

Fatigue Performance of Real-Scale Precast GFRP Reinforced Lightweight Concrete Arches

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Innovative precast arch elements with increased durability for infrastructure

POIR.02.03.02-22-0006/18

Project value: ~120 000 €



Rzeszow University
of Technology



Optem Sp. z o.o.

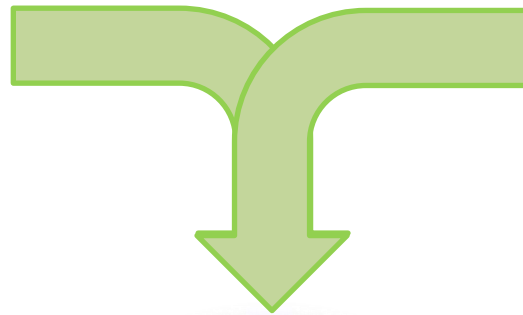


The idea of the project



Lightweight concrete

- 20% lower weight
- cheaper transport



GFRP rebars

- corrosion resistance
- high durability
- lightweight
- high tensile strength
- magnetic transparency
- electrical indifference



Precast arch bridge

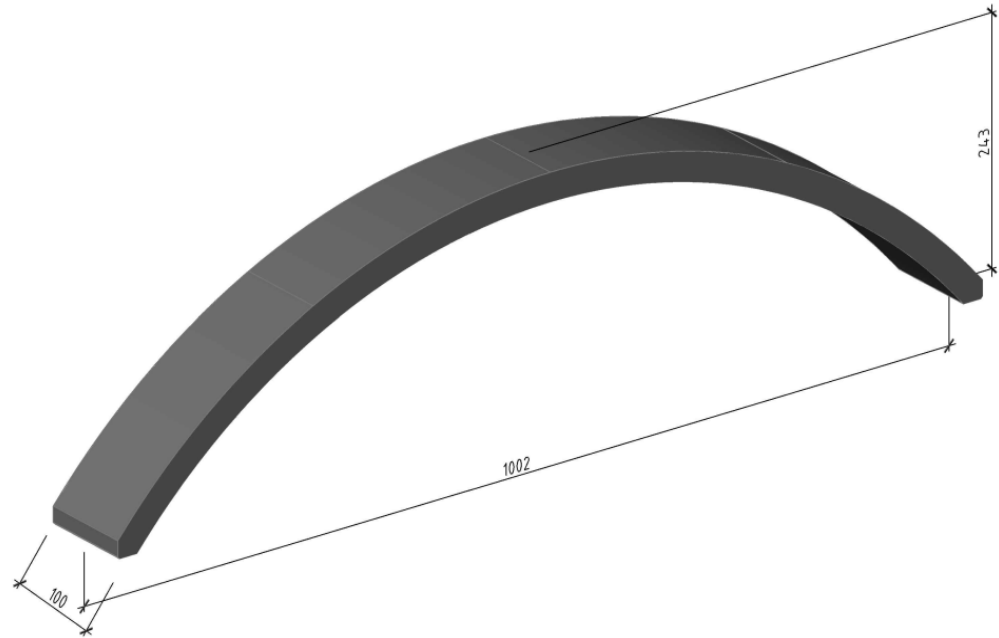
More durable, less-weight and cheaper in maintaince



Models characteristics

Geometry:

- Length: 10.0 m (33 ft)
- Width: 1.0 m (3.3 ft)
- Height: 2.4 m (7.9 ft)



Main parameters:

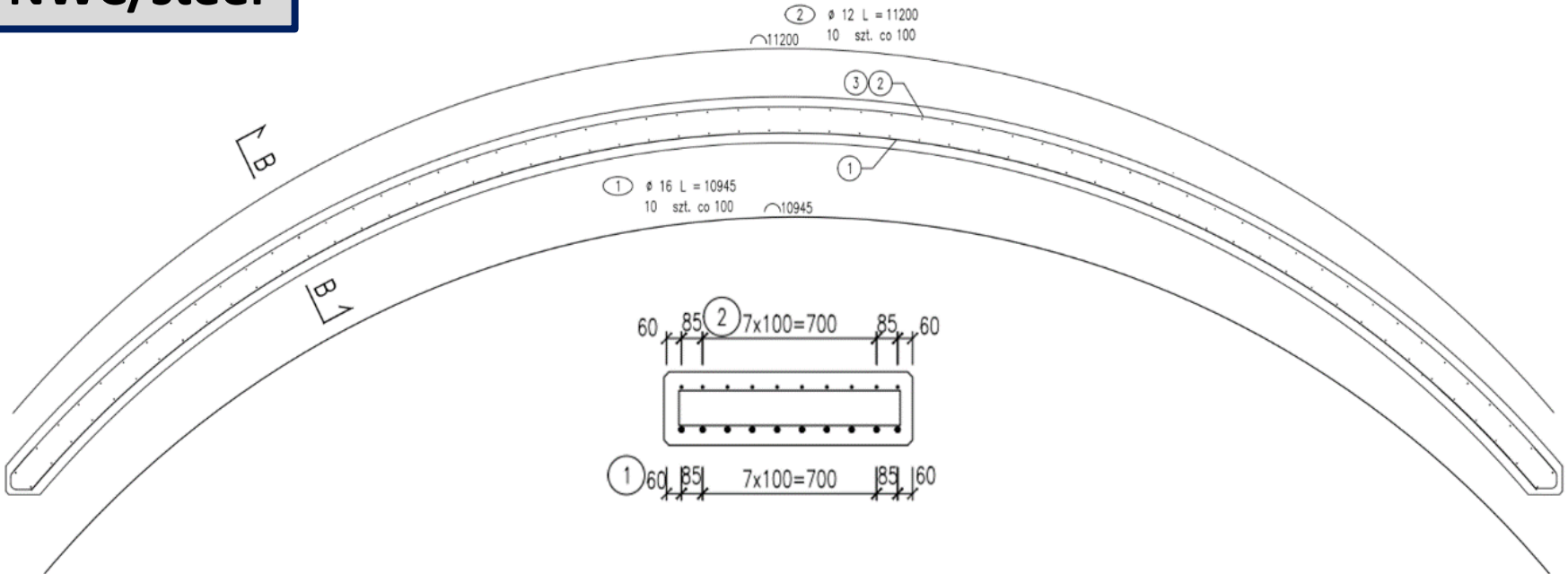
| Model | Concrete | Reinforcement | Test type | |
|-------------------|---------------------|-----------------|-----------|---------|
| | | | Static | Fatigue |
| NWC/steel | normal C70/85 | steel BSt-500-S | ✓ | ✓ |
| LWC/GFRP/S | lightweight LC60/66 | GFRP, 1100 MPa | ✓ | |
| LWC/GFRP/F | lightweight LC55/60 | GFRP, 1100 MPa | | ✓ |

(173 ksi)



Reinforcement

NWC/steel



Longitudinal reinforcement:

- bottom: 10 $\phi 16$ mm (5/8 in.)
- top: 10 $\phi 12$ mm (1/2 in.)

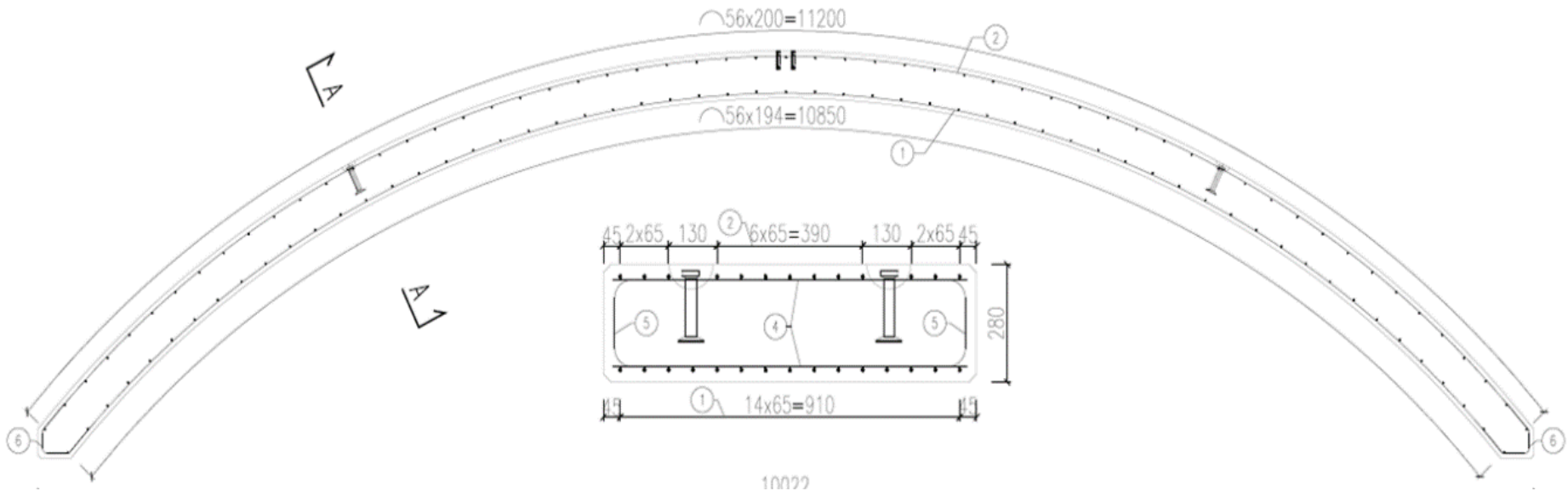
Shear reinforcement:

- stirrups: $\phi 10$ mm (3/8 in.)
in spacing 200 mm (7.9 in.)



Reinforcement

LWC/GFRP



Longitudinal reinforcement:

- bottom: 15 $\phi 8$ mm (5/16 in.)
- top: 13 $\phi 8$ mm (5/16 in.)

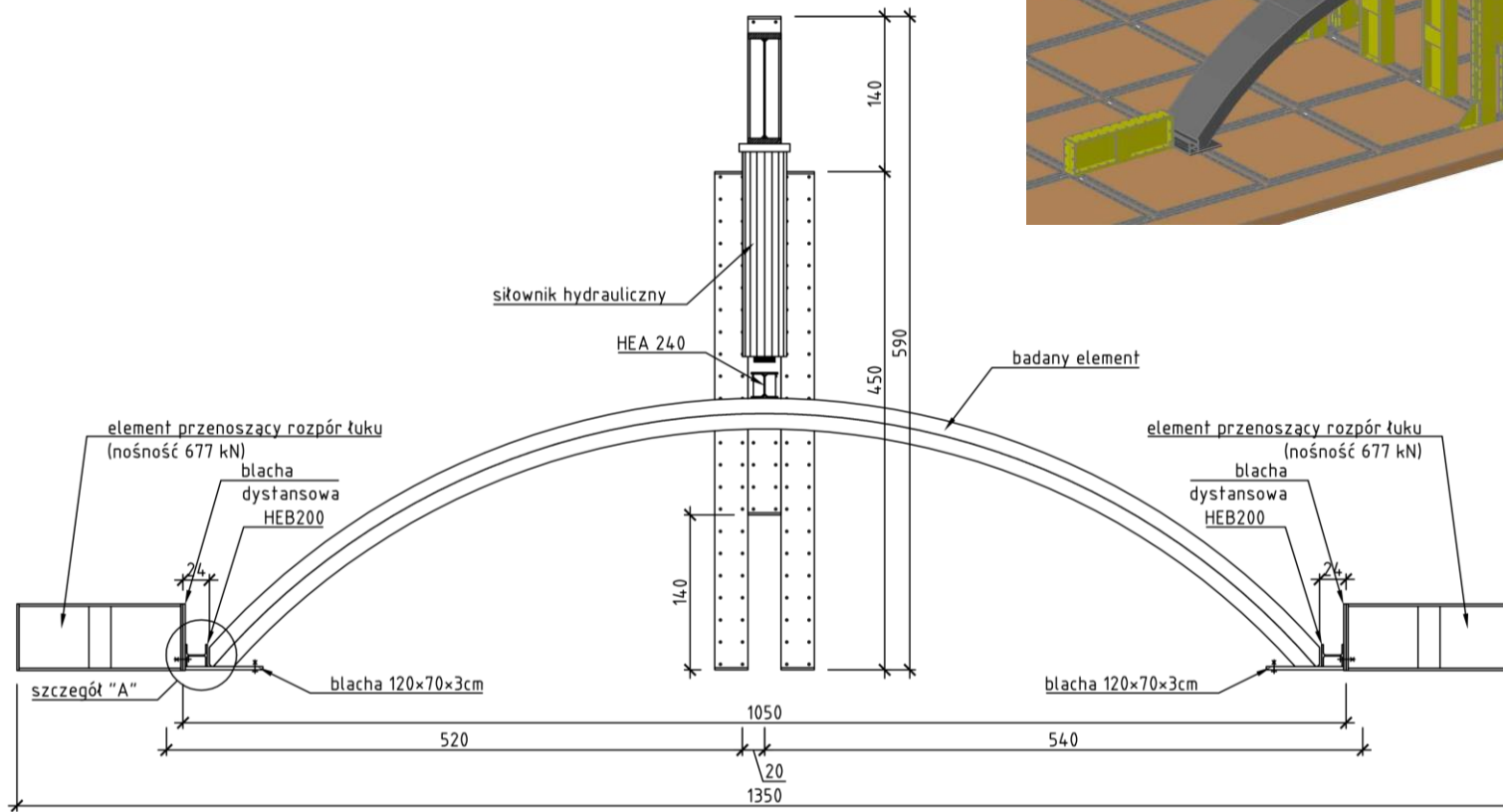
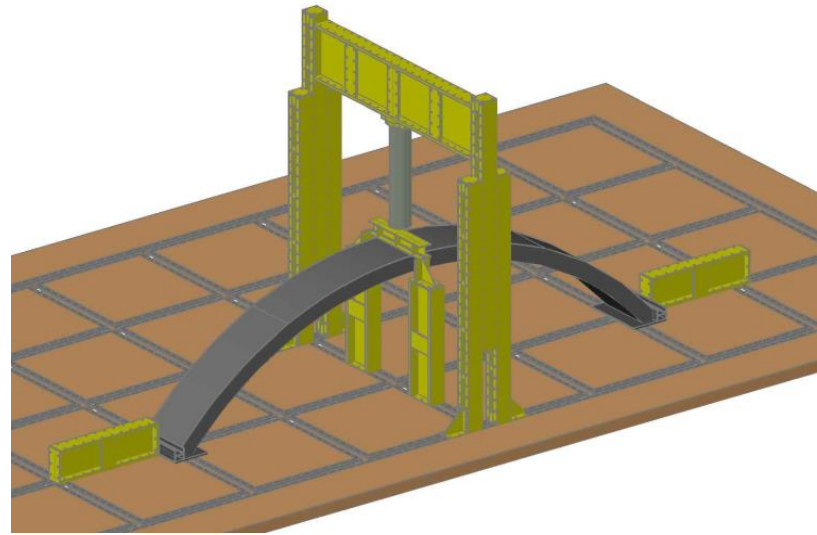
Shear reinforcement:

- stirrups: $\phi 8$ mm (5/16 in.)
in spacing 200 mm (7.9 in.)



Test setup

- Three-point bending loading scheme
- Two-hinged arch static scheme
- Maximum static load: 630 kN (142 kip)
- Maximum fatigue load: 120 kN (27 kip)

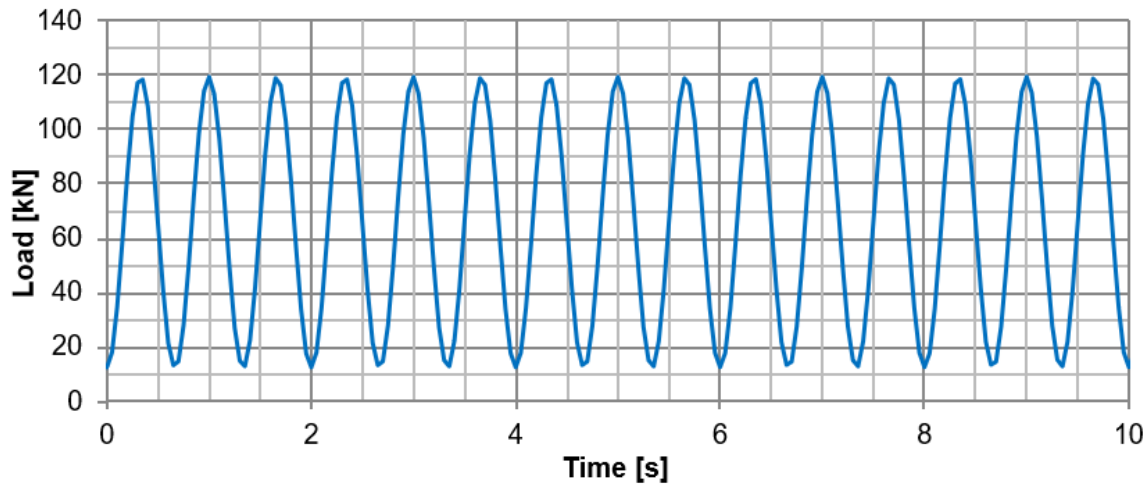
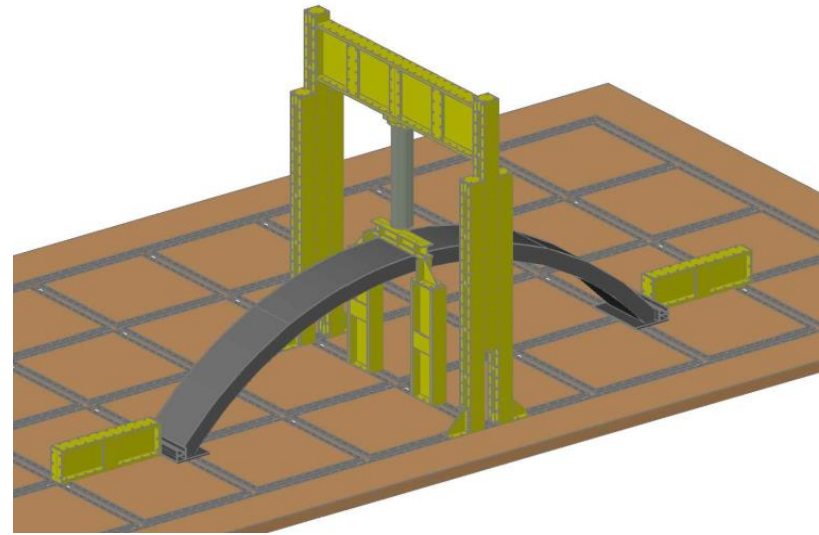




Test setup

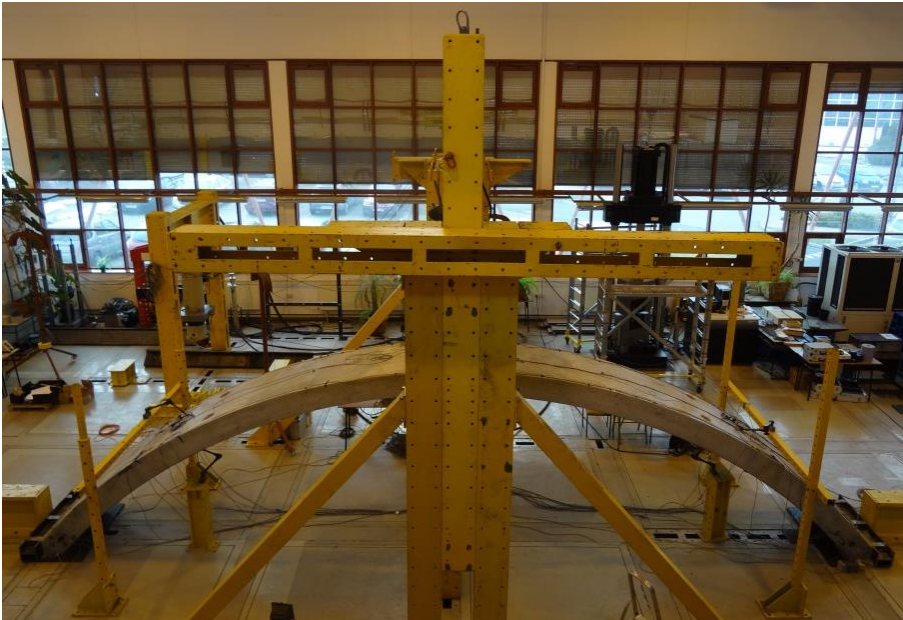
Fatigue load details:

- Load type: sinusoidal variable
- Minimum load: 12 kN (2.7 kip)
- Maximum load: 120 kN (27 kip)
- Load ratio: $R=0,1$
- Frequency: 1.5 Hz





Test setup





Measurements

Displacements:

- vertical in $L/2$,
- vertical in $L/6$,
- horizontal in $L/6$,
- horizontal of supports.

Strains of rebars (top and bottom):

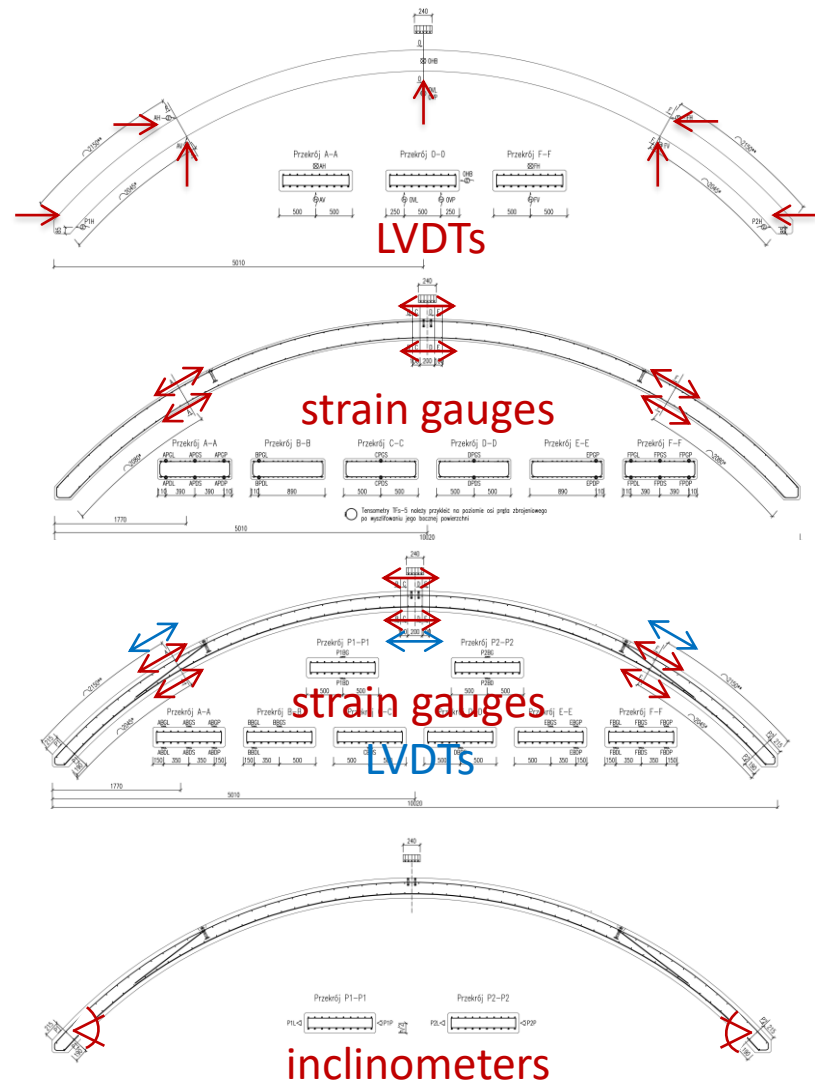
- longitudinal in $L/2$,
- longitudinal in $L/6$.

Concrete strains (top and bottom):

- longitudinal in $L/2$,
- longitudinal in $L/6$.

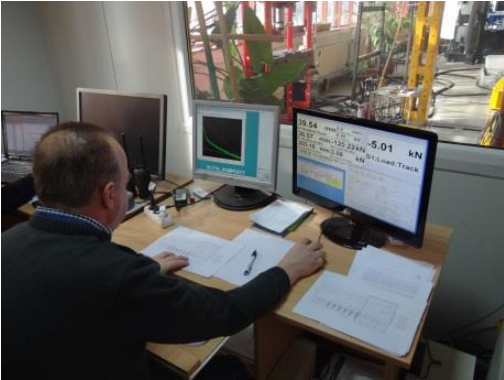
Rotation angles:

- on supports.



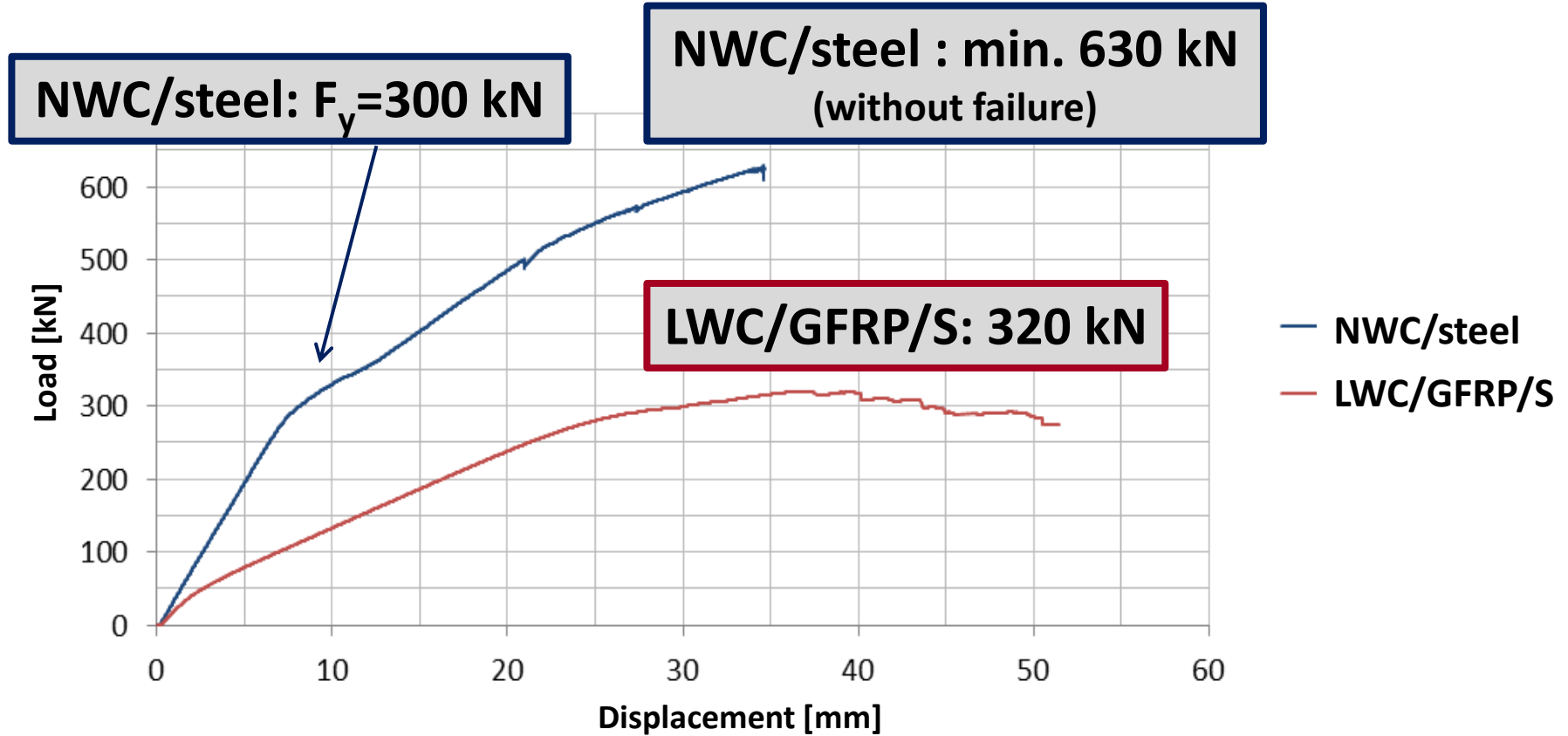


Measurements





Main results of static tests





Failure mode

LWC/GFRP/S



Crack initiation in L/2



Crack after concrete cover failure



Failure detail

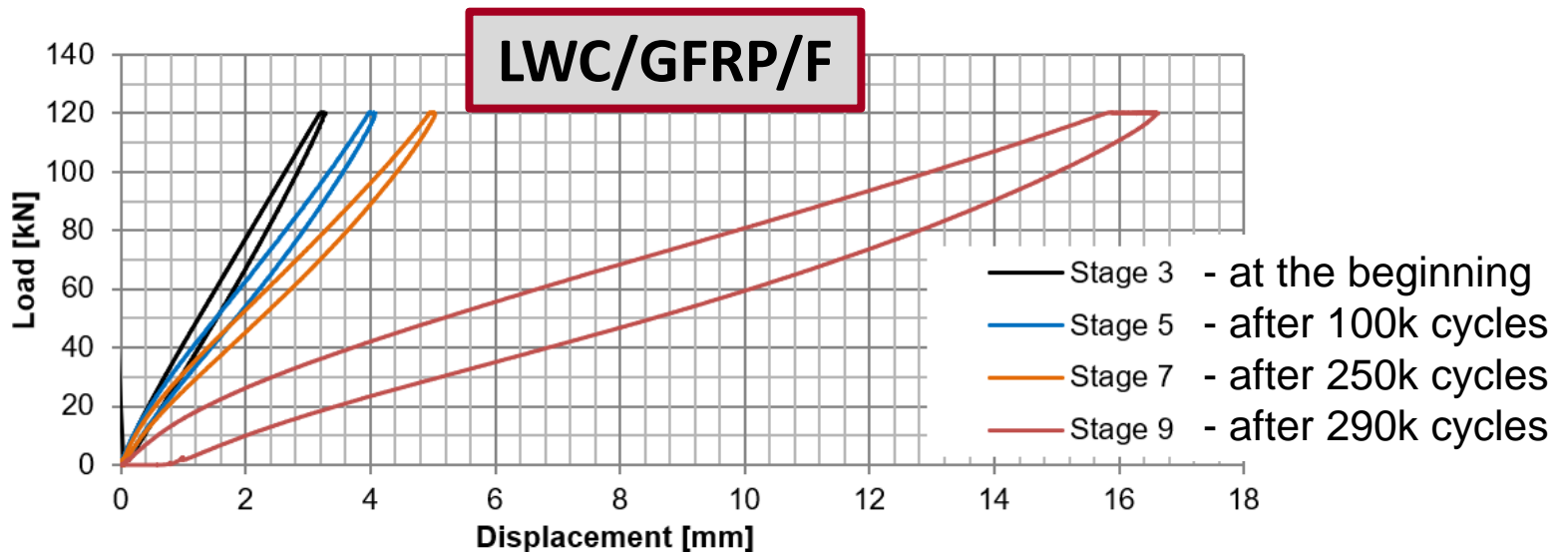
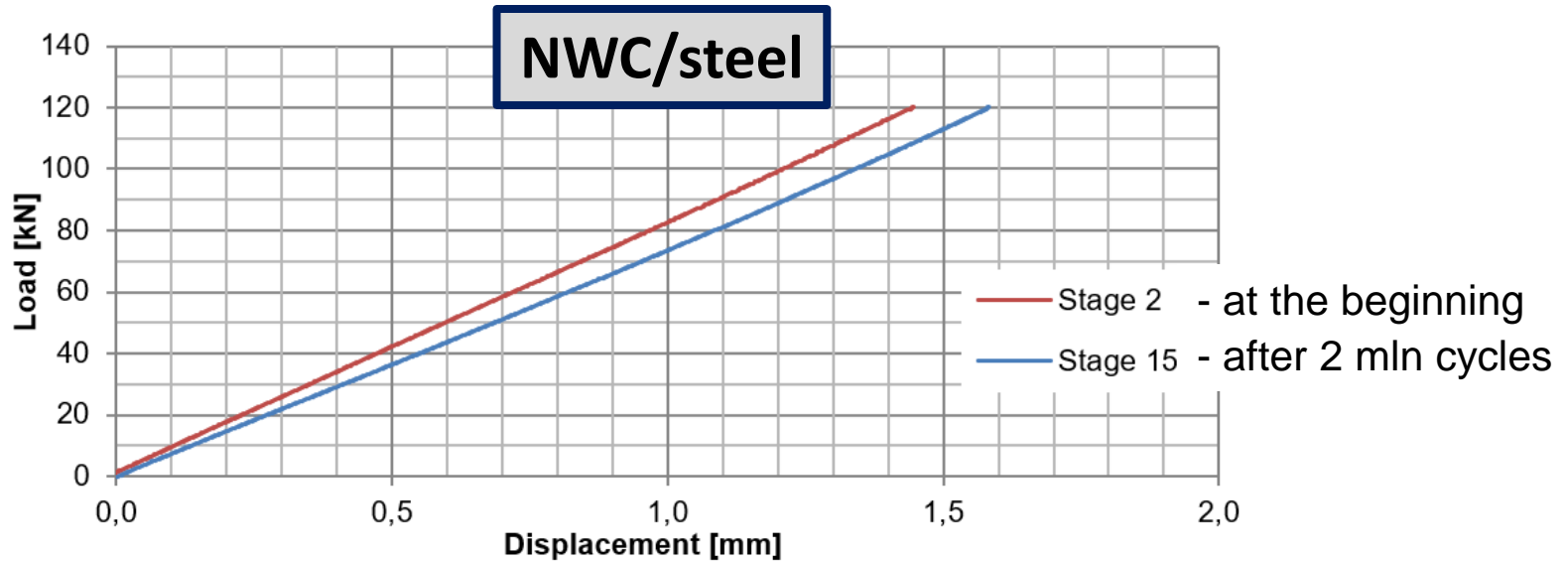


Element after failure



Results of fatigue tests

Displacements (midspan):



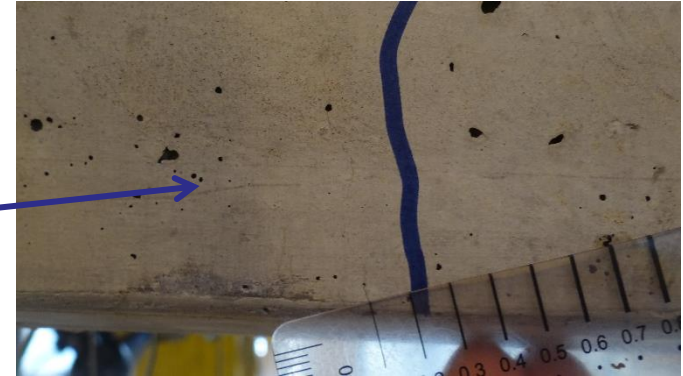


Results of fatigue tests

Cracking:

NWC/steel

| Stage | Load | Cycles | Crack width in L/2 |
|-------|------|-------------|--------------------|
| | [kN] | [-] | [mm] |
| 1 | 40 | 0 | - |
| 3-15 | 120 | 0 - 2 mln | 0.05 - 0.10 |
| 17 | 180 | after 2 mln | 0.10 – 0.15 |
| 19 | 240 | after 2 mln | 0.15 |
| 20 | 270 | after 2 mln | 0.20 |



LWC/GFRP/F

| Stage | Load | Cycles | Crack width in L/2 |
|-------|------|--------|--------------------|
| | [kN] | [-] | [mm] |
| 1 | 40 | 0 | 0.1 |
| 3 | 120 | 0 | 0.5 |
| 5 | 120 | 100k | 0.6 |
| 7 | 120 | 250k | 1.0 |
| 9 | 120 | 290k | 8.0 |
| 9 | 0 | 290k | 8.0 |



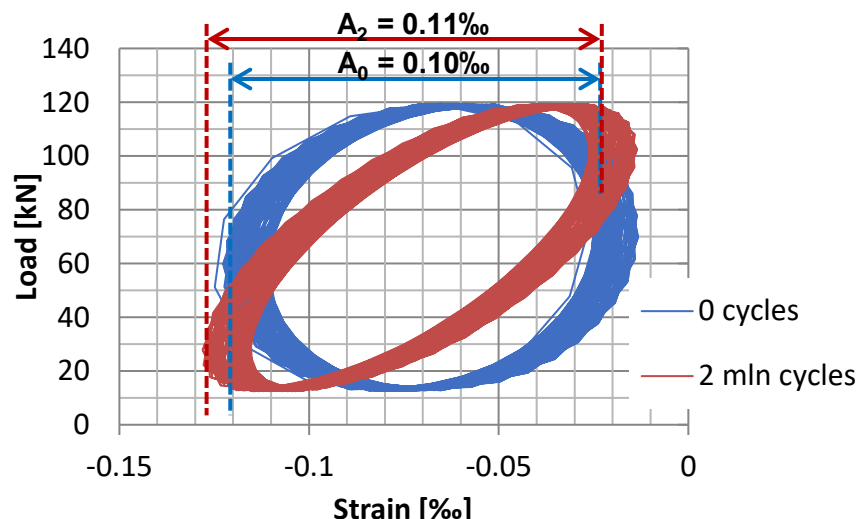
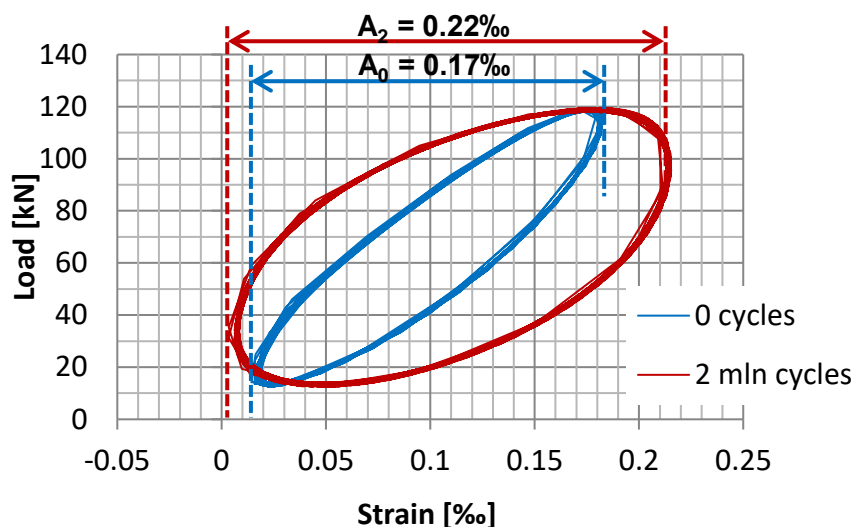


Results of fatigue tests

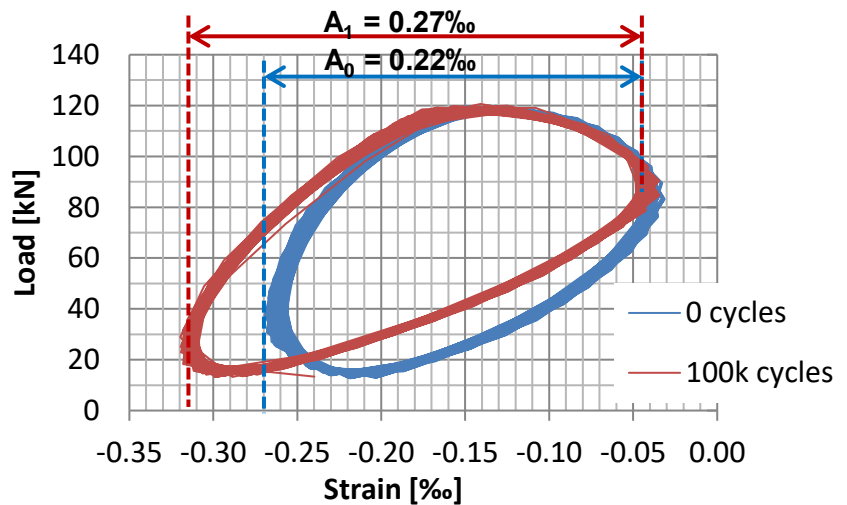
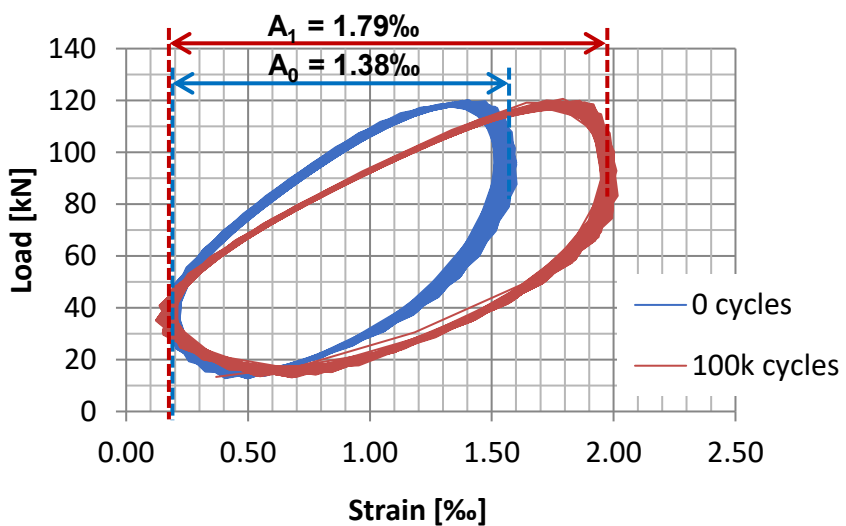
Strains of the rebars:

Concrete strains:

NWC/steel



LWC/GFRP/F





Results of fatigue tests - summary

Displacements:

| Cycles | Vertical displacement in L/2 | | | Vertical displacement in L/6 | | |
|--------|------------------------------|----------|-------------|------------------------------|----------|-------------|
| | NWC [mm] | LWC [mm] | LWC/NWC [-] | NWC [mm] | LWC [mm] | LWC/NWC [-] |
| 0 | 1,29 | 2,91 | 2,3 | 0,15 | 0,88 | 5,8 |
| 100k | 1,33 | 3,65 | 2,8 | 0,16 | 1,50 | 9,6 |
| 250k | | | | | | 11,8 |

NWC/steel: 2 mln cycles without failure

Strain

| Cycles | L/2 | | | L/6 | | |
|--------|---------|---------|-------------|---------|---------|-------------|
| | NWC [‰] | LWC [‰] | LWC/NWC [-] | NWC [‰] | LWC [‰] | LWC/NWC [-] |
| 0 | 0,14 | 1,71 | 12,2 | 0,06 | 0,05 | 0,8 |
| 100k | 0,17 | 1,90 | 10,9 | 0,06 | 0,10 | 1,8 |
| 250k | | | | | | 8,5 |

LWC/GFRP/F: failure after 390 000 cycles

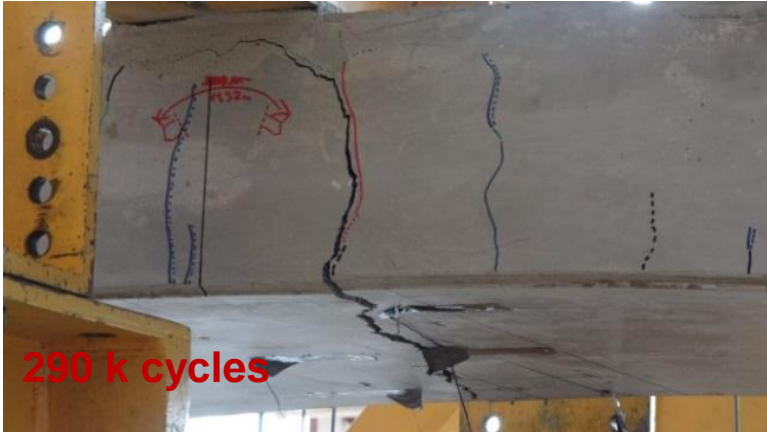
Concr

| Cycles | L/2 | | | L/6 | | |
|--------|---------|---------|-------------|---------|---------|-------------|
| | NWC [‰] | LWC [‰] | LWC/NWC [-] | NWC [‰] | LWC [‰] | LWC/NWC [-] |
| 0 | 0,12 | 0,24 | 2,1 | 0,23 | 1,53 | 6,6 |
| 100k | 0,12 | 0,27 | 2,2 | 0,28 | 2,00 | 7,2 |
| 250k | 0,12 | 0,22 | 1,8 | 0,29 | 3,44 | 11,9 |

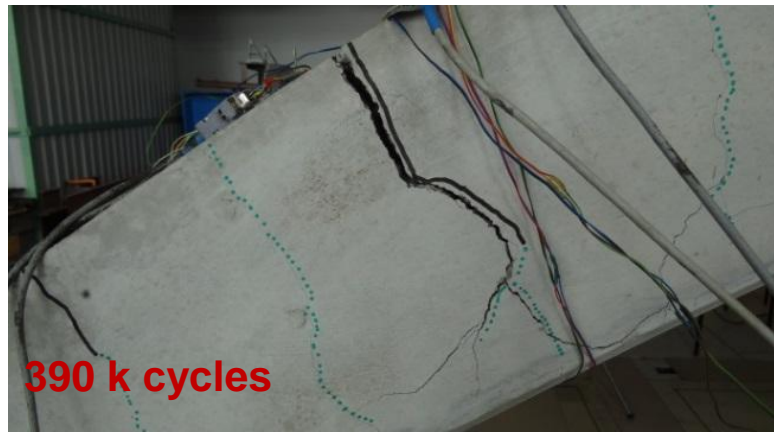


Failure mode

LWC/GFRP/F



Crack initiation in L/2



Crack initiation in L/6



Crack development



Element during final failure



Failure mode

LWC/GFRP/F





Main conclusions

- The LWC/GFRP arches exhibited **lower stiffness, static load carrying capacity and fatigue resistance** than NWC/steel arch.
- Under static load, the LWC/GFRP arch failed due to **shear**, its load carrying capacity could be improved by increasing shear reinforcement.
- **Lower fatigue resistance** of the LWC/GFRP arch was caused due to faster degradation of lightweight concrete and lower stiffness of the element (GFRP rebars).
- Nevertheless lightweight concrete arch elements with GFRP rebars can stand a good alternative for small-scale road bridges.
- In analysed case, the static ultimate load carrying capacity of LWC/GFRP arch was approximately **2.5-3.0 times higher** than the estimated **design load** for a road bridge made of an arch element. Real loading scheme is much more favorable than during the tests.
- **Further research on fatigue behaviour** of the LWC/GFRP elements are needed to establish proper design guidelines.



Thank you for your attention

Research was done within the framework of the research project POIR.02.03.02-22-0006/18:
Innovative precast arch members with increased durability for infrastructure,
co-funded by the European Union under the Innovative Development Operational Programme.



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