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RESPONSE OF WOODEN FOOTBRIDGE TO THE DYNAMIC LOAD

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ABSTRACT

Nowadays, modern bridge constructions are very sensitive to the dynamic load due to the use of light materials with high load capacity and low absorption. In case of the footbridges, it is an associated with the occurrence of vibration resulting from force effects caused by pedestrian movement. There is an excessive vibration of structure which is a problem of the serviceability limit state rather than the problem of the ultimate limit state. This type of load can cause the resonance of the structure so it is necessary to prevent this problem, for example by installing the vibration damper. The subject of this article is an analysis of a wooden footbridge in Příbor in the Czech Republic which is monitored for the effects of load models caused by persons. The article describes experimental measurement focused on this problem and the subsequent proposal for possible measures.

Keywords: wooden footbridge, dynamical load models, vibration, structure, damper, usability.

1. INTRODUCTION

The wooden footbridges as structures ensure primarily horizontal transit for pedestrians or cyclists. It is necessary to observe limits and operating criteria in terms of ultimate limit state and in terms of serviceability limit state because of people comfort. The very important parameter is a value of vibration and mode shapes structure that influence comfortable of movement along the structure and contribute significantly of reducing a service life.

The subject of this article is wooden footbridge (Figure-1) located in Příbor in Czech Republic designed as perpendicular through road I58. The footbridge is subtle so there is a high risk of presence of dynamic effects. The bridge object is exposed to dynamic load tests to verify vibrations and to investigate natural frequencies. The aim of in situ measurement is verification the equality of design response to pedestrian dynamic loads at wooden footbridge. In case of unfit response, it is necessary to design a damping correction of the structure.

Figure-1. Wooden footbridge in Příbor.

2. DESCRIPTION OF THE SUBJECT STRUCTURE

It is a wooden suspension footbridge, which was built on April in 2015 and it is characterized as a footbridge over a bicycle overland communication A footbridge has two poles with intermediate bridge deck. The total bridging length is 43.0 m with span of 4.0 m and 39.0 m and free width of the footbridge is 3.0 m. A footbridge is suspended with steel rods hinges of ϕ 28 mm diameter and steel rods hinges of ϕ 40 mm diameter of steel type S 355 at a pair of steel pylons ϕ 457 mm diameter which ~~is~~ reach a height of 10.8 m above the top of the vertical alignment located into the roadway.

The load carrying structure of wooden footbridge is formed by pair of contiguous main beams with constant height of glue laminated timber GL28h grade with dimensions 220/700 mm and with an elemental bridge deck with floor made of oak timber D35 grade with dimensions of boards 200/70 mm. Cross members are placed on the main beams, some of them are wooden and some of them are made of steel. Wooden cross members are made of glue laminated timber GL24h grade with dimensions 240/200 mm. The steel cross member's beams are located at the anchor points of steel hinges, at the place of the existing damper and at the place of the foundation of the footbridge. The steel cross members are continuous and at the point of crossing with the main beams, they cause weakening of them. Dimensions of steel cross members are the same as wooden cross members. Three wooden longitudinal beams of GL 24h grade with dimensions 120/160 mm are laid on the cross members. The space bracing of the footbridge is ensured by cross bracing with diameter 18 mm and by cross members connections. Rods are articulately connected in longitudinal direction. A damper was found on the ceiling part of the bridge deck.

The–structure is supported using bearings which are all fixed (Figure-3) and each of them is anchored by four screws directly into structural supports. As supports, reinforced concrete angular walls with stone base are designed. A footbridge is founded by deep micropyles.

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Figure-2. Articulated hitch connection.

Figure-3. View on the footbridge bearing.

3. DYNAMIC LOAD TESTS

Pedestrian footbridges are very sensitive to movement of people and it depends on number of factors. The most important factors are natural frequencies of footbridge vibration. The assessment of footbridges in terms of an ultimate limit state aimed at pedestrian – induced vibration is generally based on fulfilling the criterion that the acceleration of the vibration of the construction must be less than a specified value. The design criterion for evaluation of acceleration of vibration have been conceived for several years and ultimately embedded into standard regulations.

The footbridge is exposed to dynamic load tests to verify user's comfort. The purpose of the measurement was to derive a changing type of load to simulate the operating conditions of structure and to monitor dependence of its natural frequency on weight and stiffness of the experimental damper.

3.1 Load test of footbridge in question

In order to derive the necessary data, it was realized load models by two persons with a total weight of 200 kg. In the ordination of the first mode shapes of vertical bending vibration of the structure under the load model from own weight was load - bearing load object without experimental damper or with experimental damper. Load object was used for all load models. Load object (barrel) was placed gradually at two locations on the structure, in plane of the seismic sensors (position A) and approximately in the third of the footbridge (position B) (Figure-4). During the measurement, the shock load was also carried out by two people's jump.

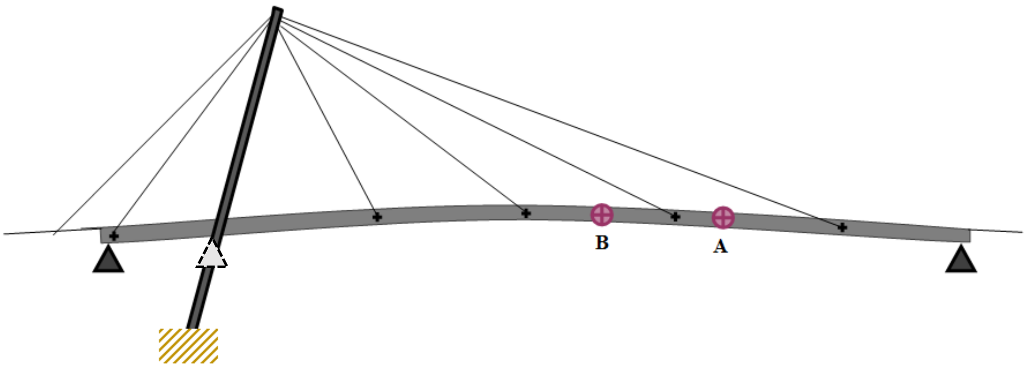

Figure-4. Locations of load object.

3.2 Load object

A barrel with an internal filling, namely crushed aggregate, was chosen as a load object for the purpose of the experiment. The aggregate weight was different in each load model, namely 200kg, 300kg, 400kg and 500kg. Load object was located in position A and in position B (Figure 4) which corresponds to the maximum or possibly sufficiently large ordination of the first mode shapes of vertical bending vibration induced by natural weight of the real structure.

3.3 Load models

Individual load models are indicated in appropriate table cells for easier orientation in subsequent graphical outputs.

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Table-1. Realized load models.

	Without load object	Position of the load object: A				Position of the load object: B			
		Weight of the load object				Weight of the load object			
	-	200 kg	300 kg	400 kg	500 kg	200 kg	300 kg	400 kg	500 kg
Walking of 2 persons (f = 1Hz)	1a								
Running of 2 persons (f = 2Hz)	1b								
Jump of 2 persons	1c								
Walking of 2 persons with load object without experimental damper (f = 1Hz)		2a	3a	4a	5a		6a		7a
Running of 2 persons with load object without experimental damper (f = 2Hz)		2b	3b	4b	5b		6b		7b
Jump of 2 persons with load object without experimental damper		2c	3c	4c	5c		6c		7c
Walking of 2 persons with load object with experimental damper (f = 1Hz)		8a	9a	10a		11a	12a	13a	
Running of 2 persons with load object with experimental damper (f = 2Hz)		8b	9b	10b		11b	12b	13b	
Jump of 2 persons with load object with experimental damper		8c	9c	10c		11c	12c	13c	

Numerical coefficient indicates the method of loading. The letter *a* indicates the load by two walking persons, the letter *b* indicates running of two persons and *c* indicates the load caused by jump of two persons.

3.2 Experimental damper of vibration

Experimental damper (Figure-5) is made as a steel closed frame with four welded springs from the bottom. Frame has been designed to accommodate the load object. In the experiment, static load test of damper with the load curve course under the load force F [kN] with a displacement of the beam Uz [mm] at time t [s] was made (see Figure-7). From the results of static load test stiffness of the damper k = 39, 25 - 44, 33 kN/mm was determined.

Figure-5. Experimental damper.

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Figure-6. Load object with experimental damper.

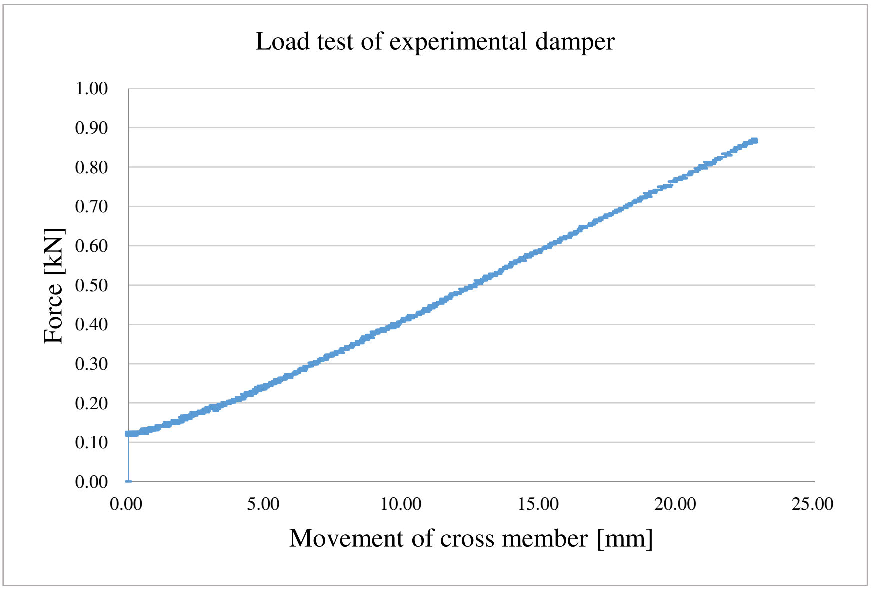

Figure-7. Graph of experimental damper test.

3.3 Climatic condition

Weather conditions were recorded at the beginning and during the dynamic load test. Weather conditions didn't change significantly during the measurement.

The temperature moved within range from 25.15 °C to 27.9°C, weather was clear and the wind speed moved within range from 0.5 m/s to 1.5 m/s.

3.4 Instruments for analysis and measurement

To verify dynamic quantities, seismic sensors of acceleration KB12VD (Figure 8) were used. The record was obtained by seismic sensor on the structure in [m/s^2] which source was [μV/V]. Two sensors for vertical vibration amplitudes and one for horizontal vibration amplitude of this type were used for the experimental measurement.
Parameters of KB12VD:

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- sensitivity 10 000 mV/g;
- range ±0,6g;
- frequency > 0,35 kHz.

The reference points for installing KB12VD seismic sensors on the footbridge (two sensors for vertical vibration amplitudes S1, S2 and one for horizontal vibration amplitudes prompted V) were selected at the points where large enough ordinations of all desired mode shapes of vibrations in the pre - created numerical model were obtained.

Reference points are shown at Figure-9.

Temperature and wind speed were recorded using anemometer.

The recording was made using a Spider 8 with sampling frequency 100 Hz so that the desired values were obtained.

Figure-8. Seismic sensor KB12VD (horizontal, vertical).

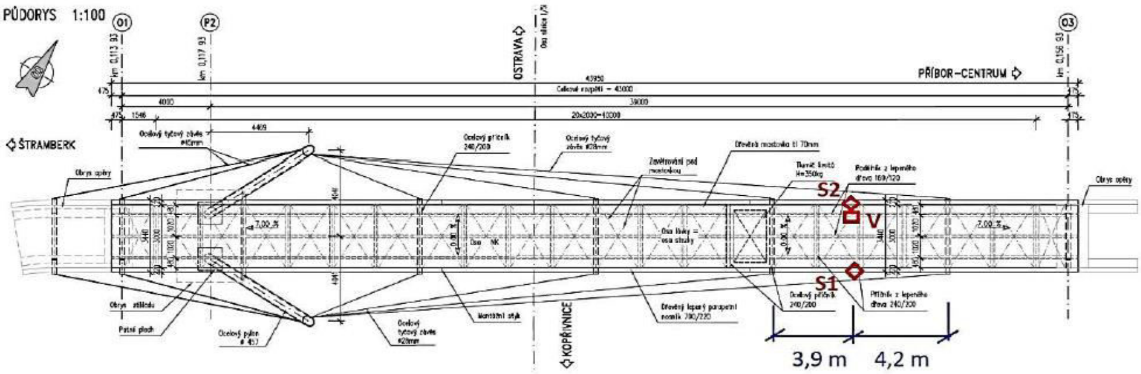

Figure-9. A plan view of the location of the seismic sensors.

3.5 Values obtained from the experimental measurement

The individual experimentally measured values from the load models described in paragraph 3.3 were measured at the point of two reference points with the seismic sensors S1, S2 and V (Figure-9).

3.5.1 Amplitudes of acceleration from forced vibration

During dynamic load test for individual load models shown in Table-1, rate of acceleration over time from forced vibration were measured. The maximum rate of acceleration from vertical vibrations obtained from the measurement were subsequently compared with values given in the valid Czech regulations and standards.

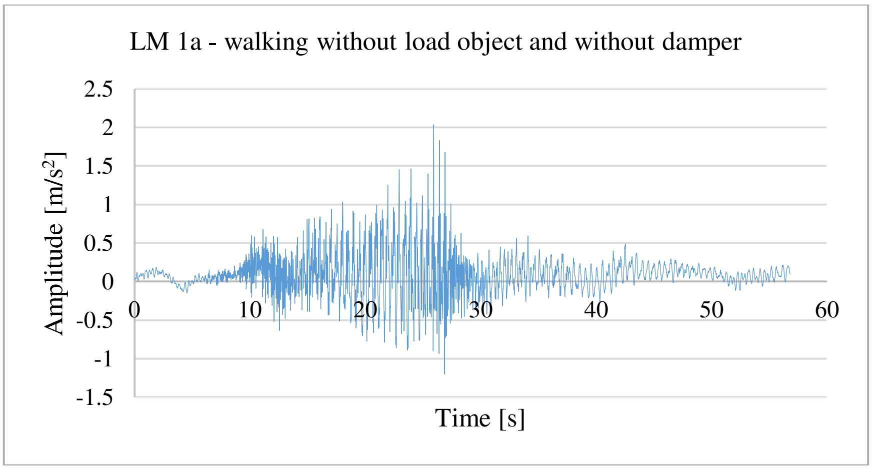

Figure-10. Graph of acceleration amplitude flow from forced vibration without load object obtained from measurement.

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3.5.2 Natural frequency

The main objectives of the experiment include the determination of the natural frequency of the structure. Predetermined load models (Table-1) caused a time span known as a vibration. From the vibration of the subjected footbridge, values of time spectrum were obtained and by using FFT analysis, these values were transferred to frequency spectrum necessary to determine their natural frequency of structure.

The values of natural frequency in vertical direction achieve value 4, 17 Hz (Figure 11).

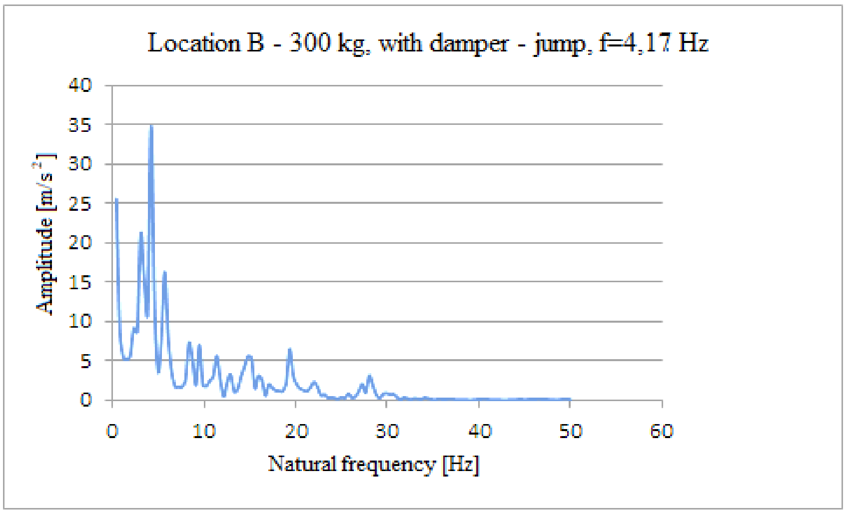

Figure-11. Graph of maximal natural frequency in vertical direction.

4. DYNAMIC LOAD TEST EVALUATION

It is clear from Figure 10 that the acceleration amplitude values of forced vibration obtained from the original measurement values are several times higher than the maximum values given in the valid Czech standard (recommended value of vertical amplitude acceleration is $0.7 m/s^2$). By measuring, it was found that all physical activities involved in the load models exhibited acceleration amplitudes from the forced vibration which also moved beyond the allowed value. For this reason, the footbridge is classified as unsatisfactory and it is necessary to design a functional damper to prevent excessive vibration.

One of the normative approaches to assessing the pedestrian comfort criterion states that these criteria should be verified if the first natural frequency of footbridge for vertical bending made shapes achieves values less than 5 Hz. Experimental measurements have shown that basic (first) natural frequency of structure for vertical bending mode shapes obtained in situ is less than 5 Hz (see Figure-12). For this reason, the pedestrian comfort should be verified.

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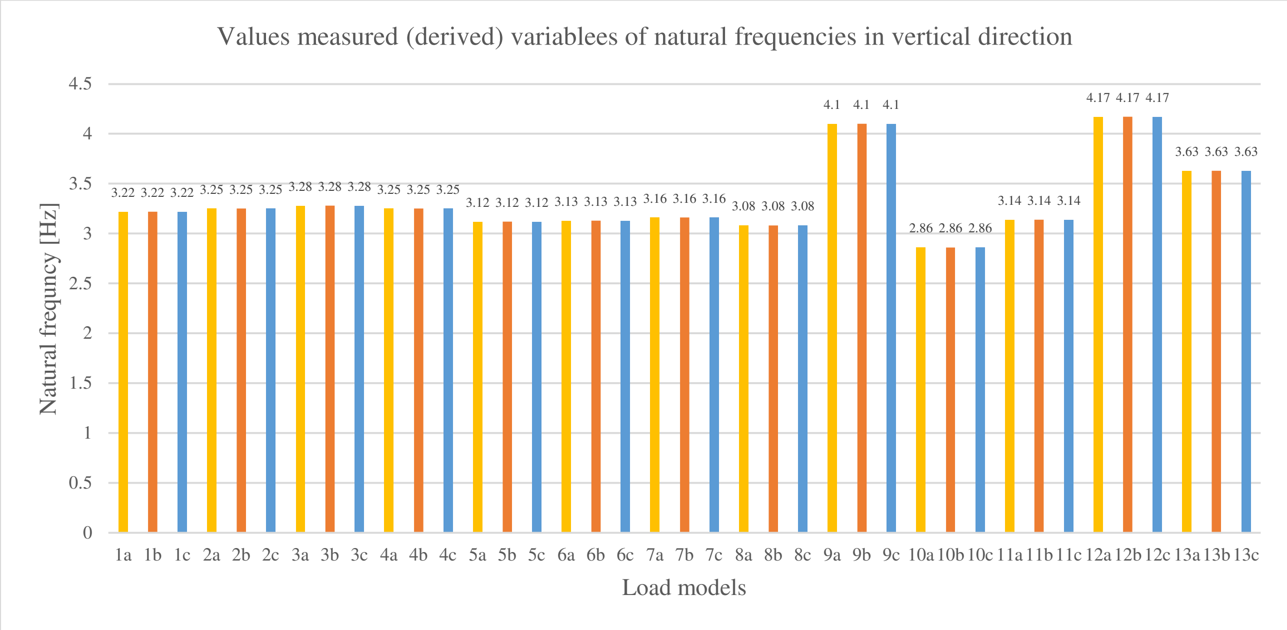

Figure-12. Graph of values of derived natural frequency in vertical direction inferred from load models.

Load models from which the natural frequencies of vibration were derived were marked by number with additional coefficient marked by letters *a, b, c*. Load models which have a common parameter, specifically they were caused by the walking of two persons were marked with letter *a*. Load models which were caused by the running of two persons were marked with letter *b* and the load models caused by jump of two persons at the same time were marked with letter *c*.

The natural frequencies of structure generally depend on the weight and stiffness of the structure. However, when it changes its stiffness, it increases its weight and at the same time reduces the load carrying capacity of the same structural elements, joints or reduces usability due to occurrence of excessive deformations. In the experiment, it was possible to solve the changes of the custom frequencies by changing the weight of the structure. It is clear form graph in Figure-12 that with change in the weight of the structure there is change in the values of the natural frequencies of the structure. The most significant improvement of natural frequencies values occurred when a load object weighting 300 kg was situated on the structure. At this point, the values of the natural frequencies were 4.17 Hz, which is closest to the standard of the determined value which states that in order to fulfill the pedestrian comfort limit; the actual frequency of the structure in vertical direction should be in range above 5Hz. There was no subsequent increase in the values of the footbridge's natural frequencies. It can be seen at Figure-12 that load models with the same load object position at its equal weight in the variant with damper or without damper achieve a single value of its natural frequencies.

Depend on experimental measurement, it is also possible to state that the use of non-active damper (the addition of mass under the bridge deck) which would serve as a weight against the footbridge's vibration is inefficient. Only in the case of load object of 300 kg at position B, the natural frequency increased to 4.17 Hz, otherwise the value of the natural frequencies decreased again. The additional weight of 300 kg despite their increasing natural frequency, proved to be inadequate because it doesn't comply with valid Czech standards.

5. CONCLUSIONS

Nowadays the footbridges have to meet the several criteria. One of the main criteria is to go with landscape and to be aesthetically. This is one of the main aspect to design of suspension footbridges which are associated with problems of serviceability limit state specifically with response of dynamic loads.

Experimental analysis of timber footbridge was realized to verify the correct behavior of the structure in terms of usability limit state specifically the values of natural frequencies at vertical direction. During the measurement, the values of accelerations amplitudes of forced vibration were found, which served to obtain the values of natural frequencies in vertical direction by using the FFT method. By in situ measurement, it has been shown that the limits of natural frequencies and the acceleration amplitude of forced vibration are exceeded in terms of the usability limit state.

By testing, it is proved that is necessary to install new active damper of vibrations, since the old non-active damper of vibrations can not to be put into operation to meet the limits given in ČSN EN 1990.

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REFERENCES

[1] Vašková V., Poništová L., Fojtík R. 2017. Dynamic effects on wooden footbridge. MATEC Web of Conferences, Article number 00012, ISSN: 2261236X, DOI: 10.1051/matecconf/201710700012.

[2] Vavrušová K., Lokaj A., Mikolášek D., Fojtík R., Žídek L. 2016. Longitudinal glued joints of timber beams and the influence of quality manufacturing onto their carrying capacity. Wood research. 61(4): 573-581, ISSN: 13364561.

[3] Lokaj A., Klajmonová K. 2014. Round timber bolted joints exposed to static and dynamic loading. Wood Research. 59(3): 439-448.

[4] Ceсháková V., Rosmanit M., Fojtík R. 2012. FEM modelling and experimental tests of timber bridge structure. Procederia Engineering. 40, 79-84, DOI 10.1016/ j. proeng.2012.07.059.

[5] Rumlová J., Fojtík R. 2015. The Timber Tie Beam: The Analysis of Spatial Framework Joint. Procedia Engineering. 114, 132-139, DOI 10.1016/j.proeng.2015.08.051.

[6] Vašková V., Fojtík R., Pustka D. 2016. Monitoring and failures of footbridges made from glued laminated wood. Procedia Engineering. 142, 87-91, DOI: 10.1016/ j. proeng.2016.02.017.

[7] Lokaj A., Vičan J., Gocál J. 2010. Theoretical and experimental analysis of timber structure behaviour. Building Materials. 7.

[8] Lokaj A., Klajmonová K. 2017. Problems of Wood - based I-beams Carrying Capacity, Procederia Engineering, pp. 271-274, ISSN: 18777058, DOI: 10.1016/j.proeng.2017.05.337.