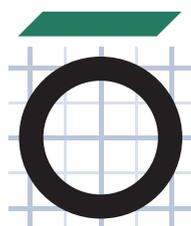


**ITAtech GUIDELINES ON STANDARD INDICATION OF LOAD CASES FOR
CALCULATION OF RATING LIFE (L_{10}) OF TBM MAIN BEARINGS**

ITAtech Activity Group
Excavation

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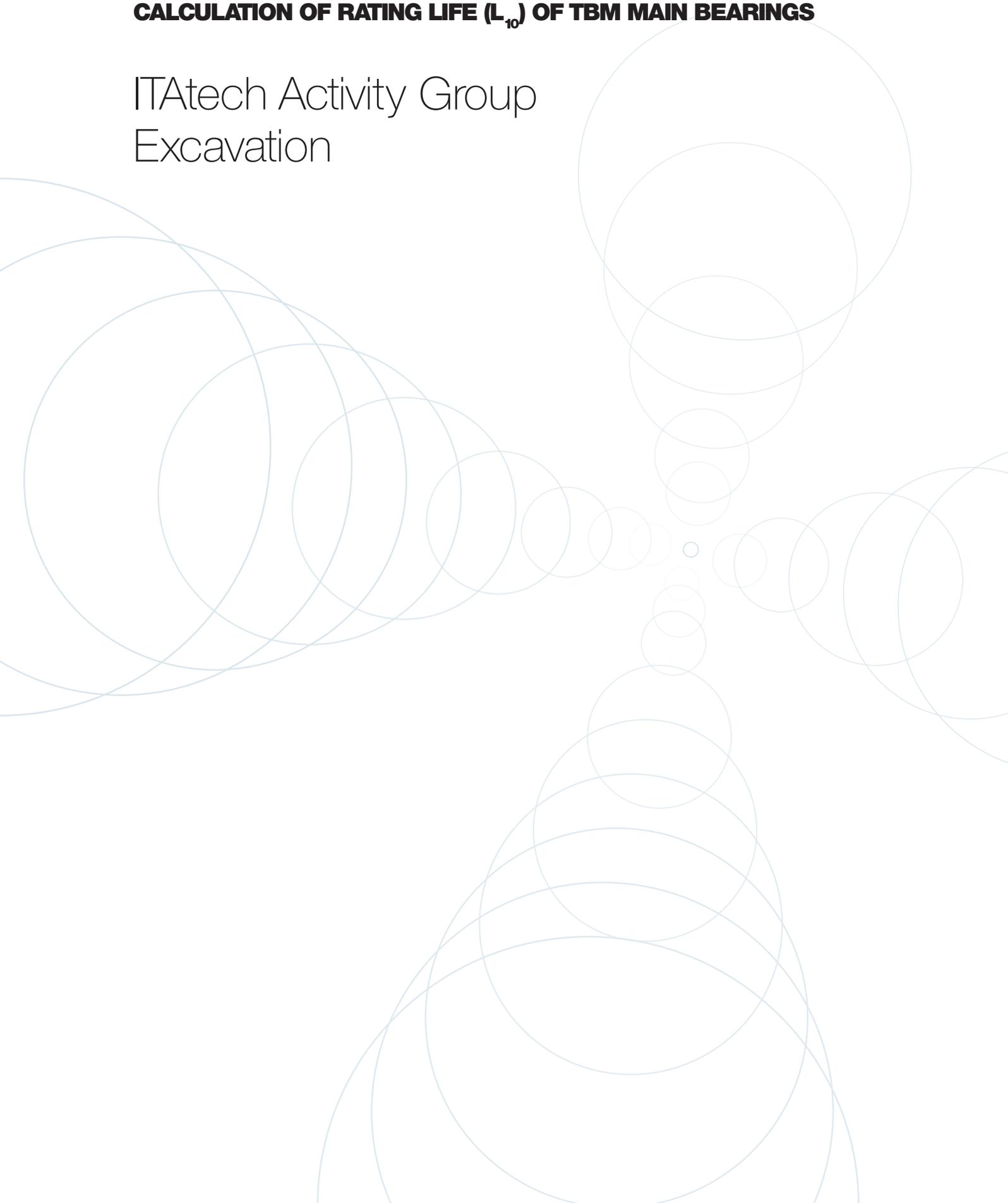
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ITAtech

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1.	INTRODUCTION	P 5
2.	DEFINITION OF RATING LIFE (L_{10}).....	P 5
3.	THE RATING LIFE (L_{10}) EQUATION.....	P 5
4.	CUTTERHEAD SPEED	P 5
5.	TBM MAIN BEARING LOADS	P 5
6.	TBM MAIN BEARING SAFETY FACTOR.....	P 7
7.	APPENDIX.....	P 8

1. INTRODUCTION

Tunnel owners, consultants, and contractors require assurance of adequate Main Bearing L_{10} Life for Tunnel Boring Machines with rotary cutterheads. This document sets out a standardized method of indicating the Main Bearing Load Assumptions. It provides a common baseline to facilitate the comparison of load assumptions and therefore the resulting L_{10} bearing lives offered by various tunneling machine manufacturers.

The document includes a standard template for presenting the bearing load cases and gives guidance for their evaluation as well as a definition to determine the TBM main bearing “safety factor”.

The document contains examples of typical standard bearing load evaluation methods of the following machine types for hard rock (A and B) and soft ground (C and D):

- A. Gripper TBM,
- B. Shielded Rock TBM, Single Shield or Double Shield (SS, DS)
- C. Earth Pressure Balance TBM (EPB)
- D. Slurry TBM (STBM)

2. DEFINITION OF RATING LIFE (L_{10})

The Rating Life is defined in ISO recommendation R281 and adopted worldwide as follows:

The rating life of a sufficiently large number of dimensionally identical bearings is expressed by the number of revolutions (or number of hours at constant speed) reached or exceeded by 90% of this bearing group before the first signs of material fatigue appear.

3. THE RATING LIFE (L_{10}) EQUATION

$$L_{10} = (C/P)^k$$

L_{10} : Rating Life in [10^6 revolutions]

C: Dynamic Load Carrying Capacity of the Bearing in [kN]

P: Applied Load in [kN]

K: for Roller Bearings =10/3

4. CUTTERHEAD SPEED

To convert the Rating Life into hours a certain cutterhead speed must be considered as follows:

$$n = V/\pi D$$
$$\text{Life in Hours} = L_{10} / 60 \times n$$

n: Cutterhead rotational speed in revolutions per minute [min^{-1}]

V: Velocity of the last gage cutter in [m/min]

Typical values (example):

For Hard Rock TBMs (A and B): $v = 150 - 185 \text{ m/min}$

For Soft Ground TBMs (C and D): $v = 15 - 30 \text{ m/min}$

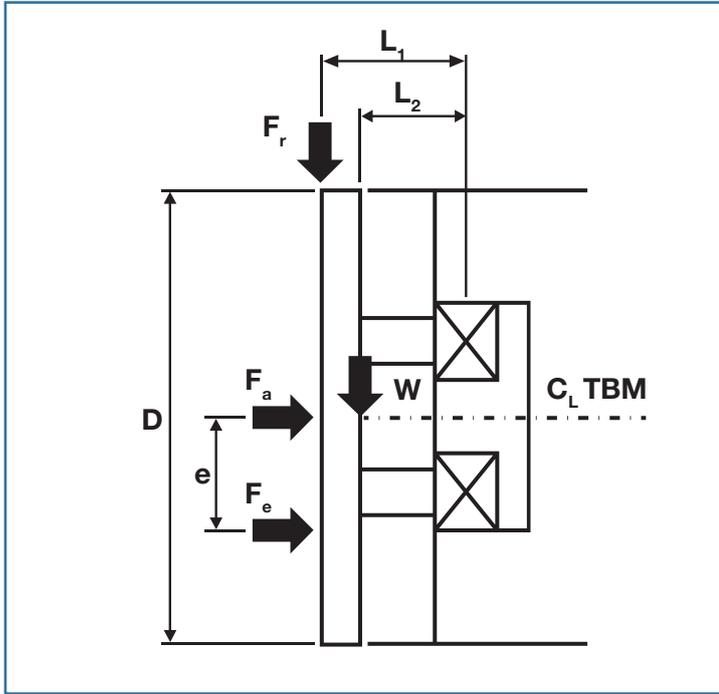
D: Cutterhead Diameter in [m]

5. TBM MAIN BEARING LOADS

In operation a TBM cutterhead is subject to a variety of loads and load combinations. Assuming a typical TBM cutterhead bearing / drive design based on a large diameter slew bearing, the final bearing load cases are presented as a combination of axial loads (F_a, F_θ), radial loads (F_r, W) and tilting moments. The tilting moments are a result of the axial or radial loads and their relevant moment arms (e, L_1, L_2) which are based on geometrical TBM design parameters, such as TBM diameter (eccentricity) or bearing to face distance.

In order to achieve a lifetime result in hours of operation, each load combination or loadcase has to be combined with an anticipated cutterhead speed and percentage of the total operation time.

If a gear calculation based on the same loadcase distribution is required the anticipated cutterhead operational torque “ T_c ” shall be additionally indicated in the load table.



LC : Load case [-]

F_a : Axial load (centric) [kN]

F_e : Axial load eccentric [kN]

F_r : Operational radial load [kN]

W : Own weight [kN]

e : Eccentricity of F_e [m]

L_1 : Moment arm operational radial load F_r [m]

L_2 : Moment arm of own weight W [m]

T_c : Cutterhead torque [kNm] ⁽¹⁾

n : Cutterhead speed [min⁻¹]

o : Duration of operation [%]

⁽¹⁾ Cutterhead torque is optional, depending on evaluation method not required for main bearing life L_{10} calculation.

TYPICAL TABLE INPUT LOADS :

LC	F_a [kN]	F_e [kN]	F_r [kN]	W [kN]	e [m]	T_c [kNm]	n [min ⁻¹]	o [%]
I						(1)		
II						(1)		
...						(1)		
...							-	stat.

RESULTING SUMMARY TABLE BEARING LOADS :

LC	$F_a + F_e$ Σ axial load [kN]	$F_r + W$ Σ radial load [kN]	$F_e \cdot e + F_r \cdot L_1 + W \cdot L_2$ Σ tilting moment [kNm]	T_c [kNm]	n [min ⁻¹]	o [%]
I				(1)		
II				(1)		
...				(1)		
...					-	stat.

Remarks

- a) A minimum of two dynamic load cases should be considered (eg. typical rock TBM load cases 90%, 10%)
- b) Number and setting of the load cases **LC_{1-n}** and expected operational parameters should take into account the anticipated ground conditions reflecting at a minimum the homogeneous sections of different nature, the transition zones in between and if existing special conditions such as shaft walls, planned partial face excavation etc.
Example:
35% full face soft ground, closed mode
20% soil – rock transition, closed mode
45% full face rock, open mode
- c) The axial load **F_a** should include the relevant part of the face support pressure acting on the active ring area between outer and inner (if any) main bearing seal system
- d) The cutterhead own weight **W** should include all elements supported by the main bearing (cutterhead structures, tools and additional equipment such as rotary union if relevant) and should be applied at the center of gravity. Depending on the anticipated operation and cutterhead design extra allowance for muck build up or clogging shall be considered.
- e) Operational radial loads **F_r** should be applied at the tunnel face position and in case of articulated cutterhead design, based on the anticipated operational cutterhead position. If no radial loads from operation are considered to be relevant for the specific application the value of **F_r** should be set to 0.
- f) TBM designs using partial or fully articulated cutterhead – main drive configurations may address inbuilt load limitations within the main bearing load cases.
- g) The main bearing calculation note can consist of two sections and should preferably be issued by the bearing manufacturer:
 - Bearing calculation note (raceway, rollers)
 - Bolt calculation (fixation bolts)

6. TBM MAIN BEARING SAFETY FACTOR

The safety factor of a TBM main bearing is defined as the relation between calculated bearing L_{10} lifetime in hours and the anticipated cutterhead operation time for the project. For used bearings the remaining lifetime should be considered.

Example: For the sake of argument let's assume a main bearing with the calculated Rating Life (L_{10}) of 6000 hours. Based on the length and geological characteristics of the tunnel and also based on the technical specifications of the machine let's assume the tunnel excavation could be completed in 2000 hours of machine operation. In this case the implied safety factor is $6000/2000 = 3$ based on the calculated Rating Life of the main bearing. Considering the fact that the Rating Life L_{10} of the main bearing is a relatively conservative value, the actual safety factor could be well over 3.



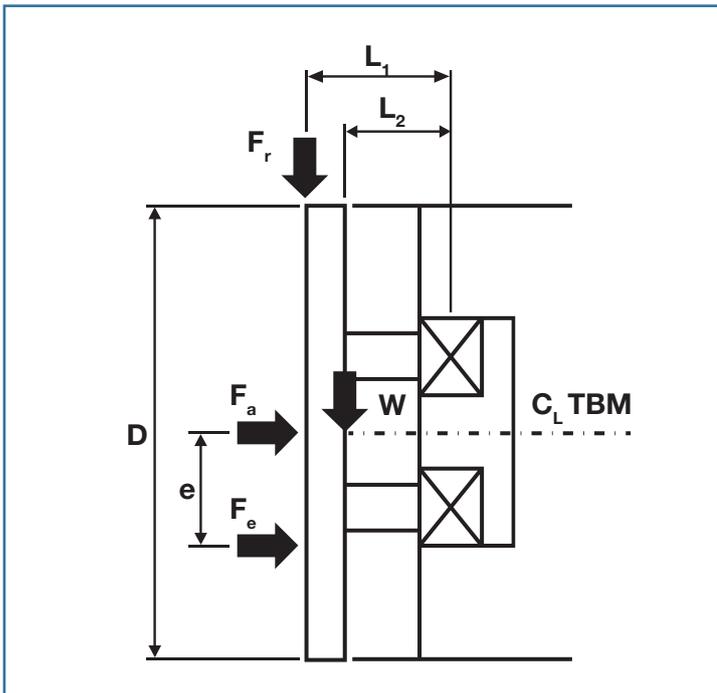
Installation of a TBM, copyright ROBBINS

>> APPENDIX - HARD ROCK TBM (GRIPPER, SS, DS)

ANNEX : TYPICAL BEARING LOAD ASSUMPTIONS AS USED IN THE INDUSTRY

A1. Hard Rock TBM (Gripper, SS, DS)

The following load assumptions may be applicable for Gripper TBMs (A) as well as Shielded Rock TBMs (B).



LC : Load case [-]

F_a : Axial load (centric) [kN]

F_e : Axial load eccentric [kN]

F_r : Operational radial load [kN]

W : Own weight [kN]

e : Eccentricity of F_e [m]

L_1 : Moment arm operational radial load F_r [m]

L_2 : Moment arm of own weight W [m]

T_c : Cutterhead torque [kNm]

n : Cutterhead speed [min^{-1}]

o : Duration of operation [%]

LC	F_a [kN]	F_e [kN]	F_r [kN]	W [kN]	e [m]	T_c [kNm]	n [min^{-1}]	o [%]
I	F_{CH}	0	0	1 x W	0	optional	max	90
II	0	F_{CH}	1 x F_r	1 x W	0,16 x D	optional	max	10
III	0	F_{CH}	0	1 x W	0,4 x D	--	--	stat.

- F_{CH} : the cutterhead thrust is defined as “total number of disc cutters” x “disc cutter load capacity”.

Example: 40 disc cutters @ 267kN
 $\rightarrow F_{CH} = 40 \times 267\text{kN} = 10.680\text{kN}$

- F_r : the operational radial load F_r (resulting from steering loads) is defined as 2 x “disc cutter load capacity”.

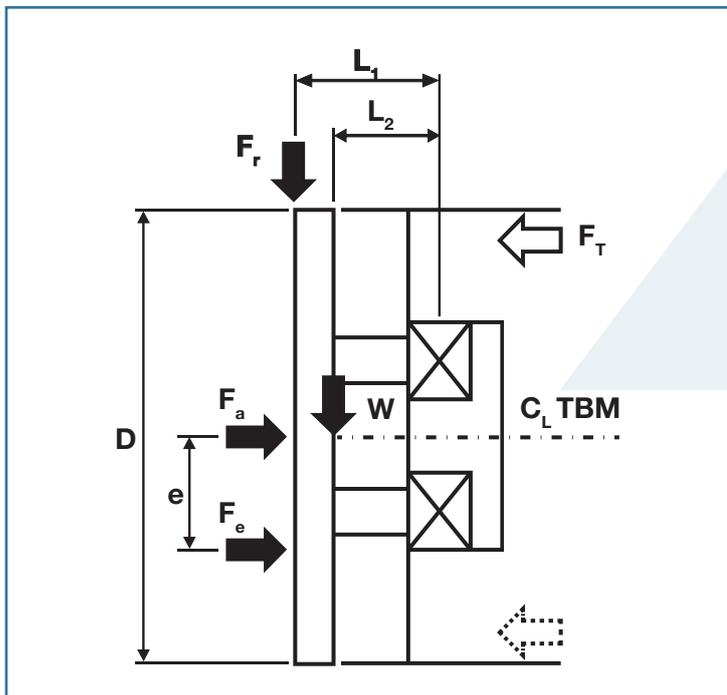
Example: disc cutter load capacity = @ 267kN
 $\rightarrow F_r = 2 \times 267\text{kN} = 532\text{kN}$

- The anticipated cutterhead torque “ T_c ” is only required in case a gear calculation should be performed.
- In load cases LC I and LC II the dynamic roller pressure allowable must not be exceeded.
- In load case LC III the static roller pressure allowable must not be exceeded.

>> APPENDIX - EARTH PRESSURE BALANCE TBM (EPB)

A2. Earth Pressure Balance TBM (EPB)

The following load assumptions may be applicable for EPB TBMs (C) as an evaluation method based on the shield diameter D.



LC : Load case [-]

F_a : Axial load (centric) [kN]

F_e : Axial load eccentric [kN]

F_r : Operational radial load [kN]

W : Own weight [kN]

e : Eccentricity of F_e [m]

L_1 : Moment arm operational radial load F_r [m]

L_2 : Moment arm of own weight W [m]

T_c : Cutterhead torque [kNm] ⁽¹⁾

n : Cutterhead speed [min⁻¹]

o : Duration of operation [%]

F_T : total equipped shield thrust [kN] ⁽¹⁾

⁽¹⁾ Shield thrust F_T typically distributed around periphery of shield structure (→ shield thrust cylinders).

For EPB without disc cutters :

LC	F_a [kN]	F_e [kN]	F_r [kN]	W [kN]	e [m]	T_c [kNm]	n [min ⁻¹]	o [%]
I	$0,126 \times F_T$	$0,088 \times F_T$	$0,026 \times F_T$	$1 \times W$	$0,125 \times D$	optional	max	90
II	$0,18 \times F_T$	$0,125 \times F_T$	$0,026 \times F_T$	$1 \times W$	$0,125 \times D$	optional	$0,5 \times \text{max}$	10
III	F_T	0	0	$1 \times W$	0	--	--	stat.

• F_T : total equipped shield thrust defined as

$$F_T = 120 \times (\pi/4) \times D^2 \times 9,81 \text{ [kN]}$$

Example: shield diameter 6,5m

$$\rightarrow F_T = 120 \times (\pi/4) \times 6,5^2 \times 9,81 = 39.063 \text{ kN}$$

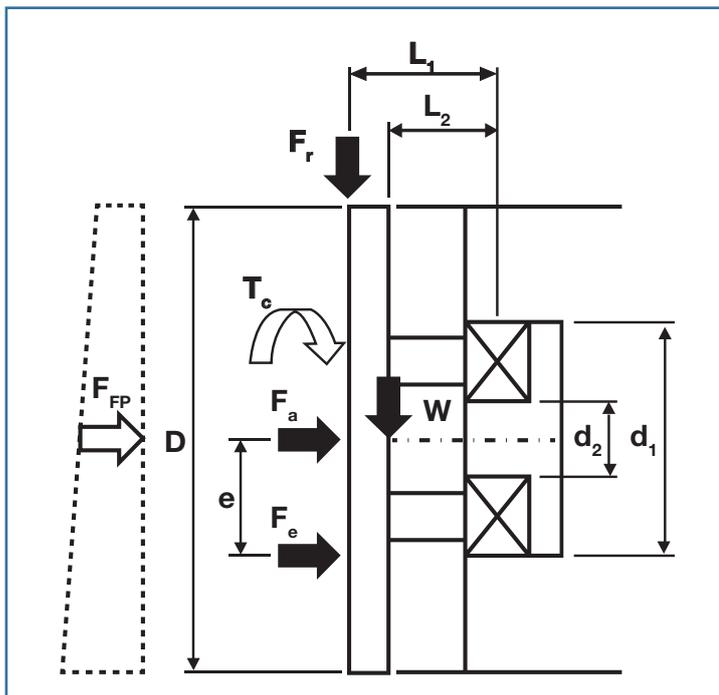
• e : for EPB cutterheads with disc cutters the eccentricity of F_e has to be increased to $0,22 \times D$.

- The anticipated cutterhead torque " T_c " is only required in case a gear calculation should be performed.
- In load cases LC I and LC II the dynamic roller pressure allowable must not be exceeded.
- In load case LC III the static roller pressure allowable must not be exceeded.

>> APPENDIX - SLURRY TBM (STBM)

A3. Slurry TBM (STBM)

The following load assumptions may be applicable for Slurry TBMs (D) and EPB TBMs (C) as an evaluation method based on the cutterhead torque T_c .



LC : Load case [-]

F_a : Axial load (centric) [kN]

F_e : Axial load eccentric [kN]

F_r : Operational radial load [kN]

W : Own weight [kN]

e : Eccentricity of F_e [m]

L_1 : Moment arm operational radial load F_r [m]

L_2 : Moment arm of own weight W [m]

T_c : Cutterhead torque [kNm]

n : Cutterhead speed [min^{-1}]

o : Duration of operation [%]

d_1 : outer diameter of drive ring [m]

d_2 : inner diameter of drive ring [m]

F_{FP} : active face support pressure at center line [kN/m^2]

LC	F_a [kN]	F_e [kN]	F_r [kN]	W [kN]	e [m]	T_c [kNm]	n [min^{-1}]	o [%]
I	$T_1 + T_2$	0 ⁽¹⁾	$2 \times T_c/D$	$1 \times W$	0 ⁽¹⁾	$1 \times T_c$	max	100
II	-	-	-	-	-	-	-	-
III	-	-	-	-	-	-	-	-

⁽¹⁾ if applicable the eccentric axial load F_e and its related eccentricity e has to be determined based on the individual project conditions.

• T_1 : thrust component due to cutterhead torque defined as

$$T_1 = 10 \times T_c / D \text{ [kN]}$$

Example: shield diameter $D = 6,5\text{m}$, cutterhead torque

$$T_c = 5000\text{kNm}$$

$$\rightarrow T_1 = 10 \times 5000 / 6,5 \text{ kN} = 7692\text{kN}$$

• T_2 : thrust component on drive ring due to support pressure

$$\text{defined as } T_2 = F_{FP} \times \pi \times (d_1^2 - d_2^2) / 4 \text{ [kN]}$$

Example: support pressure $P = 30\text{kN/m}^2$, outer diameter drive ring

$d_1 = 3\text{m}$, inner diameter drive ring $d_2 = 2\text{m}$

$$\rightarrow T_2 = 30 \times \pi \times (3^2 - 2^2) / 4 \text{ kN} = 118\text{kN}$$

• In load cases LC I the dynamic roller pressure allowable must not be exceeded.

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