Vibration of the London Millennium Bridge: Cause and Cure

David E. Newland†

Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

(Received 14 May 2002; accepted 24 July 2002)

When the London Millennium Bridge was opened in June 2000, it swayed alarmingly. This generated huge public interest and the bridge became known as London's "wobbly bridge." Pedestrians unwittingly excited the bridge's lateral vibration modes. Although previously documented, this phenomenon was not well-known. Self-excitation occurs only when such a bridge's damping is small, so the solution was to increase damping artificially by an amount that had to be determined. This proved to be a challenging design task. This paper presents a new feedback model to describe how pedestrian motion synchronises with bridge lateral movement to become a source of self-excitation.

† Fellow of the International Institute of Acoustics and Vibration (IIAV)

1. INTRODUCTION

To mark the millennium, a new footbridge was built across the river Thames in London. It is a shallow suspension bridge linking St. Paul's Cathedral on the north side of the river with the Tate Modern art gallery on the south side. The bridge is over 300 metres long and divided into three spans, the longest being the centre span of 144 metres. To meet the designers' artistic requirements, the bridge's suspension cables sag only 2.3 metres, a fraction of the sag of a traditional suspension bridge of the same span. As a result, the cables carry a very high tension force for a bridge of this size, totalling some 2000 tonnes. When the bridge was opened, it was found to sway noticeably. With a large number of pedestrians, its sideways movement was sufficient to cause people to stop walking and hold onto the handrails. Because there was danger of personal injury, it was decided to close the bridge after a few days for remedial work.

2. HISTORY

The bridge opened on 10 June 2000. For the opening ceremony, a crowd of over 1000 people had assembled on the south half of the bridge with a band in front. When they started to walk across, with the band playing, there was immediately an unexpectedly pronounced lateral movement of the bridge deck. This movement became sufficiently large for people to stop walking to retain their balance and sometimes to hold onto the handrails for support. Video pictures showed later that the south span had been moving through an amplitude of about 50 mm at 0.8 Hz and the centre span about 75 mm at 1 Hz, approximately. Probably higher amplitudes occurred periodically and several modes were involved. It was decided immediately to limit the number of people on the bridge, but even so, the deck movement was sufficient to be uncomfortable and to raise concern for public safety. On 12 June the bridge was closed until the problem could be solved and was not reopened to the public until 22 February 2002.

There was a significant wind blowing on the opening days (force 3-4), and the bridge had been decorated with large flags, but it was rapidly concluded that wind buffeting had not contributed significantly to vibration of the bridge. Another possible explanation was that coupling between lateral and torsional deck movements was allowing vertical footfall excitation to excite lateral modes, but this was not found to be a significant factor. Early evidence in support of this conclusion was that the 1 Hz mode of the centre span, which was strongly excited, was the span's second lateral mode, which had practically no torsional movement.

It was realised very quickly that the problem was one of lateral excitation, and although allowance had been made for lateral forces, it had not been expected that pedestrians would so easily fall into step or that the lateral force per person would be as great as apparently proved to be the case.

3. RESEARCH

An immediate research programme was launched by the bridge's engineering designers, Ove Arup, supported by a number of universities and research organisations.

It was found that some similar experiences had been recorded in the literature, although these were not well known and had not yet been incorporated into the relevant bridge-building codes. A German report from 1972, quoted by Bachmann and Ammann in their IABSE book (1987), described how a new steel footbridge had experienced strong lateral vibration during an opening ceremony with 300 to 400 people. They explained how the lateral sway of a person's centre of gravity occurs at half the walking pace. Since the footbridge had a lowest lateral mode of about 1.1 Hz, the frequency of excitation was very close to the mean pacing rate of walking, about 2 Hz. Thus in this case "an almost resonating vibration occurred. Moreover it could be supposed that in this case the pedestrians synchronised their step with the bridge vibration, thereby enhancing the vibration considerably" (Bachmann, 1992, p. 636). The problem is said to have been solved by the installation of horizontal tuned vibration absorbers.

The concept of synchronisation turned out to be very important, and a later paper by Fujino et al. (1993) was discovered which described observations of pedestrian-induced lateral vibration of a cable-stayed steel box girder bridge of a size similar to the Millennium Bridge. It was found that when