Vandal Loading on Footbridges

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1.0 Introduction

Current trends in footbridge design have led to structures of increasing length and slenderness. Footbridges are having lower natural frequencies and are becoming more susceptible to excessive excitation from dynamic forces induced by human activities.

A structure must be designed to sufficiently resist dynamic excitation or otherwise face expensive retrofitted solutions such as those implemented in the case of excessive lateral sway of the Millennium Bridge, Fig 1.

Fig 1 - Millennium Bridge retrofitted with damping devices beneath the deck.

One of the largest uncertainties faced by footbridge designers originates from a lack of information about what excessive loads are humanly achievable. These loads are normally associated with a group of vandals.

A study was under taken to quantify empirically a load model for a pair of vandals jumping and bouncing. Using a GAIT lab and an optical marker tracking system it was possible to measure the combined forces generated and to determine the ability of test participants to synchronise between themselves.

2.0 Aims and Objectives

- To experimentally acquire sufficient test data to characterise Jumping and Bouncing forces induced in pairs by tracking reflective markers attached to test subjects using a system of infra-red cameras in the GAIT lab.
- To evaluate the level of synchronisation between two test subjects.
- To develop idealised periodic load models for individual & pairs of vandals.
- To find a group multiplication factor.

3.0 Periodic Force Model

A way to represent the vandal-induced force is to express it in the form of a Fourier Series.

$$F_i(t) = N \cdot P_i(t) = N \cdot DLF_i \cdot W_i \cdot \sin(i\, 2\, \pi\, f_p\, t)$$

where;

$F_i(t)$ is the forcing harmonic to be considered (usually i = 1 or i = 2)
N is the group multiplication-factor
$P_i(t)$ is the average single person loading
DLF_i is the average Dynamic Load Factor (DLF) for the i^{th} harmonic
W_i is the average person weight
f_p is the activity frequency

DLF is the dynamic force normalised by the weight of the test person. For pairs it is normalised by the weigh of the two participants.

3.0 Methodology for Measuring Forces

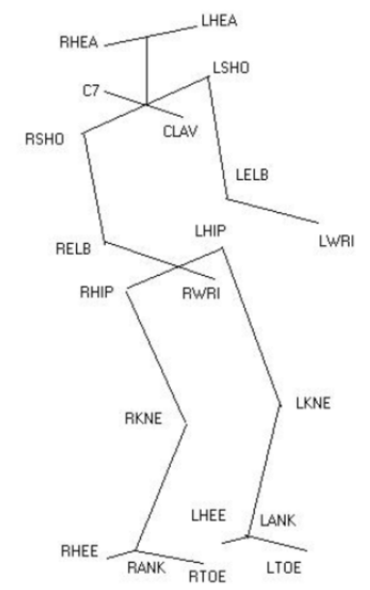


Fig 2: Representative model made of 20 reflective markers placed on subjects

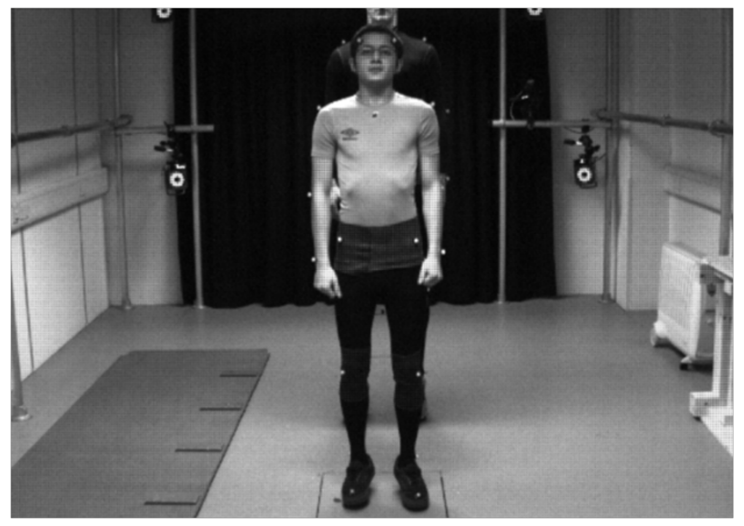


Fig 3: Arrangement of two participants performing jumping and bouncing in line in the GAIT lab.

Data collection consisted of :

- 12 subjects, of varying weight, height and gender.
- 6 Pairs both Jumping and Bouncing to a metronome beat.
- 5 Activity rates for each activity; Jumping (1.5 - 3.5 Hz) and Bouncing (2.0 - 4.0 Hz); both at 0.5Hz intervals.
- The capture of 20 body marker displacement data was aquired at a sampling rate of 200 Hz (Fig 2 & 3)
- The force was reconstructed from individual body segments using Newton's 2nd Law [1] and Anthropometric data [2] (Force = Mass x Acceleration)

4.0 Characterising Vandal Loads

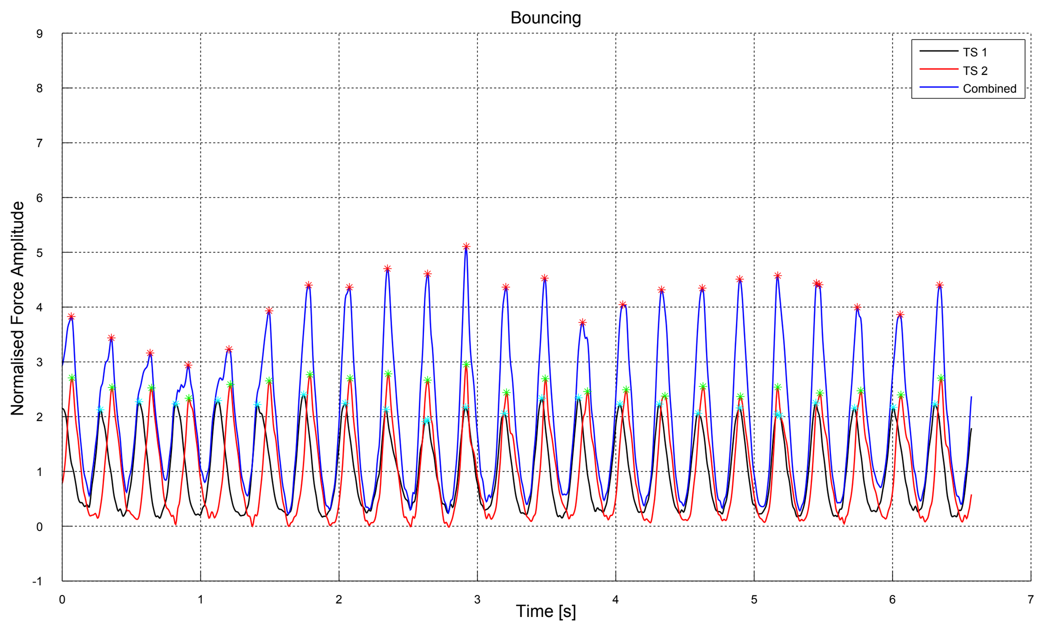
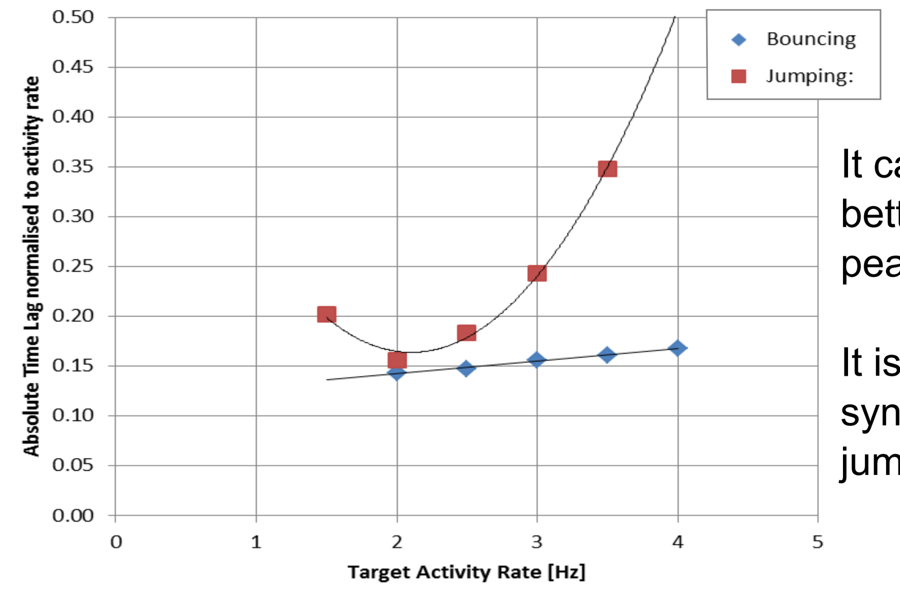


Fig 4: Force-time history of a pair Bouncing at 2 Hz

The load of a pair was determined by combining the individual contributions (Fig 4). The loads displayed have been normalised to the subject's body weight.

The mean time lag between individual forces was determined by compaing the time instant of subsequent peak forces (Fig 5).

5.0 Synchronisation



It can be seen that the synchronisation is better (i.e. time lag between individuals' peaks is smaller) for the bouncing activity.

It is also found that the best synchronisation (i.e. smallest time lag) for jumping pairs is achieved at around 2 Hz

Fig 5: Absolute Phase lag between pairs Jumping and Bouncing normalised to the Activity Rate

6.0 Proposed Loading Model for Vandals

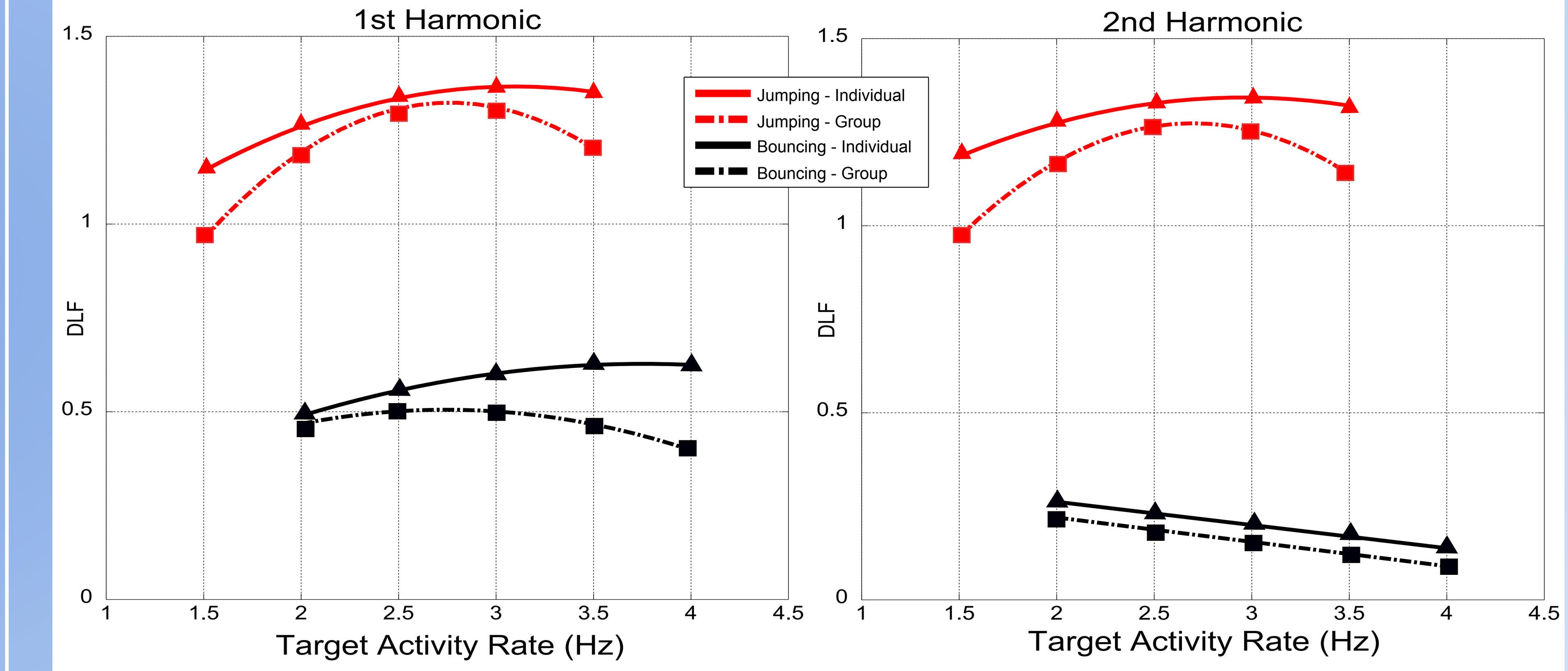


Fig 7: The magnitudes of DLFs for 1st Harmonic (top) and 2nd Harmonic (bottom)

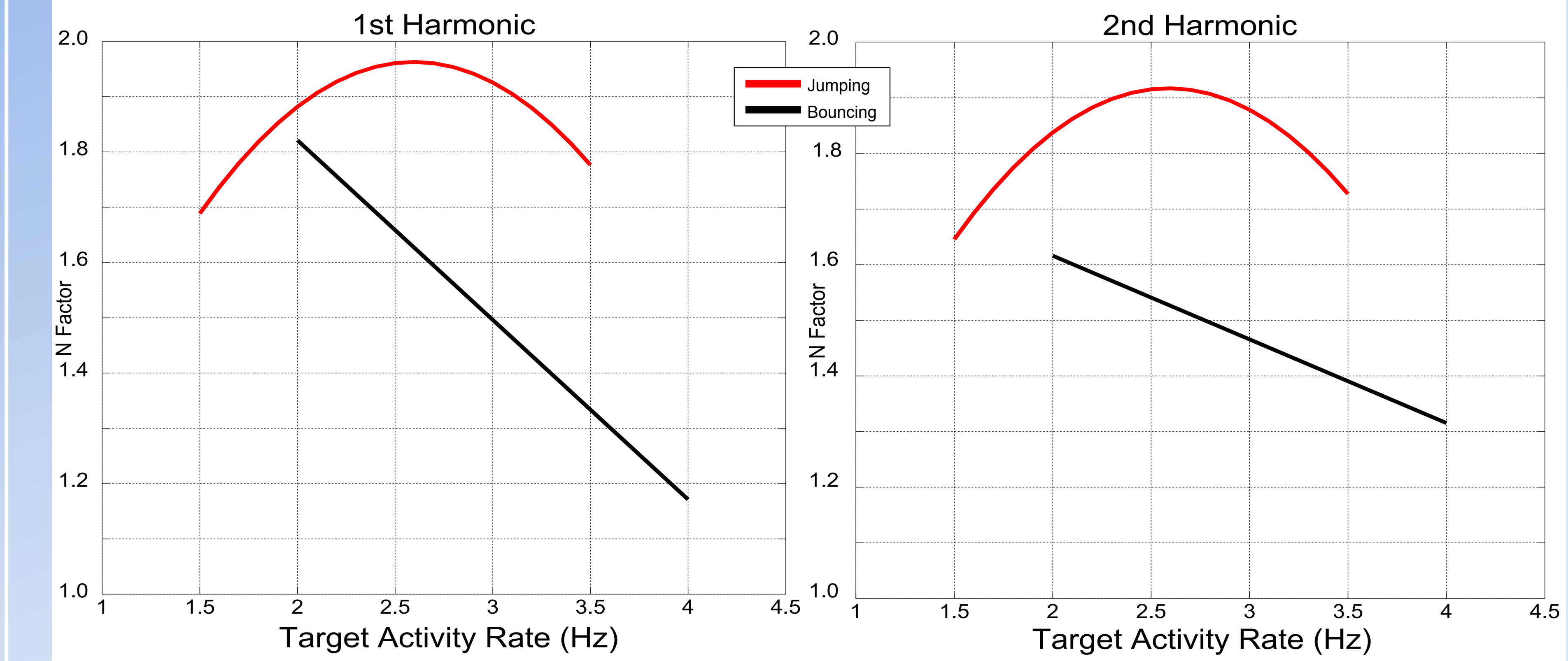


Fig 8: The multiplication factor N to convert a single person's force to represent a pair's, derived from Fig 7.

7.0 Conclusion

- It is possible to accurately model Jumping and Bouncing using optical based systems.
- Although there exists great inter and intra subject variability both Jumping and Bouncing can be modelled as idealised periodic forces. (This provides a conservative extreme case and is suitable as it is for Vandal loading)
- In general Bouncing in pairs can achieve a greater degree of synchronisation than Jumping.
- Jumping in pairs is best synchronised at around 2 Hz (Fig 5)
- Due to this lack of perfect synchronisation the multiplication factor N for pairs Bouncing and Jumping is lower than two (Fig 8)
- The largest forces produced by a pair of "vandals" is when they are jumping at 2.5Hz.

It should be noted the activities performed were on a rigid floor and it is to be expected that in practice a structure-vandal interactions would take place.

Further works should be performed to validate this load model against experimental data acquired on as-built structures subject to Vandals.

References

[1] Newton, S. I. (1687) Philosophiae Naturalis Principia Mathematica (Mathematical Principles of Natural Philosophy). Edmund Halley, ed., London
[2] De Leva, P., (1996) 'Adjustments to Zatsiorsky-Seluyanov's Segment Inertia Parameters', Biomechanics, 29 (9), 1223-1230

Acknowledgement

We would like to take this opportunity to thank Birmingham Science City for funding the GAIT lab and the IStructE for sponsoring this undergraduate project.