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THE ATTENUATION OF BRIDGE VIBRATIONS BY MEANS OF TUNED ABSORBERS: A CASE STUDY

R. T. JONES UNIVERSITY OF READING
A. J. PRETLOVE

R. EYRE TRRL, CROWTHORNE

1. Introduction

In recent years it has become important to reduce the vibrational motion of new footbridges and road-bridges. Modern designs are very slender giving greater flexibility, and the amount of vibrational energy which can be dissipated at joints is limited by the monolithic nature of the structure, be it concrete or steel. For these reasons, pedestrian induced vibration of footbridges can sometimes cause discomfort to the user[1]. The currently relevant British Standard for footbridges[2] requires that the amplitude of vertical vibrational acceleration shall not exceed $0.5\sqrt{f_n}$ when calculated according to the procedure given in the Standard.

Studies have been jointly made by TRRL and the University of Reading over a number of years to understand the existing vibration damping mechanisms in bridges and to evaluate ways in which extra damping may artificially be introduced[3]. One method studied recently has been the use of a tuned vibration absorber. Theoretical evaluations showed that the technique should work well and so model tests were conducted in the laboratory. These tests were encouraging and were followed by a full-scale experiment using a steel box-girder beam and a properly designed and engineered absorber. The results were excellent[4] giving attenuation in vibration amplitude by a factor of four under travelling harmonic load conditions.

This article gives a brief account of the work which followed, namely the design and testing of an absorber for a real footbridge.

2. The Bridge

TRRL made arrangements with West Yorkshire County Council to investigate a steel box-girder footbridge. This bridge was reputed to be very lively in vibration and preliminary measurements showed it to have a log. decrement of about 0.02 with a natural frequency of 2.62 Hz. The bridge, see Fig. 1, is of cantilever and suspended span type, the central span being of 50.5 m and the side spans of 9.5 m. It seemed to be an ideal candidate for the testing of a tuned vibration absorber so a special design was made incorporating several new features as a result of experience with the previous tests.

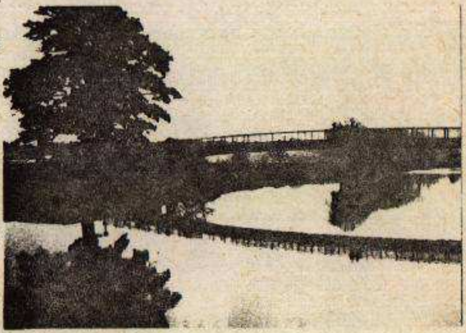

Fig. 1
Steel box girder footbridge in Yorkshire

3. Design of the Absorber

By assuming that the fundamental mode of the bridge is the only one of any importance in this problem the bridge and absorber can be modelled as shown in Fig. 2. The basic property of the absorber is the ratio μ of the absorber mass (m) to the bridge generalised mass (M). The greater the mass ratio, the easier is it to attenuate vibrations of the main mass M by diverting energy into the absorber system. However, the greater the mass ratio, the greater is the value of m with attendant cost, manageability and design disadvantages. From past experience it was decided to have a mass ratio of about 0.01.

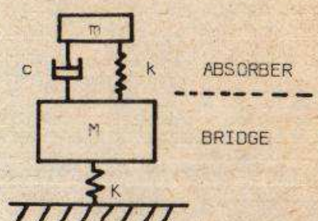

FIG.2 The simple model used for the bridge-absorber system.

The stiffness k associated with the absorber is chosen so that the absorber system is almost in tune with the natural frequency of the bridge system according to the standard formula[5]:-

$$\frac{k}{m} = \frac{K}{M} \frac{1}{(1 + \mu)^2}$$

The generalised mass of the bridge, M, is estimated from drawings to be 10080 kg. Thus m is about 100 kg and if $\sqrt{K/M}$ is 2.62 Hz this leads to a value of k of 26,800 N/m. An automobile coil spring was available which had a sufficiently great elastic extension (up to 60 mm) and with a stiffness of 31,700 N/m. This spring was used and the design mass had to be correspondingly increased to 119.7 kg. The actual mass ratio to be used was thus 0.01188.

It is also necessary to provide a viscous damper for the absorber which has an optimum value[5]:-

$$\delta = 3.85\sqrt{\frac{\mu}{1 + \mu}}$$

where δ is the log. decrement for the absorber system alone. This gives a design value for δ of 0.42.

The components of the absorber are shown in the photograph, Figure 3. The

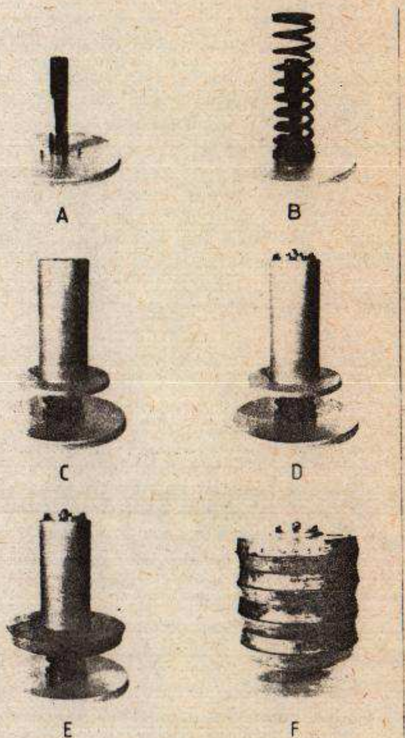

Fig. 3

Showing the construction of the absorber for the footbridge in Yorkshire.

upright cylinder shown in view A is a tube upon the outside surface of which the top-hat weight holder shown at C bears. The top-hat also contains a piston which locates inside the cylinder this latter being oil-filled to provide damping. The mass of the absorber consists of a stack of lead "doughnuts" each of which is easily manhandled. The complete absorber is 380 mm high (stationery) and 300 mm in diameter. Accurate tuning of the absorber to achieve design values of mass and damping was conducted in the laboratory.

4. Tests with the Absorber

Two types of test were conducted with the absorber in-situ at the bridge centre. First, harmonic tests were made using a hydraulically-operated inertia exciter working at a force amplitude of 90N, this value being chosen so that the resonant acceleration amplitude was above $0.5\sqrt{f_n}$ by about 40% without the absorber fitted. The test was then repeated with the absorber in place. The results are shown in Fig. 4. Secondly, walking and running tests were made by pedestrians who used an electronic metronome to keep in step with the natural frequency of the bridge. Figure 5 shows the result of one such running test in the form of central displacement vs. time. Such tests on bridges of this type often cause the response to exceed $0.5\sqrt{f_n}$, as they do in this case.

5. Conclusions

It has been a generally held belief amongst bridge designers that a minimum feasible value for the mass ratio for tuned absorbers is about 0.1 if the absorber is to be effective. The generalised mass, M, for the footbridge being about 10000 kg this belief leads to an absorber mass of at least 1000 kg. We have shown however, that on the contrary, very satisfactory reductions can be achieved with a mass ratio of as little as 0.01 and it is possible that lower mass ratios still could be useful.

To be specific, in the harmonic tests the peak amplitude was reduced by a factor of ten. In the more realistic pedestrian transit tests the peak reduction was by a factor of about 4. Thus it can be seen that in cases of bridge design where calculations according to B.S. 5400 show the bridge to be unsatisfactory, vibration absorbers may be used to bring the design within the quoted limit.

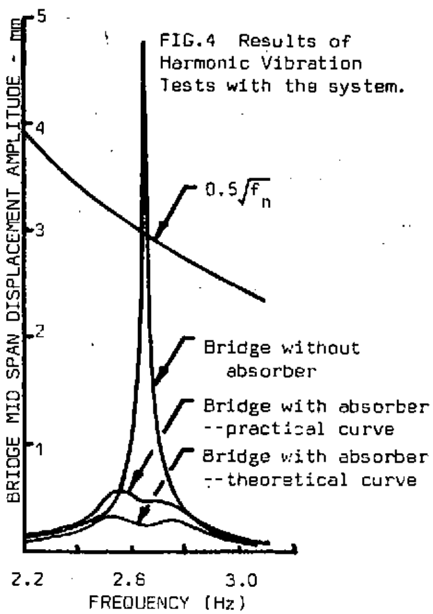

FIG.4 Results of Harmonic Vibration Tests with the system.

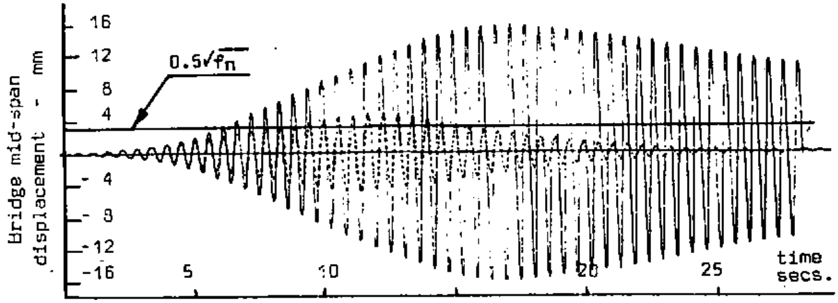

Fig. 5
Bridge Response for a pedestrian running test: solid line, without absorber; dotted line, with absorber.

In addition to reducing the peak motion of the bridge the tail of the bridge response has been considerably reduced in time (see Fig. 5). This is a valuable facet of the system behaviour because it reduces the duration of exposure for individual pedestrians and it reduces the vibration level when the bridge is excited by a successive stream of pedestrians.

Current work is investigating the effectiveness of tuned absorbers and their optimum tuning and placement for multi-span bridges which have a succession of natural frequencies within a narrow band.

6. Acknowledgements

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7. References

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