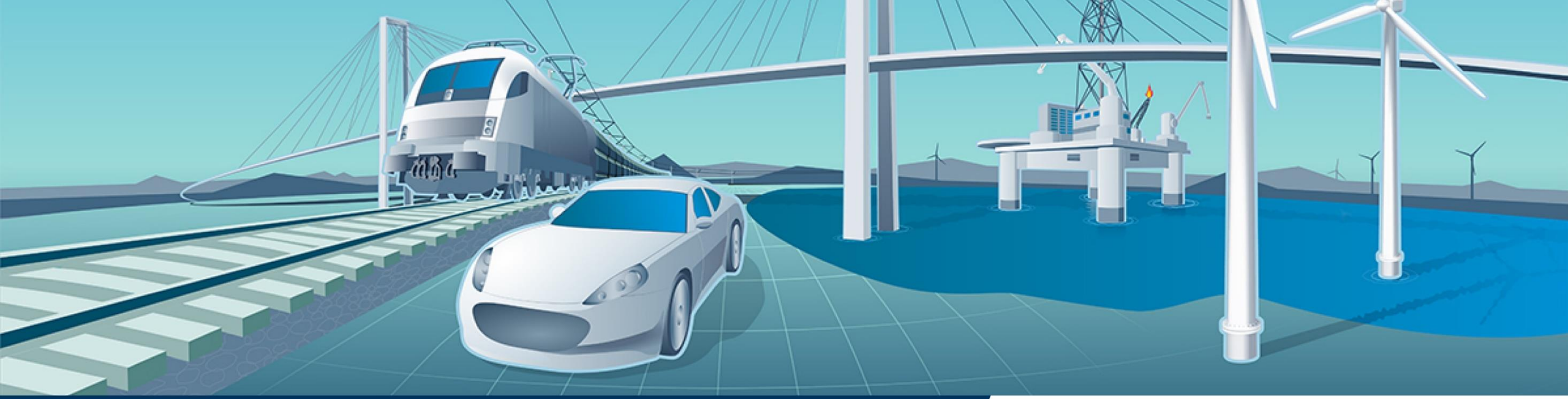

HBK Technology Days – Virtual Seminar Series

Tuesday, November 15, 2022

From Bridge Inspection to Population Based Structural Health Monitoring for Bridges

Presented by Dr. David Hester,
School of Natural and Built Environment,
Queen's University Belfast

From Bridge Inspection to Population Based Structural Health Monitoring for Bridges

Abstract

Bridges are an interesting set of structures from the point of view of infrastructure management. Firstly, they are a diverse set of structures, and secondly, they individually experience significant variation in the environmental conditions and loading. The aim of this presentation is to provide an overview of how bridges are manged, the kind of sensing/monitoring that is sometimes undertaken and the trajectory of research in this area. Initially we look at how short to medium span bridges are typically managed via periodic visual inspections. Subsequently the presentation give a sense of the kind of monitoring that has been used on bridges, as well as some of the sensing and data processing challenges that exist. Finally, the presentation looks at some of the very latest research in particular the idea of looking at bridges, or subsets of bridges, as a population of structures.

About the presenter, Dr. David Hester, School of Natural and Built Environment, Queen's University Belfast

After completing my undergrad I worked for 8 years as a bridge designer/inspector. This prompted my interest in bridge Structural Health Monitoring (SHM) and I completed my PhD on the topic in University College Dublin. Since joining QUB my research interest has been on practical ways of collecting bridge data and how to exploit this data for decision making. In particular through a collaboration with Electrical and Electronic Engineers I am working on innovative autonomous bridge monitoring functionality. I have published extensively in the area (34 journal and 38 conference papers) with 1,035 citations and a H-index of 19. I have been PI or Co-I on grants worth over £2 million to the University.

From bridge inspection toward Population Based Structural Health Monitoring

David Hester
Queen's University Belfast

Content of presentation

- Brief bio and info about Queen's University Belfast (QUB)
- How 'regular' bridges are currently managed
- What people have been doing on bridge structural health monitoring
- Population based bridge monitoring

QUB and Bio

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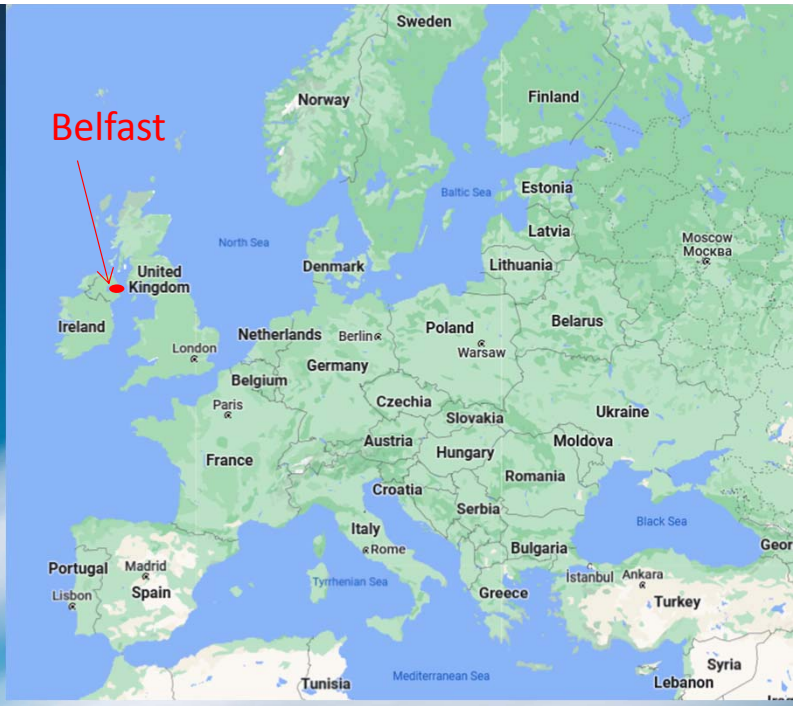
ESTD 1845



QUEEN’S UNIVERSITY

Queen’s University Belfast is one of the leading universities in the UK and Ireland with a distinguished heritage and history.

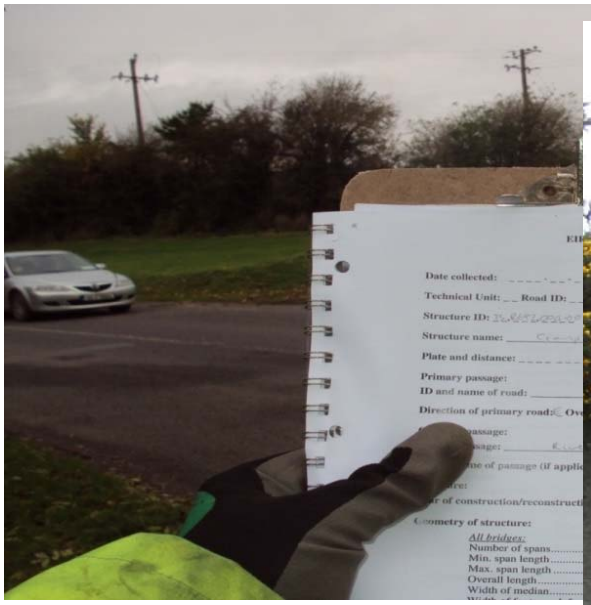
With an annual turnover of £330m, some 24,000 students and 3,800 staff, Queen’s plays a unique leadership role in Northern Ireland.

Brief Bio

Apprentice Farmer

Civil Engineer

DH Bridge inspector



Could sensor data add anything to the mix?

Someday could we have an extra row in the data base called data?

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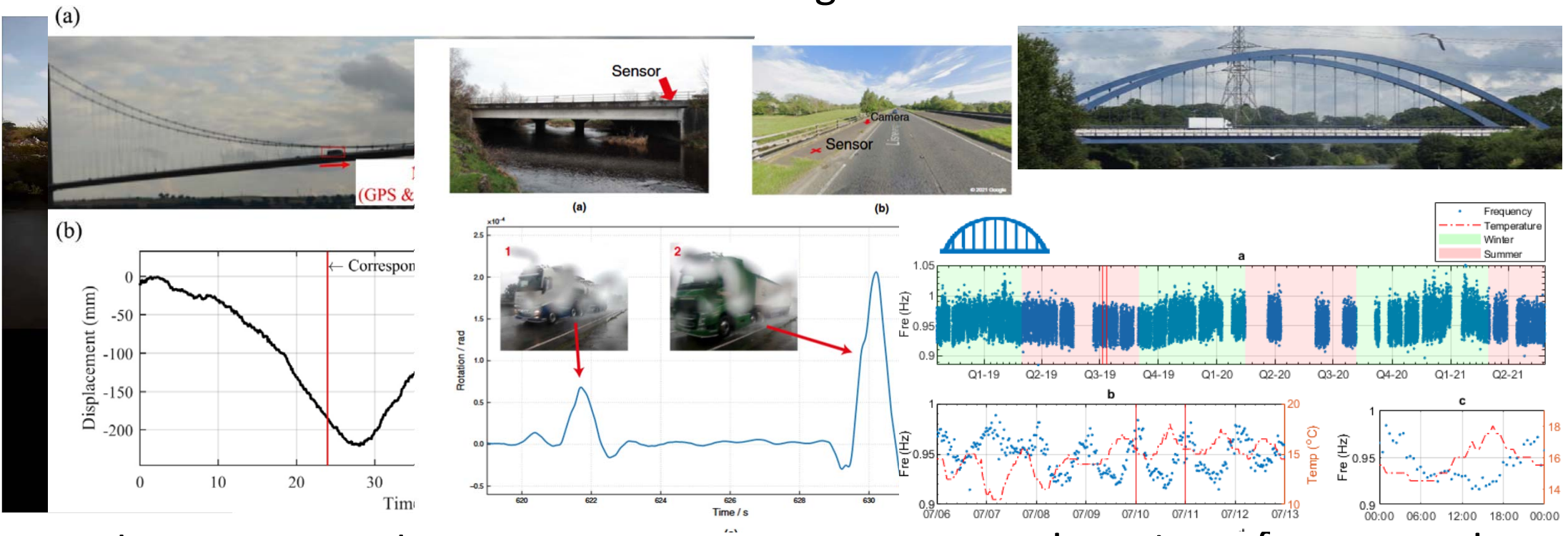
DH Research journey

To see if I could answer these two questions

PhD in bridge SHM, and I have been doing it since! Have measured all sorts



Acceleration Displacement Rotation Long term frequency- L cost

Still haven't definitively answered the two questions!

PBSHM is the best potential solution I have seen so far, will come back to this

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Bridge management systems

Bridge management in Ireland

Inspection Approach in the Ireland

No.	Inspection Type	Frequency	Description
1	Initial	As needed	Baseline condition.
2a	Routine. (Roads Supervisor)	Weekly	Superficial inspection using patrol vehicle.
2b	Routine. (Engineer)	Yearly or as needed	Visual inspection of a structure. Sets recommendations for PIs and routine maintenance work.
3	Principal	1-6 Years	Close, hands-on visual inspection of the whole structure
4	Special	When needed	Detailed investigation of a defect requiring test as necessary.

Bridge management in the UK

Inspection Approach in the UK

No.	Inspection Type	Frequency	Description
1	Safety	At frequencies which ensure timely identification of safety defects and reflect the importance of a particular route or asset	Cursory inspection carried out from a slow moving vehicle; staff may need to proceed on foot.
2	General	2 Years	Visual inspection from the ground level. Report on the physical condition of all structural elements visible from the ground level.
3	Principal	6 Years	Close visual examination, within touching distance of the entire bridge, utilizing, as necessary, suitable inspection techniques such as hammer tapping and paint thickness measurements
4	Special	As needed	Detailed investigation (including as required inspection, testing and/or monitoring) of particular areas of concern or following significant events.

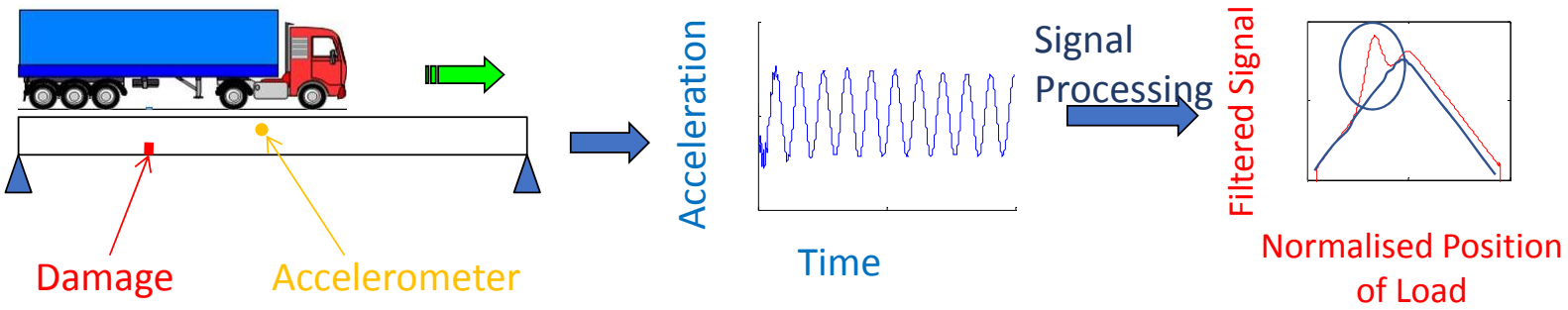
Similar to Ireland, and US is also similar

Next slide looks at the allowed for, but rarely used site measurements allowed for in bridge assessment codes

What researchers have been doing on bridge SHM

Basic concept

- Measure some data
- Do some signal processing to extract some damage sensitive ‘feature’
- When damage occurs the ‘feature’ changes
- Typically though ‘confounding effects’ make the change hard to see (will come back to this)



Various things have been tried

Wont try to describe the many methods that have been proposed, but it is useful to give a quick overview of what response signals have been used as inputs

- **Strain**- but can be quite sensitive to the location of the damage relative to the sensor
- **Acceleration**- e.g. calculate natural frequency, but natural variation due to environmental effects ('confounding effects') often larger than change due to damage. Also not great for capturing static response
- **Displacement**- capturing static response possible with recent advances in computer vision, but still logistically challenging for long term monitoring
- **Rotation** – recent improved quality / reducing cost of DC accelerometers makes this feasible. Has the advantage of being logistically easier to measure than displacement while still capturing static response

Simulation- Lab- field

- Due to a shortage of data, particularly damaged state data, most of the proposed methods have been demonstrated on simulated data or data from simplified laboratory experiments
- This is because collecting data is a significant challenge as regular bridges typically don't have power or coms, also they are big structures with difficult to access elements
- Therefore there are relatively few studies with long term data including damaged state data. Some of the most well cited in the literature include Z24, S101, Alamousa cannon bridge.
- Difficulty with interpreting long term data is there is natural variation due to environmental effects such as temperature (confounding effects). These are often appreciably larger than changes due to damage therefore need to correct for/remove the environmental effects(data normalisation)

Toward population based monitoring

Context: Bridge management - one interchange

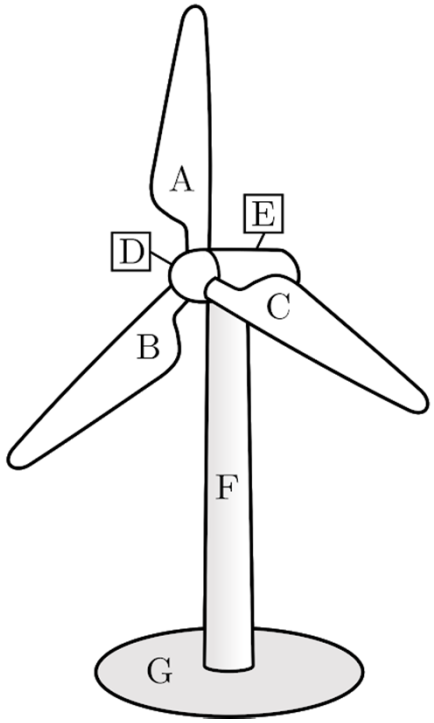
Feels like we might be missing a trick as if you are going to use data then you would want to see if notionally similar structures behaved the same

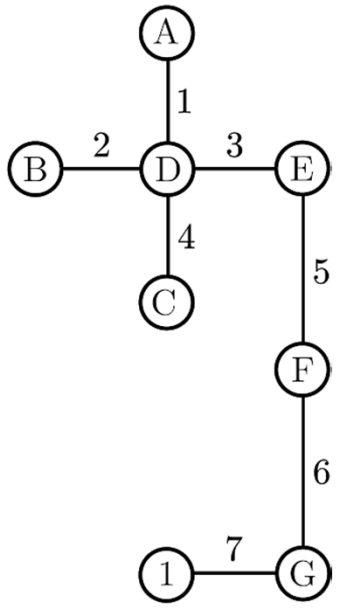
How do you measure ‘similar’?

clipboard & camera, independent forms showing defects & condition scores for all 6 bridges

PBSHM concept (developed by Prof Keith Worden, Uni of Sheffield, work presented from here was in collaboration with him and his team)

Then graph can be compared to other graphs to look for similarities. Can calculate a similarity score.





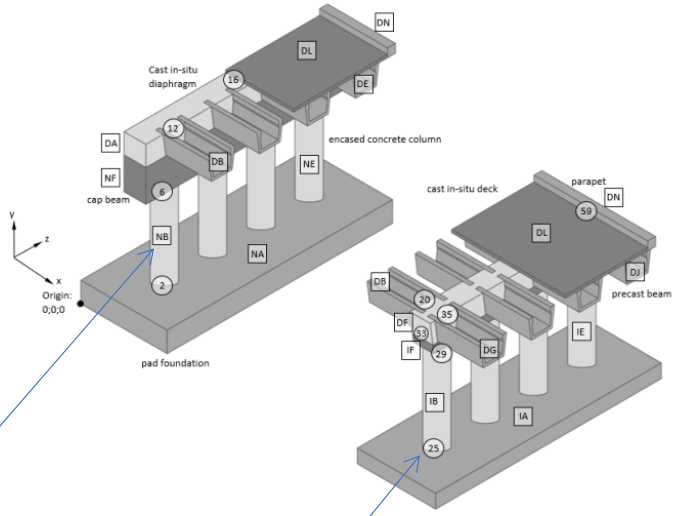
Structure → Engineering judgement → IE model → Import Function → Graph

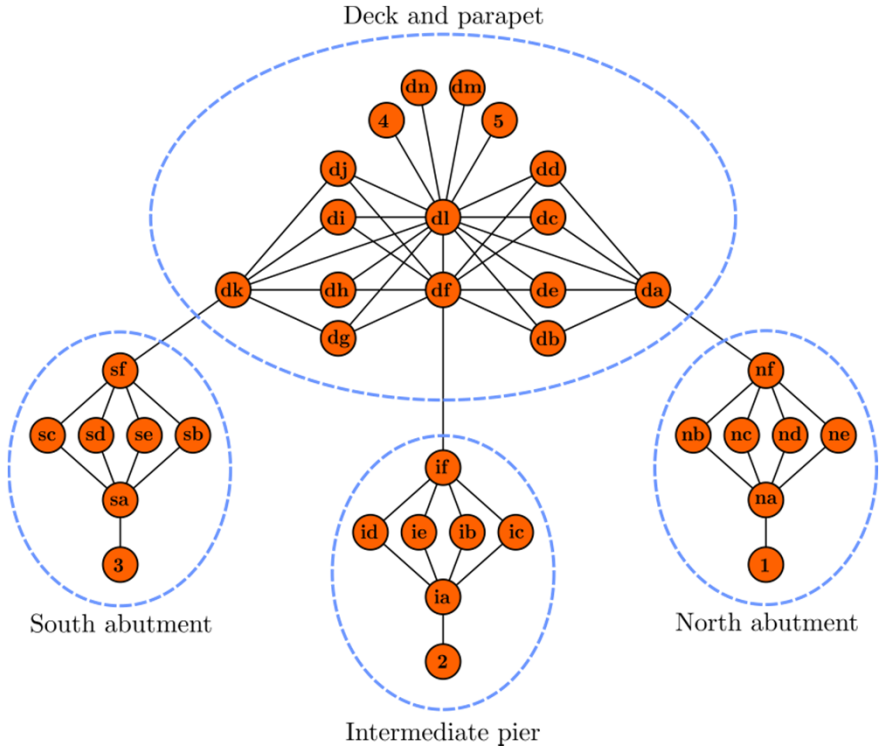
5 common bridge types we tried

Will talk though how we generated the hypergraph for each one in this sequence due to approximately increasing complexity

B&S Generating a graph

Nice type of plot as it maintains some sense of the structure. However, for more complex structures it loses this clarity, and hypergraph is better



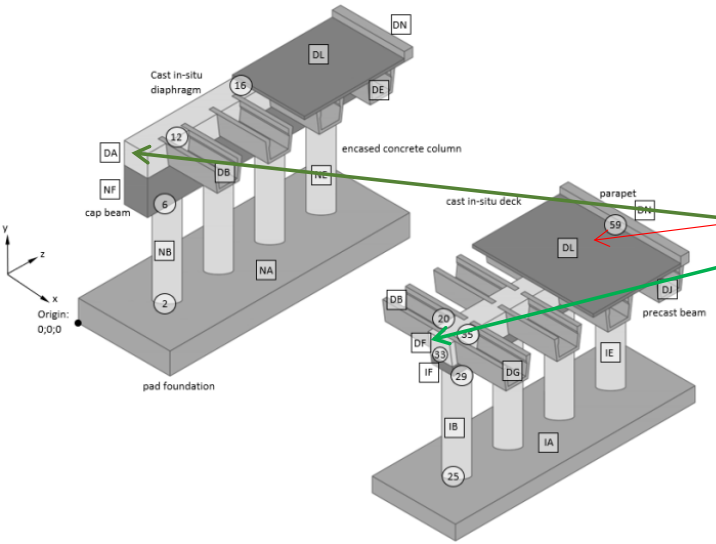


Element attributes, e.g. length, section properties etc

Joint attributes, e.g. position in x,y,z space and which elements are connected at the joint

structure → Engineering judgement → IE model → Import Function → Graph

B&S: Same information plotted as hypergraph



Deck DL
15 circles → 15 joints

Pier diaphragm (DF)

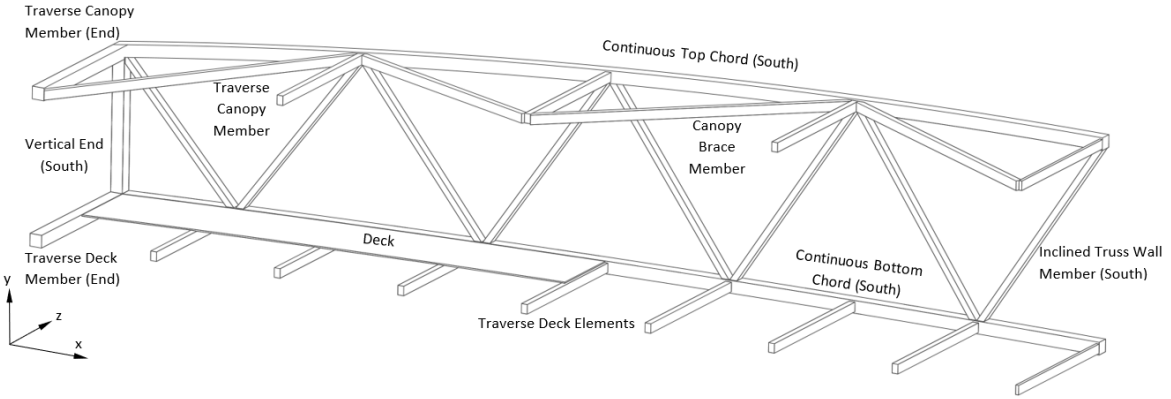
North abutment diaphragm (DA)

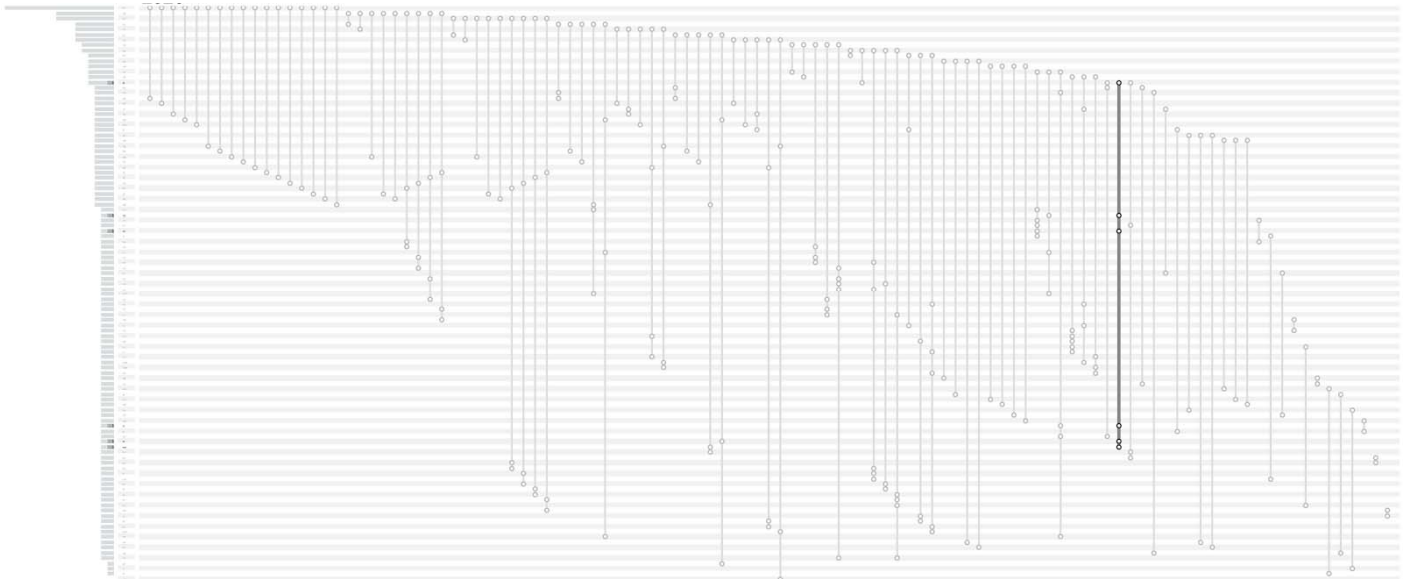
Elements DF connected to

Elements DA connected to

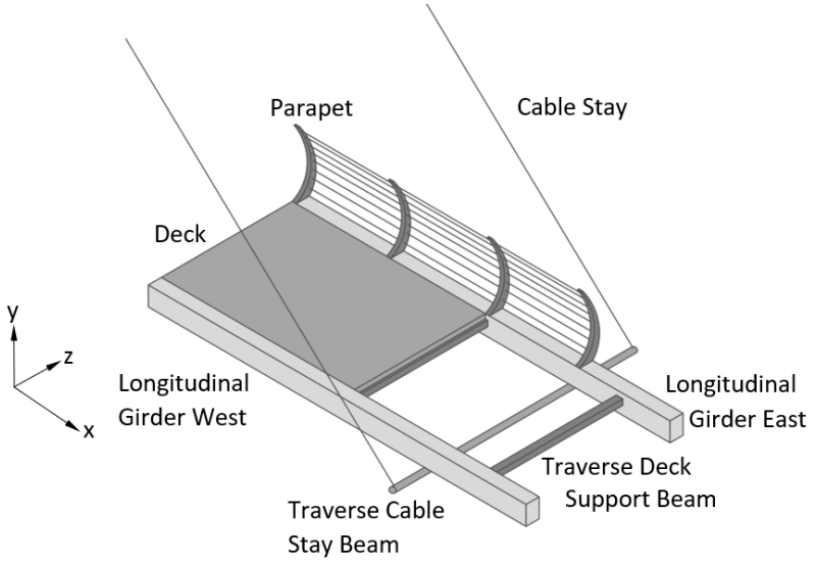
Elements deck is connected to

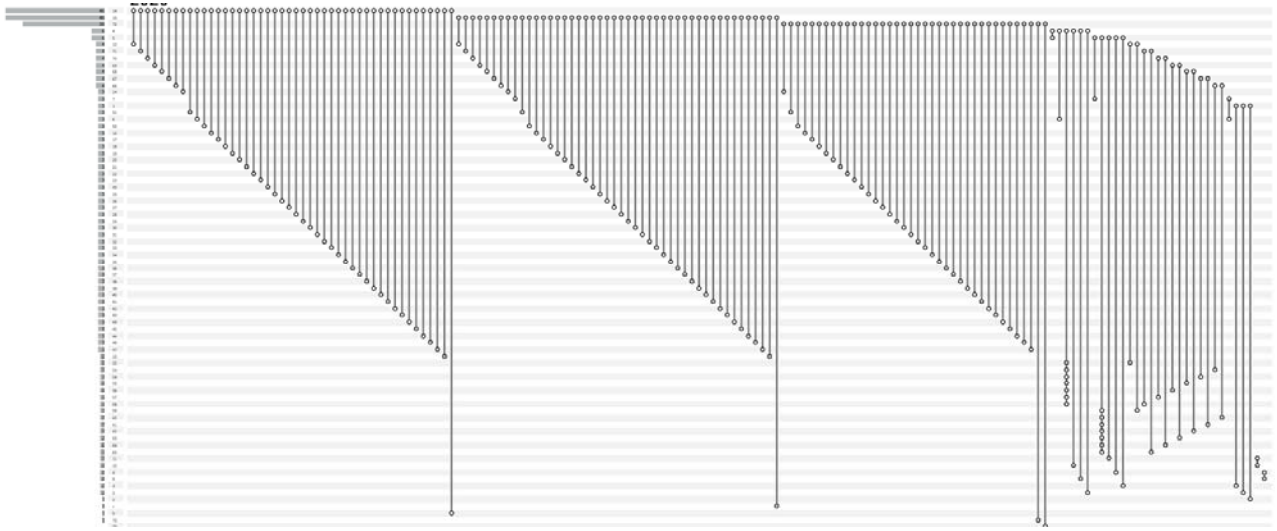
Truss bridge



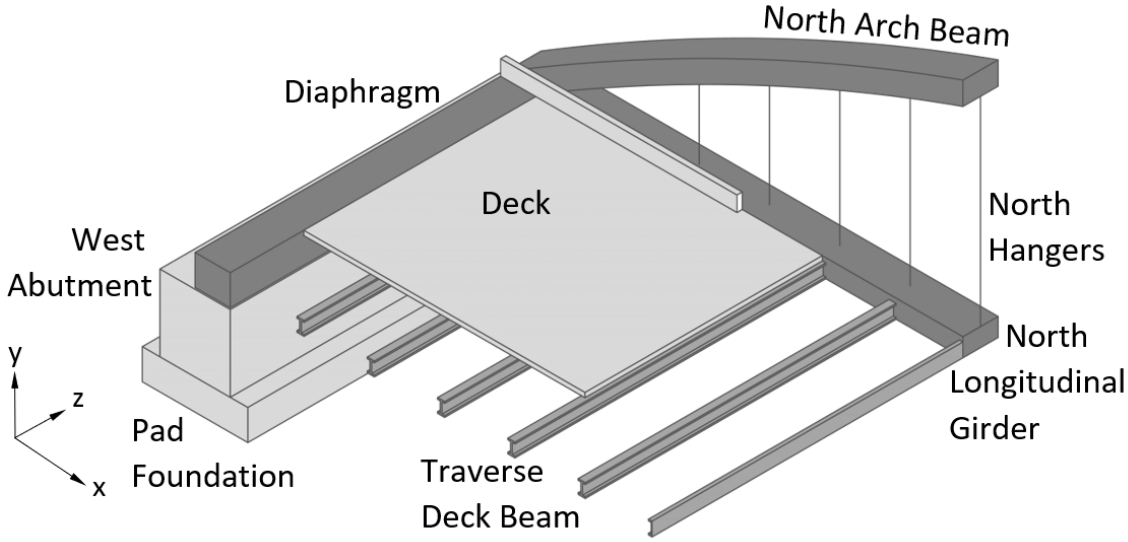


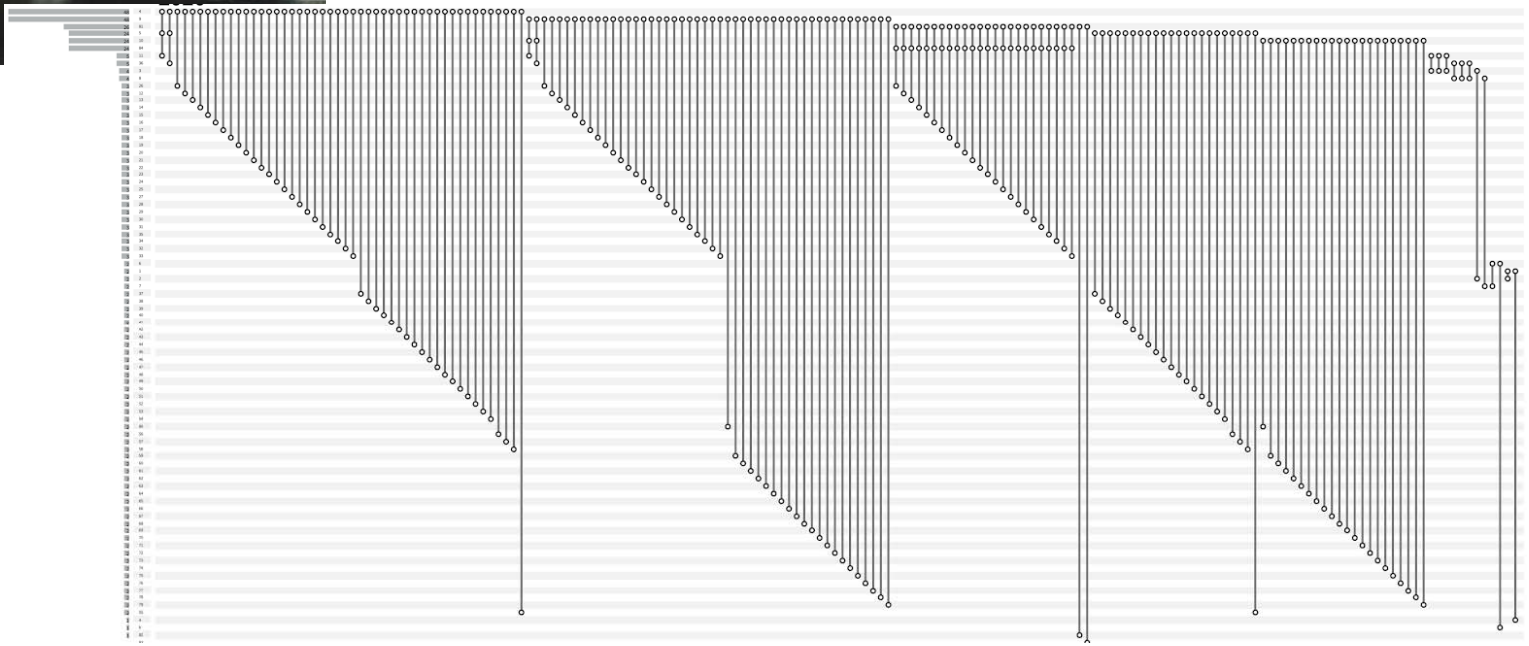
Cable stayed bridge



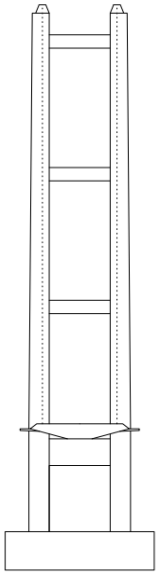


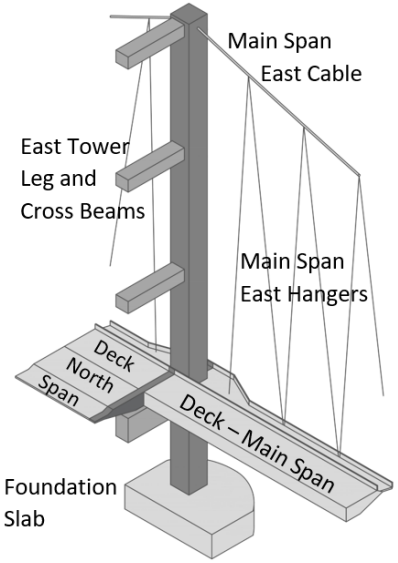
Arch bridge

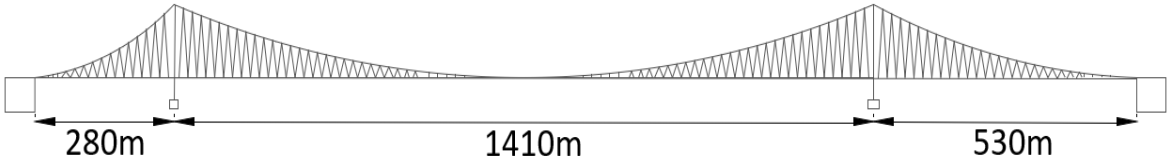

North Arch Beam
Diaphragm
Deck
North
Hangers
West
Abutment
North
Longitudinal
Girder
y
z
x
Pad
Foundation
Traverse
Deck Beam

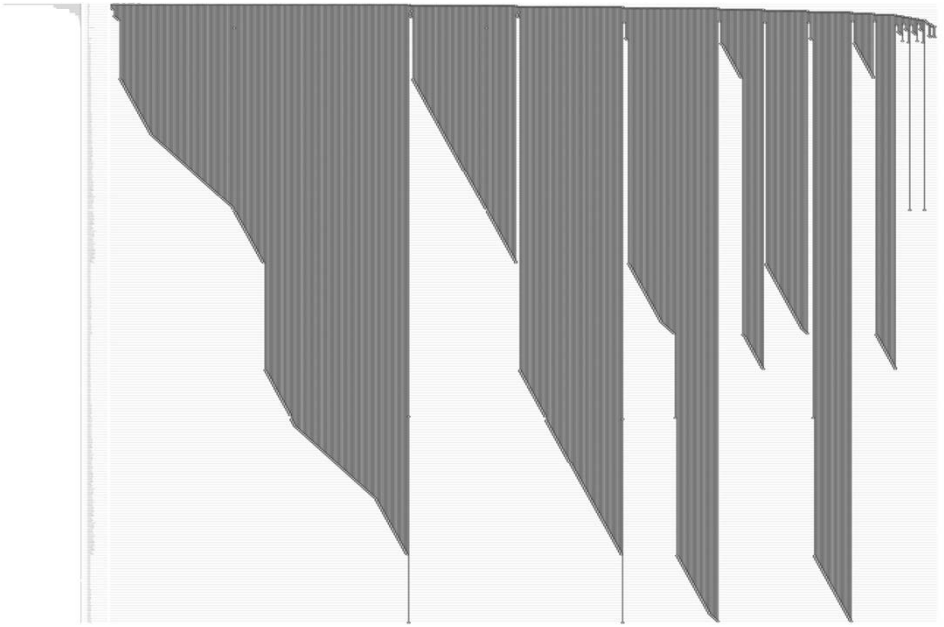


Suspension Bridge (Humber)









How to calculate similarity scores

Don’t go into detail here but it is a done using a systematic comparison of graphs.
But looking at the bridges and using engineering judgement

Gut feeling, these two as both cable supported ladder decks. But wasn’t sure
note, scoring is from 0 to 1

Similarity scores for 5 bridge types

Comparing bridge to itself a perfect match so similarity score =1

B&S to truss

Next closest match is the B&S to the cable stayed

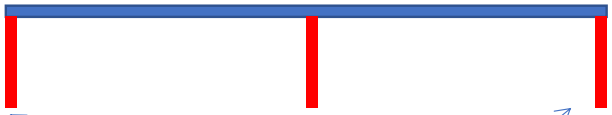
Suspension bridge does not match well with anything

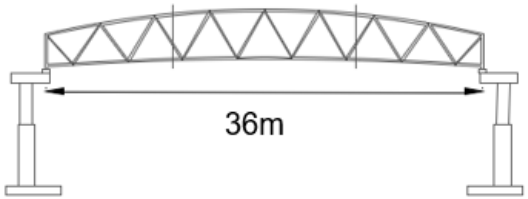
Cable stayed and arch show highest similarity score, which is what we intuitively expected

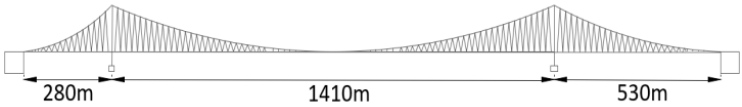
Conclusion: we were able to make IE models/graphs for the 5 bridge types, and similarity scores seem make sense.

Next step: compare two notionally 'similar' bridges to see if we get sensible answers, e.g. 2 B&S bridges

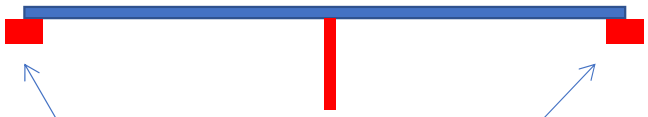
Originals & comparators

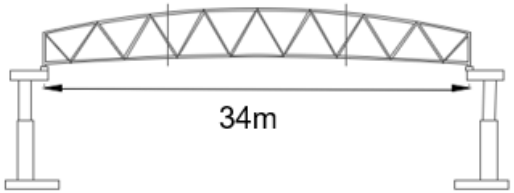


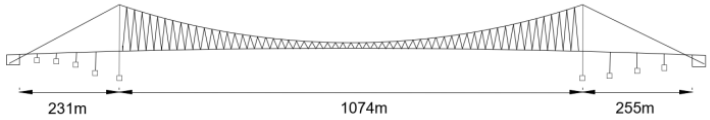




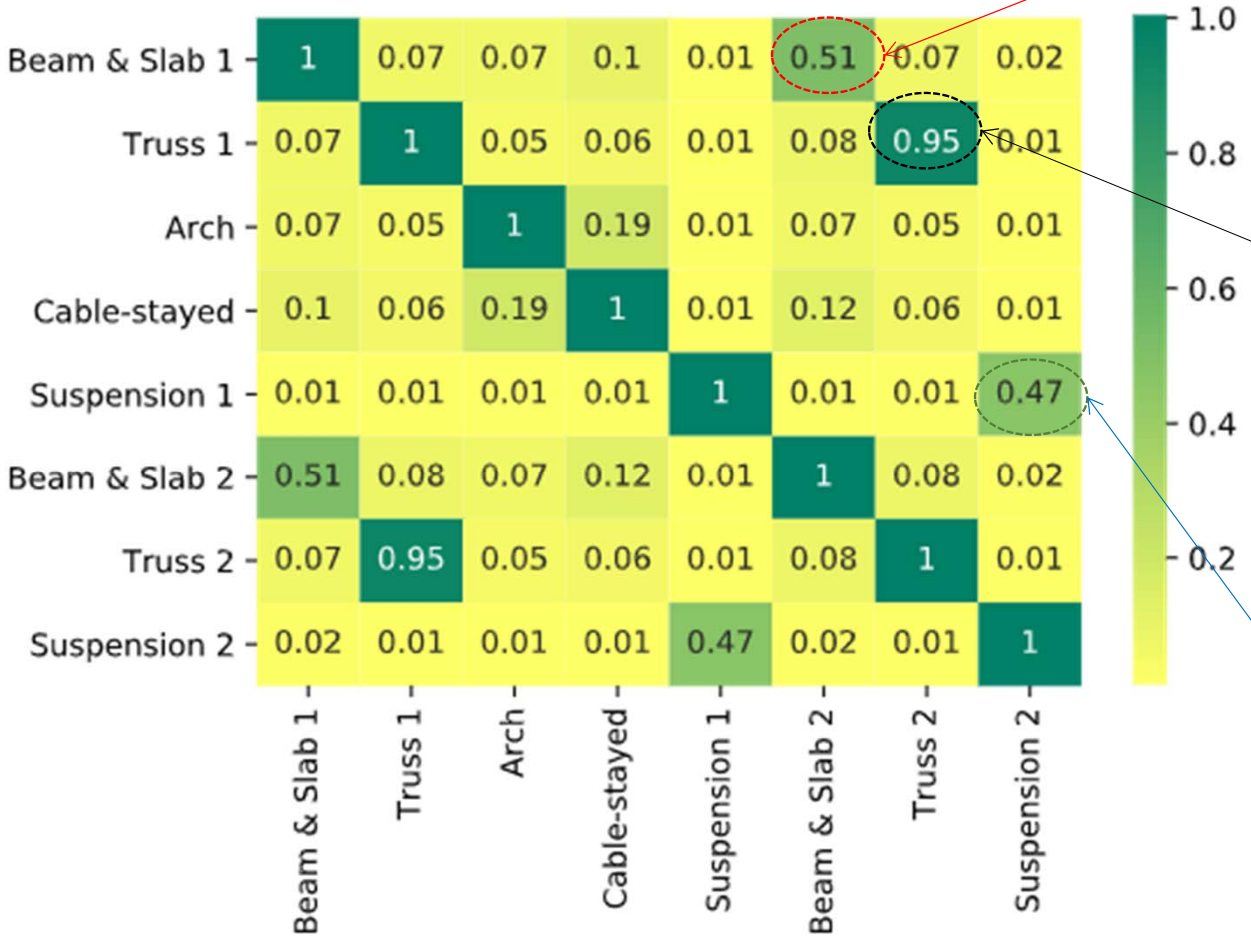
Both box girder decks with inclined hangers







Updated table



Comparing the 2 B&S bridges, this feels about right as the middle portion of the two bridges is very similar but the ends are quite different. Common subgraph is related to the deck and intermediate support

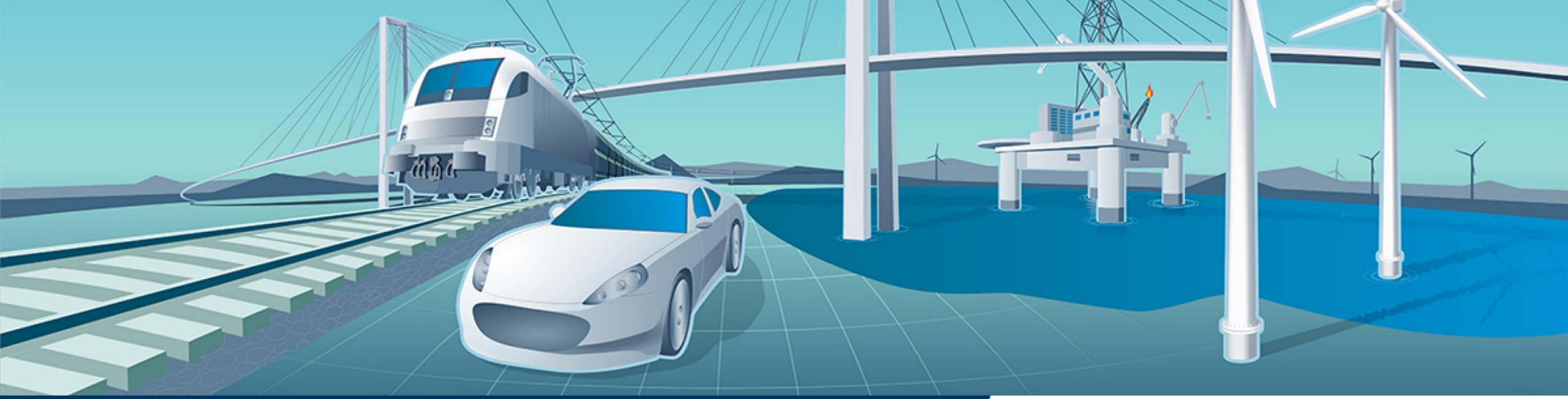
To be expected as the two truss bridges were selected to be near identical.

This seems reasonable as the main spans in both bridges are quite similar, but the back spans are different

Conclusions

- As only working with a small sample, difficult to have a good feel for the numbers yet.
- But has given sensible looking answers so far, therefore promising
- Next steps are more bridges and some data


Thanks for you attention
Any Questions



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