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EARTHQUAKE INVESTIGATIONS OF LAVANT-BRIDGE

R.G.FLESCH[1], K.KERNBICHLER[2], A.KLATZER[3] and P.MAGYAR[4]

1 Head of departement for Structural Dynamics, BVFA-Arsenal, Vienna. Member of OGE.
2,3 Institute of R/C-Structures, Technical University Graz. Member of OGE.
4 Consulting engineers Popper & Magyar

SUMMARY

The number of modes considered in response spectra calculations has a constitutive influence on the total bending moments. Results are presented for Lavant bridge. Then the problem of a nonsynchronous excitation of the piers is discussed. A relatively simple method for the generation of a "structure-related" load history is presented. This time history is used to study the influence of time lags between the excitation of the piers or groups of piers. Further, statistical information not available from response spectra calculations is presented and discussed. Finally the horizontal bending moments obtained by the two different methods are compared.

INTRODUCTION

During the last years several dynamic investigations of large prestressed bridges were carried out by BVFA and Technical University of Graz to improve the mathematical modelling. The earthquake investigations of Lavant bridge are reported in this paper. Bridges are normally lifeline structures and must not undergo severe nonlinear deformations. Mainly they are designed for earthquake loads using response spectra calculations. Two points should be considered when using that procedure:

- how many modal responses should be combined to obtain a realistic estimate of the total dynamic response
- the response spectra method is valid for excitation at a single point of the base. For large bridges with many piers a multipoint excitation takes place. Depending on local soil conditions and distances the multipoint excitation will be more or less nonsynchronous. The phase lag will have a significant influence on the dynamic load.

Both questions are studied in this paper. For the investigation of the second question time history calculations are used. The results of response spectra calculations are compared with time history calculations. Lavant Bridge consists of a main bridge with a length of 780 m and a connected hillside bridge with 299 m length (see Fig. 1). The main bridge has a hollow-girder-cross-section. The piers no. 2 - 5 are framed into the girder. The maximum shaft height is 130,35 m. Dynamic in-situ tests were carried out using an eccentric mass exciter. The response was recorded on magnetic tape and analysed later using a Modal Analysis System. Further the bridge was mathematically modelled using SAP IV. Several attempts were made to find the model with the adequate level of accuracy. Starting from a very detailed model with 166 beam elements and 124 soil springs tolerable simplifications were elaborated, taking into account that always incertainties are inherent in models of the seismic input. The quality of a seismic design cannot be increased beyond a certain level by a more sophisticated model. The results obtained from 31 different models are reported in (Ref. 1). The finally selected model has 104 beam elements and 36 soil springs and is shown in Fig. 1. This model was fitted to the experimental results for transversal excitation in a global manner via the modulus of elasticity, vicarious for all uncertainties, e.g. differences in cross sections, mass density, etc.

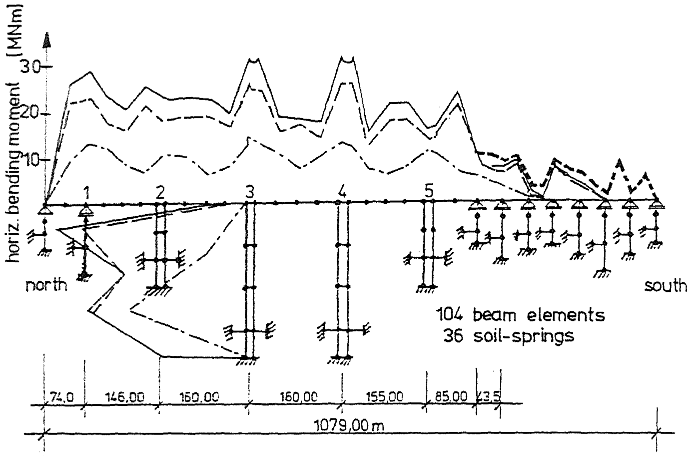

Fig.1 FE-model of Lavant bridge and bending moments from response spectra calculations

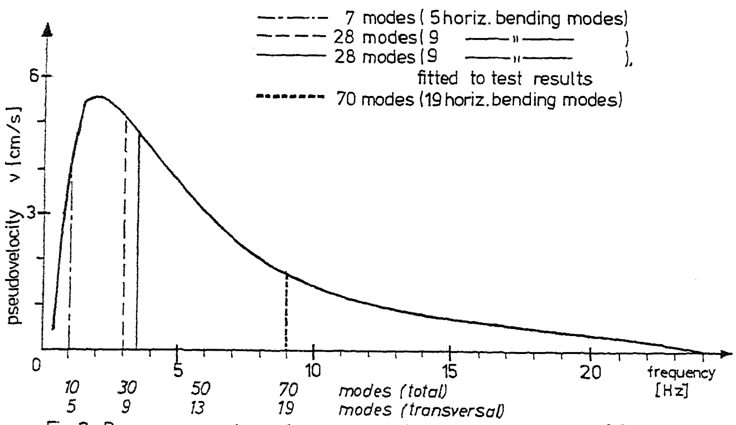

Fig. 2 Response spectrum for rock from (Ref. 2) calibrated to .03g and for $\xi = 0{,}02$

RESULTS OF RESPONSE SPECTRA CALCULATIONS

For the calculations response spectra given in (Ref. 2) were used. The spectra were mainly obtained from records of the Friulian earthquakes of 1976 and are representative for Central Europe. For the site of Lavant bridge the averaged spectrum for rock calibrated to a maximum acceleration of 0.03g and for 2 % of critical damping was used. Similar modal damping ratios were obtained by the in-situ tests. The response spectrum is given in Fig. 2. As no phase information is available when using the response spectra method, the calculated total response depends on the method used for the combination of the modal responses. For this project only the SRSS-method was used.

It is design practice in Central Europe to use a limited number of modal responses to calculate the total response. Sometimes only the modes 1 - 3 or 1 - 6 are considered without checking their significance and the sufficiency. Higher modes giving sometimes a constitutive contribution are often ignored. Especially for large bridges a limitation to few lower modes would lead to erroneous results. This problem was demonstrated for Lavant bridge. The main earthquake energy is concentrated in the frequency range 1 - 5 Hz (see Fig. 2). The lowest modal frequency in horizontal transversal direction was found to be 0,27 Hz. If the modes 1 - 7 are used for the calculation of the response, 5 horizontal bending modes are considered and the frequency range up to 1 Hz is covered. Using the modes 1 - 28, 9 bending modes are considered and the frequency range up to 3 Hz is covered. In the second case one gets a doubling of the bending moments compared with the first case (see Fig. 1). With 50 modes the frequency range 1 - 5 Hz is covered. Further due to the steep increase of the response spectrum ordinate in the range 0,35 - 1,5 Hz the total response is very sensitive to modal frequencies within this range. Hence there was a noticeable influence on the bending moments of Lavant bridge because the first five horizontal bending modes of Lavant bridge have frequencies within this range. Several improvements of the mathematical modelling (e.g. consideration of edge beams of carriageway) had a noticeable influence on the results.

Further, from Fig. 1 it follows that the contribution of higher modes to the bending moments of the large piers must not be neglected.

TIME HISTORY ANALYSIS

Since only for a few sites measured time histories are available, there is a need for artificially generated earthquakes. Several procedures are known from literature (Ref. 3 - 6). In most cases a stationary random process is made nonstationary using an envelope function, giving a time history of a certain duration. In addition the process can be filtered to consider local soil conditions and calibrated to a specific maximum or effective ground acceleration. Some works focus on the generation of spectrum compatible time histories e.g. (Ref. 6). The procedures are sometimes rather complicated. Hence a simpler approach was used to generate a "structure related" time history, which is given by Equ. (1):

$$\ddot{x}(t) = \sum_{i=1}^{n} A_i \sin(\omega_i t + \emptyset_i) \qquad (1)$$

with

A_i... acceleration amplitude for mode no. i of the bridge from response spectrum (Fig. 2)
ω_i... circular frequency of mode no. i
$\emptyset_i$... phase angle for mode no. i

Nine horizontal bending modal frequencies obtained from a FE-model similar to Fig. 1 (see Ref. 7) were used to compose the time history, with $\emptyset_i = 0,\ 1 \leq i \leq 9$. By multiplication with an envelope function the time history shown in Fig. 3 was obtained.

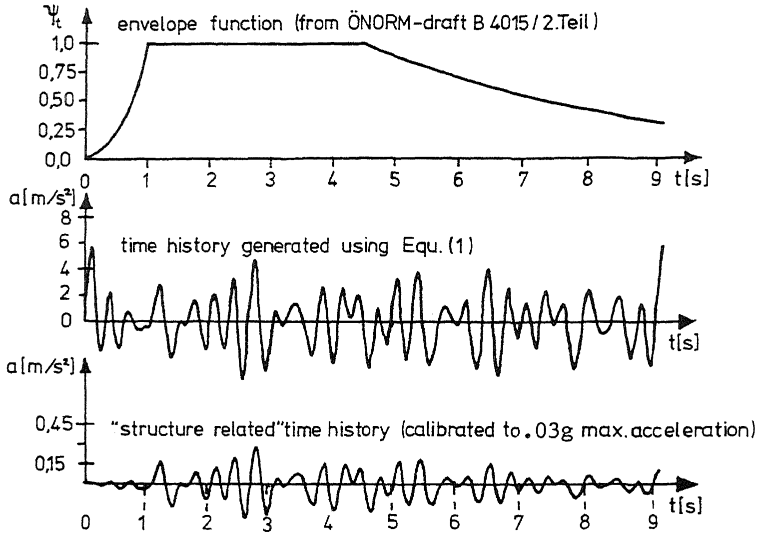

Fig. 3 Generation of a "structure related" time history

The investigations were carried out with program ADINA. The response was obtained using a step-by-step-integration method. The work focused on the following points:

* comparison of "structure related" excitations with the excitation by measured Friulian time histories
* nonsynchronous excitation of piers due to the angles of incidence of horizontal shear waves ≠ 90° relative to bridge axis (for 30° and 60°)
* assumption of a phase lag between northern and southern valley flank
* comparison of the calculated bending moments with the results obtained by response spectra calculations

13 different load cases were studied. With program ADINA base displacements must be used for a nonsynchronous excitation of the piers. Further the excitation must coincide with a global coordinate axis. Hence, in 12 cases only the time lag but not the amplitude reduction for transversal excitation was considered. Only in one case the bridge model was rotated (angle 30°) to study the exact influence. For the calculation of the time lag a shear wave velocity v_s = 800 m/s was assumed. Time histories of displacement and of bending moment were calculated in 12 selected points for each of the 13 load cases.
All results are given in (Ref. 7) and will be also presented in a forthcoming paper. As an example, the bending moments from load case 6 and 13 are compared in Fig. 4. In load case 6 the "structure related" time history was calibrated to a maximum ground acceleration of 0.03g. The angle of incidence was 90°, the duration 9 sec and the time increment 0,03 sec. In load case 13 a Friulian time history recorded at Castelfranco with a duration of 13,5 sec was used. Maximum values as well as effective values of the bending moments are given in Fig. 4. To use the information exceeding the usual response spectra results, inherent in the time history, the number of peaks of bending moments occuring in three moment classes were counted (see Fig. 5). In Fig. 6 the results obtained from the response spectra calculation are compared with the moments elaborated by time history analysis.

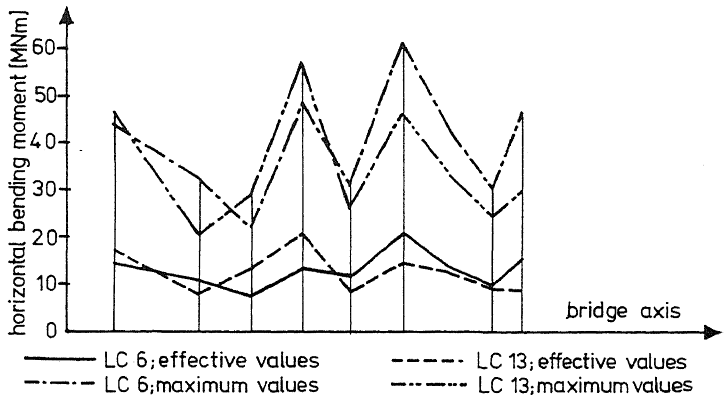

Fig.4 Comparison of "structure related" - with measured time history

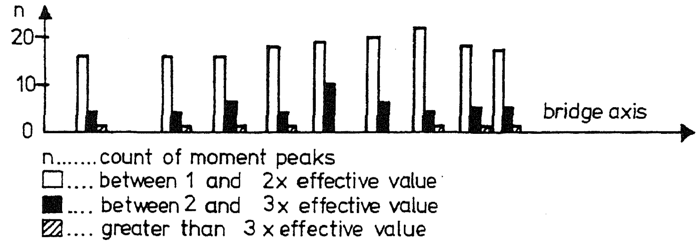

Fig.5 Count of moment peaks in different classes

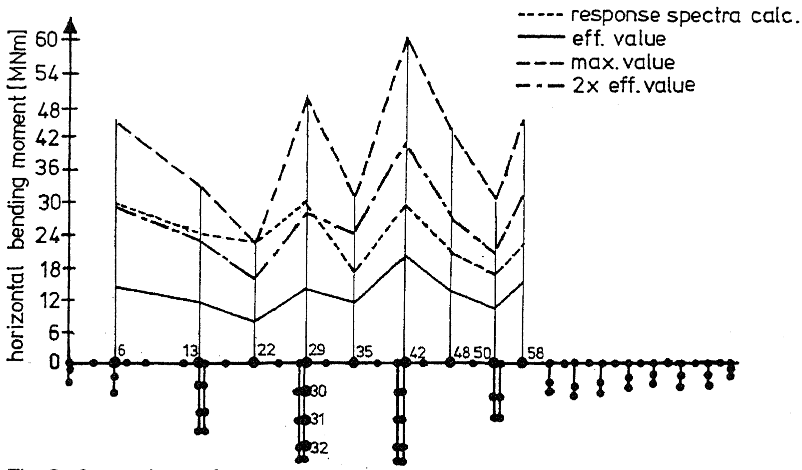

Fig. 6 Comparison of response spectra calculation with time history analysis

CONCLUSIONS

Due to the low fundamental frequency of large prestressed bridges it is necessary to use a greater number of structural modes to cover the frequency range of the response spectrum containing the main energy. When increasing the number of modes from 7 to 28 a doubling of the bending modes of Lavant bridge occured. Further due to the steep increase of the spectrum ordinate in the range 0,35 - 1,5 Hz the response is very sensitive to corresponding modal frequencies, with accurate estimates giving more realistic results.

It is shown in Fig. 4 that similar results are obtained by the "structure related" time history and by a measured time history. Hence, the generation procedure seems to be practicable. The detailed results are given in (Ref. 7). No general tendencies of the distribution of bending moments were obtained when varying the angle of horizontal incidence of earthquake waves.

Looking at the modeshapes calibrated to response spectra amplitudes it was concluded that horizontal mode no. 7 could have the greatest influence on the assymetric displacement of pier 3 and 4. Hence one half of the modal period (0,187 sec) was used as a time lag between the northern and the southern valley flank. For this load case a noticeable increase of the bending moments occured except for the area near pier 4.

Effective values of bending moments seem to be an important information about the stressing of the structure. Further, the count of moment peaks within classes between multiples of the effective value seems to be a valuable additional information. For two points (35 and 42) the influence of the maximum bending moment on the material behaviour was investigated. For these points strain rates in the range $8{,}55.10^{-5}$ to $1{,}37.10^{-4}$ $[s^{-1}]$ were found. It is concluded from (Ref. 8) that no significant increase of compression - and tension strength of concrete will result. From Fig. 6 it is concluded, that the effective values of bending moments from time history analysis are significant lower than the results from response spectra calculation. Further, the maximum values from time history analysis are much higher than the moments from response spectra calculations. The closest relationship seems to be given by the two-fold-effective-value-curve.

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