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EXPERIMENTAL STUDY ON STEEL TANK MODEL USING SHAKING TABLE

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Abstract

Cylindrical steel tanks are very popular structures used for storage of products of chemical and petroleum industries. Earthquakes are the most dangerous and also the most unpredictable dynamic loads acting on such structures. On the other hand, mining tremors are usually considered to be less severe due to lower acceleration levels observed. The aim of the present paper is to show the results of the experimental study which has been conducted on a scaled model of a real tank located in Poland. The investigation has been carried out under different dynamic excitations (earthquakes and mining tremors) using the shaking table. The results of the study indicate that stored product may significantly influence the values of dynamic parameters and confirm that the level of liquid filling is really essential in the structural analysis. The comparison of the response under moderate earthquakes and mining tremors indicate that the second excitation may be more severe in some cases.

Keywords: cylindrical steel tank, shaking table, earthquake, mining tremor, sweep-sine tests

1. INTRODUCTION

Cylindrical steel tanks are very popular structures used for storage of products of chemical and petroleum industries around the world. Their safety and reliability is really crucial because any failure may have serious consequences.

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Earthquakes, as the natural phenomena, are the most dangerous and, at the same time, the most unpredictable dynamic load acting on such structures (see [4]). On the other hand, mining tremors, which are induced due to mining activity of human being, are usually considered to be less severe due to lower acceleration levels observed. A relatively large number of numerical analyses has been focused on the behaviour of different types of steel tanks under earthquakes (see, for example, [3,4]), although, the results of the experimental studies are quite limited. On the other hand, few studies have been conducted so far concerning the behaviour of steel tanks under mining tremors (see [2]).

Structures in Poland do not have to be designed for dynamic loads associated with seismic excitations. On the other hand, in the case of mining tremors only general guidelines have been formulated [5,7]. The majority of Polish territory is the area of small or negligibly small seismicity. However, from time to time, earthquakes causing serious damages to building structures are recorded. The earthquakes 2004 in the north eastern Poland [11] as well as in Podhale [12] are the examples of such events. There are also a number of places in Poland where mining tremors occur as the result of mining industry. Vibrations recorded in these regions have different characteristics than natural earthquakes (see [7-9]), although some of them can also have destructive consequences (e.g. mining tremor in Polkowice in 2002).

The aim of the present paper is to show the results of the shaking table experimental study focused on the behaviour of the model of steel cylindrical tank under moderate earthquakes (observed in Poland) as well as mining tremors. The model has been tested with different levels of liquid filling (empty tank, tank partly filled with liquid, tank fully filled with liquid).

2. EXPERIMENTAL SETUP

The subject of the current study concerns the cylindrical steel tank for oil storage with a self-supported roof (see [10]). The real tank has a total capacity of 32000 m^3 and is located in Gdańsk. The experimental model, prepared for the purpose of the present study, has been scaled based on a scale equal to 1:33.33 (see Figure 1). Its diameter and the total height is equal to 1.5 m and 0.7 m, respectively. The model has the total weight equal to 86 kg. The thickness of the bottom plate, shell and roof are equal to 3 mm, 1.2 mm and 1.2 mm, respectively. The model has been made of stainless steel. The structure has been fixed by eighteen M10 bolts with nine plates to the platform of the shaking table.

A shaking table located at the Gdansk University of Technology has been used in the experimental study. It is a unidirectional device with the platform dimensions of 2.0×2.0 m which allows for testing the specimens with a maximum mass of 1000 kg. The structure of the model is symmetrical, and for this reason, the vibration excitation of the model has been implemented for only one horizontal direction consistent with the movement of the shaking table platform. Due to technical difficulties with experimental tests using different liquids, water has been chosen as the only possible option. The shaking table tests have been carried out for four variants of the water level:

a) empty tank,
b) tank filled with 162 mm of water (1/3 of allowable limit),
c) tank filled with 324 mm of water (2/3 of allowable limit),
d) tank filled with 486 mm of water (allowable limit).

The allowable limit has been taken as a scaled value from the real contruction project.

Fig. 1. Experimental setup

3. SWEEP-SINE TESTS

The sweep-sine harmonic tests have been firstly conducted in order to determine the natural dynamic properties of the structure (see [1]). Vibration excitations have been carried out using a dynamic actuator (see Figure 1) which generates sinusoidal vibrations with variable frequency. The tests have been conducted with a sampling frequency of 1000 Hz for a length of time of 60 and 120 seconds. Recorded acceleration signals have been subjected to data processing and analyzed. The existence of resonances and magnification of vibrations has been determined.
Examples of the results of the sweep-sine tests, in the form of Fourier spectra, are shown in Figure 2 (accelerometer no. 1, horizontal direction). The results

clearly indicate that filling the tank with water leads to substantial reduction in natural frequencies. It can be seen from Figure 2 that the value of the first natural frequency has been reduced by 17.2%, 34.5% and 48.6% by filling the empty tank with 162 mm, 324 mm and 486 mm of water, respectively.

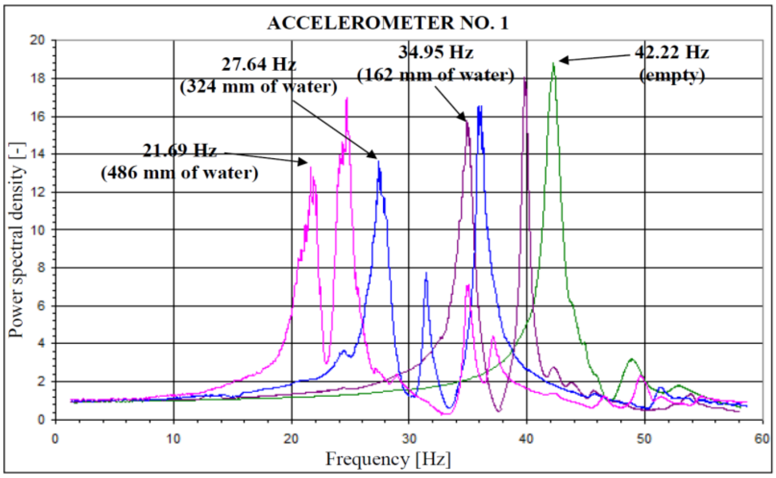

Fig. 2. Fourier spectra for the tank with different level of water filling (accelerometer no. 1, horizontal direction)

4. SEISMIC AND PARASEISMIC TESTS

In the second stage of the study, four types of dynamic excitations have been considered:

a) El Centro earthquake, 18.05.1940 (NS component, PGA=3.402 m/s^2),
b) Suwałki earthquake, 21.09.2004 (NS component, PGA=0.093 m/s^2),
c) Polkowice mining tremor, 02.02.2001 (EW component, PGA=0.503 m/s^2),
d) Polkowice mining tremor, 20.02.2002 (NS component, PGA=1.634 m/s^2).

According to the principles of similitude laws, a scaling factor (in terms of time) equal to λ_T=0.1732 has been used, as calculated from the following formula [4]:

$$\lambda_T = \frac{1}{\sqrt{S}} \tag{4.1}$$

where S is a value of the scale of experimental model (S=33.33).

Vibration excitations have been carried out using a dynamic actuator which generates time histories of seismic and mining excitations. Acceleration measurements have been conducted simultaneously in five accelerometers. They include four points located at the tank model and one point located at the shaking table platform. Locations of accelerometers are presented in Figure 1.

Experimental tests have been conducted with a sampling frequency of 1000 Hz. Recorded signals have been subjected to data processing and analyzed by DADISP computer program. The program has been used to determine the type and order of digital filtration and synchronization measurements. Recorded signals have been subjected to digital FIR filter (with frequency limit equal to 60 Hz with damping equal to 80 dB). During the data analysis, dynamic characteristics of acceleration amplitudes with extreme values for each measuring point have been obtained.

Examples of the results of structural responses, in the form of acceleration time histories under the El Centro and Suwałki earthquakes as well as the Polkowice 2001 and 2002 mining tremors, are shown in Figures 3-6. The results in these figures indicate that filling the tank with water leads initially (in most of the cases) to the increase in values of acceleration; however, beyond a certain level of water filling this regularity is inverted. It can be seen from Figure 3 that in the case of the El Centro earthquake, for example, the value of acceleration has grown by 7.2% and then has been reduced by 5.0% after filling the tank with 324 mm and 486 mm of water, respectively. It is important to underline, however, that the relation between the peak response and the peak ground acceleration might be, in some cases, more unfavourable for the mining tremors then for the earthquake excitations (similar conclusion has also been obtained for a model of tank with the total capacity of 10000 m^3 - see [2]). In the case of the Polkowice 2001 mining tremor, for example, the peak response acceleration is larger then the peak ground acceleration by as much as 236.6%. On the other hand, the same calculations for the El Centro earthquake give the value of 68.0%.

5. CONCLUSIONS

The results of the shaking table experimental study confirm that the level of liquid filling is really essential in the structural analysis. The natural vibration frequencies of the structure have been found to be lower for the fully filled tank, as compared to the case of an empty structure. Moreover, dynamic behaviour under earthquakes and mining tremors has been found to be considerably different for different levels of liquid filling.

Comparison of the responses under moderate earthquakes and mining tremors indicate that the second excitation may sometimes be more dangerous. This is mainly due to higher frequency contents of the mining tremors which tend to be closer to the natural frequencies of the tanks. Results of the study

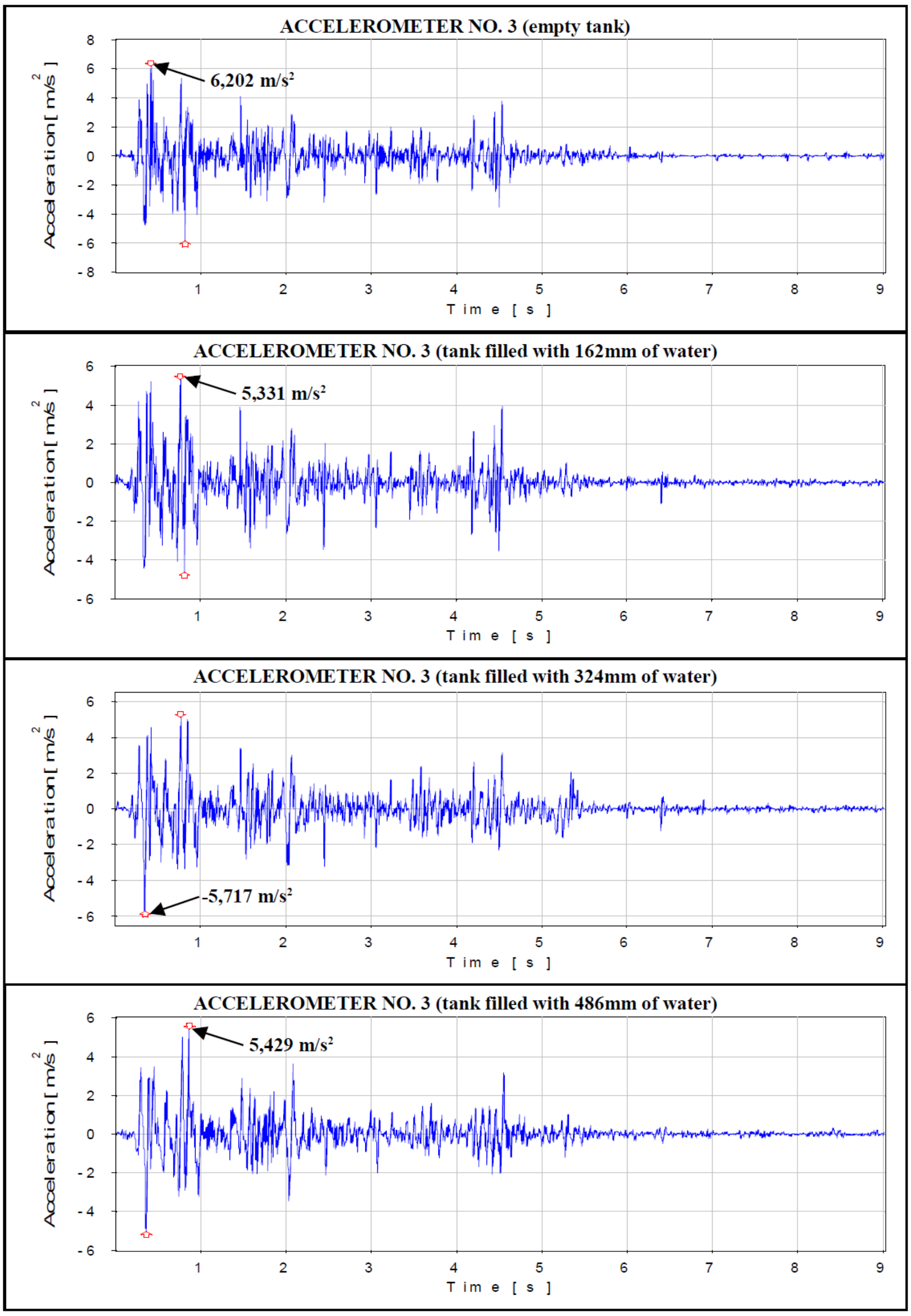

Fig. 3. Acceleration time histories under the El Centro earthquake (accelerometer no. 3)

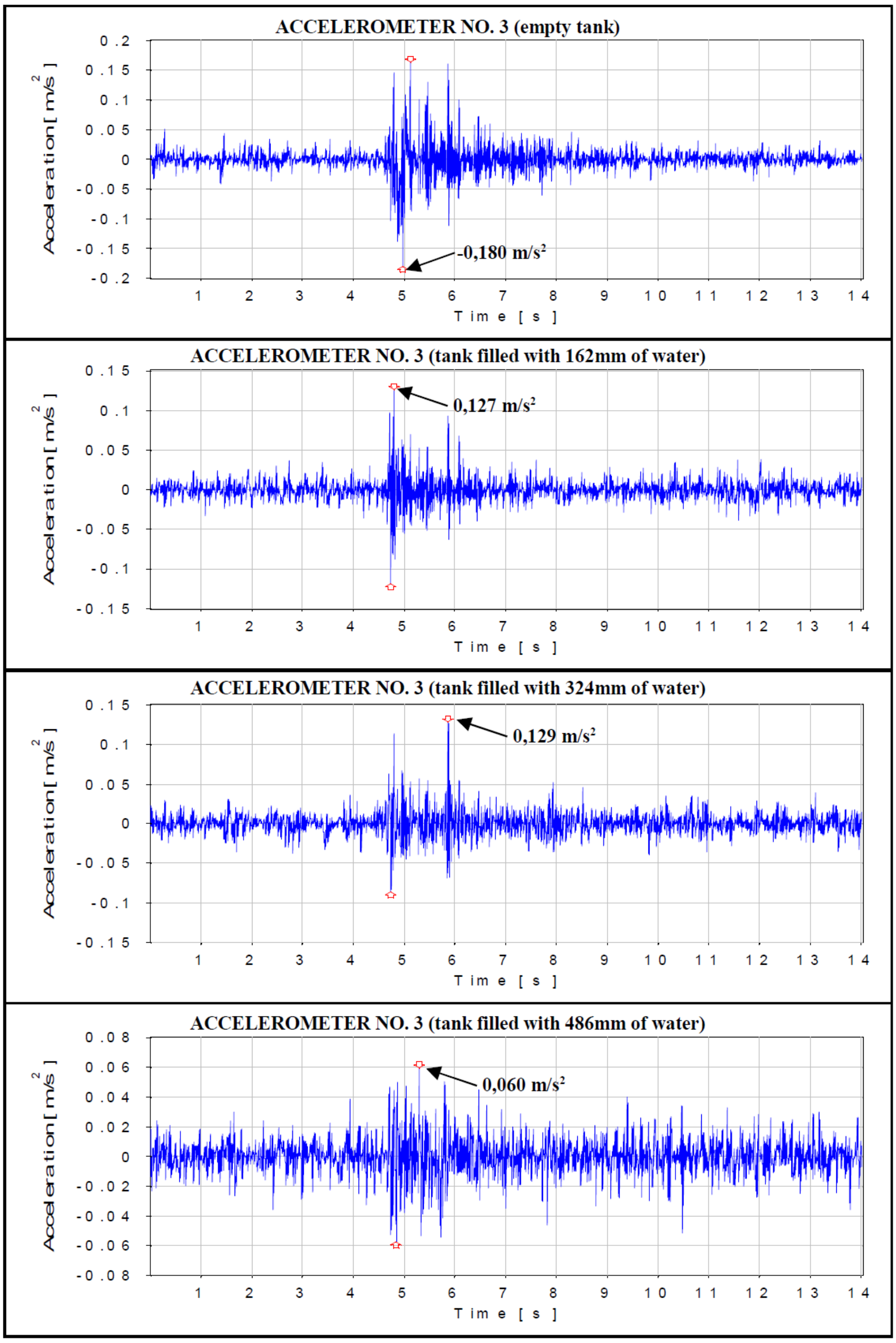

Fig. 4. Acceleration time histories under the Suwałki earthquake (accelerometer no. 3)

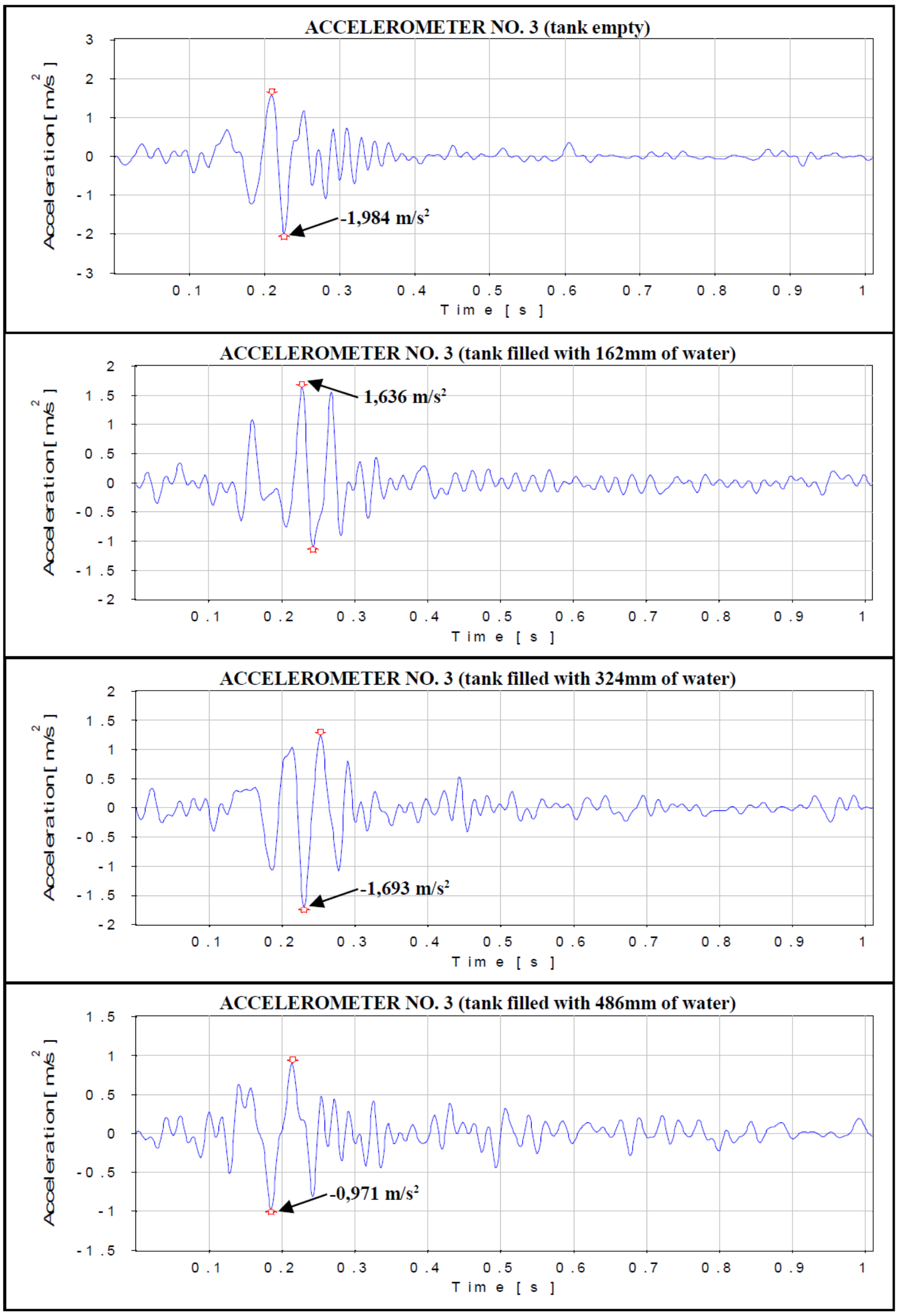

Fig. 5. Acceleration time histories under the Polkowice 2001 mining tremor (accelerometer no. 3)

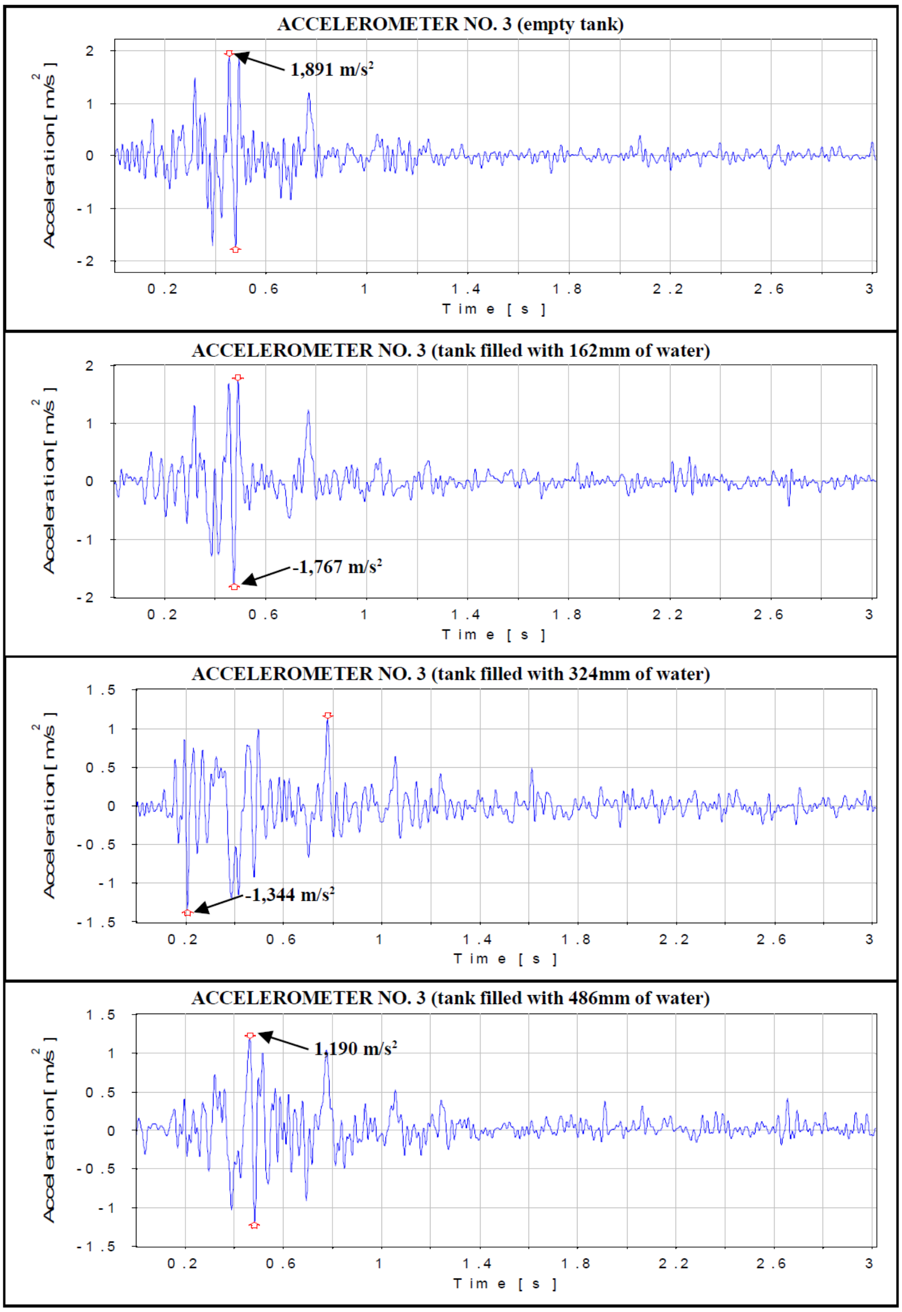

Fig. 6. Acceleration time histories under the Polkowice 2002 mining tremor (accelerometer no. 3)

indicate, however, that the appropriate design of the structures allows us to ensure their safety under different ground motions.
Further detailed numerical study is planned to be conducted so as to determine the structural response of real steel tanks under different dynamic excitations. Due to large plan dimensions of the structures, the analyses will include stochastically generated (see [6]) non-uniform ground motion excitations caused by the spatial seismic effects related to the propagation of seismic wave.

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BADANIA EKSPERYMENTALNE MODELU ZBIORNIKA STALOWEGO NA STOLE SEJSMICZNYM

S t r e s z c z e n i e

Stalowe zbiorniki walcowe są bardzo popularnymi konstrukcjami używanymi do magazynowania produktów przemysłu chemicznego i naftowego. Ich bezpieczeństwo i niezawodność są kluczowe, ponieważ każde uszkodzenie może nieść za sobą bardzo poważne konsekwencje. Trzęsienia ziemi są najbardziej niebezpiecznymi, a zarazem najbardziej nieprzewidywalnymi obciążeniami dynamicznymi, które mogą oddziaływać na tego typu konstrukcje. Z drugiej strony ruchy podłoża związane ze wstrząsami górniczymi są uważane za mniej groźne z powodu osiągania niższych poziomów wartości przyspieszeń. Celem niniejszego artykułu jest przedstawienie wyników badań eksperymentalnych, które przeprowadzono na wykonanym w skali modelu rzeczywistego zbiornika zlokalizowanego na terenie Polski. Badania wykonano przy użyciu stołu sejsmicznego. Zakres badań obejmował testy harmoniczne właściwości dynamicznych oraz zachowanie się stalowego zbiornika walcowego podczas trzęsień ziemi oraz wstrząsów górniczych dla różnych poziomów wypełnienia cieczą. Wyniki badań pokazują, że produkt magazynowany może mieć znaczący wpływ na wartości parametrów dynamicznych oraz potwierdzają, iż poziom wypełnienia cieczą jest istotny w analizie konstrukcji. Porównanie odpowiedzi podczas trzęsień ziemi oraz wstrząsów górniczych wskazuje, iż to drugie wymuszenie może być w niektórych przypadkach bardziej niekorzystne.

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