Bridge DSS

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Research Question

What are the ~~costs and~~ benefits of installing a decision support system (DSS) based on real-time sensor data, for the purpose of bridge maintenance, on a no-prestress no-postension concrete slab bridge?

- To answer this need to:
  - show benefits of having sensor data
    - base benfits on simulated data
  - ~~show what installation & maintenance costs are~~

How to acquire data and assess the potential for installing. . .

Existing SHM

- State of the art do not determine extent of damage
- Only whether damage present or not, "global monitoring"
- All one needs to know to then take further action
    - on-site examination

Existing SHM

- FHA mandates evaluation of bridges every 2 years (2003)
- Visual inspection and tap tests -> safety rating
- Bridges, many. Staff, not so many.
- Safety rating supplemented by FEA (based on best guess)
- More replacements for functionally obsolete than structurally unsound

Existing SHM: global monitoring

- Based on finding a shift in mode shapes or frequencies
  - including first and second derivatives of mode shape
- Compromised by external factors
- Deterioration of RE-steel litte effect on natural frequency
- Methods to find damage location and extent
  - typically work better when:
    - limited to assumed forms of damage
    - damage is severe

ML for SHM

- garbage-in, garbage-out
- data acquisition of utmost importance
- model validation required
- anbormality detection needs to account for external factors!

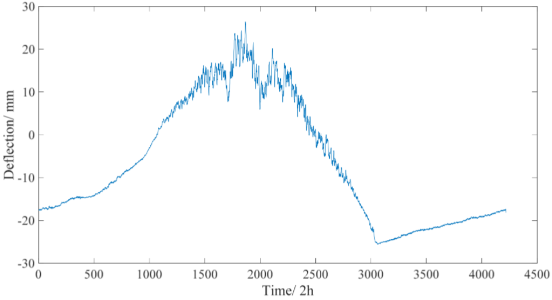


Figure 16. Long-term monitored deflection data of one year (averaged every two hours).

Types of Bridges: Hungary

Table. 3.2 Classification of primary road bridges based on structural type, relative number and value.

Structural type	Number (%)	Value (%)
Reinforced concrete	**83.1**	**44.4**
Precast multi-girder	49.9	32.6
Monolithic slab	24.1	5.5
Monolithic frame	7.6	0.8
Prestressed box girder	0.7	4.2
One or two-box girder	0.7	1.3
Steel	**1.0**	**12.4**
Riveted steel truss	0.4	4.7
Welded girder	0.4	3.5
Welded box with orthotropic deck	0.2	4.2
Composite	**1.3**	**5.7**
Composite girder	1.0	1.7
Composite box girder	0.3	4.0
Concrete or stone arch - tubosiders	**9.0**	**1.2**
Tubosider	5	0.9
Concrete, RC pipe	3	0.2
Stone or masonry arch	1	0.1
Special bridges (e.g. Duna bridges)	**2.3**	**33.9**

Bridge Model

```
data Bridge = Bridge {
  length        :: Float,
  width         :: Float,
  piers         :: [Pier],
  deck_sections :: [Section],
  lanes         :: [Lane],
  dimensions    :: Dimension
}

data Dimension = D2 | D3
data Section = Section2D | Section3D
data Pier = Pier2D | Pier3D

-- Bridge constructor ensures that dimension must match.
```

Bridge Model: 3D

```
data Pier3D = Pier3D {
  x           :: Float,
  z           :: Float,
  length      :: Float,
  height      :: Float,
  widthTop    :: Float,
  widthBottom :: Float,
  sections    :: [Section]
  baseMesh    :: (Int, Int, Int, Int)
  fixXTrans   :: Bool,
  fixYTrans ...
}
```

Bridge Model: 3D

- Pier: side view

```
<--------x---------->
             <---length-->
|------------|-----------|--------|  ↑ h
              \         /            | e
               \       /             | i
                \     /              | g
                 \   /               | h
                  \ /                ↓ t
```

Bridge Model: 3D

- Pier: top view

```
|---------------------------------|  ↑+
|---------------------------------|  |
|---------------------------------|  |
|---------------------------------|  |
|---------------------------------|  0
|------------|-----------|--------|  |
|------------|-----------|--------|  | z = -2
|------------|-----------|--------|  |
|---------------------------------|  ↓-
```

Bridge Model: 3D

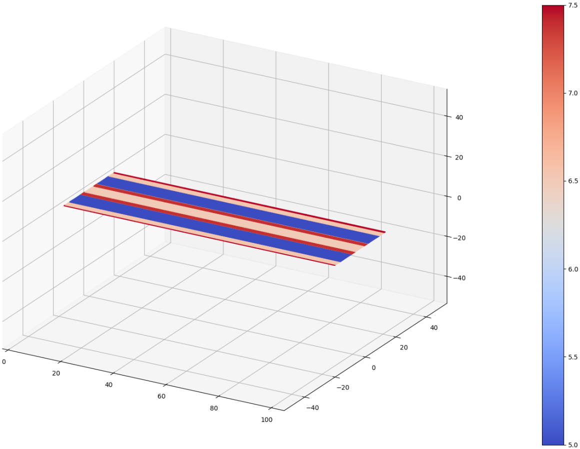
- Pier: front view

```
  width-top
<---------->
|----------|
 \         /
  \       /
   \     /
    \   /
     \_/
     <->
 width-bottom
```

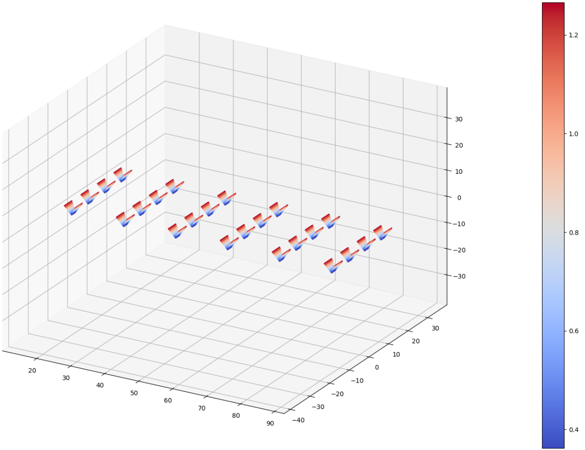
Bridge Model: 3D

```
data Section = Section {
    density     :: Float, -- density in kg/m
    thickness   :: Float, -- thickness in m
    youngs      :: Float, -- Young's modulus in MPa
    poissons    :: Float, -- Poisson's ratio
    start_x_frac :: Float, -- start position in x direction
    start_z_frac :: Float  -- start position in z direction
}
```

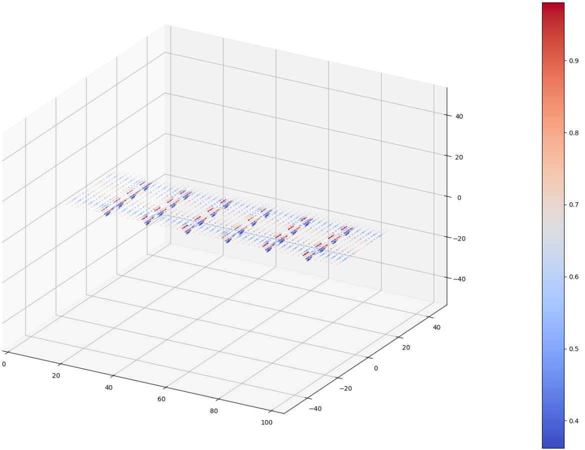
Bridge Model: thickness



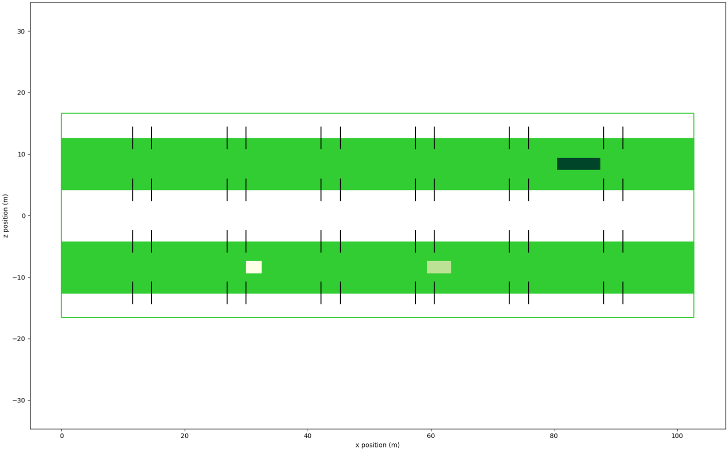
Bridge Model: thickness



Bridge Model: thickness



Bridge Model: lanes & vehicles



FEM Generation: why not just Diana?

- OpenSees format easier to modify than Diana
- Need to modify to:
  - impose damage scenarios
  - add load
- Allows targeting of many bridges, not just 705
- Open source -> reproducible research

Extensible research

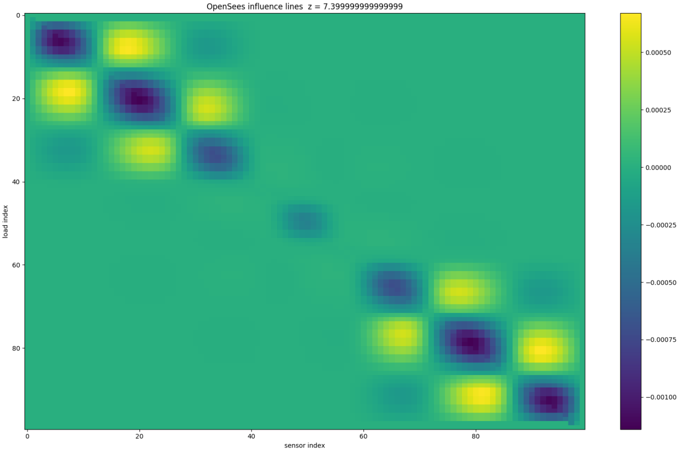
- Download & run (reproducible research)
- Extensible if easy to extend, must be:
  - Well documented
  - Uses parameters, not hardcoded values
  - Composable functions, not scripts

Data Collection

- a FEM is built according to a `Bridge` and `BridgeScenario`
- influence lines are built:
  - concentrated loads placed along wheel tracks
- traffic is generated according to:
  - `TrafficScenario` normal/heavy
  - vehicle distribution e.g. by length
  - vehicle descriptions (length, #axles, weight)
- vehicles "drive" along the bridge
- responses summed for each wheel from influence line

Data Collection: influence lines

- Influence lines for one wheel track
  - loading position on the left
  - sensor position along the bottom



Model Assumptions: Vehicles

- Vehicles drive at the same speed
- Vehicles drive along the center of a lane
- Vehicles have the same axle-width
- Vehicles arrive according to truncated poisson process
  - truncated below 2 meters
  - mean at 7 meters

Model Assumptions: FEM

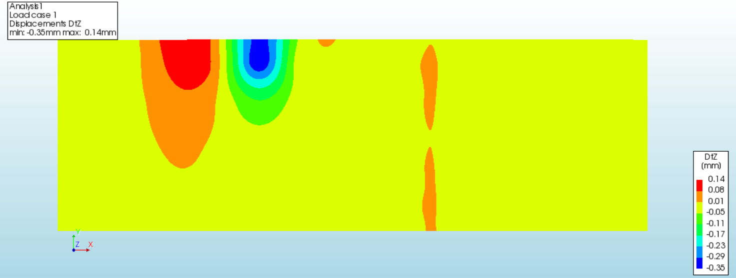
- Subset of bridge positions sufficient for FEM verification
  - Measurements from experimental campaign only for some positions
  - Assumption that bridge 705 was in a healthy state in campaign
- Linear elastic FEM captures the bridge behaviour
- [How damage scenarios are modeled]
- Responses generated are sufficiently close to real bridge behaviour that analysis techniques explored on simulated data can also work on real data
  (TODO) Limited verification by:
  - abnormality dection on real data in addition to simulated data
  - increase noise level to see how robust
  - comparison of real data to simulated data
  - Note: accuracy of simulated responses depends on discretization density
  - a trade-off of time versus accuracy which can be chosen by the user
  - accuracy shown to converge for bridge 705 in (TODO) convergence plot

Verifying Generated FEM

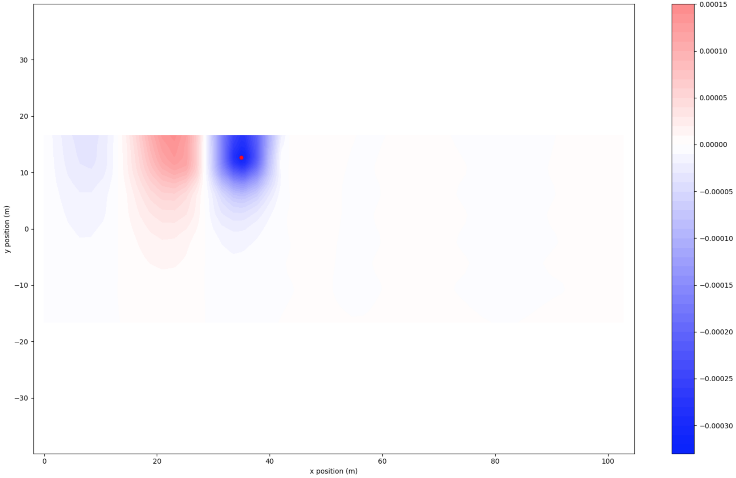
- OpenSees model in table is the low-accuracy FEM
  - base mesh of deck 50 * 20
  - base mesh of each pier wall: 5 * 5
- Units are mm

Diana	OpenSees	Point
0.49	0.465	A
0.14	0.130	B
0.162	0.180	C
0.13	0.128	D

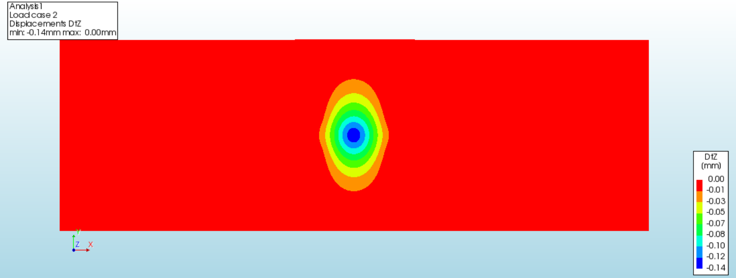
Verifying Generated FEM: Point A, Diana



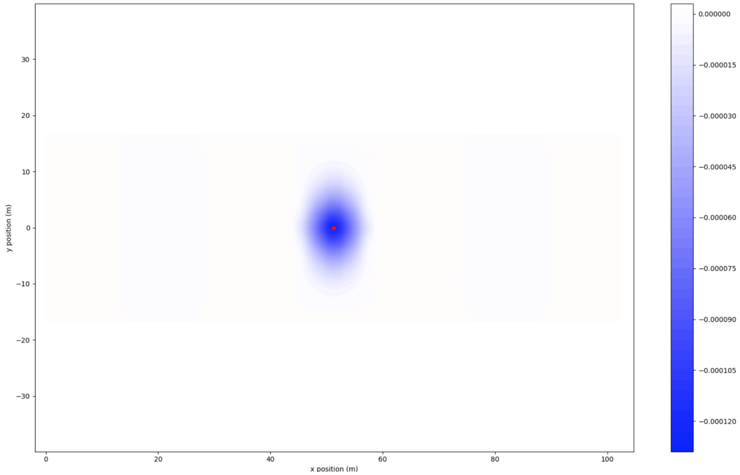
Verifying Generated FEM: Point A, OpenSees



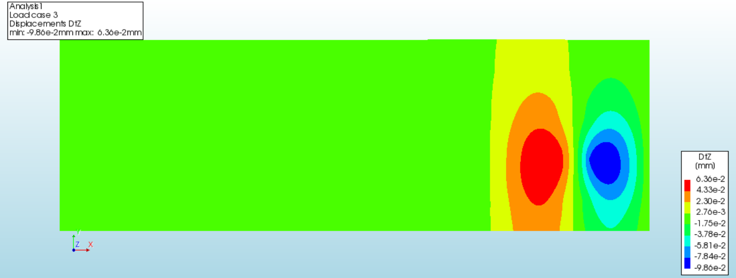
Verifying Generated FEM: Point B, Diana



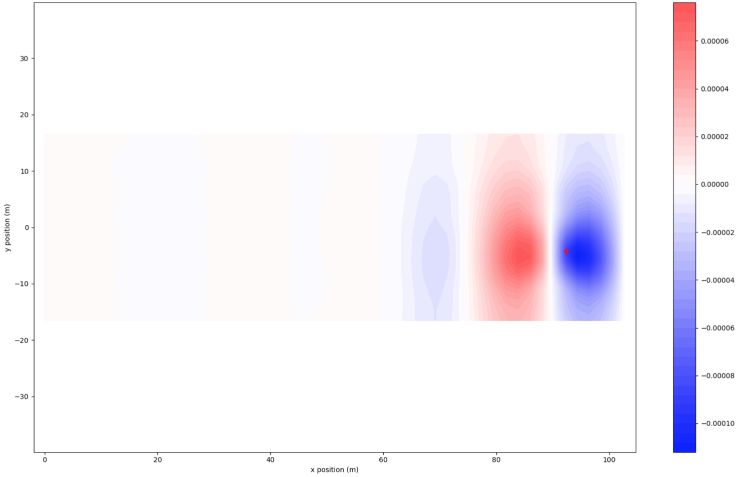
Verifying Generated FEM: Point B, OpenSees



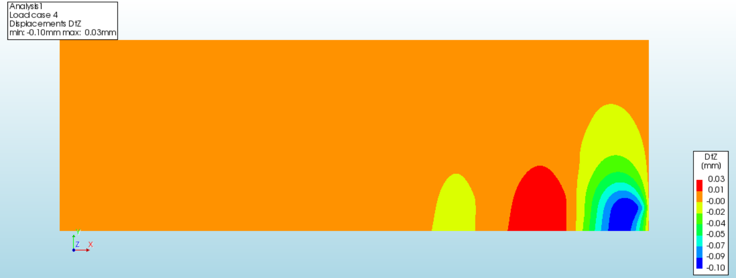
Verifying Generated FEM: Point C, Diana



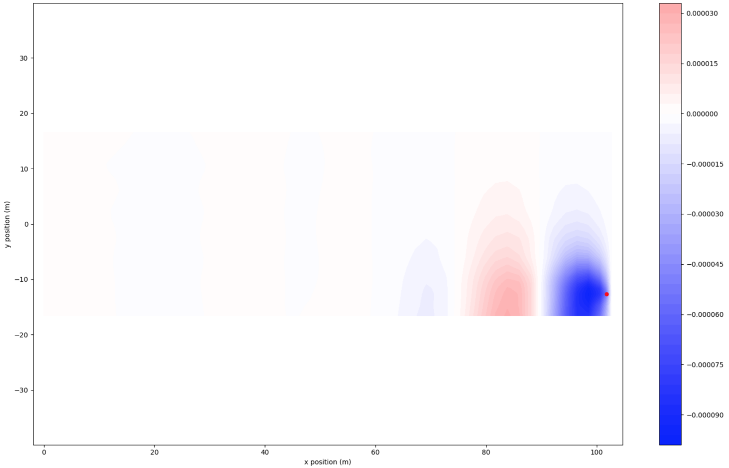
Verifying Generated FEM: Point C, OpenSees



Verifying Generated FEM: Point D, Diana



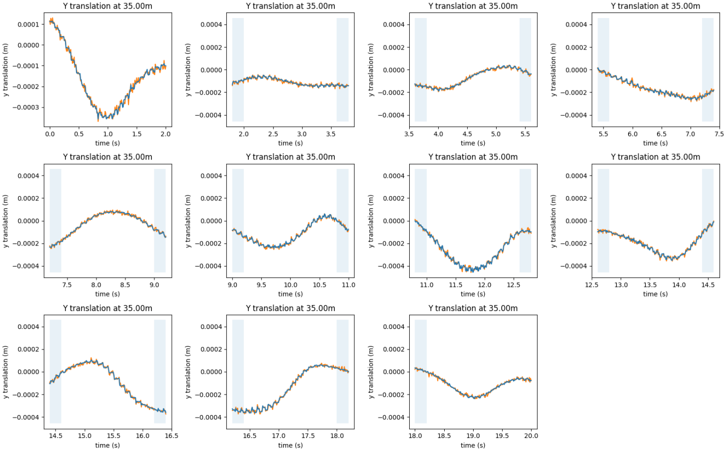
Verifying Generated FEM: Point D, OpenSees



Responses

Code: Distribution of responses

Events



Animation

./normal-lam-5.mp4

Costs

Research

Future collaboration

Future collaboration

- Don't start thesis until long-term housing is found
- TNO could ask about reserving a student room
  - Perhaps for semester start
  - Low effort, high potential

Overview

2D Model	Model Generation	+
2D Model	X, Y, Z -translation	&
2D Model	Stress & Strain	+
2D Model	Pier Displacement	+
3D Model	Model Generation	+
3D Model	X, Y, Z -translation	+
3D Model	Stress & Strain	-
3D Model	Pier Displacement	&
3D Model	Verification	&
Data Collection	Influence Lines	+
Data Collection	Event Generation	+
Model Input	Noise	&
Model Input	Traffic	&
Model Input	Low frequency Events	-
Anomaly Detection		-
Bridge Types & Costs		-

Key goals

- Verified extensible FEM
- `dataCollection : Bridge -> Scenarios -> [Event]`
- Anomaly detection
- Avoid detecting low frequency events
- Detect anomaly on real data

Plan

November week 1	writing	sensor cost emails/research
November week 2	writing	try standard classifiers
November week 3	verification plot 1	collect strain
November week 4	verification plot 2	classifiers
December week 1	writing	add temperature to model
December week 2	writing	add soil creep to model
December week 4	writing	

New Year

- Determine accurate noise-at-rest
  - Plot real time series vs simulated
- See how detection worsens with noise
- Reduce area between traffic lanes
  - See how background noise increases
  - See how detection worsens with noise
- Anomaly detection on viaduct data

My Goals

- Create something TNO value
- Create something used
  - Usable -> Useful -> Used

Reproducible

- I should be maintainer after the thesis
  - Maintainer not exact same as developer
  - I care about open source
  - I care about maintainability & usability
  - I know the code best
  - Clean-up work to be done after thesis
- Licence
  - GPL (sharing improvements)

Muchas Gracias