ZSoil Symposium: Non-Linear Deflection-Force Application

Underground Train Station of Berne

Christoph Berger, 28.08.2015
WRONG ANSWER!
Non-Linear Deflection-Force Application

development of **daily passengers** at the existing underground station

Source: leaflet May 2015, Zukunft Bahnhof Bern

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Source: www.rbs.ch
new underground train station

orange: 
**new** underground station of Berne (RBS)

Source: www.zukunftbahnhofbern.ch
Source: www.rbs.ch

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new underground train station

new underground station of Berne (RBS)

existing underground station of Berne (RBS)
existing underground train station

existing underground station of Berne (RBS)

projected tunnels for the new station (RBS)

main station of Berne (SBB CFF FFS)
construction of the train station

1961

2015

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main beam

- very stiff
- strongly reinforced

32 Ø 26 mm

\( f_{sd} = 313 \, \text{MPa} \) (Box-Steel)

1.27 m

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main beam

1.27 m

14 m
Differential settlements cause cracks or internal forces. Steepest slope cause the biggest problems. But many excavation steps and many slopes…

Soft rock: Molasse
structural behaviour

articulated joint (gerber girder)

worst case: single pillar settles exclusively

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Internal force due to settlement depends on **bending stiffness**.

Internal force due to settlement increases the shear force critically.

**Key Point:**
Is the shear resistance bigger than the total shear force?

\[
V_{Ed}^{(\text{static load})} + V(\delta) \leq V_{Rd}
\]
structural behaviour

- **Zone A**
  - big total shear force
  - many vertical stirrups
  - diagonal rebars

- **Zone B**
  - some shear force
  - few vertical stirrups

- **Zone C**
  - small total shear force
  - many vertical stirrups
  - „no“ diagonal rebars
Bending Moment M – Curvature $\chi$

- **Key Point:**
  - Bending moment $M$ – curvature $\chi$
  - Non-linear
  - Max. values at positive and negative plastic hinges

- **Tool:** ZSoil
  - Reinforcement set for beam

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non-linear force-deflection analysis

\[ \delta = 20 \text{ mm} \]
\[ \delta = 30 \text{ mm} \]

M [kNm]  plastic hinge

V [kN]
Shear force due to settlement

Zone B is more critical than Zone A.

Non-linear approach increases the allowable maximum settlement.

Assessment of Structural Safety including settlement → ok
End
Crosscheck by other static tools

Other static tools include:
- STATIK
- FAGUS
- PYRUS
settlements due to excavation of tunnels

- many different excavation steps by four tunnels
- range of geological parameters
- possible punctual geological problems

→ sensitivity analysis → 3 values

<table>
<thead>
<tr>
<th>Set</th>
<th>differential settlement $\Delta u$</th>
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</thead>
<tbody>
<tr>
<td>very likely</td>
<td>x mm</td>
</tr>
<tr>
<td>possible</td>
<td>xx mm</td>
</tr>
<tr>
<td>unlikely</td>
<td>xxx mm</td>
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