Evaluation Methods of Dynamic Response of RC Bridge to Spatially Varying Mining Shock

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***Abstract*—The paper presents the analysis of dynamic response of RC bridge to mining shock. Calculations of the dynamic response of the bridge were performed using three different methods. Initially, classical time history analysis were carried out with a model of uniform kinematic excitation (THA_U). In that method it is assumed that the velocity of wave propagation in the ground is infinite, so the excitation at all supports is identical. Then, a model of non-uniform kinematic excitation was introduced (THA_N). In that model wave passage along the bridge was taken into consideration. Finally, the response spectrum method (RSA) was used, which is most often incorporated because of the simplicity of calculation. Internal forces obtained with three methods were compared to assess the effect of non-uniformity of kinematic excitation on dynamic response of the bridge. It occurred that bending moments and shear forces obtained with the model of non-uniform excitation can exceed those obtained for with the model of uniform excitation. The comparative analysis also indicates that the response spectrum method may lead to non-conservative assessment of the dynamic response of the bridge.**

***Index Terms*—Mining shocks. non-uniform kinematic excitation, reinforced concrete bridges, response spectrum analysis.**

I. Introduction

In typical dynamic analysis of a structure subjected to kinematic excitation, spatial variation of ground motion is commonly neglected. The calculations of dynamic response of a structure to kinematic excitation are usually based on the assumption that movements of all points of the ground beneath the structure are identical. However, the influence of the spatial variation of ground motions on the dynamic response of long reinforced concrete bridges may be significant. These structures are exposed to spatially different ground motions, since their dimensions are comparable with the length of the wave in ground. Effects of non-uniformity of ground motions on bridges are especially considerable in case of mining shocks which present extremely high variability in space [3]. The following three phenomena are responsible for this effect [4]: (1) wave passage effect (difference in time when the wave reaches various points of the structure foundation); (2) incoherence effect (loss of coherence resulting from wave reflection and refraction in foundation ground); (3) local soil effect (difference in ground conditions in particular points of subsoil beneath a structure).

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The influence of non-uniform kinematic excitation on the dynamic response of large-dimensional bridges was discussed in many recent studies [2], [5-8]. Generally dynamic response of a structure to non-uniform kinematic excitation is considered to be smaller than dynamic response to uniform excitation. The decrease of dynamic response is caused by reduction of average amplitudes of kinematic excitation. On the other hand, so called quasi-static effects which result from different motion of particular support may lead to the increased global response.

In classic Response Spectrum Analysis equivalent seismic forces are derived on the assumption of uniform kinematic excitation. Hence, it may occur that the application of this method does not always lead to conservative assessment of dynamic response for large-dimensional bridges exposed to non-uniform kinematic excitation.

II. Numerical Model of the Bridge

The numerical model of the reinforced concrete bridge was based on the geometry of a real structure located in a region of mining activity in Poland. This bridge was selected because all of its structural data are readily available. The length of the bridge is 56 m. The piers of 7 m high and with a cross section of 675 x 80 cm were located regularly at a distance of 12 m. The abutments were situated 10 m away from the extreme piers.

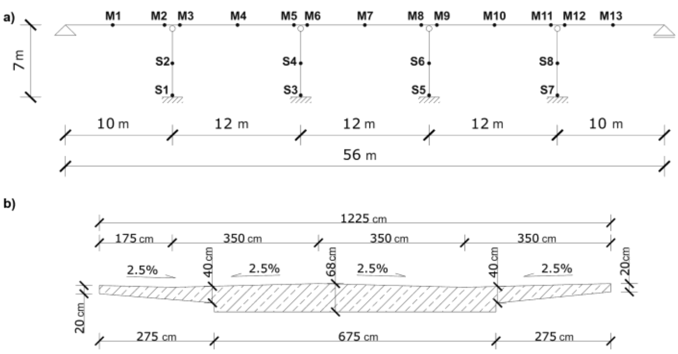

Fig. 1. (a) Scheme of the bridge with points selected for dynamic analysis, (b) Cross section of the deck

Fig. 1 shows a scheme of the bridge with points selected for further dynamic analysis and cross section of the deck. The reinforced concrete was assumed to be homogeneous and linear-elastic material. The modulus of elasticity of reinforced concrete was taken as 31 GPa. The Poisson's ratio was assumed as 0.18. The mass density of the concrete was chosen as 2500kg/m^3.

III. Data of Mining Shock From Legnica-Glogow Copper District

The dynamic analysis of the bridge was carried out for a strong mining shock registered in the Legnica-Glogow Copper District – main region of mining activity in Poland. The shock was one of the strongest events ever recorded in that area [4]. Figs 2, 3 show time histories of ground accelerations resulting from the tremor in two directions: horizontal parallel to wave propagation (lettered X) and vertical (lettered Z).

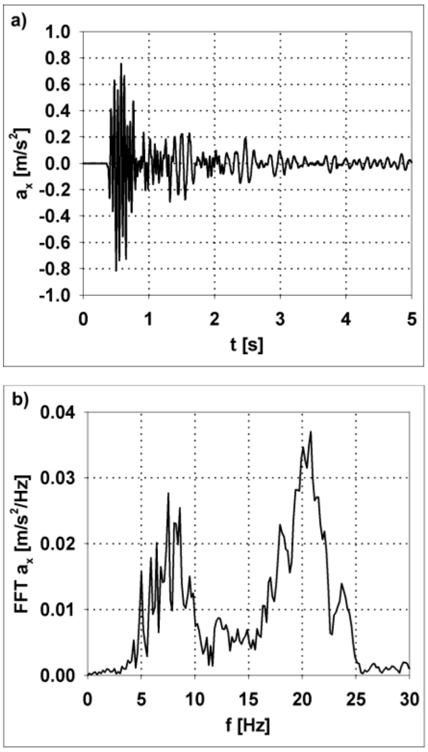

Fig. 2. (a) Time history of ground accelerations and (b) frequency spectrum resulting from mining shock in horizontal direction X

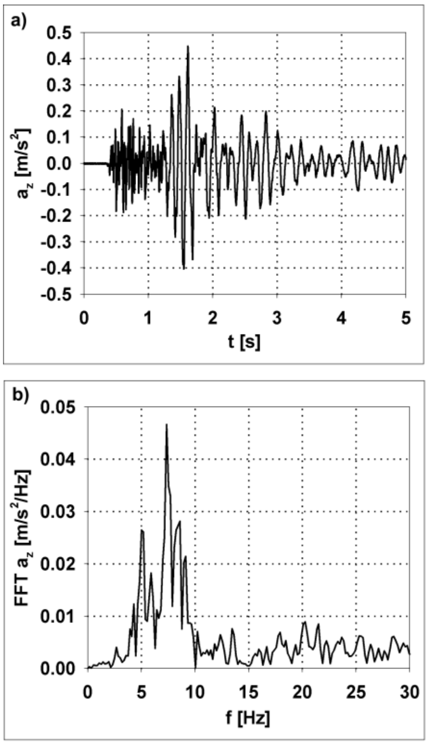

Fig. 3. (a) Time history of ground accelerations and (b) frequency spectrum resulting from mining shock in horizontal direction Z

The maximum amplitudes recorded in horizontal direction X reached 0.8 m/s2, whereas amplitudes in vertical direction Z were on the level of 0.4 m/s2. Fourier analysis of the signals indicated that dominant frequencies occurred at about 7.5 Hz for both directions and, additionally, second peak appeared at a frequency 20 Hz in horizontal direction.

IV. Comparative Analysis of the Dynamic Responses of the Bridge Obtained from Different Methods of Calculations

For the calculations of the dynamic response of the bridge subjected to the mining shock the ABAQUS program was used [1]. Three methods of calculations were applied:

1) Time History Analysis with a model of uniform kinematic excitation which corresponds to the assumption of the wave propagation velocity in the ground v = □ (THA_U),
2) Time History Analysis with a model of non-uniform kinematic excitation and with wave propagation velocity in the ground equal 400 m/s (THA_N): it was assumed in the model of non-uniform kinematic excitation that the shock wave reached the consequent supports of the bridge with a time delay depending on the wave velocity in the ground,
3) Response Spectrum Analysis (RSA).

For the dynamic analysis a critical damping fraction was assumed as 5%. The same value was used in calculations of the spectral curves for the response spectrum analysis. It was assumed that the shock wave propagated along the longitudinal axis of the bridge.

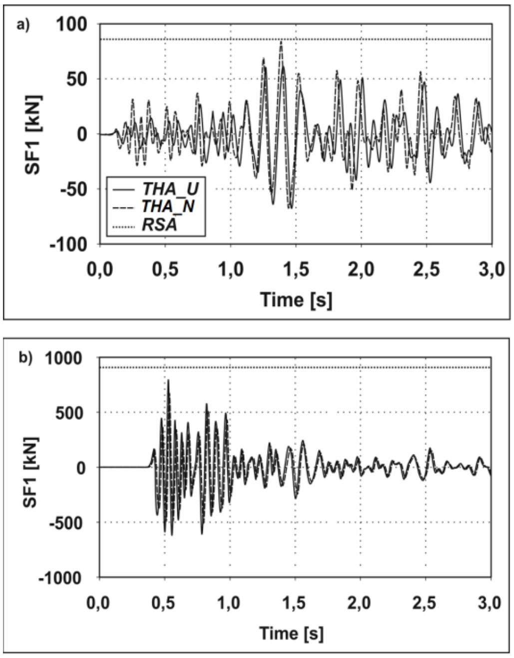

Fig. 4. Comparison of longitudinal forces SF1 obtained from different methods: (a) point S1 located on the pier of the bridge, (b) point M7 located in the middle of the deck of the bridge

The time history analyses were carried out with the Hilber-Hughes-Taylor time integration algorithm provided in the ABAQUS software for a direct step-by-step solution. A time increment 0.005 was applied in the numerical integration of equation of motion. A small value of artificial damping (0.05) was also introduced into the system to ensure numerical stability. In case of non-uniform kinematic excitation a Large Mass Method (LMM) provided by ABAQUS was used.

To examine the differences in dynamic response due to applied method of calculations the analysis of internal forces at all selected points were performed (SF1 – longitudinal forces, SF2 – shear forces, SM1 – bending moments).

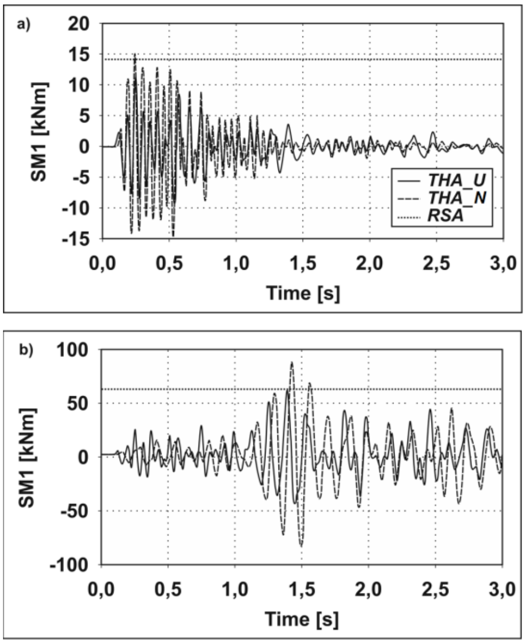

Fig. 5. Comparison of bending moments SM1 obtained from different methods: (a) point S1 located on the pier of the bridge, (b) point M7 located in the middle of the deck of the bridge

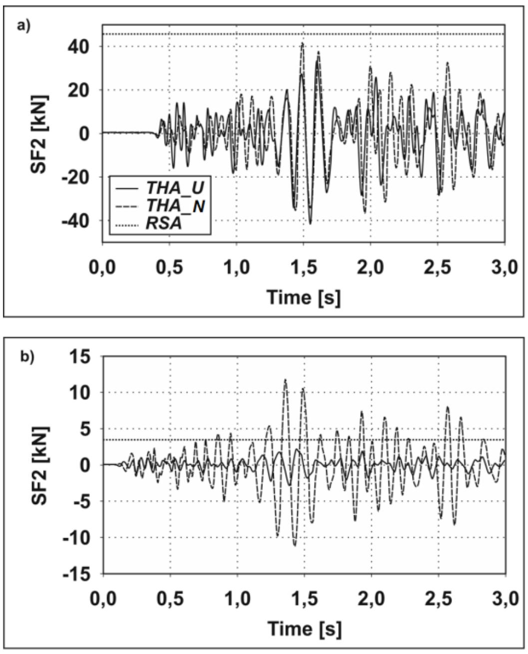

Fig. 6. Comparison of shear forces SF2 obtained from different methods: (a) point M6 located on the deck just above the pier, (b) point M7 located in the middle of the deck

Fig. 4 shows the comparison of longitudinal forces SF1: (a) at point S1 located on the left extreme pier of the bridge, (b) at point M7 located in the middle of the deck of the bridge. Fig. 5 shows the comparison of bending moments SM1: (a) at point S1 located on the pier of the bridge, (b) at point M7 located in the middle of the deck. Finally, Fig. 6 presents the comparison of shear forces: (a) at point M6 located on the deck just above the pier, (b) at point M7 located in the middle of the deck.

It could be observed that at points S1 and M7 (see Fig. 4) longitudinal forces SF1 obtained on the assumption of non-uniform kinematic excitation (THA_N) are smaller than those obtained for uniform kinematic excitation (THA_U). Both non-uniform and uniform kinematic excitation resulted in values of longitudinal forces smaller than those obtained from the response spectrum method (RSA). The same effect for longitudinal forces SF1 occurred at all selected points. Different situation occurred as far as bending moments SM1 were concerned (see Fig. 5). Bending moments obtained for non-uniform excitation (THA_N) were greater than those obtained for uniform kinematic excitation (THA_U) and they also exceeded values obtained from response spectrum analysis (RSA).

Finally, results obtained for shear forces SF2 indicated that both assumptions: uniform (THA_U) and non-uniform kinematic excitation (THA_N) led to smaller values than response spectrum analysis (RSA) at point M6 located on the deck just above the pier (see Fig. 6). However, at point M7 located in the middle of the deck of the bridge situation is different: shear forces obtained with the model of non-uniform excitation (THA_N) were almost twice as large as those obtained from response spectrum method (RSA).

V. Conclusions

The following conclusions may be drawn from the FE dynamic analysis of the reinforced concrete bridge under mining shock performed with three methods of calculations:

1) The assumption of non-uniform kinematic excitation causes the decrease of approximately 10 to 20 % in longitudinal forces at all points selected for analysis with respect to the assumption of uniform kinematic excitation. Hence, the response spectrum method well estimates longitudinal forces in the bridge.
2) The increase in bending moments occur on the assumption of non-uniform kinematic excitation with respect to the assumption of identical ground motion. This is due to quasi-static effects which result from changes of the subsoil geometry during the mining shock. In this case ignoring the wave passage effect may cause underestimation of dynamic response of the bridge. The values of bending moments obtained with the model of non-uniform kinematic excitation exceeded values obtained from the response spectrum method. Also shear forces SF2 for the elements in the middle of spans have also been underestimated with the response spectrum method.

The results presented above indicate that the simplifying assumption of uniform kinematic excitation does not always lead to conservative assessment of dynamic responses of multiple-support bridges to mining shocks. Also the application of response spectrum method for long reinforced concrete bridges may result in inexpedient underestimation of the dynamic response of a structure.

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