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# An Experimental Study Focused to Spectators-Induced Vibrations of a Cantilever Grandstand During Two Sport Matches

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**Abstract:** Synchronize movement of a larger spectator group on a sport stadium (like as jumping, bouncing, jouncing, swaying or abruptly rising) can generate a significant dynamic load of a grandstand and induce subsequently its discomforting vibrations. The large vibrations are detectable even visually in some extreme cases. The excessive grandstand vibrations may initiate a panic, a subsequent stampede and a crush resulting in injuries even in deaths of spectators. History shows that large vibrations of a grandstand could cause its collapse in a special situation. A dynamic experiment that is described in the paper was realized on a steel cantilever grandstand during two football matches in the area where the most active spectators were concentrated. Vertical accelerations were observed at the ends of three grandstand main beams. Vibrations which could be perceived by spectators as uncomfortable were detected in some special situations (scoring of a goal and fanscelebrationafter the end ofthe match for example).

**Keywords:** Football Stadium; Cantilever Grandstand; Spectators; Vibration; Dynamic Experiment.

## 1 Introduction

It is known that a synchronize movement of a larger spectator group on a sport stadium (like as jumping, bouncing, jouncing, swaying or abruptly rising) can generate a significant dynamic load of a grandstand and induce subsequently its vibrations. In some extreme cases, the vibrations are uncomfortable and detectable even visually. The excessive grandstand vibrations may initiate a panic, a subsequent stampede and a crush resulting in injuries even in deaths of spectators [1]. History shows that large vibrations of a grandstand could cause even its collapse in a special situation [1].

Humans are capable to generate forces much greater than their self-weight through undertaking intensive activities as jumping for example. Unfortunately, dynamic loads generated by a group of humans are difficult to predict because of the loads vary significantly in magnitude and frequency content depending upon the activity being undertaken by the individual subjects. Currently, the appropriate dynamic load of grandstands is not described in any standard with adequate accuracy. However, lots of new spectator's crowd load models have been developed [1,3,5,7] but appropriate experiments, which could be used for verification of the load models, have been performed less frequently [1,2,4,6].

The basic objective of the performed dynamic experiment that is described in the paper was to study spectators-induced vibrations of a grandstand during some football matches. Similar experiments have been performed also in other countries [1,2,4] not only by football matches but also by pop music concerts.

The Letná football stadium in Prague which is the home stadium of the AC Sparta Prague football club was chosen for the experiment realization because supporters of this club are historically one of the most active supporters in the Czech Republic and the observed stadium grandstand is constructed as the steel cantilever one and this grandstand construction type is inherently more susceptible to vertical motions than other types of stands [1,2].

The experiment was realized during two specific football matches – AC Sparta Praha vs. FK Teplice on November 2nd 2014, which Sparta won 2:0) and AC Sparta Praha vs. FK Mladá Boleslav on November 24th

2014 that Sparta won 4:1. Observed points of the grandstand structure were situated in the stadium area where the most active spectators (also called "Ultras") were concentrated (see Fig. 1 and Fig. 2).

## 2 Brief Description of the Letná Football Stadium and Its History

The Letná football stadium has been used since 1917. In the year 1934 it was decided to rebuild it for a capacity of 45 000 spectators, but in the same year the main grandstand was burned down. So in the year 1937, new iron-concrete one was opened. Between years 1967 and 1969 all other grandstands were replaced by new ones made from iron and concrete with the steel cantilever beams. The stadium was completely modernized in 1994, only seated places remain and the stadium meets all international standards. The stadium has a heated lawn football pitch since the year 2002.

The most active football fans are called "Ultras" or "Banner-carriers". These fans groups are usually well organized and led by one guy. "Ultras" are habitually located in a small section of a stadium during matches and this section is in Czech language called "Kotel". Ultras are, most of the time, creators of an excellent stadium atmosphere which encourages their own team and intimidates opposing players and supporters. But ultras are also responsible for the biggest problems on stadiums during matches, as using of fireworks and smoke bombs, throwing of objects onto the pitch and even violent fighting against opposing team supporters. This problematic activity may cause interrupting or even termination of a match eventually.

Fig. 1: The view on the Sparta's ultras located on the observed steel cantilever grandstand.

Fig. 2: The location and orientation of the three accelerometers used by the experiment.

In the last years, since about 2004, new supporting method was introduced in Czech sports namely jumping with shouting like "Who doesn't jump isn't Spartan! Jump! Jump! Jump!" and fans are more pulled in matches. This intensive cheering is usually started and led by "Kotel" on the AC Sparta football stadium. Passive fans, as a rule, become active and active ones get even more active. "Kotel" is well organized and quickly synchronized to the rhythm of the shout and must generate a significant dynamic load by this type of cheering.

At the beginning of the century, when the "Kotel" was located just behind the gate at the east side of the stadium, the Sparta's ultras behaved very problematic. The club management tried to expel these problematic fans out of the stadium. The tickets were sold on name only and police patrols were concentrated on this stadium sector. The result of all these acts was just that the ultras moved from the ground floor to the first one of the stadium (see Fig. 1). This means, the "Kotel" as the potential source of a significant dynamic load is located now on the steel cantilever grandstand that is more responsive to dynamic excitation.

## 3 Description of the Dynamic Experiment Arrangement

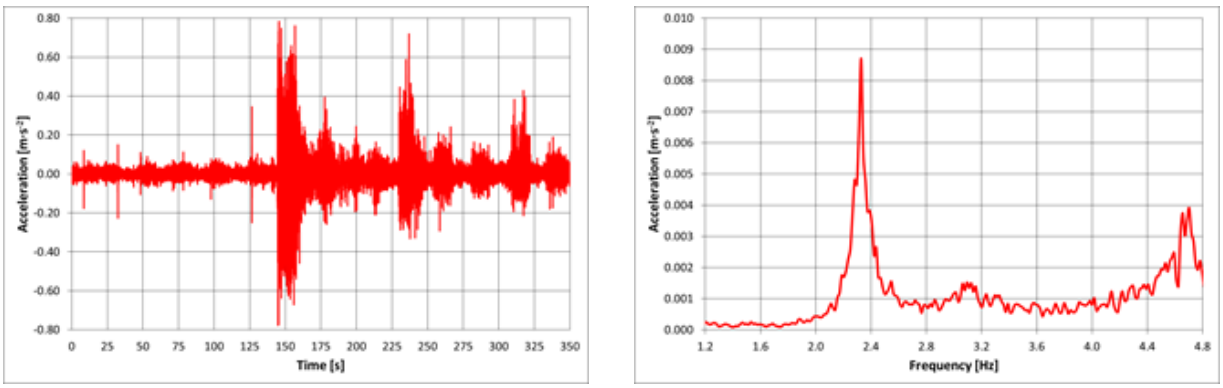
The grandstand dynamic behaviour was measured at the ends of three grandstand main beams where the maximal level of induced vibrations was supposed (see Fig. 2). The vertical accelerations were observed in these three points only. The piezoelectric sensors Brüel&Kjær of type 4507 B005 were used for the experiment. They 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 Front-end and its operator were located on the tribune close to the investigated grandstand. This leads sometimes to a potentially dangerous situation when the both of them were affected by the smoke and even fire from pyrotechnic.

## 4 The Basic Evaluated Results

The described experiment was realized during two specific football matches. At first, the dynamic grandstand behavior was observed during the match AC Sparta vs. FK Teplice which was played on November 2$^{\text{nd}}$ 2014 in the 13$^{\text{th}}$ round of the Czech premier league and which AC Sparta won 2:0. Goals for Sparta were scored by Brabec in the 45$^{\text{th}}$ minute and Costa in 81$^{\text{st}}$ minute. The large dynamic responses of grandstand were registered at these times (see Fig. 3), but the largest stand vibration was observed in time of fans celebration after the match as shown in Tab. 1 and Fig. 5. The largest grandstand vibrations from the whole experiment were observed during this celebration (see Tab. 1) because of the win in the first match gave Sparta the first-half title of the Czech premier league.

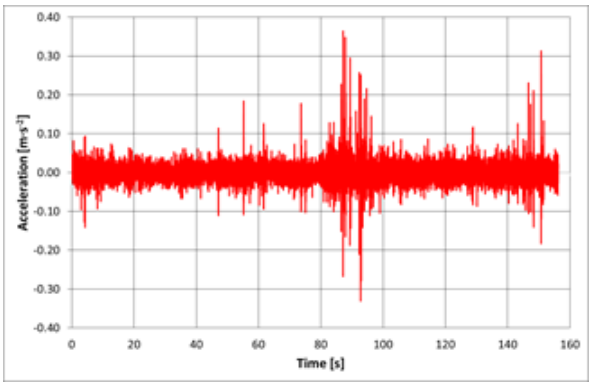
Secondly, the experiment was carried out during the match AC Sparta vs. FK Mladá Boleslav that was played on December 24$^{\text{th}}$ 2013 in the 15$^{\text{th}}$ league's round with result 4:1 for Sparta. Goals for Sparta were scored by Krejčí in the 43$^{\text{rd}}$ minute, Hušbauer in the 67$^{\text{th}}$ minute, Costa in the 81$^{\text{st}}$ minute and Bednář in the 90$^{\text{th}}$ minute. As well as during the first match, the large dynamic responses of the grandstand were registered at these times (see Fig. 8), however the largest stand vibration for the whole experiment was observed in time of fans celebration after the second match as shown in Tab. 2 and Fig. 10. Some cases of remarkable grandstand vibration were observed when fans spontaneously celebrated the lead in the match without an apparent cause on the pitch (see Fig. 9). On the Fig. 6, there is the situation when Mladá Boleslav scored. The Sparta's ultras were disappointed at first however they started the positive cheering in a few moments as is seen in the last part of vertical acceleration time record on the Fig. 6.

The dominant frequencies of forced vibrations varied slightly by intensive fans cheering approximately in the frequency interval from 2.3 Hz to 2.6 Hz in dependence of a particular fans activity how may be seen in Fig. 3, Fig. 5, Fig. 8, Fig. 9 and Fig. 10. Compared to that, the dominant frequencies of the grandstand vertical vibrations are higher and they are within the frequency band from 3.2 Hz to 4.0 Hz roughly (see Fig. 4 and Fig. 7) where the basic grandstand natural frequencies are located.

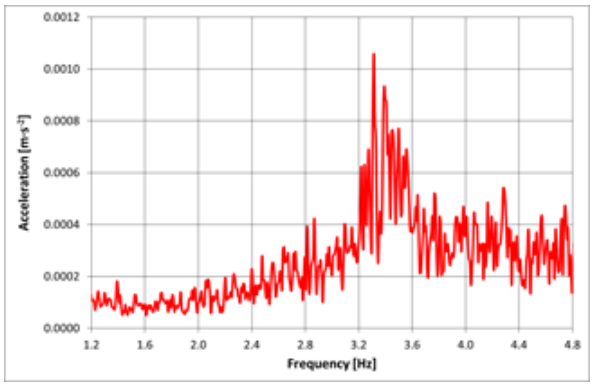



(a) the part of the vertical acceleration time record (b) the frequency spectrum of the vertical acceleration

Fig. 3: The part of the first match AC Sparta vs. FK Teplice when the first and simultaneously match winning goal for Sparta was scored.

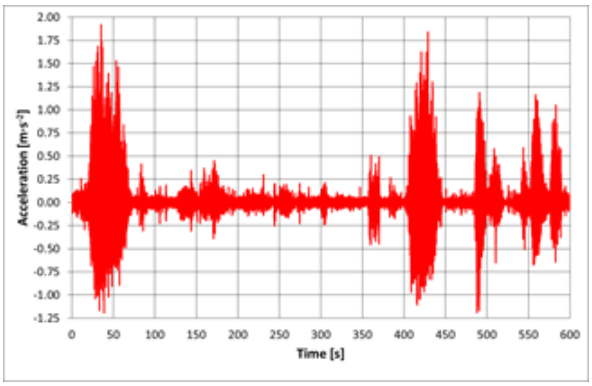



(a) the part of the vertical acceleration time record

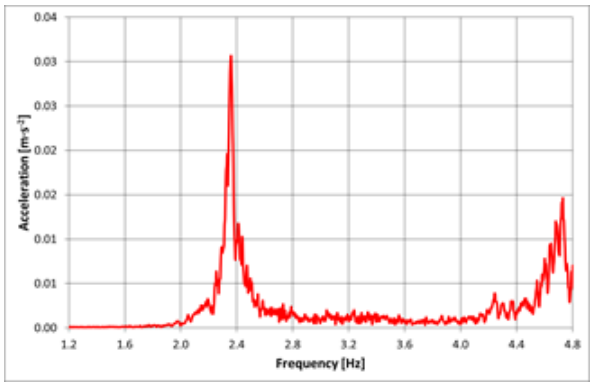



(b) the frequency spectrum of the vertical acceleration

Fig. 4: The part of the first match AC Sparta vs. FK Teplice observed during the half time.

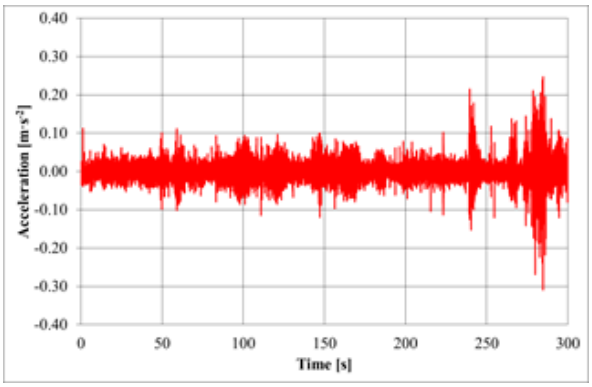



(a) the part of the vertical acceleration time record

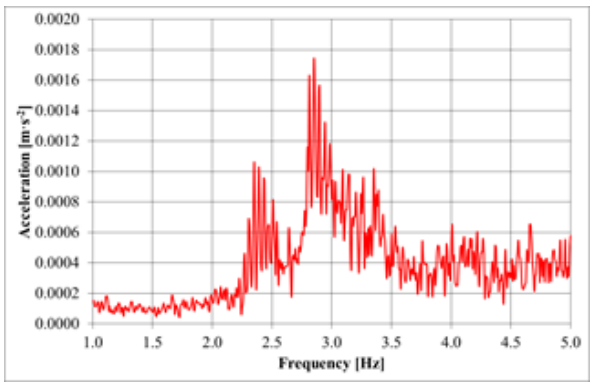



(b) the frequency spectrum of the vertical acceleration

Fig. 5: The part of the first match AC Sparta vs. FK Teplice when fans celebrated the win after the match.




(a) the part of the vertical acceleration time record

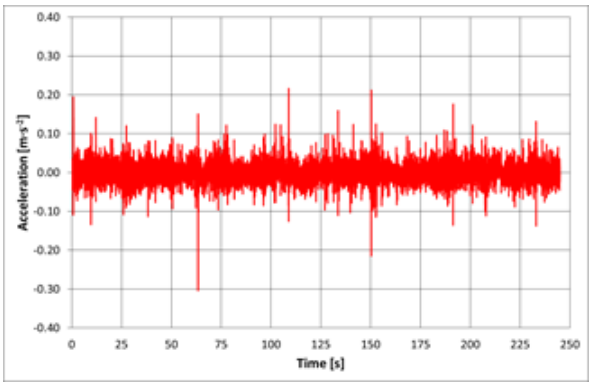



(b) the frequency spectrum of the vertical acceleration

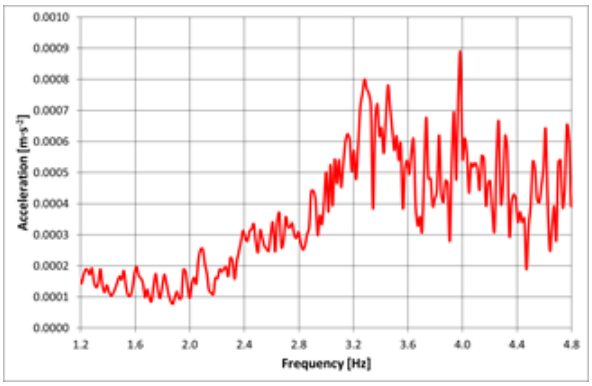
Fig. 6: The part of the second match AC Sparta vs. FK Mladá Boleslav when the goal for rival team was scored.

Tab. 1: The maximum vertical acceleration of the grandstand registered during the first match AC Sparta vs. FK Teplice.

| observed quantities | half-time | scoring of the match winning goal | spontaneous fans celebration during the first match | fans celebration after the first match |
|---|---|---|---|---|
| acceleration [ms$^{-2}$] | 0.32 | 0.92 | 0.52 | 1.96 |

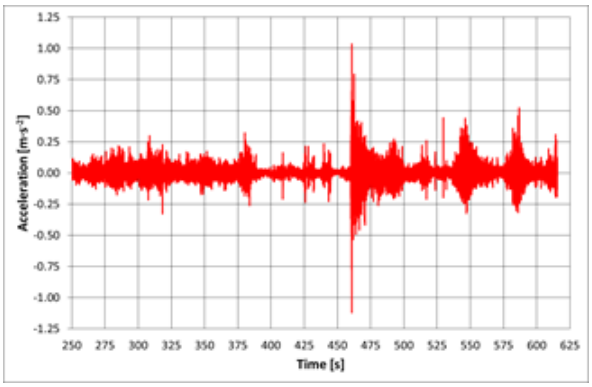



(a) the part of the vertical acceleration time record

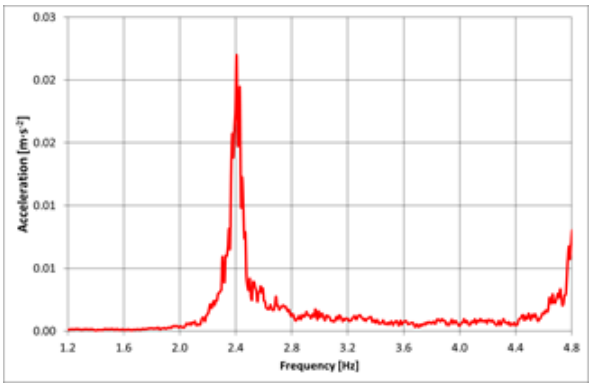



(b) the frequency spectrum of the vertical acceleration

Fig. 7: The part of the second match AC Sparta vs. FK Mladá Boleslav recorded during the half time.

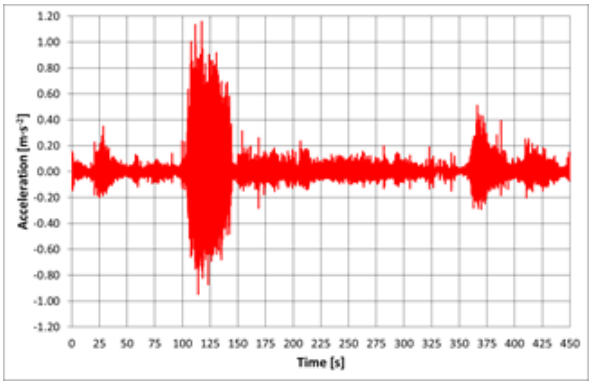



(a) the part of the vertical acceleration time record

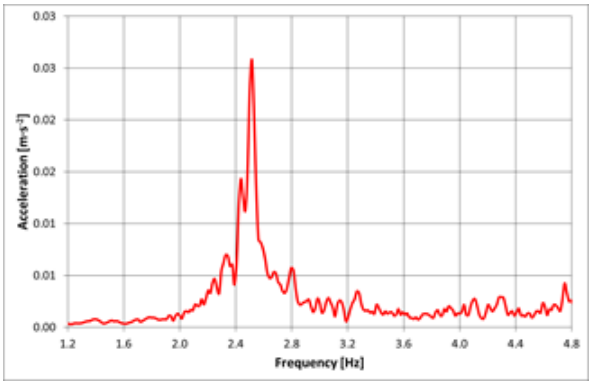



(b) the frequency spectrum of the vertical acceleration

Fig. 8: The part of the second match AC Sparta vs. FK Mladá Boleslav when the second goal for Sparta was scored.




(a) the part of the vertical acceleration time record

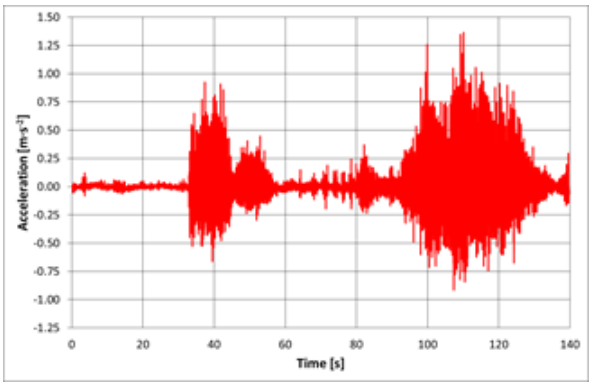



(b) the frequency spectrum of the vertical acceleration

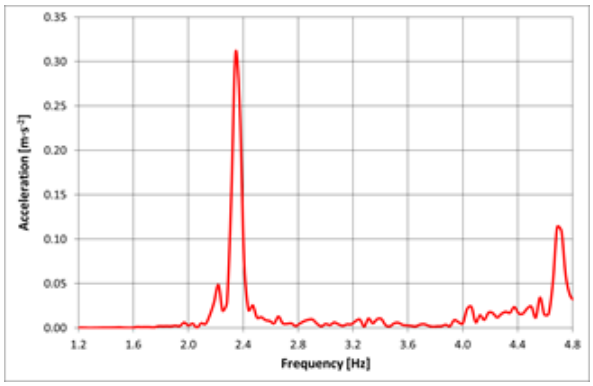
Fig. 9: The part of the second match AC Sparta vs. FK Mladá Boleslav when fans spontaneously celebrated the lead in the match without an apparent cause on the pitch during the match second half (the maximum vertical acceleration is 1.15 $m \cdot s^{-2}$).

Tab. 2: The maximum vertical acceleration of the grandstand registered during the second match AC Sparta vs. FK Mladá Boleslav.

| observed quantities | scoring of the goal for the rival team | half time | scoring of the second goal of the home team | fans celebration after the second match |
|---|---|---|---|---|
| acceleration [$ms^{-2}$] | 0.31 | 0.30 | 1.15 | 1.36 |




(a) the part of the vertical acceleration time record




(b) the frequency spectrum of the vertical acceleration

Fig. 10: The part of the second match AC Sparta vs. FK Mladá Boleslav when fans celebrated the win after the match.

## 5 Conclusion

The results of the experiment had shown predictably that fans were most active in the special situation when the home team scored a goal (see Fig. 3 and Fig. 8) and during the fans celebration after the matches especially (see Fig. 5 and Fig. 10). Vibrations which could be perceived by spectators as uncomfortable were detected in these special situations (see Tab. 1 and Tab. 2).

## Acknowledgement

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## References

[1] 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, doi: 10.1061/(ASCE)0887-3828(2006)20:3(202).

[2] A. Caprioli, M. Vanali, A. Cigada, One year of structural health monitoring of the Meazza Stadium in Milan: Analysis of the collected data (2009), in proc.: Proceedings of the IMAC-XXVII, Society for Experimental Mechanics Inc., Orlando Florida USA, 9p.

[3] O. Rokos, J. Maca, The response of grandstands driven by filtered Gaussian white noise processes, Advances in engineering software 72 (2014), 85 – 94, doi: 10.1016/j.advengsoft.2013.05.008.

[4] R. D. Bertero, A. Lehmann, J. Mussat, S. Vaquero, Vibrations in neighborhood buildings due to rock concerts in stadiums, Journal of Structural Engineering 139 (2013), 1981 – 1991, doi: 10.1061/(ASCE)ST.1943-541X.0000756.

[5] V. Rajic, A. Pavic, Stochastic approach to modeling of near-periodic jumping loads, Mechanical systems and signal processing 24 (2010), 3037 - 3059, doi: 10.1016/j.ymssp.2010.05.019.

[6] A. Comer, A. Blakeborough, M. S. Williams, Grandstand Simulator for Dynamic Human-Structure Interaction Experiments, Experimental mechanics 50 (2010), 825 - 834, doi: 10.1007.s11340-010-9334-6.

[7] J. Sim, A. Blakeborough, M. S. Williams, Modeling effects of passive crowds on grandstand vibration, Proceedings of the institution of civil engineers-structures and buildings 159 (2006), 261 - 272, doi: 10.1680/stbu.2006.159.5.261.