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

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Cross-section reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>28.98</td>
</tr>
<tr>
<td>3</td>
<td>12.85</td>
</tr>
<tr>
<td>4</td>
<td>11.75</td>
</tr>
<tr>
<td>5</td>
<td>14.72</td>
</tr>
<tr>
<td>6</td>
<td>12.66</td>
</tr>
<tr>
<td>7</td>
<td>18.82</td>
</tr>
<tr>
<td>8</td>
<td>12.39</td>
</tr>
<tr>
<td>9</td>
<td>11.79</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Resistance [kN]</th>
<th>Difference [%]</th>
<th>Cross-section reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>33.20</td>
<td>34.45</td>
<td>28.98</td>
</tr>
<tr>
<td>3</td>
<td>51.02</td>
<td>-0.73</td>
<td>12.85</td>
</tr>
<tr>
<td>4</td>
<td>41.00</td>
<td>19.05</td>
<td>11.75</td>
</tr>
<tr>
<td>5</td>
<td>50.95</td>
<td>-0.59</td>
<td>14.72</td>
</tr>
<tr>
<td>6</td>
<td>35.50</td>
<td>29.91</td>
<td>12.66</td>
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<tr>
<td>7</td>
<td>33.60</td>
<td>33.66</td>
<td>18.82</td>
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<tr>
<td>8</td>
<td>43.80</td>
<td>13.52</td>
<td>12.39</td>
</tr>
<tr>
<td>9</td>
<td>37.70</td>
<td>25.56</td>
<td>11.79</td>
</tr>
</tbody>
</table>
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
  ↓
  Design resistance

Virtual experiment
- Measured yield strength
- Determination of real imperfection
- Calibrated by the test
  ↓
  Design resistance
Behaviour

Load [kN] vs. Axial displacement [mm]

Load [kN] vs. Displacement [mm]

fib International PhD Symposium in Civil Engineering
June 20–23, 2010, Lyngby
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

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

Influence of three parameters:
- Cross–section loss (refer to the whole element)
- Geometric imperfection
- Location of corrosion

Parameter values by previous analyses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross–section reduction</td>
<td>0 %</td>
<td>6 %</td>
</tr>
<tr>
<td>Imperfection</td>
<td>L/800 (1,05 mm)</td>
<td>L/200 (4,2 mm)</td>
</tr>
<tr>
<td>Location (z)</td>
<td>105 mm</td>
<td>735</td>
</tr>
</tbody>
</table>
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
Tendencies 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!