Dynamic Investigation of the City of Manchester Stadium

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ABSTRACT

The dynamic behaviour of the City of Manchester Stadium is described in this paper. With a remote monitoring system, developed at the University of Sheffield, output-only vibration response data were acquired during a music concert. Data provided by Dr. P. Reynolds were used for the study. Modal parameters estimations were made on data acquired from different crowd activities. The crowd-structure interaction is also studied.
A finite element model has been developed and the crowd has been considered in it. Measured vibrations were compared with numerical results. A load model for future designs has been obtained.

1. INTRODUCTION

In sport stadiums design, like in most urban structures, the aesthetic values are more and more important every day. This fact, together with technological advance, lead to bigger and slenderer sport stadiums.

As many as one hundred thousands people can be in a stadium during some sport events. The crowd can have a synchronized behaviour when cheering a team on. On the other hand, there are rock/pop concerts celebrated in stadiums, with an important synchronization of people who go in it.

Vibrations induced by people in stadiums constitute a problem that affects significantly to these structures [1]. To study this problem, it is necessary to consider the crowd-structure interaction since, in precedent studies [2,3], it was shown that the crowd changes the modal properties of the structure, affecting as much natural frequencies as to damping ratios if this parameters are compared with those obtained when the structure is empty. So, in the design process, it would be adequate to consider this interaction. It can be done introducing to the crowd into the numerical model, considering the change in the dynamic characteristics because of it.

In this work, the dynamic behaviour of the City of Manchester Stadium (Figure 1) have been studied using the data acquired with a remote system developed in the University of Sheffield, during a Red Hot Chili Peppers concert celebrated 18 June 2004 [1]. Estimations of modal parameters have been made from ambient vibrations measures for the different activities of people. A finite element model of the structure where crowd is taken into account has been developed. Vibrations parameters obtained from the numerical model have been compared with results calculated from the experimental measures. This paper is intended to obtain a better understanding of crow-structure interaction, and to contribute to improve models for future design of this type of the structures.

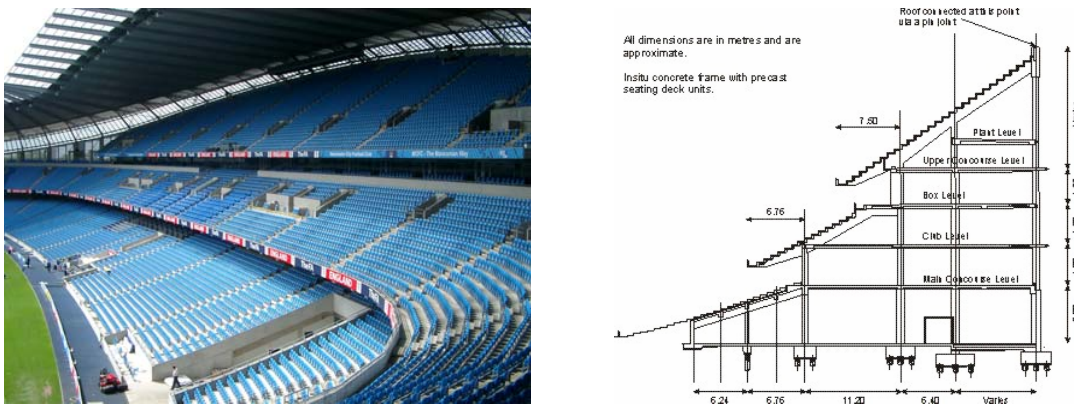

Figure 1. View of the Stadium and typical Section through the West Stand

2. FINITE ELEMENT ANALYSIS

A three dimensional finite element model using commercial software ANSYS has been developed for the study of the structure. With this model, the dynamic behaviour of the structure loaded by a dynamic force that represents crowd behaviour when making different activities (sitting, standing, jumping) is studied.

The girders have been modelled as two-node beam elements (BEAM44) with six degrees of freedom per node. This element permits the end nodes to be offset from the centroidal axis of the beam axis. Non structural elements were considered as mass elements (MASSS21) and the tiers were modelled using six node shell elements (SHELL63) with six degrees of freedom per node.

Material properties have been obtained from the analysis developed in [1]. Following this work it has been assumed that the structure is composed of concrete with a Young's modulus of 38 GPa, including the pre-cast seating deck which has been connected in a monolithic mode.

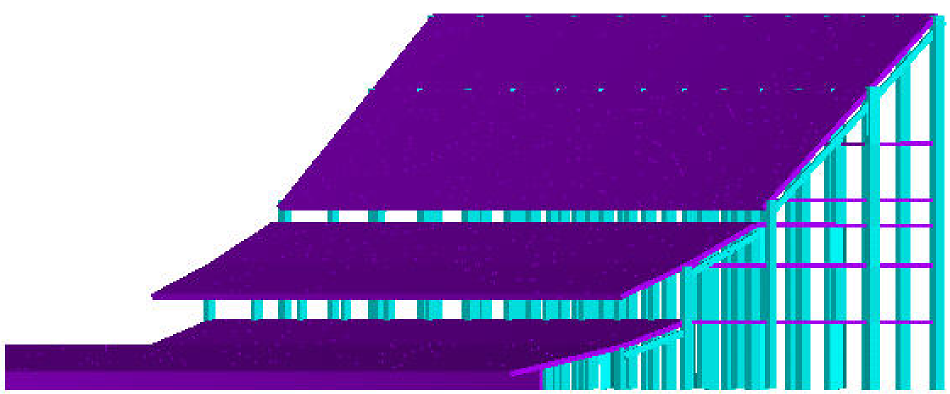

Figure 2. Finite Element Model

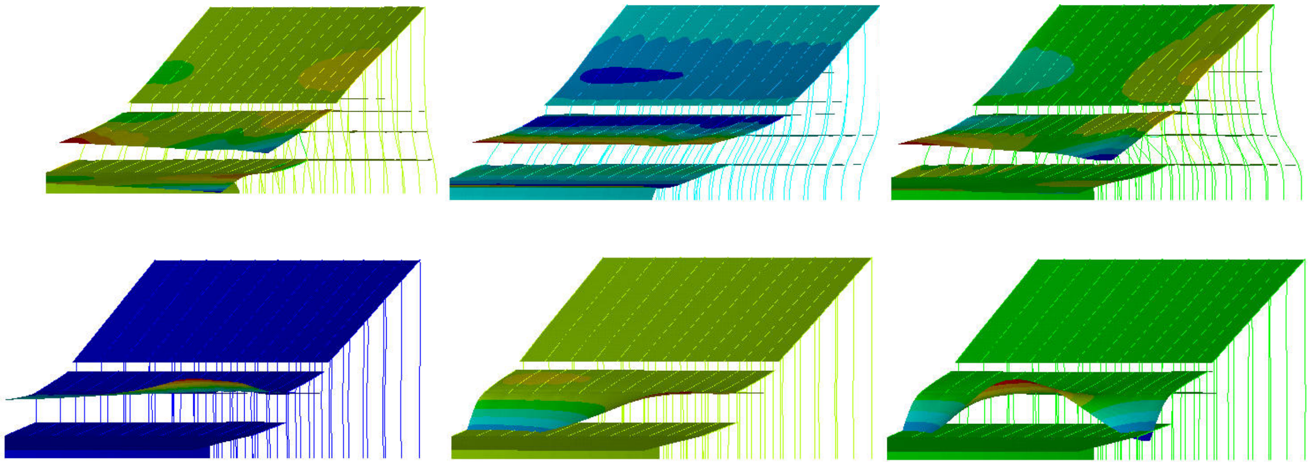

Figure 3. Results from FE Analysis

3. DATA PROCESSING AND ANALYSIS

A rock concert of Red Hot Chili Peppers was celebrated in the City of Manchester Stadium on June 14, 2005. Data from ambient vibration starting at 15:00, when the structure was empty, till 23:03, once that event was finished and the crowd had left the stadium, were acquired. During these 8 hours three rock concerts were developed in the stadium (Chicks on Speed, James Brown and Red Hot Chili Peppers) (Figure 2), each one of them being associated to a public activity intensity.

Vibration Engineering Research Section of the University of Sheffield measured the response of the structure in 12 points (Figure 3): 4 points situated at the tip of the lower cantilever tier and 4 points situated at the tip of the upper cantilever tier. The vertical response of the stadium was measured at these points. The horizontal response was measured at two points situated at the top/back of the stand. The dynamic behaviour of each one of the tiers and the global behaviour of whole stand can be obtained from the response at these points. The original sampling rate was 80 Hz. and a low-pass anti-aliasing filter was applied at 30 Hz. Data was downsampled to 20 Hz.

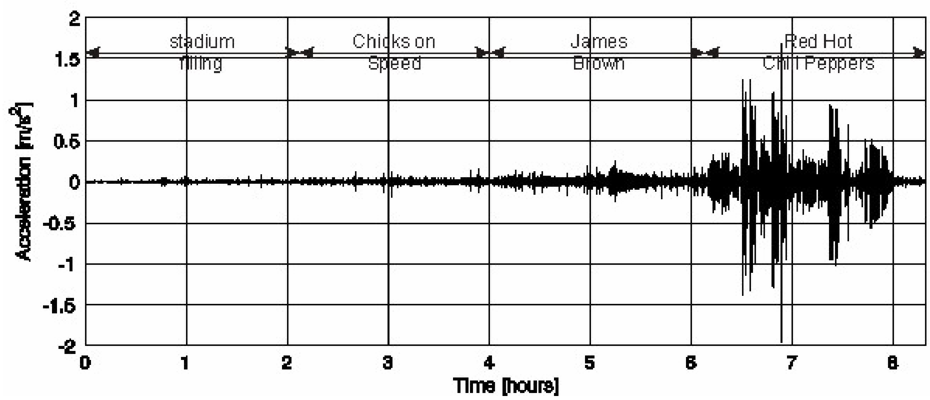

Figure 4. Time History Accelerometer 5.

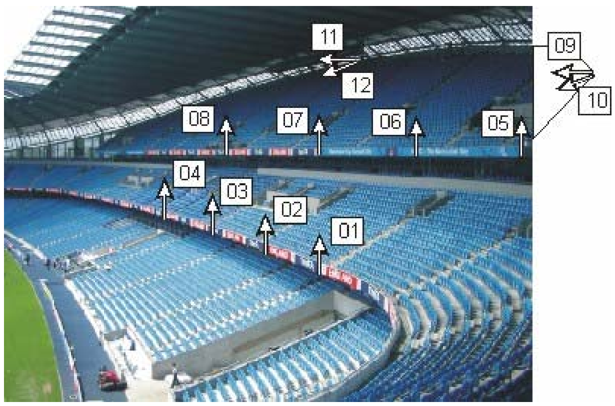

Figure 5. Accelerometer Locations.

4. DYNAMIC BEHAVIOUR

The modal parameters of the stadium were obtained from the acquired data for the different situations: empty stadium, public occupying their seats, Chicks on Speed concert, James Brown concert, Red Hot Chili Peppers concert, maximum response of the structure instants and, finally, while public were leaving the stadium.

The response acquired by sensors when the stadium was practically empty can be observed in Figure 4. Maximum acceleration recorded has a value of 0.0510 m/s^2 at accelerometer 4. The acceleration recorded by accelerometers 9, 10, 11 and 12 are much smaller that those associated with the vertical response of the structure (maximum 0.0027 m/s^2).

Modal properties of the structure have been estimated from acquired data using two different analysis techniques: classical spectral techniques [4] and Frequency Domain Decomposition [5].

Auto-spectra function, cross-spectra (reference transducer 2) and coherence function (reference transducer 2) from accelerometer 3 are shown in Figure 5. The natural frequencies of the lower and upper cantilever tier were identified from resonance peaks in auto-spectra and cross-spectra functions. Coherence function peaks are the same that the peaks of the previous functions providing still more evidence that these peaks are natural frequencies of the structure.

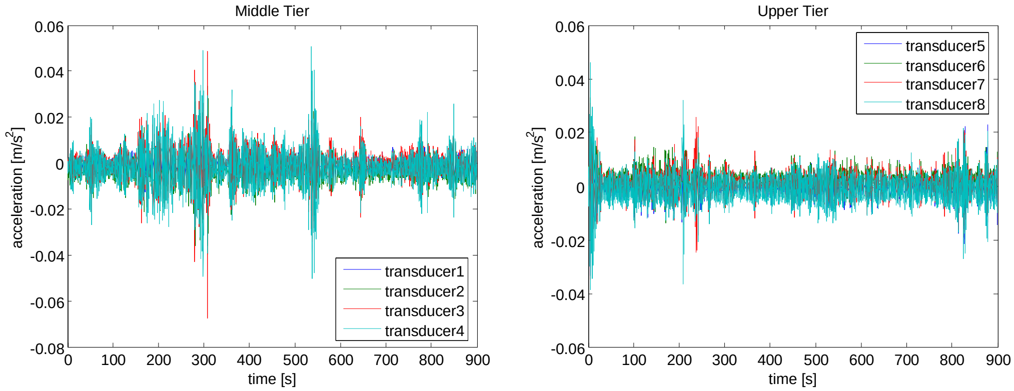

Figure 6. Response of the Structure. Empty Stadium.

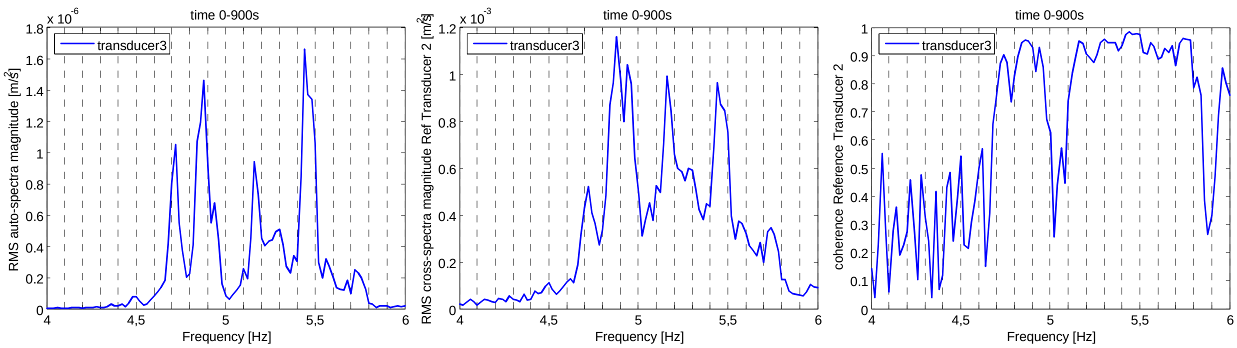

Figure 7. Auto-spectra, cross-spectra and coherence functions transducer 3. Empty Stadium.

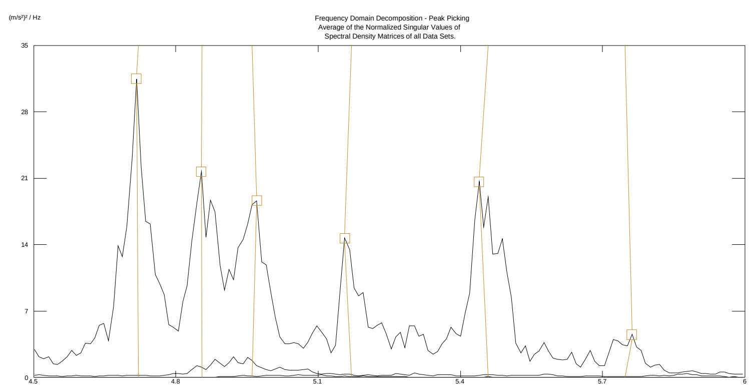

Figure 8. Singular Value Decomposition of the Spectral Densities Matrices. Middle Tier. Empty Stadium.

The singular value decomposition of the spectral density matrix obtained from sensors situated at the middle tiers are shown in Figure 6. Peaks that represent modes of the structure have been selected. The obtained modes for the middle tiers of the stadium can be seen in Figure 7. Present modal parameters agree quite well with those obtained in previous studies [1].

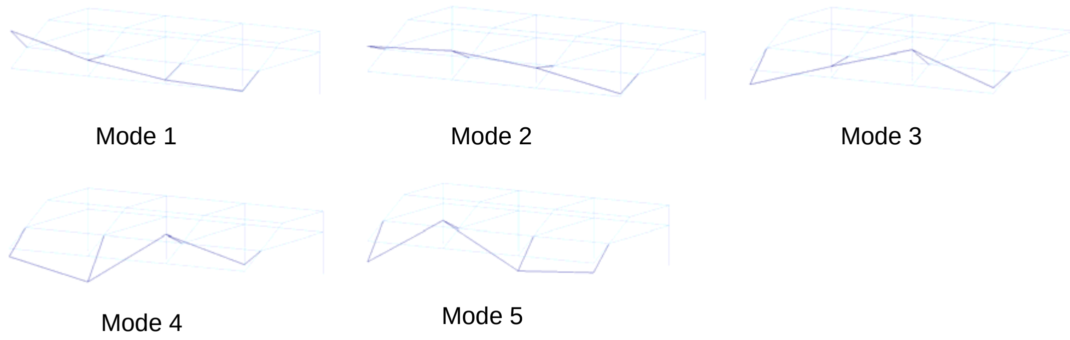

Figure 9. Middle tier mode shapes.

The analysis made for the middle tier was repeated for the upper tier. The global behaviour of the structure was also studied from the data. The modes obtained for the upper tier are shown in Figure 8 and some global modes of the stadium in Figure 9. The slower global modes are mainly controlled from registered data by accelerometers 10 and 12.

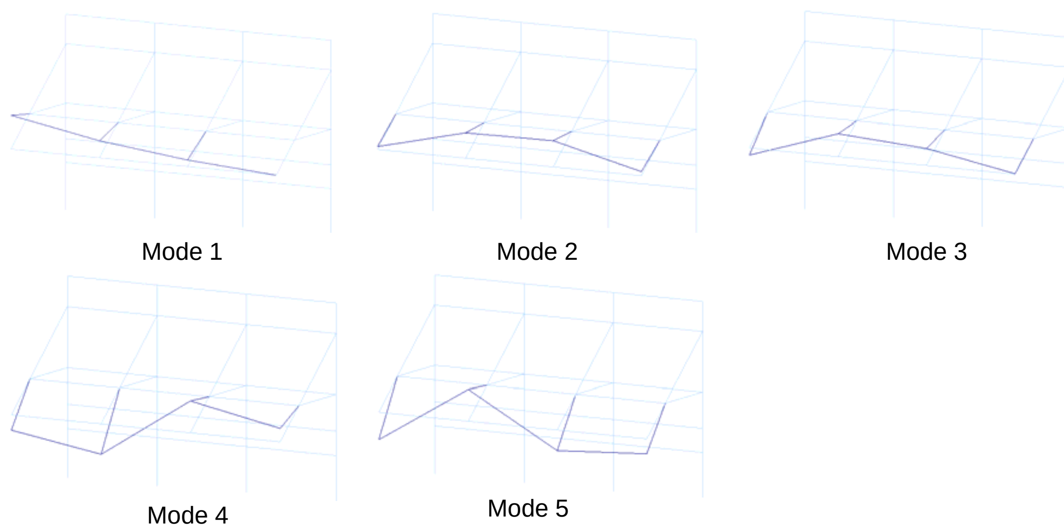

Figure 10. Upper tier mode shapes.

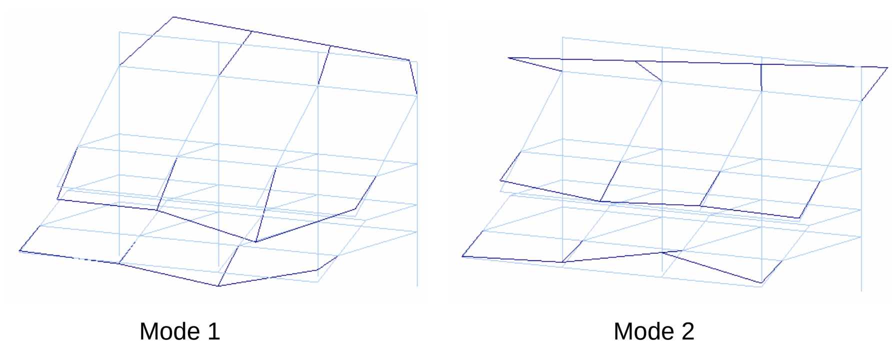

Figure 11. Global modes (fore and aft) of the stadium.

The natural frequencies and damping ratios obtained from recorded data during different events are shown in Table 1.

	Empty Stadium		Ocupando localidades	
	$f\,[Hz]$	$\xi\,[\%]$	$f\,[Hz]$	$\xi\,[\%]$
Global Modes	2.363	-	2.368	-
	2.393	-	2.393	-
Middle Tier	4.721	0.812	4.744	1.091
	4.855	0.778	4.812	0.891
	4.961	0.4744	4.923	0.451
	5.171	0.591	5.134	0.816
	5.458	0.643	5.416	1.473
Upper Tier	4.895	0.687	4.888	1.216
	5.012	0.131	5.016	0.088
	5.098	0.573	5.102	0.799
	5.323	0.547	5.289	1.039
	5.608	0.848	5.551	1.52

Table 1. Results.

Auto-spectra functions from time history at accelerometers 3 and 7 are shown in Figure 10. They were estimated from data recorded during Red Hot Chili Peppers concert (1h. 44 min.). It can be observed that the structure response is mainly affected by the two fore and aft global modes (approximately at 2.36 and 2.38 Hz), a sway global mode (approximately at 3.22 Hz), and the first bending mode of the lower and upper cantilever tier.

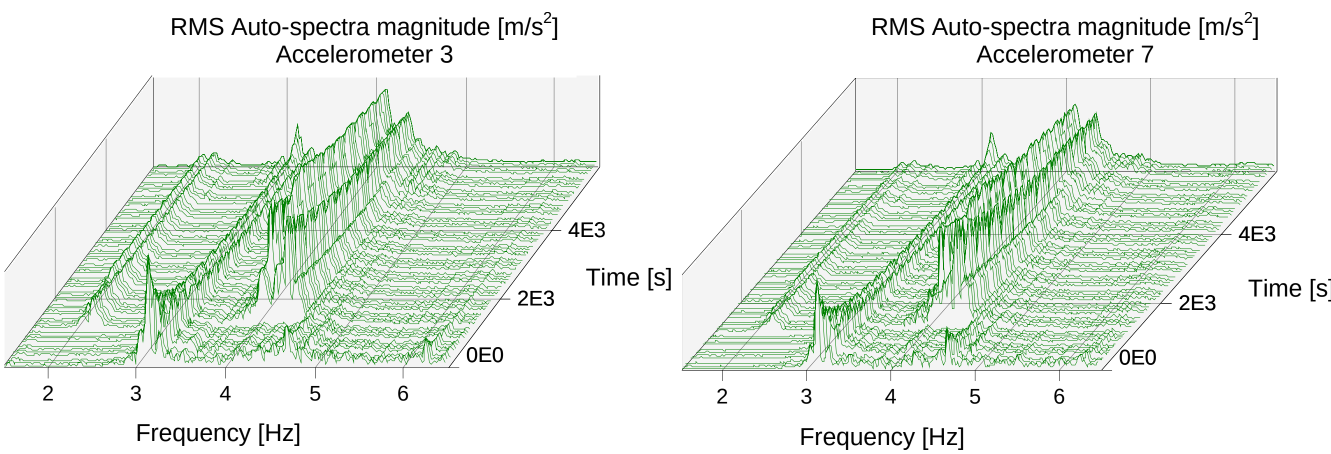

Figure 12. Auto-Spectro functions. Red Hot Chili Peppers concert.

It can be seen from the results in Table 1 that the estimated damping ratios increase when the crowd occupies the stands. This conclusion is in agreement with previous studies[2,3].

5. CONCLUSIONS

The dynamic behaviour of a football stadium when different activities take place in it has been studied in the present paper. It has been observed that the crowd not only increases the mass of the structure but also interacts with it producing a significant effect on its modal properties.

A numerical model has been developed for the stadium. The crowd effect has been introduced in the model and the obtained numerical results have been compared with experimental data. It is concluded from the analysis that the dynamic crowd-structure interaction effect should be taken into account in the design.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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