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Experimental study on the effectiveness of polymer damper in damage reduction of temporary steel grandstand

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Abstract. A large number of accidents, involving collapses of temporary grandstands during different types of events, were observed in the past. If the synchronized movement of people is tuned with the natural frequency of the affected part of the structure, resonance might occur. It may lead to severe damages of grandstands, their collapse or panic among the spectators. The aim of the paper is to assess, through preliminary experimental tests, the effectiveness of a polymer damper in damage reduction of a temporary steel grandstand. The damper considered in the study has been constructed out of two L-shape steel members bonded with polymer mass of high damping properties. The element has been installed as a diagonal one at the back part of the structure. The method has been compared with the typical solution of strengthening the grandstand with the diagonal stiffener of tubular cross section. The results of the study show that the responses of a temporary steel grandstand equipped with the polymer damper as well as with the typical stiffener are substantially different. The application of the polymer damper leads to the substantial increase in the level of structural damping ratio allowing to minimize the possibility of structural damage.

1. Introduction
There are a number of reasons for structural vibrations. Some of them are easily assessed, while others are purely random. The most common causes include: earthquakes (see, for example, [1-4]), large mechanical vibrating entities, air pressure, vibrations resulting from vehicles/trains using the nearby road/track or movement of people. The last one, if acting on relatively flexible structure, such as temporary steel grandstand, may cause serious problems [5, 6]. If the synchronised movement of people excites a natural frequency of the affected part of the structure, resonance will occur [7]. A large number of accidents, involving collapses of temporary grandstands during different types of events were observed in the past. In 1992, a collapse of such a structure took place in Corsica resulting in several deaths and hurting thousands of people [8]. Detailed analysis concerning disasters of temporary grandstands, that took place between 1889 and 2008, with 60 persons killed and around 6000 injured, has been presented in [8]. A lot of collapses were caused by wrong connections or anchors, difficulties during assembly, not properly fitted bracing system and pour quality of material.

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The main problems were related to unexpected excessive loads and more than 60% of disasters involved dynamic loads as the result of behaviour of spectators, mostly jumping.
Temporary steel grandstands are these types of structures that are commonly erected for a particular sporting or entertainment event to fit enlarged amount of spectators and they are removed when the event is finished. Temporary steel grandstands are characterized by many advantages, such as quick assembly, relatively low costs and possibility of using the same structures many times and locate them on uneven terrain. Most of them are erected using scaffolding system that gives an opportunity to use these structures during events that can fit small group of people or even thousands of spectators. Temporary grandstands are erected using different approaches that should be accurate and appropriate to the considered situation. Different configurations of structural members (mostly bracing systems), types of connection and anchors have a significant influence on changes in dynamic parameters of a structure. Dynamic loads have to be taken into account at the design stage of temporary grandstands, especially if light and slender structural members are used since they are more easily excitable to vibrations [9, 10].
In this paper, an idea of using polymer damper, in order to reduce steel grandstand vibrations and therefore minimize damage under human-induced excitations, is proposed. The polymer mass, applied in the damper, is a specially designed flexible two-component grout, which is based on polyurethane resin [11, 12]. It has been shown, based on the experimental studies, that this kind of material has very good damping properties [11]. Two different members have been analysed during the experimental study. One of them concerns a typical diagonal stiffener of tubular cross section as a solution of strengthening the grandstand, while the second member has been constructed out of two L-shape steel members bonded with polymer mass.

2. Experimental study

A typical repeatable part of a three-storey temporary steel grandstand has been considered in the study. The main dimensions of a structure are: length: 2.1 m, width: 2.7 m and height: 2.42 m (see Figure 1). The structure has been erected using scaffolding system that consists of tubular members. Additional structural members used to built the temporary grandstand are wooden benches, so as to provide seats for people, and steel platforms. Typical connections for scaffolding system have been used. All horizontal members are pushed in one to another allowing for some rotation at the connections what, actually, results in some additional damping in the structure.

Figure 1. Steel temporary grandstand with typical diagonal stiffener.

Two different members have been examined and analysed during the experimental study. One of them concerns a typical diagonal stiffener of tubular cross section as a solution of strengthening the grandstand (see Figure 1). The second one has been constructed out of two L-shape steel members (50x50x5 mm) bonded with polymer mass of thickness 5 mm of high damping properties (see Figure 2). This element, which can be called as polymer damper, has also been installed as a diagonal one at the back part of the structure (see Figure 3).

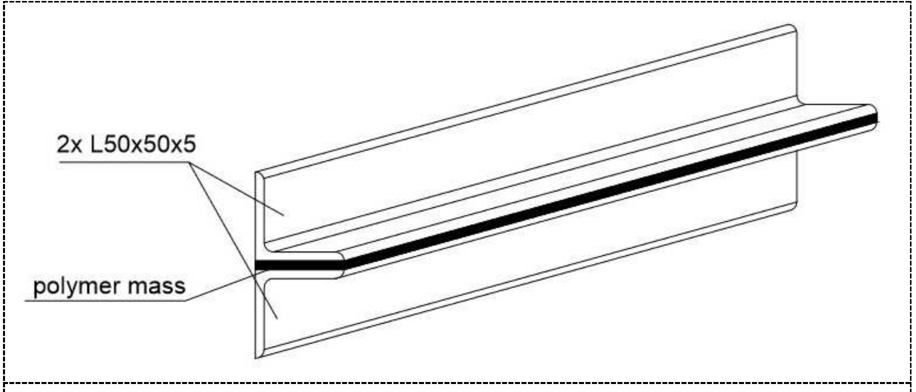

Figure 2. A scheme of polymer damper.

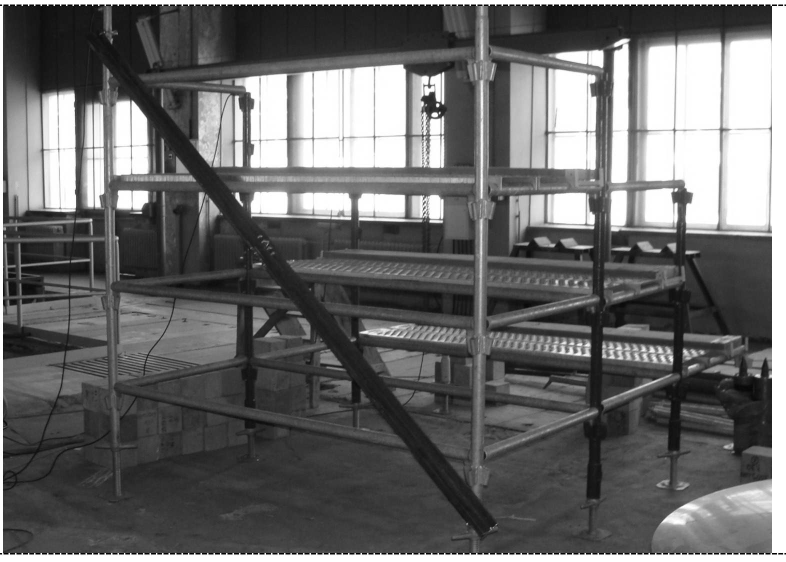

Figure 3. Steel temporary grandstand with diagonal polymer damper.

The aim of the experimental study was to assess the effectiveness of the polymer damper in reduction of vibrations of the temporary steel grandstand under two different load cases. One of them describes empty structure, while the second one takes into account mass of the spectators which, due to safety reasons, has been simulated by blocks of concrete. The weight of each spectator has been assumed to be equal to 104 kg. The mass of twelve spectators has been placed on the structure, according to existing standards, so as to allow four persons to seat on each bench (see Figure 4).

Figure 4. Front view of occupied steel temporary grandstand.

The temporary steel grandstand has been excited to free vibrations by applying an initial impact at the top of vertical tubular members. The response of the structure has been recordered by four accelerometers, placed on each vertical member, till structural damping brought the system to stop. Behaviour of empty and occupied temporary steel grandstand with typical diagonal stiffener is presented in Figure 5 and Figure 6, respectively.

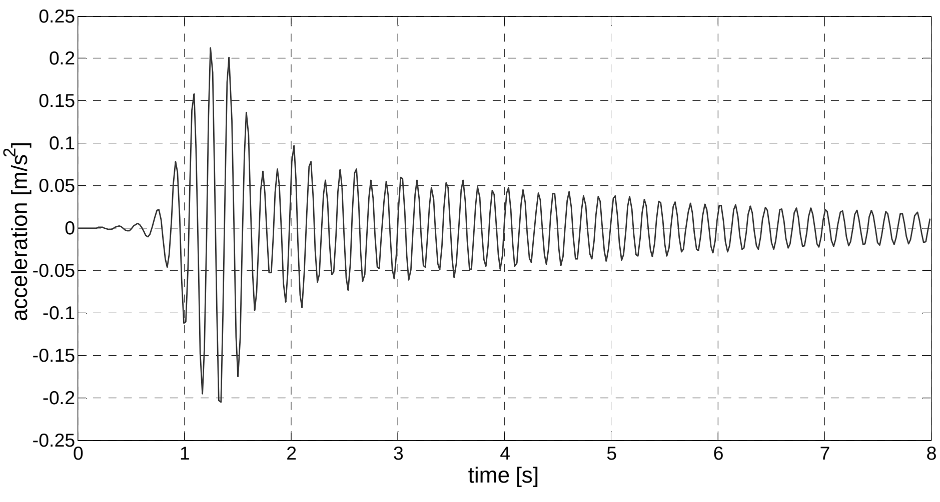

Figure 5. Acceleration time history for empty structure with typical diagonal stiffener.

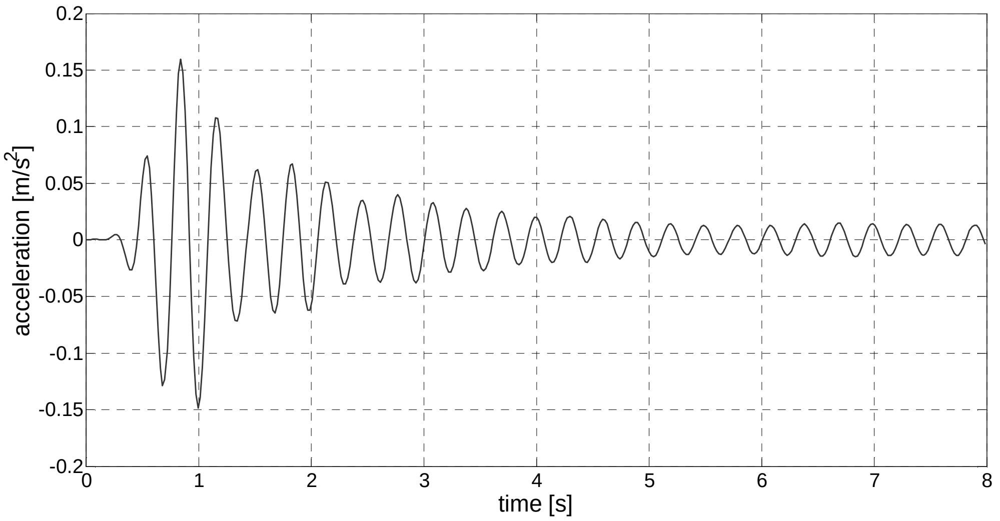

Figure 6. Acceleration time history for occupied structure with typical diagonal stiffener.

The corresponding time histories obtained for the temporary steel grandstand equipped with the polymer damper are shown in Figure 7 and Figure 8. Based on the results, dynamic parameters, such as natural frequencies and damping ratios, have been calculated. These parameters, for the empty and occupied structures with typical stiffener of tubular cross section, are summarized in Table 1. The corresponding dynamic parameters for the empty and occupied structures equipped with the polymer damper are also presented in Table 2.

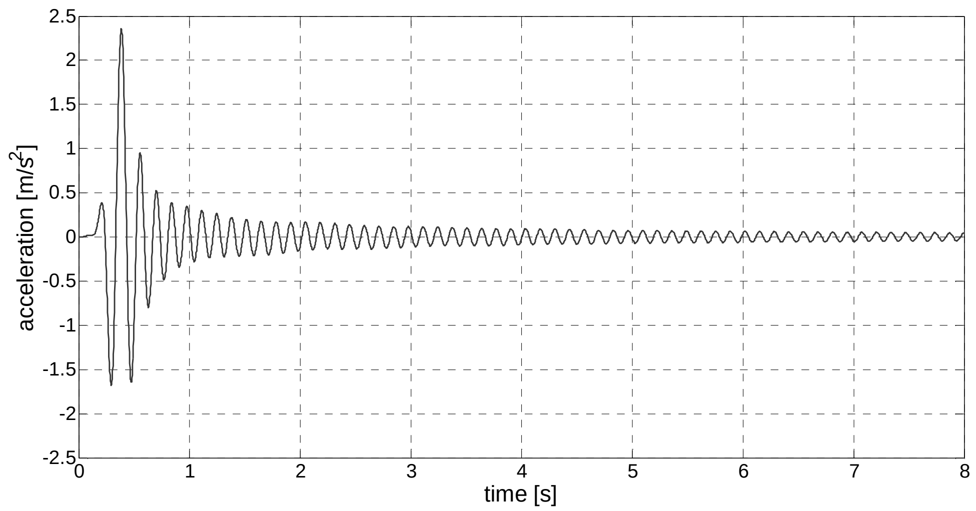

Figure 7. Acceleration time history for empty structure with polymer damper.

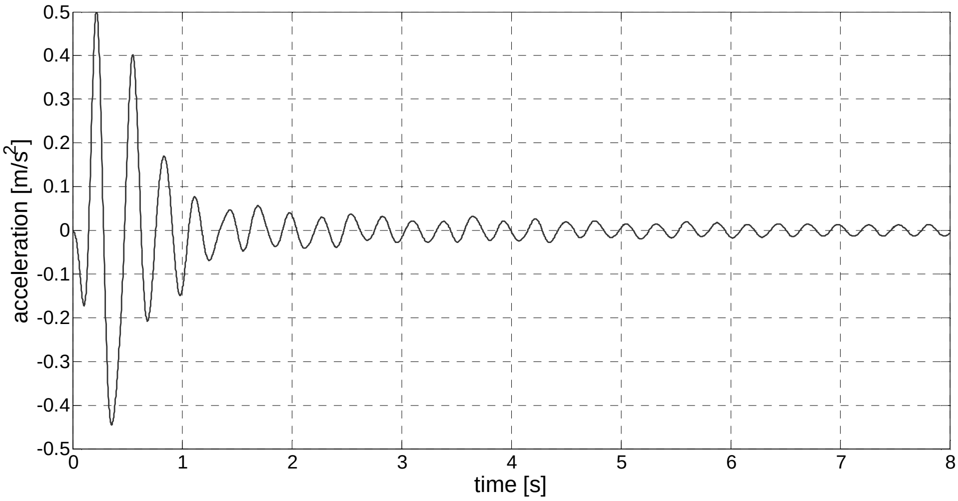

Figure 8. Acceleration time history for occupied structure with polymer damper.

Table 1. Natural frequencies and damping ratios of structure with typical diagonal stiffener member.

Type of load case	f (Hz)	ζ (%)
Empty structure	6.80	0.54
Occupied structure	3.12	0.98

Table 2. Natural frequencies and damping ratios of structure with polymer damper.

Type of load case	f (Hz)	ζ (%)
Empty structure	5.88	1.05
Occupied structure	3.38	3.05

It can be seen from Table 1 and Table 2 that mass of spectators leads to the significant decrease in the natural frequencies of the structure analyzed. The value of the natural frequency calculated for the occupied structure is about two times lower than the value obtained for the empty structure. What is more important, the results shown in Tables 1-2 and Figures 5-8 indicate that the application of polymer damper leads to much higher values of structural damping ratio comparing to the case when the typical diagonal stiffener is used. Actually, the increase in the damping ratio is as large as 95% and 211% for the empty and occupied structure, respectively.

3. Concluding remarks

The effectiveness of a polymer damper in reduction of vibrations of a temporary steel grandstand has been assessed in this paper based on the results of the preliminary experimental tests. The damper considered in the study has been constructed out of two L-shape steel members bonded with polymer mass of high damping properties. The method has been compared with the typical solution of strengthening the grandstand with the diagonal stiffener of tubular cross section. The results of the

study show that the response of the temporary steel grandstand equipped with the polymer damper as well as with the typical stiffener is substantially different. The application of the polymer damper leads to the substantial increase in the level of structural damping ratio.
The analysis described in this paper is a first stage of a wider study. The preliminary results are very promising. They show that the method of installation the polymer damper can be considered as an effective one in reduction of vibrations and therefore preventing from structural damage. However, further detailed experimental and numerical study is required so as to determine the behaviour of the steel grandstand under dynamic load induced by spectators due to their jumping. The results of further investigation will allow us to verify the effectiveness of the method.

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