# GUIDELINES

# FIXATION REQUIREMENT IN TUNNELS

**TABLE OF CONTENT**

# 1 Standards

## 1.1 Standards

[S1] Euro Code 0 (Basis of structural design)
[S2] Euro Code 1 (Actions on structures)
[S3] Euro Code 2 (Concrete design)
[S4] Euro Code 3 (Design of steel structures)
[S5] Euro Code 7 (Geotechnical design)
[S6] Euro Code 8 (Design of structures for earthquake resistance)
[S7] BS EN 14651: Test method for metallic fibre concrete. Measuring the flexural tensile strength (limit of proportionality (LOP), residual), 2005
[S8] BS EN 14889-1: Fibres for concrete- Part 1: Steel fibres, 2006

## 1.2 Software

[SW1] SOFISTIK, the structural analysis is performed with the 2D plane frame and the aid of the finite element program in 2D and 3D “Sofistik” (Sofistik AG, Germany).
As a graphical user interface, the program “WinTube” (Fides & partners, Germany) is used according to Sofistik AG; User Manual.
[SW2] DC-Software Package Soil Engineering, www.dc-software.de
[SW3] CONDIM - dimensioning by EN 1992-1-1 and EN 1992-1-1/NA

## 1.3 Related Project Documents

[PD1] Employer’s Requirements; Vol. 1 - 11
[PD2] M008-D2C-TUN-RPT-00001; Design Criteria Report; Rev. 3
[PD3] M008-PSH-TUN-RPT-00001; Durability Report – Bored Tunnel
[PD4] M008-PSH-STR-RPT-00001; Durability Report – Stations, Shafts & In-situ Tunnels
[PD5] M008-PSH-TUN-RPT-00002; Fire Design Report
[PD6] M008-PSH-STR-SPE-00001; Specifications to Concrete Structures

# 2 List of abbreviations and design parameters

## 2.1 Abbreviations

EN : European Norm
BS : British Standards
DIN : German Institution for Normalization
fib : International Federation for Structural Concrete (created from the merger of CEB and FIP)
MC : Model Code
RILEM : International Union of Laboratories and Experts in Construction Materials, Systems and Structures
ULS : ultimate limit state
SLS : serviceability limit state
RC : reinforced concrete
SFRC : steel fibre reinforcement concrete
CMOD : crack mouth opening displacement
LOP : limit of proportionality
TBM : tunnel boring machine
LRRS : left/right ring system
PGA : peak ground acceleration
MSV : multi-service vehicle load
LC : load combination
GWT : ground water table
GIR : geotechnical investigation report
FEM : Finite Element Method
SL : Simsima Limestone

## 2.2 Design parameters

$E_{cm}$ : Young's modulus of concrete
$\nu$ : Poisson's ratio
$f_c$ : cylinder compressive strength of concrete
$f_{cm}$ : mean value of compressive strength of concrete
$f_{ck}$ : characteristic value of compressive strength of concrete
$f_{cd}$ : design value of compressive strength of concrete
$f_{ct}$ : axial tensil strength of concrete
$f_{ctm}$ : mean value of axial tensile strength of concrete
$f_{ctk}$ : characteristic value of axial tensil strength of concrete
$f_{ctd}$ : design value of axial tensil strength of concrete
$f_{ct,fl}$ : flextural tensile strength
$f_{yk}$ : steel fibre yield stress
$f_L$ : limit of proportionality
$f_{R,j}$ : residual flexural tensile strength of fibre reinforced concrete corresponding to CMOD
$f_{R1k}$ : characteristic residual strength of fibre reinforced concrete significant for serviceability conditions
$f_{R3k}$ : characteristic residual strength of fibre reinforced concrete significant for ultimate conditions
4c : SFRC classification ($4<f_{R1k}<5$, $0.9<f_{R3k}/f_{R1k}<1.1$)

# 3 SCOPE

The aim of this requirement is the determination of the limitation for any fixation of tunnel services for both, temporary and permanent services. The requirement, or respectively the given limitation is mandatory to all temporary and permanent fixation for tunnel services, and provides constraints for the following:

- Maximum drilling diameter
- Allowed drilling depth
- Maximum pull out forces and shear resistance
- Limitation of clear distance between the drillings
- Definition of non-drilling lining areas.

Concrete types are C50/60 and C40/50, as may be used for the segmental tunnel lining.

# 4 DEFINITION FOR LIMITATION REQUIREMENT

## 4.1 Maximum Drilling Diameter

Drilling diameter is up to 18mm while bolts diameter is up to 16mm. Drilling tests on steel fibre reinforced concrete segment are recommended to examine the possible cracks.

## 4.2 Allowed effective anchorage/embedment depth $h_{ef}$

Allowed effective anchorage/embedment depth $h_{ef}$ is up to 200mm.

## 4.3 Allowed drilling depth $h_{dr}$

Allowed drilling depth $h_{dr}$ is up to 220mm (i.e. 10% exceed of anchorage depth $h_{ef}$)

## 4.4 Maximum pull out force and shear resistance

For C50/60 concrete, maximum pull out force is 40kN, and shear resistance is 11kN, see HILTI calculation results in chapter 5.

For C40/50 concrete, maximum pull out force is 40kN, and shear resistance is 10kN, see HILTI calculation results in chapter 6.

## 4.5 Limitation of clear distance between the drillings

The clear distance between the drillings is at least 200mm.

## 4.6 Definition of non-drilling lining areas

All drilling holes must be at least 150mm from the segment edges.

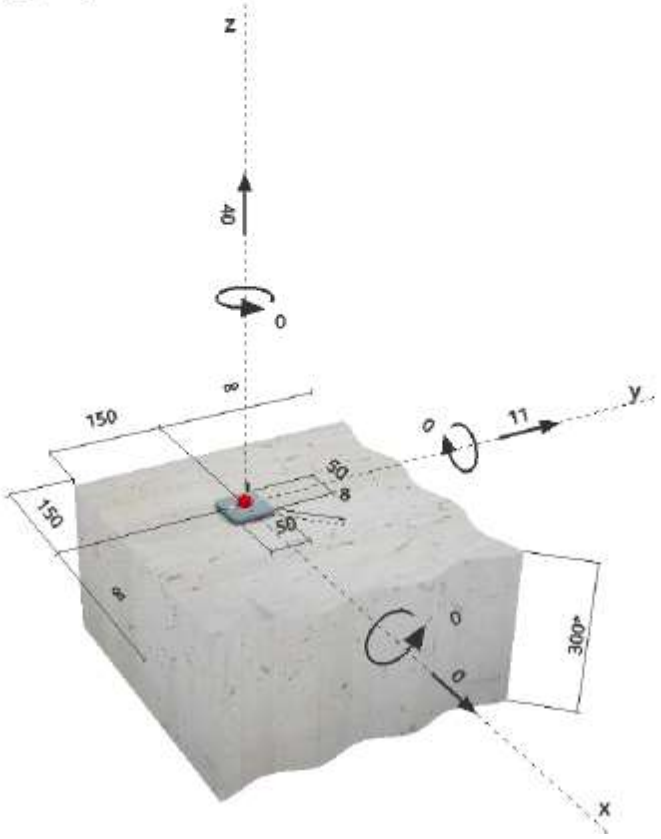
# HILTI CALCULATION RESULTS with C50/60 CONCRETE

## 5.1 Input Data

### 1 Input data

| | |
|---|---|
| **Anchor type and size:** | **HIT-RE 500 V3 + Rebar 16mm** |
| Effective embedment depth: | $h_{ef,act}$ = 200 mm ($h_{ef,limit}$ = - mm) |
| Material: | B500B |
| Approval No.: | ETA 16/0143 |
| Issued I Valid: | 18.04.2016 \| - |
| Proof: | Design method ETAG BOND (EOTA TR 029) |
| Stand-off installation: | $e_b$ = 0 mm (no stand-off); t = 8 mm |
| Baseplate: | S 235 (St 37); E = 210000,00 N/mm²; $f_{yk}$ = 235,00 N/mm²; $\gamma_{Mo}$ = 1,100<br>$l_x$ x $l_y$ x t = 50 mm x 50 mm x 8 mm; (Recommended plate thickness: calculated (8 mm)) |
| Profile: | no profile |
| Base material: | cracked concrete, C50/60, $f_{cc}$ = 60,00 N/mm²; h = 300 mm, Temp. short/long: 40/24 °C |
| **Installation:** | **hammer drilled hole, installation condition: Dry** |
| Reinforcement: | No reinforcement or Reinforcement spacing >= 150 mm (any Ø) or >= 100 mm (Ø <= 10 mm)<br>no longitudinal edge reinforcement |

**Geometry [mm] & Loading [kN, kNm]**



## 5.2 Load Case/Resulting Anchor Forces

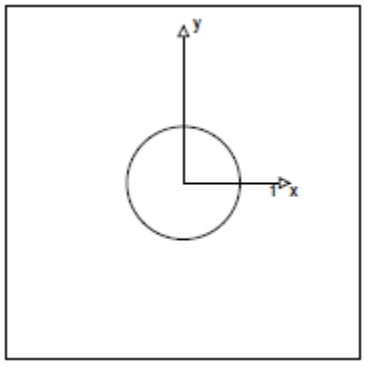
### 2 Load case/Resulting anchor forces

Load case: Design loads

**Anchor reactions [kN]**
Tension force: (+Tension, -Compression)

| Anchor | Tension force | Shear force | Shear force x | Shear force y |
|---|---|---|---|---|
| 1 | 40,000 | 11,000 | 0,000 | 11,000 |

max. concrete compressive strain: - [‰]
max. concrete compressive stress: - [N/mm²]
resulting tension force in (x/y)=(0/0): 40,000 [kN]
resulting compression force in (x/y)=(0/0): 0,000 [kN]




## 5.3 Tension Load

| | Load [kN] | Capacity [kN] | Utilisation $\beta_N$ [%] | Status |
|---|---|---|---|---|
| Steel failure* | 40,000 | 79,286 | 51 | OK |
| Combined pullout-concrete cone failure** | 40,000 | 44,747 | 90 | OK |
| Concrete cone failure** | 40,000 | 50,281 | 80 | OK |
| Splitting failure** | 40,000 | 48,570 | 83 | OK |

* most unfavourable anchor **anchor group (anchors in tension)

## 5.4 Shear Load

| | Load [kN] | Capacity [kN] | Utilisation $\beta_V$ [%] | Status |
|---|---|---|---|---|
| Steel failure (without lever arm)* | 11,000 | 36,667 | 31 | OK |
| Steel failure (with lever arm)* | N/A | N/A | N/A | N/A |
| Pryout failure** | 11,000 | 89,493 | 13 | OK |
| Concrete edge failure in direction x-** | 11,000 | 57,908 | 19 | OK |

* most unfavourable anchor **anchor group (relevant anchors)

## 5.5 Combined Tension and Shear Loads

| $\beta_N$ | $\beta_V$ | $\alpha$ | Utilisation $\beta_{NV}$ [%] | Status |
|---|---|---|---|---|
| 0,894 | 0,300 | 1,000 | 100 | OK |

$(\beta_N + \beta_V) / 1.2 \leq 1$

## 5.6 Displacements (Highest Loaded Anchor)

Short term loading:

$N_{Sk}$ = 29,630 [kN] $\delta_N$ = 0,295 [mm]
$V_{Sk}$ = 8,148 [kN] $\delta_V$ = 0,326 [mm]
$\delta_{NV}$ = 0,439 [mm]

Long term loading:

$N_{Sk}$ = 29,630 [kN] $\delta_N$ = 0,472 [mm]
$V_{Sk}$ = 8,148 [kN] $\delta_V$ = 0,469 [mm]
$\delta_{NV}$ = 0,679 [mm]

Comments: Tension displacements are valid with half of the required installation torque moment for uncracked concrete! Shear displacements are valid without friction between the concrete and the baseplate! The gap due to the drilled hole and clearance hole tolerances are not included in this calculation!

The acceptable anchor displacements depend on the fastened construction and must be defined by the designer!

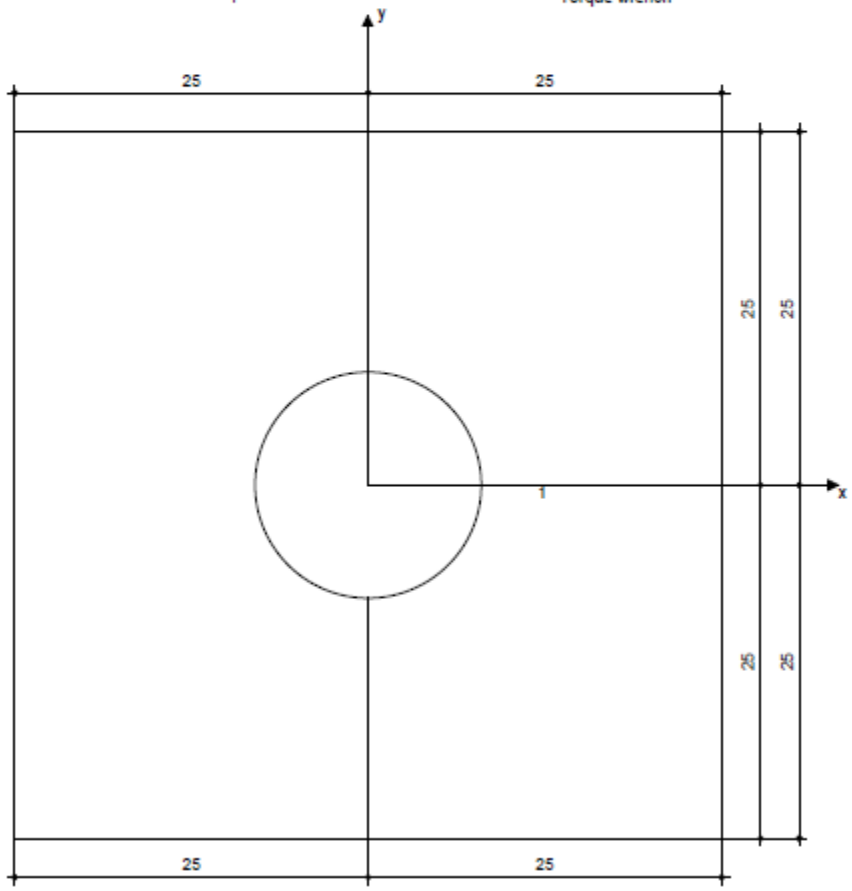
## 5.7 Installation Data

Baseplate, steel: S 235 (St 37); E = 210000,00 N/mm²; $f_{yk}$ = 235,00 N/mm²
Profile: no profile
Hole diameter in the fixture: $d_f$ = 16 mm
Plate thickness (input): 8 mm
Recommended plate thickness: calculated (8 mm)
Drilling method: Hammer drilled
Cleaning: Compressed air cleaning of the drilled hole according to instructions for use is required

Anchor type and size: HIT-RE 500 V3 + Rebar 16mm
Installation torque: -
Hole diameter in the base material: 20 mm
Hole depth in the base material: 200 mm
Minimum thickness of the base material: 240 mm

**8.1 Recommended accessories**

| Drilling | Cleaning | Setting |
|---|---|---|
| • Suitable Rotary Hammer<br>• Properly sized drill bit | • Compressed air with required accessories to blow from the bottom of the hole<br>• Proper diameter wire brush | • Dispenser including cassette and mixer<br>• For deep installations, a piston plug is necessary<br>• Torque wrench |




**Coordinates Anchor [mm]**

| Anchor | x | y | $c_{-x}$ | $c_{+x}$ | $c_{-y}$ | $c_{+y}$ |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 150 | - | 150 | - |

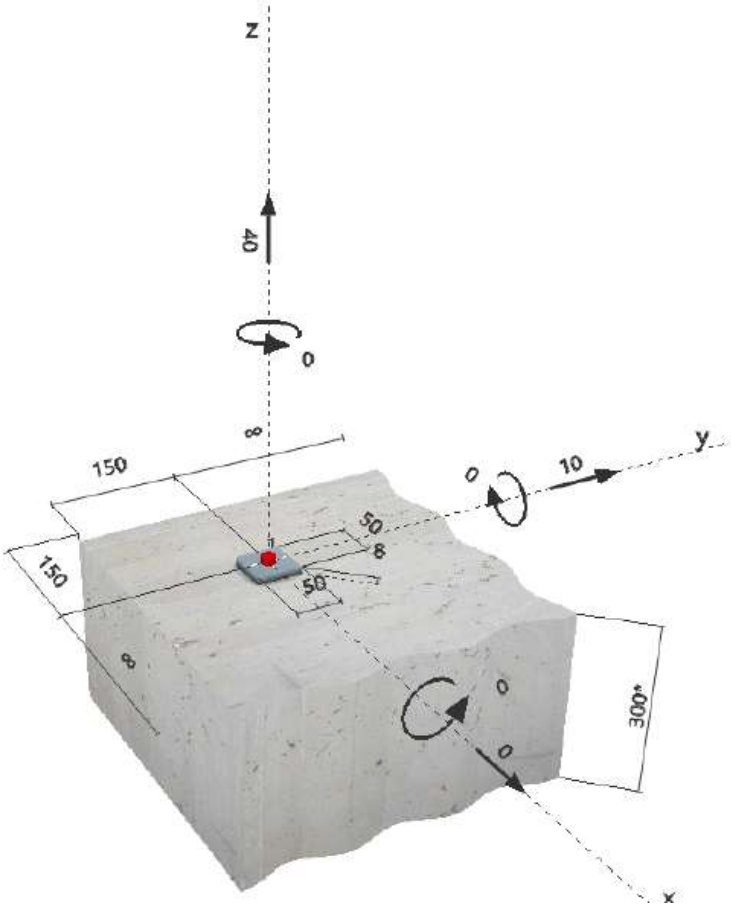
# HILTI CALCULATION RESULTS with C40/50 CONCRETE

## 6.1 Input Data

### 1 Input data

| | |
|---|---|
| **Anchor type and size:** | **HIT-RE 500 V3 + Rebar 16mm** |
| Effective embedment depth: | $h_{ef,act}$ = 200 mm ($h_{ef,limit}$ = - mm) |
| Material: | B500B |
| Approval No.: | ETA 16/0143 |
| Issued I Valid: | 18.04.2016 \| - |
| Proof: | Design method ETAG BOND (EOTA TR 029) |
| Stand-off installation: | $e_b$ = 0 mm (no stand-off); t = 8 mm |
| Baseplate: | S 235 (St 37); E = 210000,00 N/mm²; $f_{yk}$ = 235,00 N/mm²; $\gamma_{Ms}$ = 1,100<br>$l_x$ x $l_y$ x t = 50 mm x 50 mm x 8 mm; (Recommended plate thickness: calculated (8 mm)) |
| Profile: | no profile |
| Base material: | cracked concrete, C40/50, $f_{cc}$ = 50,00 N/mm²; h = 300 mm, Temp. short/long: 40/24 °C |
| **Installation:** | **hammer drilled hole, Installation condition: Dry** |
| Reinforcement: | No reinforcement or Reinforcement spacing >= 150 mm (any Ø) or >= 100 mm (Ø <= 10 mm)<br>no longitudinal edge reinforcement |

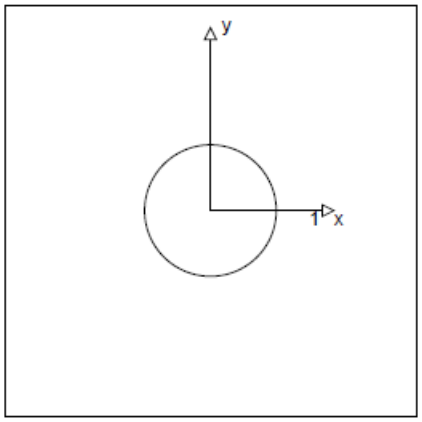
**Geometry [mm] & Loading [kN, kNm]**



## 6.2 Load Case/Resulting Anchor Forces

### 2 Load case/Resulting anchor forces

Load case: Design loads




**Anchor reactions [kN]**

Tension force: (+Tension, -Compression)

| Anchor | Tension force | Shear force | Shear force x | Shear force y |
|---|---|---|---|---|
| 1 | 40,000 | 10,000 | 0,000 | 10,000 |

max. concrete compressive strain: - [‰]
max. concrete compressive stress: - [N/mm²]
resulting tension force in (x/y)=(0/0): 40,000 [kN]
resulting compression force in (x/y)=(0/0): 0,000 [kN]

## 6.3 Tension Load

| | Load [kN] | Capacity [kN] | Utilisation $\beta_N$ [%] | Status |
|---|---|---|---|---|
| Steel failure* | 40,000 | 79,286 | 51 | OK |
| Combined pullout-concrete cone failure** | 40,000 | 43,938 | 92 | OK |
| Concrete cone failure** | 40,000 | 45,900 | 88 | OK |
| Splitting failure** | 40,000 | 44,338 | 91 | OK |

* most unfavourable anchor **anchor group (anchors in tension)

## 6.4 Shear Load

| | Load [kN] | Capacity [kN] | Utilisation $\beta_V$ [%] | Status |
|---|---|---|---|---|
| Steel failure (without lever arm)* | 10,000 | 36,667 | 28 | OK |
| Steel failure (with lever arm)* | N/A | N/A | N/A | N/A |
| Pryout failure** | 10,000 | 87,876 | 12 | OK |
| Concrete edge failure in direction x-** | 10,000 | 52,863 | 19 | OK |

* most unfavourable anchor **anchor group (relevant anchors)

## 6.5 Combined Tension and Shear Loads

| $\beta_N$ | $\beta_V$ | $\alpha$ | Utilisation $\beta_{N,V}$ [%] | Status |
|---|---|---|---|---|
| 0,910 | 0,273 | 1,000 | 99 | OK |

$(\beta_N + \beta_V) / 1.2 \leq 1$

## 6.6 Displacements (Highest Loaded Anchor)

Short term loading:

$N_{Sk}$ = 29,630 [kN] $\delta_N$ = 0,295 [mm]
$V_{Sk}$ = 7,407 [kN] $\delta_V$ = 0,296 [mm]
$\delta_{NV}$ = 0,418 [mm]

Long term loading:

$N_{Sk}$ = 29,630 [kN] $\delta_N$ = 0,472 [mm]
$V_{Sk}$ = 7,407 [kN] $\delta_V$ = 0,444 [mm]
$\delta_{NV}$ = 0,648 [mm]

Comments: Tension displacements are valid with half of the required installation torque moment for uncracked concrete! Shear displacements are valid without friction between the concrete and the baseplate! The gap due to the drilled hole and clearance hole tolerances are not included in this calculation!

The acceptable anchor displacements depend on the fastened construction and must be defined by the designer!