

A Comparison of Spectators Induced Grandstand Vibrations and Fans Behavior during Two Football Matches between the Same Teams

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Abstract: A synchronized motion of a considerable group of sport fans (like as some type of jumping, bouncing, swaying or hand-clapping) would cause a significant dynamic load to a grandstand structure and consequently its vibrations that could be sometimes noticeably large. The results of an experimental analysis focused on the football fans behavior and on grandstand vibrations induced by them at the AC Sparta football stadium in Prague are stated in the paper. The findings obtained from two football matches between the same teams are compared mutually and it is concluded that the fans behavior was substantially influenced by the actual position of both teams in the football league.

Keywords: football stadium; cantilever grandstand; sport fans' behavior; vibration; experiment.

1 Introduction

If a substantial group of sport spectators assembled on a grandstand moves synchronously, inconsiderable dynamic forces are frequently caused and grandstand oscillations are consequently induced which could be sometimes noticeably large. The large grandstand oscillations that are distinctly perceived or even visible may start a panic of fans, a following stampede and a crush that could result in injuries even in deaths of some fans [1]. History shows that undue vibrations of a grandstand could cause even its collapse in an exceptional situation [1].

Currently, the suitable dynamic load of grandstands is not described in any standard with acceptable precision. However, lots of new spectator's crowd load models have been developed [2, 3, 4] but adequate experiments, which could be applied for verification of the load models, have been performed less frequently [5, 6]

Two series of experiments focused on spectators induced grandstand vibrations and fans behavior during football matches were carried out at the Letná football stadium in Prague. First two experiments were performed during the 2013-14 season and then five ones were implemented during the 2014-15 season. Some results obtained from the experiments have been already published [7, 8].

The primary objective of the experiments was to investigate fans induced vibrations and fans behavior in the selected grandstand area as the experimental basis for specification and verification of new spectator's crowd load models that have been developed currently [4, 5] because of a lack of appropriate in situ experiments [7, 8].

The Letná football stadium in Prague is the home stadium of the AC Sparta Prague football club. Both series of experiments were focused on the stadium area where the most active fans of the home team (also called "Ultras") were gathered. This group of spectators was during all experiments (and still is) concentrated on the first floor of the stadium and it means the most significant potential source of the dynamic load is placed in the stadium area where the steel cantilever grandstand structure is most sensitive to vertical dynamic excitation.

The paper presents the brief summary and comparison of basic results obtained by two selected experiments concentrated on the spectators induced grandstand vibrations and fans behavior in the observed

stadium area during two football matches between the same teams AC Sparta Praha and FK Teplice. The investigated matches were played in various parts of seasons and in different actual position of both teams in the football league.

Between the years 1984 and 2007, the home team AC Sparta Praha became the Czech football league champion eighteen times. It means Sparta did not win the league title only in the five seasons and there were at most one-year breaks between titles during this period. However, in three league seasons foregoing the 2012-13 one, the AC Sparta finished on the second position only.

The first investigated match was played on November 2nd 2013 and the AC Sparta team won 2:0 and because of this victory the AC Sparta became the mid-season champion and its fans were well satisfied. After the defeat, the FK Teplice team remained on the third position in the Czech first football league. At the end of the 2012-13 season, the AC Sparta won the Czech football league after three “long” years again.

The second observed match was played on March 21st 2015 in a little bit different situation. This one the AC Sparta won again but only 1:0 and the decisive goal was scored from penalty kick in the 89th minute. In time of the second match the AC Sparta was on the second position and only its victory kept real hope to become national league champion because of the distance of five points between the AC Sparta and the league leader. All mentioned circumstances affected that the home team fans celebrated this win noticeably less then after the first match. The FK Teplice team remained on the fifth position in the Czech first football league after the second match. At the end of the 2014-15 league season, the AC Sparta finished on the second position.

2 The Brief Description of the Experiment Arrangement

The grandstand dynamic response was observed at the ends of grandstand main beams where the maximal levels of induced vibrations were expected. The piezoelectric sensors Brüel&Kjær of type 4507 B005 were attached to the lower beam flanges by using magnets. The measurement system Pulse and Front-end 3050-B-040 Brüel&Kjær were used for data acquisition. The sensors were connected to the Front-end via cables. The obtained vibration records were modified by use of the Butterworth high-pass filter with cut off frequency 50 Hz.

The grandstand dynamic response was measured in three spots in vertical direction only (see Fig. 1a) during the first experiment that was performed in November 2013. The sensor positions were lightly modified for the second experiment in March 2015 (see Fig. 1b). The right spot was moved more to the middle of the observed grandstand area and one horizontally oriented accelerometer was added to the central point.

During the whole second match, the fans behavior in the observed grandstand area was recorded by a camera that was placed under main grandstand roof on the special bridge which is earmarked for journalists.

The first match was not observed by our own camera. The fans behavior only for the cases of detected large grandstand vibrations was investigated on the base of the TV video record and auditory perceptions connected with a particular behavior type. The same approach was used for the second match as well because of its verification. The compared results agreed on ninety-five percent it means their high agreement.

3 The Types of Spectator Behavior Observed by the Experiment

Eleven types of spectator behavior were recognized during observed matches that have an effect on grandstand vibrations. The designations of the basic behavior types were assumed from the reference [1]. However, other additional types were detected and distinguished in the course of the matches:

- static state - all fans sit or stand statically and watch the match only passively,
- walking and running - this type of spectator behavior occurs mostly outside the play time when occupants are coming to their seats or when they are leaving their places,
- jumping of the 1st type - the fans are jumping en masse asynchronously and independently,
- jumping of the 2nd type - the spectators are joined together in separated lines and jump synchronously on the spot,
- jumping of the 3rd type – the fans are joined together in separated lines and move horizontally by synchronous jumping from right to left and back again usually in opposite directions in adjacent lines,

- jumping of the 4st type – all spectators in the entire sector of the studied grandstand sit down at first after that they concurrently jump up on a signal of their leader and begin continuous jumping promptly,
- bouncing - the fans movement similar to jumping but the feet of persons remain in contact with the grandstand surface,
- swaying – the fans sway forward to support their shouted slogan and the entire motion is intensified moreover by arm movement,
- hand-clapping,
- goal scoring,
- Mexican wave - the sitting spectators briefly stand up and raise their arms in turn creating the appearance of a wave passing through the stadium. The fans in the studied area were standing for most of the matches therefore they created Mexican wave using a wave of arms only.

The more detailed description of the recognized types of spectator behavior is stated in the reference [8].

Tab. 1: The comparison of the maximum peak values of the vertical acceleration evaluated by the particular spectator behavior types in the middle spot.

Observed match	Hand-clapping	Goal scoring	Jumping of the 1 st type	Mexican wave
First match 2013 [$\text{m}\cdot\text{s}^{-2}$]	0.32	0.96	1.11	0.49
Second match 2015 [$\text{m}\cdot\text{s}^{-2}$]	0.18	0.60	0.47	0.33

Tab. 2: The time duration of the particular types of spectator behavior which was evaluated during the second observed football match played in March 2015.

Type of spectator behavior	Minimum proportion of active fans [%]	First half [min]	First half [%]	Sec. half [min]	Sec. half [%]	Other time [min]	Other time [%]	Total time [min]	Total time [%]
Static state	80	11:53	26.6	7:26	15.4	2:08	27.6	21:27	21.3
Walking and running	100	-	-	-	-	0:59	12.7	0:59	1.0
Jumping of the 1 st type	15	2:23	5.3	2:46	5.7	-	-	5:09	5.1
Jumping of the 2 nd type	100	-	-	0:05	0.2	0:46	9.9	0:51	5.1
Jumping of the 3 rd type	100	-	-	0:59	2.0	-	-	0:59	1.0
Jumping of the 4 th type	100	1:17	2.9	-	-	-	-	1:17	1.3
Bouncing	15	5:23	12.0	5:59	12.4	1:56	25.0	13:18	13.2
Swaying	20	12:11	27.2	9:07	18.9	0:27	5.8	21:45	21.6
Hand-clapping	20	11:14	25.1	19:28	40.4	1:28	19.0	32:10	32.0
Goal scoring	85	-	-	2:13	4.6	-	-	2:13	2.2
Mexican wave	85	0:22	0.8	0:05	0.2	-	-	0:27	0.4

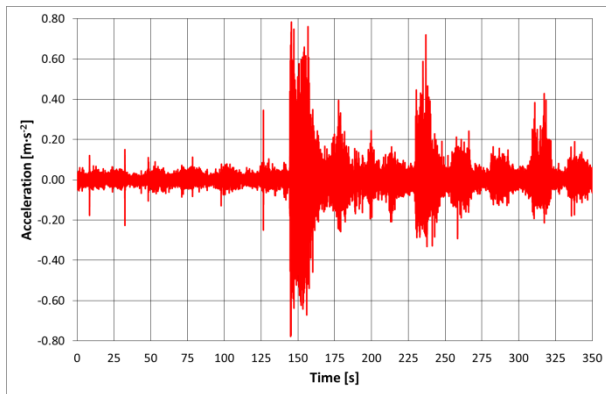


a) the sensor positions during the first match

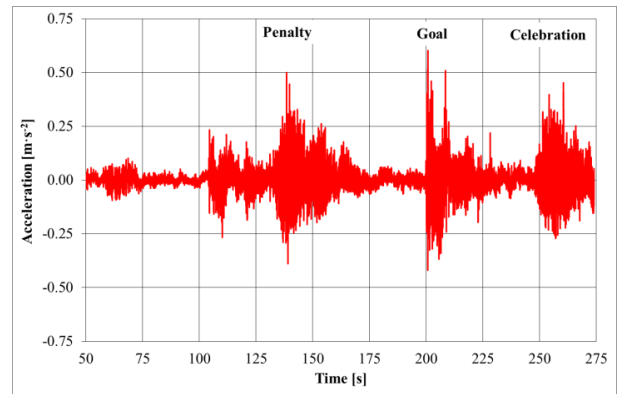


b) the sensor positions during the second match

Fig. 1: The location and orientation of the accelerometers used by the experiments performed in 2013 (on the left) and in 2015 (on the right) and the view on the observed grandstand area where the most active fans were concentrated.

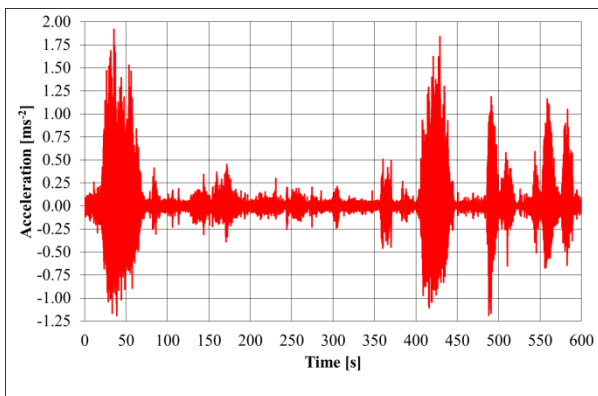


a) the first match played in 2013

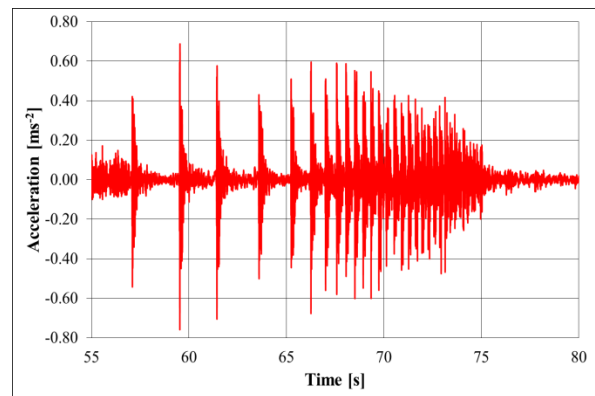


b) the second match played in 2015

Fig. 2: The detail of the grandstand vertical acceleration time records from both observed matches which were measured in the middle spot in the situation when the AC Sparta scored decisive goal.

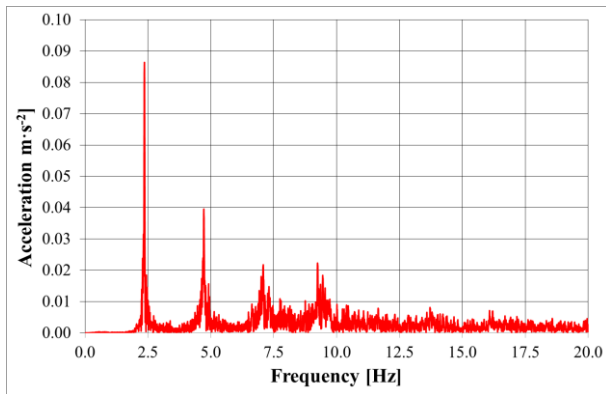


a) the first match played in 2013

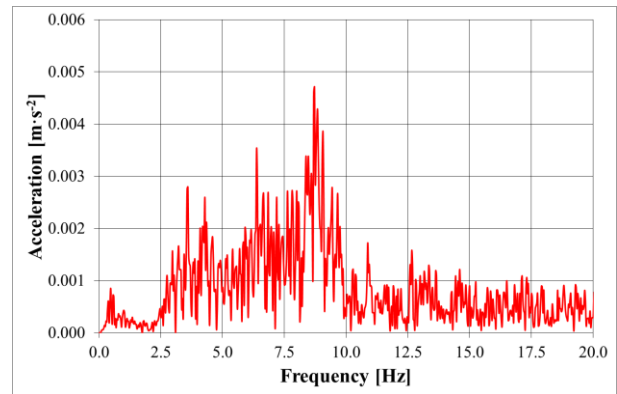


b) the second match played in 2015

Fig. 3: The detail of the grandstand vertical acceleration time records from both observed matches which were measured in the middle spot in the situation when the home fans celebrated the victory after the end of the match.



a) the first match played in 2013



b) the second match played in 2015

Fig. 4: The frequency spectrum evaluated from the vertical acceleration shown in Fig. 3 that was measured in the middle spot in the situation when the home fans celebrated the victory after the end of the match.

4 The Brief Description of the Experiment Basic Results

The both described experiments were carried out during the whole analyzed football matches from the entrance of players to the pitch to the spectator celebration at the end. The information about a number of spectators assembled in the studied grandstand area for the first match was not available. During the second match, 910 fans were gathered in the observed grandstand sector. That was 10.7 % from the total number of spectators present at the stadium (8 502).

The comparisons of the time behavior and maximum peak values of the vertical acceleration in the middle spot for the significant spectator behavior types are shown in Fig. 2, Fig. 3 and in Tab. 1.

The two frequency spectrums are compared in Fig. 4. These spectrums were evaluated from the vertical accelerations that were recorded during home fans celebration of the victory after the end of the both matches and that are depicted in Fig. 3.

The time duration of the specific behavior types evaluated only during the second match is stated in Tab. 2 where the minimum proportion of the active fans is also mentioned.

It ensued from the Fig. 2, that the fans behavior and dynamic response of the grandstand in both matches were similar to each other in the moment when the home team scored decisive goal. The vibration from the second match could be moreover clearly divided into three phases – the award of the penalty, the goal scoring and the goal celebration.

5 Conclusion

The next four main findings resulted from the carried out experimental analysis:

Firstly, it can be stated on the base of the mutual comparison of the results evaluated from both observed matches that the intensity of the grandstand vibrations induced by fans is strongly influenced by their current mood depending on the actual league position of their supported team and on its game quality. The larger grandstand vibrations in the identical situations were clearly detected during the first match when the AC Sparta team celebrated the mid-season title (see Tab. 1, Fig. 2, Fig. 3 and Fig. 4).

Secondly, the home fans most frequently used type of cheering with hand-clapping that was practically used during a third (32.0 %) of the total play time. Nevertheless, the portion of active fans get involved in this type of support was surprisingly low (about 20 % active fans only).

Thirdly, the active spectator participation in the specific support types fluctuated significantly during the observed football matches. All of fans presented in the observed grandstand area (it means 100 % of fans) attended only on the cheering type Jumping of the 2nd, 3rd and 4th type.

Fourthly, the greatest level of the examined dynamic grandstand response was determined during the cheering types on which all of fans attended actively (Jumping of the 1st, 2nd, 3rd and 4th type).

The correctness of the above stated discoveries are going to be verified based on additional results of similar experiments that were carried out during another football matches at AC Sparta stadium (in Spring 2015) and SK Slavia Praha stadium (in Spring 2016).

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References

- [1] C.A. Jones, P. Reynolds, A. Pavic, Vibration serviceability of stadia structures subjected to dynamic crowd loads: A literature review, *Journal of Sound and Vibration* 330 (2011) 1531–1566, <http://dx.doi.org/10.1016/j.jsv.2010.10.032>.
- [2] O. Rokos, J. Maca, Stochastic approach in the human-induced vibration serviceability assessment of grandstands, in *proc.: Proceedings of the IX International Conference on Structural Dynamics EURODDYN2014* (2014), eds. A. Cunha, E. Caetano, P. Ribeiro, G. Müller, Faculdade de Engenharia da Universidade do Porto, Porto Portugal, 2591-2598.
- [3] O. Rokos, J. Maca, The response of grandstands driven by filtered Gaussian white noise processes, *Advances in engineering software* 72 (2014) 85 – 94, <http://dx.doi.org/10.1016/j.advengsoft.2013.05.008>.
- [4] V. Rajic, A. Pavic, Stochastic approach to modeling of near-periodic jumping loads, *Mechanical systems and signal processing* 24 (2010) 3037 – 3059.
- [5] P. Reynolds, A. Pavic, Vibration performance of a large cantilever grandstand during an international football match, *Journal of Performance of Constructed Facilities* 20 (2006) 202 – 212.
- [6] A. Caprioli, M. Vanali, A. Cigada, One year of structural health monitoring of the Meazza Stadium in Milan: Analysis of the collected data, in *proc.: Proceedings of the 27th Conference and Exposition on Structural Dynamics 2009 IMAC-XXVII* (2009), Society for Experimental Mechanics Inc., Orlando Florida USA, 9p.
- [7] M. Verner, M. Polak, T. Plachy, An Experimental Study Focused to Spectators-induced Vibrations of a Cantilever Grandstand during two Sport Matches, in *proc.: Proceedings of 53rd International Conference on Experimental Stress Analysis 2015* (2015), eds. P. Padevet, P. Bittnar, Czech Technical University in Prague Faculty of Civil Engineering, Český Krumlov, 460–465.
- [8] M. Verner, T. Plachy, M. Polak, An Experiment Focused on Fans Behaviour and Induced Grandstand Vibrations during a Football Match, *Applied Mechanics and Materials* 837 (2016) 75–78, <http://dx.doi.org/10.4028/www.scientific.net/AMM.837.75>.