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idm@F4E UID / VERSION
2HS7W6 / 3.0
VERSION CREATED ON / STATUS
22 October 2019 / Approved
EXTERNAL REFERENCE

Supplier Document

Tool for Automatic Check of Embedded Plates (TACEP)

Cast-in place embedded plates (EPs) are an important element inside the ITER facility. They are used for attachment of plant equipment and devices and, therefore, many practitioners working in ITER need to consider their existence to some degree.
Capacity check of EPs can be tedious as it involves many variables and several failure modes. Considering the large number of EPs that need to be ...

Approval Process			
	Name	*Action*	*Affiliation*
Signatory	**Combescure D.**	**22 October 2019:signed**	**ITERD**
Co-signatories			
Reviewers	**ANTHOINE A.** **Ayneto Pou J.** **Combescure D.** **Hanna G.** **Todhunter D.**	**23 October 2019:recommended** **23 October 2019:recommended** **22 October 2019:recommended** **12 November 2019:recommended** **28 October 2019:recommended**	 **ITERD** **ITERD** **ITERP**
Approver	**Portone A.**	**13-Nov-2019: approved**	**ITERD**
RO: Combescure Didier (F4E)			
Read Access	**LG: S2O-ITER, LG: OMF-0503-team, LG: Cryogeny, LG: external-expert, LG: ITER IO-BIPS, LG: ESTEYCO_FWC, LG: IO CIO - Giulio, LG: Neutral Beam Power Supply, LG: Remote Handling, LG: PRO, AD: IDM_F4E, AD: IDM IE-TS-AN-00 Analysis and Codes, GG: IAC, project administrator, RO**		

Orig. Document MD5#: CE0FF3E7FE76069E8990942265A8E983

Change Log			
Tool for Automatic Check of Embedded Plates (TACEP) (2HS7W6)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	Revision Required	16 July 2019	
v2.0	Signed	09 August 2019	v2.0
v2.1	Signed	30 September 2019	Comments from Jordi adressed
v3.0	Approved	22 October 2019	Coherence of numbering v3.0

F4E-OMF-0503

SEISMIC, DYNAMIC AND STRUCTURAL ANALYSES OF ITER BUILDINGS AND MECHANICAL COMPONENTS

LOT 1: Seismic analysis and design of buildings and mechanical components of ITER

Task Order 4: Complementary seismic analysis of the Tokamak complex, Tokamak machine, Remote Handling Neutral Beam Crane and non-nuclear buildings

Tool for Automatic Check of Embedded Plates (TACEP)

Doc. ID: TACEP_EST_L1_TO4_TR05_v3.0

ESTEYCO

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Date: 03/09/2019	Date: 03/09/2019	Date:	Date: 03/09/2019

REVISION HISTORY

Revision Number	Date	Purpose
1.0	15/07/2019	First issue.
2.0	09/08/2019	New version of the tool.
3.0	03/09/2019	Updated version of the tool.

LIST OF CHANGES

No.	Section	Description
1	2.2	Figure 2 showing a simplified workflow of TACEP added.
2	2.3	Figure 3 and Figure 5 have been updated.
3	2.3.2	Figure 9 on selection of input file for multiple plate check has been added for clarity purposes.
4	3.3.2.5	It is noted that blow-out failure is not verified for circular plates due to the difficulties to calculate automatically the tensile force carried by the anchors near the edge for this geometry.
5	4	Figures have been updated to match the updated window menus.
6	-	Python scripts have been edited to add clarifying comments so that interpretation of the code becomes easier.

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1 INTRODUCTION

1.1 Preamble

Cast-in place embedded plates (EPs) are an important element for the ITER project. Only in the Tokamak Complex around 60.000 EPs have been planned (see Figure 1). EPs are used for attachment of plant equipment and devices to concrete walls, floors and ceilings.

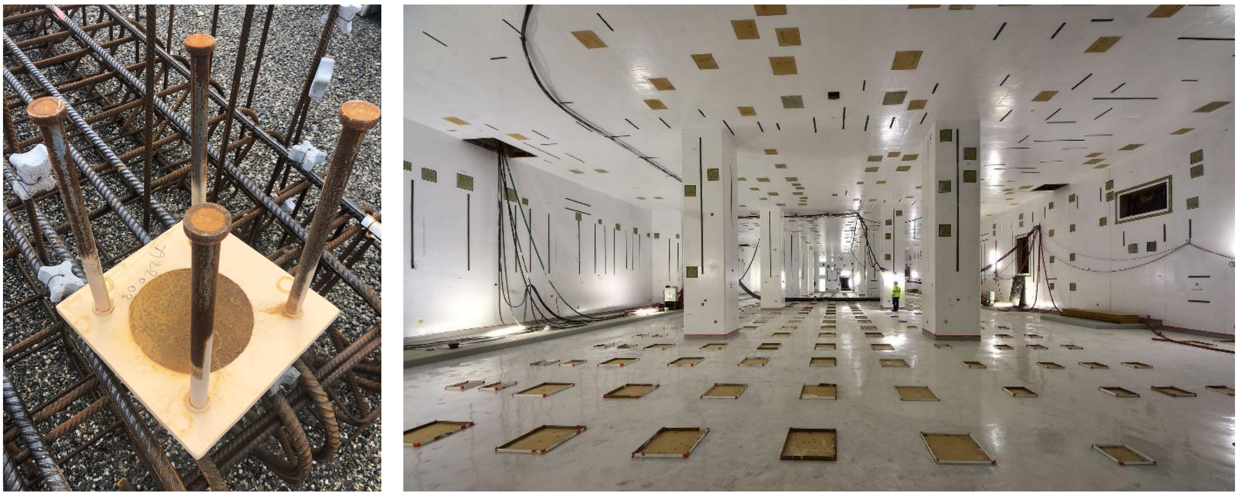


Figure 1 View of anchorage plates arranged in ITER facility.

The capacity of EPs limits the maximum forces and moments that can be transferred by the supported equipment and needs to be assessed with care, especially considering that in some cases they turn to be a design driver for the supported structure. This capacity depends on several factors determined by the plate itself such as (i) the plate dimensions, (ii) the anchor configuration (number and spacing), (iii) the fastener properties (diameter, anchor head diameter, steel resistance …); but it is also influenced by (iv) the concrete properties, (v) the boundary conditions (existence of concrete edges or adjacent plates) and (vi) the action itself. Design guidelines exist to guarantee a safe design (Refs. [1], [2], [3]).

Considering (i) the large number of EPs of different typologies that are going to be used in the ITER project, (ii) which need to be checked under different actions and conditions, and (iii) that the capacity assessment can be tedious, some automatization is needed. ENGAGE developed a tool (Calculation Book Tool CBT) (Ref. [4]) to facilitate the capacity check of standard EPs described in the design catalogue of EPs for the Tokamak Complex (Ref. [5]). During Lot3 TO4 of Framework Contract F4E-O503 ESTEYCO started to develop a new calculation tool in Python to validate the CBT (Ref. [6]). This tool ended up showing more flexibility than the CBT, permitting to perform unlimited number of checks in an automatic manner. Considering the advantages shown by ESTEYCO's tool F4E asked to extend the tool capabilities and to adapt it to provide a more user-friendlier environment which may facilitate its use in the future by interested parties other than its developers.

1.2 Objectives and scope

The main objective of this document is to describe TACEP v1.0 (Tool for Automatic Check of Embedded Plates), the tool developed by ESTEYCO for the capacity check of EPs. This description includes how to use the tool, required input data, available options and calculations performed internally by the program. For its validation some examples of application are included, and the obtained results are compared with those obtained by hand calculations.

TACEP was originally developed for ESTEYCO's internal use and adapted afterwards to facilitate its use by third parties. Operation of the tool has been checked and validated by ESTEYCO in a limited number of applications. Considering the large number of combinations and options offered by the tool, appearance of bugs during a more extensive use of the tool cannot be fully discarded. Therefore, in its current status, its use by third practitioners must be done with care.

1.3 Organization of the document

The report is organized into five additional chapters.

Chapter 2 is devoted to describing TACEP, including its capabilities, required input and provided output data.

Chapter 3 describes in detail the calculations performed internally by the tool. Provisions for three design guidelines have been implemented: EN 1992-4 (Ref. [1]), RCC-CW (Ref. [2]) and CEB (Ref. [3]).

Chapter 4 presents some examples of application and the corresponding results obtained by hand calculations to validate output data from TACEP.

Finally, Chapter 5 gathers the conclusions of the work and Chapter 6 includes the references cited along the report.

1.4 Notation

A_s =	Cross sectional area of anchor = $\pi\ d^2\ /\ 4$
A_h =	Load bearing area of the head of the anchor = $\pi\ (d_h^2 - d^2)\ /\ 4$
D =	Plate diameter for circular plates.
E_c =	Elastic modulus of concrete.
E_s =	Elastic modulus of steel.
N_{Ed} =	Design axial force on plate (>0 for tension, <0 for compression) (see Figure 4).
N_{Ed}^{g} =	Design value of total tensile load acting on all the fasteners of a group in tension.
N_{Ed}^{h} =	Design value of tensile load acting on the most stressed fastener of a group.
$N_{Rd,a}$ =	Design resistance of supplementary reinforcement to anchorage failure in tension.

$N_{Rk,c}$	=	Characteristic resistance of plate to concrete cone failure in tension.
$N_{Rk,cb}$	=	Characteristic resistance of plate to blow-out failure in tension.
$N_{Rk,p}$	=	Characteristic resistance of anchor in case of pull-out failure in tension.
$N_{Rk,re}$	=	Characteristic resistance of supplementary reinforcement to steel failure in tension.
$N_{Rk,s}$	=	Characteristic resistance of anchor in case of steel failure in tension.
$N_{Rk,sp}$	=	Characteristic resistance of plate to splitting failure in tension.
$V_{Ed,x}$	=	Design shear force in X-direction (see Figure 4).
$V_{Ed,y}$	=	Design shear force in Y-direction (see Figure 4).
$V_{Rk,cp}$	=	Characteristic resistance of plate to concrete pry-out failure.
$V_{Rk,c}$	=	Characteristic resistance of plate to concrete edge failure.
$V_{Rk,s}$	=	Characteristic resistance of anchor in case of steel failure in shear.
$V_{Rk,s,M}$	=	Characteristic resistance of anchor with lever arm in case of steel failure in shear.
$M_{Ed,x}$	=	Design bending moment around X-direction (see Figure 4).
$M'_{Ed,x}$	=	Design bending moment around X-direction considering eccentricity of axial load.
$M_{Ed,y}$	=	Design bending moment around Y-direction (see Figure 4).
$M'_{Ed,y}$	=	Design bending moment around Y-direction considering eccentricity of axial load.
$M_{Ed,z}$	=	Design torsional moment (see Figure 4).
$M'_{Ed,z}$	=	Design torsional moment considering eccentricity of shear loads.
R_d	=	Design resistance.
R_k	=	Characteristic resistance.
c	=	Distance to edge.
c_{nom}	=	Concrete cover.
$c_{cr,N}$	=	Characteristic edge resistance. Edge distance necessary to develop the characteristic tension resistance of a single anchor without spacing and edge effects in the case of concrete cone failure.
c_{x-}	=	Minimum distance from plate edge to a concrete edge or fictive edge on the negative X-direction of the plate (see Figure 4).
c_{x+}	=	Minimum distance from plate edge to a concrete edge or fictive edge on the positive X-direction of the plate (see Figure 4).
c_{y-}	=	Minimum distance from plate edge to a concrete edge or fictive edge on the negative Y-direction of the plate (see Figure 4).
c_{y+}	=	Minimum distance from plate edge to a concrete edge or fictive edge on the positive Y-direction of the plate (see Figure 4).

d =	Diameter of the anchor.
d_h =	Diameter of the anchor head.
e_x =	Distance in X-direction between centre of plate and point of application of loading.
$e_{x,tol}$ =	Installation tolerance to account for eccentricity in X-direction.
e_y =	Distance in Y-direction between centre of plate and point of application of loading.
$e_{y,tol}$ =	Installation tolerance to account for eccentricity in Y-direction.
e_{shear} =	Lever arm to be accounted for in shear check.
f_{bd} =	Design bond strength.
f_{ck} =	Characteristic compressive strength of concrete.
f_{ctd} =	Design tensile strength of concrete.
$f_{yk,re}$ =	Characteristic yielding stress of reinforcing steel.
$f_{yk,s}$ =	Characteristic yielding stress of steel for anchors.
$f_{uk,s}$ =	Characteristic ultimate stress of steel for anchors.
h_{ef} =	Effective embedded length of anchor = $h_n + t_p - t_h$
h_n =	Nominal length of anchor, including anchor head if existing (see Figure 4).
h_{slab} =	Thickness of the concrete element (see Figure 4).
k_1 =	Factor to determine the characteristic strength in case of concrete cone failure.
k_8 =	Factor to determine the characteristic strength in case of pry-out failure.
l_1 =	Anchorage length of hanger reinforcement inside the break-out body.
l_x =	Plate side length in X-direction for rectangular plates (see Figure 4).
l_y =	Plate side length in Y-direction for rectangular plates (see Figure 4).
n_θ =	Number of sectors in circumferential direction in circular plates
n_{legs} =	Number of hanger legs/stirrups per anchor arranged to resist tensile forces on the plate.
n_r =	Number of anchors in radial direction in circular plates.
n_x =	Number of anchors in X-direction in rectangular plates.
n_y =	Number of anchors in Y-direction in rectangular plates.
$s_{cr,N}$ =	Characteristic spacing = 2 $c_{cr,N}$. Necessary spacing to develop the characteristic tension resistance of a single anchor without spacing and edge effects in the case of concrete cone failure.
s_r =	Spacing of anchors in radial direction for circular plates.
s_x =	Spacing of anchors in X-direction for rectangular plates.

s_y =	Spacing of anchors in Y-direction for rectangular plates.
t_p =	Plate thickness (see Figure 4).
t_h =	Thickness of anchor head, plus distance from head bottom to the anchor bottom if gap (see Figure 4).
α_1 =	Anchorage factor for supplementary hanger reinforcement accounting for detailing.
α_2 =	Anchorage factor for supplementary hanger reinforcement accounting for concrete cover.
ϵ_c =	Maximum compressive strain in concrete under the fixture.
ϕ =	Diameter of supplementary reinforcement.
γ_M =	Material safety factor.
$\gamma_{Mc,tension,NO}$ =	Material safety factor for concrete in tension for normal operation conditions.
$\gamma_{Mc,tension,AO}$ =	Material safety factor for concrete in tension for accidental operation conditions.
$\gamma_{Mc,comp,NO}$ =	Material safety factor for concrete in compression for normal operation conditions.
$\gamma_{Mc,comp,AO}$ =	Material safety factor for concrete in compression for accidental operation conditions.
$\gamma_{Mre,NO}$ =	Material safety factor for reinforcing steel for normal operation conditions.
$\gamma_{Mre,AO}$ =	Material safety factor for reinforcing steel for accidental operation conditions.
$\gamma_{Ms,shear,NO}$=	Material safety factor for steel of anchors in shear for normal operation conditions.
$\gamma_{Ms,shear,AO}$ =	Material safety factor for steel of anchors in shear for accidental operation conditions.
$\gamma_{Ms,tension,NO}$ =	Material safety factor for steel of anchors in tension for normal operation conditions.
$\gamma_{Ms,tension,AO}$ =	Material safety factor for steel of anchors in tension for accidental operation conditions.
σ_c =	Maximum compressive stress in concrete under the fixture.

2 TOOL DESCRIPTION

2.1 Introduction

This chapter describes the main aspects related to the use of TACEP for the capacity assessment of EPs. Its functions and capabilities are briefly commented in section 2.2. The introduction of input data is organized in different windows as detailed in section 2.3. Section 2.4 describes the output data that can be obtained from the tool. Finally, section 2.5 describes how to execute the tool.

2.2 Functions and capabilities

TACEP offers three options: (i) checking a plate subjected to a single load case, (ii) checking multiple plates under variable actions and (iii) generation of interaction diagrams.

Firstly, the option to check a plate subjected to a single load case is analogous to that already offered by the CBT. However, some differences must be noted. TACEP allows for more flexibility than the CBT as it permits, for instance, to modify input parameters such as the concrete strength or material safety factors, introduce new plates, account for compressive axial forces or select different design guidelines (EN 1992-4 (Ref. [1]), RCC-CW (Ref. [2]) and CEB code (Ref. [3]). Moreover, the computation time of each capacity check in TACEP is around 0.01-0.02 seconds, while in the CBT each verification takes 10 seconds or more.

Secondly, one of the main limitations of the CBT is that for each EP the verification of every load case needs to be performed one by one. Even without considering the significant computation time for each verification, this makes treatment of large number of EPs under different loads very time consuming and unapproachable in some cases. A function is implemented in TACEP which permits to read data from an input file in which plates and loads are defined and to perform the capacity assessment for each one automatically. This, together with the short computation time of each verification, permits to treat thousands of cases in a short time. Ref. [7] shows an example of application by ESTEYCO where 1 million cases were assessed automatically in around 6 hours.

Thirdly, TACEP allows for generating automatically interaction diagrams. These interaction diagrams provide the maximum allowable force/moment, so the capacity of the EP is not exceeded. It must be noted that only the two selected forces/moments are modified during the process of generation of the interaction diagram. The rest of variables (edge distances, concomitant forces, eccentricities, concrete properties, plate characteristics) are taken as defined in the main window. This permits for instance to obtain interaction diagrams for different levels of concomitant forces or considering different edge distances. Computation time of each interaction diagram is in the order of seconds.

Figure 2 shows a simplified workflow illustrating the different calculation paths, inputs and outputs.

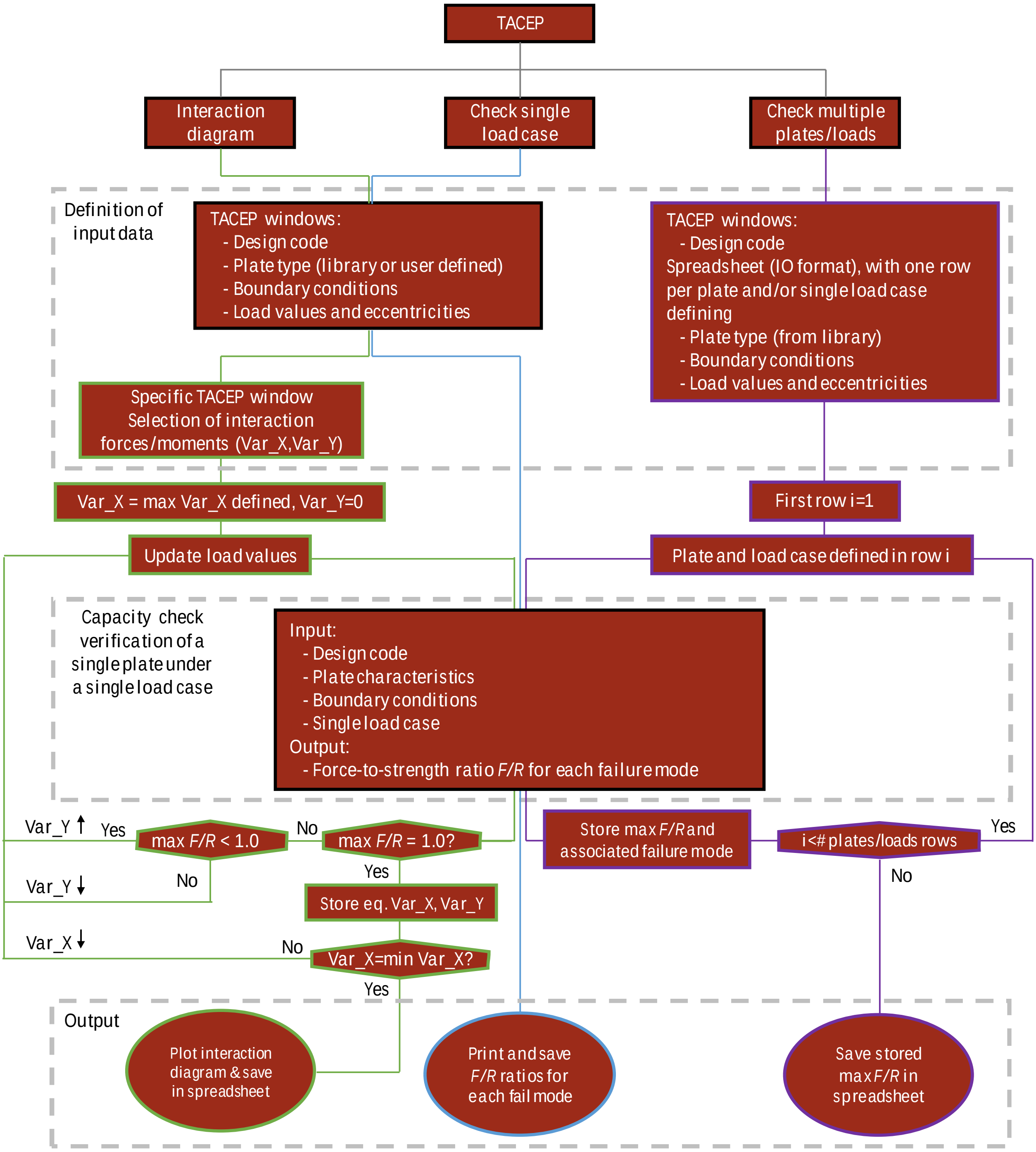


Figure 2 TACEP workflow

2.3 Input data

2.3.1 General

Input data is introduced in TACEP in different windows, organized based on the type of data as commented next.

2.3.1.1 Loads, boundary conditions and reference code

The main window (Figure 3) appears right after launching the tool (see section 2.5). It gathers the main design variables: (i) design code, (ii) type of plate, (iii) slab thickness, (iv) distance from plate edges to concrete and fictive edges (the latter to consider adjacent plates), (v) design forces and (vi) load eccentricities (see Figure 4). A more detailed description of the input data and default values is given in Table 1. At the bottom of the window three buttons permit to make use of the options offered by the program (see section 2.2): (i) check single load (for considering the loads defined in the main window), (ii) check load file (for checking multiple plates under variable actions as defined in an external file which is selected by the user) and (iii) interaction diagram (for generating an interaction diagram relating two forces/moments).

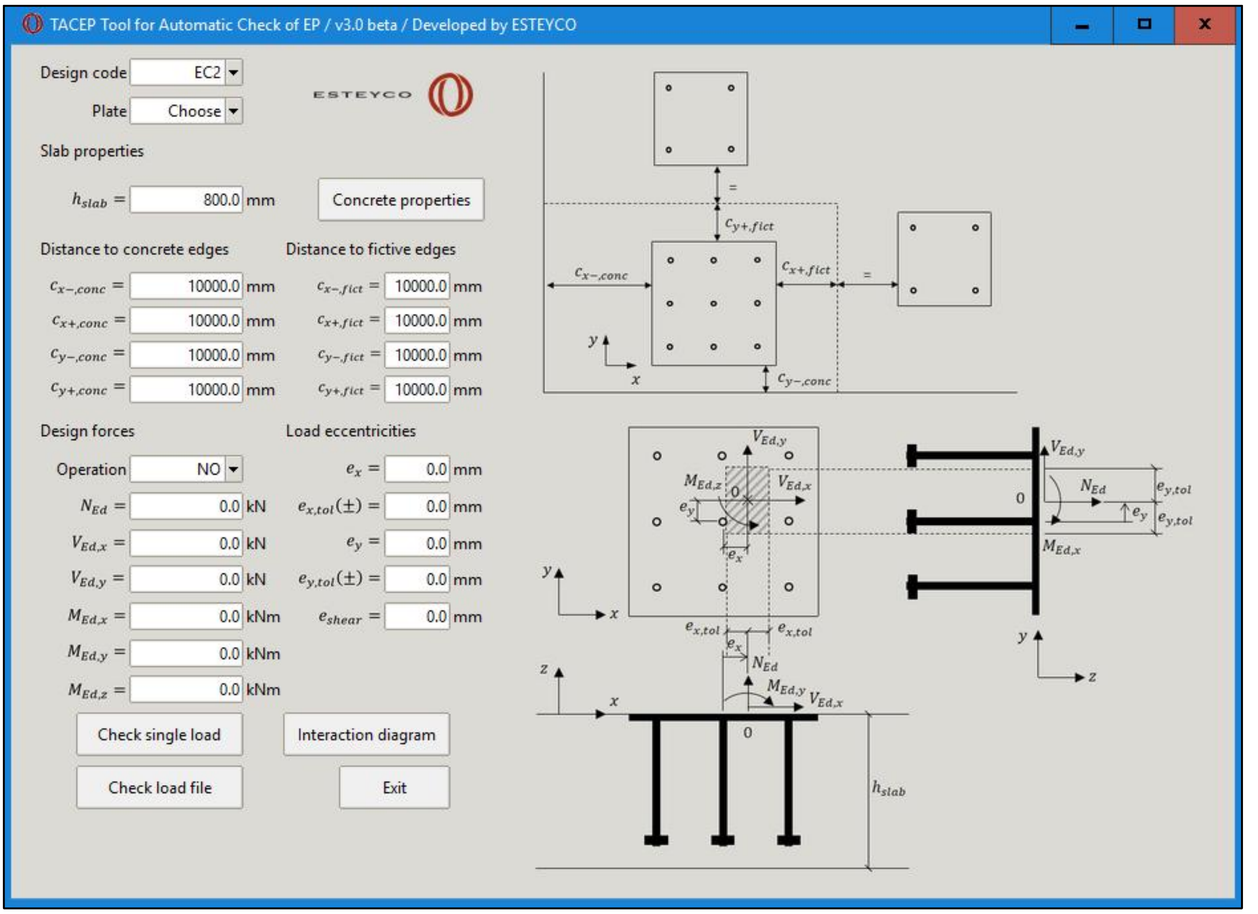


Figure 3 Main window

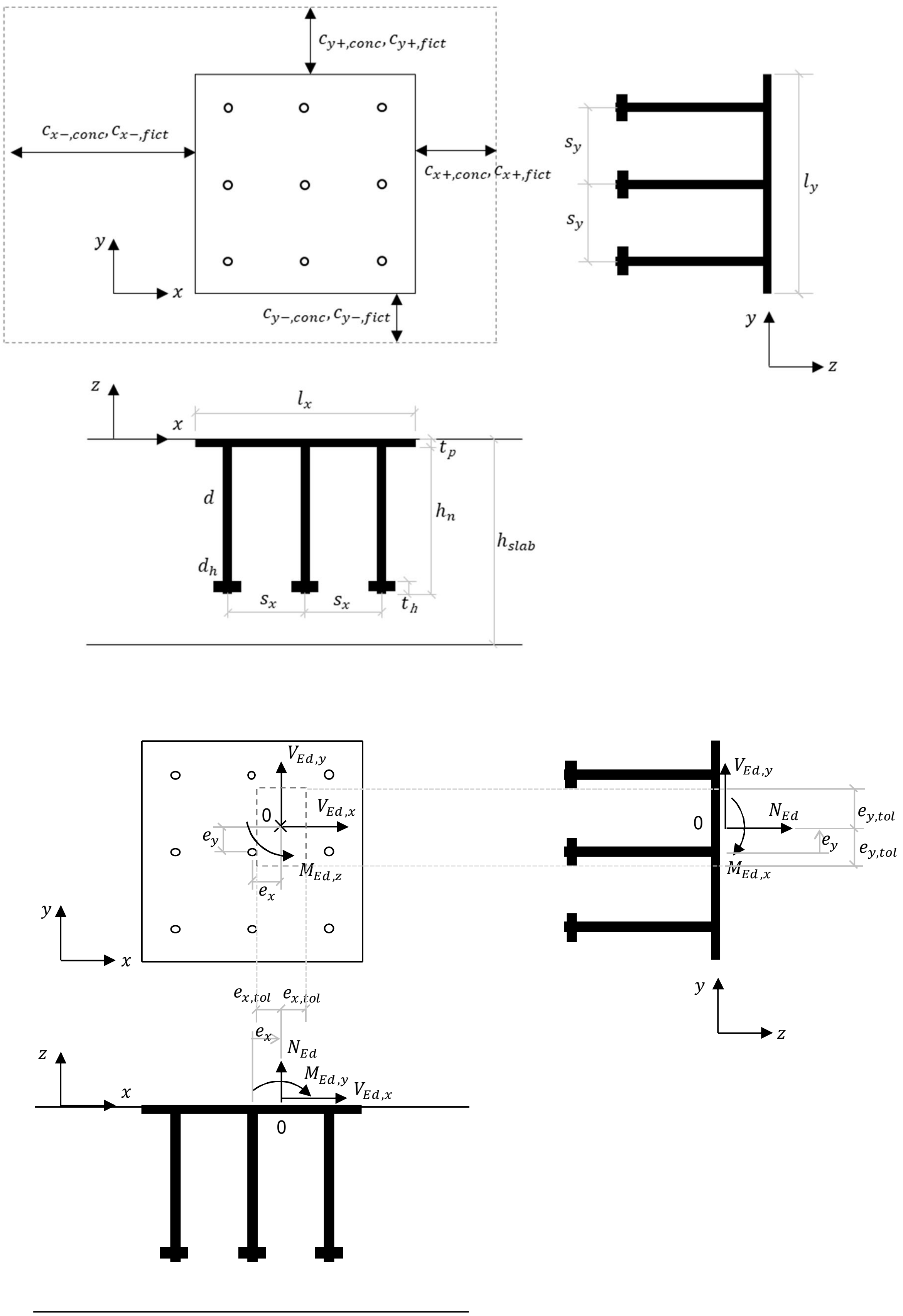


Figure 4 Geometry and load input data.

Variable	Description	Options	Units	Default	Where
General					
Design code	Design code to be consider for the verification of the embedded plate. Note that EC2 stands for EN 1992-4 (Ref. [1]).	EC2 RCC-CW CEB	N/A	EC2	Drop-down list (Figure 3)
Plate	Plate type selected from the library (see section 2.3.1.6) or to be defined by the user.	Plate library + User defined	N/A	P200	Drop-down list (Figure 3)
Slab and concrete properties					
h_{slab}	Thickness of the concrete slab	Double number	mm	800.0	Text box (Figure 3)
Distance to concrete edges					
c_{x-conc}	Minimum distance from the plate edges to the concrete edge on the west side of the plate (negative X-direction)	Double number	mm	10000	Text box (Figure 3)
$c_{x+,conc}$	Minimum distance from the plate edges to the concrete edge on the east side of the plate (positive X-direction)	Double number	mm	10000	Text box (Figure 3)
$c_{y-,conc}$	Minimum distance from the plate edges to the concrete edge on the south side of the plate (negative Y-direction)	Double number	mm	10000	Text box (Figure 3)
$c_{y+,conc}$	Minimum distance from the plate edges to the concrete edge on the north side of the plate (positive Y-direction)	Double number	mm	10000	Text box (Figure 3)
Distance to fictive edges					
$c_{x-,fict}$	Minimum distance from the plate edges to the fictive edge on the west side of the plate (negative X-direction)	Double number	mm	10000	Text box (Figure 3)
$c_{x+,fict}$	Minimum distance from the plate edges to the fictive edge on the east side of the plate (positive X-direction)	Double number	mm	10000	Text box (Figure 3)
$c_{y-,fict}$	Minimum distance from the plate edges to the fictive edge on the south side of the plate (negative Y-direction)	Double number	mm	10000	Text box (Figure 3)

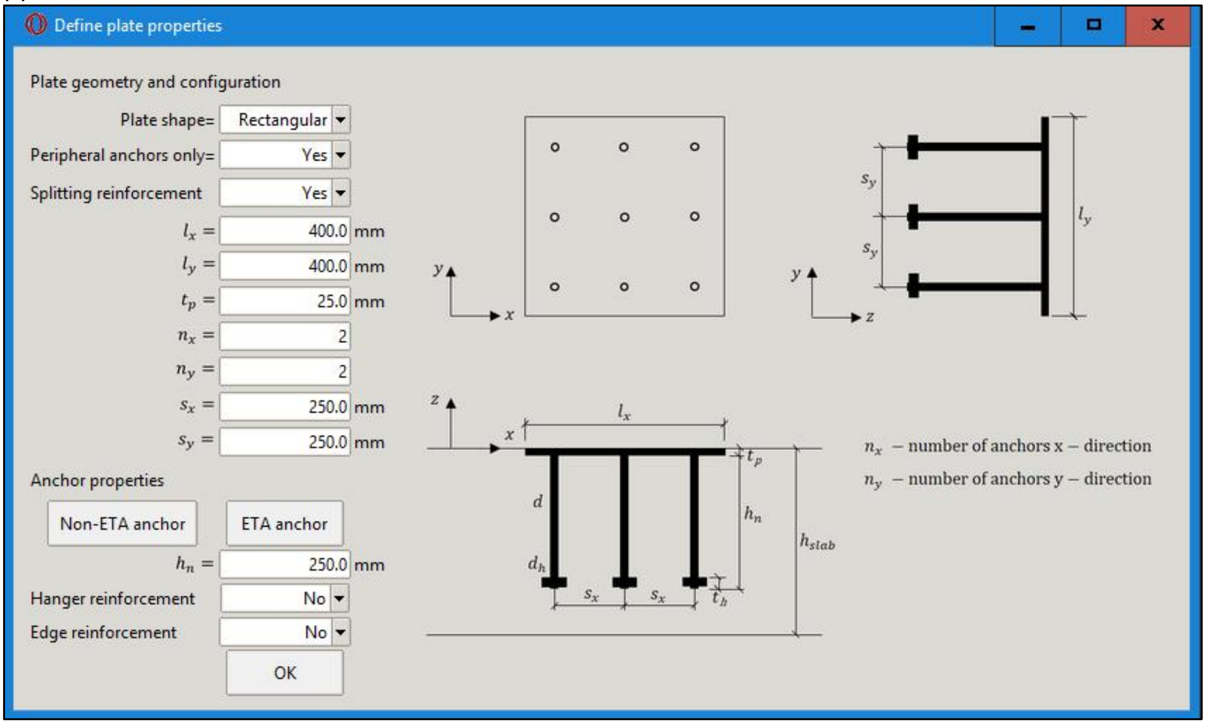
Variable	Description	Options	Units	Default	Where
$c_{y+,fict}$	Minimum distance from the plate edges to the fictive edge on the north side of the plate (positive Y-direction)	Double number	mm	10000	Text box (Figure 3)
Design forces					
Operation	Type of load based on which material safety factors and elastic modulus will be selected.	NO AO	N/A	NO	Drop-down list (Figure 3)
N_{Ed}	Design axial force on plate (>0 for tension, <0 for compression).	Double number	kN	0.0	Text box (Figure 3)
$V_{Ed,x}$	Design shear force in X-direction.	Double number	kN	0.0	Text box (Figure 3)
$V_{Ed,y}$	Design shear force in Y-direction.	Double number	kN	0.0	Text box (Figure 3)
$M_{Ed,x}$	Design bending moment around X-direction.	Double number	kNm	0.0	Text box (Figure 3)
$M_{Ed,y}$	Design bending moment around Y-direction	Double number	kNm	0.0	Text box (Figure 3)
$M_{Ed,z}$	Design torsional moment.	Double number	kNm	0.0	Text box (Figure 3)
Load eccentricities					
e_x	Distance in X-direction between centre of plate and point of application of load.	Double number	mm	0.0	Text box (Figure 3)
$e_{x,tol}$ $(\pm)$	Installation tolerance to account for eccentricity in X-direction.	Double number	mm	0.0	Text box (Figure 3)
e_y	Distance in Y-direction between centre of plate and point of application of load.	Double number	mm	0.0	Text box (Figure 3)
$e_{y,tol}$ $(\pm)$	Installation tolerance to account for eccentricity in Y-direction.	Double number	mm	0.0	Text box (Figure 3)
e_{shear}	Lever arm to be accounted for in shear check (see section 6.2.2.3 EN 1992-4).	Double number	mm	0.0	Text box (Figure 3)

Table 1 Input data of main window.

2.3.1.2 Plate properties

In the drop-down list "Plate" the user can select the type of plate from one of the EPs defined in the file "input_plate_library.xlsx" (see section 2.3.1.6) or choose the option "User defined". If the latter, a new window opens for the definition of the plate properties (see Figure 5). In this window the user can define the (i) plate shape (rectangular or circular), (ii) if there fasteners only around the plate perimeter or also in the central part, (iii) the existence or not of sufficient splitting reinforcement, (iv) plate dimensions, (v) number of anchors, (vi) spacing, (vii) nominal length of fasteners and (viii) the existence or not of supplementary reinforcement for tension and shear. A more detailed description of the input data and default values is given in Table 2. Note that options in the panel are updated depending on the selected plate shape (see Figure 5(a) for rectangular plates and Figure 5(b) for circular plates).

(a)



(b)

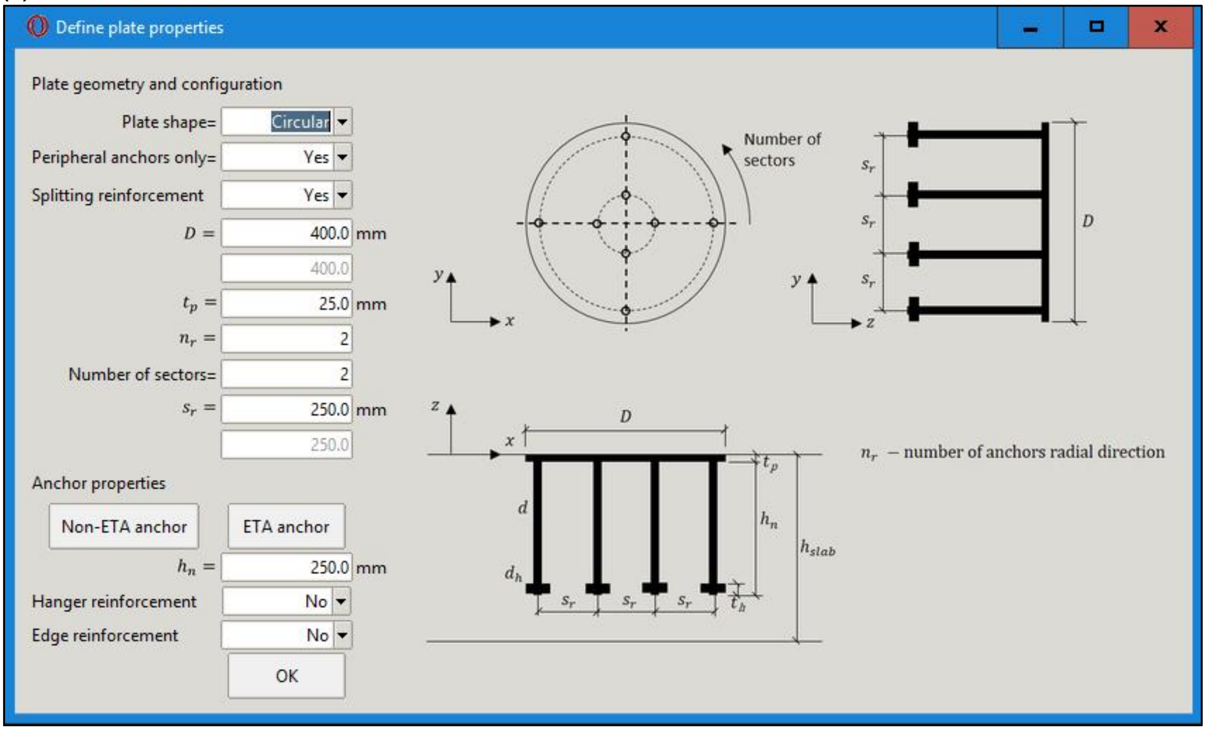
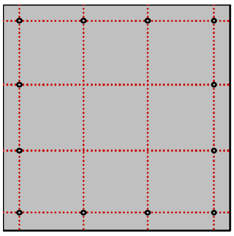
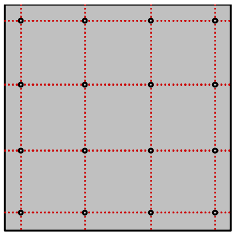


Figure 5 Window for the definition of plate properties: (a) Rectangular plate, (b) Circular plate

Variable	Description	Options	Units	Default	Where
Plate geometry and configuration: only necessary if "User defined" option selected under "Plate" drop-down.					
Plate shape	Shape of the steel plate.	Rectangular Circular	N/A	Square	Drop-down list (Figure 5)
Peripheral anchors only	Anchor configuration: if the plate has only peripheral anchors, option "Yes" must be selected; if there are also anchors in the central part, the option "No" must be chosen Peripheral = Yes  Peripheral = No 	Yes No	N/A	No	Drop-down list (Figure 5)
Splitting reinforcement	Existence or not of splitting reinforcement based on EN 1992-4, section 7.2.1.7. $\sum A_{s,re}$ must be larger than $0.5 \frac{\sum N_{Ed}}{f_{yk,re} / \gamma_{Mre}}$ to mark option "Yes".	Yes No	N/A	Yes	Drop-down list (Figure 5)
l_x	Plate side in X-direction (activated if "Rectangular" plate shape is selected).	Double number	mm	400.0	Text box (Figure 5)
l_y	Plate side in Y-direction (activated if "Rectangular" plate shape is selected).	Double number	mm	400.0	Text box (Figure 5)
t_p	Plate thickness.	Double number	mm	25.0	Text box (Figure 5)
n_x	Number of anchors in X-direction (activated if "Rectangular" plate shape is selected).	Integer number	-	2	Text box (Figure 5)
n_y	Number of anchors in Y-direction (activated if "Rectangular" plate shape is selected).	Integer number	-	2	Text box (Figure 5)
s_x	Spacing of anchors in X-direction (activated if "Rectangular" plate shape is selected).	Double number	mm	250.0	Text box (Figure 5)
s_y	Spacing of anchors in Y-direction (activated if "Rectangular" plate shape is selected).	Double number	mm	250.0	Text box (Figure 5)
D	Plate diameter (activated if "Circular" plate shape is selected).	Double number	mm	400.0	Text box (Figure 5)

Variable	Description	Options	Units	Default	Where
n_r	Number of anchors in radial direction (activated if "Circular" plate shape is selected).	Integer number	-	2	Text box (Figure 5)
Number of sectors, n_θ	Number of radial sectors (activated if "Circular" plate shape is selected).	Integer number	-	2	Text box (Figure 5)
s_r	Spacing between anchors in radial direction (activated if "Circular" plate shape is selected).	Double number	mm	250.0	Text box (Figure 5)
Nominal length, h_n	Nominal length of the anchor, including anchor head if so (see Figure 4).	Double number	mm	250.0	Text box (Figure 5)
Hanger. reinforcement	If supplementary hanger reinforcement exists, select "Yes"; otherwise, "No".	Yes No	N/A	Yes	Drop-down list (Figure 5)
Edge. reinforcement	If supplementary edge shear reinforcement exists, select "Yes"; otherwise, "No".	Yes No	N/A	Yes	Drop-down list (Figure 5)

Table 2 Input data in window for the definition of plate properties.

2.3.1.3 Anchor properties

Anchor properties can be defined after pressing the buttons "Non-ETA anchor" or "ETA anchor" in the window for the definition of plate properties (see Figure 5). Different input data is required depending if the fastener has a certificate of approval in which characteristic values are already given (button "ETA anchor") or does not have such a certificate and, hence, these values must be derived from its basic properties (button "Non-ETA anchor).

When pressing button "Non-ETA anchor", the user needs to define the properties requested in the panel shown in Figure 6(a): (i) diameter of the fastener, (ii) diameter and thickness of the anchor head (this diameter should be equal or smaller than that defined in the textbox above if the fastener has no anchor head), (iii) characteristic yielding and ultimate stress of steel and (iv) the material safety factors for tension and shear for both normal and accidental operation.

When selecting "ETA anchor", the required data is that shown in Figure 6(b) and refers to the values provided in the corresponding certificate of approval: (i) anchor diameter, (ii) head thickness, (iii) characteristic yielding and ultimate stress of steel, (iv) characteristic strengths to steel failure in tension and shear and pull-out failure, (v) factors to determine the characteristic strength to concrete cone failure in tension and pry-out failure in shear and (vi) the corresponding material safety factors for tension and shear for both normal and accidental operation. A more detailed description of the input data and default values is given in Table 3.

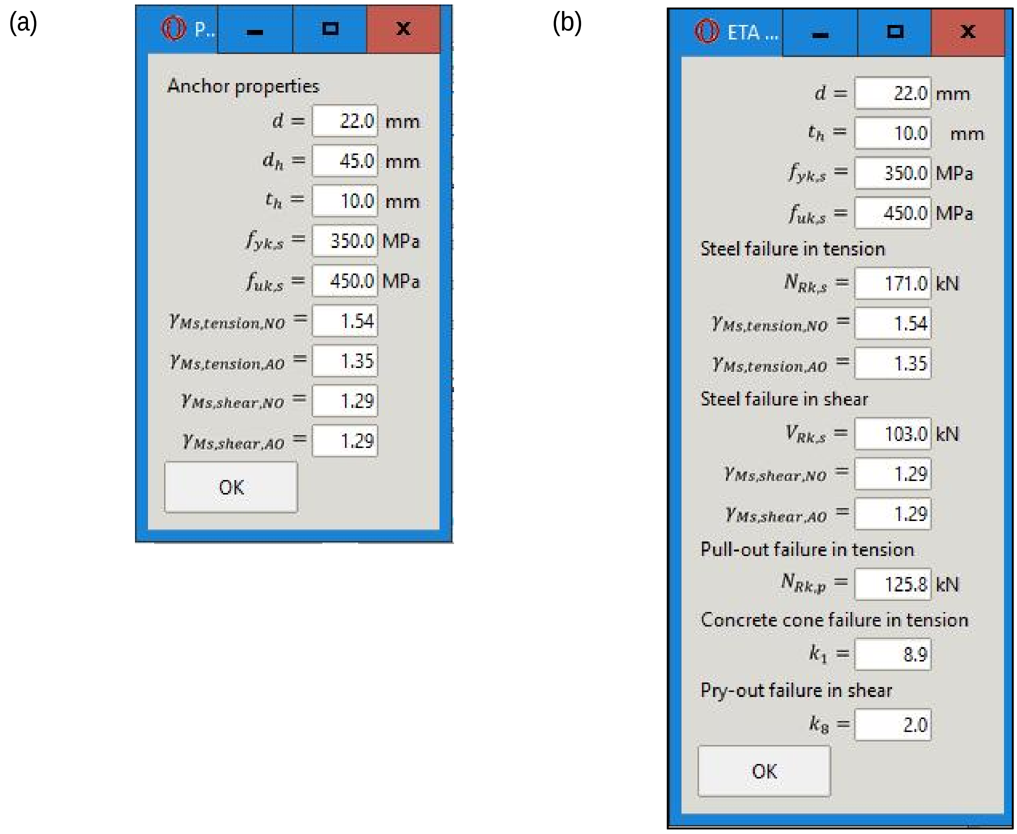


Figure 6 Window for the definition of anchor properties: (a) Non-ETA anchors, (b) ETA anchors.

Variable	Description	Options	Units	Default	Where
Anchor properties					
Diameter, d	Diameter of anchor.	Double number	mm	22.0	Text box (Figure 6)
Head diameter, d_h	Diameter of anchor head (only for Non-ETA anchors). If $d_h \leq d$, the tool will assume that there is no anchor head.	Double number	mm	45.0	Text box (Figure 6)
Head thickness, t_h	Thickness of the anchor head plus the distance from the head bottom to the anchor bottom (see Figure 4).	Double number	mm	10.0	Text box (Figure 5)
$f_{yk,s}$	Yielding stress of steel.	Double number	MPa	350.0	Text box (Figure 6)
$f_{uk,s}$	Ultimate stress of steel.	Double number	MPa	450.0	Text box (Figure 6)
$\gamma_{Ms,tension,NO}$	Material safety factor for steel in tension under normal operation conditions.	Double number	-	1.54	Text box (Figure 6)

Variable	Description	Options	Units	Default	Where
$\gamma_{Ms,tension,AO}$	Material safety factor for steel in tension under accidental operation conditions.	Double number	-	1.35	Text box (Figure 6)
$\gamma_{Ms,shear,NO}$	Material safety factor for steel in shear under normal operation conditions.	Double number	-	1.29	Text box (Figure 6)
$\gamma_{Ms,shear,AO}$	Material safety factor for steel in shear under accidental operation conditions.	Double number	-	1.29	Text box (Figure 6)
$N_{Rk,s}$	Characteristic resistance of anchor in case of steel failure in tension (only for ETA anchors).	Double number	kN	171.0	Text box (Figure 6)
$V_{Rk,s}$	Characteristic resistance of anchor in case of steel failure in shear (only for ETA anchors).	Double number	kN	103.0	Text box (Figure 6)
$N_{Rk,p}$	Characteristic resistance of anchor in case of pull-out failure (only for ETA anchors).	Double number	kN	125.8	Text box (Figure 6)
k_1	Factor to determine the characteristic strength in case of concrete cone failure (see Eq. (20)).	Double number	-	8.9	Text box (Figure 6)
k_8	Factor to determine the characteristic strength in case of pry-out failure (see Eq. (62))	Double number	-	2.0	Text box (Figure 6)

Table 3 Input data in window for the definition of anchor properties

2.3.1.4 Hanger reinforcement properties

A new window pop ups for the definition of the rebar characteristics if option “Yes” is selected in the drop-down list “Hanger reinforcement” (Figure 7). Required input data is (i) the number of stirrups/legs per fastener, (ii) the rebar diameter (which should not larger than 16 mm to agree with existing provisions), (iii) the anchorage length inside the break-out body, (iv) an anchorage factor to account for reinforcement detailing, (v) the characteristic yielding stress of steel and (vi) material safety factors for both normal and accidental operation. A more detailed description of the input data and default values is given in Table 4.

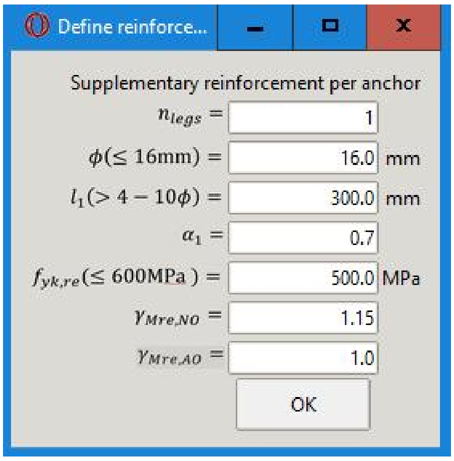


Figure 7 Window for the definition of hanger reinforcement properties.

Variable	Description	Options	Units	Default	Where
Supplementary reinforcement properties: only if option "Yes" in hanger reinforcement is selected.					
Number of legs, n_{legs}	Number of hanger legs/stirrups per anchor which are effective for restraining concrete cone failure.	Integer number	-	1	Text box (Figure 7)
Rebar diameter, ϕ	Diameter of the supplementary reinforcement.	Double number	mm	16.0	Text box (Figure 7)
Anchorage length, l_1	Anchorage length in the break-out body.	Double number	mm	$h_n - 50$	Text box (Figure 7)
Anchorage factor, α_1	Factor to account for rebar detailing in the anchorage strength (see EN 1992-1 section 8.4.4; α_1=1.0 for straight anchorage; α_1=0.7 otherwise).	Double number	-	0.7	Text box (Figure 7)
Yielding stress, $f_{yk,re}$	Characteristic yielding stress of reinforcing steel.	Double number	MPa	500.0	Text box (Figure 7)
$\gamma_{Mre,NO}$	Material safety factor for reinforcing steel under normal operation conditions.	Double number	-	1.15	Text box (Figure 7)
$\gamma_{Mre,AO}$	Material safety factor for reinforcing steel under accidental operation conditions.	Double number	-	1.00	Text box (Figure 7)

Table 4 Input data in window for definition of hanger reinforcement properties.

2.3.1.5 *Concrete properties*

Concrete properties can be defined when pressing the button “Concrete properties”. The user can modify concrete properties at different stages as this button is accessible at different windows (see Figure 3 and Figure 6). When pressing this button, the window shown in Figure 8 pop ups. The user can define (i) the characteristic compressive strength of concrete, (ii) material safety factors for tension and compression for both normal and accidental operation and (iii) the elastic moduli. A more detailed description of the input data and default values is given in Table 5.

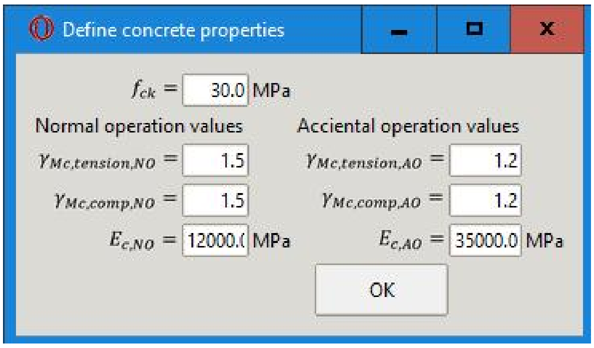


Figure 8 Window for the definition of concrete properties.

Variable	Description	Options	Units	Default	Where
Slab and concrete properties					
$f_{ck,conc}$	Compressive strength of concrete	Double number	MPa	30.0	Text box (Figure 8)
$\gamma_{Mc,tension,NO}$	Material safety factor for concrete in tension for normal operation	Double number	-	1.5	Text box (Figure 8)
$\gamma_{Mc,comp,NO}$	Material safety factor for concrete in compression for normal operation	Double number	-	1.5	Text box (Figure 8)
$\gamma_{Mc,tension,AO}$	Material safety factor for concrete in tension for accidental operation	Double number	-	1.2	Text box (Figure 8)
$\gamma_{Mc,comp,AO}$	Material safety factor for concrete in compression for accidental operation	Double number	-	1.2	Text box (Figure 8)
$E_{c,NO}$	Concrete elastic modulus for normal operation	Double number	MPa	12000	Text box (Figure 8)
$E_{c,AO}$	Concrete elastic modulus for accidental operation	Double number	MPa	35000	Text box (Figure 8)

Table 5 Input data in window for the definition of concrete properties.

2.3.1.6 Plate library

As mentioned above, in the dropdown list under “Plate” the user can select an EP which has been previously defined. The plate needs to be included in the file “input_plate_library.xlsx”, included in the same folder as the tool files. Selection of an already-defined EP instead of using the “User defined” option is especially recommended for standard EPs whose design is fixed but may also be appealing for testing new designs. The input file can be modified to add new plates following the format shown in Table 6. For reference, plates shown in Table 6 correspond to some of the standard EPs included in the EPs catalogue for the Tokamak Complex (Ref. [5]). The anchor column refers to the type of fastener used, which is selected from those defined in the sheet “Anchor” in the same input file; new anchors can be defined following the format shown in Table 7.

Name	Shape	Peripheral	l_x/D (mm)	$l_y/-$ (mm)	t_p (mm)	n_x/n_r	n_y/n_θ	s_x/s_r (mm)	$s_y/-$ (mm)	Anchor	h_n (mm)	Hanger reinf	Shear edge reinf	Splitting reinf
NS-CT300/225	Circular	Yes	300	-	15	1	2	135	-	KB22	225	No	No	Yes
P200	Rectangular	No	200	200	25	2	2	100	100	KB22	225	No	No	Yes
P300	Rectangular	No	300	300	25	2	2	200	200	KB22	325	No	No	Yes
P300b	Rectangular	No	300	300	25	2	2	200	200	KB22	225	No	No	Yes
P300b2	Rectangular	No	300	300	15	2	2	200	200	KB22	335	Yes	No	Yes
P400	Rectangular	No	400	400	25	2	2	300	300	KB22	325	No	No	Yes
P400b	Rectangular	No	400	400	25	2	2	300	300	KB22	225	No	No	Yes
P400b2	Rectangular	No	400	400	20	2	2	300	300	KB22	330	Yes	No	Yes
P500	Rectangular	No	500	500	25	3	3	200	200	KB25	525	No	No	Yes
P500b	Rectangular	No	500	500	25	3	3	200	200	KB25	275	No	No	Yes
P500b2	Rectangular	No	500	500	25	3	3	200	200	KB25	225	No	No	Yes
P500b4	Rectangular	No	500	500	25	3	3	200	200	KB25	525	No	No	Yes
P500b5	Rectangular	No	500	500	25	3	3	200	200	KB25	525	Yes	No	Yes
P700	Rectangular	No	700	700	35	4	4	200	200	KB25	525	No	No	Yes
P700b1	Rectangular	No	700	700	35	4	4	200	200	KB25	225	No	No	Yes
P700b2	Rectangular	No	700	700	35	4	4	200	200	KB25	325	No	No	Yes
P700b5	Rectangular	No	700	700	35	4	4	200	200	KB25	525	Yes	No	Yes
P900	Rectangular	No	900	900	35	4	4	200	200	KB25	525	No	No	Yes
P900b1	Rectangular	No	900	900	35	4	4	200	200	KB25	225	No	No	Yes
P900b2	Rectangular	No	900	900	35	4	4	200	200	KB25	325	No	No	Yes
P900b5	Rectangular	No	900	900	35	4	4	200	200	KB25	525	Yes	No	Yes

Table 6 Plate library format.

Type	ETA	d (mm)	d_h (mm)	t_h (mm)	$N_{Rk,s}$ (kN)	$\gamma_{Ms,tension,NO}$	$\gamma_{Ms,tension,AO}$	$N_{Rk,p}$ (kN)	k_1	$V_{Rk,s}$ (kN)	$\gamma_{Ms,shear,NO}$	$\gamma_{Ms,shear,AO}$	k_8	f_{syk} (MPa)	f_{usk} (MPa)
KB22	Yes	22	35	10	171	1.54	1.35	125.8	8.5	103	1.28	1.28	2	350	450
KB25	Yes	25	40	12	221	1.54	1.35	170.2	8.5	133	1.28	1.28	2	350	450

Table 7 Anchor library format.

2.3.2 Multiple plate check

When pressing the button “Check load file” (see Figure 3) a new window opens to select the input file from which plates and loads will be read (Figure 9). The user needs to provide the input data following the format currently used by ITER Organization (see Figure 10). As many rows as desired can be added to consider multiple EPs and/or actions. The following data is required: (i) type (must coincide with one of the EPs defined in the plate library (see section 2.3.1.6), (ii) additional reinforcement, (iii) local loading (e_x, e_y, e_{shear}, $e_{x,tol}$, $e_{y,tol}$, F_x, F_y, F_z, M_x, M_y, M_z and conditions (NO or AO)) and (iv) all columns referring to the boundary conditions (l, t, r, b standing for c_{x-}, c_{y+}, c_{x+}, c_{y-}, respectively).

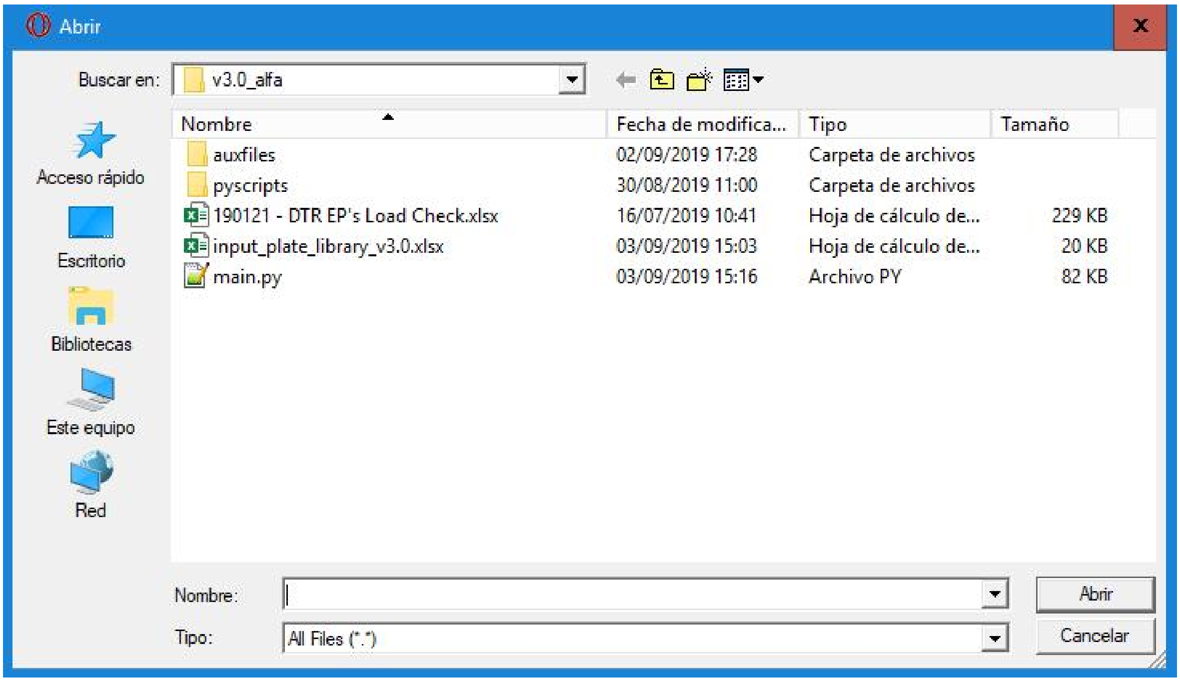


Figure 9 Input file selection for multiple plate check.

If there is no additional reinforcement the user must specified in the corresponding column “No Reinforcement”. For cases with additional reinforcement it must be noted that, considering that configuration of supplementary reinforcement can vary significantly from case to case and that no standardised coding has been established yet for its definition, default reinforcement values (see Table 4) are considered regardless what it is defined in this column (other than “No Reinforcement”). This limitation could be overcome in the future if reinforcement configurations are fixed and coding.

Date										
	Tagging EP	Type	Additional Reinforcement	Customized	Calculation report (plate)	Owner	Model reference	Status	Tagging support	Shared EP

Owner input																		
EP Location							Local Loading											
Absolute coordinates			Rotation	Building	Room	Wall / slab reference	Load Point location Absolute			Support eccentricity Absolute			Reaction forces					
X	Y	Z					X	Y	Z	e.x	e.y	e.z	Fx	Fy	Fz	Mx	My	Mz

		Catia Extract							
		Boundary conditions							
Conditions (AO / NO)	Loading Calculation report	Surrounding plates				surrounding openings			
		d.ep.l	d.ep.t	d.ep.r	d.ep.b	d.edge.l	d.edge.t	d.edge.r	d.edge.b

Figure 10 Multiple plate check format.

2.3.3 Generation of interaction diagrams

If the user wants to generate an interaction diagram and presses the button “Interaction diagram” at the main window (see Figure 3), a new window pop ups (see Figure 11). In this new window the user can select (i) the two forces/moments that will be related in the interaction diagram, (ii) the maximum and minimum values of the first selected variable that need to be accounted for, (iii) the step increment between different points of the interaction diagram and (iv) the tolerance ratio to accept a solution as in the capacity curve. A more detailed description of the input data and default values is given in Table 8.

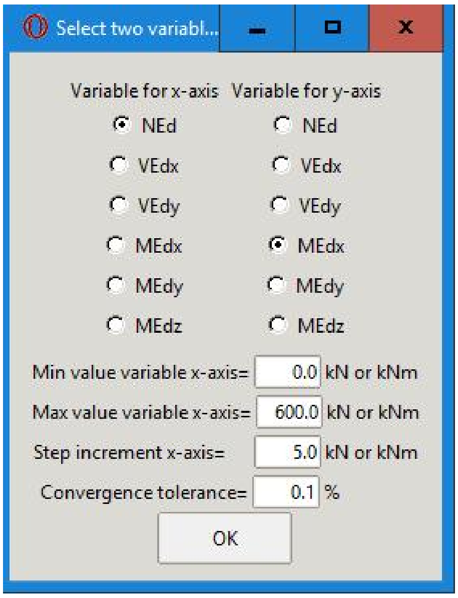


Figure 11 Window for the definition of interaction diagram.

Variable	Description	Options	Units	Default	Where
Interaction diagram options					
Min value variable x-axis	Minimum value that will be considered for the variable selected for the x-axis in the generation of the interaction diagram.	Double number	kN / kNm	0.0	Text box (Figure 11)
Max value variable x-axis	Maximum value that will be considered for the variable selected for the x-axis in the generation of the interaction diagram.	Double number	kN / kNm	600.0	Text box (Figure 11)
Step increment x-axis	Step increment between load steps during the generation of the interaction diagram.	Double number	kN / kNm	5.0	Text box (Figure 11)
Convergence tolerance	Maximum error permitted to accept a solution as valid during the generation of the interaction diagram (e.g. if a convergence tolerance equal to 1% is selected, only a force combination leading to a force-to-strength ratio between [0.99-1.00] will be accepted.	Double number	%	1.0	Text box (Figure 11)

Table 8 Input data in window for the definition of interaction diagram.

2.4 Output data

2.4.1 General

TACEP determines for every mode of failure (see Chapter 3) the force-to-strength ratio. Obtained results are printed on the screen and saved in the file “list_of_checking.txt” (see Figure 12). If any of these ratios is larger than 1.0 it implies that applied design loads exceed the design resistance of the plate. In the example shown below the maximum force-to-strength ratio is 0.868.

```
************************SUMMARY OF RESULTS*************************
**************************STRENGTH RATIO***************************
********************Resistance to tension load*********************
Steel failure to tensile load               = 0.706 [0.706 < 1.0: OK]
Concrete cone failure                       = 0.635 [0.635 < 1.0: OK]
Pull-out failure                            = 0.935 [0.935 < 1.0: OK]
Splitting failure                           = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X- edge)            = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X+ edge)            = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y- edge)            = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y+ edge)            = 0.000 [0.000 < 1.0: OK]
Steel failure of suppl. reinforcement       = 0.000 [0.000 < 1.0: OK]
Anchorage failure of suppl. reinforcement   = 0.000 [0.000 < 1.0: OK]
**********************Resistance to shear load*********************
Steel failure for one anchor                = 0.000 [0.000 < 1.0: OK]
Steel failure for group of anchor           = 0.000 [0.000 < 1.0: OK]
Shear failure with lever arm                = 0.000 [0.000 < 1.0: OK]
Concrete pry-out failure                    = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X- edge)             = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X+ edge)             = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y- edge)             = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y+ edge)             = 0.000 [0.000 < 1.0: OK]
********************Combined shear and tension*********************
Steel failure driven                        = 0.499 [0.499 < 1.0: OK]
Concrete failure driven                     = 0.904 [0.904 < 1.0: OK]
*********************Resistance to compression*********************
Concrete compression                        = 0.037 [0.037 < 1.0: OK]
*******************************************************************
Maximum ratio                               = 0.935 [0.935 < 1.0: OK]
*******************************************************************
```

Figure 12 Output data for single load case.

2.4.2 Multiple plate check

In this case the force-to-strength ratio of every mode of failure for every plate/load case is not printed neither saved as this could lead to a large amount of unnecessary data. Only the maximum force-to-strength ratio and the mode of failure giving this ratio is provided as output. A new spreadsheet is created by copying the input file and the name of the new file is completed with the suffix "_TACEP_check" (e.g. 190121 - DTR EP's Load Check_TACEP_check); obtained results are printed in the columns of the spreadsheet "Utilization ratio" (column AU) (maximum force-to-strength ratio determined for each load case considering all failure modes) and "Status" (associated failure mode to the maximum force-to-strength ratio) (column AV) (see Figure 13).

	Utilization Ratio	Status
.....	0.470807609	Pass, minimum strength given by concrete cone
.....	0.750861237	Pass, minimum strength given by blow out failure at Y- edge
.....	0.158991231	Pass, minimum strength given by concrete pry-out
.....	0.945678912	Pass, minimum strength given by steel in shear

Figure 13 Output data for multiple plate check.

2.4.3 Generation of interaction diagrams

Once the iterative process is completed the interaction diagram relating the two selected variables is automatically plotted on the screen (see Figure 14) and the data points are saved in the file “interaction_diagram.csv”. It must be noted that the maximum value of the X-variable in the interaction diagram will be smaller than that defined by the user if the latter value exceeds the capacity of the plate.

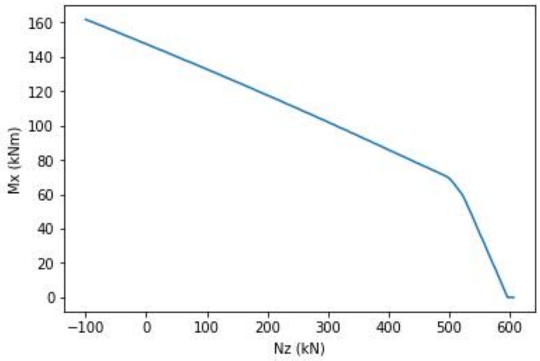


Figure 14 Output data for interaction diagram.

2.5 Execution

TACEP has been developed in Python 2.7.15. To execute the tool Python needs to be installed in the system. The following packages are needed to run the scripts: Tkinter, ttk, tkMessageBox, csv, math, PIL, tkFileDialog, openpyxl, pandas, os, numpy, shapely.geometry, shapely.ops, descartes, scipy.optimize, scipy, random, time. TACEP is launched by executing the python script “main.pyc”. Windows users must pass the path of the program as an argument to the Python interpreter as follows:

C:\ProgramData\Anaconda\python.exe C:\Users\Username\Desktop\TACEP\main.py

If the user wants to type simply python.exe instead of the whole path, python.exe must be added to her path environmental variable.

3 BASIS OF VERIFICATION

3.1 Introduction

This chapter details the calculations performed by TACEP for the assessment of the capacity of EPs. Section 3.3 describes the determination of resistances for the different failure modes in both tension and shear following the reference design guidelines EN 1992-4 (Ref. [1]), RCC-CW (Ref. [2]) and CEB (Ref. [3]). Section 3.2 details the calculation of tension and shear forces on the anchors and the concrete stresses from the defined actions.

3.2 Determination of action effects

3.2.1 Effect of eccentricity

In order to consider eccentricities of the input load, defined design forces are transformed into design forces at the centre of gravity of the plate as follows:

$$M'_{Ed,x} = M_{Ex} + N_{Ed}\left(e_y \pm e_{y,tol}\right) \quad \text{Eq. (1)}$$

$$M'_{Ed,y} = M_{Ey} - N_{Ed}\left(e_x \pm e_{x,tol}\right) \quad \text{Eq. (2)}$$

$$M'_{Ed,z} = M_{Ed,z} + V_{Ed,y}\left(e_x \pm e_{x,tol}\right) - V_{Ed,x}\left(e_y \pm e_{y,tol}\right) \quad \text{Eq. (3)}$$

$$M'_{Ed} = \sqrt{\max\left(M'^2_{Ed,x}\right) + \max\left(M'^2_{Ed,y}\right)} \quad \text{Eq. (4)}$$

3.2.2 Axial forces at anchors

The correct determination of the resulting tensile forces on anchors is critical for capacity checking and design of anchorage plates. These forces are derived from sectional analysis, a process which can become tedious, especially for biaxial moment configurations. A function was integrated in TACEP for obtaining these for both rectangular and circular plate sections Resultant forces are obtained after solving the system of equations formed by the equilibrium of axial forces and bending moments (see Figure 15):

$$N_{Ed} = \iint \sigma_c \, dx\, dy + \sum_{i=1}^{n} A_{s,i}\, \sigma_{s,i} = \iint E_c\, \epsilon_c \, dx\, dy + \sum_{i=1}^{n} A_{s,i}\, E_s\, \epsilon_{s,i} \quad \text{Eq. (5)}$$

$$M'_{Ed} = \iint \sigma_c\, z \, dx\, dy + \sum_{i=1}^{n} A_{s,i}\, \sigma_{s,i}\, z_{s,i} = \iint E_c\, \epsilon_c\, z \, dx\, dy + \sum_{i=1}^{n} A_{s,i}\, E_s\, \epsilon_{s,i}\, z_{s,i} \quad \text{Eq. (6)}$$

with

$$\frac{\epsilon_{c0}}{d_1} = \frac{\epsilon_c}{d_1 - d} = \frac{\epsilon_{s,i}}{d_1 - d_{s,i}} \quad \text{Eq. (7)}$$

where ϵ_{c0} (maximum concrete strain) and d_1 (depth of the neutral axis) are the unknowns. The maximum stress on concrete is limited to the design concrete strength $f_{cd} = f_{ck} / \gamma_{Mc,comp}$.

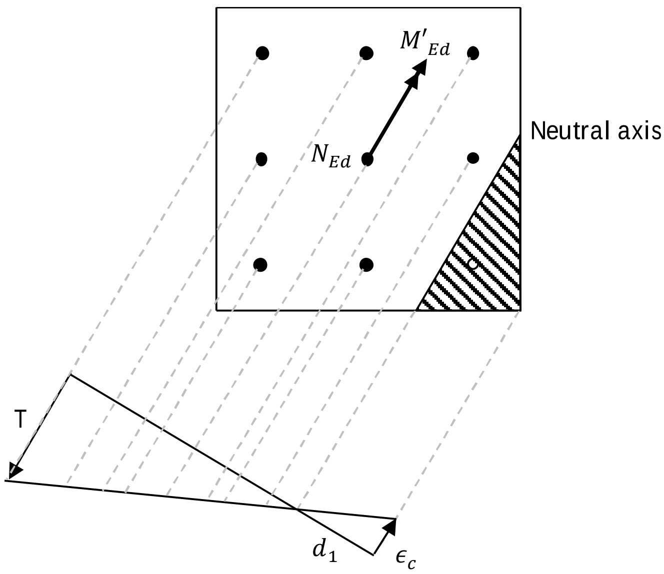


Figure 15 Sectional analysis of embedded plate subjected to axial force and biaxial moment

3.2.3 Shear forces at anchors

The total shear force to be resisted by each anchor $V_{Ed,anchor}$ is calculated as:

$$V_{Ed,anchor} = \sqrt{\left(\frac{|V_{Ed,x}|}{n} + |M'_{Ed,z}|\ \alpha_x\right)^2 + \left(\frac{|V_{Ed,y}|}{n} + |M'_{Ed,z}|\ \alpha_y\right)^2} \quad \text{Eq. (8)}$$

n = number of anchors

α_x, α_y = factors used to obtain the shear force due a twisting moment in X- and Y-direction, respectively.

Factors α_x and α_y can be derived as follows. Given a twisting moment $M_{Ed,z}$ applied at the centre of the plate, the equilibrium of forces implies that resulting shear forces at the anchors $V_{anchor,T,i}$ are such that (see Figure 16):

$$M_{Ed,z} = \sum_{i=1}^{n} V_{anchor,T,i}\, d_{anchor,i}^{cg} \quad \text{Eq. (9)}$$

where $V_{anchor,T,i}$ is the shear force induced at anchor i and $d^{cg}_{anchor,i}$ is the distance from the anchor to the reference point of the twisting moment, which in this case is the centre of gravity of the plate (see Figure 16).

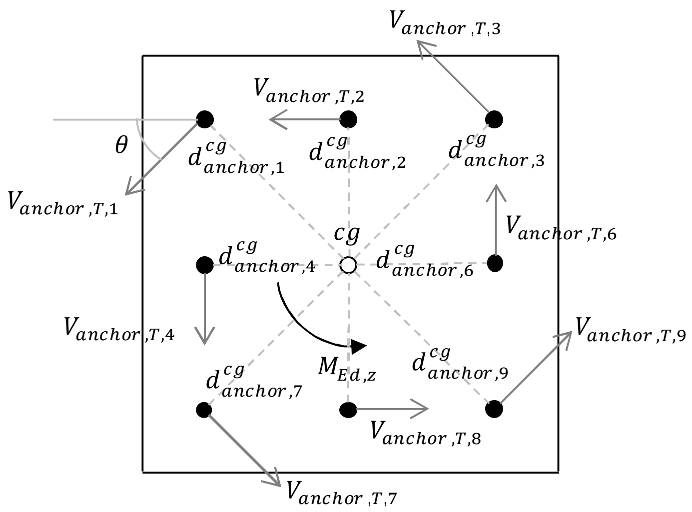


Figure 16 Distribution of shear forces for torsional moment

Assuming a linear variation with distance of the induced shear force, the shear force at each anchor can be written as a function of the maximum shear force induced at an anchor by the twisting moment $V_{anchor,T,max}$ as:

$$V_{anchor,T,i} = V_{anchor,T,max} \frac{d^{cg}_{anchor,i}}{d^{cg}_{anchor,max}} \qquad \text{Eq. (10)}$$

where $d^{cg}_{anchor,max}$ is the maximum distance from the centre of gravity of the plate to an anchor, which corresponds to the anchor where the maximum shear will be induced. Eq. (9) can be now written as:

$$M_{Ed,z} = \sum_{i}^{n} V_{anchor,T,max} \frac{\left(d^{cg}_{anchor,i}\right)^2}{d^{cg}_{anchor,max}} = \frac{V_{anchor,T,max}}{d^{cg}_{anchor,max}} \sum_{i}^{n} \left(d^{cg}_{anchor,i}\right)^2 \qquad \text{Eq. (11)}$$

From which the maximum shear force induced by the twisting moment $V_{anchor,T,max}$ can be derived as:

$$V_{anchor,T,max} = M_{Ed,z} \frac{d^{cg}_{anchor,max}}{\sum_{i}^{n}\left(d^{cg}_{anchor,i}\right)^2} \qquad \text{Eq. (12)}$$

The shear force at any anchor can be calculated similarly as:

$$V_{anchor,T,i} = M_{Ed,z} \frac{d^{cg}_{anchor,i}}{\sum_i^n \left(d^{cg}_{anchor,i}\right)^2} \quad \text{Eq. (13)}$$

The components in X- and -Y-direction can be obtained by projecting this force onto the corresponding axis. For the X-direction this is given by:

$$V_{anchor,T,i,x} = M_{Ed,z} \frac{d^{cg}_{anchor,i}}{\sum_i^n \left(d^{cg}_{anchor,i}\right)^2} cos\theta = M_{Ed,z} \frac{d^{cg}_{anchor,i}}{\sum_i^n \left(d^{cg}_{anchor,i}\right)^2} \frac{d^{cg}_{anchor,i,y}}{d^{cg}_{anchor,i}} = M_{Ed,z} \frac{d^{cg}_{anchor,i,y}}{\sum_i^n \left(d^{cg}_{anchor,i}\right)^2} \quad \text{Eq. (14)}$$

Factor α_x which relates the x component of the shear force induced by the twisting moment can be derived:

$$\alpha_{i,x} = \frac{V_{anchor,T,i,x}}{M_{Ed,z}} = \frac{d^{cg}_{anchor,i,y}}{\sum_i^n \left(d^{cg}_{anchor,i}\right)^2} \quad \text{Eq. (15)}$$

Factor α_y is derived from the y-component and can be calculated similarly as:

$$\alpha_{i,y} = \frac{V_{anchor,T,i,y}}{M_{Ed,z}} = \frac{d^{cg}_{anchor,i,x}}{\sum_i^n \left(d^{cg}_{anchor,i}\right)^2} \quad \text{Eq. (16)}$$

3.3 Determination of resistances

3.3.1 Material safety factor

Determination of the characteristic resistance R_k for each failure mode in tension and shear is described in sections 3.3.2 and 3.3.2.7, respectively. For each failure mode the design resistance R_d is calculated from the characteristic resistance R_k as:

$$R_d = R_k \ / \ \gamma_M \quad \text{Eq. (17)}$$

where γ_M is the partial safety factor for the material. Different safety factors apply for steel, concrete and reinforcing steel.

Four safety factors can be defined for steel for anchors considering the load type (normal or accidental operation) and the type of demand (tension or shear) (see Figure 6):

- $\gamma_{Ms,tension,NO}$, $\gamma_{Ms,tension,AO}$: applicable to failure mode (i) steel failure of fastener.
- $\gamma_{Ms,shear,NO}$, $\gamma_{Ms,shear,AO}$: applicable to failure modes (i) steel failure of fastener without lever arm and (ii) steel failure of fastener with lever arm.

Four safety factors can be defined for concrete considering the load type (normal or accidental operation) and the type of demand (tension or compression) (see Figure 8):

- $\gamma_{Mc,tension,NO}$, $\gamma_{Mc,tension,AO}$: applicable to failure modes (i) concrete cone failure, (ii) pull-out failure of fastener, (iii) concrete splitting failure, (iv) concrete blow-out failure, (v) concrete pry-out failure, (vi) concrete edge failure and (vii) anchorage failure of reinforcement.
- $\gamma_{Mc,comp,NO}$, $\gamma_{Mc,comp,AO}$: applicable to failure mode compression failure under the fixture. Concrete failure in compression under the fixture does not generally limit the capacity of anchorage plates and is not explicitly included in anchorage design guidelines. However, this verification was included in the tool for the sake of comprehensiveness (see section 3.3.5). For the sake of simplicity same safety factors may be applied for tension and compression.

Two safety factors can be defined for reinforcing steel considering the load type (normal or accidental operation): $\gamma_{Mre,NO}$ and $\gamma_{Mre,AO}$. This material factor is applicable to failure mode (i) steel failure of reinforcement.

Material safety factors adopted by default in the tool are based on the values proposed in EN 1992-4 (see Table 9), but these can be modified by the user in the corresponding windows. Note that material safety factors are also defined in the relevant certificate of approval for anchors entitled with it and these values generally agree with those derived from EN 1992-4. Different material safety factors are proposed in CEB code (see Table 10). Regarding the difference observed for material safety factors for steel between EN 1992-4 and CEB, it must be mentioned that, as noted later, the characteristic resistance of steel failure modes is based on $f_{uk,s}$ in EN 1992-4 and on $f_{yk,s}$ in CEB.

γ_M	Normal operation	Accidental operation
$\gamma_{Ms,tension}$	= 1.2 $f_{uk,s}$ / $f_{yk,s}$ ≥ 1.4	= 1.05 $f_{uk,s}$ / $f_{yk,s}$ ≥ 1.25
$\gamma_{Ms,shear}$	= 1.0 $f_{uk,s}$ / $f_{yk,s}$ ≥ 1.25 when $f_{uk,s}$ ≤ 800 MPa and $f_{yk,s}$ / $f_{uk,s}$ ≤ 0.8	= 1.0 $f_{uk,s}$ / $f_{yk,s}$ ≥ 1.25 when $f_{uk,s}$ ≤ 800 MPa and $f_{yk,s}$ / $f_{uk,s}$ ≤ 0.8
	= 1.5 when $f_{uk,s}$ > 800MPa or $f_{yk,s}$ / $f_{uk,s}$ > 0.8	= 1.3 when $f_{uk,s}$ > 800MPa or $f_{yk,s}$ / $f_{uk,s}$ > 0.8
$\gamma_{Mc,tension}$	= 1.5	= 1.2
γ_{Mre}	= 1.15	= 1.0

Table 9 Recommended material safety factor values from EN 1992-4.

γ_M	Normal operation	Accidental operation
$\gamma_{Ms,tension}$	= 1.2	Not defined
$\gamma_{Ms,shear}$	= 1.2 when $f_{uk,s} \leq$ 800 MPa and $f_{yk,s} / f_{uk,s} \leq 0.8$	Not defined
	= 1.5 when $f_{uk,s} >$ 800MPa or $f_{yk,s} / f_{uk,s} > 0.8$	Not defined
$\gamma_{Mc,tension}$	= 1.8	Not defined
γ_{Mre}	= 1.15	Not defined

Table 10 Recommended material safety factor values from CEB code.

3.3.2 Tension load

Table 11 shows the verifications undertaken by the tool in tension. Some checks are undertaken at anchor level, considering the largest tension load acting on an anchor N_{Ed}^{h}; other verifications are performed at group level, considering the total tensile force acting on the anchors N_{Ed}^{g}.

Failure mode	Most loaded fastener	Group
Steel failure of fastener (section 3.3.2.1)	$N_{Ed}^{h} \leq N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms,tension}}$	
Concrete cone failure (section 3.3.2.2)		$N_{Ed}^{g} \leq N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc,tension}}$
Pull-out failure of fastener (section 3.3.2.3.1)	$N_{Ed}^{h} \leq N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mc,tension}}$	
Combined pull-out and concrete cone failure (section 3.3.2.3.2)		$N_{Ed}^{g} \leq N_{Rd,p}$
Concrete splitting failure (section 3.3.2.4)		$N_{Ed}^{g} \leq N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Mc,tension}}$
Concrete blow-out failure (section 3.3.2.5)		$N_{Ed}^{g} \leq N_{Rd,cb} = \frac{N_{Rk,cb}}{\gamma_{Mc,tension}}$
Steel failure of reinforcement (section 3.3.2.6.1)	$N_{Ed}^{h} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Mre}}$	
Anchorage failure of reinforcement (section 3.3.2.6.2)	$N_{Ed}^{h} \leq N_{Rd,a}$	

Table 11 Verifications in tension.

3.3.2.1 Steel failure of fastener

If plate failure is driven by failure of the steel, then the ultimate load is limited by the largest tensile load acting on an individual anchor N_{Ed}^{h} and the characteristic steel resistance of the fastener $N_{Rk,s}$. For anchors with ETA certificate $N_{Rk,s}$ is directly defined by the user taken the value given in the relevant approval certificate (see Figure 6). For anchors without ETA certificate $N_{Rk,s}$ is calculated from the defined anchor diameter d and tensile strength of steel $f_{uk,s}$ as follows:

$$N_{Rk,s} = A_s \, f_s = (\pi \, d^2/4) \, f_s \qquad \text{Eq. (18)}$$

Following the corresponding design codes: if EC2 or RCC-CW code are selected, then $f_s = f_{uk,s}$; if CEB code is chosen, then $f_s = f_{yk,s}$.

3.3.2.2 Concrete cone failure

If plate failure is driven by failure of the concrete cone, then the ultimate load is limited by the total tensile force acting on the anchors N_{Ed}^{g} and the characteristic resistance of the concrete cone $N_{Rk,c}$, which is calculated as:

$$N_{Rk,c} = N_{Rk,c}^{0} \, \psi_{A,N} \, \psi_{s,N} \, \psi_{ec,N} \, \psi_{re,N} \, \psi_{M,N} \qquad \text{Eq. (19)}$$

$N_{Rk,c}^{0}$ refers to the characteristic resistance of a single anchor without considering edge and spacing effects and is calculated as:

$$N_{Rk,c}^{0} = k_1 \sqrt{f_{ck}} \, h_{ef}^{1.5} \qquad \text{Eq. (20)}$$

where f_{ck} (in MPa) is the compressive strength of concrete defined by the user and h_{ef} (in mm) is the anchor embedded length. For anchors with approval certificate the value of k_1 is that defined by the user as given in the corresponding document (e.g. for Nelson studs $k_1 = 8.5$ (Ref. [8])); for anchors without approval certificate the value of k_1 depends on the selected design code: $k_1 = 8.9$ if EC2 or RCC-CW are chosen; $k_1 = 9.0$ if CEB is selected.

Factor $\psi_{A,N}$ accounts for geometric effects of spacing between anchors and edge effect and is calculated as:

$$\psi_{A,N} = \frac{A_{c,N}}{A_{c,N}^{0}} \qquad \text{Eq. (21)}$$

where $A_{c,N}^{0}$ is the projected area of a single anchor and $A_{c,N}$ is the projected area of the anchorage plate obtained from the union of the projected individual areas and limited by overlapping concrete cones of adjacent fasteners ($s \leq s_{cr,N}$) as well as by edges of the concrete member or fictive edges ($c \leq c_{cr,N}$). The projected area of an individual anchor is taken equal to a square of side $s_{cr,N} = 3\,h_{ef}$, as defined in both EN 1992-4 and CEB, where $s_{cr,N}$ is the characteristic spacing.

Factor $\psi_{s,N}$ accounts for the disruption of the stress field in the concrete due to the proximity of a corner of the concrete member. Following both EN 1992-4 and CEB this factor is taken equal to:

$$\psi_{s,N} = 0.7 + 0.3\frac{c}{c_{cr,N}} \leq 1 \qquad \text{Eq. (22)}$$

where c is the smallest edge distance and $c_{cr,N} = 1.5\,h_{ef}$. Only distances to concrete edges are considered to calculate this factor, i.e. fictive edges defined to account for adjacent plates are not accounted for as the existence of a nearby plate does not disturb the stress field.

Factor $\psi_{ec,N}$ accounts for the influence of the eccentricity of the resultant tensile force. Following both EN 1992-4 and CEB this factor is taken equal to:

$$\psi_{ec,N} = \frac{1}{1+\frac{2e_{n,x}}{s_{cr,N}}} \cdot \frac{1}{1+\frac{2e_{n,y}}{s_{cr,N}}} \leq 1 \qquad \text{Eq. (23)}$$

where $e_{n,x}$ and $e_{n,y}$ are the distance between the position of the resultant tensile force on the tension-loaded anchors and the geometric centroid of these anchors, in X- and Y-direction, respectively.

Factor $\psi_{re,N}$ accounts for the effect of dense reinforcement near the surface of the concrete between fasteners when $h_{ef} < 100$ mm. Following both EN 1992-4 and CEB this factor is taken equal to:

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1 \qquad \text{Eq. (24)}$$

with h_{ef} in mm. Based on EN 1992-4 and CEB this reduction only applies if rebar spacing is less than 150 mm for any any diameter or less than 100 mm for rebars of diameter 10 mm or less. Being conservatively TACEP applies this factor regardless of reinforcement density if $h_{ef} < 100$ mm, but it should be noted that this condition will not be generally applicable as expected anchors in ITER will be generally longer than 100 mm.

Factor $\psi_{M,N}$ accounts for the influence of the compressive block under the fixture in cases of bending moment, increasing the concrete cone strength. This factor is taken equal to 1 if the CEB Code is selected as this guideline does not consider this factor. If EC2 or RCC-CW are selected, then this factor is calculated as:

$\psi_{M,N} = 1$ for the following cases: Eq. (25)

- Fastenings with an edge distance $c < 1.5\, h_{ef}$
- Fastenings with $c \geq 1.5\, h_{ef}$ where the resultant compressive force between fixture and concrete C_{Ed} is smaller than 0.8 N_{Ed}.
- $z \geq 1.5\, h_{ef}$

$$\psi_{M,N} = 2 - \frac{z}{1.5\, h_{ef}} \geq 1 \text{ for all other cases}$$

Following EN 1992-4 (7.2.1.4(8))) and CEB, for the case of fasteners in an application with three or more edge distances less than $c_{cr,N}$ from the fasteners the value of the embedded depth h_{ef} is replaced by:

$$h'_{ef} = \max\left(\frac{c_{max}}{c_{cr,N}}\, h_{ef}, \frac{s_{max}}{s_{cr,N}}\, h_{ef}\right) \qquad \text{Eq. (26)}$$

where c_{max} is the maximum edge distance being smaller than 1.5 h_{ef} and s_{max} the maximum distance between anchors. Without considering this modification the failure load of plates with three or more near edges would be inversely proportional to $h_{ef}^{0.5}$, i.e. increasing the embedded length would lead to lower resistances.

3.3.2.3 *Pull-out failure of fastener*

If plate failure is driven by pull-out of the fastener from the concrete, two cases are distinguished depending if an anchor head exists (see section 3.3.2.3.1) or not (section 3.3.2.3.2). It is assumed that there is no anchor head if the diameter head d_h is smaller or equal to the diameter of the shaft d.

3.3.2.3.1 *Headed studs*

If plate failure is driven by pull-out failure of the headed fastener, then the ultimate load is limited by the largest tensile load acting on an individual anchor N_{Ed}^{h} and the characteristic resistance of the fastener to pull-out $N_{Rk,p}$. For anchors with approval certificate $N_{Rk,p}$ is directly defined by the user taken the value given in the relevant approval certificate (see Figure 6). For anchors without approval certificate $N_{Rk,p}$ is calculated as follows:

$$N_{Rk,p} = k_2\, A_h\, f_{ck} \qquad \text{Eq. (27)}$$

where A_h is the load bearing area of the head of the fastener:

$$A_h = \pi\, (d_h^2 - d^2)/4 \qquad \text{Eq. (28)}$$

The value of k_2 depends on the selected design code: k_2 = 7.5 if EC2 or CEB are chosen; k_2 = 3.0 if RCC-CW is selected. The lower value of k_2 proposed in RCC-CW compared to that in EC2 and CEB is intended to reduce plate displacements rather than related to strength limitations; indeed, in CEB guidelines it is noted that it may necessary to reduce the pull-out capacity obtained with $k_2 = 7.5$ to fulfil the requirements in the serviceability limit state.

3.3.2.3.2 Studs without anchor head

If plate failure is driven by pull-out failure of studs without anchor heads, then the ultimate load is limited by the total tensile force acting on the anchors N_{Ed}^{g} and the characteristic resistance of the combined pull-out and concrete failure $N_{Rk,p}$. The latter is calculated based on the formulation proposed for post-installed bonded fasteners and considering the bond resistance for ribbed rebars as:

$$N_{Rd,p} = N_{Rd,p}^{0} \psi_{A,Np}\ \psi_{g,Np}\ \psi_{s,Np}\ \psi_{ec,Np}\ \ \psi_{re,N} \qquad \text{Eq. (29)}$$

$N_{Rd,p}^{0}$ refers to the design resistance of a single bonded anchor without considering edge and spacing effects and is calculated as:

$$N_{Rd,p}^{0} = \frac{f_{bd}\ \pi\ d\ h_{ef}}{\alpha_2} \qquad \text{Eq. (30)}$$

where f_{bd} is the design bond strength and α_2 is an bond influencing factor. In Eq. (30) it is assumed that the ratio between the value of sustained loads and the value of total actions considered at ultimate limit state is smaller tha 0.6; this formulae would not be valid if this condition is not fulfilled (see EN 1992-4, clause 7.2.1.6). Based on EN 1992-1-1, section 8.4.4 α_2 is taken equal to 0.7 assuming the concrete cover will be always larger than three times the shaft diameter ($c_b \geq 3d$). Based on EN 1992-1-1, section 8.4.2, and assuming ribbed rebars are used as anchors, the design value of the ultimate bond stress f_{bd} is calculated as:

$$f_{bd} = 2.25\, \eta_1\ \eta_2\ f_{ctd} \qquad \text{Eq. (31)}$$

with

$$\eta_1 = 1.0 \text{ (assuming good bonding conditions)}$$

$$\eta_2 = \begin{cases} 1.0 \text{ for } d \leq 32 \text{ mm} \\ (132 - d)\,/\,100 \text{ for } d > 32\text{mm} \end{cases} \qquad \text{Eq. (32)}$$

$$f_{ctd} = f_{ctk,0.05}\ /\ \gamma_{Mc,tension} = \left(0.7 \cdot 0.3\, f_{ck}^{2/3}\right)\ /\ \gamma_{Mc,tension} \qquad \text{Eq. (33)}$$

Factor $\psi_{A,N}$ accounts for geometric effects of spacing between anchors and edge effect and is calculated as:

$$\psi_{A,Np} = \frac{A_{p,N}}{A_{p,N}^{0}} \qquad \text{Eq. (34)}$$

where $A^0_{p,N}$ is the projected area of a single anchor and $A_{p,N}$ is the projected area of the anchorage plate obtained from the union of the projected individual areas and limited by overlapping areas of adjacent fasteners ($s \leq s_{cr,Np}$) as well as by edges of the concrete member or fictive edges ($c \leq c_{cr,Np}$). The projected area of an individual anchor is taken equal to a square of side $s_{cr,N}$ = 7.3 $d\ (f_{bd})^{0.5} \leq 3\ h_{ef}$ following section 7.2.1.6 in EN 1992-4 for bonded anchors.

The factor $\psi_{g,Np}$ accounts for group effect of closely spaced bonded fasteners and is calculated as:

$$\psi_{g,Np} = \psi^0_{g,Np} - \left(\frac{s}{s_{cr,Np}}\right)^{0.5} \cdot \left(\psi^0_{g,Np} - 1\right) \geq 1 \qquad \text{Eq. (35)}$$

$$\psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right)\left(\frac{\tau_{Rk}}{\tau_{Rk,c}}\right)^{1.5} \geq 1 \qquad \text{Eq. (36)}$$

where n is the number of anchors under tension.

Factor $\psi_{s,Np}$ accounts for the disruption of the stress field in the concrete due to the proximity of a corner of the concrete member. Following both EN 1992-4 and CEB this factor is taken equal to:

$$\psi_{s,Np} = 0.7 + 0.3\frac{c}{c_{cr,Np}} \leq 1 \qquad \text{Eq. (37)}$$

where c is the smallest edge distance and $c_{cr,Np}$ = 3.65 $d\ (f_{bd})^{0.5} \leq 1.5\ h_{ef}$. Only distances to concrete edges are considered to calculate this factor, i.e. fictive edges defined to account for adjacent plates are not accounted for as the existence of a nearby plate does not disturb the stress field.

Factor $\psi_{ec,N}$ accounts for the influence of the eccentricity of the resultant tensile force. Following both EN 1992-4 and CEB this factor is taken equal to:

$$\psi_{ec,N} = \frac{1}{1 + \frac{2e_{n,x}}{s_{cr,Np}}} \cdot \frac{1}{1 + \frac{2e_{n,y}}{s_{cr,Np}}} \leq 1 \qquad \text{Eq. (38)}$$

where $e_{n,x}$ and $e_{n,y}$ is the distance between the position of the resultant tensile force on the tension-loaded anchors and the geometric centroid of these anchors, in X- and Y-direction, respectively.

Factor $\psi_{re,N}$ accounts for the effect of dense reinforcement near the surface of the concrete between fasteners when h_{ef} < 100 mm. Eq. (24) applies.

Following EN 1992-4 (7.2.1.6(8)) and CEB, for the case of fasteners in an application with three or more edge distances less than $c_{cr,Np}$ from the fasteners the value of the embedded depth h_{ef} is replaced by:

$$h'_{ef} = \max\left(\frac{c_{max}}{c_{cr,Np}}\, h_{ef}, \frac{s_{max}}{s_{cr,Np}}\, h_{ef}\right) \qquad \text{Eq. (39)}$$

where c_{max} is the maximum edge distance being smaller than $c_{cr,Np}$ and s_{max} the maximum distance between anchors.

3.3.2.4 Concrete splitting failure

Splitting failure mode during anchor loading may occur with fastenings located near to an edge or a corner, especially in a thin member. No concrete splitting verification is performed if one of the following conditions is fulfilled:

(a) The edge distance in all directions c and the thickness of the concrete element are larger than a certain magnitude, the value of which depends on the adopted design code:

- EC2 or RCC-CW: the edge distance in all directions is $c \geq 1.2\, c_{cr,sp}$ and the thickness of concrete member is $h_{slab} \geq h_{min}$, with $h_{min} = h_{ef} + t_p + c_{nom}$ as it is generally given in the approval certificate of cast-in anchors (see Refs. [8], [9], [10]). c_{nom}, the required concrete cover, is taken conservatively equal to 10 cm.
- CEB: the edge distance in all directions is $c \geq 1.5\, c_{cr,sp}$ and the thickness of concrete member is $h_{slab} \geq h_{min}$, with $h_{min} = 2.0\, h_{ef}$ as defined in Ref. [3].

where $c_{cr,sp}$ is the characteristic edge distance in the case of splitting under load. In the tool $c_{cr,sp}$ is taken equal to 1.5 h_{ef} as it is generally the case for anchors with approval certificate (see Refs. [8], [9], [10]).

(b) Reinforcement is arranged to resist splitting forces. The user can define the existence of this reinforcement when defining the plate (see Figure 5), but she needs to check first that sufficient reinforcement is arranged to resist these splitting forces, as this is not verified by the tool; according to EN 1992-4 the area of the splitting reinforcement can be determined as:

$$\sum A_{s,re} = 0.5 \frac{\sum N_{Ed}}{f_{yk,re} \,/\, \gamma_{Mre}} \qquad \text{Eq. (40)}$$

where $\sum N_{Ed}$ is the sum of the design tensile force of the fasteners in tension under the design value of actions. It is recommended that this reinforcement is placed symmetrically and close to the fasteners.

If none of the above conditions is fulfilled the characteristic resistance of the plate in case of concrete splitting failure $N_{Rk,sp}$ is calculated as:

$$N_{Rk,sp} = N^0_{Rk,sp}\, \psi_{AN}\, \psi_{s,N}\, \psi_{re,N}\, \psi_{ec,N}\, \psi_{h,sp} \qquad \text{Eq. (41)}$$

$N^0_{Rd,p}$ refers to the splitting resistance of a single bonded anchor without considering edge and spacing effects and its value depends on the selected design code:

- If EC2 or RCC-CW are selected, $N^0_{Rk,sp} = \min\left(N_{Rk,p}; N^0_{Rk,c}\right)$, with $N^0_{Rk,c}$ calculated according to Eq. (20) and $N_{Rk,p}$ calculated with Eq. (27) for headed anchors and with Eq. (30) for studs without head, analogously to bonded fasteners.
- If CEB is selected, $N^0_{Rd,p} = N^0_{Rk,c}$ (see Eq. (20)).

$\psi_{A,N}$, $\psi_{s,N}$, $\psi_{re,N}$, $\psi_{ec,N}$ are calculated as for concrete cone failure (see section 3.3.2.2), however the values $c_{cr,N}$ and $s_{cr,N}$ are replaced by $c_{cr,sp}$ and $s_{cr,sp}$. As commented above, $c_{cr,sp}$ is taken equal to 1.5 h_{ef} as it is generally the case for anchors with approval certificate (see Refs. [8], [9], [10]), so in this case there is no difference.

$\psi_{h,sp}$ takes into account the influence of the actual member thickness h_{slab} on the splitting resistance and its value depends on the selected code:

$$\psi_{h,sp} = \left(\frac{h_{slab}}{h_{min}}\right)^{\frac{2}{3}} \leq \max\left\{1; \left(\frac{h_{ef} + 1.5\, c_1}{h_{min}}\right)^{\frac{2}{3}}\right\} \leq 2 \qquad \text{for EC2 and RCC-CW} \qquad \text{Eq. (42)}$$

$$\psi_{h,sp} = \left(\frac{h_{slab}}{2\, h_{ef}}\right)^{\frac{2}{3}} \leq 1.2 \qquad \text{for CEB} \qquad \text{Eq. (43)}$$

3.3.2.5 Concrete blow-out failure

Tension-loaded headed anchors placed at a small edge distance can generate local blow-out failure in the vicinity of the head. Following EC2 and CEB, blow-out failure is not checked for anchorages with an edge distance $c > 0.5\, h_{ef}$. Note that only concrete edges are considered in this verification, i.e. fictive edges are not accounted for. For those edges where this condition is not fulfilled, blow-out failure is checked. The tensile force acting at the anchors closest to the corresponding edge and the characteristic resistance to blow-out failure of the edge $N_{Rk,cb}$ are considered. The latter is calculated as follows:

$$N_{Rk,cb} = N^0_{Rk,cb}\, \psi_{A,Nb}\, \psi_{s,Nb}\, \psi_{g,Nb}\, \psi_{ec,Nb} \qquad \text{Eq. (44)}$$

$N^0_{Rk,cb}$ refers to the characteristic resistance of a single anchor, not influenced by adjacent fasteners or further edges and is calculated as:

$$N_{Rk,cb}^{0} = k_5\, c_1 \sqrt{A_h} \sqrt{f_{ck}} \qquad \text{Eq. (45)}$$

where c_1 is the distance from the centre of the fastener to the edge under consideration (see Figure 17), A_h the load bearing area of the head of the fastener (Eq. (28)) and f_{ck} (in MPa) is the compressive strength of concrete defined by the user. The value of k_5 depends on the selected code: $k_5 = 8.7$ if EC2 or RCC-CW are chosen; $k_1 = 8.1$ if CEB is selected (obtained from $8.0 \cdot 0.9 \cdot \sqrt{4/\pi}$).

Factor $\psi_{A,Nb}$ accounts for geometric effect of axial spacing and edge distance and is calculated as:

$$\psi_{A,Nb} = \frac{A_{c,Nb}}{A_{c,Nb}^{0}} \qquad \text{Eq. (46)}$$

where $A_{c,Nb}^{0}$ is the reference projected area for an individual fastener with an edge distance c_1 and $A_{c,Nb}$ is the actual projected area, limited by overlapping concrete break-out bodies of adjacent fasteners as well as by proximity of edges of the concrete member or the member thickness. The projected area of an individual anchor is a square the dimensions of which depends on the adopted code: the side is equal to 4 c_1 if EC2 or RCC-CW are selected or 6 c_1 if CEB is chosen (see Figure 17).

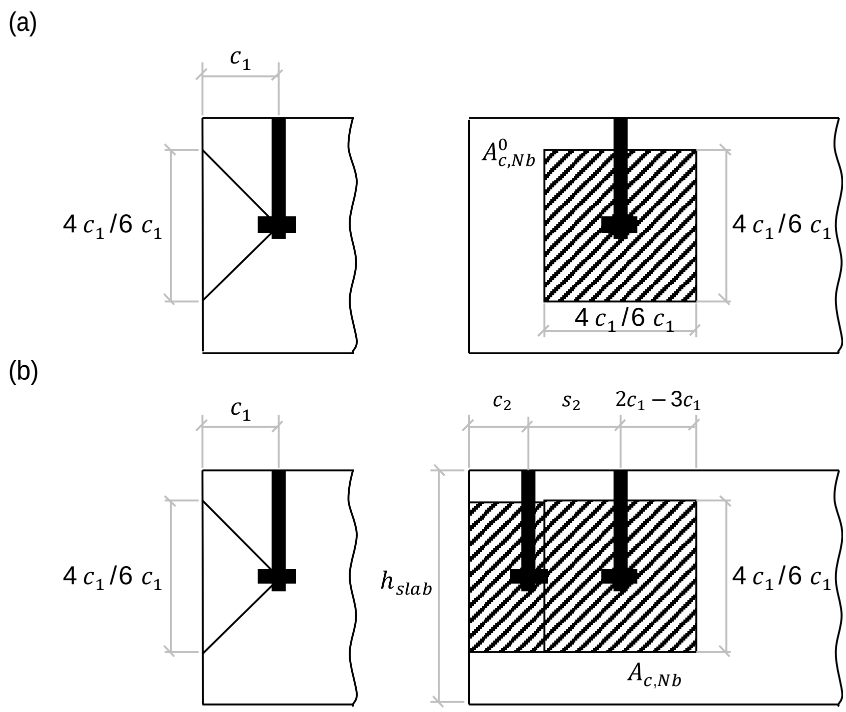


Figure 17 Concrete break body for blow-out failure: (a) Individual fastener; (b) Fastener group limited by near edge.

Factor $\psi_{s,Nb}$ accounts for the disruption of the stress field in the concrete due to the proximity of a corner of the concrete member. Analogously to the determination of the concrete break-out body, different dimensions apply depending on the selected code, affecting to the determination of $\psi_{s,Nb}$ as follows:

$$\psi_{s,Nb} = 0.7 + 0.3\frac{c_2}{2\,c_1} \leq 1 \quad \text{for EC2 and RCC-CW} \qquad \text{Eq. (47)}$$

$$\psi_{s,Nb} = 0.7 + 0.3\frac{c_2}{3\,c_1} \leq 1 \quad \text{for CEB} \qquad \text{Eq. (48)}$$

where c_2 is the smallest edge distance in the direction parallel to the edge under verification.

Factor $\psi_{g,Nb}$ accounts for the group effect of a number of fasteners n in a row parallel to the edge. This factor is taken equal to 1 if the CEB code is selected as this code does not consider this effect. If the EC2 or RCC-CW are selected, this factor is calculated as:

$$\psi_{g,Nb} = \sqrt{n} + \left(1 - \sqrt{n}\right)\frac{s_2}{4\,c_1} \geq 1 \qquad \text{Eq. (49)}$$

where n is the number of anchor under tension parallel and close to the edge and s_2 the spacing in-between the anchors.

Factor $\psi_{ec,Nb}$ takes account of a group effect when different tension loads are acting on the individual anchors of a group. Analogously to the determination of the concrete break-out body, different dimensions apply depending on the selected code, affecting to the determination of $\psi_{ec,Nb}$ as follows:

$$\psi_{ec,Nb} = \frac{1}{1 + 2\,e_N / (4\,c_1)} \quad \text{for EC2 and RCC-CW} \qquad \text{Eq. (50)}$$

$$\psi_{ec,Nb} = \frac{1}{1 + 2\,e_N / (6\,c_1)} \quad \text{for CEB} \qquad \text{Eq. (51)}$$

where e_N is the eccentricity of the resulting tension force of the tensioned anchors in the row near the edge with respect to their centre of gravity.

It should be noted that for circular plates blow-out failure is not verified by the tool due to the difficulties to calculate automatically the total tensile force carried by the anchors near the edge. Therefore, when required, the user should check this verification independently.

3.3.2.6 Failure of supplementary reinforcement

According to EN 1992-4 the supplementary reinforcement for tension shall be designed for the most tension-loaded fastener N_{Ed}^{h} and then applied this reinforcement to all fasteners. Considering this, the tool checks the tensile load acting on the most stressed anchor against the steel resistance (see section 3.3.2.6.1) and anchorage failure (see section 3.3.2.6.2), assuming the reinforcement arranged at each anchor is equal to that defined by the user (see Figure 7).

Note that supplementary reinforcement is arranged to prevent concrete cone failure (see section 3.3.2.2). If the maximum force-to-strength ratio obtained for steel failure and anchorage failure of supplementary reinforcement is smaller than that obtained for the concrete cone failure, then the value of the latter is substituted by the maximum force-to-strength ratio obtained for failure of the supplementary reinforcement.

3.3.2.6.1 Steel failure of supplementary reinforcement

The characteristic yield resistance of the supplementary reinforcement for one fastener is obtained as:

$$N_{Rk,re} = \sum_{i}^{nlegs} A_{s,re,i}\, f_{yk,re} \qquad \text{Eq. (52)}$$

where n_{legs} is the number of bars of supplementary reinforcement effective for one fastener. Note that according to EN 1992-4 and CEB the diameter of the supplementary reinforcement and the characteristic yield stress shall not be larger than 16 mm and 600 MPa, respectively.

3.3.2.6.2 Anchorage failure of supplementary reinforcement

The design resistance of the supplementary rebars provided for one fastener associated with anchorage failure $N_{Rd,a}$ is calculated as:

$$N_{Rd,a} = \sum_{i}^{nlegs} N_{Rd,a,i}^{0} \qquad \text{Eq. (53)}$$

where

$$N_{Rd,a}^{0} = \frac{l_1\, \pi\, \phi\, f_{bd}}{\alpha_1\, \alpha_2} \leq A_{s,re}\, f_{yk,re} \qquad \text{Eq. (54)}$$

with l_1 being the anchorage length in the break-out body and f_{bd} the design bond strength (see Eq. (31)). α_1, α_2 account for anchorage conditions in accordance with EN 1992-1-1 section 8.4.4: α_1 accounts for the effect of the anchorage detailing (α_1 = 1.0 for straight rebars and α_1 = 0.7 for other than straight) and is defined by the user (anchorage factor in Figure 7); α_2 accounts for the effect of concrete minimum cover and is taken equal to 0.7 assuming the concrete cover will be always larger than three times the rebar diameter ($c_{nom} \geq 3\phi$).

3.3.2.7 On the determination of the concrete cone and combined pull-out and concrete cone strength

The concrete cone strength and the combined pull-out and concrete cone strength depend on (i) the number of anchors in tension and (ii) the load distribution between anchors. The former affects factor $\psi_{A,N}$ through the concrete cone area $A_{c,N}$ and in the case of combined pull-out and concrete cone strength also to factor $\psi_{g,Np}$; and the latter affects factor $\psi_{ec,N}$. The latter equation can result into excessively conservative results for cases in which the eccentricity between the geometrical centre of tensioned anchors and the resulting tensile force is significant and, ultimately to pronounced discontinuities that are not are not consistent with engineering judgement.

There is an interrelationship between factor ψ_{AN} and factor $\psi_{ec,N}$, which can lead to discontinuities when one or several of the anchors start (stop) being in tension: factor ψ_{AN} increases (decreases) as the concrete cone area enlarges (diminishes) and factor $\psi_{ec,N}$ decreases (increases) as the eccentricity increases (decreases) when considering a "new" anchor that is only slightly in tension. If one factor increases (decreases) more than what the other decreases (increases), a discontinuity occurs. If the discontinuity occurs or not, and in which direction, depends on the anchor embedded length and spacing and the design actions.

The approach followed by TACEP is described next:

- Step 1: determine the concrete cone strength and/or the combined pull-out and concrete cone strength considering all anchors in tension.
- Step 2: determine the concrete cone strength and/or the combined pull-out and concrete cone strength considering all anchors in tension except the one whose tensile force is the lowest. If the obtained resistance is larger than that obtained in Step 1, adopt the new resistance and continue to Step 3; otherwise, adopt the resistance from Step 1 and finish the process.
- Step 3: determine the concrete cone strength and/or the combined pull-out and concrete cone strength considering all anchors in tension except the (two) whose tensile forces are the lowest. If the obtained resistance is larger than that obtained in Step 2, adopt the new resistance and continue the process; otherwise, adopt the resistance from Step 2 and finish the process.
- ...

This approach prevents discontinuities caused by an overestimation of the influence of eccentricity on the reduction of the concrete cone strength through $\psi_{ec,N}$ but does not prevent discontinuities caused by the concrete cone area through ψ_{AN}.

3.3.3 Shear load

Table 12 shows the verifications undertaken by the tool in shear. Some checks are undertaken at anchor level, considering the largest tension load acting on an anchor V_{Ed}^{h}; other verifications are performed at group level, i.e. considering the total tensile force acting on the anchors V_{Ed}^{g}.

Failure mode	Most loaded fastener	Group
Steel failure of fastener without lever arm (section 3.3.3.1)	$V_{Ed}^{h} \leq V_{Rd,s} = \dfrac{V_{Rk,s}}{\gamma_{Ms,shear}}$	
Steel failure of fastener with lever arm (section 3.3.3.2)	$V_{Ed}^{h} \leq V_{Rd,s,M} = \dfrac{V_{Rk,s,M}}{\gamma_{Ms,shear}}$	
Concrete pry-out failure (section 3.3.3.3)		$V_{Ed}^{g} \leq V_{Rd,cp} = \dfrac{V_{Rk,cp}}{\gamma_{Mc,tension}}$
Concrete edge failure (section 3.3.3.4)		$V_{Ed}^{g} \leq V_{Rd,c} = \dfrac{V_{Rk,c}}{\gamma_{Mc,tension}}$

Table 12 Verifications in shear.

3.3.3.1 Steel failure of fastener without lever arm

Anchors loaded in shear exhibit steel failure when the edge distance and the embedded length are sufficiently large. If plate failure is driven by failure of the steel, then the ultimate load is limited by the largest shear load acting on an individual anchor V_{Ed}^{h} and the characteristic steel resistance of the fastener $V_{Rk,s}$. For anchors with ETA certificate $V_{Rk,s}$ is directly defined by the user taken the value given in the relevant approval certificate (see Figure 6). For anchors without ETA certificate $V_{Rk,s}$ is calculated from the defined anchor diameter d and tensile strength of steel $f_{uk,s}$ as follows:

$$V_{Rk,s} = k_6\, A_s\, f_s = k_6\, (\pi\, d^2/4)\, f_s \qquad \text{Eq. (55)}$$

Following the corresponding design codes: if EC2 or RCC-CW code are selected, then $f_s = f_{uk,s}$ and $k_6 = 0.6$ for $f_{uk,s} \leq 500$ MPa or $k_6 = 0.5$ otherwise; if CEB code is chosen, then $f_s = f_{yk,s}$ and $k_6 = 0.75$.

It is assumed that all anchors will be ductile with a rupture elongation $A_5 \geq 8\%$ and, therefore, the ductility of the fastener in a group is not considered. In case this condition is not fulfilled, the characteristic strength $V_{Rk,s}$ calculated with Eq. (55) should be multiplied by 0.80; this can be considered indirectly in the tool if the desired material safety factor for steel in shear is multiplied by 1.25.

3.3.3.2 *Steel failure of fastener with lever arm*

No lever arm is to be expected in embedded plates (e_{shear} = 0). However, this check is included for the sake of comprehensiveness. The characteristic resistance $V_{Rk,s,M}$ is calculated as:

$$V_{Rk,s,M} = \frac{\alpha_M \, M_{Rk,s}}{l_a} \quad \text{Eq. (56)}$$

$$M_{Rk,s} = M^0_{Rk,s} \left(1 - N_{Ed} \;/\; N_{Rd,s}\right) \quad \text{Eq. (57)}$$

$$M^0_{Rk,s} = 1.5\, W_{el}\, f_{yk,s} = 1.5 \frac{\pi\, d^3}{32} f_{yk,s} \quad \text{Eq. (58)}$$

$$N_{Rd,s} = N_{Rk,s} \;/\; \gamma_{Ms,tension} \quad \text{Eq. (59)}$$

with $N_{Rk,s}$ (Eq. (18)) and $M_{Rk,s}$ the characteristic tensile and bending resistance of a fastener, respectively. Factor α accounts for the degree of restraint of the anchor at the side of the fixture; a value equal to 2.0 is adopted considering full restraint of the rotation of the fixture. l_a represent the lever arm, which is taken equal to:

$$l_a = e_{shear} + a_3 \quad \text{Eq. (60)}$$

where e_{shear} is the distance between shear load and concrete surface defined by the user (e_1 inFigure 18) and a_3 is taken conservatively equal to 0.5 d following EN 1992-4 and CEB.

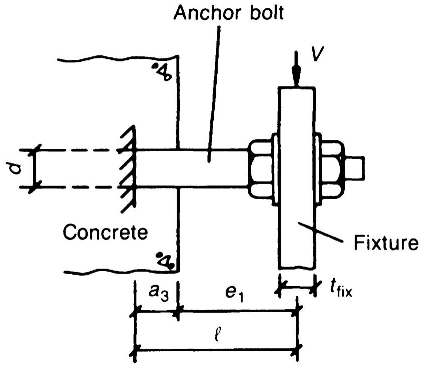


Figure 18 Lever arm (from [3]).

3.3.3.3 *Concrete pry-out failure*

Pry-out failure occurs at the side opposite to the shear direction and/or due to a tension force introduced in the fasteners by the shear load. If plate failure is driven by pry-out failure, then the ultimate load is limited by the total shear force acting on the anchors V_{Ed}^{g}. As noted later, the determination of the characteristic resistance to pry-out failure requires to take into account the eccentricity of the shear forces. Considering the eccentricity in X- an Y-direction simultaneously (as in Eq. (23) and Eq. (38)) could leave to excessively conservative results when the shear load is acting mainly in one of the directions; to avoid this over-conservatism the capacity check is performed in each direction separately and then the global shear-force-to-strength ratio is obtained as:

$$\frac{V_{Ed}}{V_{Rk,cp}} = \frac{V_{Ed,x}}{V_{Rk,cp,x}} + \frac{V_{Ed,y}}{V_{Rk,cp,y}} \qquad \text{Eq. (61)}$$

By doing this the shear eccentricity in X-direction does not penalize the pry-out resistance in Y-direction, and vice versa.

For headed anchors the characteristic resistance to pry-out failure in each direction $V_{Rk,c,i}$ is calculated as:

$$V_{Rk,cp,i} = k_8\, N_{Rk,c,i} \qquad \text{Eq. (62)}$$

and for bonded anchors as:

$$V_{Rk,cp,i} = k_8 \min\{N_{Rk,c,i}, N_{Rk,p,i}\} \qquad \text{Eq. (63)}$$

where $N_{Rk,c}$ is determined according to Eq. (19) and $N_{Rk,p}$ from Eq. (29). In the calculation of these values it is assumed that all fasteners of the plate contribute to the shear resistance and, hence, the area of the break-out body ($A_{c,N}$ in Eq. (21) and $A_{p,N}$ in Eq. (34)) is obtained considering all anchors and not only those under tension. Similarly to what is done for the concrete cone failure and the pull-out failure, for the case of fasteners in an application with three or more edge distances less than $c_{cr,Np}$ from the fasteners the value of the embedded depth h_{ef} is replaced by Eq. (26). Factor ψ_{ecN} accounting for the eccentricity of the shear load in each direction i is taken equal to:

$$\psi_{ec,N,i} = \frac{1}{1 + \frac{2\max|e_i \pm e_{itol}|}{s_{cr,N}}} \leq 1 \qquad \text{Eq. (64)}$$

where e_i and e_{itol} refer to the eccentricity and eccentricity tolerance defined by the user in the perpendicular direction to the shear direction under consideration.

Regarding factor k_8, for anchors with approval certificate that value is defined by user (see Figure 6) as given in the corresponding document (e.g. for Nelson studs k_8 = 2.0 (Ref. [8])); for anchors without approval certificate the value of k_8 is taken as follows based on the corresponding codes:

if h_{ef} < 60 mm $\quad k_8 = 1.0 \quad$ for EC2, RCC-CW and CEB

if $h_{ef} \geq 60$ mm $\quad \begin{cases} k_8 = 2.0 & \text{for EC2 and CEB} \\ k_8 = 2.5 & \text{for RCC-CW} \end{cases}$ Eq. (65)

Following EN 1992-4 and CEB, if supplementary reinforcement is arranged and it is effective to restrict the concrete cone failure (i.e. the force-to-strength ratio determined for concrete cone failure is larger than that obtained for steel and anchorage failure of the supplementary reinforcement), then the characteristic resistance to pry-out failure for each direction $V_{Rk,cp,i}$ determined from Eq. (62) and Eq. (63) is multiplied by 0.75 to account for that anchors may be significantly deformed before failure, hence increasing the force causing pry-out failure.

As noted earlier, the verification of pry-out failure is performed at group level. For fastenings loaded predominantly by a torsion moment, with shear forces in opposing directions, the most unfavourable fastener shall be verified according to EN 1992-4 (7.2.2.4(4)). This verification is not performed by the tool and, therefore, should be undertaken by the user independently in case of large torsion moments.

3.3.3.4 Concrete edge failure

Anchors loaded in shear perpendicular to a close edge may fail by development of a concrete cone from the point of bearing before the steel capacity is reached. For fastenings with more than edge, the verification shall be carried out for all the edges. According to CEB, no concrete edge failure will occur if the edge distance $c > 60\,d$; in EN 1992-4 the anchor embedded length is also account far and the limitation is $c \geq \max\{10\,h_{ef}, 60\,d\}$. Regardless the selected code, the tool considers the condition established in EN 1992-4 for the sake of conservatism.

When concrete edge failure needs to be verified the characteristic resistance $V_{Rk,c}$ of the fasteners or group of fasteners loaded towards the edge is calculated as:

$$V_{Rk,c} = V^0_{Rk,c}\, \psi_{A,V}\, \psi_{s,V}\, \psi_{h,V}\, \psi_{ec,V}\, \psi_{\alpha,V}\, \psi_{re,V} \quad \text{Eq. (66)}$$

$V^0_{Rk,c}$ refers to the characteristic resistance of a single anchor loaded perpendicular to the edge. Depending on the selected code it is calculated as:

- For EC2 and RCC-CW:

$$V^0_{Rk,c} = 1.7\, d^{\alpha}\, l_f^{\beta}\, \sqrt{f_{ck}}\, c_1^{1.5} \quad \text{Eq. (67)}$$

$$\alpha = 0.1 \left(\frac{l_f}{c_1}\right)^{0.5} \quad \text{Eq. (68)}$$

$$\beta = 0.1 \left(\frac{d}{c_1}\right)^{0.2}$$ Eq. (69)

$$l_{ef} = h_{ef} \leq \begin{cases} 12\, d & \text{if } d \leq 24 \text{ mm} \\ \max\{8\, d, 300 \text{ mm}\} & \text{if } d > 24 \text{ mm} \end{cases}$$ Eq. (70)

- For CEB:

$$V^0_{Rk,c} = 0.5\, d^{0.5} \left(l_f \,/\, d\right)^{0.2} \sqrt{f_{ck}}\, c_1^{1.5}$$ Eq. (71)

where the maximum values inserted for $d \leq 30$ mm and for $l_f \,/\, d \leq 8$ following the CEB provisions.

Factor $\psi_{A,N}$ accounts for geometric effects of spacing between anchors as well as further edge distances and the effect of thickness of the concrete member on the characteristic resistance and is calculated as:

$$\psi_{A,V} = \frac{A_{c,V}}{A^0_{c,V}}$$ Eq. (72)

where $A^0_{c,V}$ is the projected area of a single anchor and $A_{c,V}$ is the projected area of the anchorage plate obtained from the union of the projected individual areas and considering edges, limited by overlapping concrete cones of adjacent fasteners ($s \leq 3\, c_1$) as well as by edges parallel to the assuming loading direction ($c_2 \leq 1.5\, c_1$) and by the member thickness ($h \leq 1.5\, c_1$). The projected area of an individual anchor is taken equal to rectangle of sides $3\, c_1$ and $1.5\, c_1$ in the horizontal and vertical direction, respectively, as defined in both EN 1992-4 and CEB. Note that while only actual concrete edges perpendicular to the shear direction are accounting for to determine c_1, both concrete and fictive edges are considered are considered in the direction parallel to the assuming loading direction.

Factor $\psi_{s,V}$ accounts for the disturbance of the distribution of stresses in the concrete due to further edges of the concrete member on the shear resistance. For fastenings with two concrete edges parallel to the direction of loading the smaller value of these edge distance is used for c_2. $\psi_{s,V}$ is calculated following EN 1992-4 and CEB as follows:

$$\psi_{s,V} = 0.7 + 0.3 \frac{c_2}{1.5\, c_1} \leq 1$$ Eq. (73)

Only distances to concrete edges are considered to calculate this factor, i.e. fictive edges defined to account for adjacent plates are not accounted for as the existence of a nearby plate does not disturb the stress field.

Factor $\psi_{h,V}$ takes account of the fact that the concrete edge resistance does not decreases proportionally to the member thickness and is calculated following EN 1992-4 and CEB as:

$$\psi_{h,V} = \left(\frac{1.5\,c_1}{h_{slab}}\right)^{\alpha} \geq 1 \qquad \text{Eq. (74)}$$

with $\alpha = 0.5$ if EC2 or RCC-CW are selected or $\alpha = 1/3$ if CEB code is chosen.

Factor $\psi_{ec,V}$ accounts for the group effect when different shear loads are acting on the individual fasteners and is calculated as:

$$\psi_{ec,V} = \frac{1}{1 + 2\max|e_i \pm e_{itol}| \,/\, (3\,c_1)} \leq 1 \qquad \text{Eq. (75)}$$

where e_i and e_{itol} refer to the eccentricity and eccentricity tolerance defined by the user in the parallel direction to the edge under consideration.

Factor $\psi_{\alpha,V}$ takes account of the influence of a shear load inclined to the edge under consideration on the concrete edge resistance. Depending the adopted code, this factor is calculated as:

$$\psi_{\alpha,V} = \begin{cases} \sqrt{\dfrac{1}{(\cos\alpha_V)^2 + 0.5\,(\sin\alpha_V)^2}} \geq 1 & \text{for } 0° \leq \alpha_V \leq 90° \\ 2.0 & \text{for } \alpha_V > 90° \end{cases} \qquad \text{for EC2 and RCC-CW} \qquad \text{Eq. (76)}$$

$$\psi_{\alpha,V} = \begin{cases} 1.0 & \text{for } 0° \leq \alpha_V \leq 55° \\ \dfrac{1}{\cos\alpha_V + 0.5\sin\alpha_V} & \text{for } 55° \leq \alpha_V \leq 90° \\ 2.0 & \text{for } \alpha_V \geq 90° \end{cases} \qquad \text{for CEB} \qquad \text{Eq. (77)}$$

where α_V is the angle between design shear load V_{Ed} and a line perpendicular to the verified edge. Note that the EN 1992-4 only refers to angles between $0° \leq \alpha_V \leq 90°$; conservatively, and following CEB, $\psi_{\alpha,V}$ is taken equal to 2.0 for larger angles.

$\psi_{re,V}$ takes account of the effect of the reinforcement located on the edge. Conservatively and for the sake of generality this factor is taken equal to 1.0 assuming there is no edge reinforcement. The user should note that this factor can be increased up to 1.4 if edge reinforcement and closely spaced stirrups are arranged (see EN 1994-4, 7.2.2.5(13)).

Following EN 1992-4 (7.2.2.5(14))) and CEB, for fastenings in a narrow, thin member with $c_{2,max} \leq 1.5\,c_1$ and $h_{slab} \leq 1.5\,c_1$, the edge distance c_1 to be considered is replaced by:

$$c_1' = \max\left(\frac{c_{2,max}}{1.5}, h_{ef}, \frac{h_{slab}}{1.5}, \frac{s_{2,max}}{3}\right) \quad \text{Eq. (78)}$$

where $c_{2,\max}$ is the larger of the two distances to the edges parallel to the direction of loading and $s_{2,max}$ is the spacing in direction 2 between fasteners within a group.

Analogously to pry-out failure, the verification of concrete edge failure is performed at group level. For fastenings loaded predominantly by a torsion moment, with shear forces in opposing directions, the characteristic concrete edge resistance $V_{Rk,c}$ calculated according to Eq. (66) may be need to be multiplied by 0.8 depending on the ratio between the concrete edge breakout resistance to the concrete breakout resistance of the second fastener (EN 1992-4, 7.2.2.5(8)). This reduction is not considered by the tool, so the user should check this in case of large torsion moments.

3.3.4 Combined tension and shear loads

Table 13 shows the verifications undertaken by the tool for combined tension-shear considering the obtained force-to-strength ratio in tension (see section 3.3.2) and shear (see section 3.3.2.7).

Failure mode	Verification
Steel failure of fastener	$\left(\frac{N_{Ed}}{N_{Rd,s}}\right)^2 + \left(\frac{V_{Ed}}{V_{Rd,s}}\right)^2 \leq 1$
Failure modes other than steel failure when no supplementary reinforcement	$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{1.5} \leq 1.0$
Failure modes other than steel failure when supplementary reinforcement	If hanger reinforcement is present for both tension and shear: $\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{1.5} \leq 1.0$ If hanger reinforcement is present for tension or for shear only: $\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{2/3} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{2/3} \leq 1.0$

Table 13 Verifications in combined tension-shear.

In case of fastenings with supplementary reinforcement to take up tension loads only, $N_{Rd,i}$ and $V_{Rd,i}$ represent the design resistances $N_{Rd,p}$, $N_{Rd,sp}$, $N_{Rd,cb}$, $N_{Rd,re}$, $N_{Rd,a}$ and $V_{Rd,c}$ and $V_{Rd,cp}$, respectively. If supplementary reinforcement is used to take up shear loads only, $N_{Rd,i}$ and $V_{Rd,i}$ represent the design resistances $N_{Rd,c}$, $N_{Rd,p}$, $N_{Rd,sp}$, $N_{Rd,cb}$ and $V_{Rd,cp}$, $N_{Rd,re}$ and $N_{Rd,a}$, respectively.

3.3.5 Compression load

The maximum compressive stress on concrete is limited to the design concrete strength as mentioned in section 3.2.2. Moreover, the tool verifies that the ultimate strain of concrete under the fixture is not exceeded. The force-to-strength ratio is given by the ratio between the maximum concrete strain ϵ_c and the ultimate strain of concrete ϵ_u, which is taken equal to 0.0035:

$$\frac{N_{Ed}^{c}}{N_{Rd,c}^{c}} = \frac{\epsilon_c}{\epsilon_u} \qquad \text{Eq. (79)}$$

4 VALIDATION THROUGH EXAMPLES OF APPLICATION

4.1 Introduction

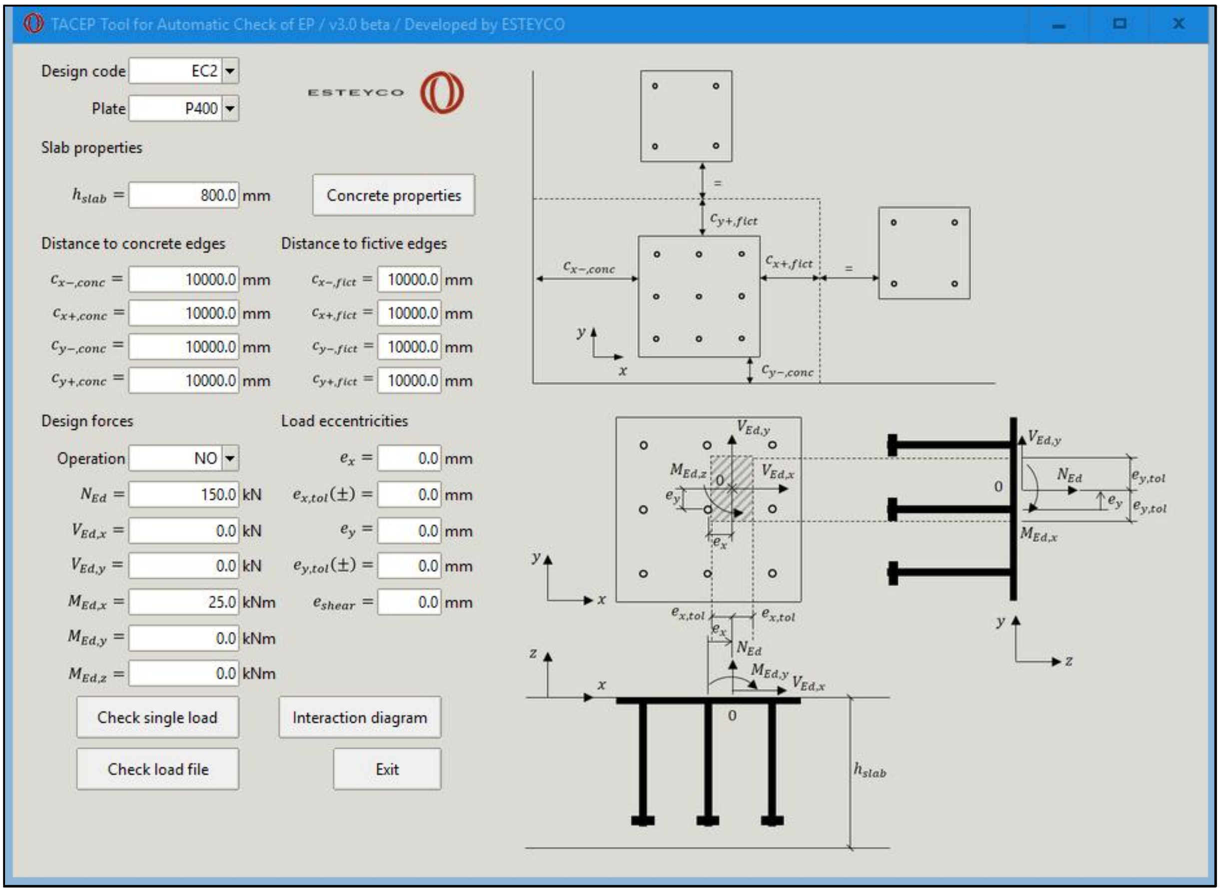
Some examples of application are presented in this chapter with two purposes: (i) clarify the operation and the definition of input data of the tool and (ii) validate the output data obtained with TACEP by comparison against results derived by hand calculations.

4.2 Example 1

4.2.1 Introduction

This example entails a P400 subjected to a tensile force N_{Ed} = 150 kN and a uniaxial bending moment $M_{Ed,x}$ = 25 kNm in normal operation, placed far enough from edges so that they do not affect the response of the plate. The effective embedded length h_{ef} of the KB22 anchors in this plate is 340 mm ($h_n + t_p - t_h$ = 325 + 25 – 10).

4.2.2 Input data



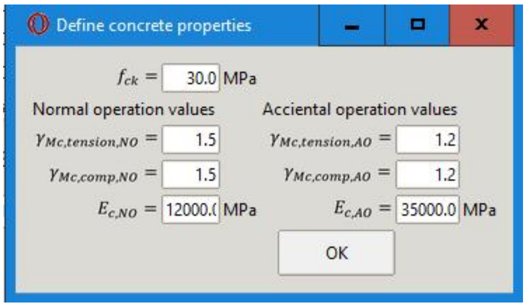


Figure 19 Example 1: input data.

4.2.3 Results from TACEP

Results obtained with the tool are shown in Figure 20.

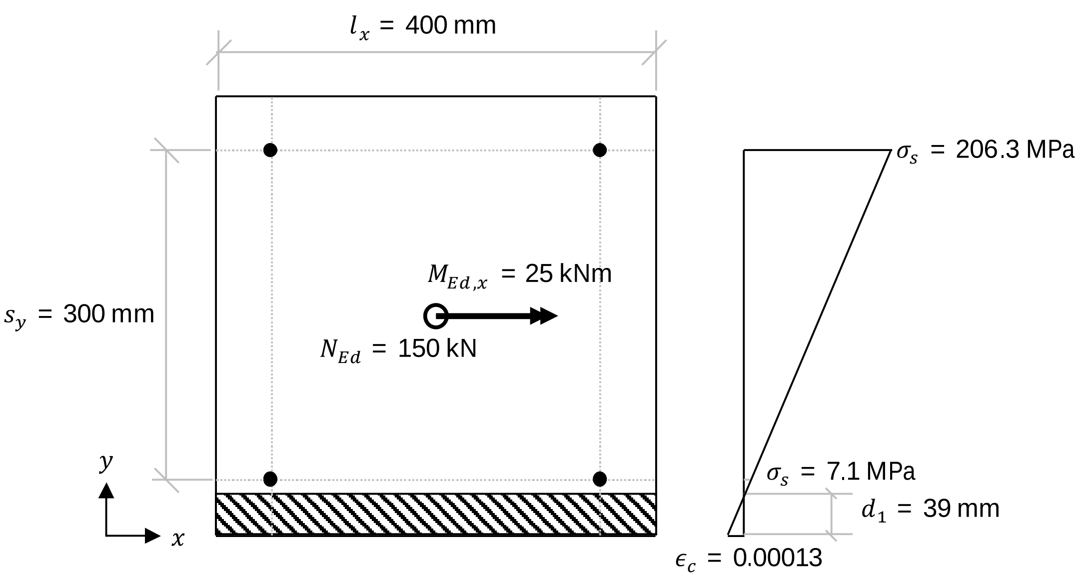
```
************************SUMMARY OF RESULTS*************************
**************************STRENGTH RATIO***************************
********************Resistance to tension load*********************
Steel failure to tensile load              = 0.706 [0.706 < 1.0: OK]
Concrete cone failure                      = 0.635 [0.635 < 1.0: OK]
Pull-out failure                           = 0.935 [0.935 < 1.0: OK]
Splitting failure                          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X- edge)           = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X+ edge)           = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y- edge)           = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y+ edge)           = 0.000 [0.000 < 1.0: OK]
Steel failure of suppl. reinforcement      = 0.000 [0.000 < 1.0: OK]
Anchorage failure of suppl. reinforcement = 0.000 [0.000 < 1.0: OK]
**********************Resistance to shear load*********************
Steel failure for one anchor               = 0.000 [0.000 < 1.0: OK]
Steel failure for group of anchor          = 0.000 [0.000 < 1.0: OK]
Shear failure with lever arm               = 0.000 [0.000 < 1.0: OK]
Concrete pry-out failure                   = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X- edge)            = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X+ edge)            = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y- edge)            = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y+ edge)            = 0.000 [0.000 < 1.0: OK]
********************Combined shear and tension*********************
Steel failure driven                       = 0.499 [0.499 < 1.0: OK]
Concrete failure driven                    = 0.904 [0.904 < 1.0: OK]
*********************Resistance to compression*********************
Concrete compression                       = 0.037 [0.037 < 1.0: OK]
*******************************************************************
Maximum ratio                              = 0.935 [0.935 < 1.0: OK]
*******************************************************************
```

Figure 20 Example 1: TACEP output data.

4.2.4 Verification of results by hand calculations

4.2.4.1 Determination of action effects

Axial forces on the fasteners can be obtained from sectional analysis (see Figure 21). The largest tension load acting on an anchor N_{Ed}^{h} is 78.4 kN and the total axial load acting on the anchors N_{Ed}^{g} is 162.2 kN. No shear forces are to be considered as $V_{Ed,x} = V_{Ed,y} = M_{Ed,z} = 0$.



$$\sum N = 1/2\epsilon_c E_c l_x d_1 + \sum A_{si}\sigma_{si} = -12.2 + 5.4 + 156.8 = 150 \text{ kN}$$

$$\sum M = 1/2\epsilon_c E_c l_x d_1 d_g + \sum A_{si}\sigma_{si} d_{gsi} = 2.3 - 0.8 + 23.5 = 25 \text{ kNm}$$

Figure 21 Example 1: sectional analysis.

4.2.4.2 Determination of resistances

Considering that the shear forces acting on the anchors are zero, only the calculation of the tensile and compressive resistances is detailed next.

4.2.4.2.1 Resistance to tension load

- Steel failure of fastener (see section 3.3.2.1)

$$N_{Rd,s} = N_{Rk,s} \,/\, \gamma_{Ms,tension,NO} = 171 \,/\, 1.54 = 111.0 \text{ kN} \qquad \text{Eq. (80)}$$

- Concrete cone failure (see section 3.3.2.2)

$$N_{Rd,c} = N^0_{Rk,c}\, \psi_{A,N}\, \psi_{s,N}\, \psi_{ec,N}\, \psi_{re,N}\, \psi_{M,N} \,/\, \gamma_{Mc,tension,NO} = 383.5 \,/\, 1.5 = 255.7 \text{ kN} \qquad \text{Eq. (81)}$$

$$N^0_{Rk,c} = k_1 \sqrt{f_{ck}}\, h_{ef}^{1.5} = 8.5 \cdot \sqrt{30} \cdot 340^{1.5} = 291.9 \text{ kN} \qquad \text{Eq. (82)}$$

$$\psi_{A,N} = \frac{A_{c,N}}{A^0_{c,N}} = \frac{(300 + 3 \cdot 340)^2}{(3 \cdot 340)^2} = \frac{1742400}{1040400} = 1.675 \qquad \text{Eq. (83)}$$

$$\psi_{s,N} = 0.7 + 0.3 \frac{c}{c_{cr,N}} = 1 \qquad \text{Eq. (84)}$$

$$\psi_{ec,N} = \frac{1}{1+\frac{2e_{n,x}}{s_{cr,N}}} \frac{1}{1+\frac{2e_{n,y}}{s_{cr,N}}} = 1 \cdot \frac{1}{1+2 \cdot 140/(3 \cdot 340)} = 0.785 \qquad \text{Eq. (85)}$$

$$e_{n,y} = \frac{2 \cdot 206.3 \cdot 350 + 2 \cdot 7.1 \cdot 50}{2 \cdot 206.3 + 2 \cdot 7.1} - 200 = 340 - 200 = 140 \text{ mm} \qquad \text{Eq. (86)}$$

$$\psi_{re,N} = 1 \qquad \text{Eq. (87)}$$

$$\psi_{M,N} = 1 \left(\frac{z}{h_{ef}} = \frac{340 - 1/3 \cdot 39}{340} = \frac{327}{340} < 1.5 \right) \qquad \text{Eq. (88)}$$

- Pull-out failure of fastener (see section 3.3.2.3)

$$N_{Rd,p} = N_{Rk,p} \;/\; \gamma_{Mc,tension,NO} = (85 \cdot 1.48) \;/\; 1.5 = 125.8 \;/\; 1.5 = 83.9 \text{ kN} \qquad \text{Eq. (89)}$$

- Concrete splitting failure (see section 3.3.2.4)

No concrete splitting failure check is required as it is assumed that the arranged reinforcement is sufficient to withstand splitting forces.

- Concrete blow-out failure (see section 3.3.2.5)

No concrete blow-out failure is required as c_{min} > 0.5 h_{ef} = 170 mm.

- Failure of supplementary reinforcement (see section 3.3.2.6)

No supplementary reinforcement arranged, so this verification does not apply.

4.2.4.2.2 Resistance to compression load

$$\frac{N^{c}_{Ed}}{N^{c}_{Rd,c}} = \frac{0.00013}{0.0035} = 0.037 \qquad \text{Eq. (90)}$$

4.2.4.3 Capacity check

Results obtained in sections 4.2.4.1 and 4.2.4.2 on loads on anchors and plate resistance are summarized in Table 14. Only applicable verifications are given. These results are in agreement with those obtained with the tool (see Figure 20).

Failure mode	Most loaded fastener	Group
Tension load		
Steel failure of fastener (section 3.3.2.1)	$\frac{N_{Ed}^{h}}{N_{Rd,s}} = \frac{78.4}{111.0} = 0.706$	
Concrete cone failure (section 3.3.2.2)		$\frac{N_{Ed}^{g}}{N_{Rd,d}} = \frac{162.2}{255.7} = 0.634$
Pull-out failure of fastener (section 3.3.2.3)	$\frac{N_{Ed}^{h}}{N_{Rd,p}} = \frac{78.4}{83.9} = \mathbf{0.934}$	
Compression load		
Compressive failure of concrete under fixtures (section 3.3.5)		$\frac{N_{Ed}^{c}}{N_{Rd,c}^{c}} = 0.037$
Combined tension and shear loads		
Steel failure of fastener (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,s}}\right)^{2} + \left(\frac{V_{Ed}}{V_{Rd,s}}\right)^{2} = 0.706^{2} = 0.499$	
Failure mode other than steel (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{1.5} = 0.934^{1.5} = 0.903$	

Table 14 Example 1: capacity check summary

4.3 Example 2

4.3.1 Introduction

This example entails a P500b subjected to a tensile force N_{Ed} = 150 kN and a uniaxial bending moment $M_{Ed,x}$ = 50 kNm in accidental operation, placed relatively close to a concrete corner (see Figure 22) The effective embedded length h_{ef} of the KB25 anchors in this plate is 288 mm ($h_n + t_p - t_h$ = 275 + 25 – 12).

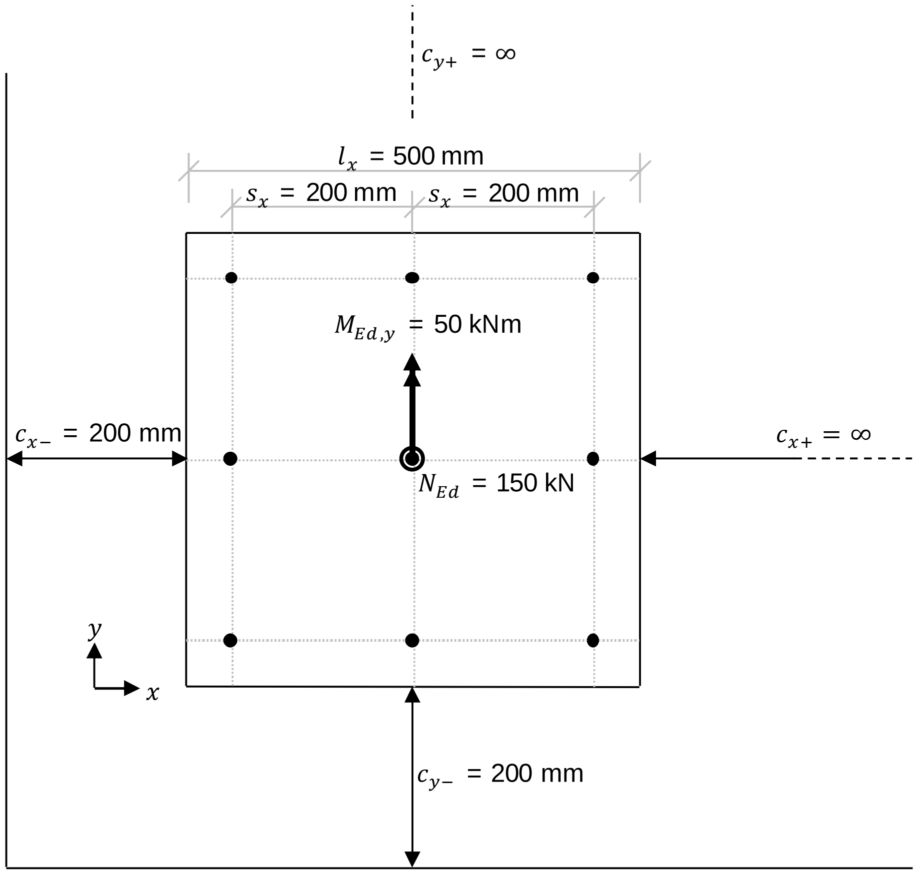
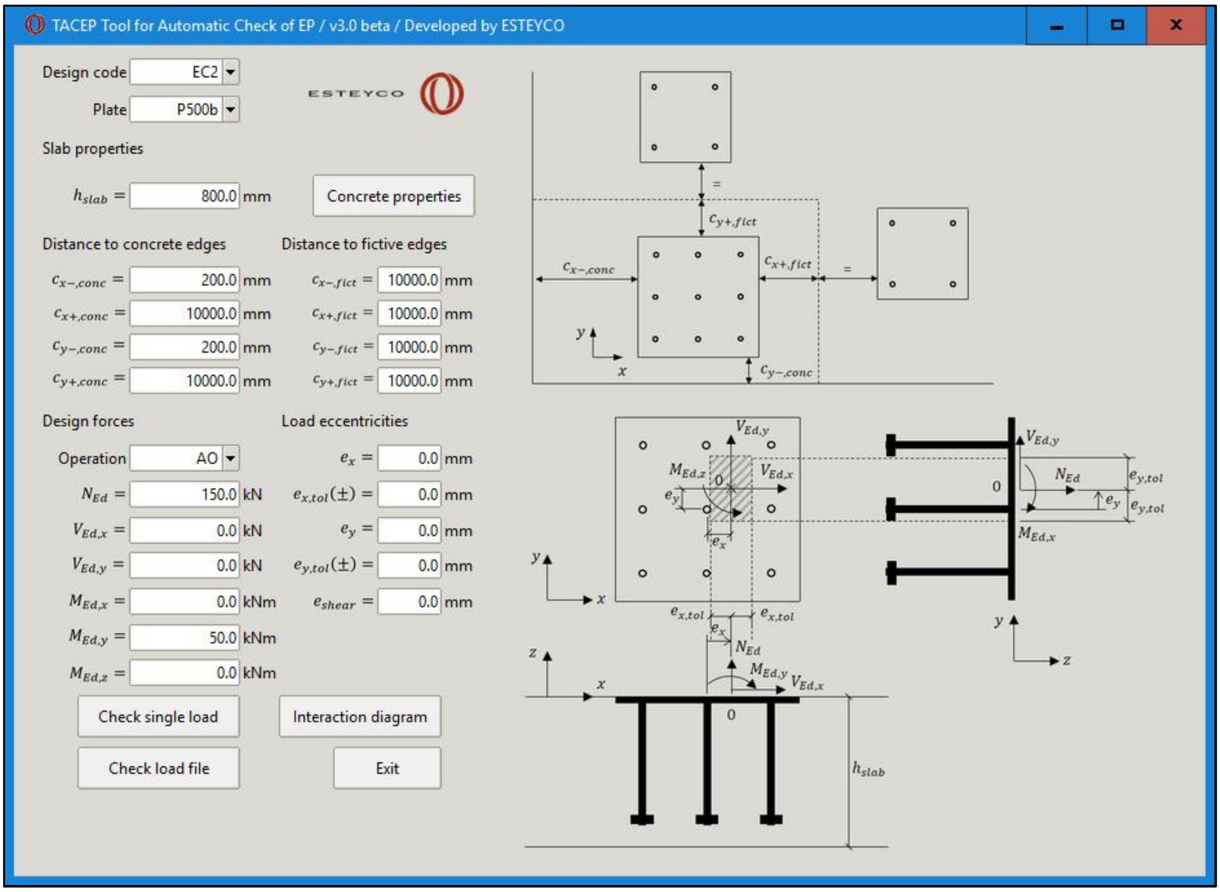


Figure 22 Example 2: problem description.

4.3.2 Input data



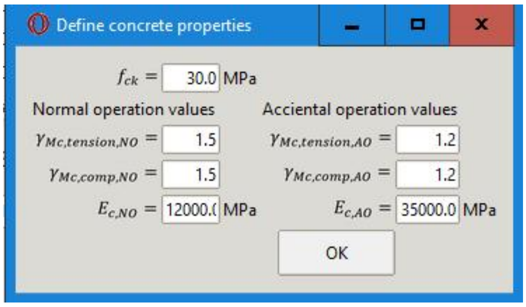


Figure 23 Example 2: input data.

4.3.3 Results from TACEP

Results obtained with the tool are shown in Figure 24.

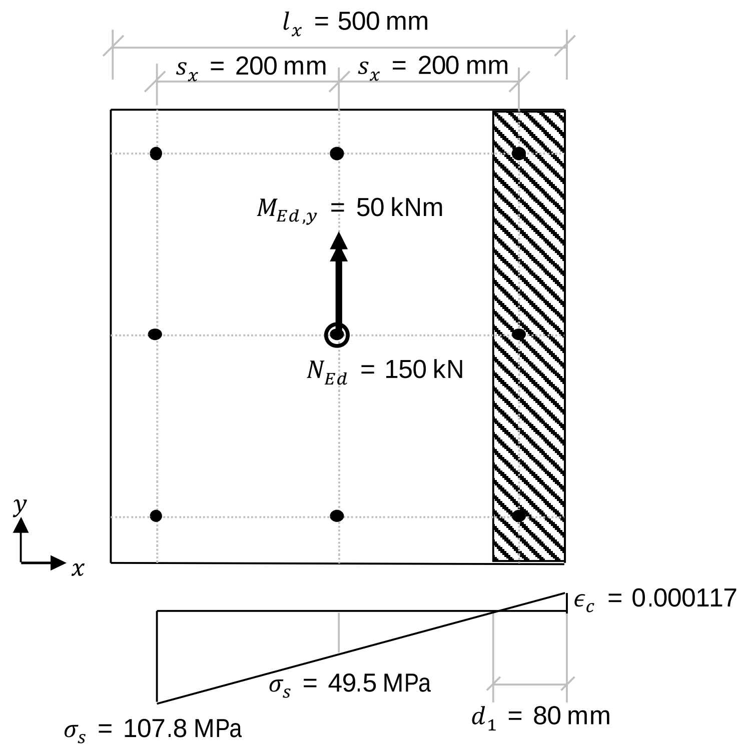
```
************************SUMMARY OF RESULTS*************************
**************************STRENGTH RATIO***************************
********************Resistance to tension load*********************
Steel failure to tensile load             = 0.323 [0.323 < 1.0: OK]
Concrete cone failure                    = 1.188 [1.188 > 1.0: Failed]
Pull-out failure                          = 0.373 [0.373 < 1.0: OK]
Splitting failure                         = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X- edge)          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X+ edge)          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y- edge)          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y+ edge)          = 0.000 [0.000 < 1.0: OK]
Steel failure of suppl. reinforcement     = 0.000 [0.000 < 1.0: OK]
Anchorage failure of suppl. reinforcement = 0.000 [0.000 < 1.0: OK]
**********************Resistance to shear load*********************
Steel failure for one anchor              = 0.000 [0.000 < 1.0: OK]
Steel failure for group of anchor         = 0.000 [0.000 < 1.0: OK]
Shear failure with lever arm              = 0.000 [0.000 < 1.0: OK]
Concrete pry-out failure                  = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X- edge)           = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X+ edge)           = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y- edge)           = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y+ edge)           = 0.000 [0.000 < 1.0: OK]
********************Combined shear and tension*********************
Steel failure driven                      = 0.105 [0.105 < 1.0: OK]
Concrete failure driven                  = 1.295 [1.295 > 1.0: Failed]
*********************Resistance to compression*********************
Concrete compression                      = 0.033 [0.033 < 1.0: OK]
*******************************************************************
Maximum ratio                            = 1.295 [1.295 > 1.0: Failed]
*******************************************************************
```

Figure 24 Example 2: TACEP output data.

4.3.4 Verification of results by hand calculations

4.3.4.1 Determination of action effects

Axial forces on the fasteners can be obtained from sectional analysis (see Figure 25). The largest tension load acting on an anchor N_{Ed}^{h} is 52.9 kN and the total axial load acting on the anchors N_{Ed}^{g} is 231.6 kN. No shear forces are to be considered as $V_{Ed,x} = V_{Ed,y} = M_{Ed,z} = 0$.



$$\sum N = 1/2\epsilon_c E_c l_y d_1 + \sum A_{si}\sigma_{si} = -81.6 + 72.9 + 158.7 = 150 \text{ kN}$$

$$\sum M = 1/2\epsilon_c E_c l_y d_1 d_g + \sum A_{si}\sigma_{si} d_{gsi} = 18.2 + 31.8 = 50 \text{ kNm}$$

Figure 25 Example 2: sectional analysis.

4.3.4.2 Determination of resistances

Considering that the shear forces acting on the anchors are zero, only the calculation of the tensile and compressive resistances is detailed next.

4.3.4.2.1 Resistance to tension load

- Steel failure of fastener (see section 3.3.2.1)

$$N_{Rd,s} = N_{Rk,s} \,/\, \gamma_{Ms,tension,AO} = 221 \,/\, 1.35 = 163.7 \text{ kN} \qquad \text{Eq. (91)}$$

- Concrete cone failure (see section 3.3.2.2)

$$N_{Rd,c} = N^0_{Rk,c}\, \psi_{A,N}\, \psi_{s,N}\, \psi_{ec,N}\, \psi_{re,N}\, \psi_{M,N} \,/\, \gamma_{Mc,tension,AO} = 234.0 \,/\, 1.2 = 195.0 \text{ kN} \qquad \text{Eq. (92)}$$

$$N^0_{Rk,c} = k_1 \sqrt{f_{ck}}\, h_{ef}^{1.5} = 8.5 \cdot \sqrt{30} \cdot 288^{1.5} = 227.5 \text{ kN} \qquad \text{Eq. (93)}$$

$$\psi_{A,N} = \frac{A_{c,N}}{A_{c,N}^0} = \frac{(250 + 200 + 1.5 \cdot 288)(250 + 400 + 1.5 \cdot 288)}{(3 \cdot 288)^2} = \frac{954324}{746496} = 1.278 \qquad \text{Eq. (94)}$$

$$\psi_{s,N} = 0.7 + 0.3\frac{c}{c_{cr,N}} = 0.7 + 0.3\frac{250}{1.5 \cdot 288} = 0.874 \qquad \text{Eq. (95)}$$

$$\psi_{ec,N} = \frac{1}{1 + \frac{2e_{n,x}}{s_{cr,N}}}\frac{1}{1 + \frac{2e_{n,y}}{s_{cr,N}}} = \frac{1}{1 + 2 \cdot 37.1/(3 \cdot 288)} \cdot 1 = 0.921 \qquad \text{Eq. (96)}$$

$$e_{n,x} = \frac{3 \cdot 107.8 \cdot 50 + 3 \cdot 49.5 \cdot 250}{3 \cdot 107.8 + 3 \cdot 49.5} - 250 = 112.9 - 150 = -37.1 \qquad \text{Eq. (97)}$$

$$\psi_{re,N} = 1 \qquad \text{Eq. (98)}$$

$$\psi_{M,N} = 1 \left(\frac{z}{h_{ef}} = \frac{250 - 112.9 + 250 + 1/3 \cdot 80}{288} = \frac{413.8}{288} < 1.5\right) \qquad \text{Eq. (99)}$$

- Pull-out failure of fastener (see section 3.3.2.3)

$$N_{Rd,p} = N_{Rk,p} \;/\; \gamma_{Mc,tension,AO} = (115 \cdot 1.48) \;/\; 1.2 = 170.2 \;/\; 1.2 = 141.8 \text{ kN} \qquad \text{Eq. (100)}$$

- Concrete splitting failure (see section 3.3.2.4)

No concrete splitting failure check is required as it is assumed that the arranged reinforcement is sufficient to withstand splitting forces.

- Concrete blow-out failure (see section 3.3.2.5)

No concrete blow-out failure is required as c_{min} = 250 mm > 0.5 h_{ef} = 144 mm.

- Failure of supplementary reinforcement (see section 3.3.2.6)

No supplementary reinforcement arranged, so this verification does not apply.

4.3.4.2.2 Resistance to compression load

$$\frac{N_{Ed}^c}{N_{Rd,c}^c} = \frac{0.000117}{0.0035} = 0.033 \qquad \text{Eq. (101)}$$

4.3.4.3 Capacity check

Results obtained in sections 4.3.4.1 and 4.3.4.2 on loads on anchors and plate resistance are summarized in Table 15. Only applicable verifications are given. These results are in agreement with those obtained with the tool (see Figure 24).

Failure mode	Most loaded fastener	Group
Tension load		
Steel failure of fastener (section 3.3.2.1)	$\frac{N_{Ed}^{h}}{N_{Rd,s}} = \frac{52.9}{163.7} = 0.323$	
Concrete cone failure (section 3.3.2.2)		$\frac{N_{Ed}^{g}}{N_{Rd,d}} = \frac{231.6}{195.0} = 1.188$
Pull-out failure of fastener (section 3.3.2.3)	$\frac{N_{Ed}^{h}}{N_{Rd,p}} = \frac{52.9}{141.8} = 0.373$	
Compression load		
Compressive failure of concrete under fixtures (section 3.3.5)		$\frac{N_{Ed}^{c}}{N_{Rd,c}^{c}} = 0.033$
Combined tension and shear loads		
Steel failure of fastener (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,s}}\right)^2 + \left(\frac{V_{Ed}}{V_{Rd,s}}\right)^2 = 0.323^2 = 0.104$	
Failure mode other than steel (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{1.5} = 1.188^{1.5} = \mathbf{1.295}$	

Table 15 Example 2: capacity check summary

4.4 Example 3

4.4.1 Introduction

This example entails a P500 subjected to a tensile force N_{Ed} = 100 kN and a biaxial bending moment $M_{Ed,x}$ = $M_{Ed,y}$ = 10 kNm in normal operation, placed relatively close to three concrete edges (see Figure 22). An eccentricity tolerance of ± 50 mm will be considered for both directions. The effective embedded length h_{ef} of the KB25 anchors in this plate is 538 mm ($h_n + t_p - t_h$ = 525 + 25 – 12).

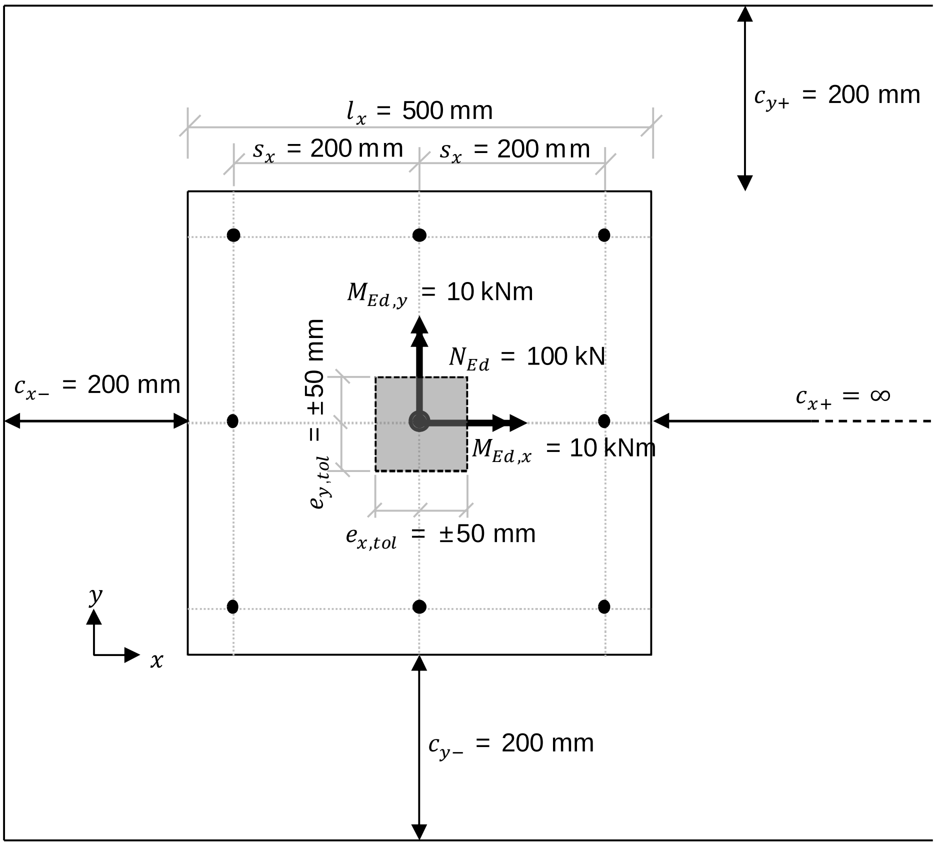
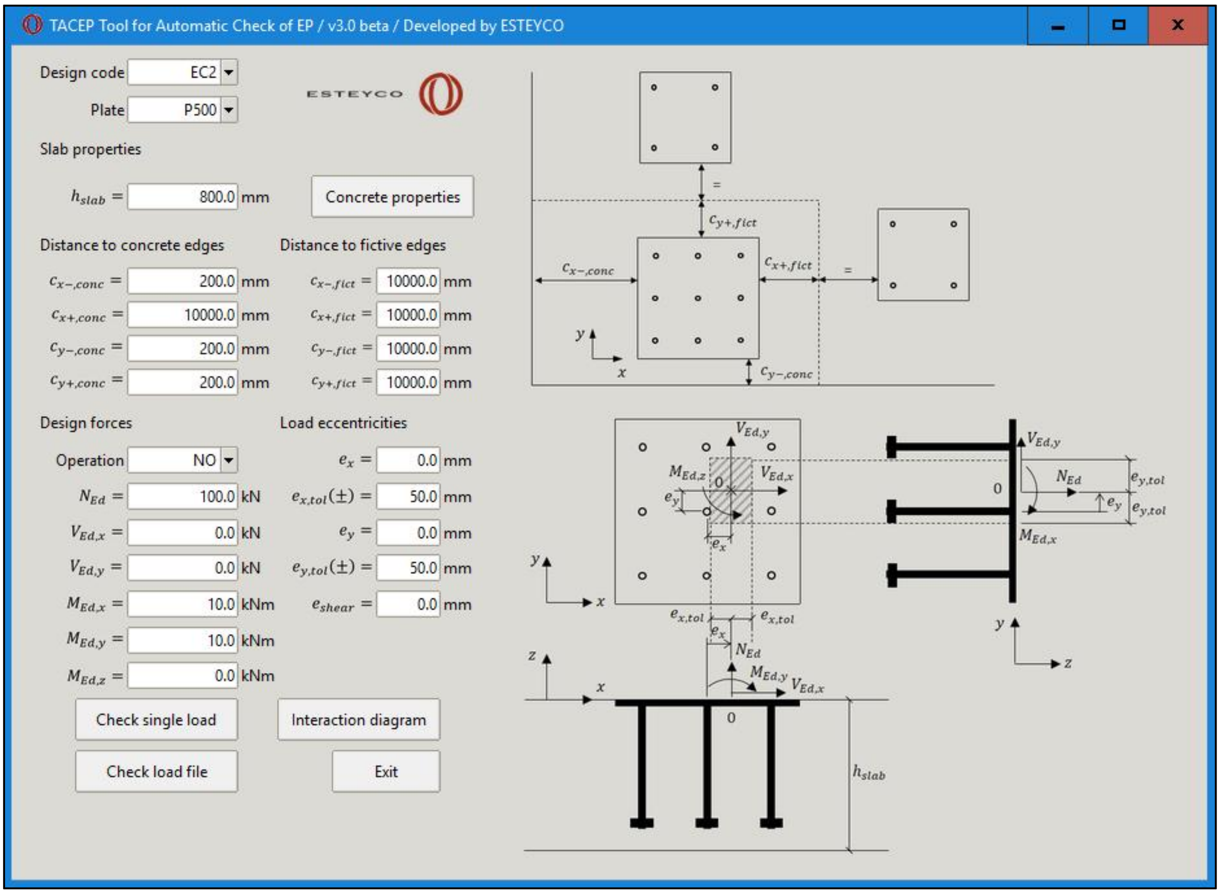


Figure 26 Example 3: problem description.

4.4.2 Input data



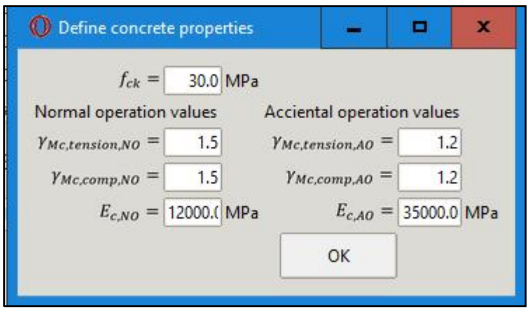


Figure 27 Example 3: input data.

4.4.3 Results from TACEP

Results obtained with the tool are shown in Figure 28.

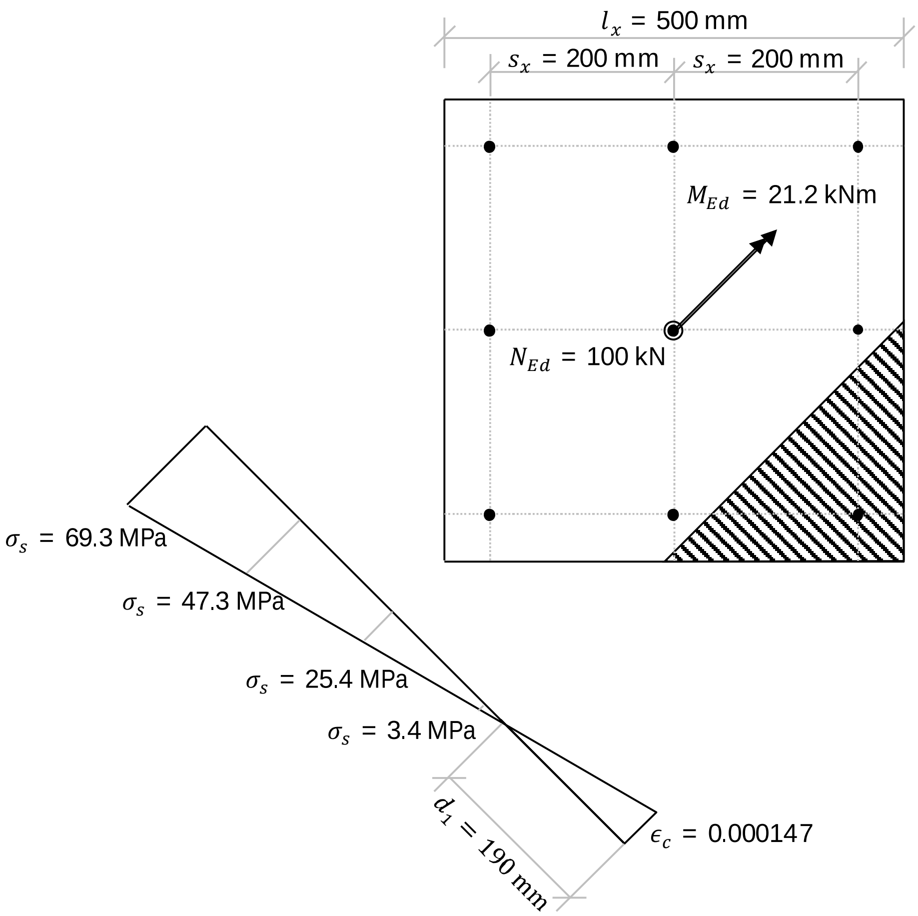
```
************************SUMMARY OF RESULTS*************************
**************************STRENGTH RATIO***************************
********************Resistance to tension load*********************
Steel failure to tensile load              = 0.237 [0.237 < 1.0: OK]
Concrete cone failure                      = 0.828 [0.828 < 1.0: OK]
Pull-out failure                           = 0.300 [0.300 < 1.0: OK]
Splitting failure                          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X- edge)           = 0.392 [0.392 < 1.0: OK]
Local blow out failure (X+ edge)           = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y- edge)           = 0.092 [0.092 < 1.0: OK]
Local blow out failure (Y+ edge)           = 0.307 [0.307 < 1.0: OK]
Steel failure of suppl. reinforcement      = 0.000 [0.000 < 1.0: OK]
Anchorage failure of suppl. reinforcement = 0.000 [0.000 < 1.0: OK]
**********************Resistance to shear load*********************
Steel failure for one anchor               = 0.000 [0.000 < 1.0: OK]
Steel failure for group of anchor          = 0.000 [0.000 < 1.0: OK]
Shear failure with lever arm               = 0.000 [0.000 < 1.0: OK]
Concrete pry-out failure                   = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X- edge)            = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X+ edge)            = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y- edge)            = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y+ edge)            = 0.000 [0.000 < 1.0: OK]
********************Combined shear and tension*********************
Steel failure driven                       = 0.056 [0.056 < 1.0: OK]
Concrete failure driven                    = 0.753 [0.753 < 1.0: OK]
*********************Resistance to compression*********************
Concrete compression                       = 0.042 [0.042 < 1.0: OK]
*******************************************************************
Maximum ratio                              = 0.828 [0.828 < 1.0: OK]
*******************************************************************
```

Figure 28 Example 3: TACEP output data.

4.4.4 Verification of results by hand calculations

4.4.4.1 Determination of action effects

Axial forces on the fasteners can be obtained from sectional analysis (see Figure 29). It must be noted that the effective bending moment M_{Ed} increases compared to the defined value (14.1 kNm) due to the eccentricity tolerance; the most unfavourable situation is $e_x = -50$ mm, $e_y = 50$ mm, which leads to an increment of the bending moment $\Delta M_{Ed,x} = \Delta M_{Ed,y} = 5$ kNm. The largest tension load acting on an anchor N_{Ed}^h is 34.0 kN and the total axial load acting on the anchors N_{Ed}^g is 121.2 kN. No shear forces are to be considered as $V_{Ed,x} = V_{Ed,y} = M_{Ed,z} = 0$.



$$\sum N = \int \epsilon\, E_c\, dx\, dy + \sum A_{si}\sigma_{si} = -21.2 + 3.3 + 37.4 + 46.4 + 34.0 = 100 \text{ kN}$$

$$\sum M = \int \epsilon\, E_c\, d_1\, dx\, dy + \sum A_{si}\sigma_{si} d_{gsi} = 5.5 - 0.5 + 0.0 + 6.6 + 9.6 = 21.2 \text{ kNm}$$

Figure 29 Example 3: sectional analysis.

4.4.4.2 Determination of resistances

Considering that the shear forces acting on the anchors are zero, only the calculation of the tensile and compressive resistances is detailed next.

4.4.4.2.1 Resistance to tension load

- Steel failure of fastener (see section 3.3.2.1)

$$N_{Rd,s} = N_{Rk,s} \,/\, \gamma_{Ms,tension,NO} = 221 \,/\, 1.54 = 143.5 \text{ kN} \qquad \text{Eq. (102)}$$

- Concrete cone failure (see section 3.3.2.2)

As there are three edges distance less than $c_{cr,N}$ = 807 mm, the value of the embedded depth h_{ef} is replaced by:

$$h'_{ef} = \max\left(\frac{c_{max}}{c_{cr,N}}\,h_{ef}, \frac{s_{max}}{s_{cr,N}}\,h_{ef}\right) = \max\left(\frac{250}{807}\cdot 538, \frac{200}{1614}\cdot 538\right) = 166.7 \qquad \text{Eq. (103)}$$

$$N_{Rd,c} = N^0_{Rk,c}\,\psi_{A,N}\,\psi_{s,N}\,\psi_{ec,N}\,\psi_{re,N}\,\psi_{M,N}\,/\,\gamma_{Mc,tension,NO} = 219.7\,/\,1.5 = 146.5\text{ kN} \qquad \text{Eq. (104)}$$

$$N^0_{Rk,c} = k_1\sqrt{f_{ck}}\,h^{1.5}_{ef} = 8.5\cdot\sqrt{30}\cdot 166.7^{1.5} = 100.2\text{ kN} \qquad \text{Eq. (105)}$$

$$\psi_{s,N} = 0.7 + 0.3\frac{c}{c_{cr,N}} = 0.7 + 0.3\frac{250}{1.5\cdot 166.7} = 1.0 \qquad \text{Eq. (106)}$$

Considering the eight anchors in tension:

$$\psi_{A,N} = \frac{A_{c,N}}{A^0_{c,N}} = \frac{(400+3\cdot 166.7)(200+3\cdot 166.7)+(200+3\cdot 166.7)(200)}{(3\cdot 166.7)^2} = 3.080 \qquad \text{Eq. (107)}$$

$$\psi_{ec,N} = \frac{1}{1+\frac{2e_{n,x}}{s_{cr,N}}}\frac{1}{1+\frac{2e_{n,y}}{s_{cr,N}}} = \frac{1}{1+2\cdot 66.7/(3\cdot 166.7)}\cdot\frac{1}{1+2\cdot 66.7/(3\cdot 166.7)} = 0.623 \qquad \text{Eq. (108)}$$

$$e_{n,x} = \frac{50\cdot(69.3+47.3+25.4)+250\cdot(47.3+25.4+3.4)+450\cdot(25.4+3.4)}{69.3+2\cdot 47.3+3\cdot 25.4+2\cdot 3.4} - \frac{50\cdot 3+250\cdot 3+450\cdot 2}{8} = 158.3 - 225 = -66.7 \qquad \text{Eq. (109)}$$

Considering only the six most tension-loaded anchors:

$$\psi_{A,N} = \frac{A_{c,N}}{A^0_{c,N}} = 2.760 \qquad \text{Eq. (110)}$$

$$\psi_{ec,N} = 0.7945 \qquad \text{Eq. (111)}$$

The product of the latter (2.76*0.7945=2.19) is larger than the former (3.080*0.623=1.92), so factors $\psi_{A,N}$ and $\psi_{ec,N}$ obtained for the six most tension loaded anchors will be considered in Eq. (104).

$$\psi_{re,N} = 1\ (h_{ef} = 538\text{ mm}) \qquad \text{Eq. (112)}$$

$$\psi_{M,N} = 1\left(\frac{z}{h_{ef}} = \frac{388}{538} < 1.5\right) \qquad \text{Eq. (113)}$$

Note that not considering the reduction of the effective embedded length would result into

- Pull-out failure of fastener (see section 3.3.2.3)

$$N_{Rd,p} = N_{Rk,p} \;/\; \gamma_{Mc,tension,NO} = (115 \cdot 1.48) \;/\; 1.5 = 170.2 \;/\; 1.5 = 113.5 \text{ kN} \qquad \text{Eq. (114)}$$

- Concrete splitting failure (see section 3.3.2.4)

No concrete splitting failure check is required as it is assumed that the arranged reinforcement is sufficient to withstand splitting forces.

- Concrete blow-out failure (see section 3.3.2.5)

Concrete blow-out failure check is required in this case as the distance to some edges is smaller than 0.5 h_{ef} = 269 mm.

- East edge (c_{x-} = 200 mm): the three anchors parallel to the edge are in tension, with total tensile force N_{Ed}^{g} = 69.7 kN.

$$N_{Rd,cb} = N_{Rk,cb}^{0} \, \psi_{A,Nb} \, \psi_{s,Nb} \, \psi_{g,Nb} \, \psi_{ec,N} \;/\; \gamma_{Mc,tension} = 267.0 \;/\; 1.5 = 178.0 \text{ kN} \qquad \text{Eq. (115)}$$

$$N_{Rk,cb}^{0} = k_5 \, c_1 \, \sqrt{A_h} \, \sqrt{f_{ck}} = 8.7 \cdot 250 \cdot \sqrt{\frac{\pi \cdot (40^2 - 25^2)}{4}} \cdot \sqrt{30} = 329.7 \text{ kN} \qquad \text{Eq. (116)}$$

$$\psi_{A,Nb} = \frac{A_{c,Nb}}{A_{c,Nb}^{0}} = \frac{(400 + 250 + 250)(2 \cdot 250 + 800 - 525 - 25)}{(4 \cdot 250)^2} = \frac{675000}{1000000} = 0.675 \qquad \text{Eq. (117)}$$

$$\psi_{s,Nb} = 0.7 + 0.3 \frac{c_2}{2\,c_1} = 0.7 + 0.3 \frac{250}{2 \cdot 250} = 0.85 \qquad \text{Eq. (118)}$$

$$\psi_{g,Nb} = \sqrt{n} + \left(1 - \sqrt{n}\right) \frac{s_2}{4\,c_1} = \sqrt{3} + \left(1 - \sqrt{3}\right) \frac{200}{4 \cdot 250} = 1.586 \qquad \text{Eq. (119)}$$

$$\psi_{ec,Nb} = \frac{1}{1 + 2 \cdot 61.8 / \,(4 \cdot 250)} = 0.890 \qquad \text{Eq. (120)}$$

$$e_N = \frac{69.3 \cdot 450 + 47.3 \cdot 250 + 25.4 \cdot 50}{69.3 + 47.3 + 25} - 250 = 311.8 - 250 = 61.8 \text{ mm} \qquad \text{Eq. (121)}$$

- West edge (c_{x+} = 10000 mm)

No concrete blow-out failure is required as c > 0.5 h_{ef} = 269 mm.

- South edge (c_{y-} = 200 mm): two of the anchors parallel to the edge are in tension, with total tensile force N_{Ed}^{g} = 14.1 kN.

$$N_{Rd,cb} = N_{Rk,cb}^{0}\,\psi_{A,Nb}\,\psi_{s,Nb}\,\psi_{g,Nb}\,\psi_{ec,N}\,/\,\gamma_{Mc,tension} = 230.3\,/\,1.5 = 153.5 \text{ kN} \qquad \text{Eq. (122)}$$

$$N_{Rk,cb}^{0} = k_5\,c_1\,\sqrt{A_h}\,\sqrt{f_{ck}} = 8.7\cdot 250\cdot\sqrt{\frac{\pi\cdot(40^2-25^2)}{4}}\cdot\sqrt{30} = 329.7 \text{ kN} \qquad \text{Eq. (123)}$$

$$\psi_{A,Nb} = \frac{A_{c,Nb}}{A_{c,Nb}^{0}} = \frac{(200+250+2\cdot 250)(2\cdot 250+800-525-25)}{(4\cdot 250)^2} = \frac{712500}{1000000} = 0.712 \qquad \text{Eq. (124)}$$

$$\psi_{s,Nb} = 0.7+0.3\frac{c_2}{2\,c_1} = 0.7+0.3\frac{250}{2\cdot 250} = 0.85 \qquad \text{Eq. (125)}$$

$$\psi_{g,Nb} = \sqrt{n}+\left(1-\sqrt{n}\right)\frac{s_2}{4\,c_1} = \sqrt{2}+\left(1-\sqrt{2}\right)\frac{200}{4\cdot 250} = 1.331 \qquad \text{Eq. (126)}$$

$$\psi_{ec,Nb} = \frac{1}{1+2\cdot 76.4/\,(4\cdot 250)} = 0.867 \qquad \text{Eq. (127)}$$

$$e_N = \frac{25.4\cdot 50+3.4\cdot 250}{25.4+3.4} - 150 = 73.6-150 = -76.4 \text{ mm} \qquad \text{Eq. (128)}$$

- North edge (c_{y+} = 200 mm): the three anchors parallel to the edge are in tension, with total tensile force N_{Ed}^{g} = 69.7 kN.

$$N_{Rd,cb} = N_{Rk,cb}^{0}\,\psi_{A,Nb}\,\psi_{s,Nb}\,\psi_{g,Nb}\,\psi_{ec,N}\,/\,\gamma_{Mc,tension} = 341.4\,/\,1.5 = 227.6 \text{ kN} \qquad \text{Eq. (129)}$$

$$N_{Rk,cb}^{0} = k_5\,c_1\,\sqrt{A_h}\,\sqrt{f_{ck}} = 8.7\cdot 250\cdot\sqrt{\frac{\pi\cdot(40^2-25^2)}{4}}\cdot\sqrt{30} = 329.7 \text{ kN} \qquad \text{Eq. (130)}$$

$$\psi_{A,Nb} = \frac{A_{c,Nb}}{A_{c,Nb}^{0}} = \frac{(400+250+2\cdot 250)(2\cdot 250+800-525-25)}{(4\cdot 250)^2} = \frac{862500}{1000000} = 0.863 \qquad \text{Eq. (131)}$$

$$\psi_{s,Nb} = 0.7+0.3\frac{c_2}{2\,c_1} = 0.7+0.3\frac{250}{2\cdot 250} = 0.85 \qquad \text{Eq. (132)}$$

$$\psi_{g,Nb} = \sqrt{n} + (1 - \sqrt{n})\frac{s_2}{4\,c_1} = \sqrt{3} + (1 - \sqrt{3})\frac{200}{4 \cdot 250} = 1.586$$ Eq. (133)

$$\psi_{ec,Nb} = \frac{1}{1 + 2 \cdot 61.8/\ (4 \cdot 250)} = 0.890$$ Eq. (134)

$$e_N = \frac{69.3 \cdot 50 + 47.3 \cdot 250 + 25.4 \cdot 450}{69.3 + 47.3 + 25.4} - 250 = 188.2 - 250 = -61.8\ \mathrm{mm}$$ Eq. (135)

- Failure of supplementary reinforcement (see section 3.3.2.6)

No supplementary reinforcement arranged, so this verification does not apply.

4.4.4.2.2 Resistance to compression load

$$\frac{N_{Ed}^{c}}{N_{Rd,c}^{c}} = \frac{0.000147}{0.0035} = 0.042$$ Eq. (136)

4.4.4.3 Capacity check

Results obtained in sections 4.4.4.1 and 4.4.4.2 on loads on anchors and plate resistance are summarized in Table 16. Only applicable verifications are given. These results are in agreement with those obtained with the tool (see Figure 28).

Failure mode	Most loaded fastener	Group
Tension load		
Steel failure of fastener (section 3.3.2.1)	$\frac{N_{Ed}^{h}}{N_{Rd,s}} = \frac{34.0}{143.5} = 0.237$	
Concrete cone failure (section 3.3.2.2)		$\frac{N_{Ed}^{g}}{N_{Rd,d}} = \frac{121.2}{146.5} = \mathbf{0.827}$
Pull-out failure of fastener (section 3.3.2.3)	$\frac{N_{Ed}^{h}}{N_{Rd,p}} = \frac{34.0}{113.5} = 0.300$	
Concrete blow out failure (X-) (section 3.3.2.5)		$\frac{N_{Ed}^{g}}{N_{Rd,cb}} = \frac{69.7}{178.0} = 0.392$
Concrete blow out failure (Y-) (section 3.3.2.5)		$\frac{N_{Ed}^{g}}{N_{Rd,cb}} = \frac{14.1}{153.5} = 0.092$
Concrete blow out failure (Y+) (section 3.3.2.5)		$\frac{N_{Ed}^{g}}{N_{Rd,cb}} = \frac{69.7}{227.6} = 0.306$
Compression load		
Compressive failure of concrete under fixtures (section 3.3.5)		$\frac{N_{Ed}^{c}}{N_{Rd,c}^{c}} = 0.042$
Combined tension and shear loads		
Steel failure of fastener (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,s}}\right)^{2} + \left(\frac{V_{Ed}}{V_{Rd,s}}\right)^{2} = 0.237^{2} = 0.056$	
Failure mode other than steel (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{1.5} = 0.827^{1.5} = 0.753$	

Table 16 Example 3: capacity check summary

4.5 Example 4

4.5.1 Introduction

This example entails a circular, customized plate subjected to a tensile force N_{Ed} = 150 kN and a shear force $V_{Ed,x}$ = 50 kN in normal operation, with a vertical eccentricity equal to 50 mm, placed far enough from any edge. The plate diameter is 450 mm, has four anchors KB22 of nominal length 250 mm, which are spaced 354 mm in the radial direction (250 mm between anchors) (see Figure 30). The effective embedded length h_{ef} of the KB22 anchors is 265 mm ($h_n + t_p - t_h$ = 250 + 25 – 10). Hanger reinforcement for tension is arranged as well.

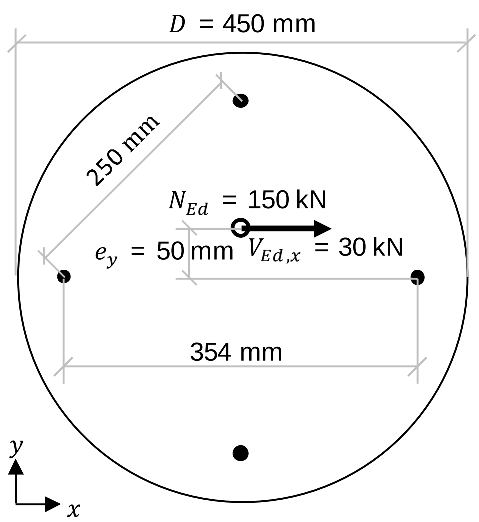
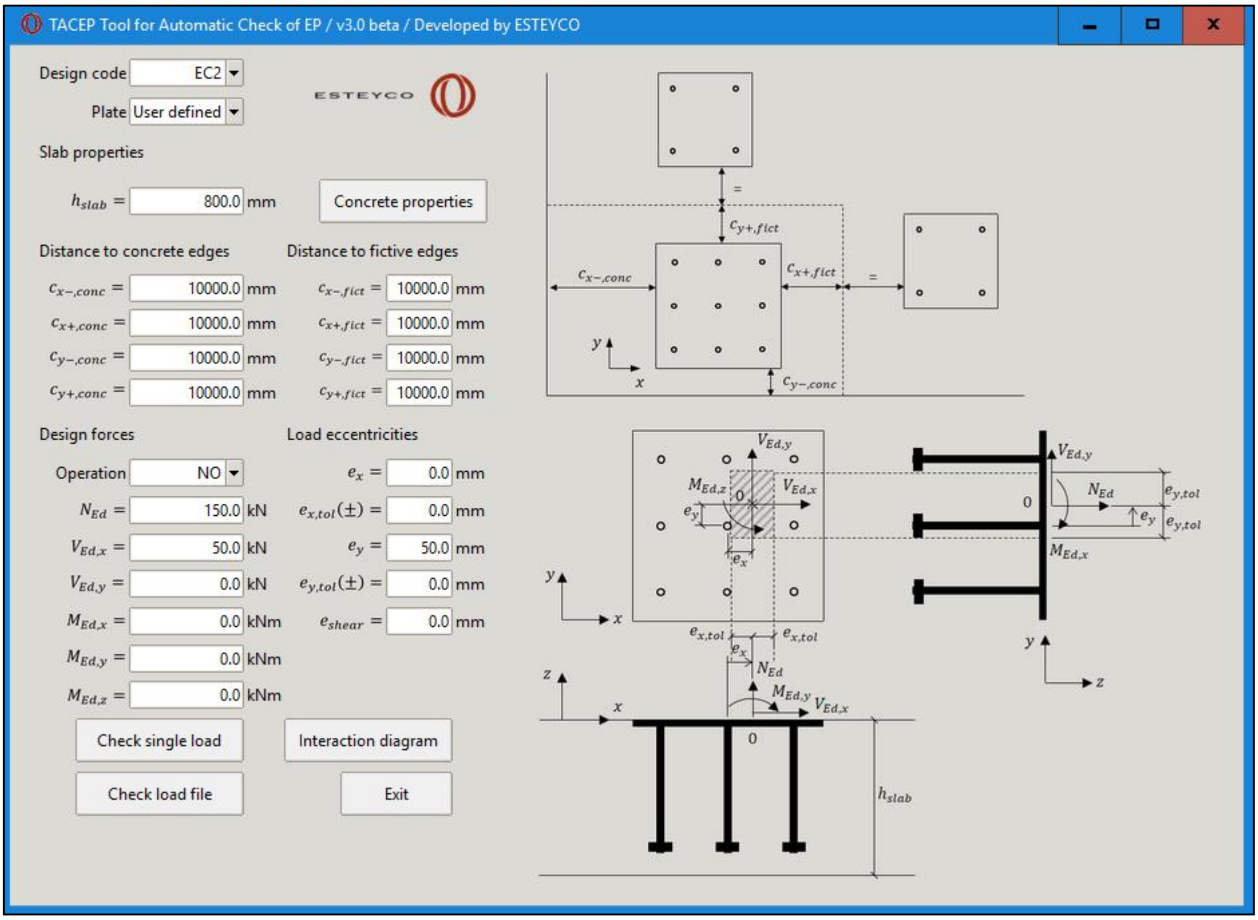
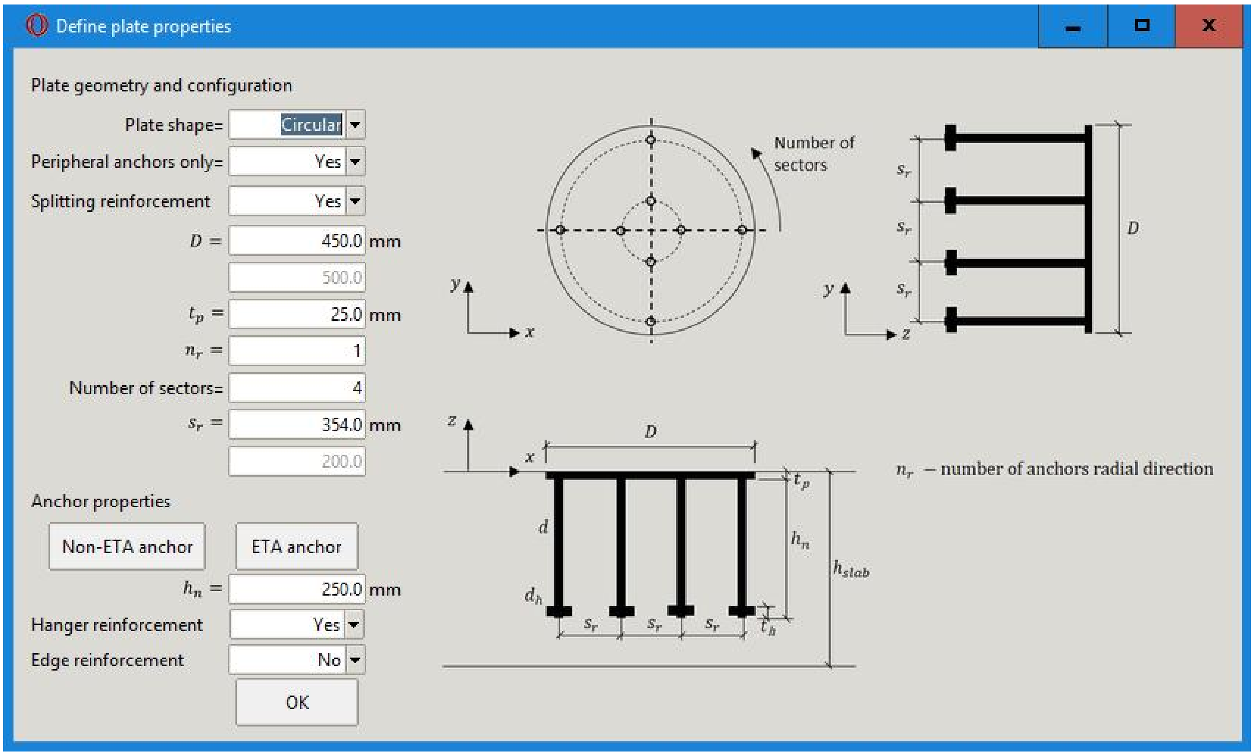


Figure 30 Example 4: problem description.

4.5.2 Input data





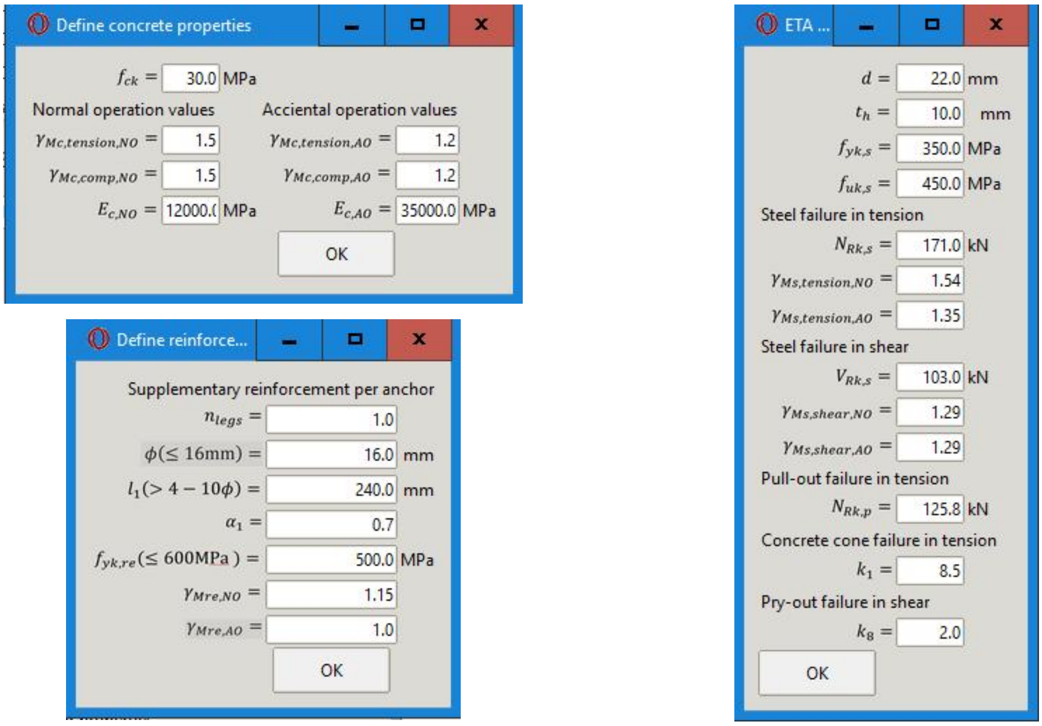


Figure 31 Example 4: input data.

4.5.3 Results from TACEP

Results obtained with the tool are shown in Figure 32.

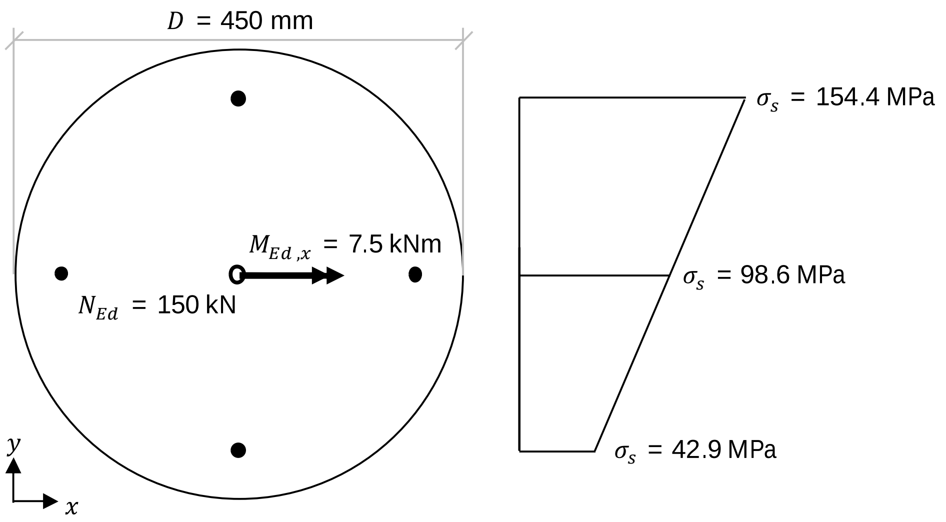
```
************************SUMMARY OF RESULTS*************************
**************************STRENGTH RATIO***************************
********************Resistance to tension load*********************
Steel failure to tensile load             = 0.529 [0.529 < 1.0: OK]
Concrete cone failure                     = 0.667 [0.667 < 1.0: OK]
Pull-out failure                          = 0.700 [0.700 < 1.0: OK]
Splitting failure                         = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X- edge)          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (X+ edge)          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y- edge)          = 0.000 [0.000 < 1.0: OK]
Local blow out failure (Y+ edge)          = 0.000 [0.000 < 1.0: OK]
Steel failure of suppl. reinforcement     = 0.671 [0.671 < 1.0: OK]
Anchorage failure of suppl. reinforcement = 0.784 [0.784 < 1.0: OK]
**********************Resistance to shear load*********************
Steel failure for one anchor              = 0.201 [0.201 < 1.0: OK]
Steel failure for group of anchor         = 0.201 [0.201 < 1.0: OK]
Shear failure with lever arm              = 0.000 [0.000 < 1.0: OK]
Concrete pry-out failure                  = 0.148 [0.148 < 1.0: OK]
Concrete edge failure (X- edge)           = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (X+ edge)           = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y- edge)           = 0.000 [0.000 < 1.0: OK]
Concrete edge failure (Y+ edge)           = 0.000 [0.000 < 1.0: OK]
********************Combined shear and tension*********************
Steel failure driven                      = 0.320 [0.320 < 1.0: OK]
Concrete failure driven                   = 0.642 [0.642 < 1.0: OK]
*********************Resistance to compression*********************
Concrete compression                      = 0.000 [0.000 < 1.0: OK]
*******************************************************************
Maximum ratio                             = 0.700 [0.700 < 1.0: OK]
*******************************************************************
```

Figure 32 Example 4: TACEP output data.

4.5.4 Verification of results by hand calculations

4.5.4.1 Determination of action effects

Axial forces on the fasteners can be obtained from sectional analysis (see Figure 33). The bending moment arises due to the eccentricity. The largest tension load acting on an anchor N_{Ed}^{h} is 58.7 kN and the total axial load acting on the anchors N_{Ed}^{g} is 150.0 kN.



$$\sum N = \sum A_{si}\sigma_{si} = 58.7 + 75 + 16.3 = 150\text{kN}$$

$$\sum M = \sum A_{si}\sigma_{si}d_{gsi} = 10.4 + 0 - 2.9 = 7.5\text{ kNm}$$

Figure 33 Example 4: sectional analysis.

Due to the load eccentricity, there is a torsion moment, induces a shear load on each anchor; this shear is equal to 3.5 kN (M_T/2/0.354). Considering this, the largest shear load acting on an anchor V_{Ed}^h is 16.0 kN and the total shear load acting on the anchors V_{Ed}^g is 50.0 kN.

4.5.4.2 Determination of resistances

4.5.4.2.1 Resistance to tension load

- Steel failure of fastener (see section 3.3.2.1)

$$N_{Rd,s} = N_{Rk,s} \,/\, \gamma_{Ms,tension,NO} = 171 \,/\, 1.54 = 111.0\text{ kN} \qquad \text{Eq. (137)}$$

- Concrete cone failure (see section 3.3.2.2)

$$N_{Rd,c} = N_{Rk,c}^0\, \psi_{A,N}\, \psi_{s,N}\, \psi_{ec,N}\, \psi_{re,N}\, \psi_{M,N} \,/\, \gamma_{Mc,tension,NO} = 336.6 \,/\, 1.5 = 224.4\text{ kN} \qquad \text{Eq. (138)}$$

$$N_{Rk,c}^0 = k_1 \sqrt{f_{ck}}\, h_{ef}^{1.5} = 8.5 \cdot \sqrt{30} \cdot 265^{1.5} = 200.8\text{ kN} \qquad \text{Eq. (139)}$$

$$\psi_{A,N} = \frac{A_{c,N}}{A_{c,N}^0} = \frac{(354 + 3 \cdot 265)(3 \cdot 265) + 2 \cdot (3 \cdot 265) \cdot (354/2)}{(3 \cdot 265)^2} = \frac{1194885}{632025} = 1.891 \qquad \text{Eq. (140)}$$

$$\psi_{s,N} = 0.7 + 0.3\frac{c}{c_{cr,N}} = 1 \qquad \text{Eq. (141)}$$

$$\psi_{ec,N} = \frac{1}{1+\frac{2e_{n,x}}{s_{cr,N}}}\frac{1}{1+\frac{2e_{n,y}}{s_{cr,N}}} = 1\cdot\frac{1}{1+\frac{2\cdot 50}{3\cdot 260}} = 0.886 \quad \text{Eq. (142)}$$

$$\psi_{re,N} = 1 \quad \text{Eq. (143)}$$

$$\psi_{M,N} = 1 \quad \text{Eq. (144)}$$

- Pull-out failure of fastener (see section 3.3.2.3)

$$N_{Rd,p} = N_{Rk,p} \;/\; \gamma_{Mc,tension,NO} = 125.8 \;/\; 1.5 = 83.9 \text{ kN} \quad \text{Eq. (145)}$$

- Concrete splitting failure (see section 3.3.2.4)

No concrete splitting failure check is required as it is assumed that the arranged reinforcement is sufficient to withstand splitting forces.

- Concrete blow-out failure (see section 3.3.2.5)

No concrete blow-out failure is required as c_{min} = 250 mm > 0.5 h_{ef} = 130 mm.

- Failure of supplementary reinforcement (see section 3.3.2.6)
  - Steel failure of supplementary reinforcement

$$N_{Rd,re} = \sum_{i}^{legs} A_{s,re,i}\, f_{yd,re} = \frac{\pi\cdot 16^2}{4}\frac{500}{1.15} = 87.4 \text{ kN} \quad \text{Eq. (146)}$$

  - Anchorage failure of supplementary reinforcement

$$N^0_{Rd,a} = \frac{l_1\,\pi\,\phi\,f_{bd}}{\alpha_1\,\alpha_2} = \frac{240\cdot\pi\cdot 16\cdot 3.04}{0.7\cdot 0.7} = 74.8 \text{ kN} \leq A_{s,re}\, f_{yk,re} \quad \text{Eq. (147)}$$

$$f_{bd} = 2.25\,\eta_1\,\eta_2\,f_{ctd} = 2.25\,\eta_1\,\eta_2\frac{0.7\cdot 0.3\,f_{ck}^{2/3}}{\gamma_{Mc,tension}} = 2.25\cdot 1\cdot 1\cdot\frac{0.7\cdot 0.3\cdot 30^{2/3}}{1.5} = 3.04 \text{ MPa} \quad \text{Eq. (148)}$$

4.5.4.2.2 Resistance to shear load

- Steel failure of fastener without lever arm (see section 3.3.3.1)

$$V_{Rd,s} = V_{Rk,s} \ / \ \gamma_{Ms,shear,NO} = 103.0 \ / \ 1.29 = 79.8 \text{ kN} \quad \text{Eq. (149)}$$

- Concrete pry-out failure (see section 3.3.3.3)

$$V_{Rd,c,x} = k_8 \, N_{Rd,c,x} = 2.0 \cdot 224.3 = 448.6 \text{ kN} \quad \text{Eq. (150)}$$

$$N_{Rd,c,x} = N^0_{Rk,c} \, \psi_{A,N} \, \psi_{s,N} \, \psi_{ec,Nx} \, \psi_{re,N} \, \psi_{M,N} \ / \ \gamma_{Mc,tension,NO} = 336.4 \ / \ 1.5 = 224.3 \text{ kN} \quad \text{Eq. (151)}$$

$$N^0_{Rk,c} = k_1 \sqrt{f_{ck}} \, h_{ef}^{1.5} = 8.5 \cdot \sqrt{30} \cdot 265^{1.5} = 200.8 \text{ kN} \quad \text{Eq. (152)}$$

$$\psi_{A,N} = \frac{A_{c,N}}{A^0_{c,N}} = \frac{(354 + 3 \cdot 265)(3 \cdot 265) + 2 \cdot (3 \cdot 265) \cdot (354/2)}{(3 \cdot 265)^2} = \frac{1194885}{632025} = 1.891 \quad \text{Eq. (153)}$$

$$\psi_{s,N} = \psi_{re,N} = \psi_{M,N} = 1 \quad \text{Eq. (154)}$$

$$\psi_{ec,N} = \frac{1}{1 + \frac{2e_{n,y}}{s_{cr,N}}} = \frac{1}{1 + \frac{2 \cdot 50}{3 \cdot 260}} = 0.886 \quad \text{Eq. (155)}$$

4.5.4.3 Capacity check

Results obtained in sections 4.4.4.1 and 4.4.4.2 on loads on anchors and plate resistance are summarized in Table 17. Only applicable verifications are given. These results are in agreement with those obtained with the tool (see Figure 32). Note that for the calculation of the combined tension-shear load, for concrete failure, the exponent is 1.5 even when reinforcement was arranged only for tension, because rebars were not effective as the concrete cone strength ratio (0.669) is lower than that of supplementary reinforcement failure (0.785).

Failure mode	Most loaded fastener	Group
Tension load		
Steel failure of fastener (section 3.3.2.1)	$\frac{N_{Ed}^{h}}{N_{Rd,s}} = \frac{58.7}{111.0} = 0.529$	
Concrete cone failure (section 3.3.2.2)		$\frac{N_{Ed}^{g}}{N_{Rd,d}} = \frac{150.0}{224.4} = 0.669$
Pull-out failure of fastener (section 3.3.2.3)	$\frac{N_{Ed}^{h}}{N_{Rd,p}} = \frac{58.7}{83.9} = \mathbf{0.700}$	
Steel failure of supplementary reinforcement (section 3.3.2.6.1)	$\frac{N_{Ed}^{h}}{N_{Rd,re}} = \frac{58.7}{87.4} = 0.672$	
Anchorage failure of supplementary reinforcement (section 3.3.2.6.2)	$\frac{N_{Ed}^{h}}{N_{Rd,a}} = \frac{58.7}{74.8} = 0.785$	
Shear load		
Steel failure of fastener without lever arm (section 3.2.3.1)	$\frac{V_{Ed}^{h}}{V_{Rd,s}} = \frac{16.0}{79.8} = 0.201$	
Concrete pry-out failure (section 3.2.3.3)		$\frac{V_{Ed,x}^{g}}{V_{Rd,cp,x}} = \frac{50}{448.6} = 0.111$
Combined tension and shear loads		
Steel failure of fastener (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,s}}\right)^{2} + \left(\frac{V_{Ed}}{V_{Rd,s}}\right)^{2} = 0.529^{2} + 0.201^{2} = 0.320$	
Failure mode other than steel (section 3.3.4)	$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{1.5} = 0.700^{1.5} + 0.111^{1.5} = 0.622$	

Table 17 Example 4: capacity check summary

5 SUMMARY AND COMMENTS

Cast-in place embedded plates (EPs) are an important element inside the ITER facility, where they are counted in tens of thousands. They are used for attachment of plant equipment and devices and, therefore, many practitioners working in ITER need to consider their existence to some degree as the forces transferred by the supported elements cannot exceed their capacity.

Capacity check of EPs can be tedious as it involves many variables and several failure modes. Considering the large number of EPs that need to be checked, under multiple load cases in many cases, some automatization is required. To overcome some of the current limitations inside the ITER project regarding this matter, ESTEYCO has developed the tool TACEP (Tool for Automatic Check of Embedded Plates), which is presented in this document. Main function of this tool are: (i) capacity check of single plates, (ii) automatic capacity check of multiple plates and (iii) development of interaction diagrams. Operation of the tool is described in Chapter 2, and basis of verification are detailed in Chapter 3. Some examples of application are presented in Chapter 4. These same examples have been evaluated by hand calculations and the obtained results are presented to validate the output data provided by TACEP.

It is believed that TACEP offers a good potential for its use inside the ITER project. However, it must be acknowledged that its use by practitioners not familiar with the topic must be done with care considering the background of the tool. TACEP was originally developed by ESTEYCO for its own internal use and adapted afterwards to facilitate its use by third parties after F4E request. It has been used in a limited number of applications obtaining good results, but, in the author's opinion, the large number of variables and situations involved would require further validation before the tool can be used by practitioners not experienced with EPs.

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