Effect of corrosion on the buckling of steel angle elements

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Introduction

Corrosion: significant problem

Many types of corrosion:

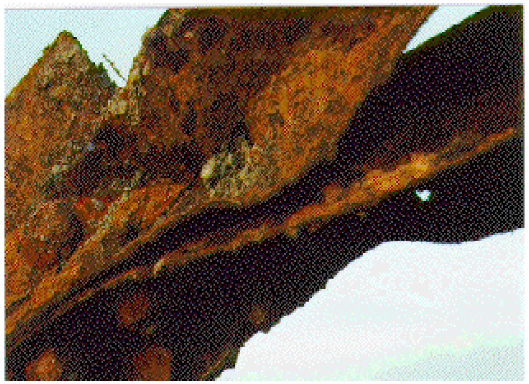
- Uniform corrosion
- Pitting corrosion
- Crevice corrosion
- Corrosion with fatigue

Steel structures are exposed to corrosion:

- Structures under soil (pipelines)
- Structures in the air
- Transmission line columns
- Bridges

Transmission line columns

- Pitting corrosion
- Crevice corrosion
- „Korell” steel – MVM (Hungarian Power Companies Co.)
- Corrosion on column base and intersection

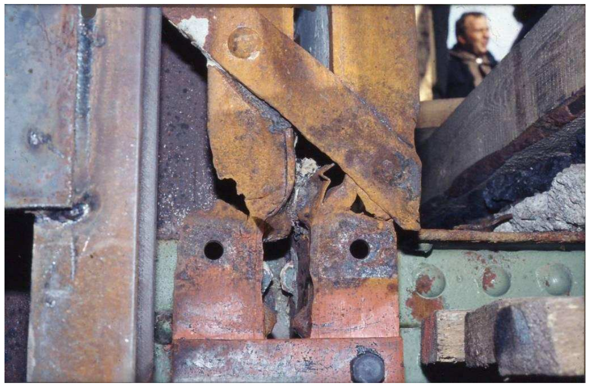


Liberty Bridge in Budapest

Construction failure

Excavation

Corrosion → significant reduction of cross-section



Aims of study

Previous studies on the effect of corrosion:

- Bended beam (Rahgozar, 2009)
- Sheared plate (Paik, Lee, 2004)
- Compressed plate (Sadovsky, Drdacky, 2001)
- Pitting corrosion (Nakai, 2004)

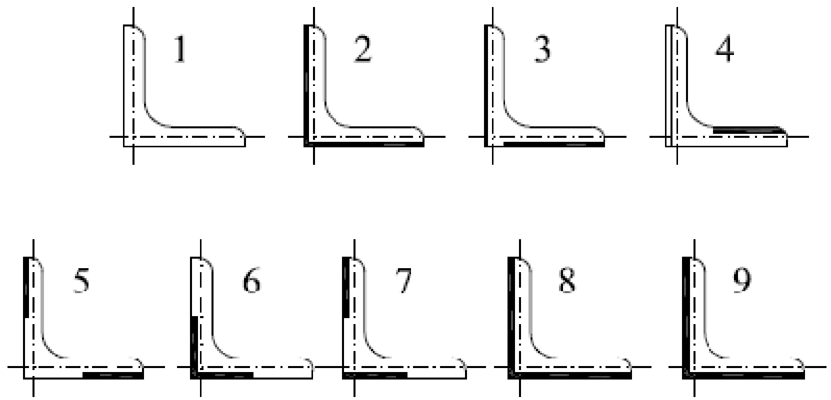
Analysis of corroded angle section members:

- Ultimate behaviour
- Resistance reduction
- Effect of – loss of cross-section
  - location of corrosion
  - size and shape of imperfection

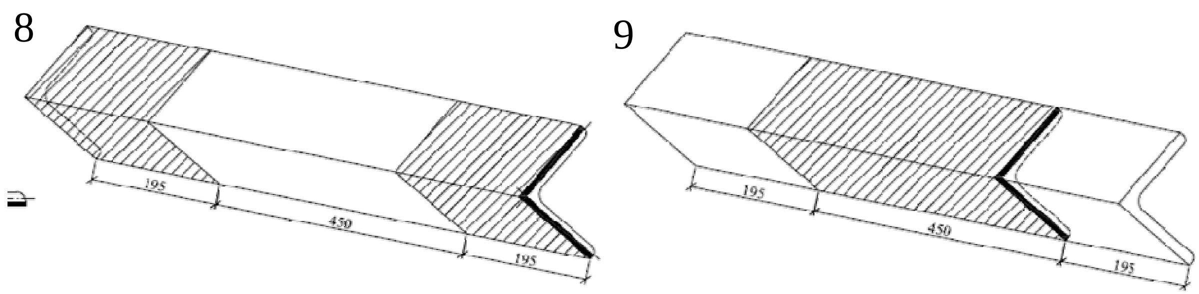
Buckling tests

Specimens

- Corrosion – cross-section reduction
- Artificial reduction – milling process
- 9 pieces of specimen
- Section: 40×40×4
- Length: 840 mm



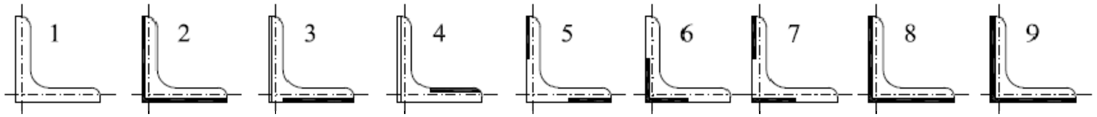
Specimen	Cross-section reduction [%]
1	–
2	28,98
3	12,85
4	11,75
5	14,72
6	12,66
7	18,82
8	12,39
9	11,79

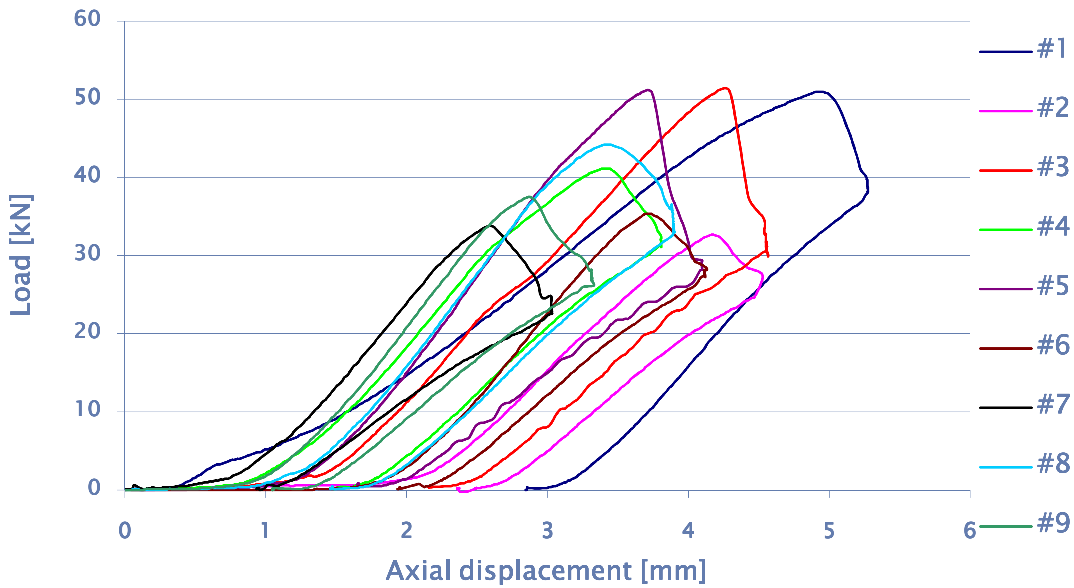


Test results

Centric compression, measure load, axial and horizontal displacements

Failure mode: global buckling in every case





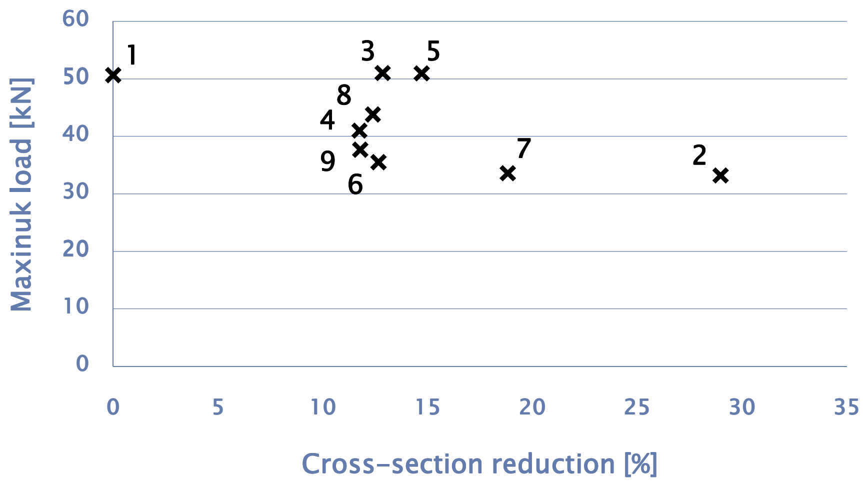
Test results

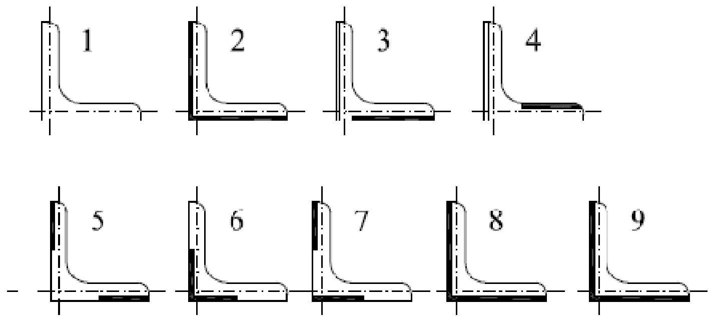
Significant differences observed in the cases of same amount of cross-section reduction

Effect of corrosion location

- Inside and outside reduction
- Location on the leg
- Reduction by element length

Specimen	Resistance [kN]	Difference [%]	Cross-section reduction [%]
1	50,65	–	–
2	33,20	34,45	28,98
3	51,02	-0,73	12,85
4	41,00	19,05	11,75
5	50,95	-0,59	14,72
6	35,50	29,91	12,66
7	33,60	33,66	18,82
8	43,80	13,52	12,39
9	37,70	25,56	11,79





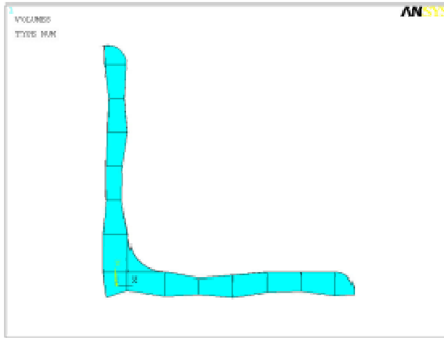
Finite element model

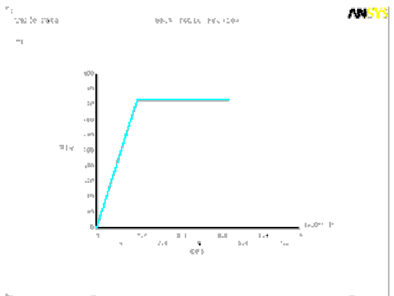
Ansys program

Brick finite element – large deformations and strains

Material model

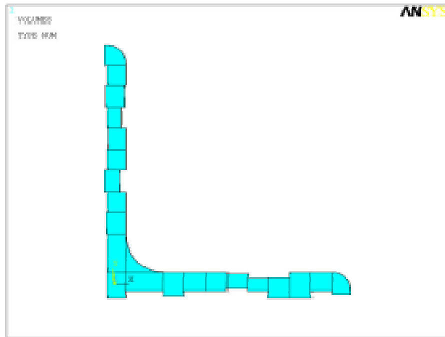
- Linear elastic
- Linear elastic–hardening plastic





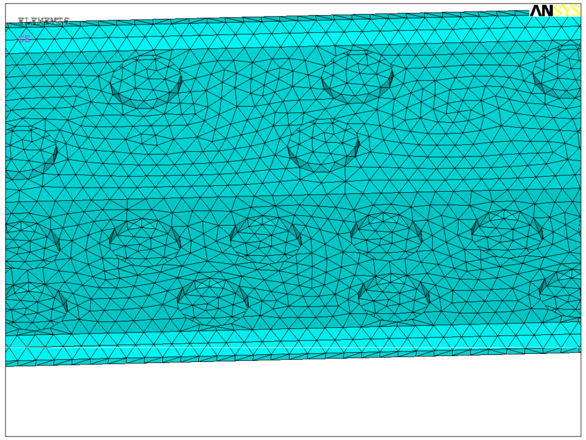
Corrosion – thickness reduction

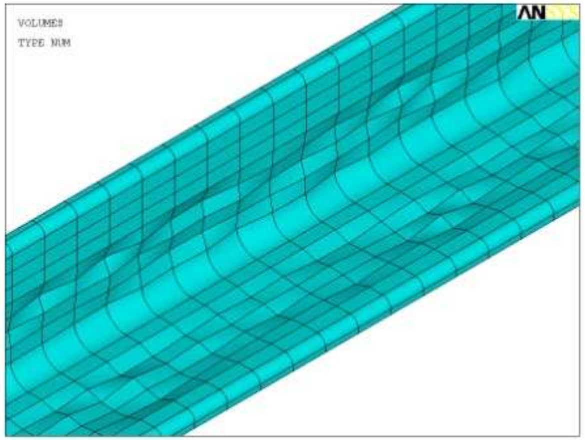
Different geometrical shape



Modelling different types of corrosion

- Uniform corrosion – uniform thickness reduction
- According to distribution cross-section reduction
  - Average
  - Betha
  - Gauss
- Pitting corrosion
- Option
  - Location
  - Size





Nonlinear studies

Simulation

- Design yield strength
- Linear elastic-hardening plastic material model
- Equivalent geometric imperfection

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Design resistance

Virtual experiment

- Measured yield strength
- Determination of real imperfection
- Calibrated by the test

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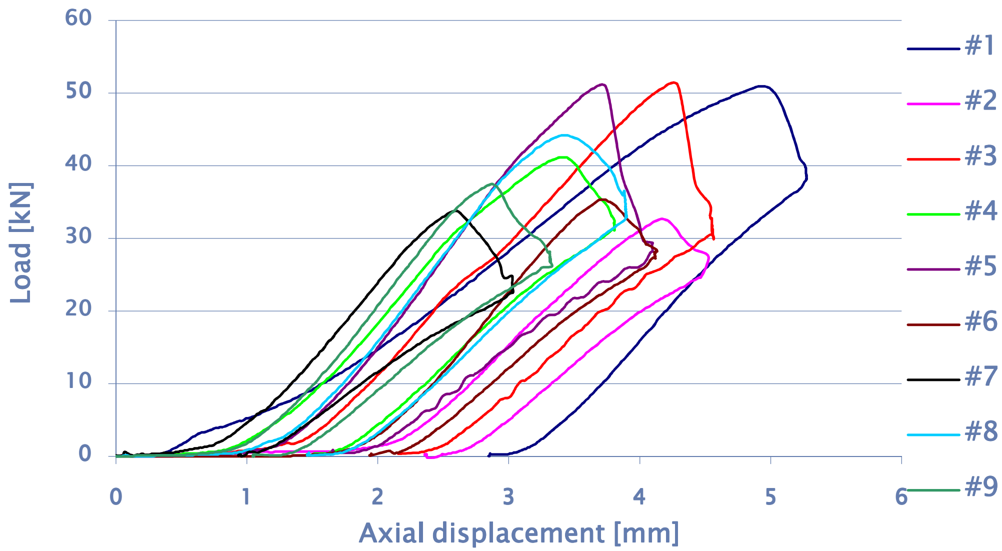
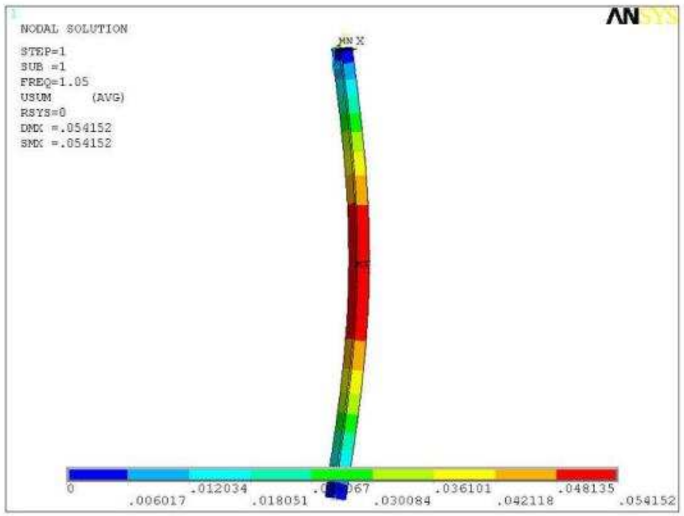
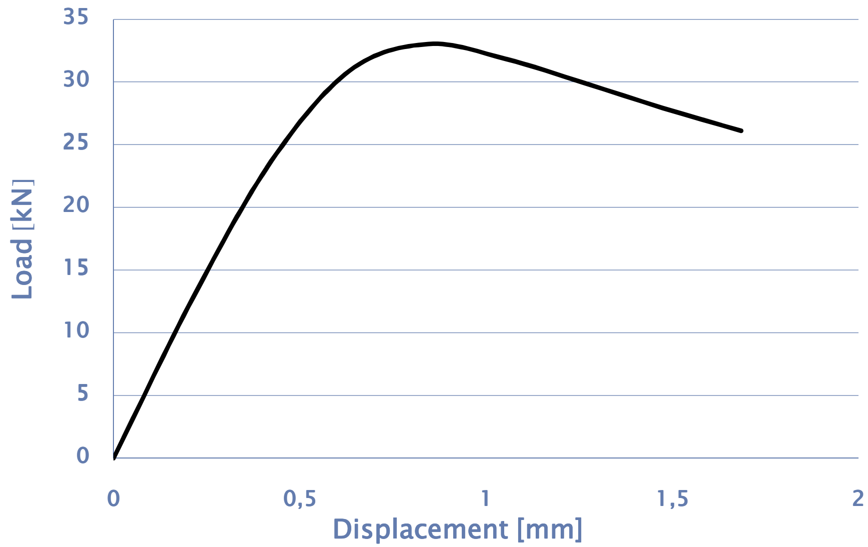
Design resistance

Behaviour

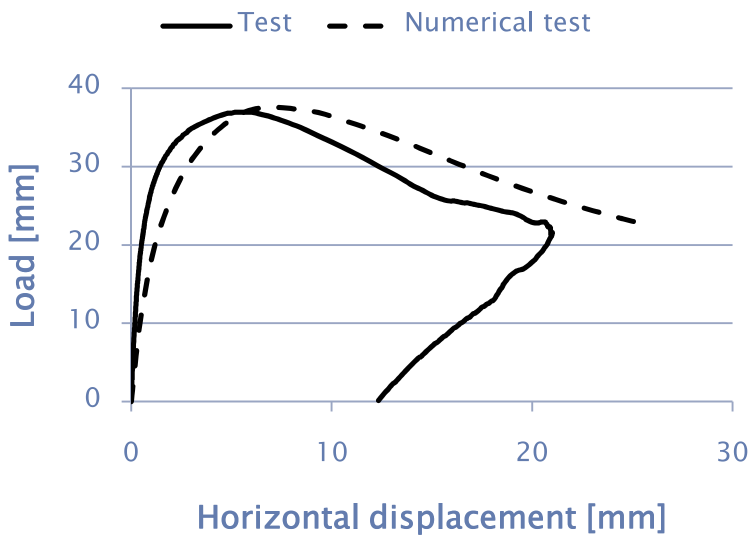

60
50
40
30
20
10
0
Load [kN]
0
1
2
3
4
5
6
Axial displacement [mm]
#1
#2
#3
#4
#5
#6
#7
#8
#9


NODAL SOLUTION
STEP=1
SUB =1
FREQ=1.05
USUM (AVG)
RSYS=0
DMX =.054152
SMX =.054152
0
.006017
.012034
.018051
.030084
.036101
.042118
.048135
.054152


35
30
25
20
15
10
5
0
Load [kN]
0
0,5
1
1,5
2
Displacement [mm]

Model verification

Verification by linear and geometrically nonlinear buckling analyses



Same behaviour

Differences

- Resistance
- Stiffness

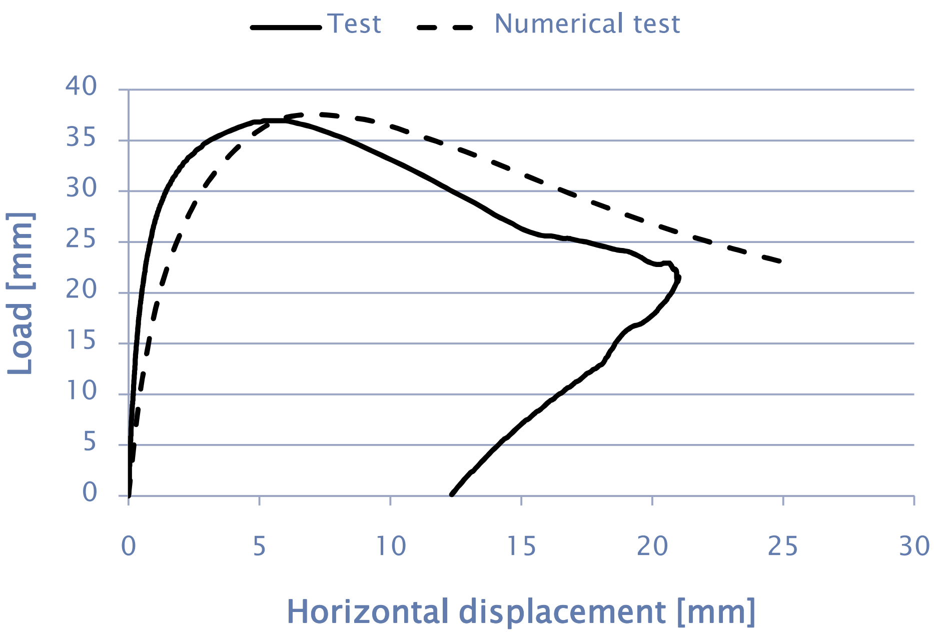
Investigation to predict the resistance

- Changing imperfection
- Application eccentricity
- Rotational spring support

Verified modell by imperfection

Equivalent geometric imperfection (Eurocode 3): L/200

Applied imperfection



Specimen	Imperfection	Resistance [kN]		Differen ce
		Virtual	Real	[%]
1	L/1500	50,71	50,65	0,1
2	L/800	32,54	33,20	2,0
3	L/1500	47,87	51,02	6,6
4	L/400	42,68	41,00	3,9
5	L/800	50,86	50,95	0,1
6	L/500	33,10	35,50	7,3
7	L/350	33,03	33,60	1,7
8	L/700	43,79	43,80	0,0
9	L/600	37,14	37,70	1,5

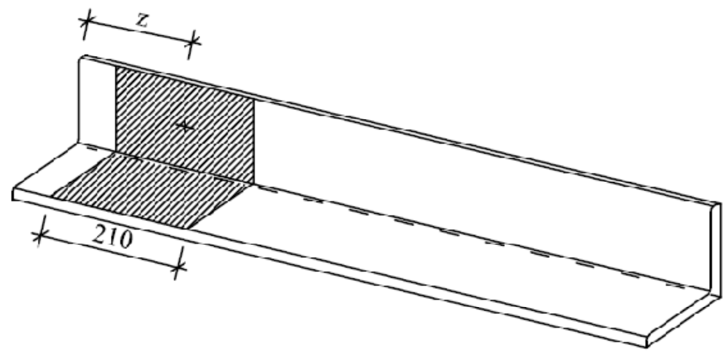
Virtual experiments

Influence of three parameters:

- Cross-section loss (refer to the whole element)
- Geometric imperfection
- Location of corrosion

Parameter values by previous analyses

Parameter	Min	Max
Cross-section reduction	0 %	6 %
Imperfection	L/800 (1,05 mm)	L/200 (4,2 mm)
Location (z)	105 mm	735



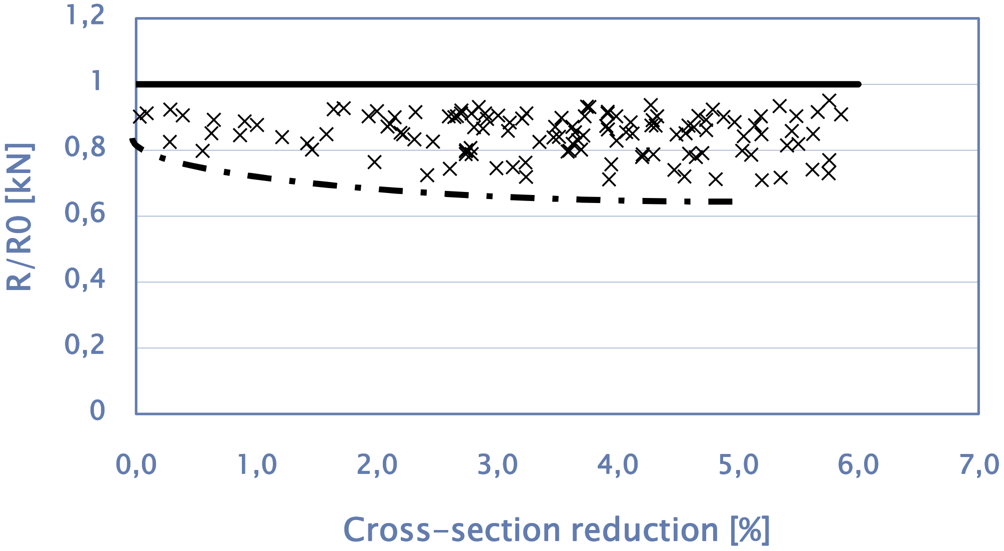
Analyses and results

Tendencies of resistance reduction

- Cross-section reduction → nonlinear decrease
- Big standard deviation

5% cross-section reduction

- Maximal resistance reduction:30%
- Average reduction: 17%

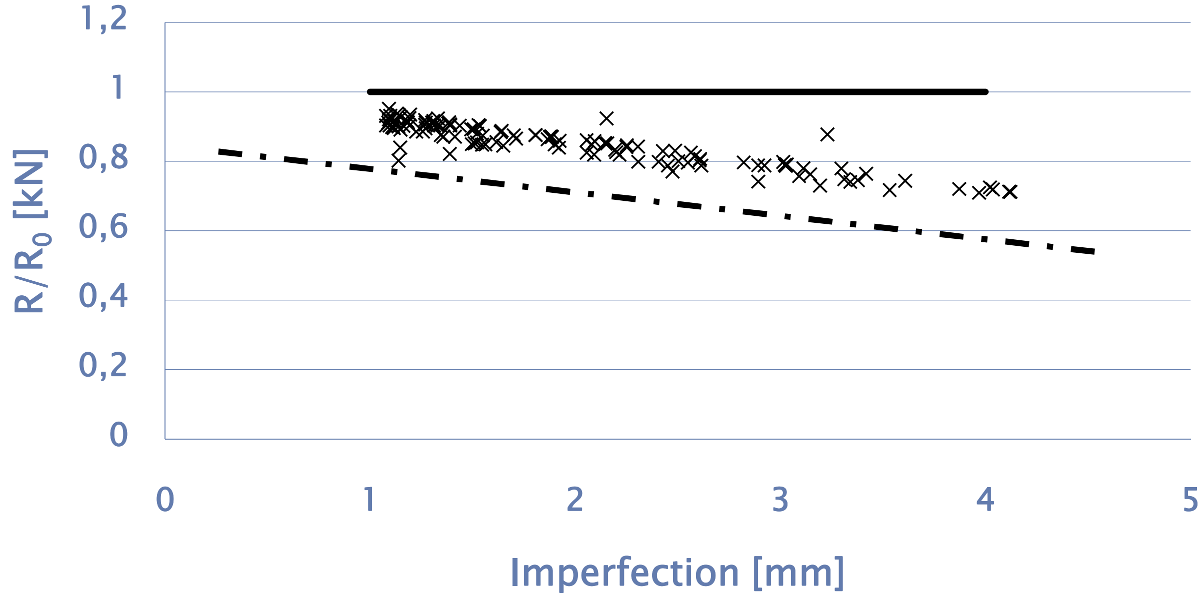


Analyses and results

Tendencies of resistance reduction

- Imperfection → ~ linear decrease
- Small standard deviation

Dominant effect



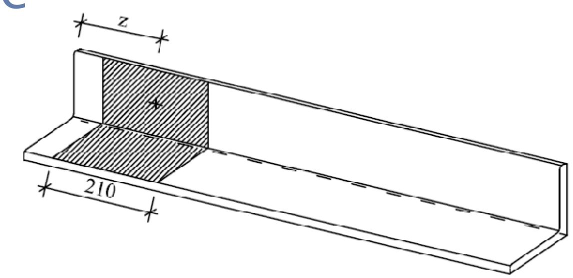
Analyses and results

Tendencies of resistance reduction

- Corrosion location→ nonlinear decrease
- Big standard deviation

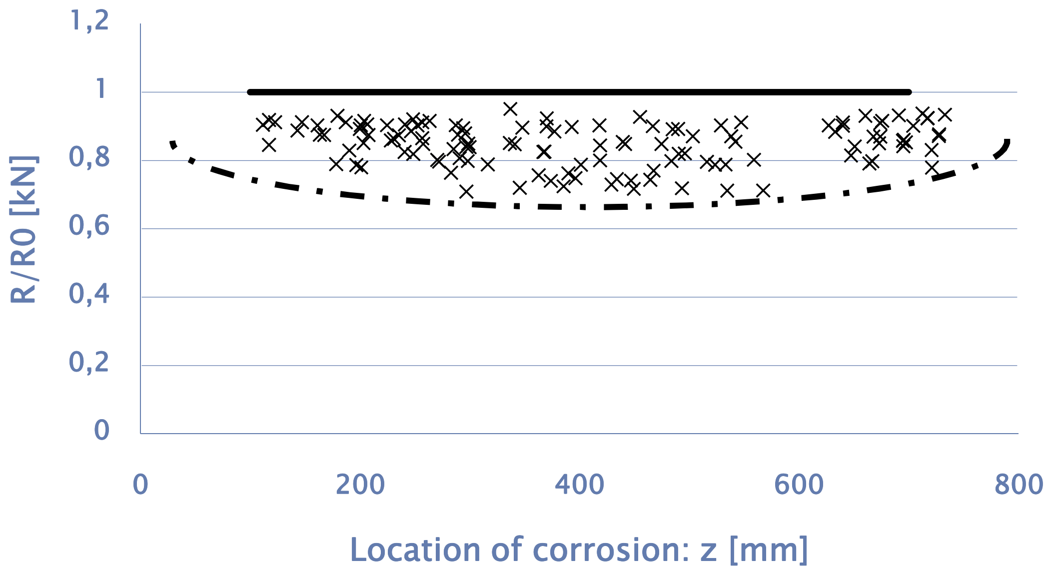
Middle of the element – bigger decrease

Tendecies like results of tests



Max. reduction: 30%

Min. reduction: 7%



Concluding remarks

Experiments – 9 specimens

- Corrosion – cross-section reduction
- Different location

⇒ Resistance and behaviour

Modelling – verified and calibrated by experimental results

- Application for further analysis

Numerical analysis – effect of three parameters

- cross-section reduction
- imperfection
- corrosion location

⇒ Determination main tendencies

Further studies

- Speeded corrosion test
  - Alternate immersion corrosion test – NaCl solution – artificial generates
  - Specimens
    - Angle section (5 pieces) for compressive buckling test
    - Plate (10 pieces) for fatigue test
- Analysis corroded (pitting corrosion) angle section

Thank you for your kind attention!