allow it for longitudinal displacement. Material properties are assigned to be; Young's Modulus (E) = 3.3 MPa, weight density (ρ) = 2.498 t/m^3 and Poisson ratio (v) = 0.166667 whereas, the effects of pre-stressing force are considered to be zero. Figure 10 shows the plotted model of the bridge.

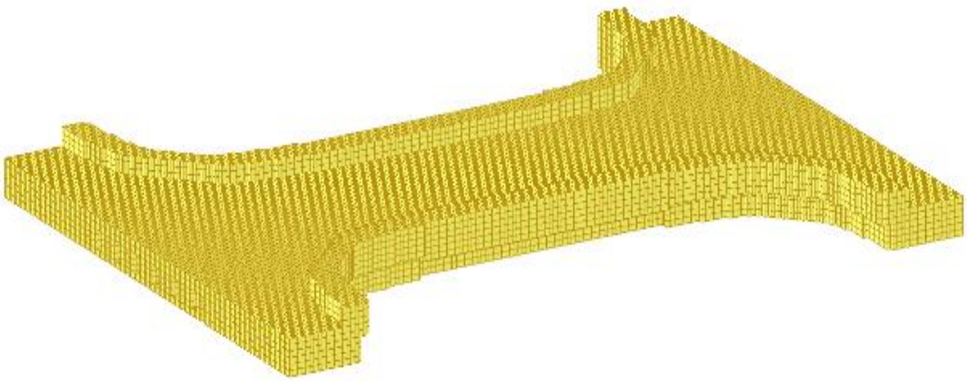

Fig. 10 Numerical model of the bridge deck

6.1.1 Numerical Result

In the numerical analysis, the first four mode shapes, associated with natural frequencies obtain from eigenvalue analysis that illustrate intact (pre-damage) state of the bridge are presented in Fig. 11. The fundamental mode is the vertical bending mode of the deck with the impact vibration on the center that corresponds to the natural frequency of 7.61 Hz. Table 1 shows that all the four modes are involved in the deck vibration and most included coupled vertical bending and torsional modes of the bridge deck. It should be recalled that damage increases flexibility of a structure, unlike decreases natural frequency stated by (Sridhar and Prasad 2019). Therefore, FE model represents the as-built sate of the structure by showing higher values of numerically plotted natural frequencies than those experimental obtained through accelerometers and microtremors.

Table 2 Numerical natural frequencies

Mode	Experimental (Hz)	Numerical (Hz)	Frequency difference (%)
#1	6.71	7.61	11.82
#2	16.7	18.81	11.21
#3	-	28.05	-
#4	-	38.28	-

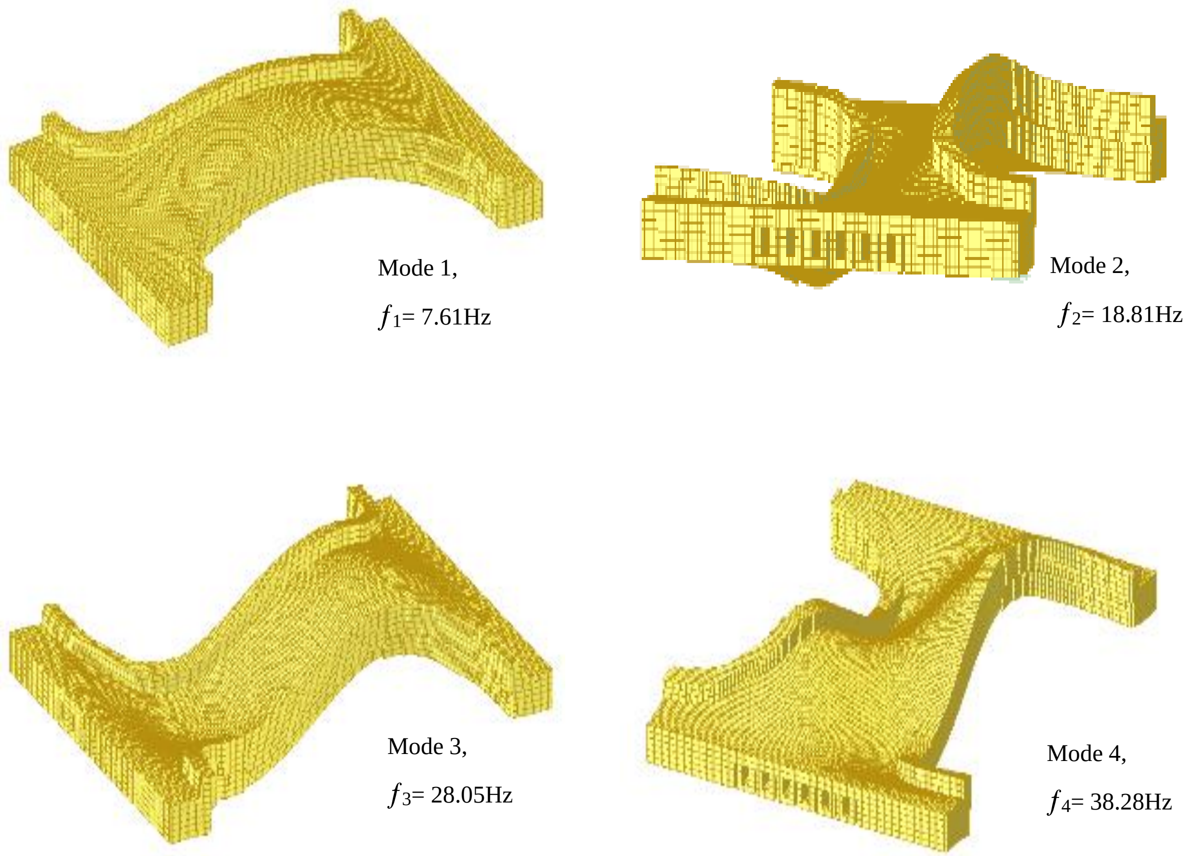

Fig. 11 Plotted mode shapes and their corresponding natural frequency of eigenvalue analysis of the bridge

7. DISCUSSION

Based on the results obtained through experimental method using measured natural frequencies extracted from accelerometer transducers and microtremors. It was found that the frequencies acquired from the evaluation of accelerometers were identical by showing 6.71 Hz in all three tests. Whereas, the response recorded from two microtremors reasonably matched as well, with a minor difference of less than 0.3% in natural frequencies, and the change was considerably small to the extent of negligible level. This minor variation in microtremors data was most likely the environmental interference in the form of noise that influenced the data at the time of data acquisition.

Overall, the experimental results obtained using both measuring sensors from the bridge illustrated quite good agreement as shown in Fig. 12. Furthermore, there is another important information of mode shapes that was obtained from Eigenvalue analysis using finite element analysis in this work, that is usually used for assessing a structure. The information is the deflection pattern which is associated with each natural frequency. The interested modes of this study were the first and second modes that associated with first and second natural frequencies of the experimental response. The numerical results showed higher values of natural frequencies of corresponding mode shapes than those captured by the sensors as expected, that confirmed the accuracy of accelerometers and microtremors. Moreover, numerical results were adopted to illustrate the as-built sate of the bridge and declination in its serviceability.

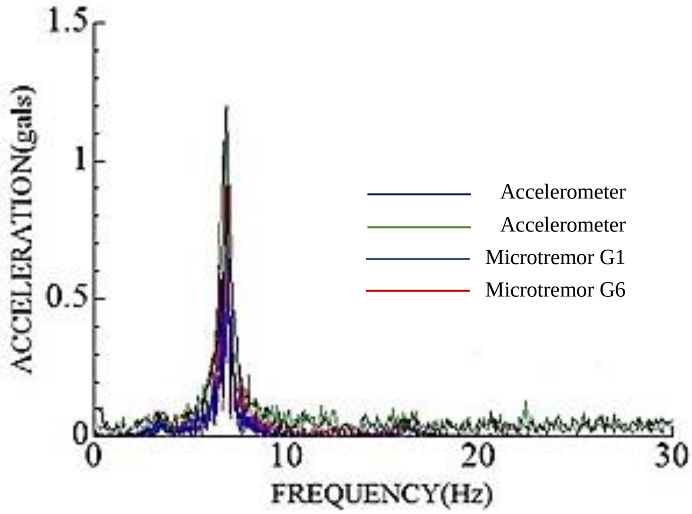

Fig. 12 Comparison of the accelerometers' and microtremors' results

8. CONCLUSION

In this study, an experimental research; including accelerometer transducer test, microtremor test and finite element model using Midas Civil software were carried out to verify the validity of two sensors (accelerometer and microtremor) by evaluating a pre-tensioned PC box-girder bridge. The primary aim was to compare natural frequencies of accelerometers obtained from the evaluation to the natural frequencies measured by microtremors to confirm the accuracy of both measurements. In fact, the acquired results of both sensors were quite reliable showing error less than 0.3%.

Also, modal analysis was performed in order to obtained first few modes and their corresponding natural frequencies using eigenvalue analysis to present the as-built state of the bridge. furthermore, numerical result was used as a reference data to illustrate declination in bridge's serviceability by comparing it with experimental data that shows the current state of the bridge. Since, the girders of the downstream side of the bridge contain some cracks that could lead to decrease the natural frequency of the structure by 11.2% that is an increase in structure's flexibility which represents decline in bridge's serviceability.

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