P1384 – BEQTAQARI Detail Engineering

RMG AURAMINE

300-TK-001 TANK CALCULATION REPORT

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Document Name	300-TK-001 TANK CALCULATION REPORT		

Chemitec Consulting Oy

Protón Ingenieros

CONTENT

1 INTRODUCTION

1.1 Equipment description

The equipment consists on an agitated tank with two structural elements that are designed separately, the tank shell and the top platform to support the mixer and provide accessibility to it and also for pipe support.

The top platform is supported on the tank and fixed by bolted connections. Floor will consist on grating mesh and a peripheral handrail will be installed.

The tank shell is designed in order to withstand the loads in the operation and lifting conditions. Operational condition includes the loads transmitted by the top platform and the hydrostatic pressure from the inner fluid together with environmental and seismic load. For lifting condition only self-weight is considered, with the applicable loading factors.

Lifting lugs are added to the tank shell border, together with some reinforcements for the tank shell due to the concentrated load mentioned above, namely over-thickness and/or stiffeners.

The tank is anchored vertically to the floor or supporting structure with anchoring chairs. To avoid lateral displacement due to possible seismic loads, seismic stoppers with 1 mm gap between stopper and platform will be considered for each anchor point.

1.2 Design process

Due to the design of the agitator tank consists of two different structural elements, platform and tank, each element have been calculated separately. Next steps are followed for the agitated tank design:

1) Top platform calculation: The top platform is designed with standard structure calculation methods, considering the loads from the mixer and other environmental loads. Apart from the ULS and SLS check of the platform this calculation is delivering the support reactions as a result, that are transferred to the tank shell calculation.

2) Top platform connection: In the case of the bolt connection between the platform and the tank, the bolts are designed to withstand the shear effect from the lateral forces of the platform. See annex 1.

3) The tank shell is predimensioned according with API650 criteria. Also others checks are done according with this code regarding overturning and anchor chairs check-up. See annex 1.

4) Finally, a Finite Element Analysis is done to the predimensioned tank adding the top platform loads and also the lifting condition, performing the tank shell verification and checking the need of reinforcements. This analysis consists in three calculations: the analysis in operation condition, the check of the lifting condition and a separate check of the lifting point (padeye).

2 INPUT DATA

2.1 Codes, Standards and References

- API 650 Welded Tanks For Oil Storage, Twelfth Edition March 2013.
- AISI Steel Plate Engineering Data, Volume 2.
- Eurocode 3: Design of steel structures Part 1-8: Design of joints.
- Eurocode 8: Design of structures for earthquake resistance.

2.2 Material properties

All elements to be S275JR steel.

2.3 Software input data

2.3.1 Top platform

The top platform structure is modelled and calculated with SAP2000 by single line elements (nodes and bars). Boundary conditions are included as well as material properties, slenderness and deflection limits, together with loads and the applicable calculation code.

The points where the platform connects with the tanks are considered pinned supports.

2.3.2 Tank shell

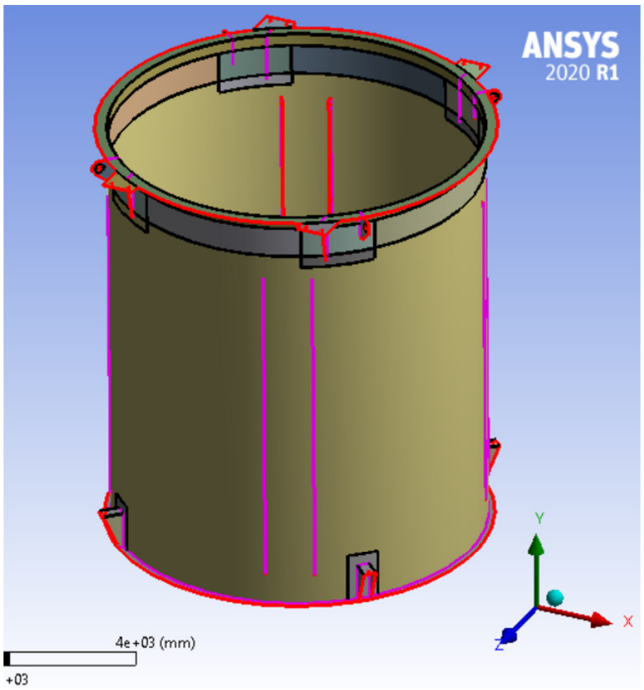
2.3.2.1 Tank shell general model

The tank shell is analysed by Finite Element Method in ANSYS Mechanical 2020 R1, and have been built with shell elements, including: the tank, the lift points, the anchor chairs, the platform supports and other stiffeners.

Corrosion allowance is considered in the way that all tank thicknesses in contact with the fluid have 3 mm thickness reduction in the ANSYS design model.

The model is composed by lineal order shell elements. The finite element is defined through an element size ranging of 10 mm in the most compromises areas. Those are 2D elements defined by 4 nodes with six degrees of freedom at each node.

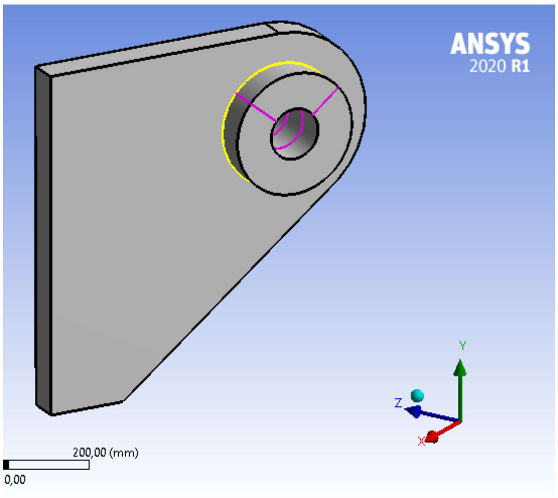
In the following figure, a typical model of the tank shell is shown:



2.3.2.2 Padeyes

The lifting padeyes have been verified in a different model separated from the tank shell by lineal order solid elements. The finite element mesh is defined through a global element size of 10mm which leads to accommodate at least 3 elements across the plate thickness direction. Those are 3D solid elements defined by 8 nodes having three degrees of freedom at each node (three translations). This element has plasticity, creep, stress stiffening, large deflection, and large strain capabilities.

In the following figure, a typical model of the padeye is shown:

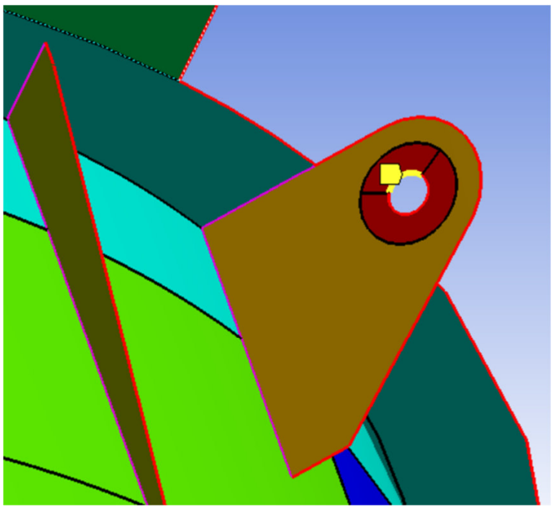


2.3.2.3 Tank shell boundary conditions

For operation condition, the whole face of the bottom plate of the tank has been defined as simply supported.

The bolt holes of the anchor chair has been displacement restricted in X and Z (horizontal directions).

For the lifting condition, pinned support has been applied in each lifting point with a sling contact angle of 100 degrees as shown in the following figure:



2.4 Loads

2.4.1 Top platform loads

Next table shows the loads that have been considered on the top platform structure:

Item	Load	Unit	Comments
DEAD LOADS			
Steel selfweight	77,02	kN/m³	Software generated
Grating	0,50	kN/m^2	
Handrail	0,50	kN/m	
Mixer	4,60	kN	
LIVE LOADS			
Live load on platform	5,00	kN/m^2	
Mixer	See comments Bending moment amplification factor = 3 Torque amplification factor = 2,5		*MixPro Quote: Q21-7786 Revs.B, C and D as Approved for Design provided info from Chemitec.* ***To be verified once equipment is purchased and confirmed.*** Bending moment = 2,43 kNm Torque reaction = 1,66 kNm
SEISMIC LOAD			
Seismic load	2,94	m/s²	Significance coefficient: gI = 1,2. Ground acceleration: ag = 2,94 (m/s²) = 0,3*9,81 Background parameters: s = 1,35.
WIND LOADS			
	0,00	kN/m^2	
SNOW LOADS			
	0,00	kN/m^2	

2.4.2 Tank shell loads

2.4.2.1 Top platform loads

This section covers the loads directly applied to the tank shell, which also includes those transferred from the top platform.

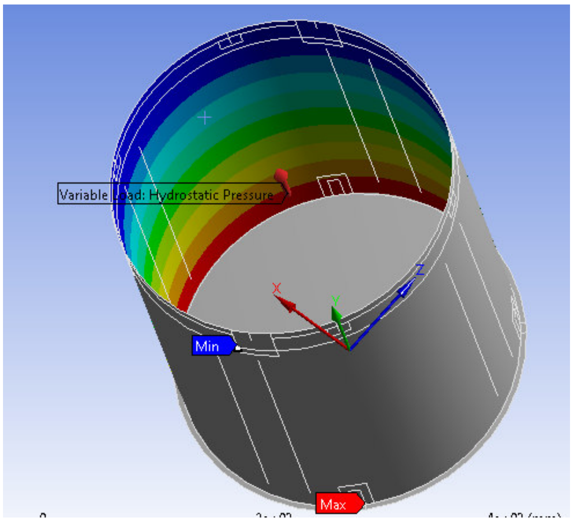
The vertical reactions have been introduced in the platform support plates, as all the loads act as compression. The horizontal reactions have been introduced in the bolt holes of the support plates.

2.4.2.2 Tank selfweight

Selfweight load is software generated according to modelled elements. To take into account the non-modelled elements this load have been multiplied by 1,3.

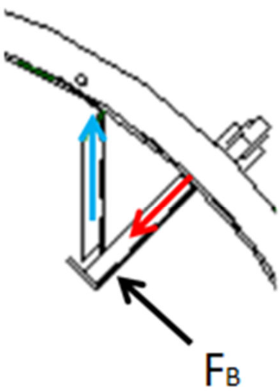
2.4.2.3 Hydrostatic pressure

The hydrostatic pressure simulates the pressure load due to the fluid inside the tank. A slurry density of 1,4 t/m3 has been considered in the calculation. In the figure below, a typical distribution of the pressure inside the tank is shown:



2.4.2.4 Baffles loads

Baffles reduce swirling in the bulk fluid, generating a tension-compression load in the wall of the tank where the baffles are connected, as shown in the figure below:



The expression for the calculation of the force applied in the baffle is the following:

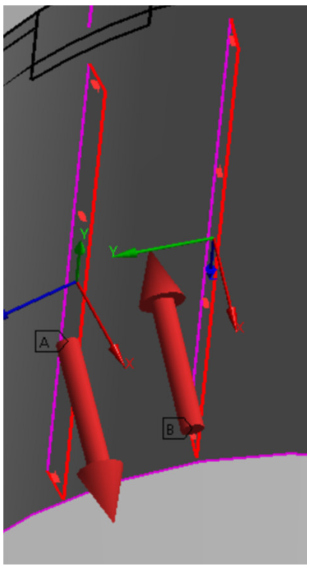
$$F_B = \frac{\tau \times A_f \times 1000}{N_B \times [(T/2)] - (B_w/2) - B_c]}$$

Where:

- F_B is the force on each baffle (N).
- A_f is the adjustment factor (set to value of 1 for a conservative design).
- N_B is the number of baffles.
- T is tank diameter (mm).
- B_w is the baffle width (mm).
- B_c is the baffle off wall clearance (mm).
- τ is the mixer torque (Nm).

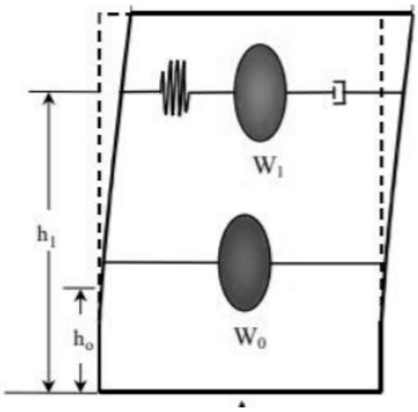
300-AG-001		
Torque reaction	1660	Nm
A_f	1	
N_B	4	
T	3000	mm
B_w	250	mm
B_c	10	mm
F_B	304	N

The force on each baffle is divided in a compression-tension load in the baffle support and introduced in the model as shown in the following figure:



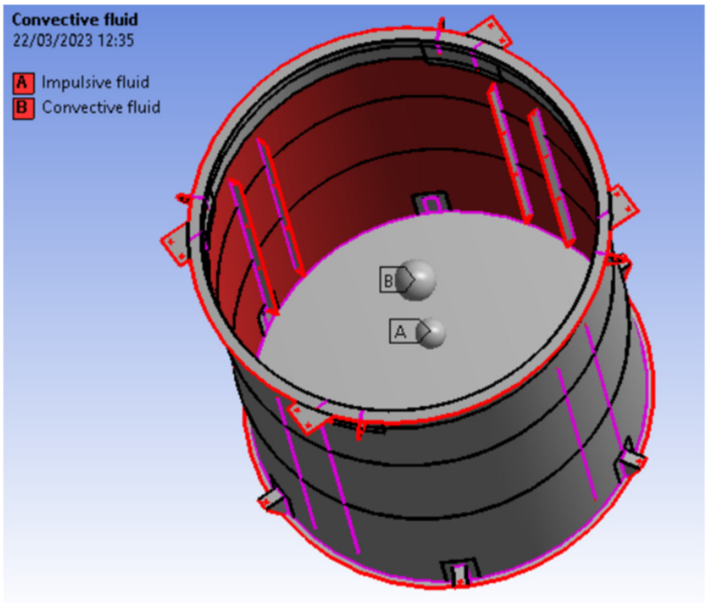
2.4.2.5 Seismic inertial load

To study the seismic behaviour of the tank, the following model is simulated:

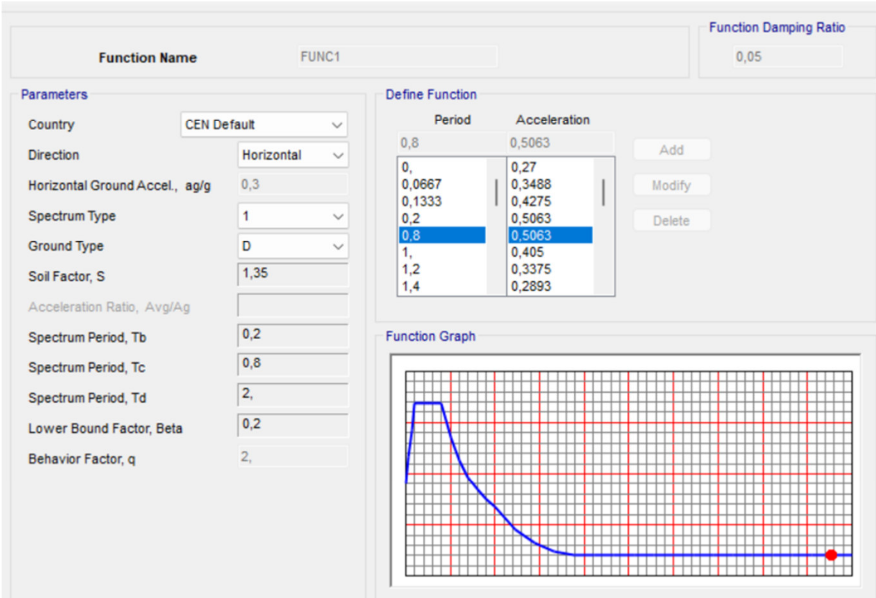


Two different masses are observed: an impulsive mass that rigidly accompanies the movement of the tank walls (W_0), simulating the behaviour of the fluid that moves with the tank (impulsive) and a convective mass in which the fluid that is located near the free surface is subjected to oscillations (W_1).

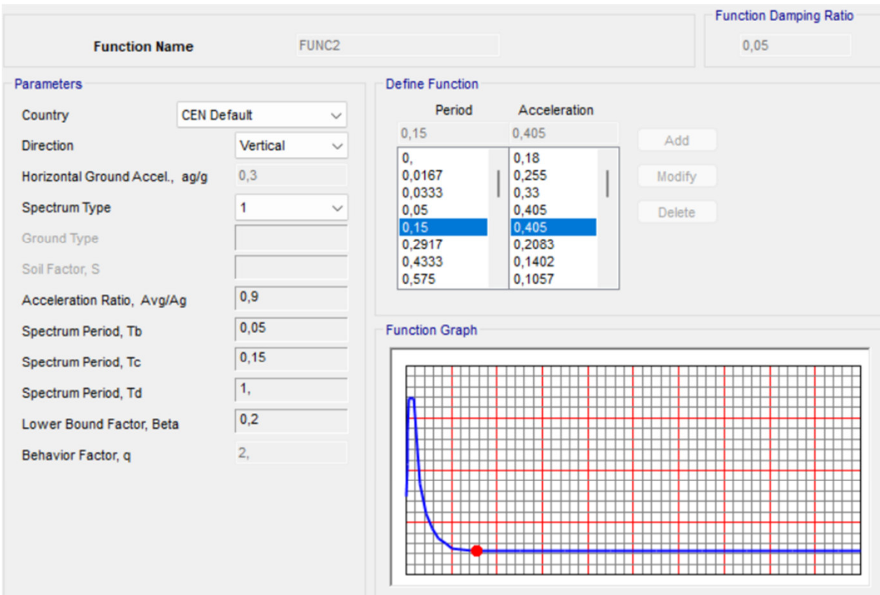
To calculate the masses of impulsive and convective fluids, the formulation of API650 has been followed. In the following figure, the introduction of impulsive and convective fluid masses in a typical tank is shown:



Apart from the inertial fluid load, the seismic load of the tank structure has been introduced as an acceleration load in all modelled items. For the horizontal inertial load due to horizontal accelerations, the following response spectrum has been applied, with a maximum value of acceleration of 0,5g:



For the vertical inertial load due to vertical accelerations, the following response spectrum has been applied, with a maximum value of acceleration of 0,4g:



2.4.3 Tank shell loads on lifting condition

Following the requirements of API650 for lifting maneuvers, the selfweight load of the tank structure has been introduced to fulfil twice the empty weight of the tank.

Only permanent loads from platform have been taken into account in the lifting analysis. The vertical reactions have been introduced in the platform support plate, as all the loads act as compression.

2.4.4 Load combinations

The load combinations for the operation condition are shown in the table below:

Load case	Description
1	SLS: $1D_L+L_L+H$
2	ULS: $1{,}35D_L+1{,}5L_L+H$
3,4,5	Seismic: $D_L+0{,}5\ L_L+E$

The load combinations for the lifting condition are shown in the table below:

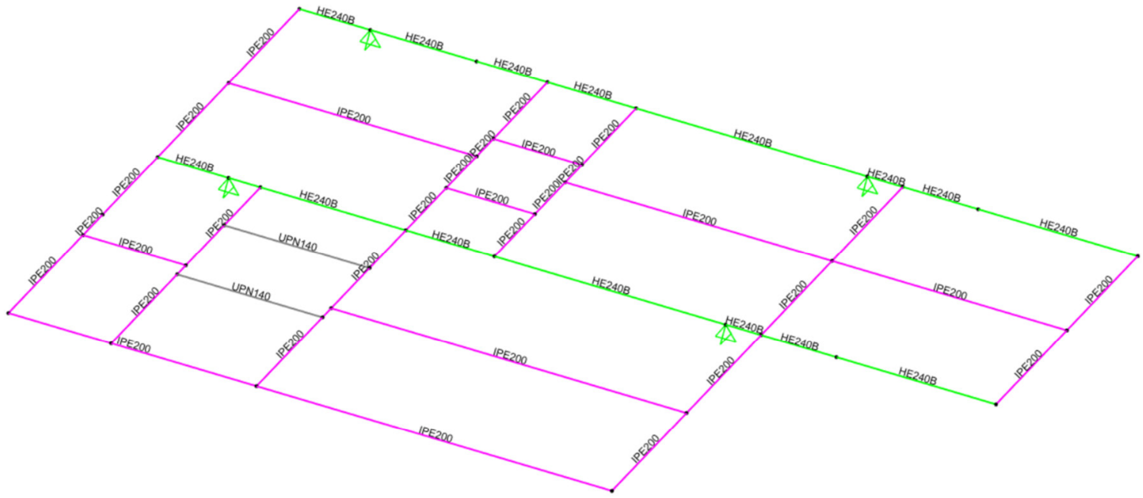
Load case	Description
1	Dead load: DL

3 CALCULATIONS AND RESULTS

3.1 Top platform calculation

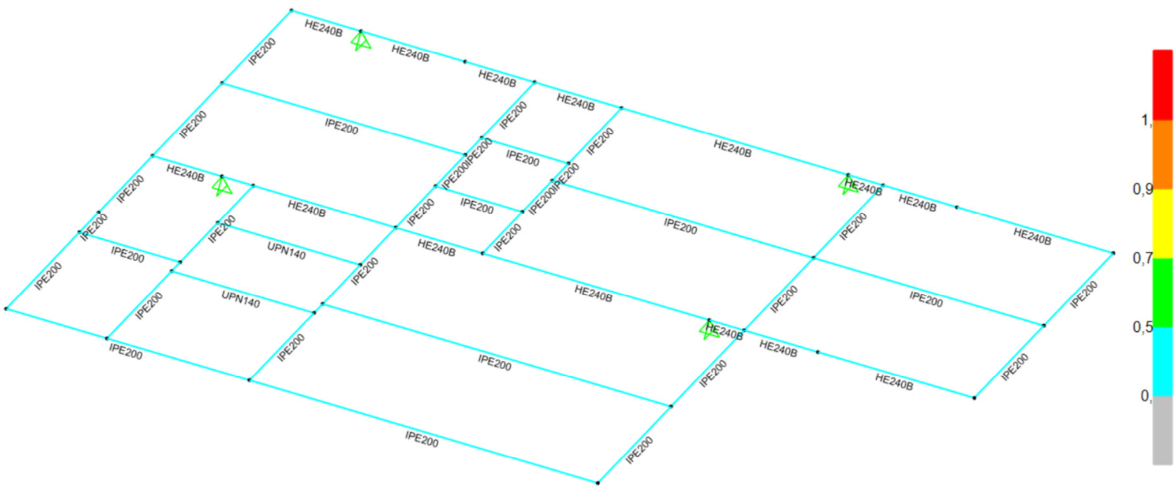
3.1.1 Platform structure geometry

The geometry and sections of the platform structure are shown in the following figure:



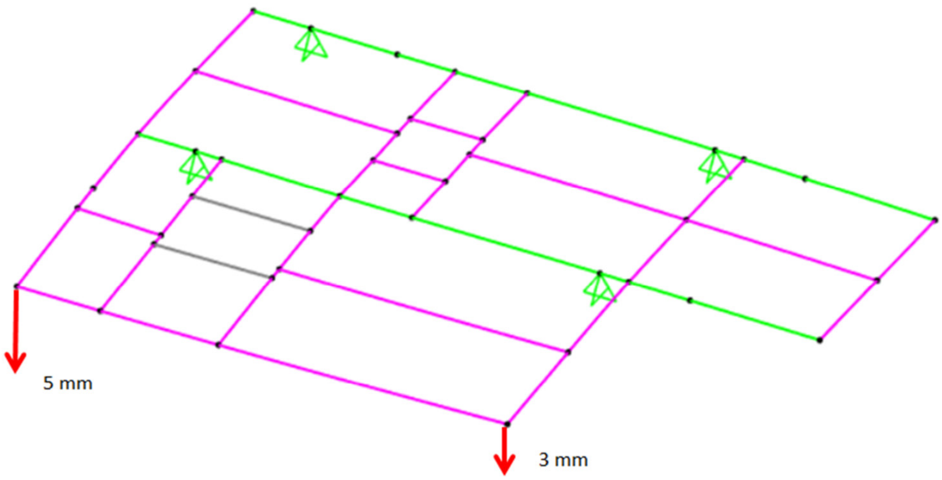
3.1.2 Platform structure ultimate limit state verification

All members fulfil ULS as shown in the following figure:



3.1.3 Platform structure SLS Verification

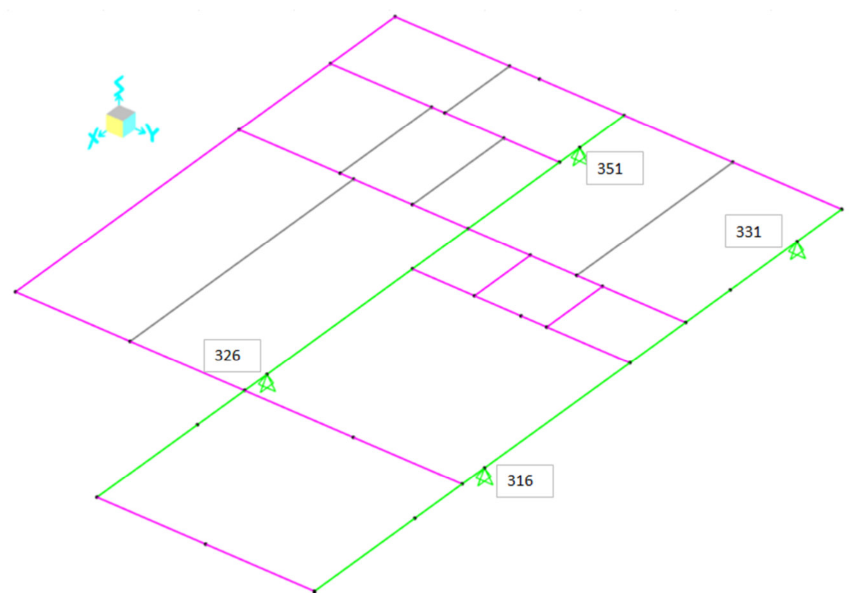
All members fulfil relative maximum displacement of L/300.
Maximum deformations in the mixer supports are below vendor limit recommendations.



3.1.4 Platform structure support reactions

In the following table, the reactions for each platform support are shown:

TABLE: Joint Reactions				
Joint	**OutputCase**	**Fx**	**Fz**	**Fy**
Text	Text	KN	KN	KN
316	LIVE LOAD	0,101	11,043	0,04
316	PERMANENT	0,053	9,339	0,021
316	EX	0,775	0,000004347	0,203
316	EY	0,746	0,00000577	0,19
316	EZ	0,000004052	0,903	0,000002963
326	LIVE LOAD	0,217	30,104	-0,029
326	PERMANENT	0,114	13,12	-0,015
326	EX	0,533	0,000002843	0,744
326	EY	0,848	0,000002878	0,194
326	EZ	0,000003829	1,831	0,000002086
331	LIVE LOAD	5,436	0,734	0,021
331	PERMANENT	2,84	3,093	0,011
331	EX	0,447	0,000003536	0,252
331	EY	0,488	0,000004326	0,118
331	EZ	0,000003213	1,818	0,000005749
351	LIVE LOAD	2,259	36,769	-0,032
351	PERMANENT	1,18	14,765	-0,017
351	EX	0,406	0,000003714	1,7
351	EY	0,412	0,000004278	0,313
351	EZ	0,000002451	3,676	0,000002073



3.2 Tank shell pre-dimensioning according to API650

See annex 1.

3.3 Top platform bolted connections.

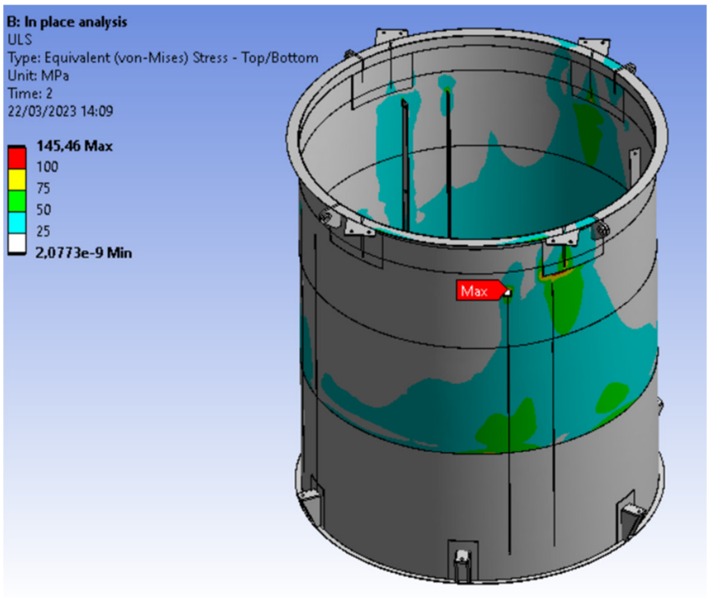
See annex 1.

3.4 Tank shell FEM calculation

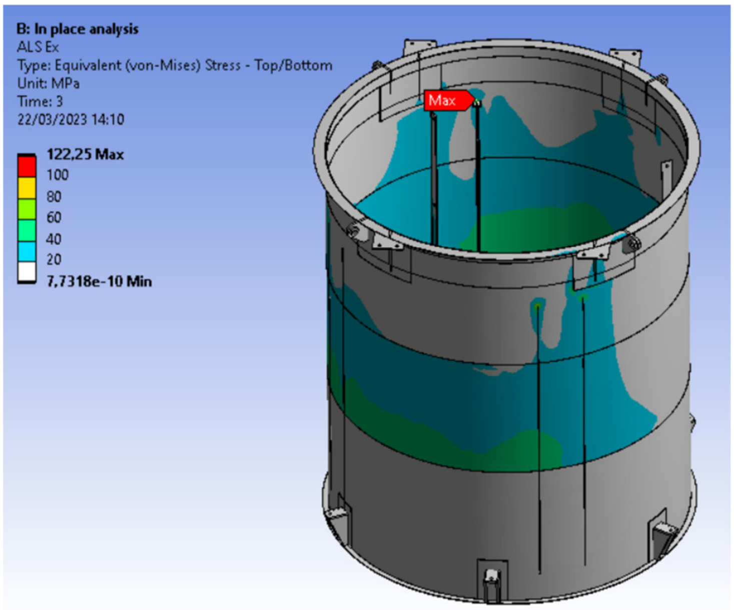
3.4.1 Operation condition analysis results

In all cases, stresses are below allowable value:

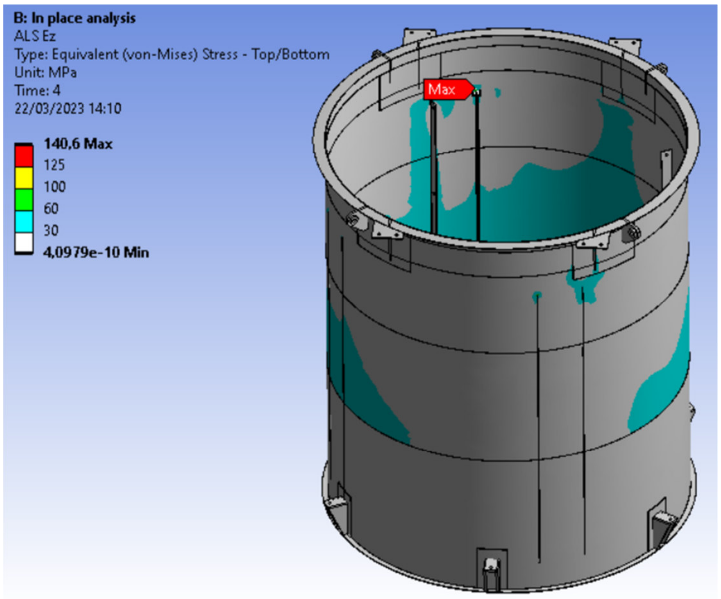
Ultimate limit state scenario:



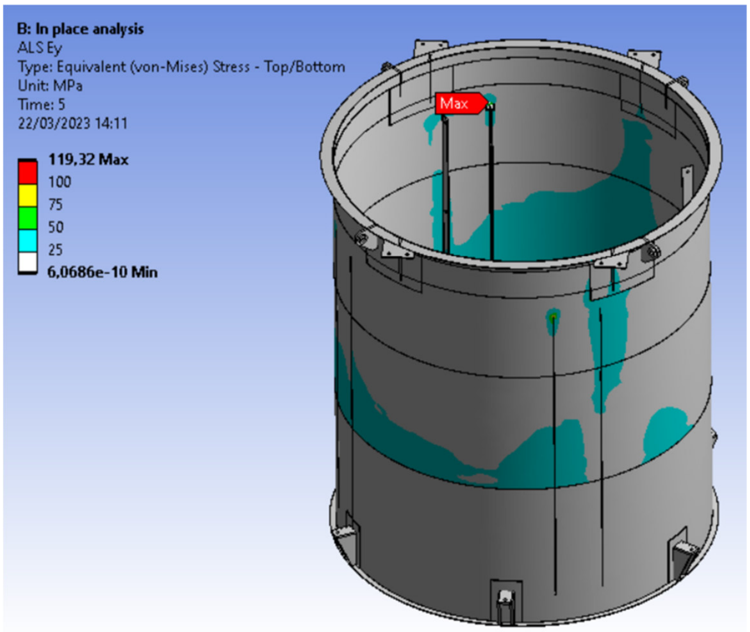
X direction seismic scenario:



Z direction seismic scenario:

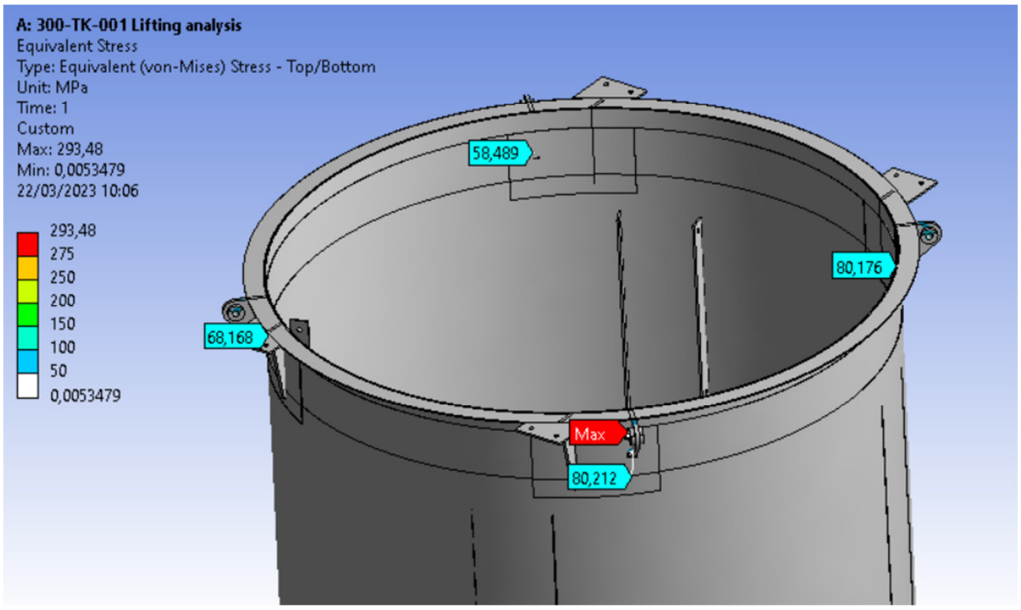


Y direction (vertical) seismic scenario:

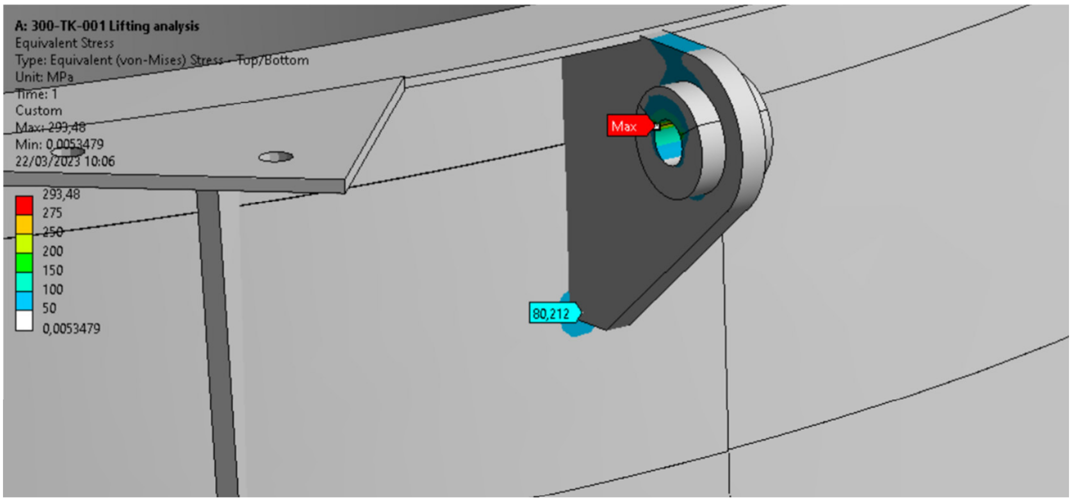


3.4.2 Lifting condition analysis results

In all cases, stresses in the tank shell are below allowable value:

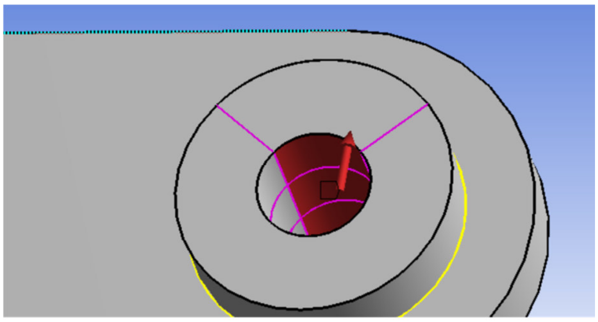


The maximum peak of tension in the tank shell is shown in the figure below:

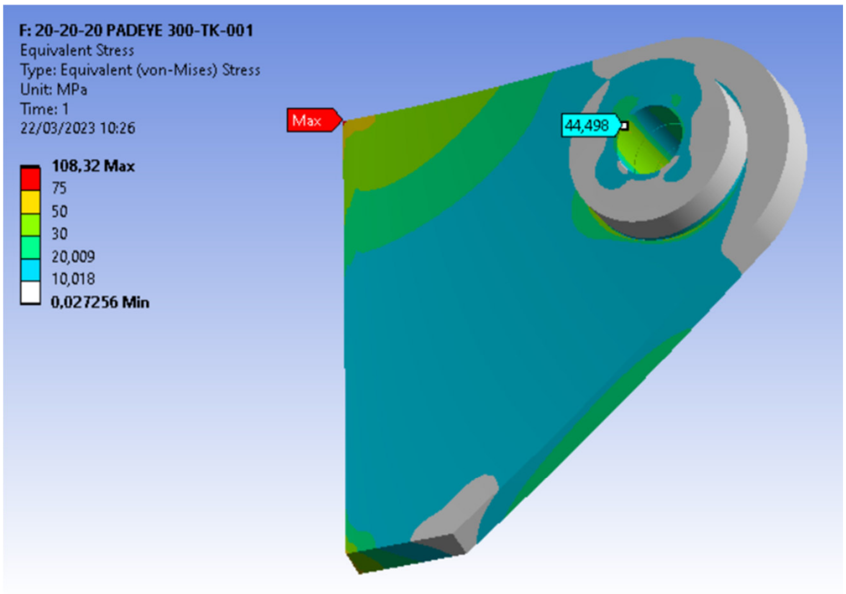


3.4.3 Padeye verification

Sling tension loads extracted from the tank analysis has been used for the lifting point design verification. The worst peak tension obtained has been considered to calculate the lifting points. In the following figure, the typical introduction of the sling load in the model is shown:



In all cases, stresses are below allowable value:



ANNEX 1
AGITATED TANK API650 DESIGN AND TOP PLATFORM BOLTS VERIFICATION

Project:	BEQTAQARI DETAIL ENGINEERING	Client:	JSC RMG Auramine LLC
Tank:	300-TK-001	3D BIM Model:	P1364-3D-001-38
Rev:	0		

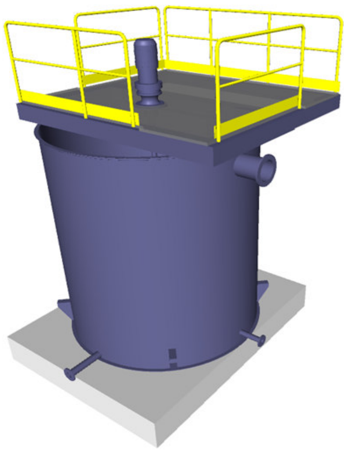
Emissions:

Revision	Author	Checked	Approved	Date	Concept / Comments
0	J. Nuñez	A. Toscano	A. Toscano	31/03/2023	For comments / Approval

TANK	300-TK-001	Rev:	0
AGITATED TANK API650 DESIGN			
Project:	BEQTAQARI DETAIL ENGINEERING	Ref:	P1384

INPUT DATA

Sketch



Nominal tank diameter (m)	D	3,000
Tank height (m)	Ht	3,500
Freeboard (m)	Hf	0,350
Design liquid level (m)	H	3,150
Liquid specific gravity (t/m³) (1)	G	1,40
Bottom type	Flat	
Roof type	N/A	
Roof slope (degrees)	0,0	
Corrosion allowance (mm)	CA	3,0
Standard plate length (m)	5,000	
Standard plate width (m)	W_p	2,000
Design temperature (°C)	-15 to 39	
Steel designation	EN 10025 S275J0	
Minimum Yield Strength (MPa)	275	
Minimum Tensile Strength (MPa)	410	
Product Design Stress (MPa) (5.6.2)	Sd	164
Hydrostatic Test Stress (MPa) (5.6.2)	St	176

Notes:
1) Slurry specific gravity during operation (worst case)

1 FOOT METHOD

The required minimum thickness of shell plates shall be the greater of the values computed by the following formulas:

$$t_d = \frac{4{,}9D(H-0{,}3)G}{S_d} + CA \qquad t_t = \frac{4{,}9D(H-0{,}3)}{S_t}$$

Where:

t_d	is the design shell thickness, in mm.
t_t	is the hydrostatic test shell thickness, in mm.
D	is the nominal tank diameter, in m.
H	is the design liquid level, in m.
G	is the design specific gravity of the liquid to be stored.
CA	is the corrosion allowance, in mm.
S_d	is the allowable stress for the design condition, in MPa.
S_t	is the allowable stress for the hydrostatic test condition, in MPa.

COURSES THICKNESS

Standard plate height courses number		2
Course area, m²	Cs	18,85
Number of sheets required per course	Sc	2

COURSE	Course liquid H (m)	1 Foot Method thicknesses			Minimum course th.	Minimum (5.6.1.1)	Course thickness
1	3,150	Design shell thickness (mm)	t_d	3,4	3,4	5	6
		Hydrostatic test shell thickness (mm)	t_t	0,2			
2	1,150	Design shell thickness (mm)	t_d	3,1	3,1	5	6
		Hydrostatic test shell thickness (mm)	t_t	0,1			

Vct=	Tank body volume, m³	0,24
Pct=	Body tank weight, Kg	1.905
Vct_corroded=	Tank body corroded volume, m³	0,12
Pct_corroded=	Body tank corroded weight, Kg	953

Tank bottom plate

NLbottom=	Bottom plate area, m²	7,07
Tbottom=	Minimum bottom plate thickness required mm	9,00
Tbottom n =	Nominal bottom plate thickness, mm	10,00
Vpt=	Tank bottom plate volume, m³	0,07
Ppt=	Tank bottom plate weight, Kg	554,88

Volume & Weight

Volume=	Stored slurry total volume, m³	22,09	
Total Tank Weight=	Empty tank total weight, Kg	2.460	
	Filled tank total weight, Kg	33.383	
Top Platform	Platform total weight, Kg	4.180	<< From structure calculation (SAP2000)
Total weight (Tank + Platform)	Empty tank + platform total weight, Kg	6.640	
Total corroded weight	Corroded tank weight + Platform weight, Kg	5.133	

2. TANK OVERTURNING ANCHOR CHECKUP

2.1 Overturning due to seismic loads (API 650)

Seismic response spectrum (EN 1998-1): As API650 refers to code ASCE 7 to obtain the response spectrum in USA only, then Eurocode 8 is used in this case to find equivalent response spectrum for the site location that applies.

Input Data	
Soil type	D
Elastic response spectrum	1
a_g	0,3 g
T	0,785 sec
ξ	0,05
η	1
Horizontal response spectrum (Design)	
q	2
beta	0,2
S	1,35
TB (s)	0,2 sec
TC (s)	0,8 sec
TD (s)	2,0 sec
Vertical response spectrum (Design)	
q	1,5
a_{vg}	0,27
a_{vg} / a_g	0,9
S	1
TB (s)	0,1 sec
TC (s)	0,2 sec
TD (s)	1,0 sec

T, sec	Horizontal Acc.	T, sec	Vertical Acc.
0	0,2700	0	0,1800
0,0667	0,3488	0,0167	0,2702
0,1333	0,4275	0,0333	0,3598
0,2	**0,5063**	0,05	0,4500
0,8	0,5063	0,15	0,4500
1	**0,4050**	0,2917	0,2314
1,2	0,3375	0,4333	0,1558
1,4	0,2893	0,575	0,1174
1,6	0,2531	0,7167	0,0942
1,8	0,2250	0,8583	0,0786
2	0,2025	1	0,0675
2,4444	0,1356	1,5	0,0300
2,8889	0,0971	2	0,0169
3,3333	0,0729	2,5	0,0108
3,7778	0,0568	3	0,0075
4,2222	0,0454	3,5	0,0055

Seismic load (API 650)

Impulsive natural period (E.4.5.1)			
T_i	0,025	sec	
C_i	6,25		
t_u	6	mm	
ρ	1400	kg/m3	
E	210.000	MPa	
H/D	1,05		
Convective (sloshing) period (E.4.5.2)			
T_c	1,80	sec	
K_s	0,58		
Impulsive spectral acceleration parameter (E.4.6.1-1)			
A_i	0,16		
ι (Table E.5)	1,25		
R_{wi}	4		
Convective spectral acceleration parameter (E.4.6.1-2)			
A_c	0,21		
K	1,5		
S_{d1}	0,41		
T_L	6	seg	
R_{wc}	2		
Effective Weight of Product (E.6.1.1)			
W_p	303,36	kN	
W_i	240,38	kN	
W_c	66,39	kN	
Design loads (E.6.1)			
V_i	38	kN	
V_c	14	kN	
V	40,5	kN	To be considered for seismic stoppers. See section 2.3.
Center ot Action tor Ringwall Overturning Moment (E.6.1.2.1)			
X_i	1,29	m	
X_c	2,38	m	
Tank weight	24,13	kN	
Tank CoG height	2,05	m	
Platform weight	41,01	kN	
Platform CoG height	3,650	m	

Seismic Overturning Moment (E.6.1.5)

Ringwall Moment (E.6.1.5-1)		
M_i	80,68	kN*m
M_c	33,33	kN*m
M_{rw}	**87,29**	**kN*m**

Slab Moment (E.6.1.5-2)		
X_{is}	1,76	m
X_{cs}	2,40	m
M_i	98,24	kN*m
M_c	33,54	kN*m
M_s	**87,37**	**kN*m**

Vertical seismic effects (E.6.1.3)			
A_v	0,095175		
W_{eff}	303	kN	
F_v	**28,87**	**kN**	
Dynamic liquid hoop forces E.6.1.4			
N_i	5,18	N/mm	
Y	3,144	m	
N_c	0,11	N/mm	
N_h	129,8	N/mm	
t	6	mm	
σ_T	**1,19**	**Mpa**	OK

2.2 Overturning due to Wind load (Table 5.21a)

Wind overtuning calculation			
D	3,000	m	
H	3,500	m	
Wind velocity	0,00	Km/h	97,20 Km/h for tanks at outdoor location.
P_{ws} Wind pressure	0,00	(KPa) kN/m^2	
M_{ws} Overturning moment	**0,00**	**kN*m**	

2.3 Anchor verification (5.12)

N (Number of spaces between anchors)	6,0

Uplift loads (Table 5.21a)	Net uplift (N)	Load per anchor (N)
Wind reaction load	0	0
Seismic reaction load	67942	11324

NOTE:

Only steel failure for anchors is checked. Anchor length to concrete foundation or supporting slab to be determined by civil work designer taking into account other failure modes such as extraction, concrete edge failure, concrete cone or cracking failure or spalling.

Same applies to seismic stoppers. 100x200 plates should be installed in positions arround the tank base 1 mm off the tank perimeter and fixed to the foundation. Design load V seismic shear to be considered for seismic stoppers anchoring design under above mentioned failure modes by civil designer.

Anchor properties		
Class	8,8	
M	27,00	mm
S	41	mm
A_s	456	mm²
f_{ub}	800	N/mm²
γ_{M2}	1,25	

Tension verification (EN-1993-8)		
k_2	0,90	
f_{ub}	800	N/mm²
$F_{t,Rd}$	262656	N
Max. Load per anchor (N)	**11324**	**N**
Verification	0,04	Fail Ratio

2.4 Anchor chair verification (AISI Steel Plate Engineering Data, Volume 2 - Part VII Anchor bolt chairs)

Anchor chair dimensions			
t (Reinforced shell tank considering CA)	12,00	mm	
$c_{anchor\ chair}$	20,00	mm	
h	300,00	mm	
a	100,00	mm	
f	40,00	mm	
g	100,00	mm	
e	135,00	mm	
m	10,00	mm	
R	1500	mm	
d	27	mm	
Stress at top plate			
S	**22,34**	**MPa**	OK
Bending Strees			
Z	0,046		
S	**3,1**	**MPa**	OK

Normal load applied to tank she	**5095,65**	**N**	>> To FEM calculation (ANSYS)

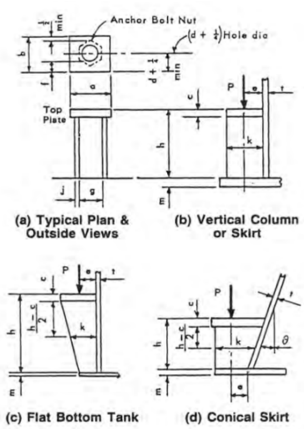


Figure 7-1. Anchor-Bolt Chairs.

	TANK	300-TK-001	Rev:	0
	TOP PLATFORM SUPPORT - BOLTED CONNECTION VERIFICATION (EN 1993-1-8)			
Project: BEQTAQARI DETAIL ENGINEERING			Ref:	P1384

PLATFORM SUPPORT - BOLTS VERIFICATION (EN 1993-1-8)

Bolt properties		
Class	8,8	
M	22	mm
S	32	mm
A_s	303	mm²
f_{ub}	800	N/mm²
γ_{M2}	1,25	
Plate properties		
f_u	430	N/mm²
t	10	mm
Bolt holes distribution		
e_1	57	mm
p_1	140	mm
d_0	24	mm
e_2	55	mm
p_2	140	mm

Number of bolts	2	α_d	k1
Shear planes n	1	1,86	4,72
Load direcction	end	0,79	6,47
		1,00	2,50

Loads				
Shear load	Shear	Fx	5400	N
		Fz	1700	N
	Torsion	Mx	0	N·mm
		rx	0	mm
		rz	0	mm
		Ip	0	mm²
	Resultant	Fv,Ed	2831	N
Tension	Axial load	Fy	0	N
	Resultant	Ft,Ed	0,00	N

1. SHEAR RESISTANCE PER SHEAR PLANE

$F_{v,Rd}$	98899,2	N
Reduction		
Verification	0,03	
n	1	
α_v	0,6	
f_{ub}	800	N/mm²
A_s	303	mm2

$$F_{v,Rd} = \frac{\alpha_v \ f_{ub} \ A}{\gamma_{M2}}$$

2. BEARING RESISTANCE

$F_{b,Rd}$	149783,333	N
Verification	0,02	
k_1	2,5	
α_b	0,79166667	
f_u	430	N/mm²
t	10	mm
d	22	mm

$$F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$$

3. TENSION RESISTANCE

$F_{t,Rd}$	174528	N
Verification	0,00	
k_2	0,9	
f_{ub}	800	N/mm²
A_s	303	mm²

$$F_{t,Rd} = \frac{k_2 \ f_{ub} \ A_s}{\gamma_{M2}}$$

4. PUNCHING RESISTANCE

$B_{p,Rd}$	175074,675	N
Verification	0,00	
d_m	27	mm
t	10	
f_u	430	N/mm²

$$B_{p,Rd} = 0{,}6 \, \pi \, d_m \, t_p f_u / \gamma_{M2}$$

5. COMBINED SHEAR + TENSION

Verification 0,03

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1{,}4 \, F_{t,Rd}} \leq 1{,}0$$