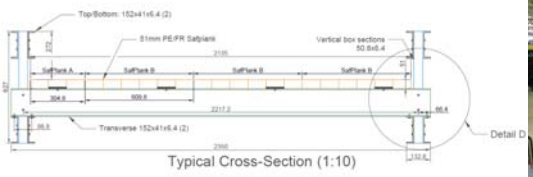
Warwick FRP Bridge: Design and Performance

Justin Russell, Stana Živanović



22th June 2018, University of Warwick

Design Brief

- Constructed from pultruded FRP sections
- Fit within the structures lab (plan area 20x2.5 m)
- Lightweight
- Low natural frequency (around 2 Hz)
- Adjustable (change span lengths, replace elements etc.)
- Safe for intended usage, but not necessarily compliant with design standards

Design Approach

- Concept design
- Hand calculations
- Finite element analysis
  - Forces
  - Deflections
  - Modal properties
- Connection design
- Other details
- Assembly

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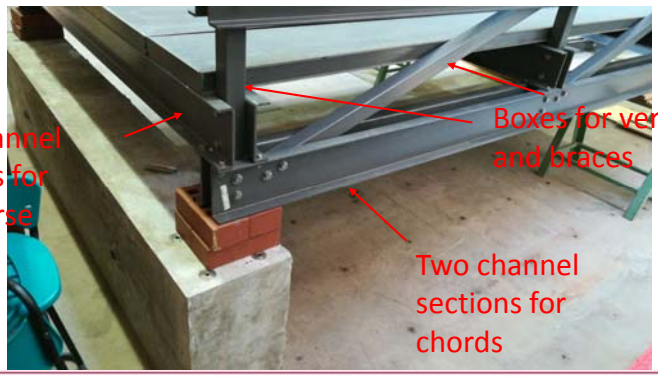
Design concept

- Bolted truss bridge
  - Removable parts, modifiable, assemble in the lab
- Based on two main structural profiles
  - Channel sections for chords and transverse elements
  - Box sections in-between the channels for vertical and braces



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Design concept

- Bolted truss bridge
  - Removable parts, modifiable, assemble in the lab
- Based on two main structural profiles
  - Channel sections for chords and transverse elements
  - Box sections in-between the channels for vertical and braces
- Convenient geometry led to nodes at 1.4 m
  - Total length of 19.6m (+bit extra at ends)
- Due to available suitable profiles:
  - Channels chosen as 152x41x6.4 mm
  - Boxes are 50.8x6.4 mm
  - Deck is 51 mm deep 'SafPlank' product
- Lightweight (mass=1400kg) and flexible (truss height 475mm)

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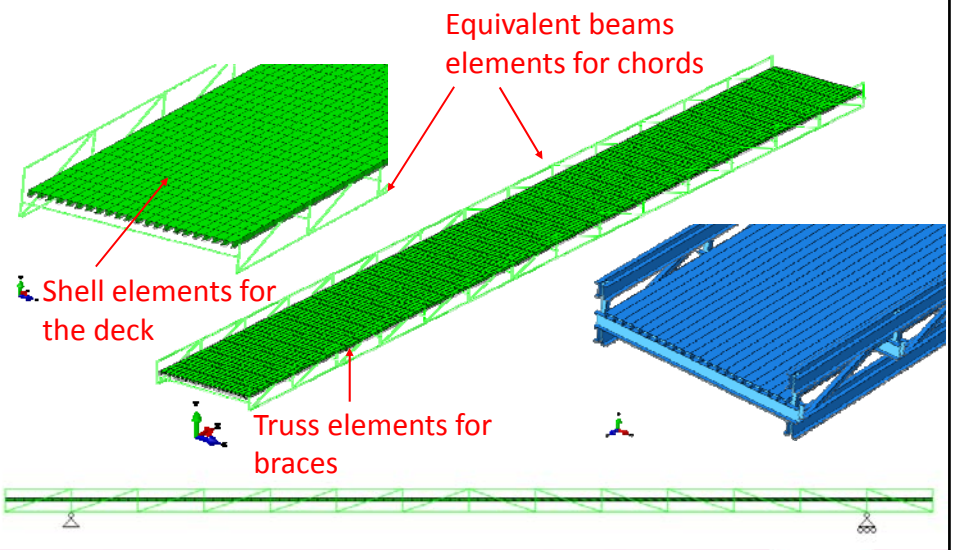
Finite element analysis



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Finite element analysis

- Design case is self-weight plus mid-span point force to cause 100 mm deflection
- Three span lengths checked

	Max Chord force [Compression] (kN)			Max Chord force [Tension] (kN)			Max Brace force (kN)			Max Vertical force (kN)		
Span (m)	Gravity	@100mm	**Total**	Gravity	@100mm	**Total**	Gravity	@100mm	**Total**	Gravity	@100mm	**Total**
19.6	-35.81	-43.13	**-78.95**	37.32	46.43	**83.75**	-7.22	-5.18	**-12.41**	5.67	4.67	**10.34**
16.8	-25.51	-55.21	**-80.72**	26.55	59.62	**86.17**	-5.54	-7.80	**-13.34**	4.65	6.94	**11.59**
14	-15.15	-71.67	**-86.82**	15.81	77.89	**93.70**	-4.40	-11.71	**-16.11**	3.66	10.78	**14.44**

	Static Displacement (mm)		Frequencies (Hz)			
Span (m)	Gravity	75kg	1st Vertical	Torsional	Lateral	2nd Vertical
19.6	89.09	9.80	1.87	2.7	6.15	6.74
16.8	47.48	6.52	2.51	3.58	7.79	8.66
14	20.20	4.14	3.37	4.78	10.04	9.75

Design Case

Chord Connection	
Compression	Tension
-86.82 kN	93.70 kN
Brace Connection	Vertical
-16.11 kN	14.44 kN

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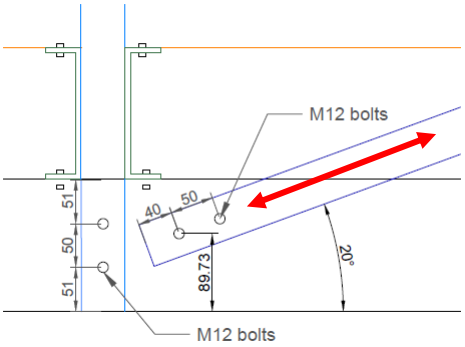
Connection Design Brace

- Design according to Chapter 8 of ASCE Pre-standard



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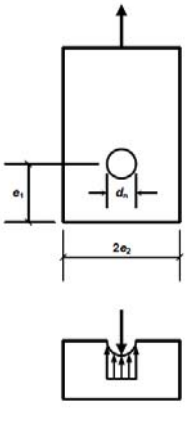
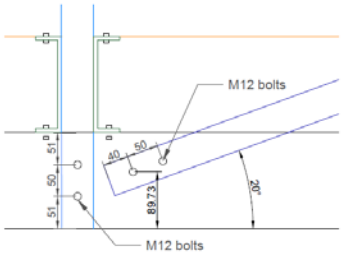
Connection Design Brace

- Design according to Chapter 8 of ASCE Pre-standard
- Checking the box section part:
- R_u = 18.3 kN (failure in pin bearing)
- Design force = 16.1 kN Pass





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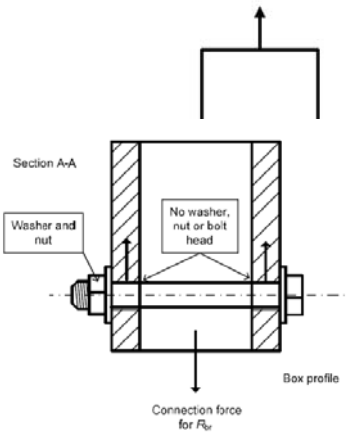
Connection Design Brace

- Checking the channel web part:
- Wider (improves net tension capacity)
- Loading direction 20° from pultruded
  - Take transverse material strength
- Pin bearing capacity even more critical
- Note single sided washer:
- Recommend reduction factor of 0.5 due to bolt flexure



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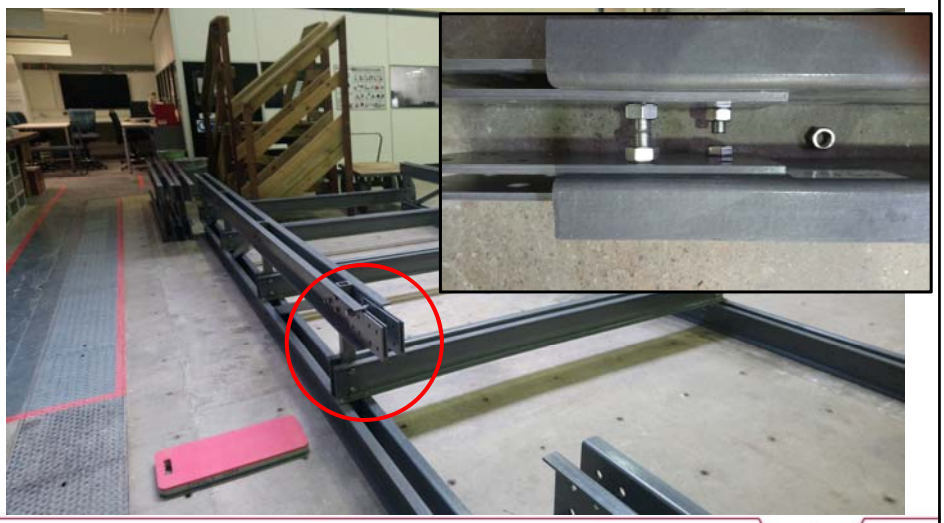
Connection Design Chord Splice



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Connection Design Chord Splice

- Consists of two 6.4 mm FRP plates either side of the 6.4 mm channel web
- All stresses work in the pultruded direction
- Double-lap shear connections
- 4 M16 bolts chosen (largest practical)
- R_u = 29.8kN (two webs gives 59.6kN)
- Design force = 93.7kN
- Fails in Net Tension
- Bonded on extra 6.4 mm plate to web
- R_u includes 50% reduction due to, φ, resis
  factor for net tension

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Connection Design Chord Splice

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Connection Design Chord Splice

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Buckling check

- Concern about buckling of the top chord

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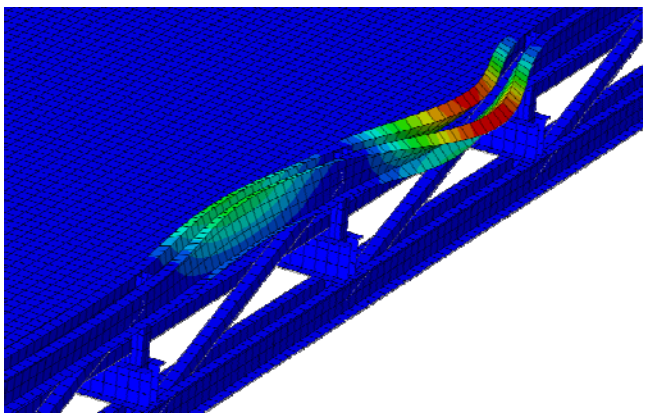
Buckling check

- Concern about buckling of the top chord
- Used Abaqus buckling Eigen analysis to predict deformed shape



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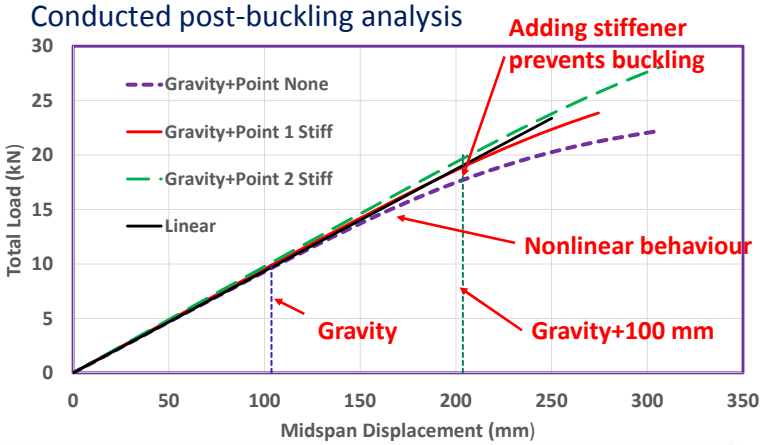
Buckling check

- Concern about buckling of the top chord
- Used Abaqus buckling Eigen analysis to predict deformed shape
- Conducted post-buckling analysis



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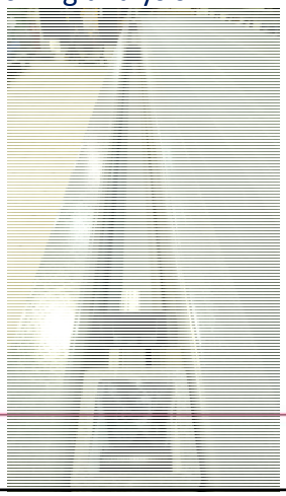

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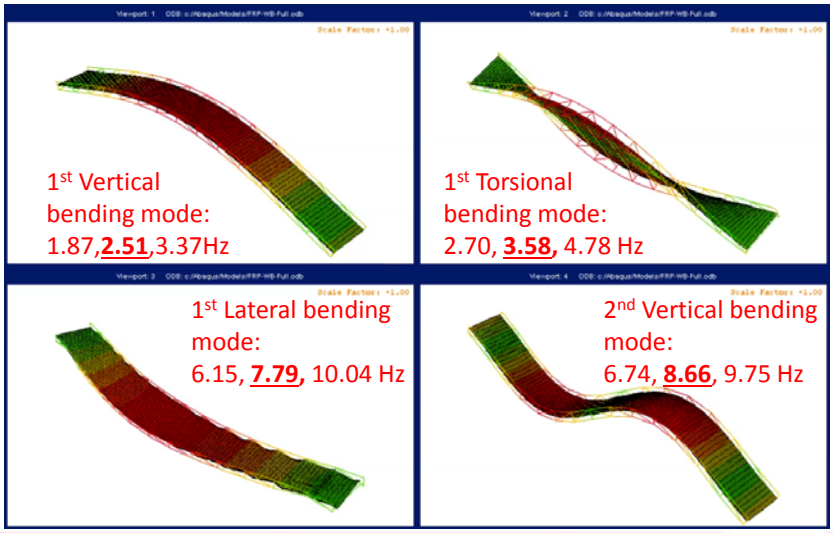
Modal properties



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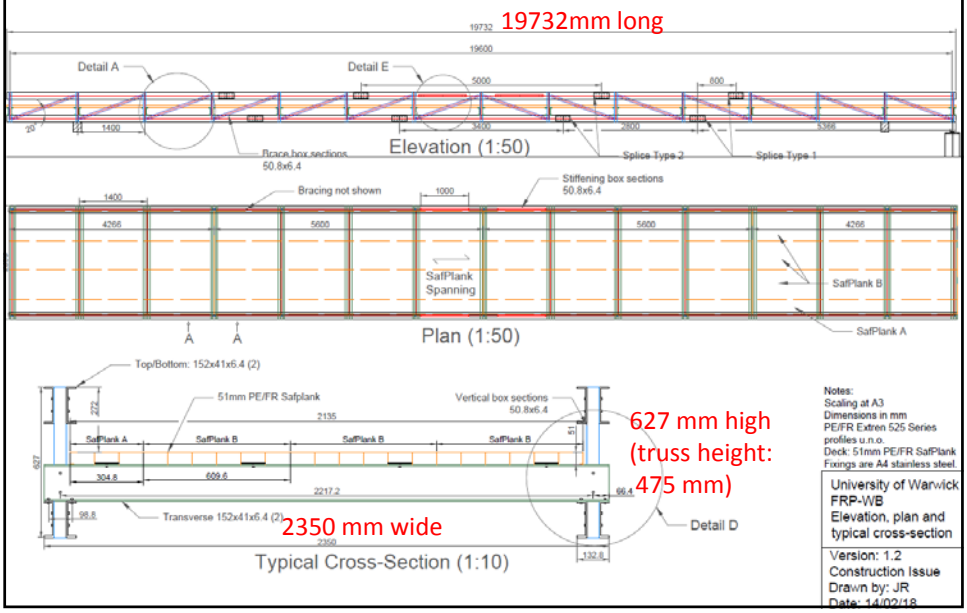
Final Design



Assembly

- Box sections (50.8x6.4mm):
  - 30 vertical elements
  - 28 brace elements
  - 4 stiffening elements
- Channel sections (152x41x6.4mm)
  - 40 chord elements
  - 30 transverse elements
- Other parts
  - 64 splice plates (310x120x6.4 mm)
  - 16 deck panels
- 832 bolts!

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Assembly

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Assembly

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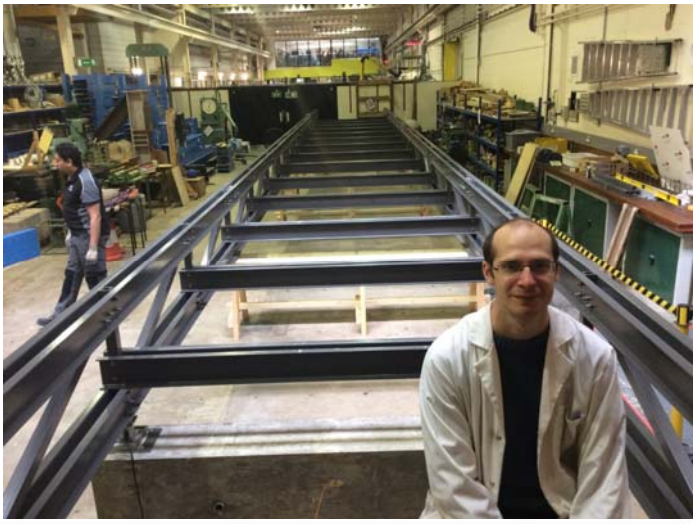
Assembly



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Assembly

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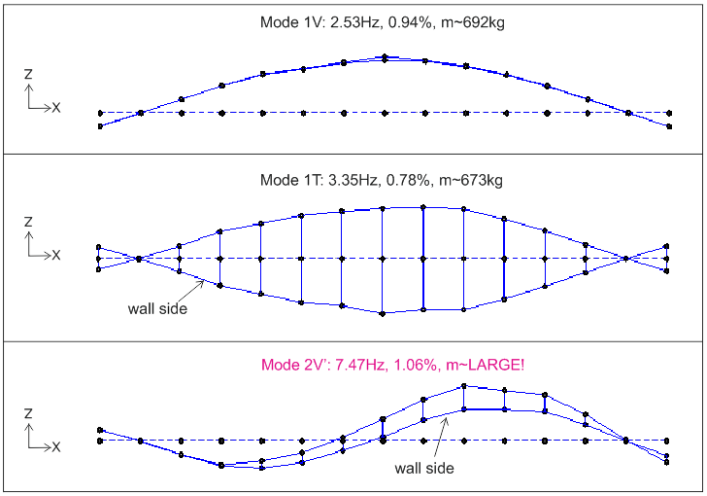
Performance: vibration modes



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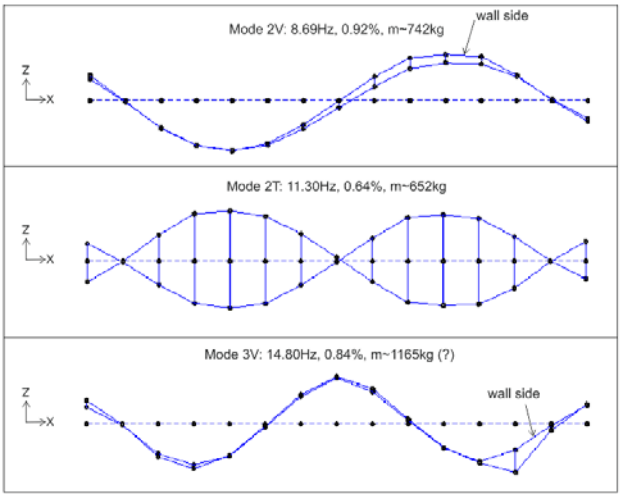
Performance: vibration modes



Very much in line with predictions from FE model

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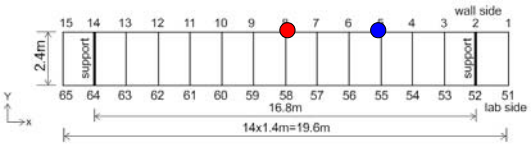
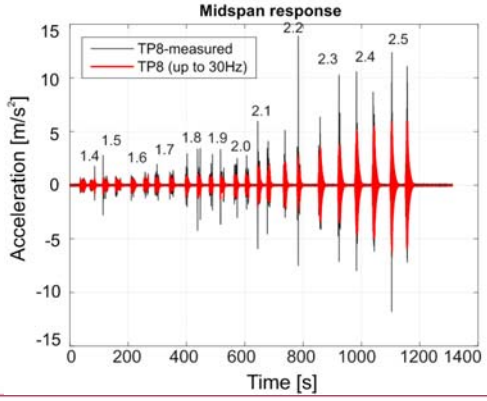
Performance: vibration response to walking





Lots of noise - ignore black line!

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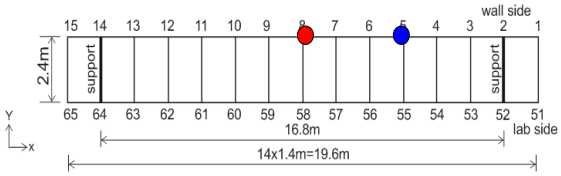
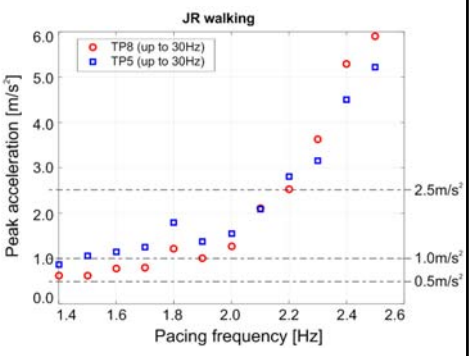
Performance: vibration response to walking



Peak-to-peak: 4-5cm => 6m/s² (at 2.5Hz)



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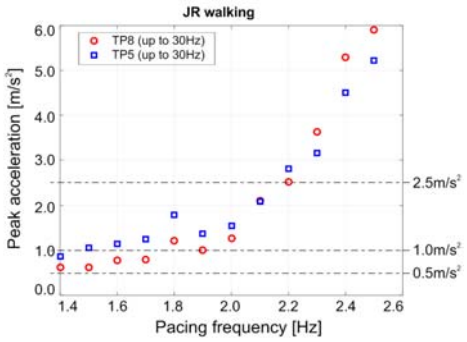

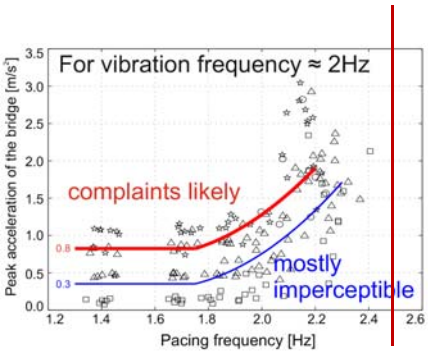

Demo on the lab bridge

Aims:

- To excite the bridge by walking
- To experience liveliness of the bridge

Divided in two groups

H&S:

- Do not enter other than designated areas of the Lab
- **Walking activity only** allowed whilst on the bridge
- Stop the test if something does not feel right to you (e.g. vibrations are too high)
- Best not to participate if you suffer from **motion sickness**

Important info:

- One group in the Lab at a time
- Volunteers to walk over the bridge, one at a time, at **"normal" pacing rate**
- Vibration at points 8 (mid-span) and 5 (quarter span) to be measured (for each volunteer) and shown on a screen
- **Rate perceived vibration on scale 0 (not felt) to 10 (extreme vibration for a structure)**

What's next?

At 13:35 we all go to the School of Engineering Lab
(we will split into two groups there)
We aim to be back in time to start next talk at 15:00

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