Damage detection of concrete slab bridges

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Dutch Main Road Network

Stucture type	Number	Deck Area (m2)
Concrete bridge	3'131	3'319'002
Steel bridge (fixed)	88	301'997
Movable bridge	43	347'876
Tunnel	14	475'228
Aqueduct	7	86'491
Total	3'283	4'530'593

Existing SHM

- State of the art do not determine extent of damage
- If they do:
  - assumptions are made
  - or in a controlled experiment
- Only determine whether damage present or not
  - global health monitoring
- Detection only necessary to then take further action
  - on-site examination

Ultimate Goal

- Damage detection of concrete slab bridges
- Major problem:
  - data of damaged state not available
    - can't go around damaging bridges
- Then how to prototype damage detection systems without data?

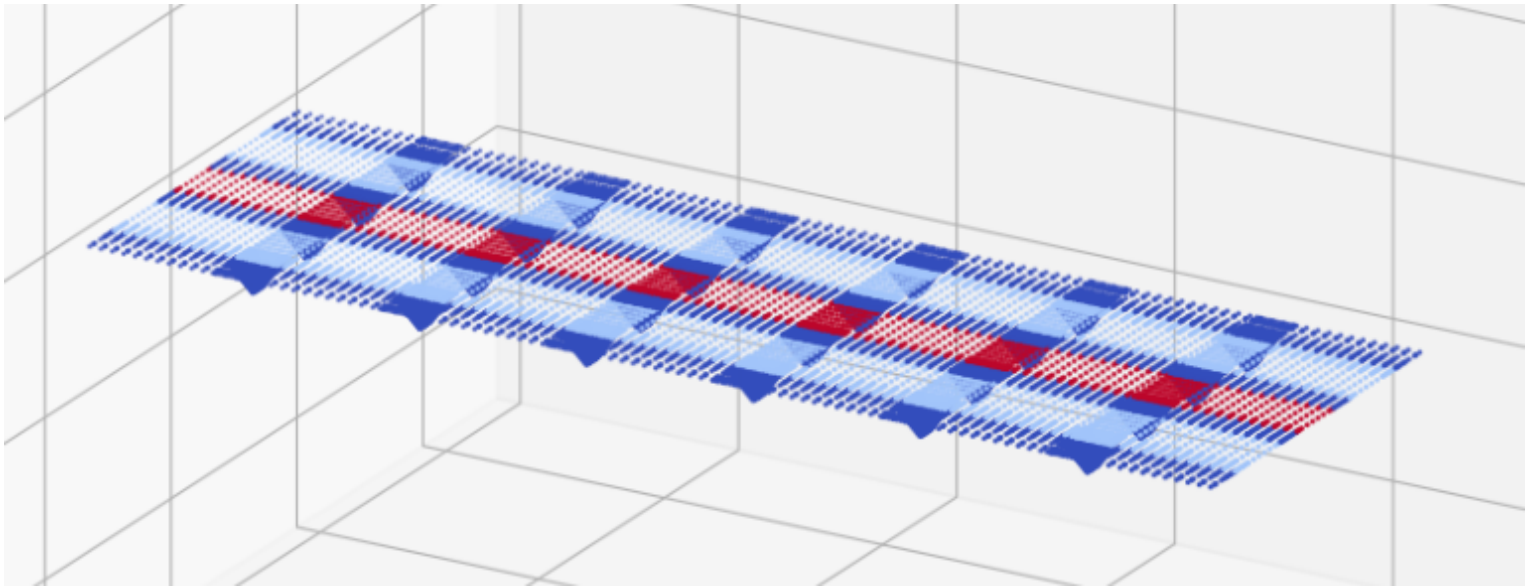
Ultimate Goal

- Damage detection of concrete slab bridges
- Based on simulated data
- Validated against real data
- System can be applied to many concrete bridges
  - model is parametric
  - not just for one bridge

Bridge Model: Parametric

```
data Bridge {
  length          :: Float,
  width           :: Float,
  piers           :: [Pier],
  deck_materials  :: [Material],
  lanes           :: [Lane],
}
```

Generated Model: Bridge 705



Generated Model

- `Bridge` model is parametric
  - material propertes, dimensions
- can generate 2D beam or 3D shell model

Mesh: Deck Nodes

- base mesh = 50 * 20
- from piers = 12 * 68
- from loads = 0 * 0
- from materials = 0 * 24
- from pier refinement = 66 * 0
- total = 128 * 112

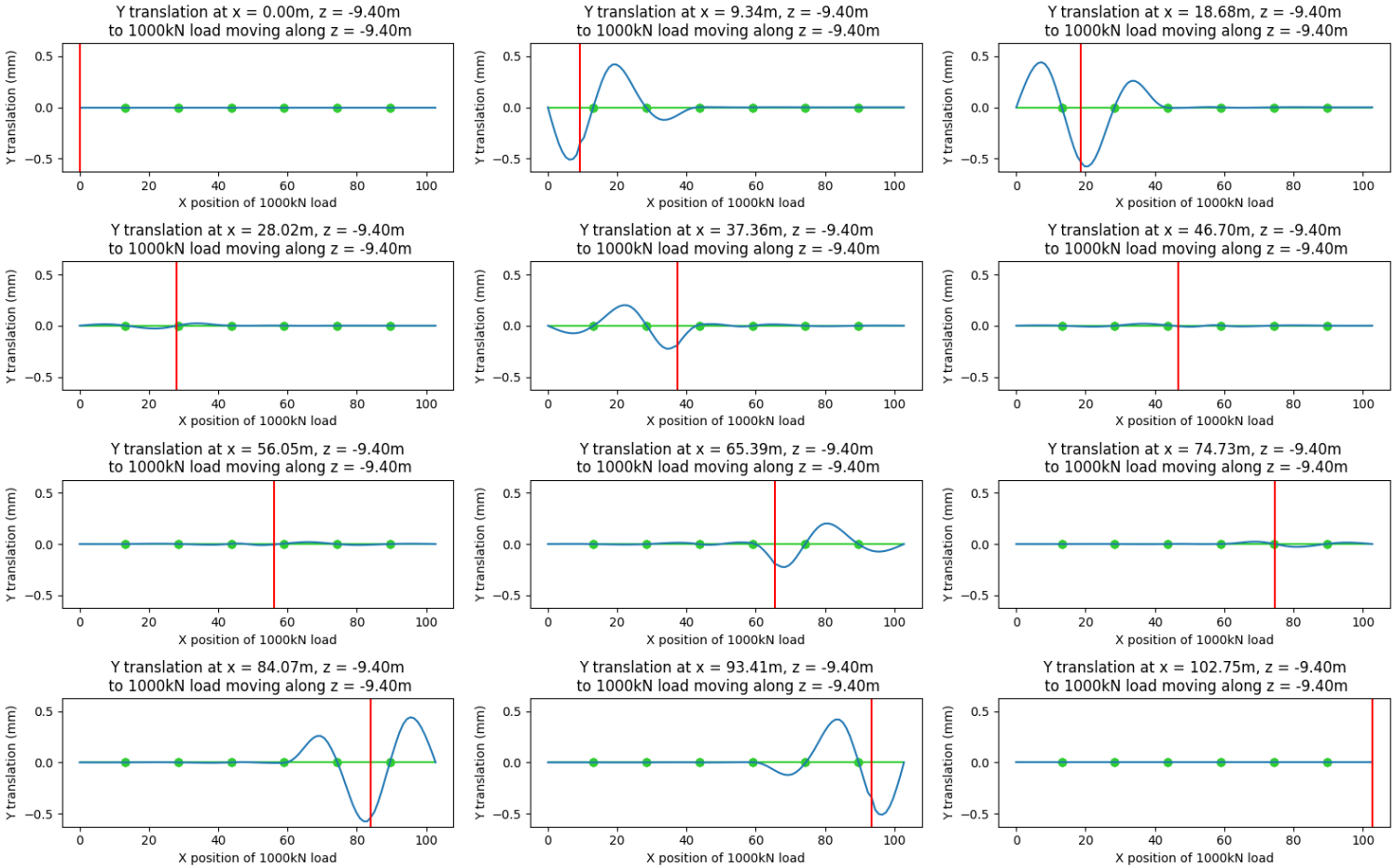
Mesh: Pier Nodes

- base mesh = 17 * 17
- from deck = 0.0 * 7.0 (mean)
- total = 17 * 24

Animation

./animation.mp4

Unit Load Simulations



Responses via Superposition: Traffic

- 2 lanes, 4 wheel tracks
- vehicle leaving on bottom lane
- lighter vehicle leaving top lane

```
traffic_at_time_0 = [
    1, 2, 0,
    1, 2, 0,
    0, 3, 3,
    0, 3, 3]
```

Responses via Superposition: Traffic

- `t` rows, one per unit time
- `n * 4` columns, n per wheel track
- currently using `n=100` (Bridge 705 = 102.75m)
- TODO: `n = 102.75 / wheel print length`

```
traffic = [
    [1, 2, 0, 1, 2, 0, 0, 3, 3, 0, 3, 3],
    [2, 0, 0, 2, 0, 0, 0, 0, 3, 0, 0, 3],
    [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]]
```

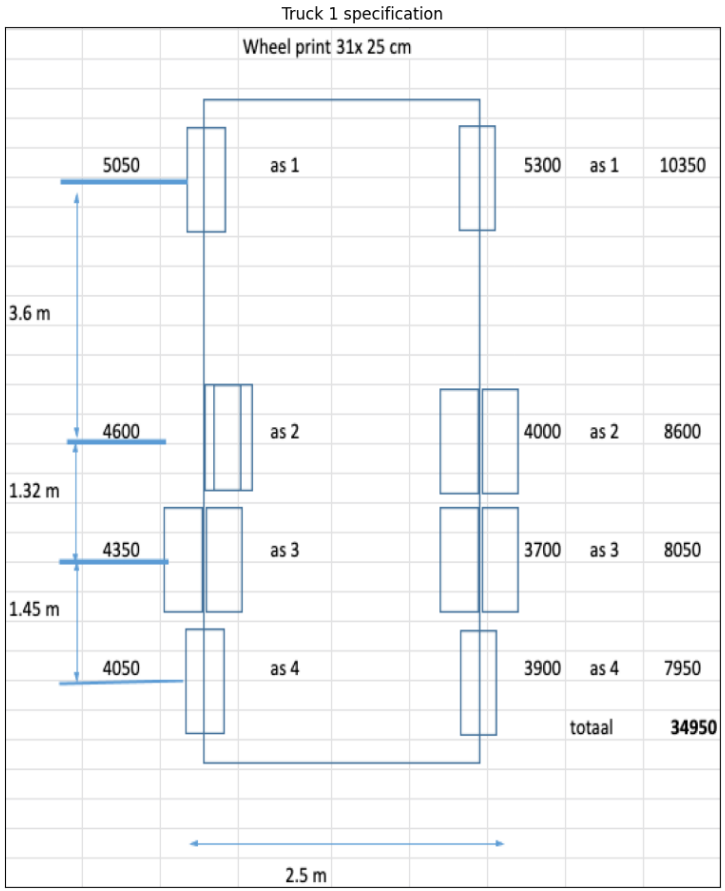
Responses via Superposition: Unit Load Simulations

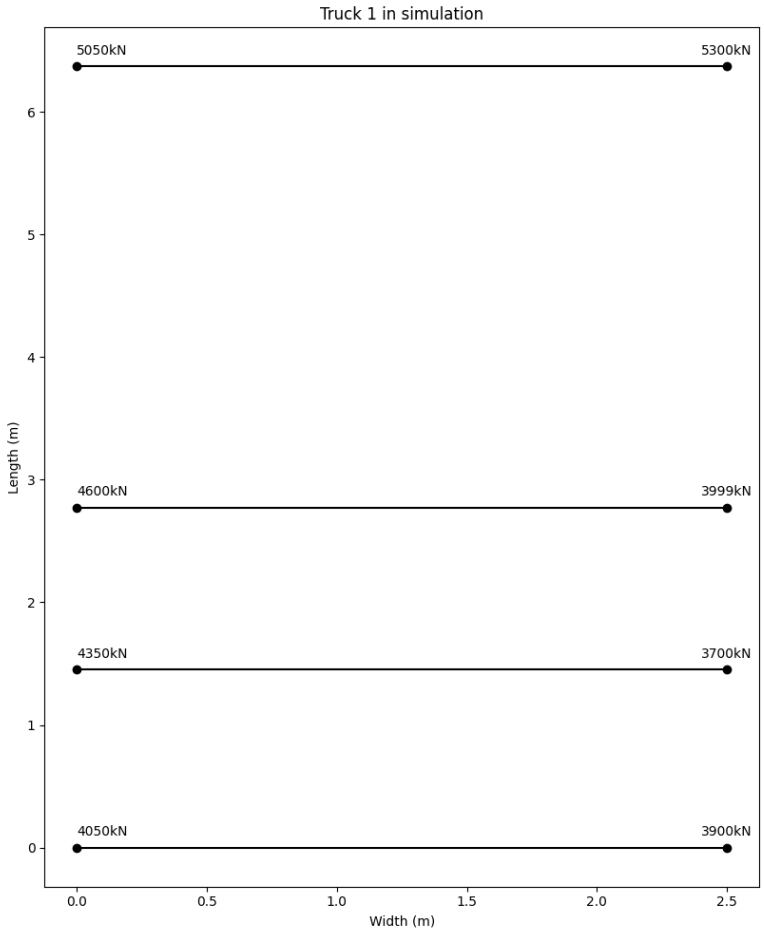
- `n * 4` rows, n per wheel track
- `p` columns, points you want a response at
- Each cell is
  - the response at point p_i
  - from unit load simulation `j`

```
points = [
    [1, 0, 0, 2]
    [1, 0, 0, 3]
    [2, 1, 0, 3]
    [2, 1, 0, 2]
    [1, 2, 1, 2]
    [1, 2, 1, 1]
    [0, 1, 0, 1]
    ...
```

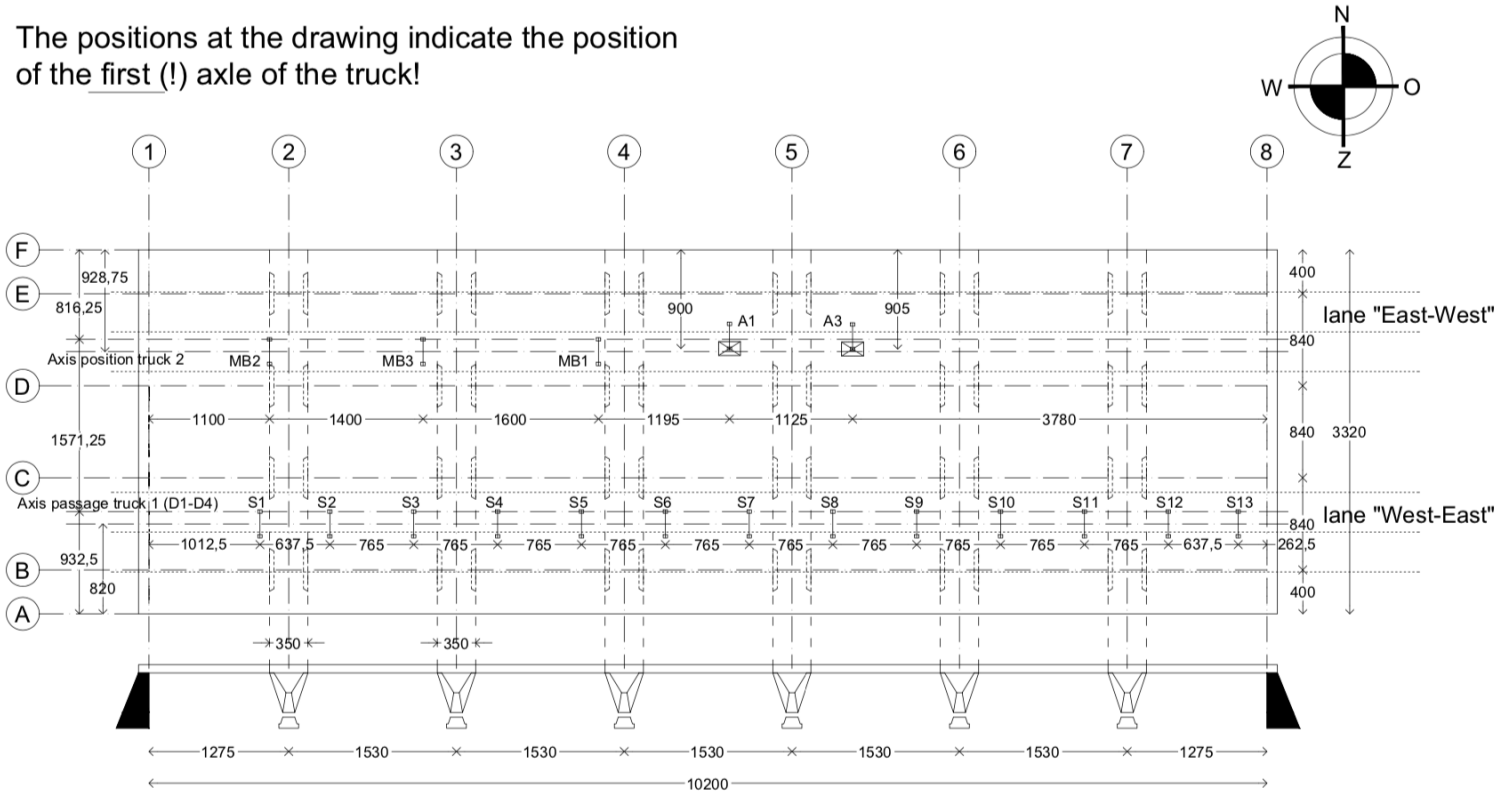
Validation: Truck 1 in experimental campaign

fix plot

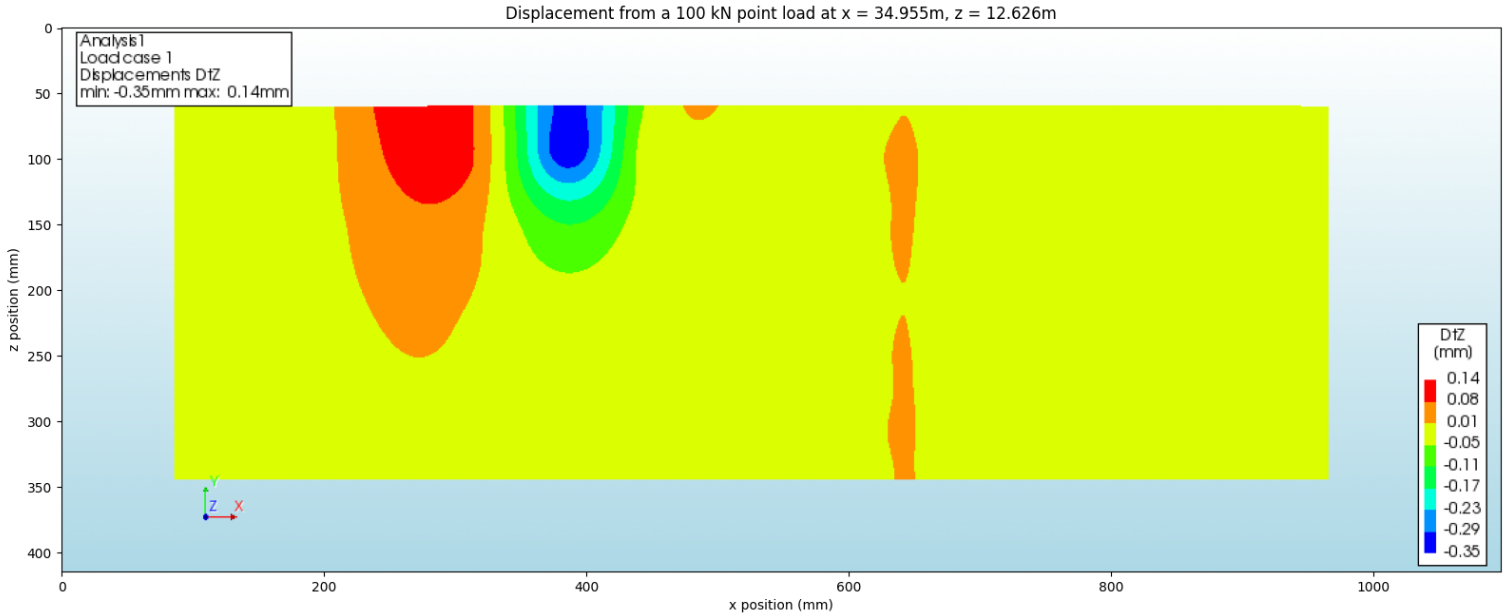




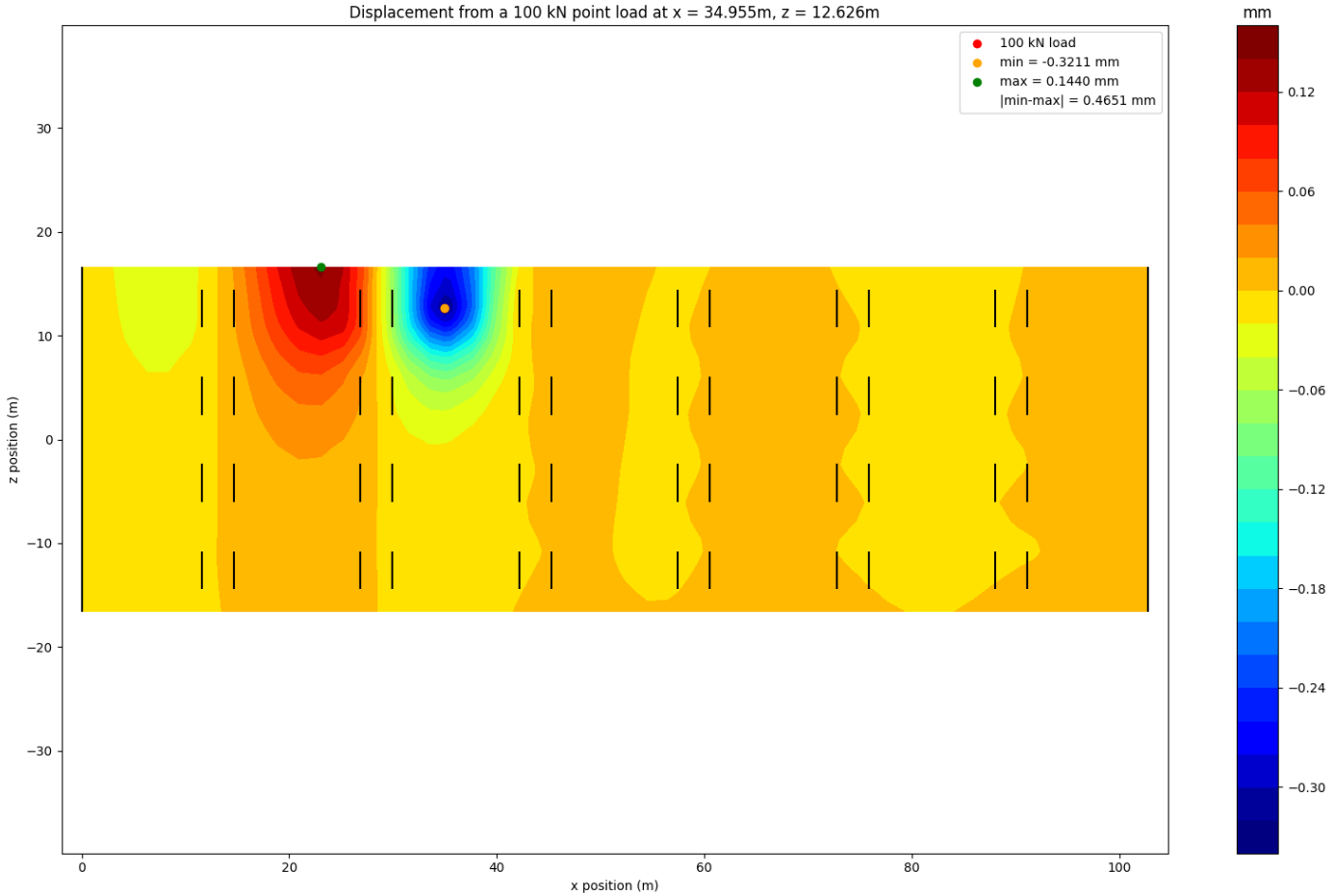
Validation: Truck positions in Experimental Campaign



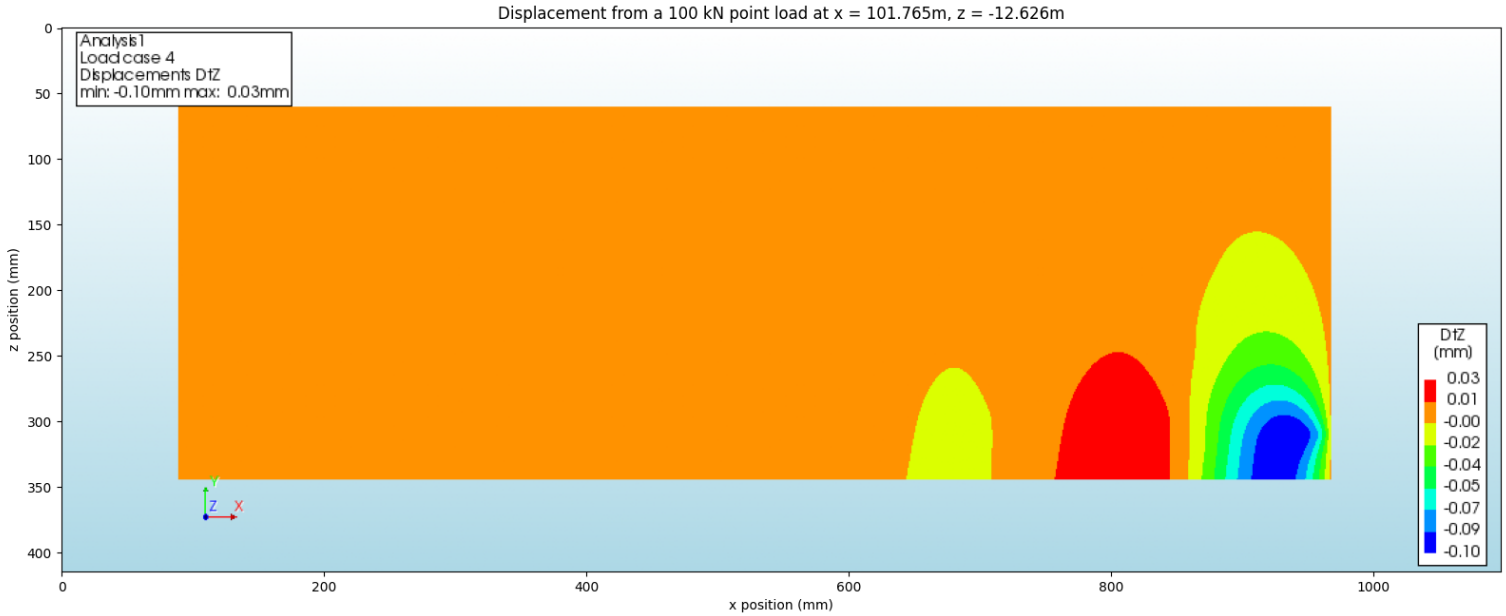
Validation: Displacement Diana



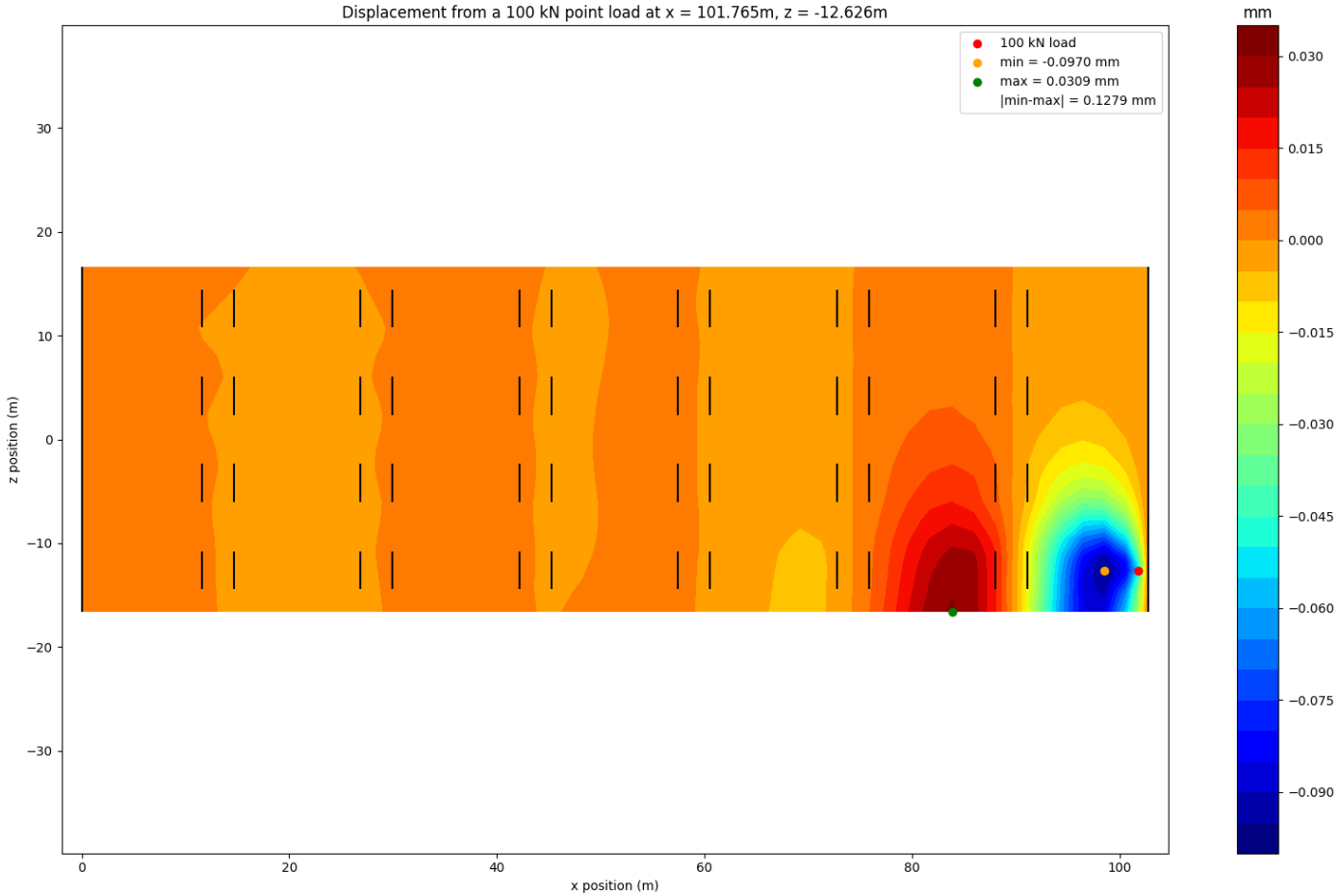
Validation: Displacement OpenSees



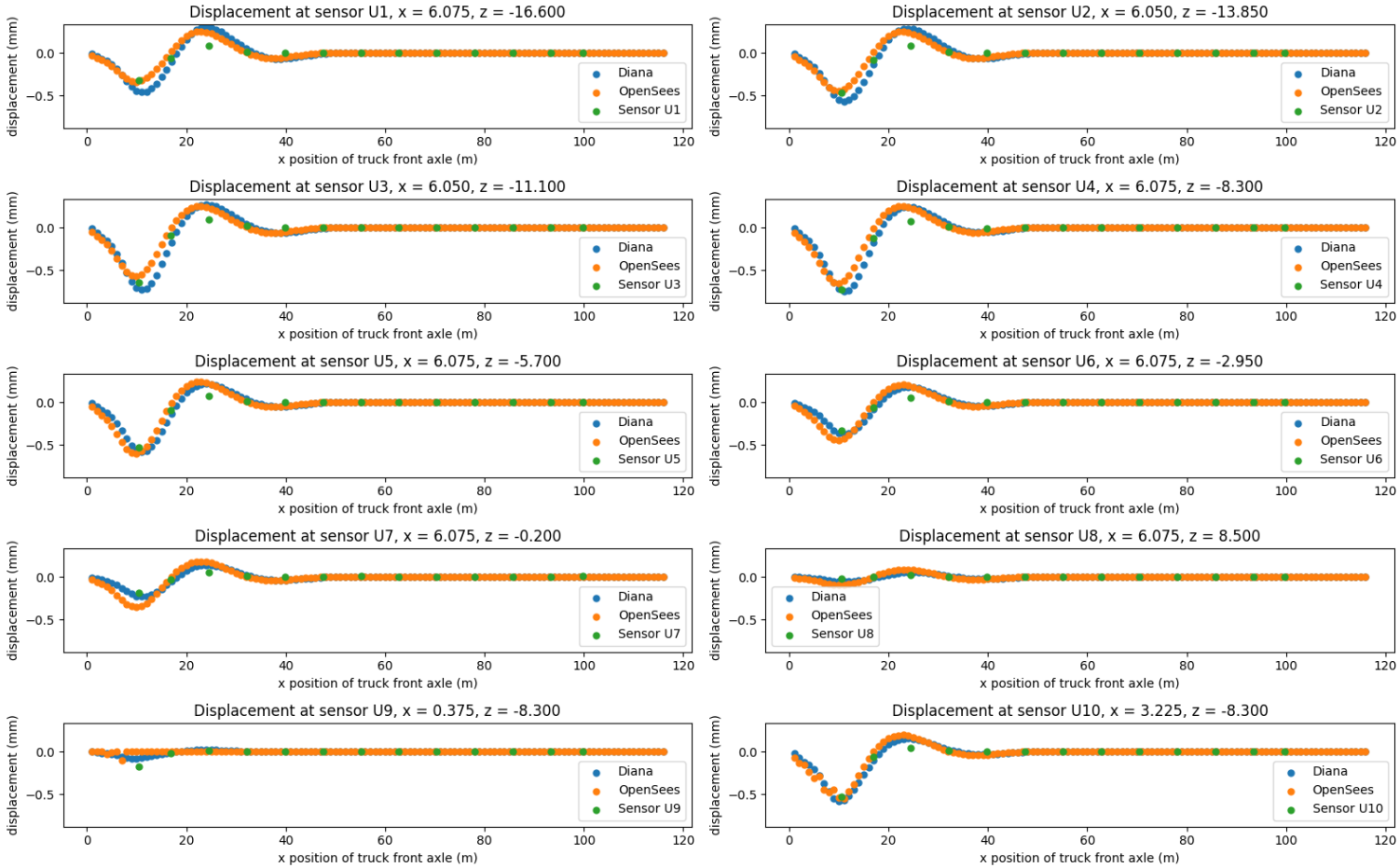
Validation: Displacement Diana



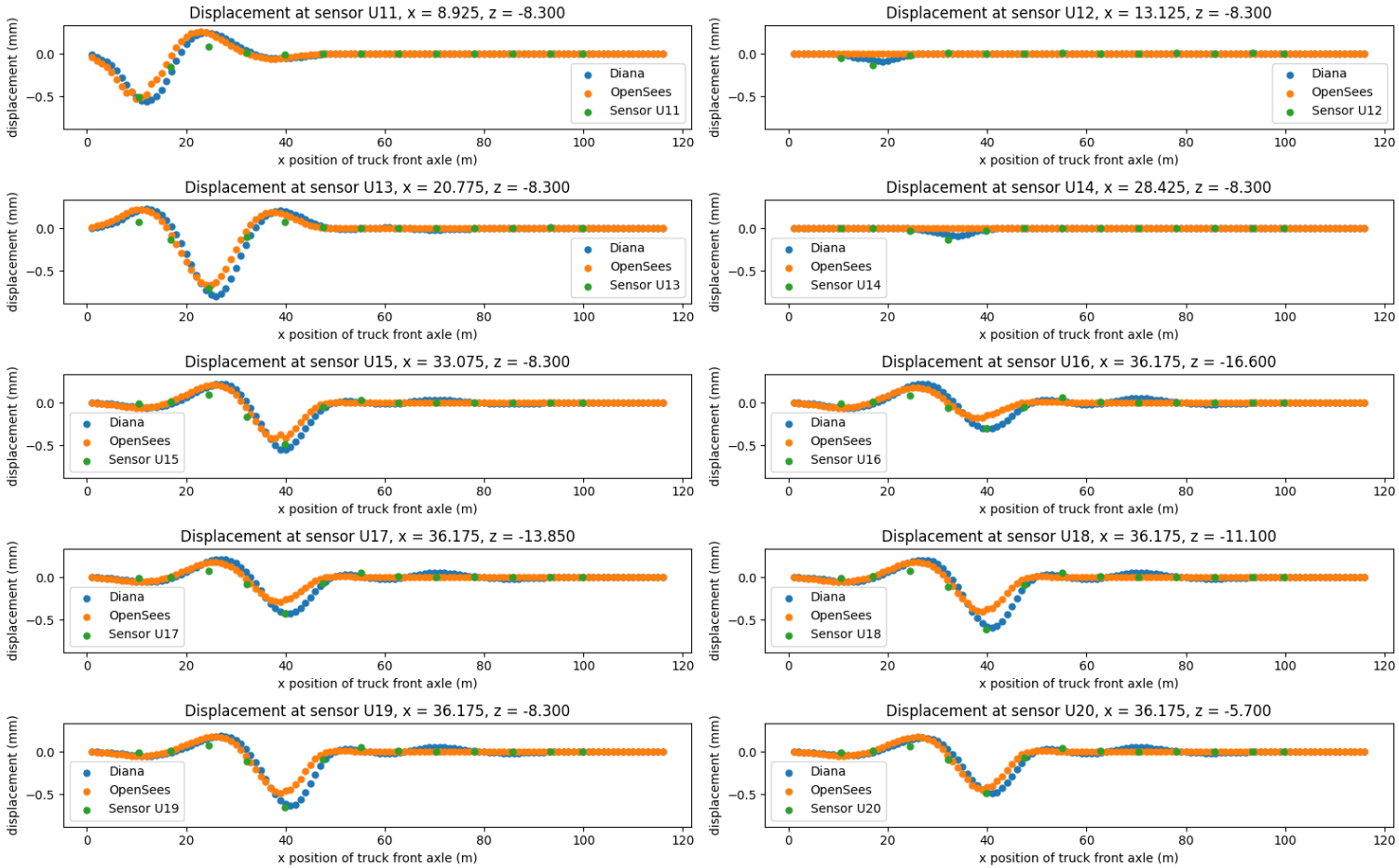
Validation: Displacement OpenSees



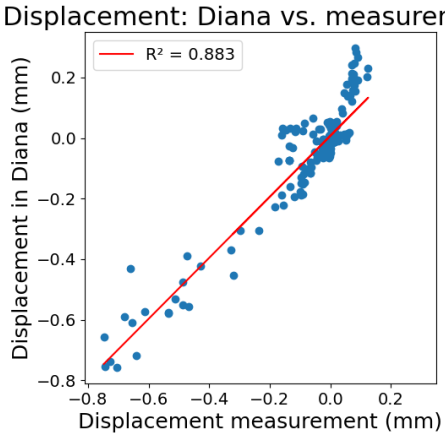
Validation: Displacement

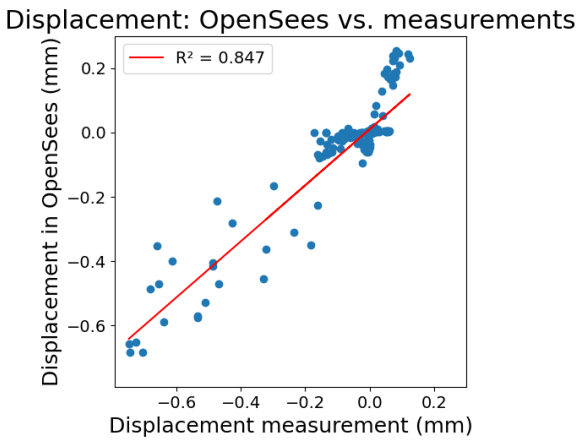


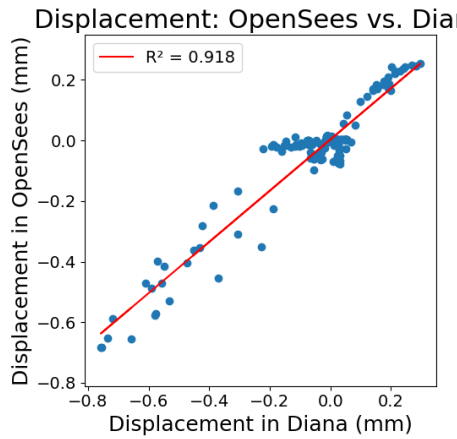
Validation: Displacement



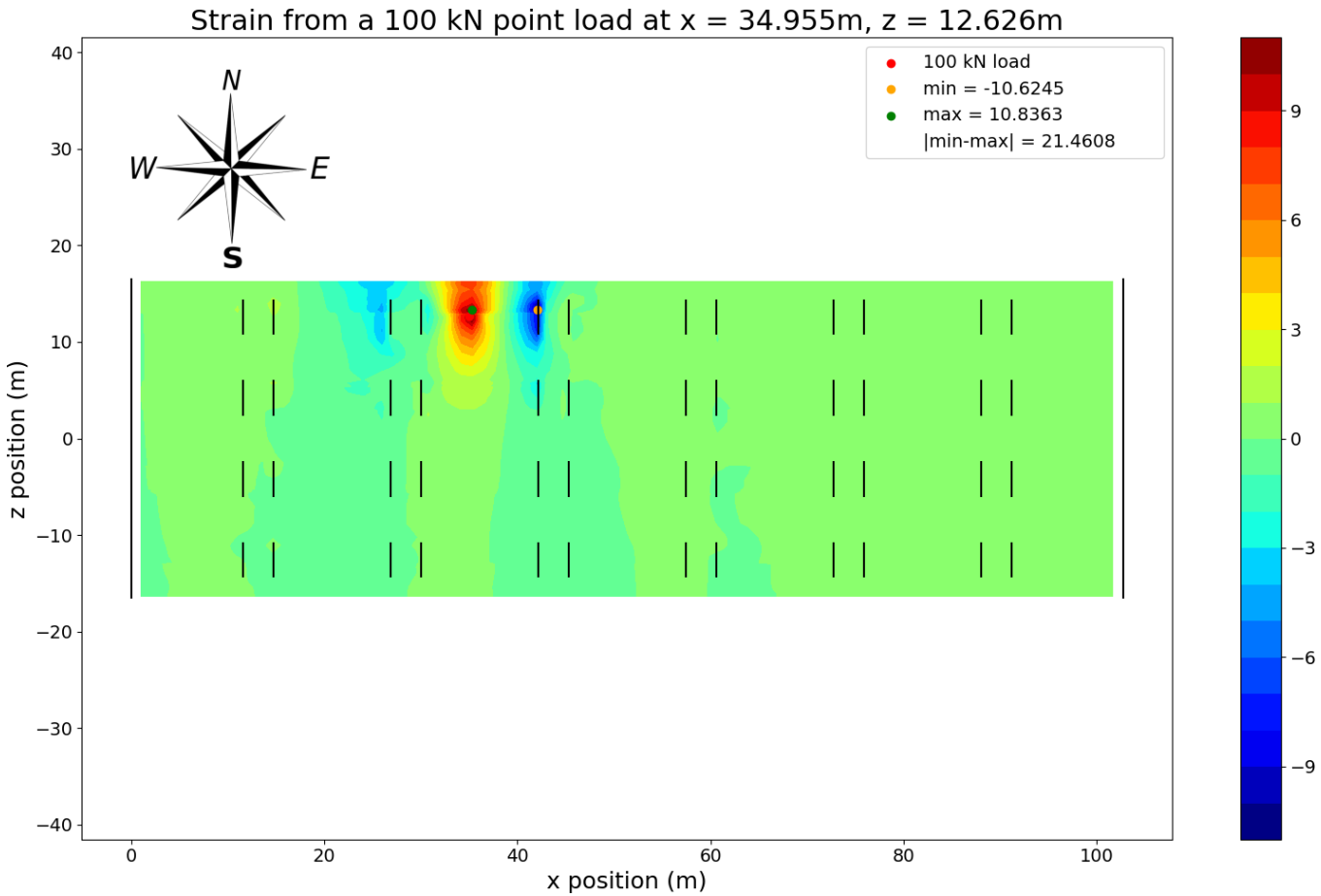
Validation: Displacement



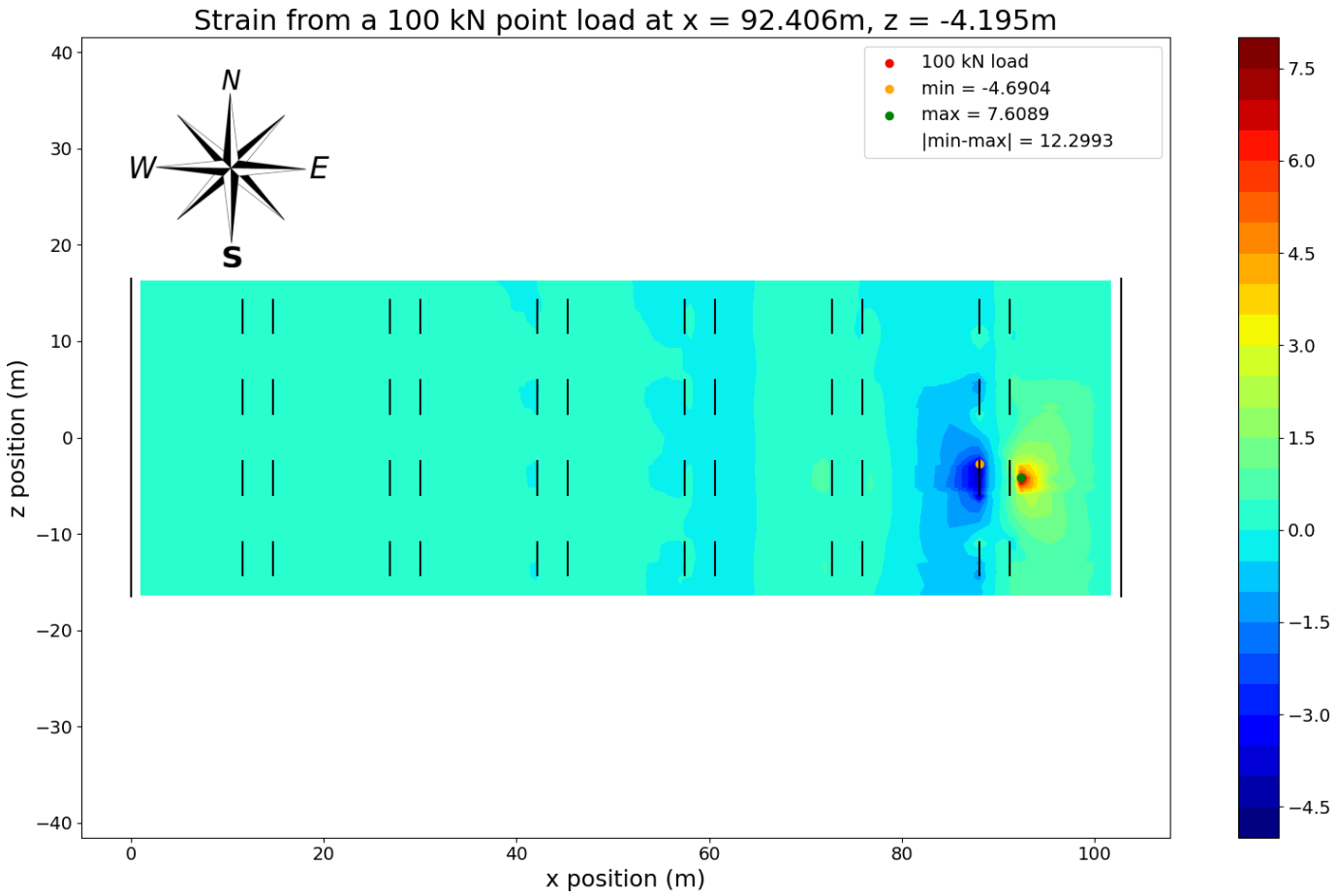




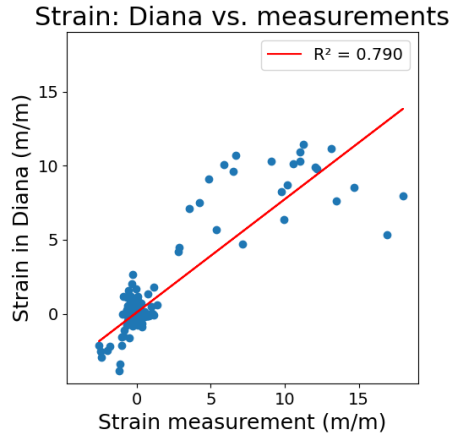
Validation Strain: OpenSees

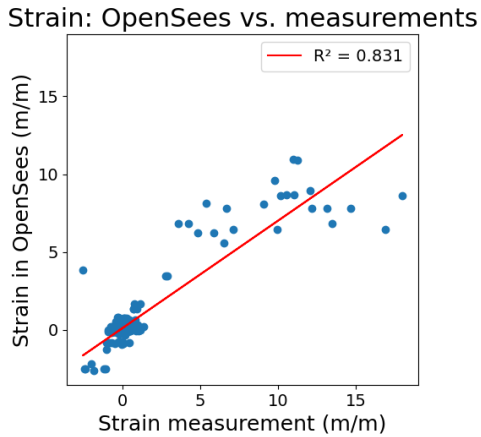


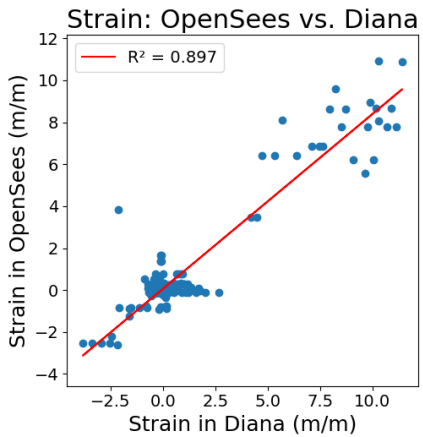
Validation Strain: OpenSees



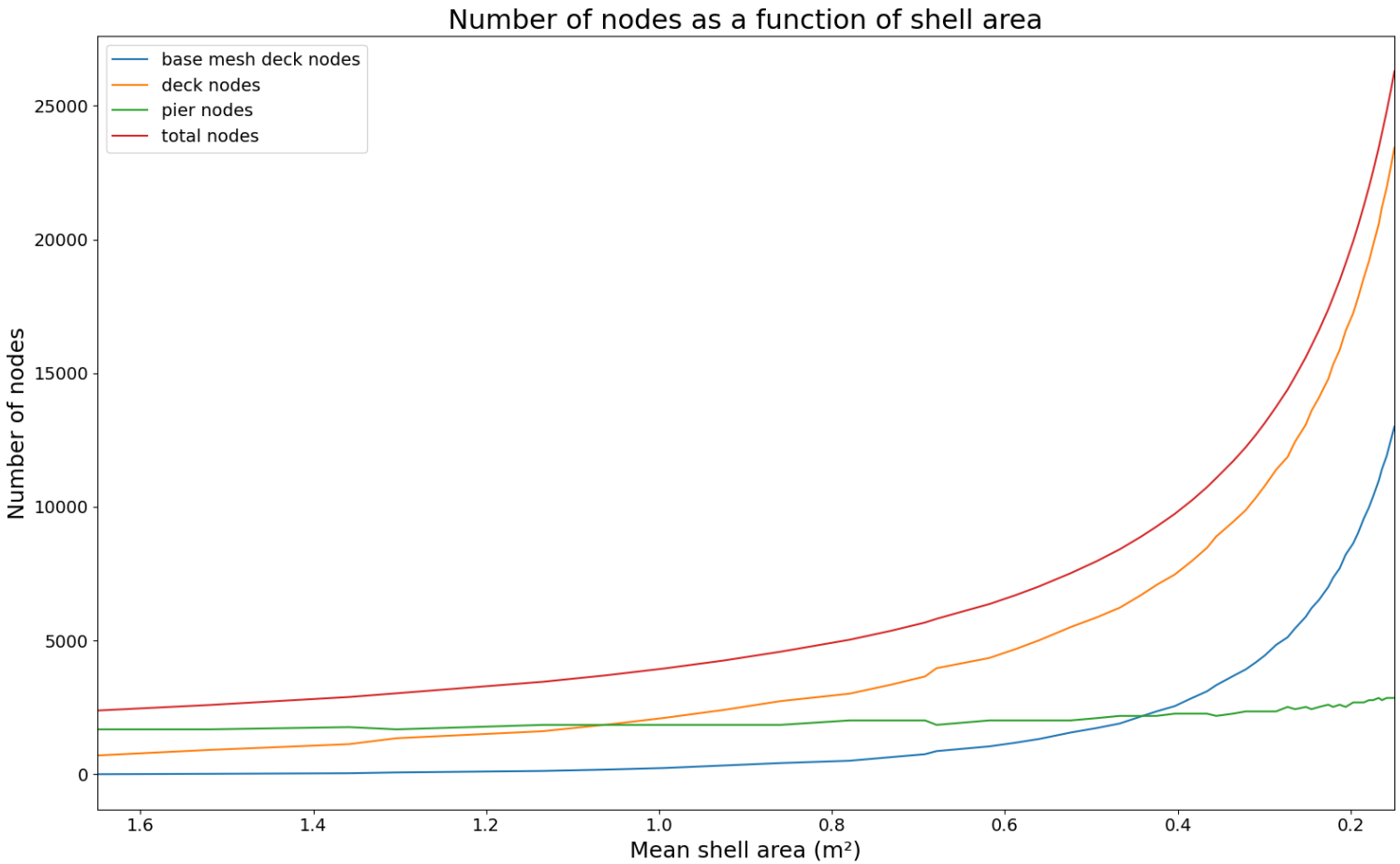
Validation: Strain



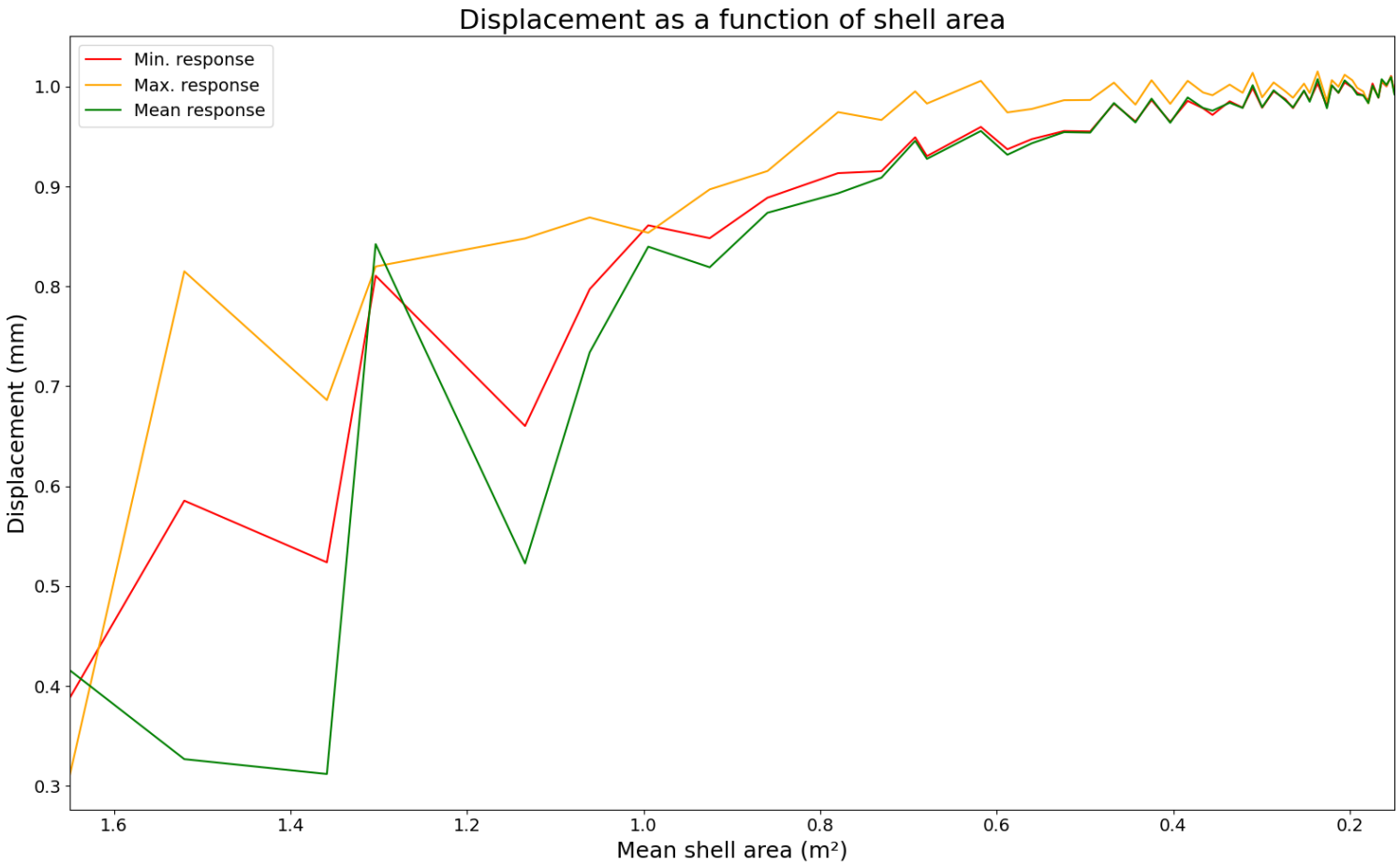




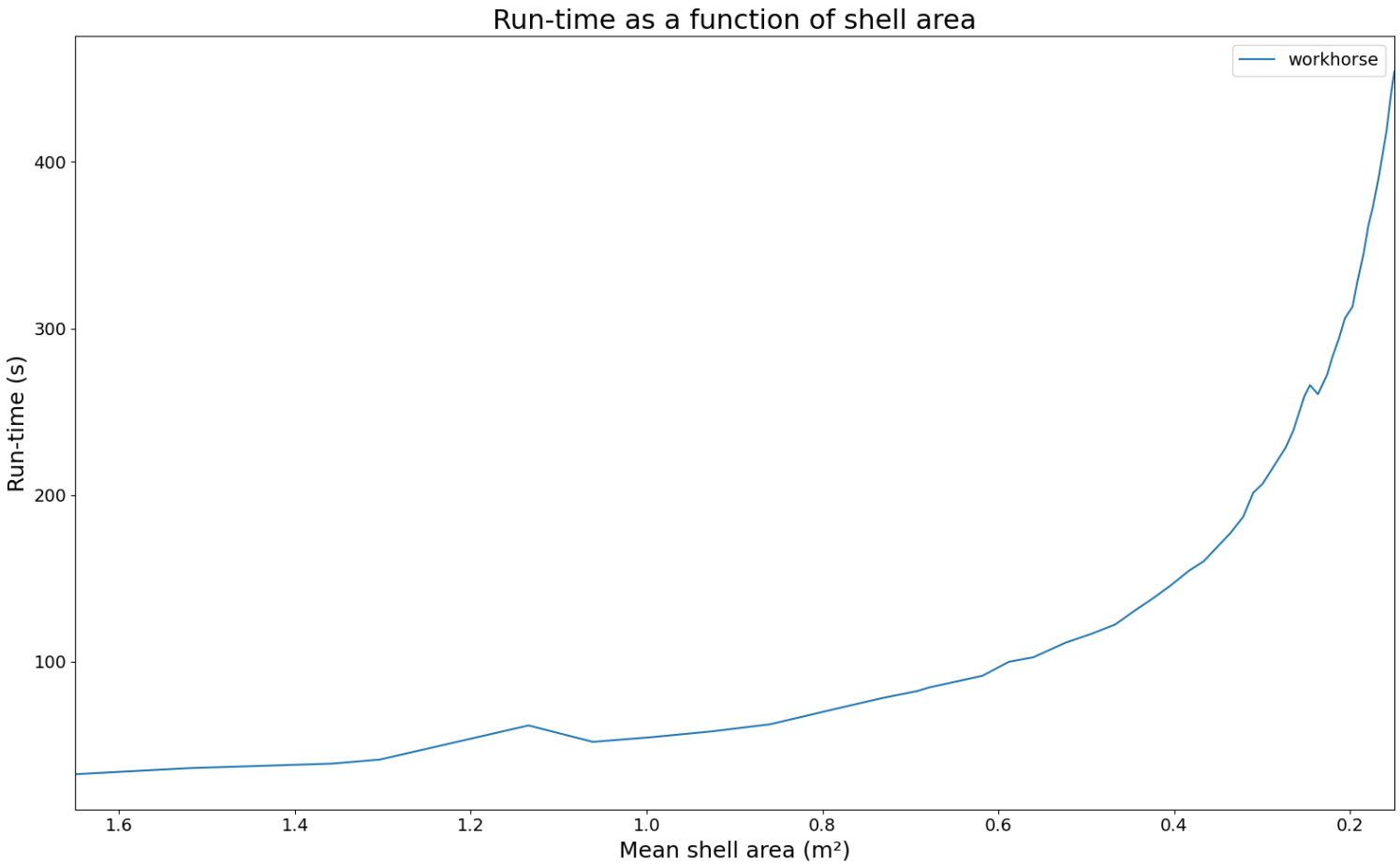
Model size


Number of nodes as a function of shell area
base mesh deck nodes
deck nodes
pier nodes
total nodes
Number of nodes
25000
20000
15000
10000
5000
0
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Mean shell area (m²)

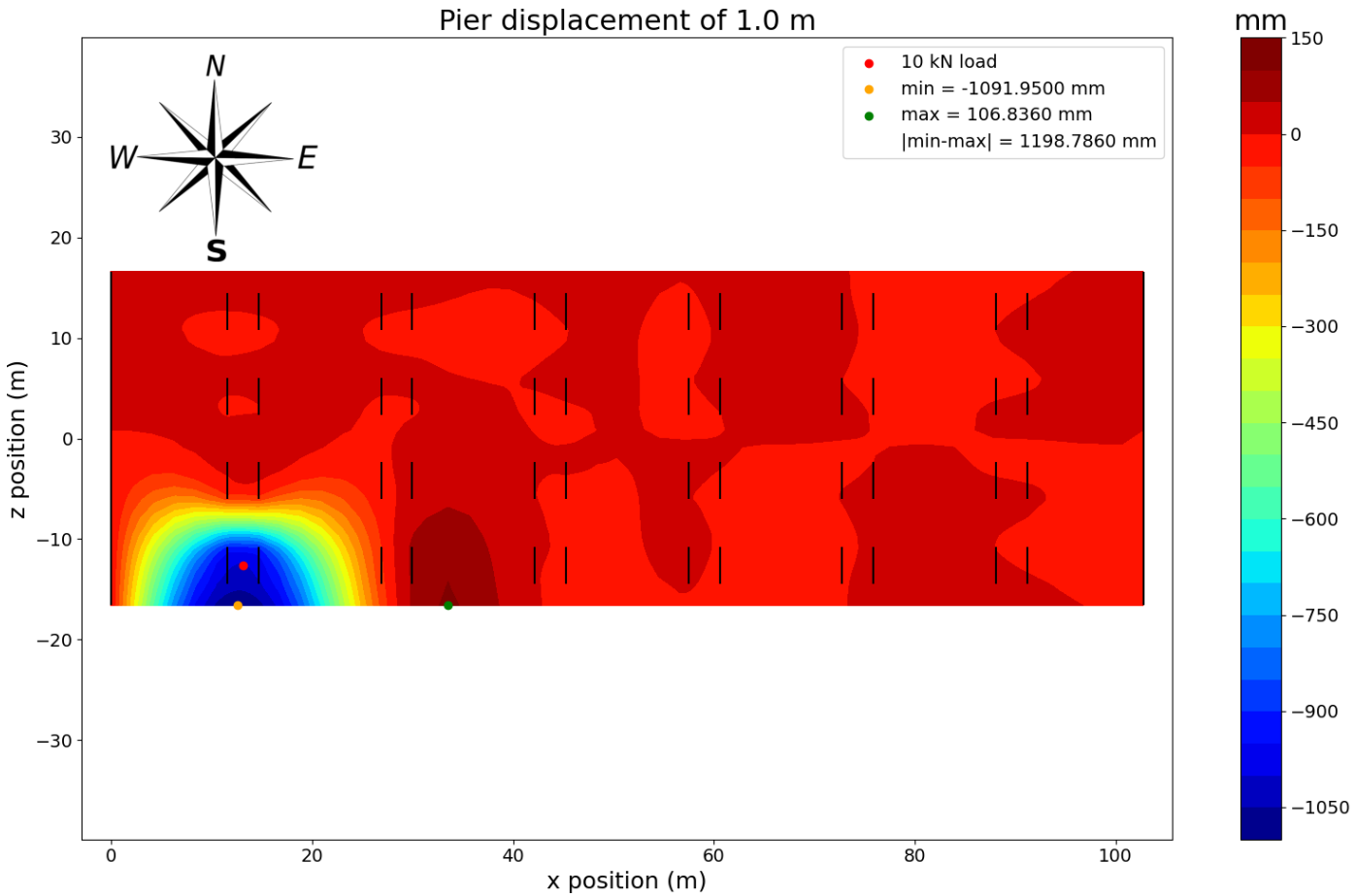
Model convergence



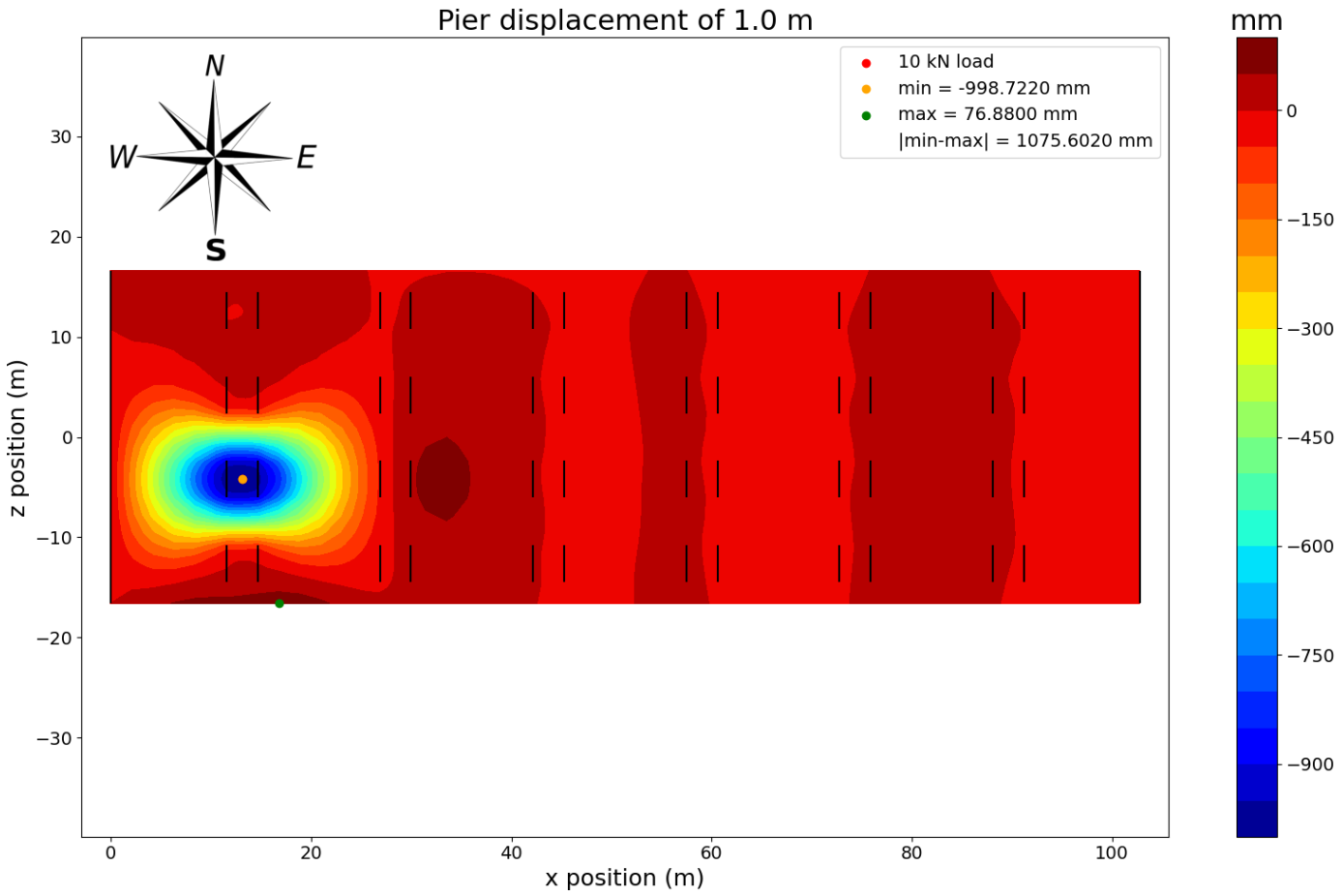
Model run-time



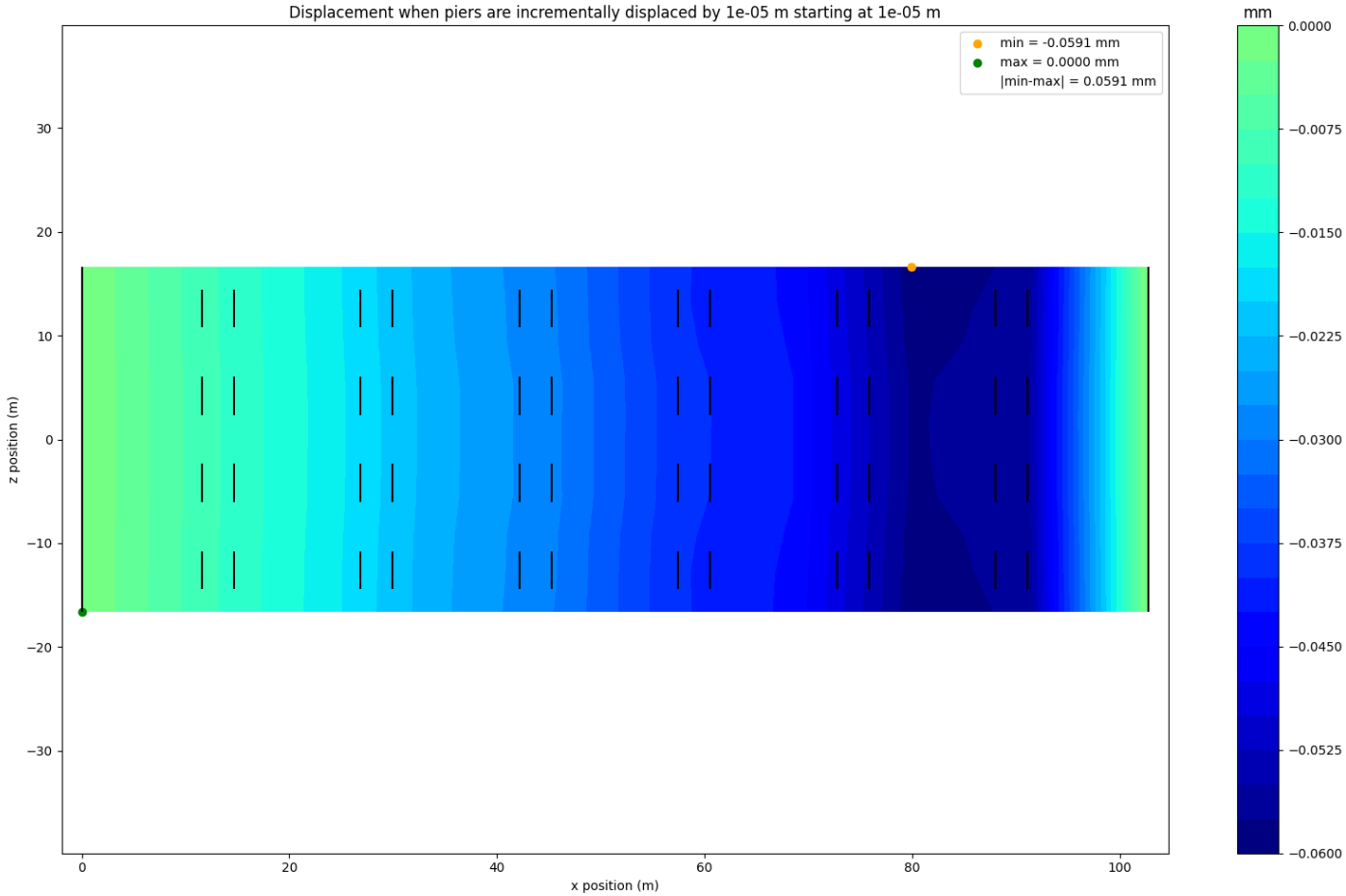
Pier Settlement



Pier Settlement

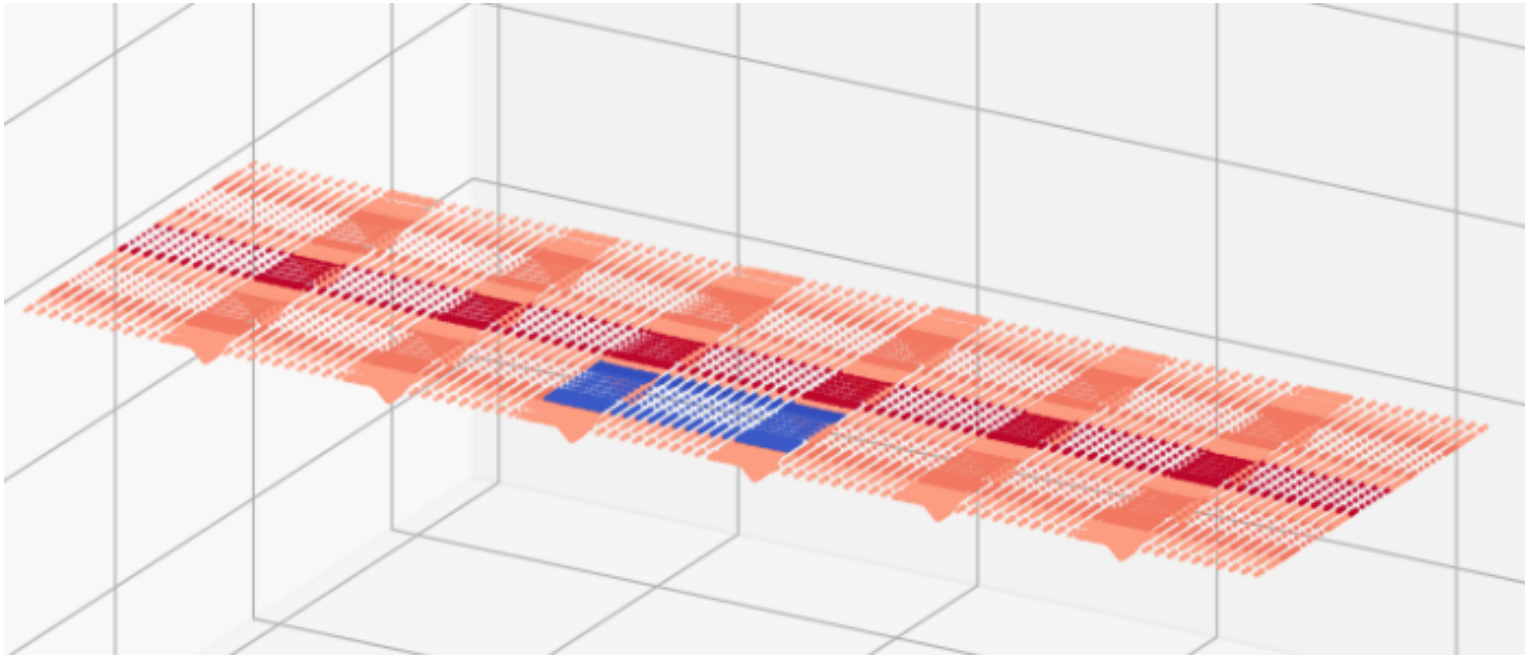


Pier Settlement

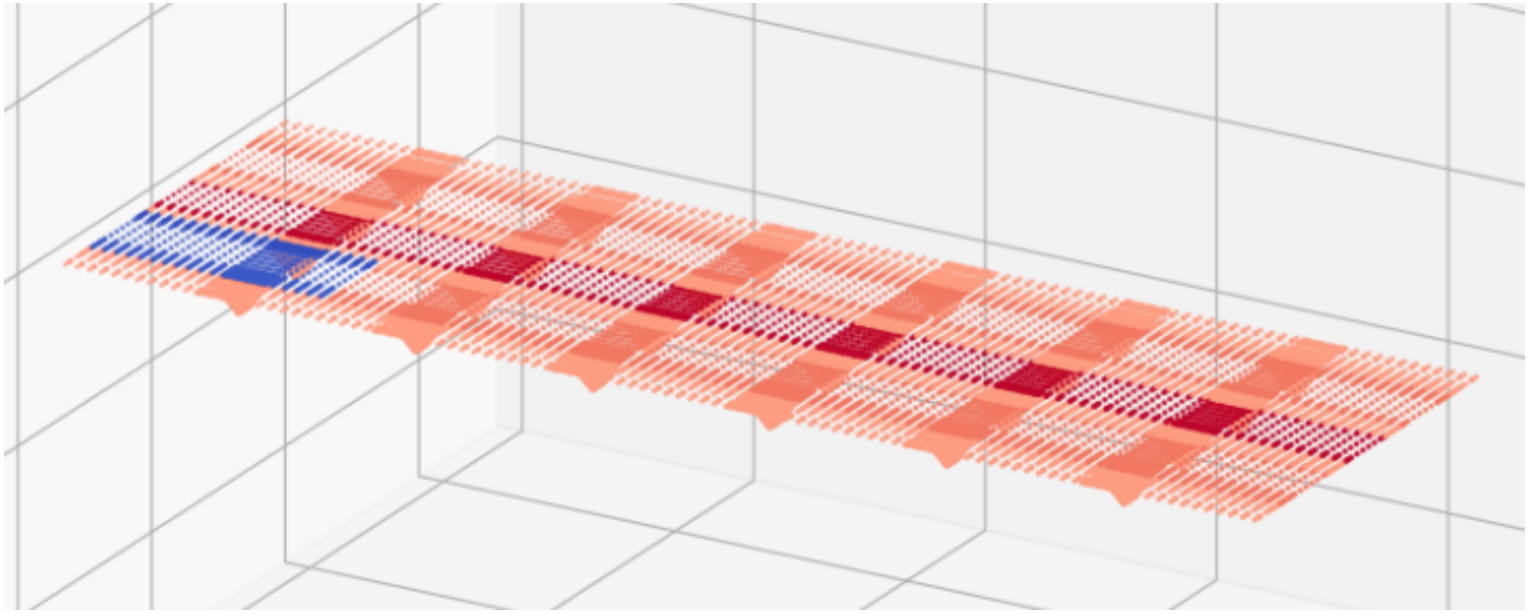


Crack Zone

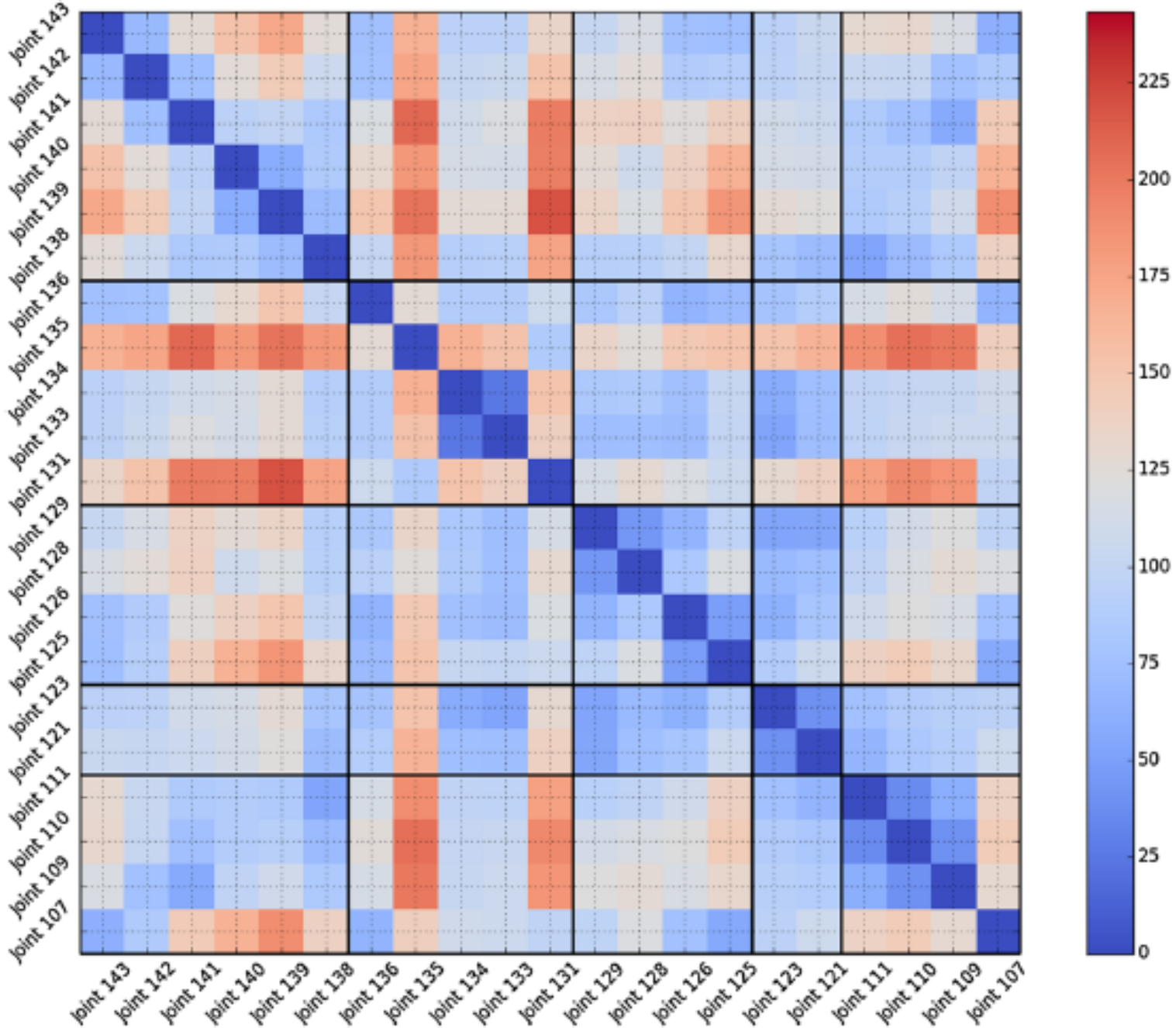
- Young's modulus *= 1/3



Crack Zone



Sydney Harbour Bridge

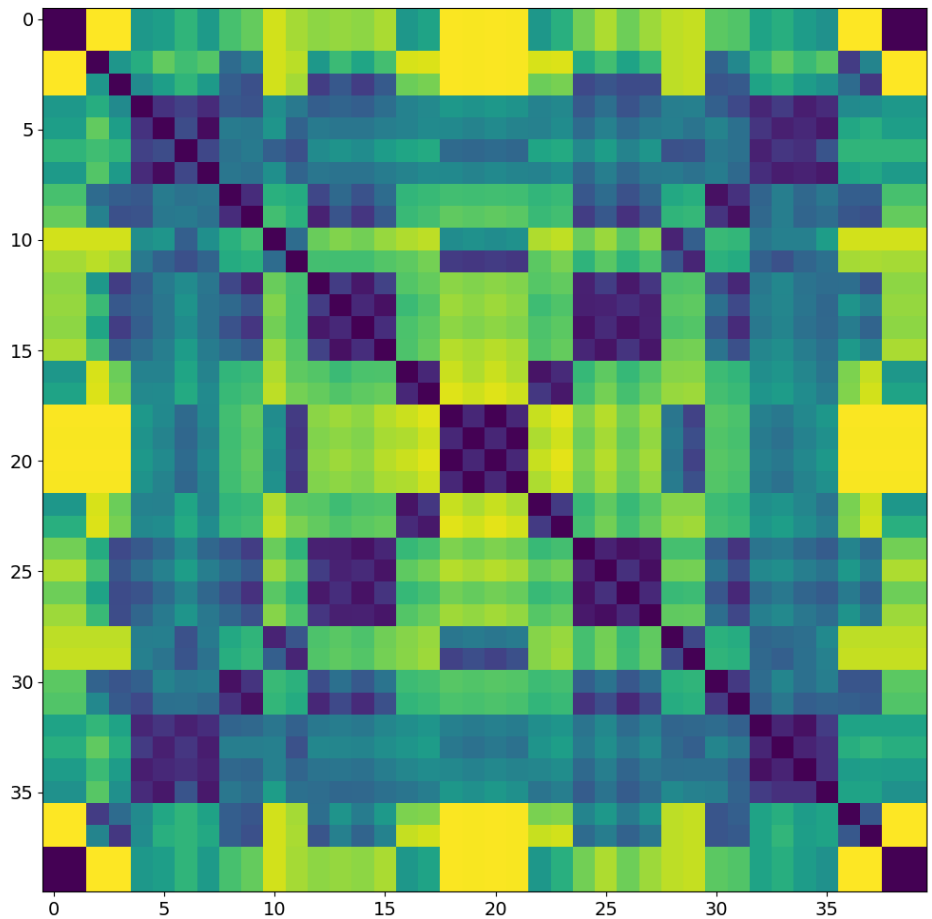


Baseline Detection

- "baseline" as in
  - compares to a previous baseline (snapshot)
  - baseline method to compare methods to

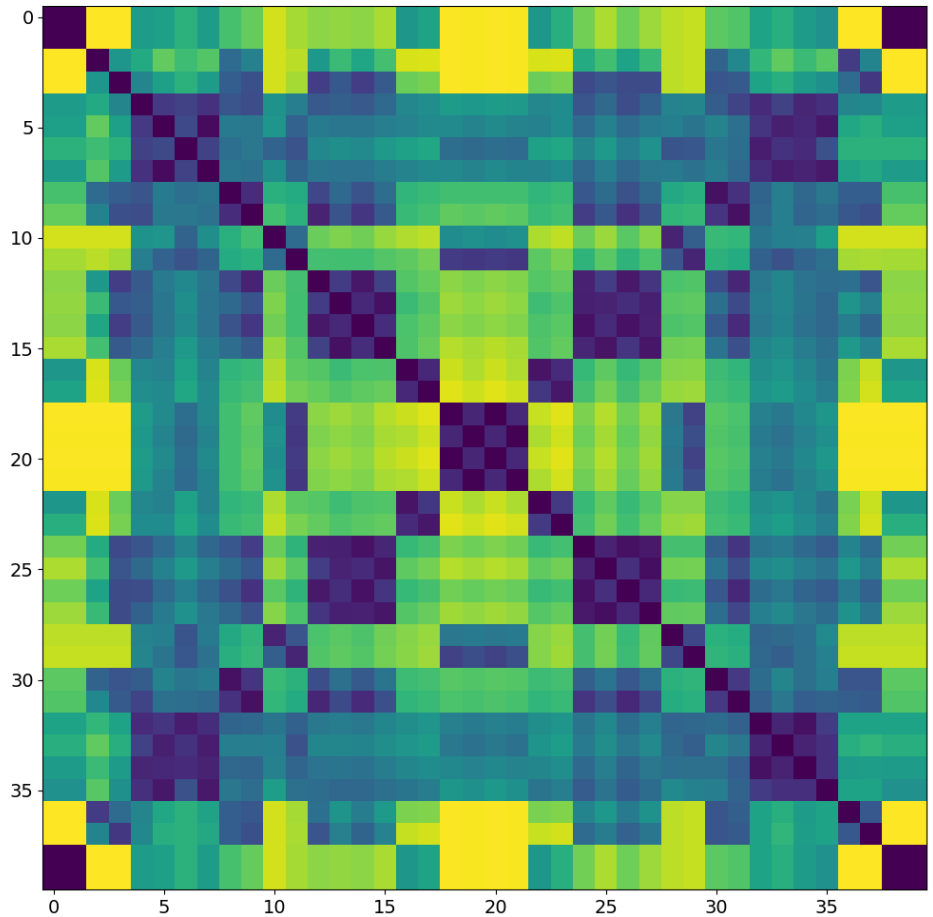
Baseline Detection

- at a point in time, record snapshot
- compare each sensor to each sensor: `C0_pi_pj`



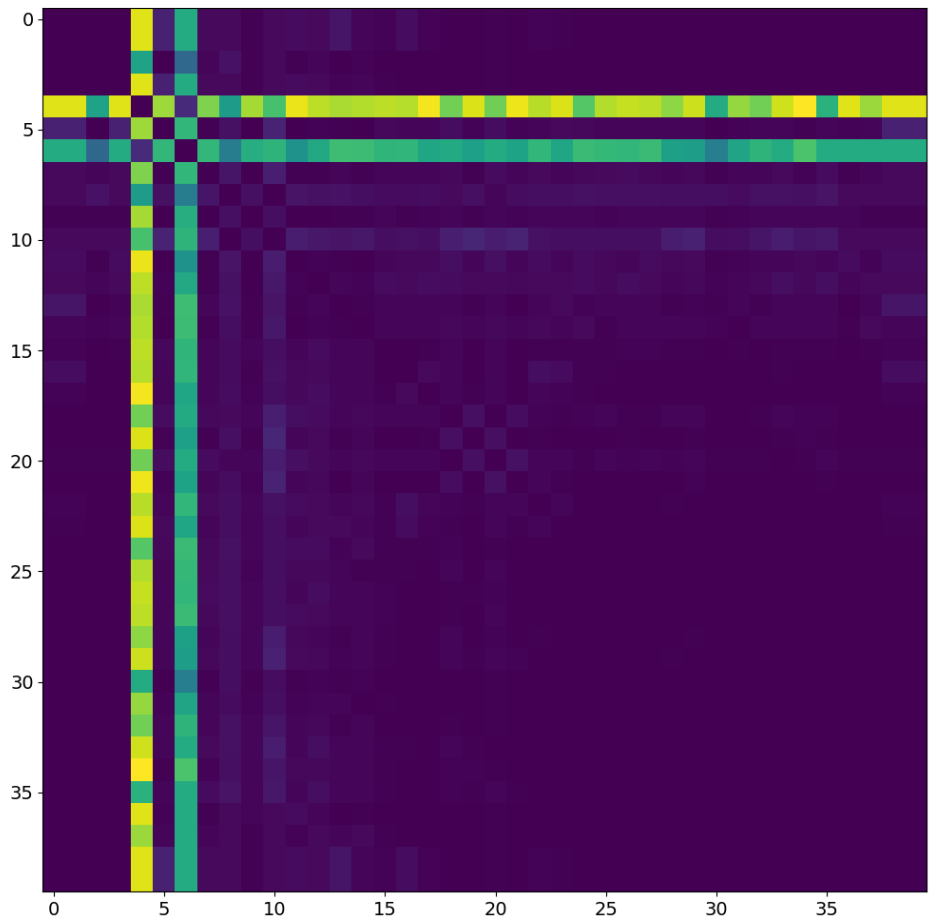
Baseline Detection

- at a later time
- compare each sensor to each sensor: `C1_pi_pj`



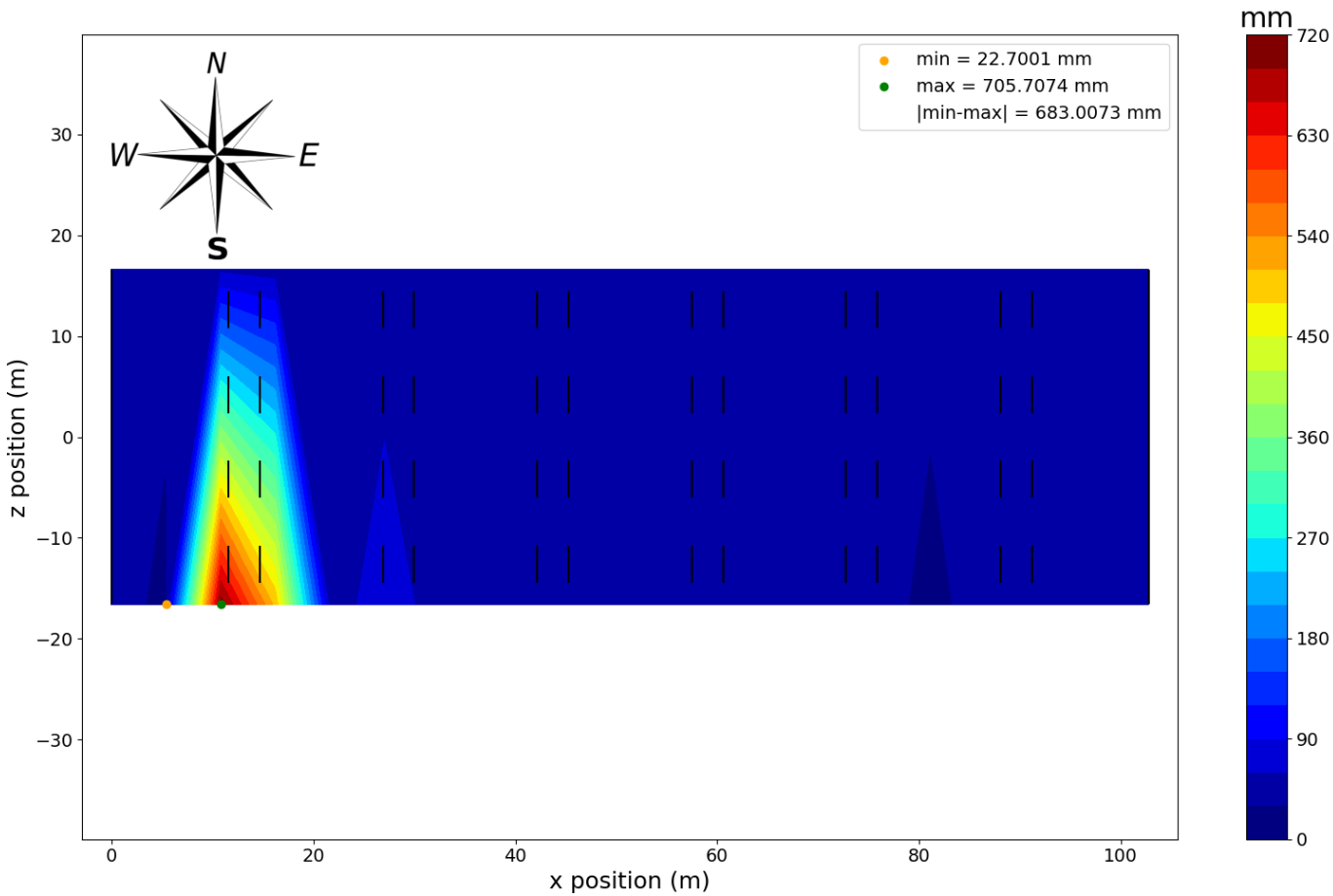
Baseline Detection

- determine difference between snapshots
- `D_pi_pj = | C0_pi_pj - C1_pi_pj |`



Baseline Detection

- map `D_pi_pj` to sensor positions



December - February

- December Remainder
  - Model agreement
  - Temperature in model
  - First ML-based damage experiment
- January/February
  - Further classification...

Questions for You

- Data on passenger vehicles?
  - Axles distances and weights
- Typical size and position of crack zones?
  - Concrete slab bridges
- Convinced by 5 variables for classification experiments?
  - vehicle loading
  - temperature load
  - pier settlement
  - cracked concrete
  - sensor noise
- What needs better explaining in this presentation?