# JET GROUTED COLUMNS – A CASE RECORD

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    - Foundation Methods
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# 1. Introduction

A 35 m high warehouse was successfully founded using

- Jet-grouted columns
- Surface stabilised soil layers
- Steel fibres reinforced concrete slab

Building 45 × 92 $m^2$, height 35 m

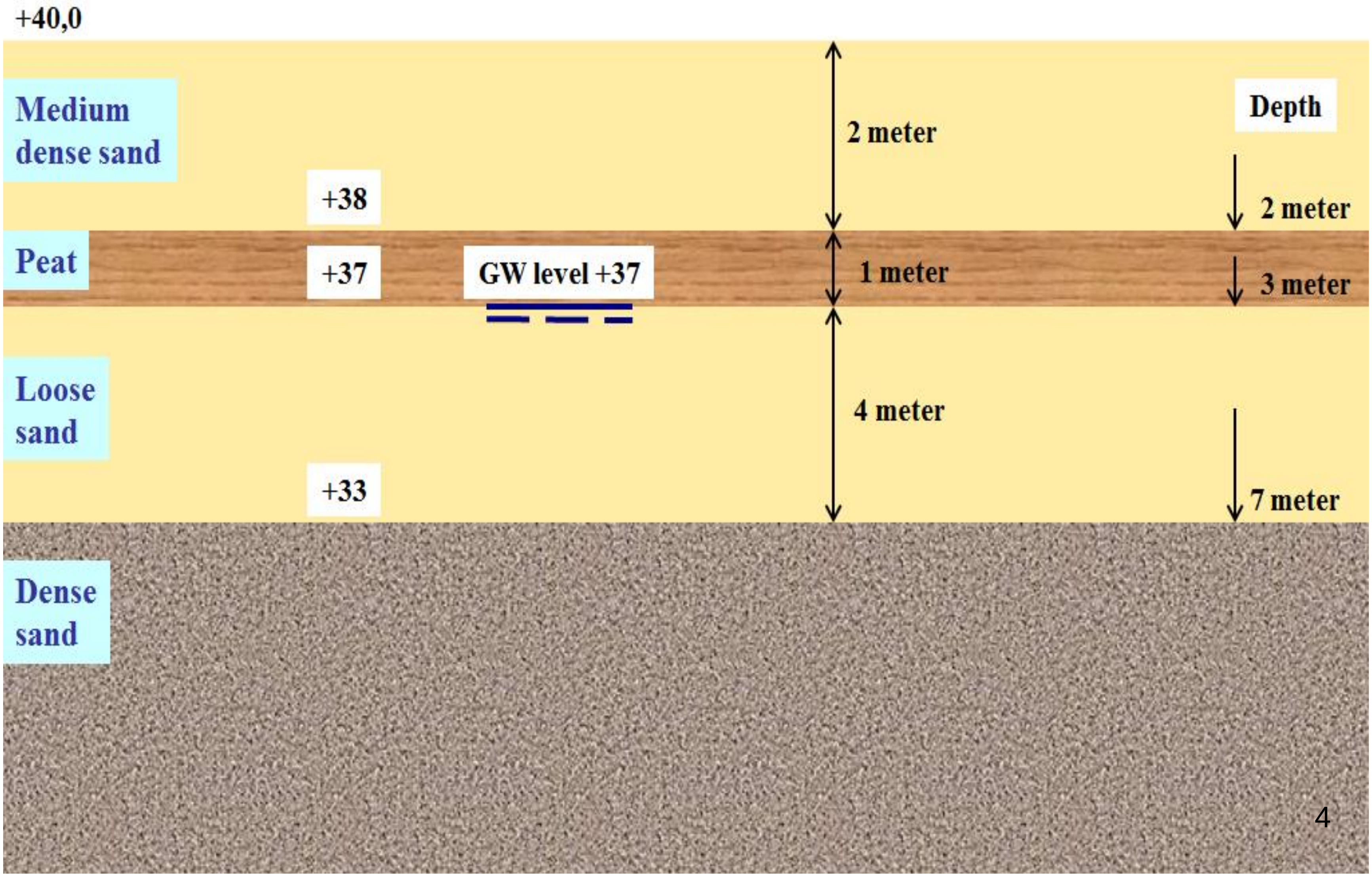
Load effects from crane:

| | |
|---|---|
| • Static point load | 65 kN |
| • Dynamic point load | 100 kN |

Maximum acceptable inclination difference at loading $0.5\times10^{-3}$ in SLS

# 1. Introduction

## Geological Model



# 1. Introduction

## Geological Conditions

Mean values of some soil properties

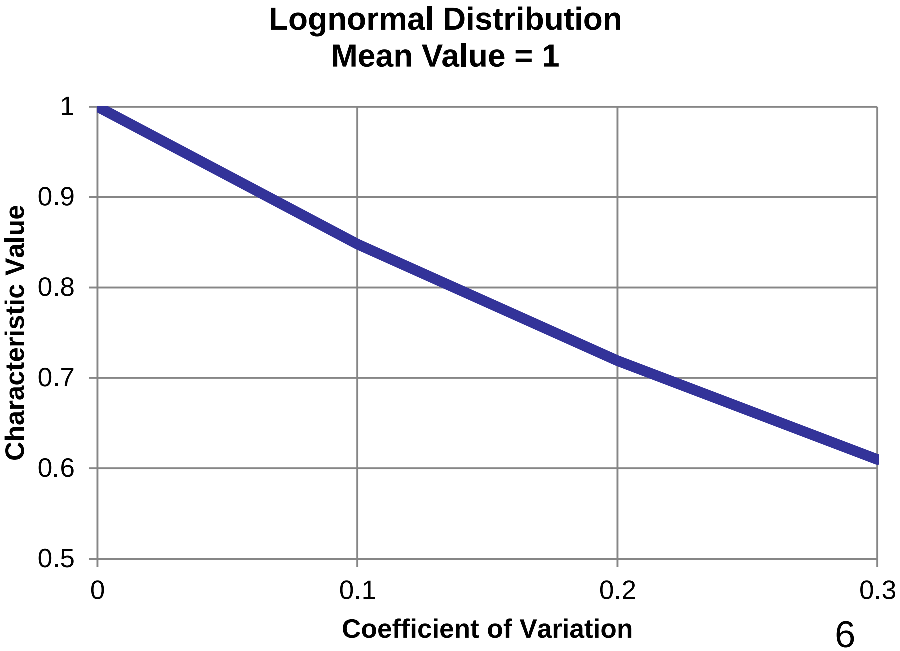
| Property | Unit | Soil | | | |
|---|---|---|---|---|---|
| | | Peat | Loose sand | Medium dense sand | Dense sand |
| Density | kN/m$^3$ | 12 | 17 | 18 | 20 |
| Effective friction angle | Degr. | 28 | 32 | 35 | 38 |
| Ev2, plate loading test | MPa | - | 10 | 20 | 40 |

# 1. Introduction

Characteristic value of soil properties at 5 % percentile and lognormal distribution:

$f_k = f_m / \exp(1.65 \cdot V)$ where

$f_k$ = Characteristic value of soil property
$f_m$ = Mean value of soil property
$V$ = Coefficient of variation



# 1. Introduction

## Foundation Methods

1. Soil improvement and interacting concrete slab

2. Alternative piling foundation methods were initially discussed and analysed:

   - Precast concrete piles
     - Noise and vibrations
     - Risk for damaged piles during installation
     - Settlement of existing building

   - Steel pipe piles and free bearing concrete slab
     - Not stiff enough
     - 2 000 000 USD more expensive than alt. 1 above

   - Large diameter bored piles
     - too expensive

# 1. Introduction

## Chosen Foundation Method

**Ground improvement**

- 3 cement/slag-stabilised surface layers, Totally 1.0 m
- Jet-grouted columns, Minimum diameter 0.8 m

**Concrete slab**

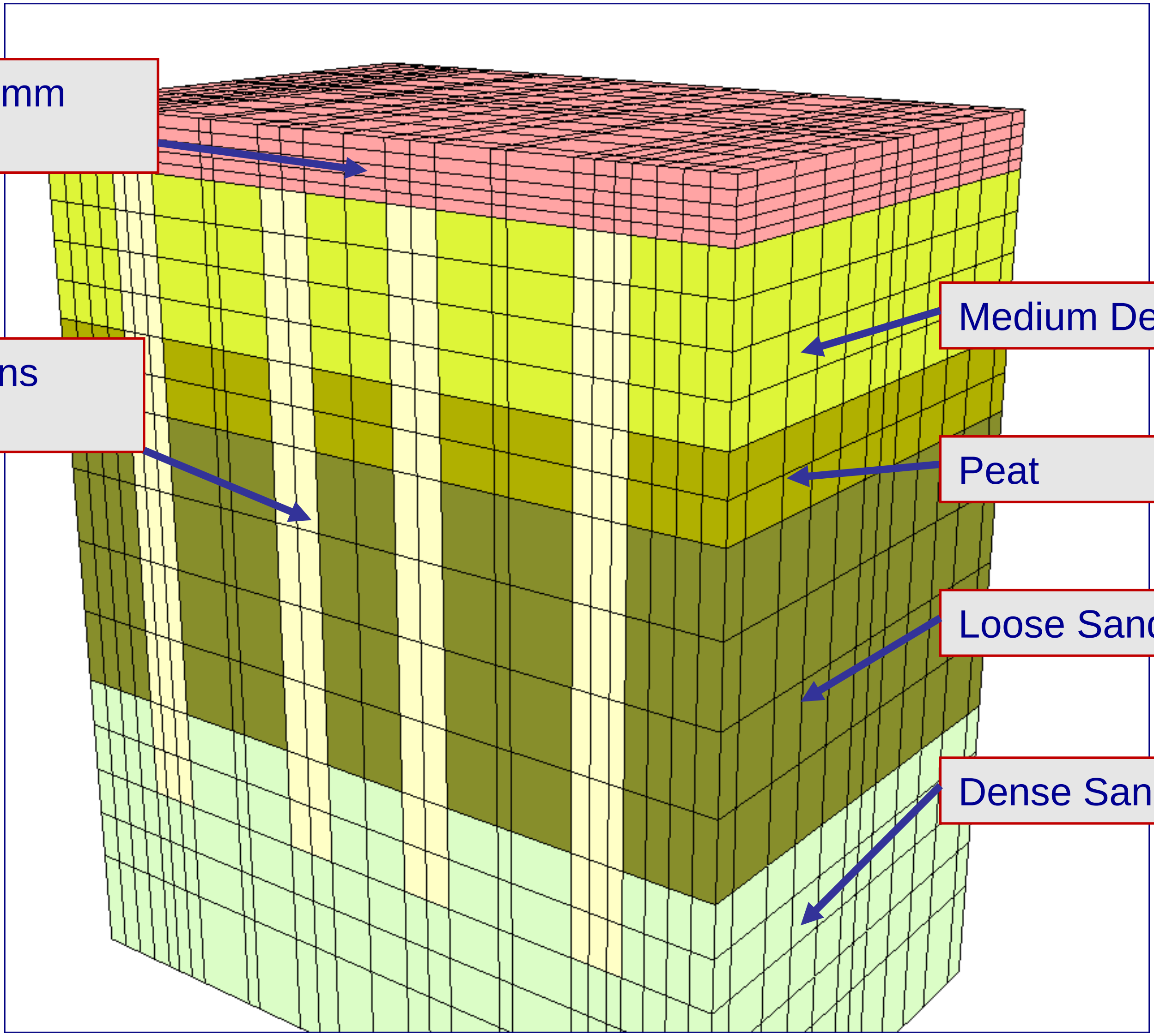
- Thickness 200 mm, Reinforced with end-hooked steel fibres 1×49 mm, 35 kg /$m^3$

**Mean properties of stabilised sand and jet-grouted columns:**

| *Parameter* | *Cement/Slag stabilised sand* | *Jet-grouted columns* |
|---|---|---|
| Uniaxial Compressive Strength, MPa | 2 | 4 |
| Coefficient of Variation of Compressive Strength, % | 20 | 20 |
| Tensile Strength, MPa | 0.38 | 0.60 |
| Modulus of Elasticity, MPa | 8,600 | 15,500 |

# 2. Design

1) **2 Layers of Cement/Slag Stabilised Sand**
2) **Compaction**
3) **Jet-grouted Columns**



2 Layers 300+400 mm
Stabilised Sand

Jet-grouted Columns
Diameter 0.8 m

Medium Dense Sand

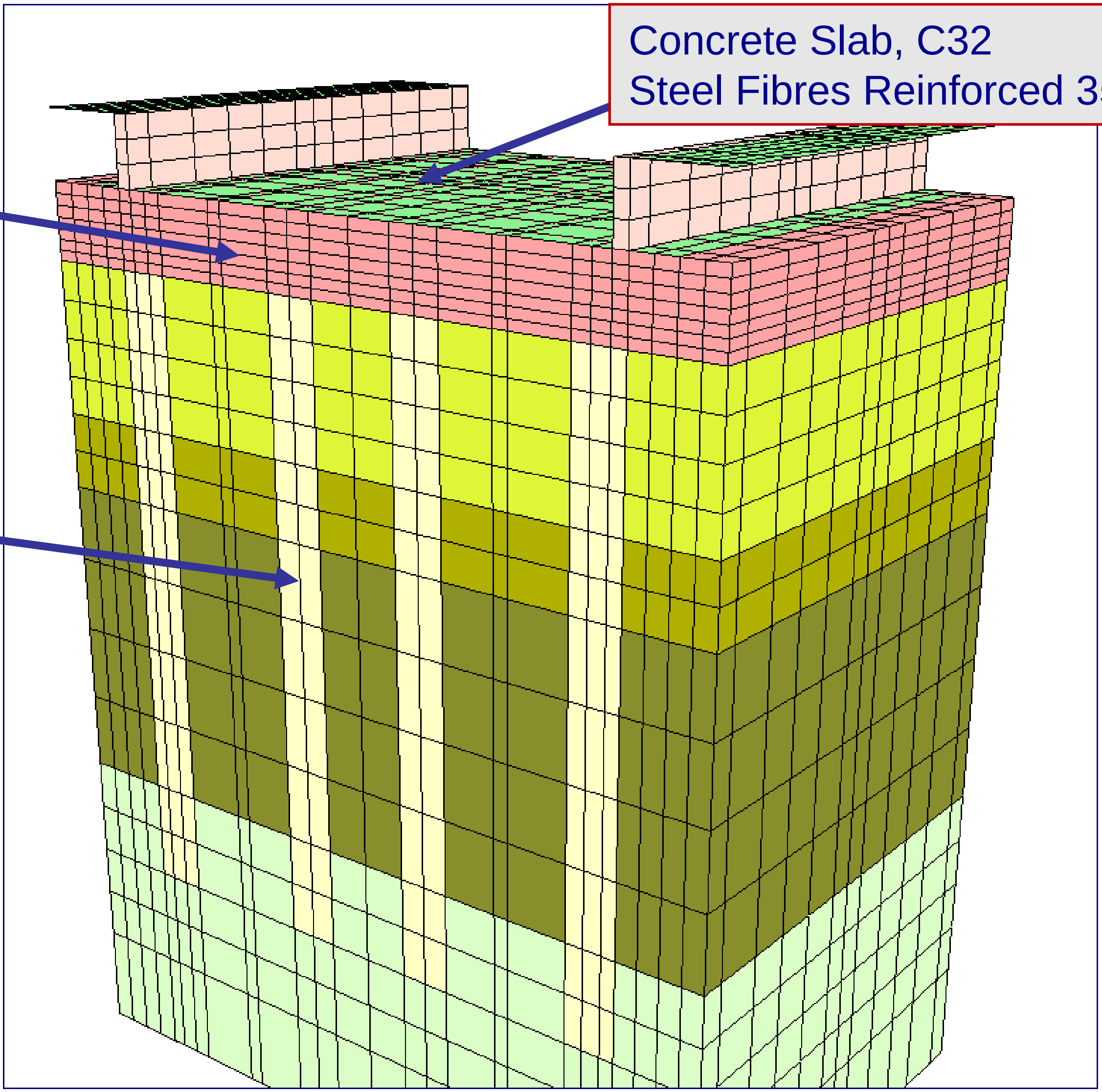
Peat

Loose Sand

Dense Sand

# 2. Design

4) **Layer #3 of Cement/Slag Stabilised Sand**
5) **Compaction**
6) **Steel Fibres Reinforced Concrete Slab**

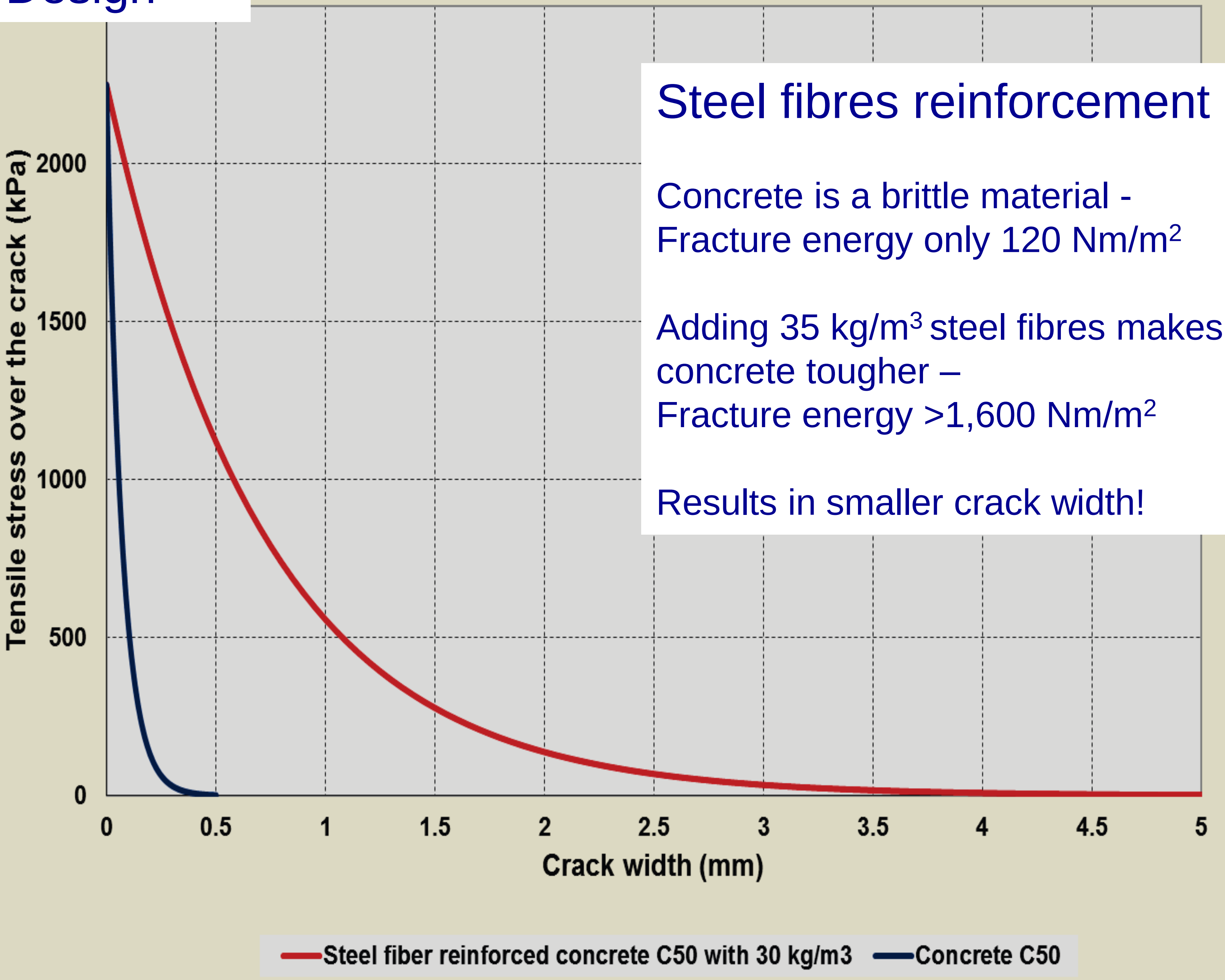


Concrete Slab, C32
Steel Fibres Reinforced 35 kg/m$^3$

3 Layers of
Stabilised Sand
300+300+400 mm

Jet-grouted Columns
D = 0.8 m

# 2. Design



## Steel fibres reinforcement

Concrete is a brittle material -
Fracture energy only 120 Nm/m$^2$

Adding 35 kg/m$^3$ steel fibres makes concrete tougher –
Fracture energy >1,600 Nm/m$^2$

Results in smaller crack width!

# 2. Design

## Design Methodology

- Highest Geotechnical Category - GC3
- Independent reviewers in GC3 according to Swedish requirements
- Advanced numerical analyses 2D and 3D FEM in ZSOIL
- Observational Method in accordance with EuroCode to avoid exceeding limit states
- Field and laboratory tests to verify material property conditions and construction work
- Test results compared to FEM calculated deflection curves based on verified material properties

# 2. Design

## Design requirements

- Bearing capacity has to be verified in ULS and SLS
- ULS - to ensure adequate security against material failure
- SLS - to limit fractures and deformations
- Pallet rack loads and truckloads are variable loads
- Maximum acceptable inclination difference at loading $0.5 \times 10^{-3}$ in SLS

# 2. Design

## Safety principles

- Non-linear 3D FEM analyses to calculate bearing capacity of geotechnical structures

- Mean values as input data

- Safety verification with global safety factor $\gamma_{Rg}$

  $\gamma_{Rg} = \exp(\alpha_R \beta V_R)$
  $\alpha_R$ = sensitivity factor for bearing capacity R
  $\beta$ = safety index

Here

$\alpha_R = 0.8$ - Conservative value
$\beta = 4.3$ - Swedish requirement

# 2. Design

## Safety principles

Overall uncertainty $V_R$ related to bearing capacity R:

$V_R = (V_f^2 + V_C^2)^{0.5}$ where

$V_f$ = coefficient of variation for **bearing capacity**
$V_c$ = coefficient of variation for **model uncertainty**

$V_f = (1/1.65) \times \ln (R_m/R_k)$ where

$R_m$ = Mean value of bearing capacity
$R_k$ = Characteristic value of bearing capacity

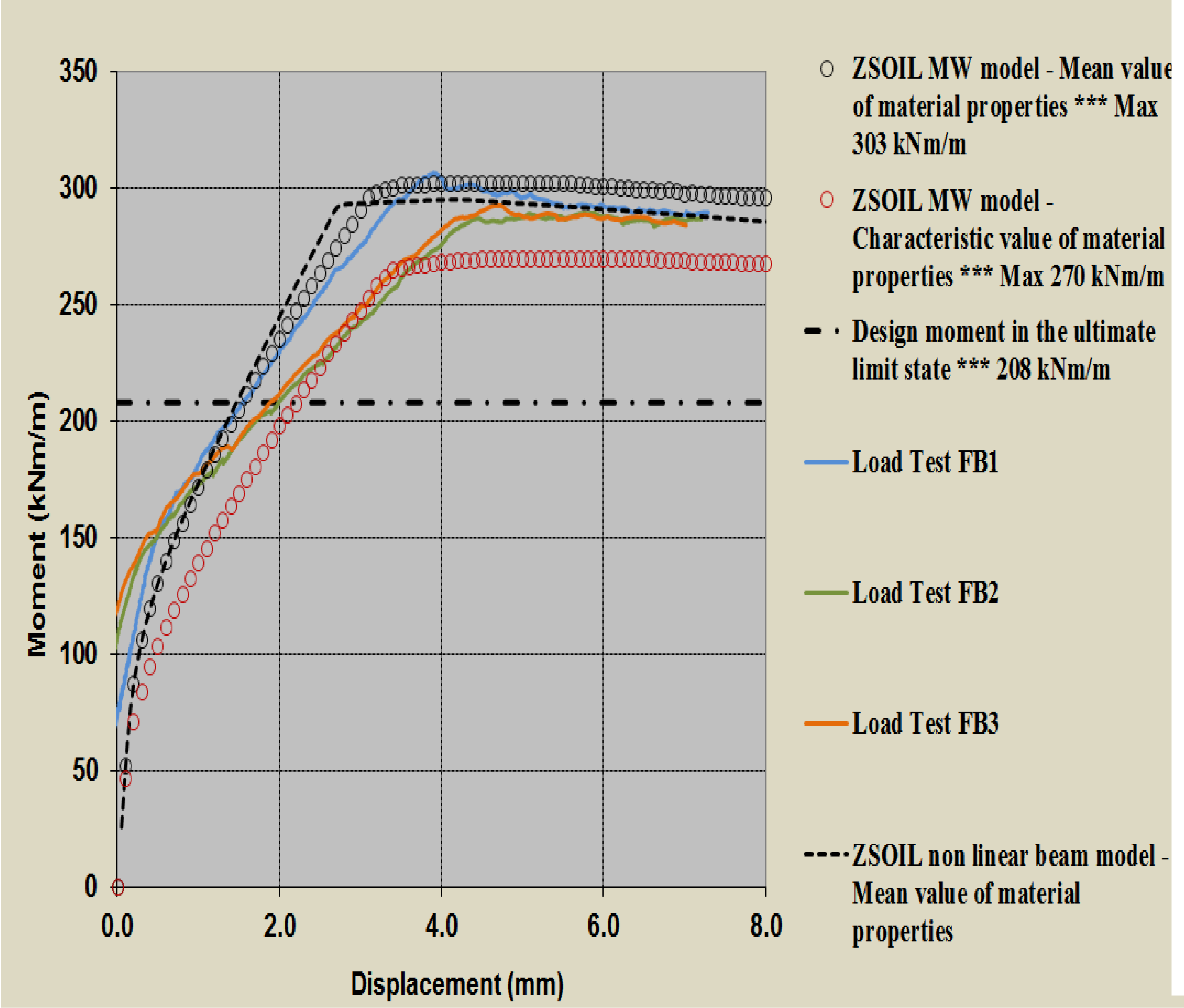
# 2. Design

## Safety principles

$V_c$ for Model uncertainty - Three criteria must be fulfilled:

- $V_C$ = 7 % may be adopted when bearing capacity of concrete slab is **calculated** and when bearing capacity of soil, stabilised soil and jet-grouted columns is **inspected**
- Partial coefficient $\gamma_m$ = 1.0 in SLS
- Model factor $\gamma_{Rd}$ = 1.3 applied on calculated displacement and inclination difference

# 2. Design



## FEM Analyses

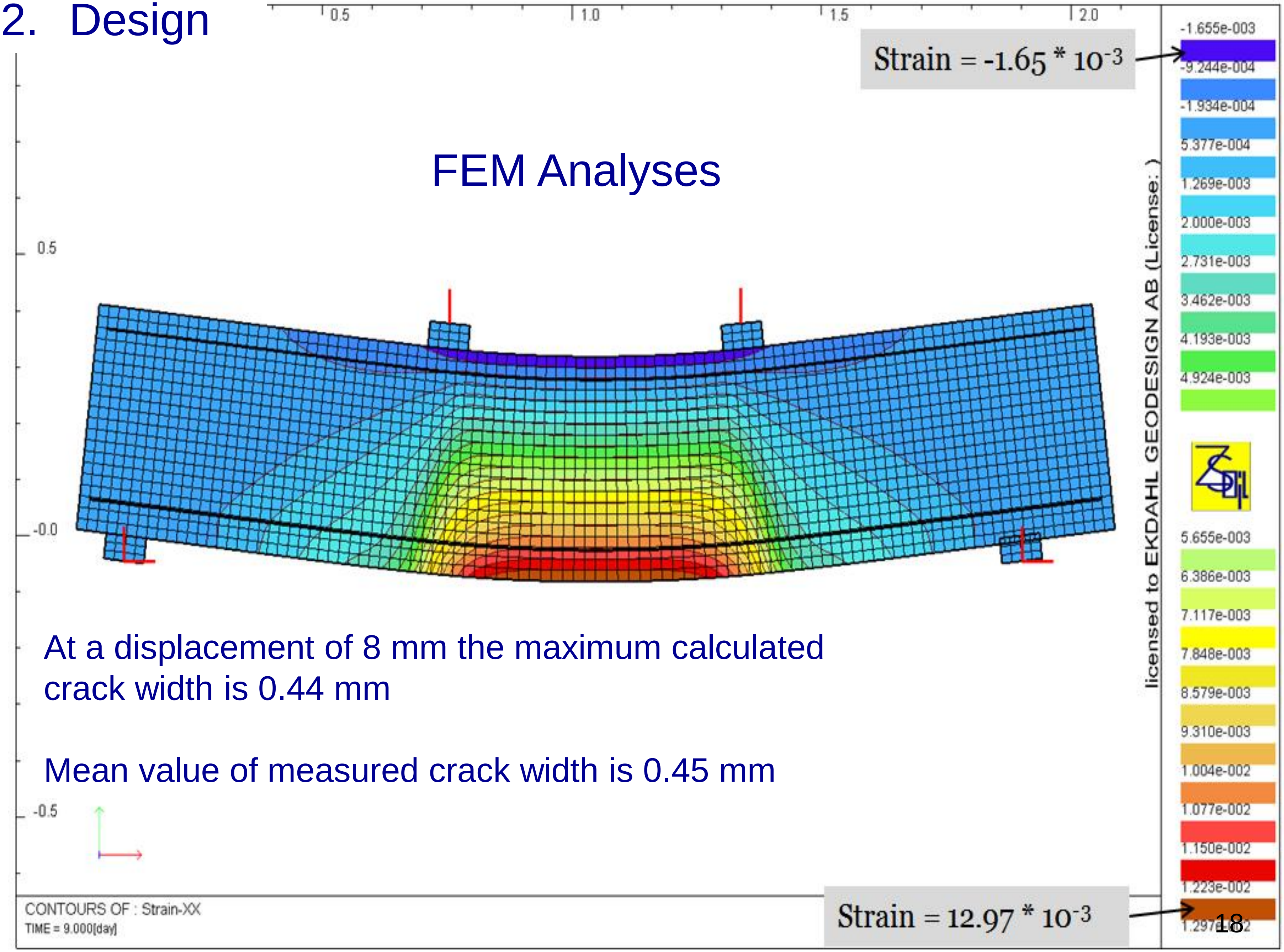
FEM-analyses incl. a Deformation-Softening Model (DSM) to calculate fracturing of concrete

Validation of the DSM by comparing predicted behaviour with results from laboratory tests on concrete steel fibres reinforced beams

Predicted crack widths are consistent with those measured!

# 2. Design

## FEM Analyses



At a displacement of 8 mm the maximum calculated crack width is 0.44 mm

Mean value of measured crack width is 0.45 mm

# 2. Design

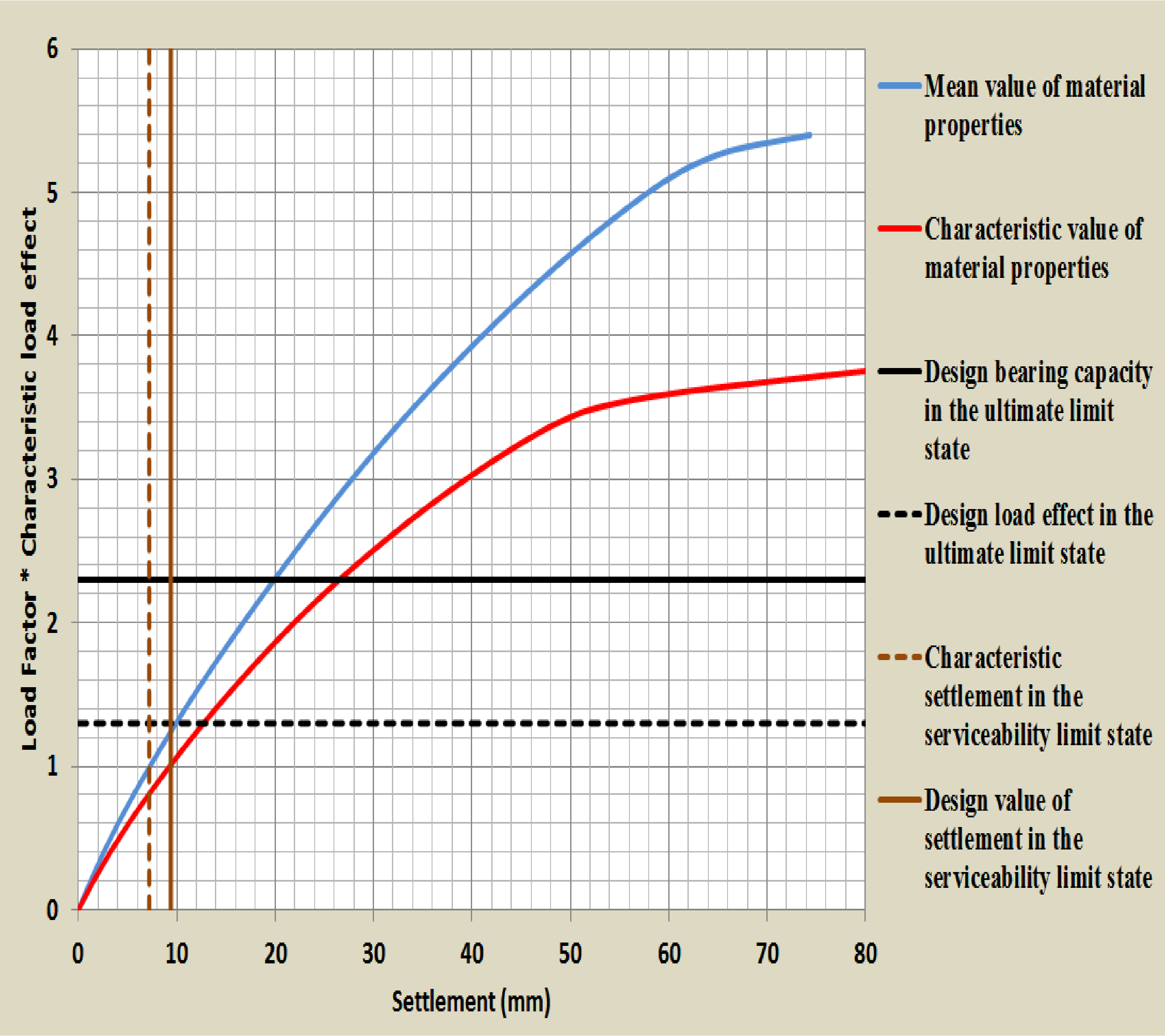
## FEM Analyses

3D-FEM analyses of bearing capacity in ULS and design settlement in SLS

Design bearing capacity is 2.3 times design load effect

Largest calculated design displacement in SLS = 9.4 mm

Largest calculated design inclination difference in SLS = $0.07 \times 10^{-3}$



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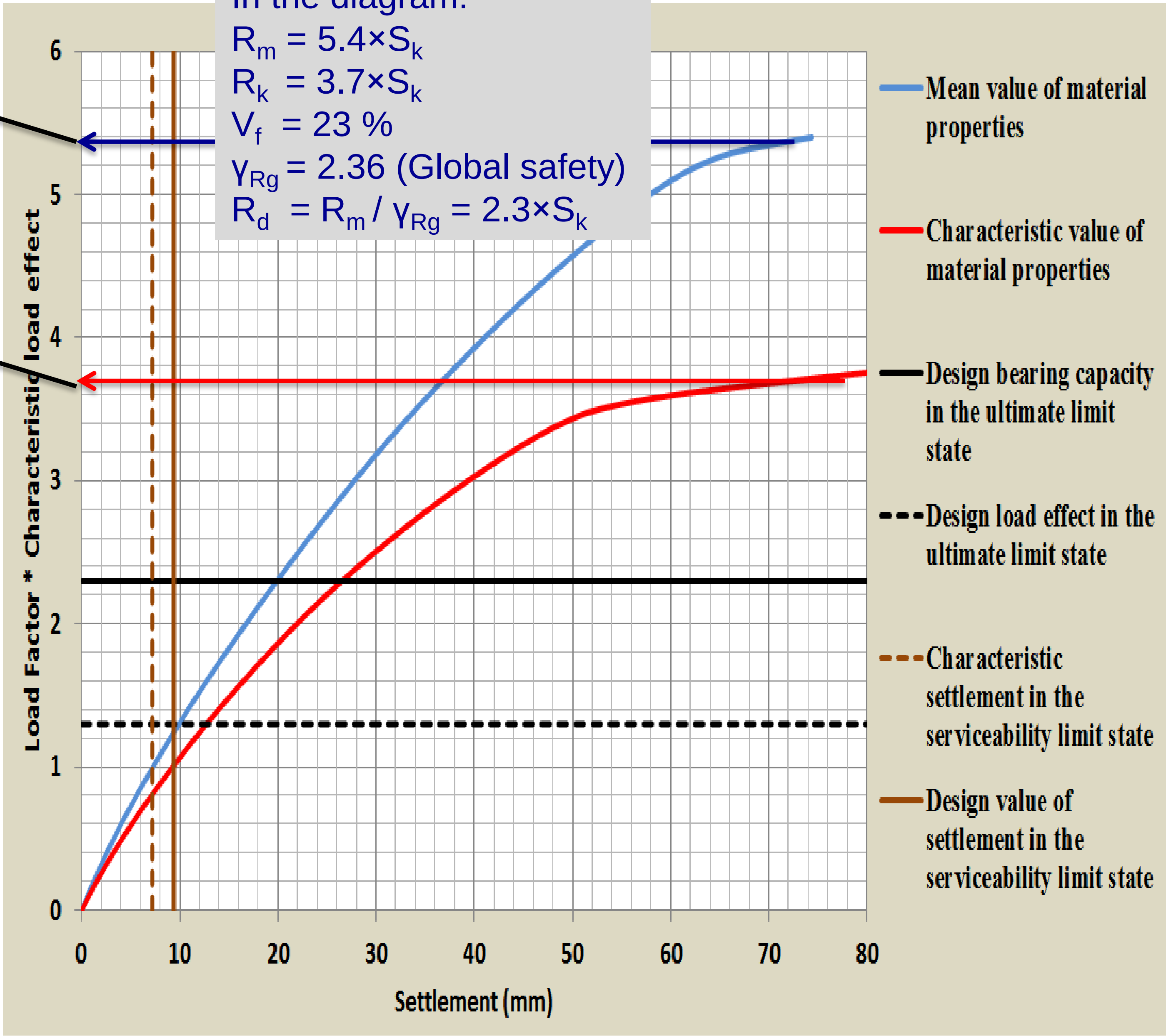
In the diagram:
$R_m$ = 5.4×$S_k$
$R_k$ = 3.7×$S_k$
$V_f$ = 23 %
$\gamma_{Rg}$ = 2.36 (Global safety)
$R_d$ = $R_m$ / $\gamma_{Rg}$ = 2.3×$S_k$



# 3. Work and Control Plan

**Work Performance Stages**

- Spreading of sand
- Layer Elevation Adjustment
- Stabilisation and Watering
- Milling and Watering
- Levelling and Compaction incl. CCC

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**Control**

- Water Content Control
- Control of Stabilising Material
- Water Content Control
- Elevation Control
- Control of Air Voids < 5 %
- Control that Characteristic Compression Strength > 2.0 MPa

**OK**

# 4. Conclusions

Factors that made it feasible:

- Input parameters of the material model are directly linked to field tests where design parameters are validated in-situ during work performance – Presumption for the Observational Method
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- Advanced non-linear analyses
- Observational Method with accurate planning including
    - Meticulous design, 2D and 3D FEM analyses
    - Field & Laboratory tests
    - Reviewing procedure
    - Pre-testing
    - Control at site before-during-after work operations

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**And maybe most important:**

- **Inter-active Communication between:**

**Client - Contractor - Engineers - Workmen**

# One obvious conclusion: Happy Engineers