Extreme dynamic loading by humans on footbridges

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Introduction
When crossing a footbridge, the largest dynamic load on a person can occur when running or jumping. Running is much more likely for people to be crossing a bridge, especially if it is a large footbridge. While this makes the predictability that these runners will run across a bridge either in a race or on a training run, causing the risk that the bridge will react differently to a running user than a walking user. This would not only affect the speed that the runner can travel but could also cause long term sensitivities if the bridge is continually overloaded. The European standards of structural design do not consider running within normal use, and only suggest a group of joggers may cross a footbridge with a frequency of 5Hz. This is incorrect as shown by the large differences in figure 5, comparing the force produced when running, walking and speed-walking. The use of structural codes and guidelines means that people will only ever cross a bridge walking or jogging very slowly, therefore a better method of using these frequency and force produced by a runner is required. Therefore a parametric study was conducted to assess vibrations produced by a runner so it can be seen how a footbridge of given metrics would react, using a full load per person in figure 2. The system of the runner was modelled so that the metrics would be systematically changed so that the metrics with the greatest effect can be found.

Aims and objectives

Aims and Objectives
The aim of this project is to discover which running metric causes the greatest speed that the runner can travel but could also cause long term sensitivities issues for the bridge.

1. The aim of this project is to discover which running metric causes the greatest acceleration of a bridge.

2. To model the force exerted on the ground by a person running.

3. To apply this force to a bridge with given metrics, obtaining the resultant acceleration of the bridge.

4. To systematically change the running metrics in the model and compare resultant accelerations.

Method

Method
To find the force produced by a runner, the Clark model (3) was used to find the force produced by a single step. The mass of the runner is split into m1 and m2 using the percentages shown in figure 4. The values of the change in vertical velocity of m1 (dv1) and the time interval for m1 (dt1) are added together. This graph is then normalized by the natural mode (half sine) to obtain the modal frequency of this footbridge, causing a smaller response. The values of the change in vertical velocity of m1 (dv1) and the time interval for m1 (dt1) are multiplied by the natural mode (half sine) to obtain the modal force produced by the runner. This graph is then multiplied by the Fox-Goodwin algorithm is then used to obtain the acceleration of the midpoint and the perceived acceleration as the runner crosses the bridge. The inputs to this are:

• The model mass of the bridge (M)
• The stiffness coefficient (k)
• The damping coefficient (C)
• The modal force produced by the runner
• The time interval

The acceleration is then plotted against time (shown in figure 7). The acceleration produced can be decreased by the runner changing their running style or speed. This would be at their detriment, as it would mean they are sacrificing either energy or time.

1. The combination of speed and stride length that factors that determine the frequency of the runner may cause the largest change in response from the bridge.

When the frequency was kept constant, the ground contact time of the runner caused the largest acceleration of the bridge.

The acceleration produced can be decreased by the runner changing their running style or speed. This would be at their detriment, as it would mean they are sacrificing either energy or time.

Increasing the mass increases the acceleration of the footbridge.

A forefoot strike causes a greater acceleration than a rear foot strike.

Only a few of the results are less than the maximum recommended acceleration from literature, shown in figure 10. An unpleasant, even if infrequent, user experience would be noted with an increased probability of synchronization errors, which would likely cause the runner to negatively impact their running technique and economy in order to mitigate this.

When comparing these values in table 2 to the values in literature, it shows that the footbridge’s natural frequency is very similar to those of a conventional bridge. These values were chosen as they are typical of a conventional footbridge (as shown in figure 2). The simulations were each run three times with the same metric to ensure that human or machine error does not affect results.

Analysis and Conclusions

The results in table 2 show that:

• The combination of speed and stride length that factors that determine the frequency of the runner may cause the largest change in response from the bridge.

• When the frequency was kept constant, the ground contact time of the runner caused the largest acceleration of the bridge.

• The acceleration produced can be decreased by the runner changing their running style or speed. This would be at their detriment, as it would mean they are sacrificing either energy or time.

• Increasing the mass increases the acceleration of the footbridge.

• A forefoot strike causes a greater acceleration than a rear foot strike.

Table 1: the ‘dv1’ and ‘dt1’ values for various running speeds and foot strike patterns, each with three speeds investigated.

<table>
<thead>
<tr>
<th>Running metric</th>
<th>dv1 (m/s²)</th>
<th>dt1 (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast (7 mph)</td>
<td>2.010</td>
<td>0.027</td>
</tr>
<tr>
<td>Median (5.5 mph)</td>
<td>1.558</td>
<td>0.022</td>
</tr>
<tr>
<td>Slow (3 mph)</td>
<td>1.280</td>
<td>0.021</td>
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</tbody>
</table>

Table 2: Results of simulations

<table>
<thead>
<tr>
<th>Ground contact time</th>
<th>dv1 (m/s²)</th>
<th>dt1 (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12</td>
<td>0.028</td>
<td>0.012</td>
</tr>
<tr>
<td>0.08</td>
<td>0.038</td>
<td>0.015</td>
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<tr>
<td>0.05</td>
<td>0.034</td>
<td>0.010</td>
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</table>

References


