Truss bridge under dynamic loading

A dataset containing the reaction of a laboratory-scale truss bridge to dynamic loading

# Introduction

This dataset is designed to identify the response of a truss bridge when subjected to dynamic forces. The bridge was excited across various damage scenarios, and the effect of detaching and reattaching a single strut was also assessed. The tests were carried out at the Laboratory for Verification and Validation (LVV) at the University of Sheffield.

# A person working on a machine Description automatically generated with low confidence

Figure 1: The bridge set up for testing at the LVV

This suite of tests follows up and builds on the tests carried out by Rob Barthorpe, Paul Gardner and Aidan Hughes in September 2019 [1], following similar methodology to acquire healthy and damaged-state data from the bridge structure shown in Figure 1. Similar tests were carried out in the present study, with the addition of a test to identify the impact of boundary condition uncertainty on the results.

The tests were carried out in two phases. The first phase entailed a roving hammer tap test in order to identify the mode shapes of the structure under excitation in its nominal, undamaged state. The second phase entailed hammer-excited damage-state testing to identify the effect that increasing damage had on the response of the structure. Damage was introduced by saw cut to the mid-point of the struts that were symmetrically ‘unique’ in the structure, i.e. the two diagonal and vertical struts located in one ‘corner’ of the bridge – these were the four struts in the far corner in Figure 1, closest to the laptop. Damage was introduced at 2.5mm intervals up to 17.5mm, at which point the strut was replaced before commencing the test on the next strut. Due to the lines of symmetry of the structure in the *x-* and *z-*directions, damage in any individual strut would be expected to result in a similar effect on the response as these.

# Bridge geometry

The structure of interest is a laboratory-scale truss bridge, shown in Figure 1, which was constructed at the Laboratory for Verification and Validation (LVV) in Sheffield. The bridge is a truss bridge of standard design, and it can be compared to many real-life structures around the world.

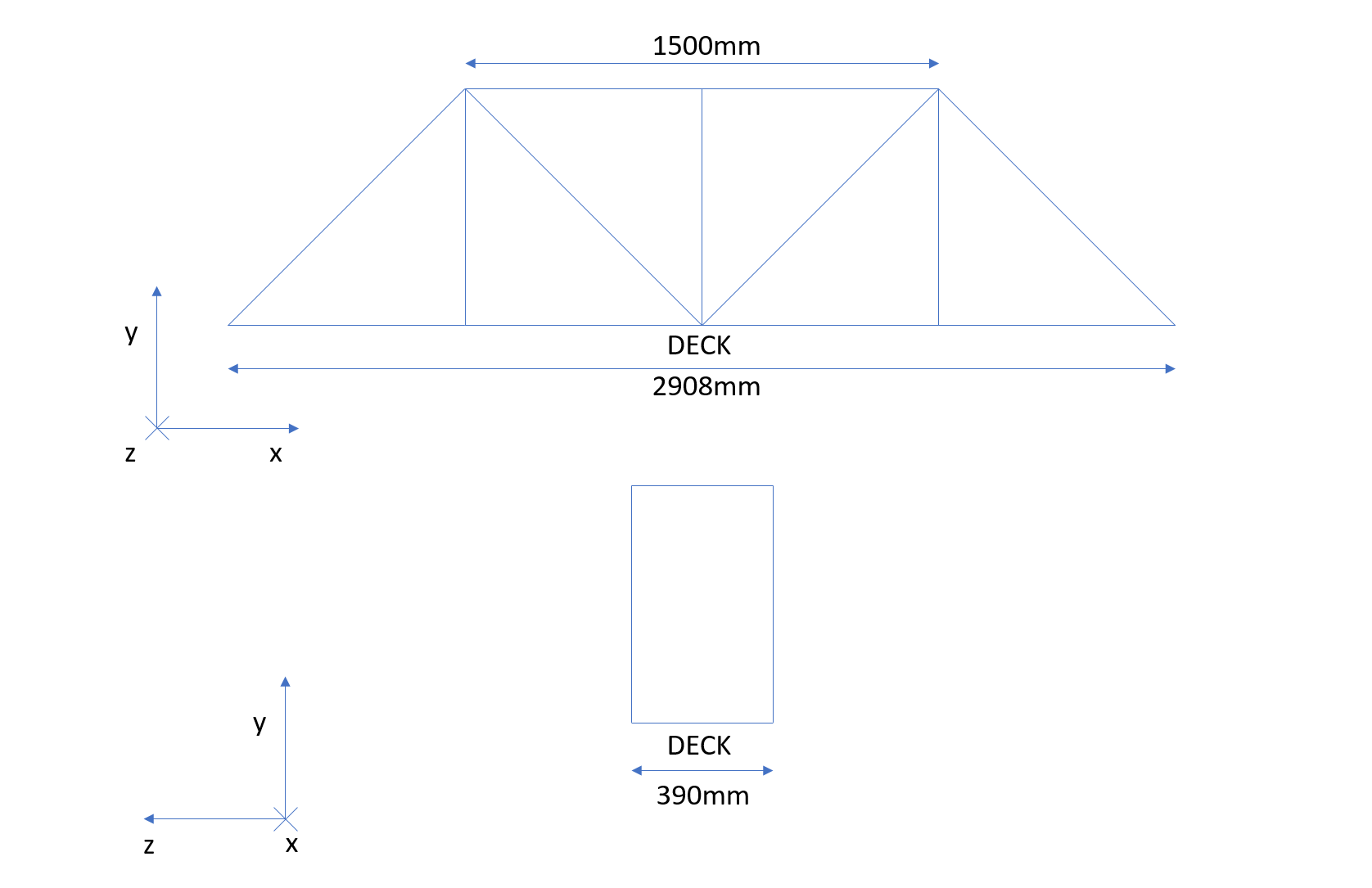


Figure 2: A schematic of the bridge structure with key dimensions marked

The bridge is 700mm in height, 390mm in width and 2908mm in length; see Figure 2. The struts and deck are cut from aluminium plate of 4mm and 3mm depth respectively. The longer, diagonal, struts are 1006.52mm in length and the shorter, vertical, struts are 700mm in length; both are 20mm in height. The deck border and upper frame are constructed from aluminium Rexroth, which is of 20mm in depth and height; the upper frame is of 1500mm in length. The deck is of 390mm width and 2908mm length, which are the same as the bridge as a whole.

# Methodology

## Healthy state tap-testing

Tap testing was used to identify the mode shapes for the lower modes of the bridge structure using the roving hammer method. This allowed for a large number of test points to be used without adding many accelerometers, which could impact the dynamic response of the structure. The make and type of the hammer were PCB Piezotronics, model 086C03.

Prior to testing, the ambient temperature was measured at 17oC using a local digital thermometer in the vicinity of the bridge – this remained constant throughout the test period. The bolts that fixed the struts to the bridge deck and Rexroth were tightened using a torque wrench to 8Nm.

A triaxial accelerometer was used to record the response of the bridge to the impacts. This was attached to the Rexroth on the upper frame of the bridge, as the mobility of the structure was significant in that location, and many of the lower natural frequencies had mode shapes which involved displacement of this part of the structure. The accelerometer was fixed to the upper Rexroth on the near side of the bridge, between the first two joints in the *x*-direction (see Figure 1). The make and type of accelerometer were PCB Piezotronics, model 356B21.

Five repeat impacts were carried out at each damage location in order to reduce the noise in the results through averaging. Additional pre-processing measures to increase the cleanliness of the data was carried out by windowing (an exponential window was used) the recorded excitation and response data.

Data acquisition was performed using the Siemens LMS system, with modal analysis carried out using the PolyMAX algorithm which uses a curvefitting method to isolate modal characteristics each recorded frequency response functions (FRF). The final chosen modes are to be extracted concurrently with the modes used in the damage-state testing to ensure compatibility between the two datasets.

## Damaged-state shaker-testing

Tap tests were carried out on the bridge across a range of damage conditions using the same impact hammer as was used in the roving hammer testing. A single tap location was used with multiple accelerometers attached in the *y*- and *z*-directions at each joint (see Figure 3). The accelerometers used were PCB Piezotronics 353B18s. As with the roving hammer tests, repeats and windowing were used to reduce the noise level in the recorded data.

Prior to testing, the ambient temperature was measured at 17.3oC – this had increased to 17.4oC by the end of the damage tests and remained constant at this temperature during the BC tests. The bolts that fixed the struts to the bridge deck and Rexroth were tightened using a torque wrench to 8Nm. The same measured spectrum was used as for the roving hammer tests and the same feature extraction method was used to acquire the modal data from the recorded FRFs.

Damage was introduced to struts 1, 2, 5 and 6 by saw cut at the midpoint at 2.5mm intervals, up to a maximum ‘crack’ depth of 17.5mm. When each damage run was completed the strut of interest was replaced with a new strut. The damage locations and tap location are illustrated in Figure 3.

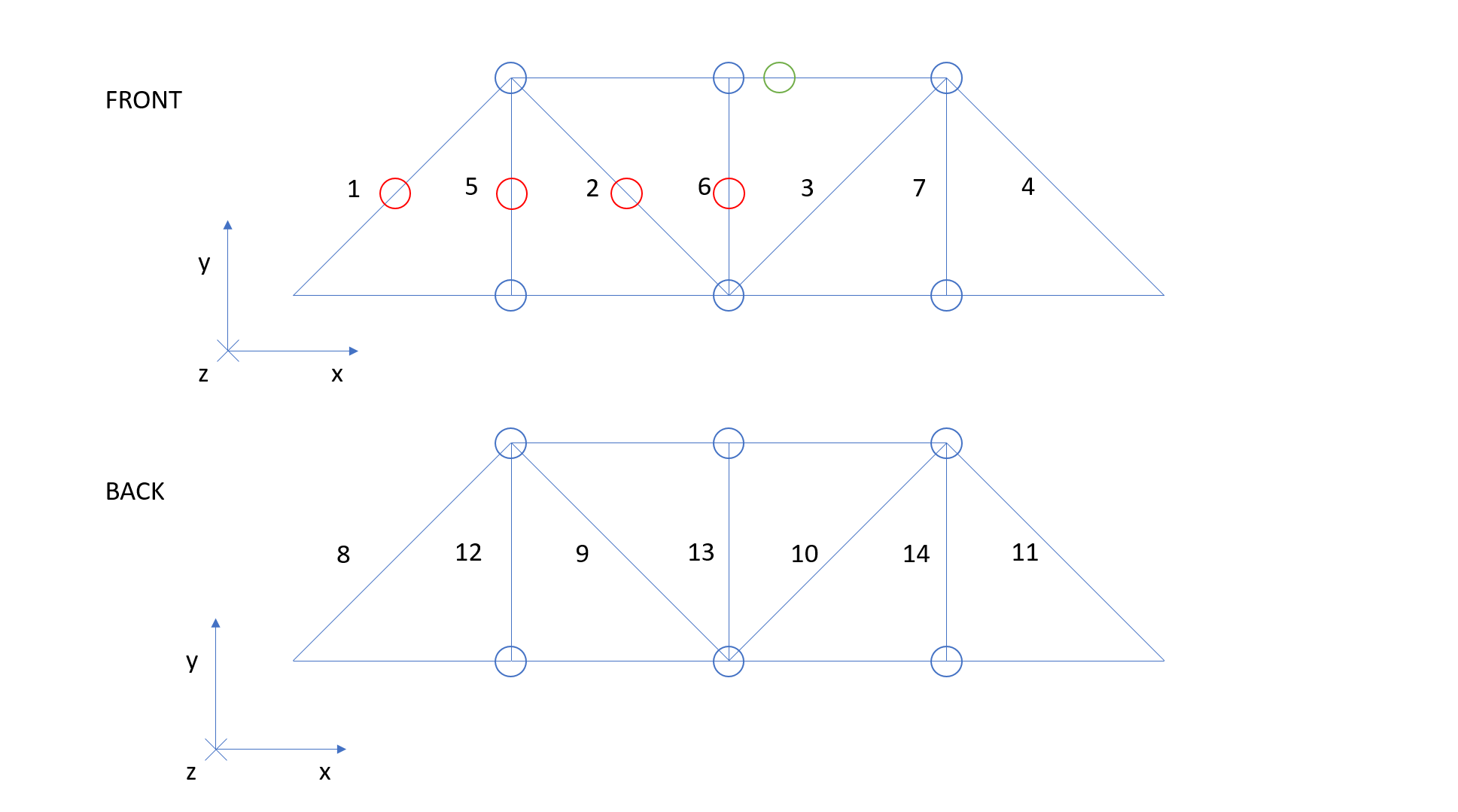


Figure 3: A schematic of the bridge structure, with damage locations marked in red, tap location in green and accelerometer locations marked in blue

## Healthy-state boundary condition investigation

In the boundary condition testing, strut 1 was removed and reattached three times, with tap tests carried out following each reattachment. This was in order to assess the uncertainty caused by the boundary conditions, which are not captured in the model. The methodology was otherwise the same as for the damage state testing, described above.

# Results

FRFs and power spectral densities were recorded for each test. The modal results were extracted using the PolyMAX curvefitting algorithm. This method utilises a numerical approach to isolate the natural frequencies, damping ratios and mode shapes from manually selected resonance peaks on the FRFs. The key parameters guiding this process are the tolerances set for the natural frequencies, damping ratios and mode shape vectors for each peak, the maximum number of degrees-of-freedom allocated to the curve fit and engineering judgement. These tolerances describe the stability of a modal fit for a given resonance peak, where the solution would be considered stable if it was within each tolerance criterion when compared to the solution with one fewer degree-of-freedom. The tolerances set for this analysis were 0.1% for the frequency, 5% for the damping ratio and 0.5% for the mode shape.

Following feature extraction, the datasets were matched to each other using the natural frequency values, which resulted in an experimental dataset of 18 natural frequencies for each test. These are plotted as features across the full range of damage for each strut in Figure 5.6; this figure shows that, of the extracted features, some are sensitive to damage but others are relatively insensitive – this indicates the requirement for further feature selection activities. The plotted feature is proportional deviation from the undamaged natural frequency for each mode to allow comparison between different natural frequencies across the full range of damage.

# Format of dataset

The dataset is a structure containing:

1. roving\_hammer, containing substructures for the spectral and modal data
   1. modal contains the following:
      1. geometry: an array containing the coordinates of the tap locations and the triaxial accelerometer on the bridge
      2. fn: an array containing the extracted natural frequencies of the bridge
      3. phi: a cell containing the extracted mode shapes of the bridge
   2. spectra contains the following for each tap location:
      1. freq: the recorded frequency array
      2. FRF: an array where each column contains the FRF of the responses in z, -y and x respectively
      3. PSD: an array where each column contains the PSD of the responses in z, -y and x respectively followed by the PSD of the excitation signal
2. damage\_tests, containing cells for the spectral and modal data where each row contains the data for a single strut and each column contains the data for a single damage extent
   1. modal is a cell where each entry contains the following:
      1. strut\_ID: a numeric referring to the strut of the bridge containing the damage (see Figure 3)
      2. damage\_extent: a numeric referring to the depth of the saw cut in mm
      3. geometry: an array containing the coordinates of the accelerometers on the bridge (in order) followed by the tap location
      4. fn: an array containing the extracted natural frequencies of the bridge
      5. phi: a cell containing the extracted mode shapes of the bridge
   2. spectra is a cell where each entry contains the following:
      1. strut\_ID: a numeric referring to the strut of the bridge containing the damage (see Figure 3)
      2. damage\_extent: a numeric referring to the depth of the saw cut in mm
      3. freq: the recorded frequency array
      4. FRF: an array where each column contains an FRF of the response; an index for these is provided in Table 1
      5. PSD: an array where each column contains an PSD of the response; an index for these is provided in Table 1

Table 1: Index of the FRF and PSD cell array columns for the damage tests (25th column not included in FRF data)

|  |  |  |
| --- | --- | --- |
| **Column** | **Sensor** | **Direction** |
| 1 | 12 | -z |
| 2 | 12 | -y |
| 3 | 9 | z |
| 4 | 9 | -y |
| 5 | 11 | -z |
| 6 | 11 | -y |
| 7 | 8 | z |
| 8 | 8 | -y |
| 9 | 10 | -z |
| 10 | 10 | -y |
| 11 | 7 | z |
| 12 | 7 | -y |
| 13 | 6 | z |
| 14 | 6 | -y |
| 15 | 3 | -z |
| 16 | 3 | -y |
| 17 | 5 | z |
| 18 | 5 | -y |
| 19 | 2 | -z |
| 20 | 2 | -y |
| 21 | 4 | z |
| 22 | 4 | -y |
| 23 | 1 | -z |
| 24 | 1 | -y |
| 25 | HAMMER | z |

# References

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| [1] | R. J. Barthorpe, A. J. Hughes and P. Gardner, “A Forward Model Driven Structural Health Monitoring Paradigm: Damage Detection,” in *Proceedings of the Society for Experimental Mechanics Series*, Cham, 2022. |