Dynamic Testing of Corrugated Steel Plate Culvert Using Radar

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***Abstract*—The paper presents the results of selected experimental tests under dynamic loads that were conducted on a corrugated steel plate culvert. The tested railway object in the cross section has two spans in shape of closed arch. The effective length of shells is *L1* = *L2* = 4400 mm. The dynamic loads were caused by the passages of various trains. The displacements and vibration frequencies of the culvert were determined. The microwave interferometric radar was used for monitoring of displacements of this railway culvert. The maximum displacements of the culvert crown do not exceed 0.65 × 10 $^{-3}$ m. The typical frequencies of the railway culvert to passing trains were usually in the range of 0.6 to 3.0 Hz. They were obtained during passage of the heavy freight trains. Conclusions drawn from the tests can be helpful in the measurements of such culverts using the microwave interferometry method.**

***Index Terms*—Dynamic testing, steel culvert, radar, interferometry method.**

I. Introduction

The dynamic and static tests of bridges and culverts are conducted in order to confirm structural specifications, or to provide diagnostic surveys for planning maintenance and modernization. Typical experimental tests are usually carried out using accelerometers, strain and inductive (or dial) gauges. These gauges are quite accurate and reliable. Moreover, testing of structures can give rise to accessibility problems, often requiring the use of scaffolds. For these reasons, the application of radar measurements is a quite good alternative.

The interferometric radar applied in tests, is a precision microwave instrument suitable to the non-contact vibrations and displacements monitoring of various engineering structures. The high accuracy and quickness of measurement are among of the main characteristic features of the radar. The comparison of the interferometric radar vs. the accelerometer used for dynamic monitoring of various large bridges is given by Pieraccini et al. [1] and Gentile and Bernardini [2]. The interferometry method for non-contact dynamic and static measurement of the vibration of various engineering structures was described by Dei et al. [3], Gentile [4], Fratini et al. [5].

The main aim of this paper is the evaluation of possibility of the interferometric radar application for the measurements of corrugated steel plate (CSP) culvert under dynamic train loads. The vertical displacements and vibration frequencies were determined during the field load tests. The measurements were made for all trains which had been running over the culvert during 24 hours.

II. Short Culvert Description

The tested railway object in the cross section has two spans in shape of closed arch. The effective length of shells is $L1$ = $L2$ = 4400 mm that are placed directly on a special profiled layer of soil substructure about 0.20 m thickness and compacted to reach the indicator density I_D = 0.98–0.95 according to the Proctor Normal scale (Fig. 1).

The load bearing structure was constructed as two shells assembled from the CSP sheets. The corrugation depth of a = 50 mm, pitch of b = 150 mm and plate thickness of t = 3.00 mm were designed. The individual sheets were connected together using high strength bolts ø = 20 mm, and covered with the layers of soil (about 0.20–0.30 m thick) properly compacted (in the Proctor Normal scale I_D = 0.95 for the soil connected directly with the steel structure and I_D = 0.98 for the remaining part of the backfill – blanket). The soil cover over the CSP structures (including ballast, blanket and backfill) equals 2400 mm. The width of the culvert shell at the top is Bt = 16000 mm, whereas at the bottom is Bb = 21800 mm. The height of culverts is $H1$ = $H2$ = 2800 mm.

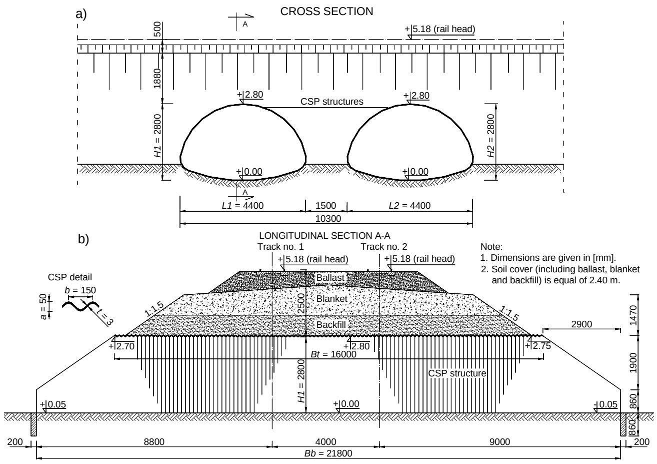

Fig. 1. The corrugated steel plate culvert.

III. The Measurements Methodology

Detailed description of microwave interferometer is given by Gentile [4] and Beben [6]. The interferometric radar with a range of 1000 m is designed to measure and analyse fast-changing movements and vibrations of the structure. The interferometric system performs the precision measurement of changes of the reflected signal phase in relation to the

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emitted signal. In typical measurement conditions, the radar has the following characteristics: range resolution of 0.50 m, the displacement measurement accuracy of 0.01 mm, the sampling rate up to 200 Hz. It should be noted that the tested object may be situated 10 – 4000 m from the instrument. A coherent microwave beam with a very low power and variable frequencies is emitted by the microwave interferometeric radar in direction of the tested object. Next, the reflected signal is received and analysed.

The experimental tests were conducted in one cross section (in crown directly under the railway line) of the CSP culvert where the maximum displacements and vibration frequencies were expected. The experimental tests were conducted continuously for 24 hours. The forty-one various trains were noticed. Fig. 2 shows the railway culvert during tests by using the radar.

Fig. 2. View of the culvert during experimental tests using the radar.

In order to evaluate the possibility of the interferometric radar application, at the same time, the inductive gauge was used [6]. The maximum measurement results of the CSP culvert using the interferometric radar were quite similar to results received using the inductive gauge (the differences did not exceed 5%).

IV. Results of Measurements and Their Analyses

The vertical displacements of shell structure of the CSP culvert were measured during conducted experimental tests using interferometric radar. The frequencies of the culvert were also calculated using Frequency Domain Decomposition method. In order to prove the possibility of using the radar for measurements of these specific culverts, one passage of trains is analyzed in detail.

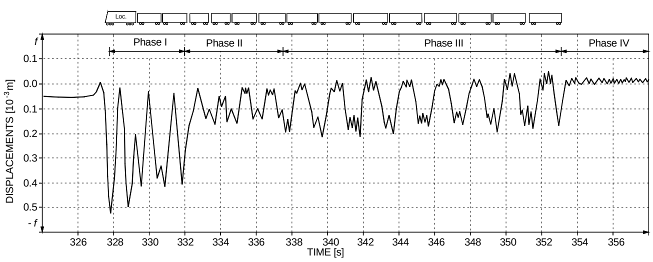

Fig. 3. The courses of displacements measured using the radar during passage of the freight train no. 29.

Fig. 3 shows example of displacements of the crown of CSP culvert. The effect of each axle of the freight train (no. 29) can actually be also observed from the displacement versus time plots. The total weight of passing train was 11846 kN. During train rides, four main phases of displacements were emphasized. The first phase represents impact of locomotive and two heavy wagons. The maximum displacements amounted to $f = 0.53 \times 10^{-3}$ m. In this stage the highest frequencies were 1.2 and 1.7 Hz (Fig. 4a). The second phase relates to passage of four lighter wagons. In this stage the maximum displacements equaled almost $f = 0.15 \times 10^{-3}$ m with frequency of 0.6 Hz. The third phase represents impact of eight heavy wagons. The largest displacements amounted to $f = 0.22 \times 10^{-3}$ m with frequencies of 0.6 Hz (less distinct frequencies were 0.9 1.8 and 2.5 Hz – Fig. 4b). The fourth phase relates to vibration reduction (damping) after passage of the freight train. This stage was dominated by frequency of 8.9 Hz which was identified, according to the preliminary tests, as a natural frequency of the "transmission gear" [6].

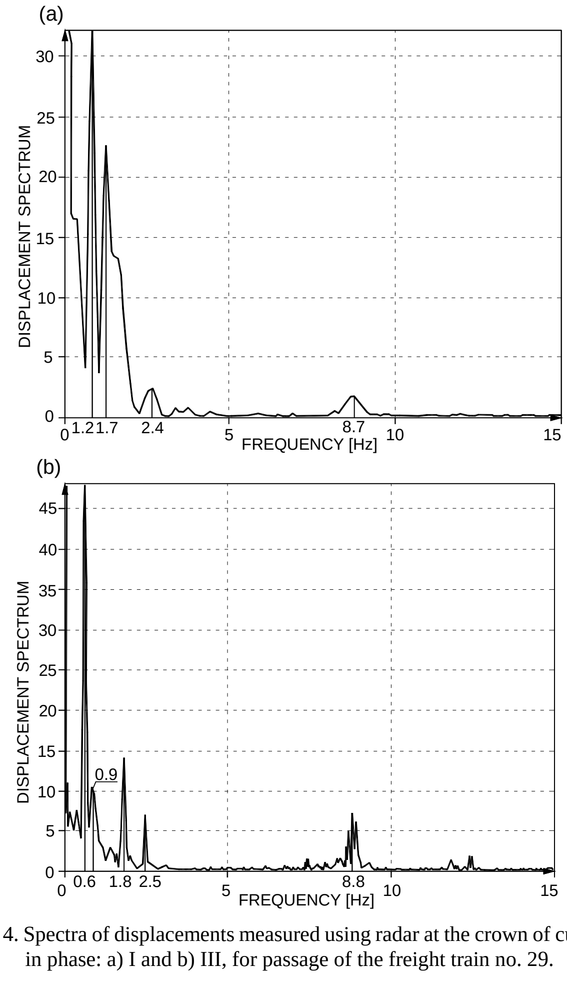

Fig. 4. Spectra of displacements measured using radar at the crown of culvert in phase: a) I and b) III, for passage of the freight train no. 29.

The typical frequencies of the railway culvert to passing trains were usually in the range of 0.6 to 3.0 Hz. The highest frequencies were caused by passage of the express trains (speed was 120 km/h). The maximum displacements of the culvert crown do not exceed 0.65×10^{-3} m. They were obtained during passage of the heavy freight trains. Then, the smallest deflection of the culvert registered during tests was $f = 0.08 \times 10^{-3}$ m.

V. CONCLUSIONS

As a result of the experimental tests, carried out on the corrugated steel plate (CSP) railway culvert during service loads, the vertical displacements and vibration frequencies of the shell structure were determined. Based on the practical experience gained from this study the following general conclusions can be drawn:

1) The interferometric radar is a suitable measurement instrument to long-term monitoring of small-to-medium culverts or bridges. It allowed getting the displacements and frequencies of this specific type of the CSP culverts very fast and with a high accuracy level. The radar registered even very small values of displacements and frequencies of the culvert (with the order accuracy of 0.01 mm and 0.1 Hz respectively).
2) During experimental tests under service loads any irregularities of behavior of the railway culvert were not found after thirteen years of service. The highest dynamic response of this culvert has been mostly caused by passages of the freight trains and the passenger express trains. Other types of trains, i.e. slow passenger trains, locomotives have not a significant dynamic impact on the culvert.

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