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Reliability Analysis of a Tunnel Design with RELY

W.Betz, I. Papaioannou, M. Eckl, H. Heidkamp, D.Straub

Reliability-based structural design

Eurocode 0	
partial safety factors	probabilistic techniques
decrease capacity / increase load	describe uncertainties probabilistically
characteristic values & design values	perform reliability analysis
maintain: capacity > demand	*maintain:* reliability > target reliability

Reliability analysis – road map

Step 1: mechanical model

Step 2: failure criterion

Step 3: stochastic model

Step 4: reliability analysis

Step 5: interpretation of the results

How does RELY work?

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FEM-model

as dat-file

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dat-file

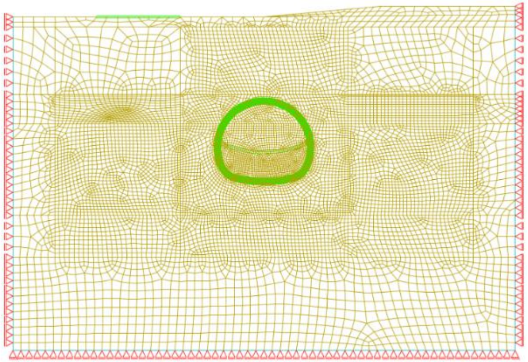
Example application: reliability analysis of a tunnel

example based on *Westtangente Freising*

mechanical model supplied by *EDR GmbH, Munich*

perform reliability analysis exemplarily for a single cross-section

investigate reliability of tunnel lining



This is an exemplary analysis that is performed independently of the actual tunnel design.

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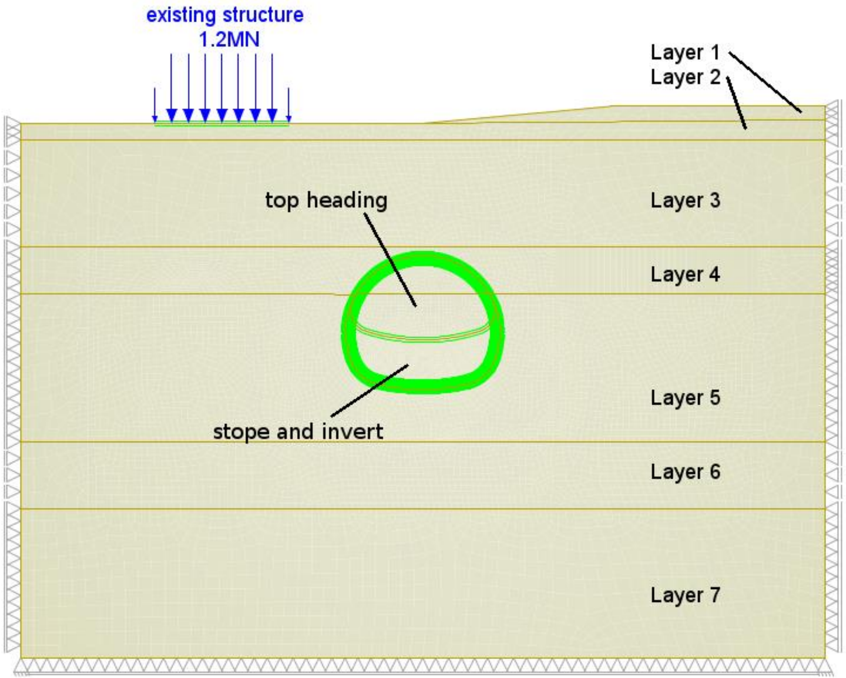
- ▶ Step 1: mechanical model
- Step 2: failure criterion
- Step 3: stochastic model
- Step 4: reliability analysis
- Step 5: interpretation of the results

Step 1: mechanical model



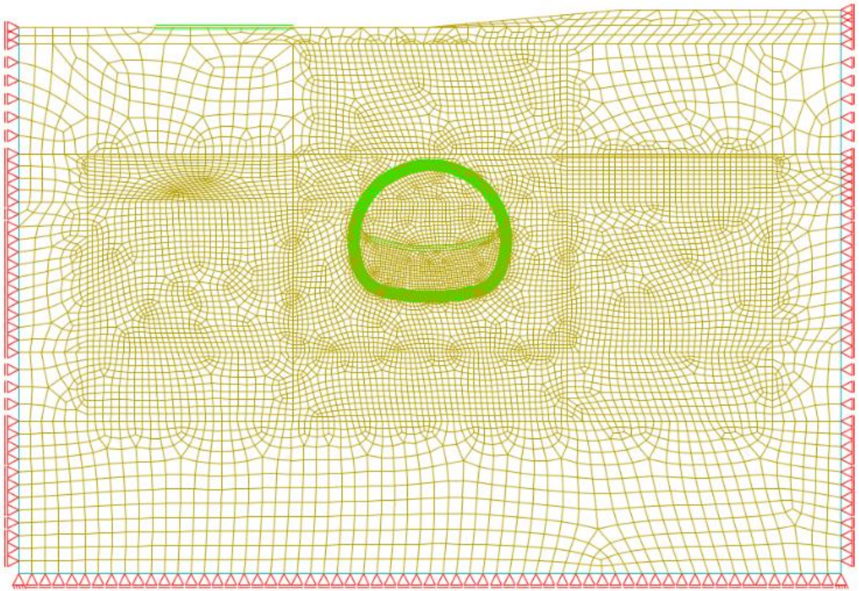
Step 1: mechanical model (cont’d)

2D plain strain finite elements (TALPA)

shotcrete lining modeled linear elastic

stress reduction method
(account for 3D effect)

excavation process modeled in 5 steps



Step 1: mechanical model

► Step 2: failure criterion

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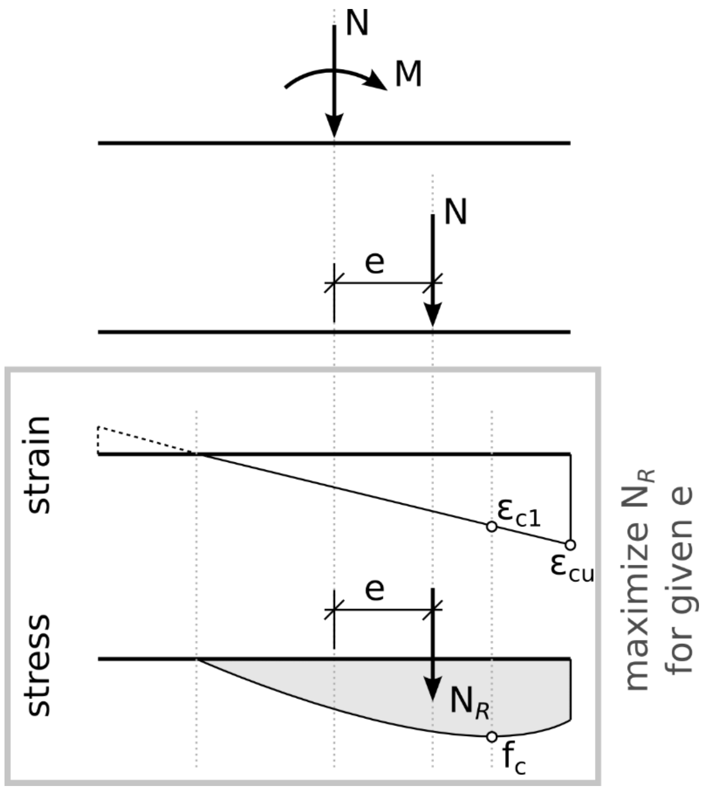
Step 2: failure criterion

failure: admissible normal forces and bending moments exceeded on at least one location of the shotcrete lining

(local) limit-state function:

$$g = N_R - N$$



Step 2: failure criterion (cont'd)

At the end of the DAT-file of the FE-model (*tunnel_fem.dat*), append:

```
! store the result of the limit-state function in the CDB
sto#rel_fun(LSFFUN)
```

In the DAT-file of RELY, write:

```
PROJ dat 'tunnel_fem'
FUNC rel_fun
```

Step 1: mechanical model

Step 2: failure criterion

► Step 3: stochastic model

Step 4: reliability analysis

Step 5: interpretation of the results

Step 3: stochastic model

Uncertainties are mainly in

soil parameters

p_{ref} reference pressure

m exponent of material model

K_0 coefficient of lateral earth pressure

material parameters of shotcrete

Young's modulus

strength

modeling uncertainties

α from stress reduction method

Step 3: stochastic model (list of uncertain variables)

name	group	type	mean	CV
f_{co}	concrete	lognormal	$33 \mathrm{N/mm^2}$	16%
Y_c	concrete	lognormal	0.8	10%
Y_E	concrete	lognormal	1.0	15%
α	model	beta	0.4	10%
$p_{\mathrm{ref},i}$	soil	lognormal	167 kN/m	33%
m_i	soil	lognormal	0.47	11%
$K_{0,4}$, $K_{0,7}$	soil	lognormal	0.68	10%
$K_{0,5}$, $K_{0,6}$	soil	lognormal	0.49	13%

distributions and moments based on JCSS and geological report

Step 3: stochastic model (DAT-files)

DAT-file of RELY

```
VAR 'rv_fco'   TYPE LOGN PTYP MOME  P1 33    P2 33*0.16
VAR 'rv_Yc'    TYPE LOGN PTYP MOME  P1 0.8   P2 0.08
VAR 'rv_YE'    TYPE LOGN PTYP MOME  P1 1.0   P2 0.15
VAR 'rv_beta'  TYPE BETA PTYP MOME  P1 0.4   P2 0.04      P3 0  P4 1
VAR 'rv_pref1' TYPE LOGN PTYP MOME  P1 167   P2 55
VAR 'rv_pref2' TYPE LOGN PTYP MOME  P1 167   P2 55
VAR 'rv_pref3' TYPE LOGN PTYP MOME  P1 167   P2 55
VAR 'rv_pref4' TYPE LOGN PTYP MOME  P1 167   P2 55
VAR 'rv_pref5' TYPE LOGN PTYP MOME  P1 167   P2 55
VAR 'rv_pref6' TYPE LOGN PTYP MOME  P1 167   P2 55
VAR 'rv_pref7' TYPE LOGN PTYP MOME  P1 167   P2 55
VAR 'rv_m1'    TYPE LOGN PTYP MOME  P1 0.47 P2 0.47*0.11
VAR 'rv_m2'    TYPE LOGN PTYP MOME  P1 0.47 P2 0.47*0.11
VAR 'rv_m3'    TYPE LOGN PTYP MOME  P1 0.47 P2 0.47*0.11
VAR 'rv_m4'    TYPE LOGN PTYP MOME  P1 0.47 P2 0.47*0.11
VAR 'rv_m5'    TYPE LOGN PTYP MOME  P1 0.47 P2 0.47*0.11
VAR 'rv_m6'    TYPE LOGN PTYP MOME  P1 0.47 P2 0.47*0.11
VAR 'rv_m7'    TYPE LOGN PTYP MOME  P1 0.47 P2 0.47*0.11
VAR 'rv_K04'   TYPE LOGN PTYP MOME  P1 0.68 P2 0.068
VAR 'rv_K05'   TYPE LOGN PTYP MOME  P1 0.49 P2 0.064
VAR 'rv_K06'   TYPE LOGN PTYP MOME  P1 0.49 P2 0.064
VAR 'rv_K07'   TYPE LOGN PTYP MOME  P1 0.68 P2 0.068
```

tunnel_fem.dat

```
!Layer 5
MAT  NR    9  E    250000  MUE 0.350  GAM 22.00  GAMA 12.00  BEZ 'TS2'
NMAT NR    9  ART GRAN  P1   37.50  P2    0.00  P5 120000.000  P6   0.500  P9 120000.000  P10  #rv_m5  P12 #rv_pref5
```

Step 1: mechanical model

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▶ Step 4: reliability analysis

Step 5: interpretation of the results

Step 4: reliability analysis

Reliability methods available in RELY:

- Monte Carlo simulation
- **FORM**
- SORM
- Importance sampling
- Line sampling
- Adaptive sampling
- Subset simulation

Step 4: FORM

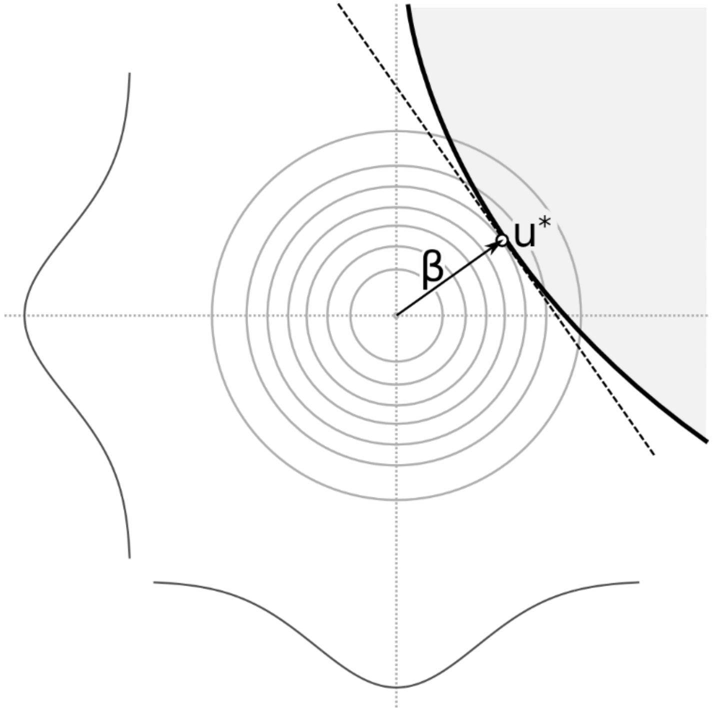
FORM

$$\beta = 4.6$$

$$p_{f,\mathrm{FORM}} = 2 \cdot 10^{-6}$$

EC 0

Reliability Class	β (50 year reference)
RC 3	4.3
RC 2	3.8
RC 1	3.3



Step 1: mechanical model

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▸ Step 5: interpretation of the results

parameter	mean	x^*	α^2
f_{co}	$33\mathrm{N/mm^2}$	$32\mathrm{N/mm^2}$	0.2%
Y_c	0.8	0.8	0.1%
Y_E	1.0	1.8	70.3%
α	0.4	0.4	0.2%
$p_{\mathrm{ref},1}$	167 kN/m	158 kN/m	0%
$p_{\mathrm{ref},2}$	167 kN/m	160 kN/m	0%
$p_{\mathrm{ref},3}$	167 kN/m	160 kN/m	0%
$p_{\mathrm{ref},4}$	167 kN/m	159 kN/m	0%
$p_{\mathrm{ref},5}$	167 kN/m	337 kN/m	27.5%
$p_{\mathrm{ref},6}$	167 kN/m	187 kN/m	1%
$p_{\mathrm{ref},7}$	167 kN/m	180 kN/m	0.6%
m_1	0.47	0.47	0%
m_2	0.47	0.47	0%
m_3	0.47	0.47	0%
m_4	0.47	0.47	0%
m_5	0.47	0.39	0.2%
m_6	0.47	0.45	0%
m_7	0.47	0.45	0%
$K_{0,4}$	0.68	0.68	0%
$K_{0,5}$	0.49	0.49	0%
$K_{0,6}$	0.49	0.49	0%
$K_{0,7}$	0.68	0.68	0%

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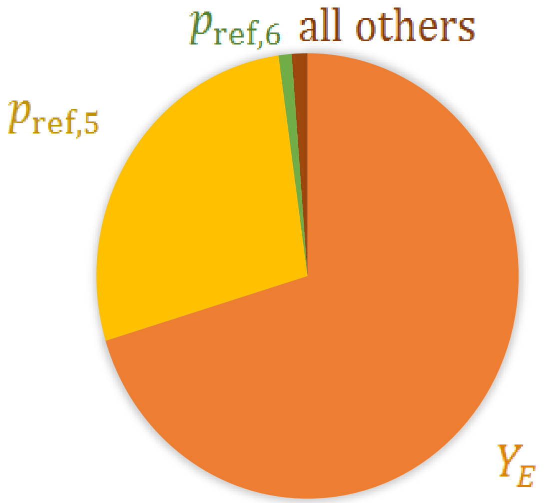

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