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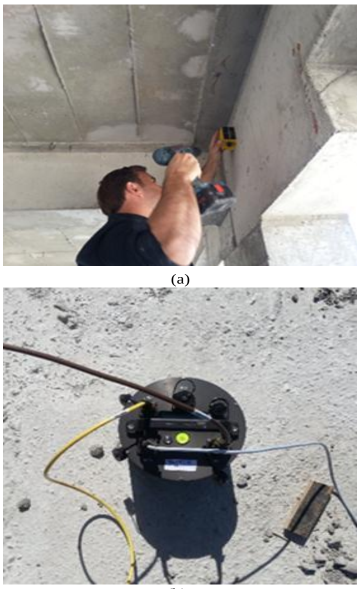
Figure 1. General view of the building

III. Materials and Methods

Two ambient vibration measurements were conducted in order to compare three different sensors. The first measurement (M1) was carried out when the infill walls of the building were constructed. Two accelerometers, Guralp CMG-5TCDE (G5) and TDG Sensebox-7021 (TDG) were used simultaneously in the M1. Eight of TDG sensors and four of G5 sensors were placed to the corners of the building at the last floor. TDG sensors were fixed to the columns by bolts while the G5 sensors just were put on the floor without mounting see Figure 2. The second measurement (M2) was conducted when the infill walls plastered with gypsum. The seismometer Guralp CMG-6TD (G6) and the accelerometer G5 were used simultaneously in the M2. The same layout was applied with the M1 and both the G5 and G6 sensors put on the floor at the four corner of the building without mounting. The G5 and the G6 sensors are shown in Figure 3. Some technical specifications of all three sensors are shown in Table 1.



(a)

(b)

Figure 2. Test layout of M1 (a) TDG sensor, mounted to the columns (b) G5 sensor, put on the floor

Figure 3. The G5 and the G6 sensors located at the same place

TABLE I. Summary of the Specifications of the Sensors

Code	TDG	G5	G6
Producer	TDG	Guralp Systems	Guralp Systems
Number of axis	1	3	3
Type	F-B Accelerometer	F-B Accelerometer	F-B Velocity Sensor
Operating Temperature	-40 to +65 ℃	-20 to +75 ℃	-20 to +65 ℃
Sampling Rate	200 Hz	100 Hz	100 Hz
Output Sensitivity	±3g	±4g or ±0.1g	2400 V/ms^{-1} (2*1200 V/ms^{-1})
Digitizer	Separate 24-Bit	On-board 24-Bit	On-board 24-Bit
Data Storage	External Disk	Internal Disk	Internal Disk

IV. Results and Discussions

In the first measurement (M1), it is observed that the power spectrums of both recordings conducted by TDG and G5 are quite similar to each other. The power spectrums are shown in Figure 4. There are two clear peaks in the spectrums, which represent the first two modes of the building. According to results, the difference between two frequencies obtained by the TDG and the G5, which represent the first mode of the building, is 0.93%. The difference between the second mode frequencies is 1.06%. The ratios are calculated by taking the G5 as reference see Table II.

TABLE II. Comparison of the Measured Frequencies in M1

	1.Mode Frequency (Hz)	2.Mode Frequency (Hz)	3.Mode Frequency (Hz)
(a) G5	4.29	5.62	-
(b) TDG	4.25	5.56	-
(%) (b-a)/a	- 0.93	- 1.06	-

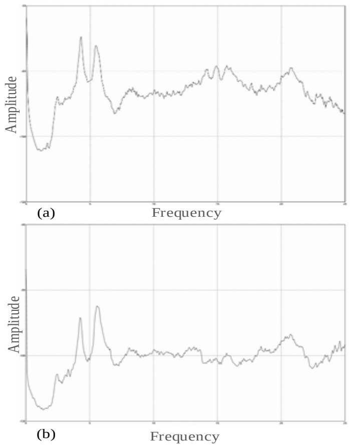


Figure 4. Power spectrum of: (a) G5 in M1; (b) TDG in M1

The results are very similar to each other and they seem satisfactory to determine the dynamic characteristics of the building. Among this, the main difference in two sensors is the practicality of the application. The G5 sensors have their own digitizers on-board and also internal hard disks contrary to the TDG. The TDG needs a separate digitizer for data acquisition and a computer for data storage. Additionally, the TDG sensors should be connected to the digitizer with cables and the sensors have to be fixed to the structural elements. These setups need considerable amount of time. The G5 sensors need GPS synchronization in order to get vibration signals simultaneously. TDG sensors do not need GPS synchronization because they are connected to the digitizer and a computer, take the computers time to operate simultaneously. GPS synchronization sometimes generates trouble according to buildings location and conditions. Obviously, being uniaxial of TDG sensors is another disadvantage for practicality. Due to this, in M1, while four tri-axial G5 sensors were used, which supply 12 channels of data, eight TDG sensors were used which supply eight channels of data. There was no vertical data in TDG measurements.

In the second measurement (M2), it is seen that the power spectrums of both recordings conducted by G5 and G6 are similar to each other. The power spectrums are shown in Figure 5. There are three clear peaks in the spectrums, which represent the first three modes of the building. According to results, the difference between two frequencies obtained by the G5 and the G6, which represent the first three modes of the building, is zero see Table III.

TABLE III. COMPARISON OF THE MEASURED FREQUENCIES IN M2

	1.Mode Frequency (Hz)	2.Mode Frequency (Hz)	3.Mode Frequency (Hz)
(a) G6	4.54	5.86	6.15
(b) G5	4.54	5.86	6.15
(%) (b-a)/a	0	0	0

In operational manner, which has discussed above for the M1, there is no difference between the G5 and the G6 sensors. The G6 sensors have same features with the G5 sensors. Obviously, the main difference is being of G6 is a seismometer and the G5 is an accelerometer. Two sensors were compared to each other according to their signal to noise ratios (SNR) in the M2. SNR graphic of the G5 record is shown in Figure 6 and the SNR graphic of the G6 record is shown in Figure 7. SNR of the seismometer (G6) is higher than the accelerometer (G5).

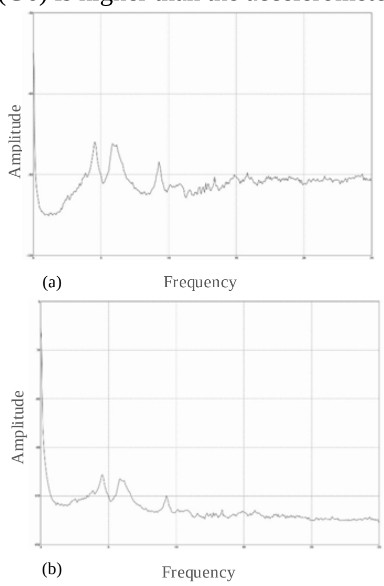


Figure 5. Power spectrum of: (a) G5 in M2; (b) G6 in M2

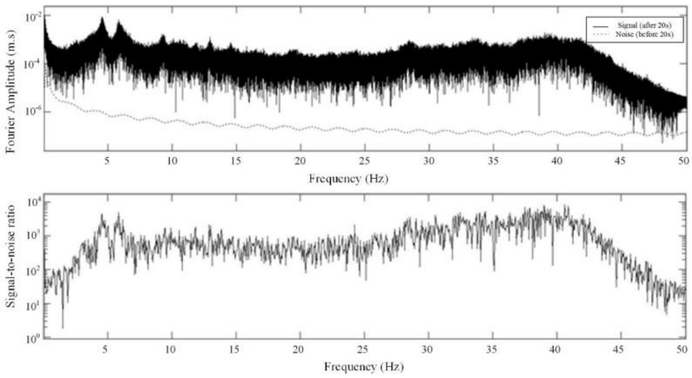


Figure 6. SNR graphic of the G5 record

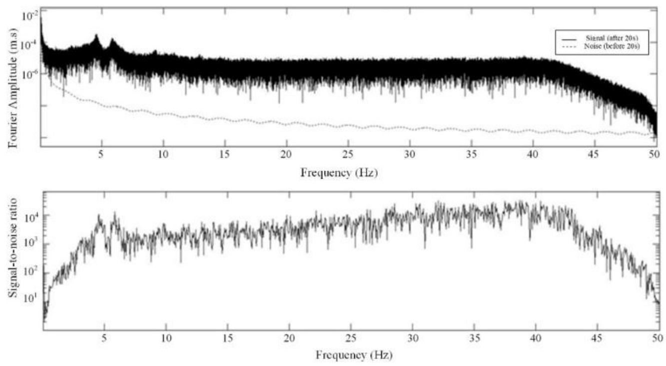


Figure 7. SNR graphic of the G6 record

V. CONCLUSIONS

In all comparisons, the first mode's frequencies were very close to each other and the power spectrums, which established by means of the compared instruments were quite similar to each other. It is understood from the results that, all of the three investigated sensors are capable to determine the dynamic characteristics of the RC buildings which their fundamental periods around five hertz (short and rigid RC frame buildings). The G5 and the G6 sensors are relatively more practical than the TDG sensors in operational manner. There can be some situations, where the TDG sensors are more useful due to their relatively small size and being fixable to the vertical surfaces. It is also concluded that the signal to noise ratio of the G6 seismometer is higher than the G5 accelerometer.

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