RiloTank 3D

Design and calculation of welded vertical cylindrical metal tanks, for storage of fluids.
API Standard 650 - 13 th Edition, March 2020

BROCHURE

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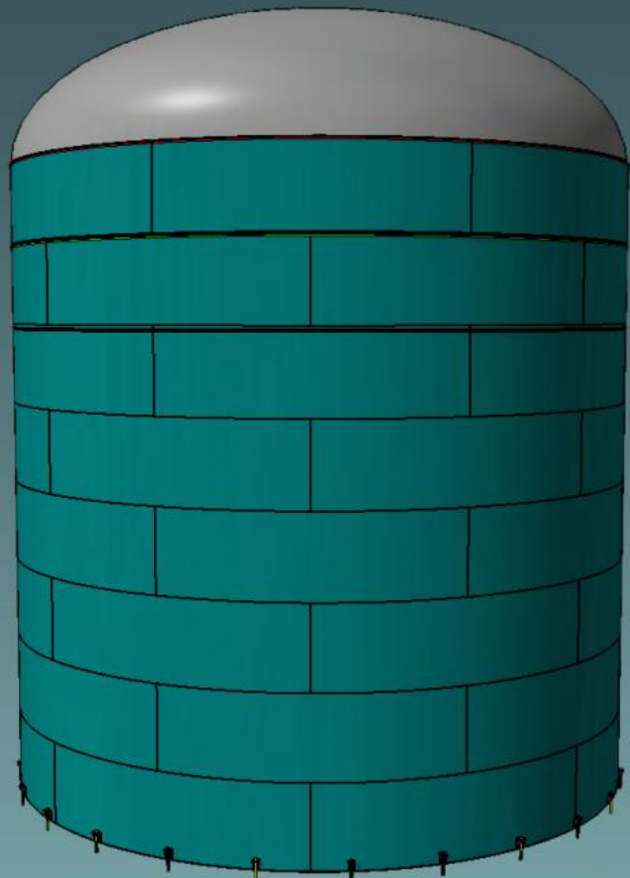

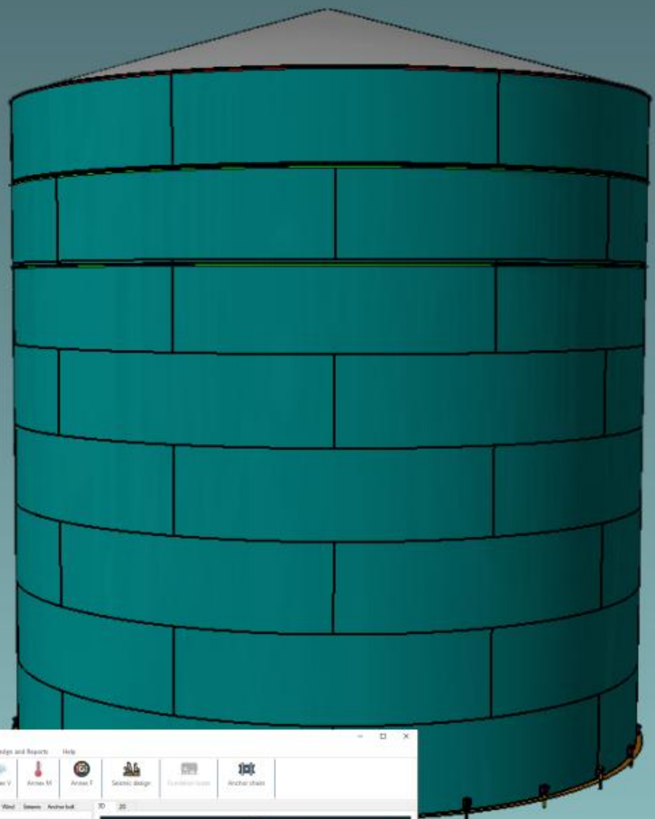

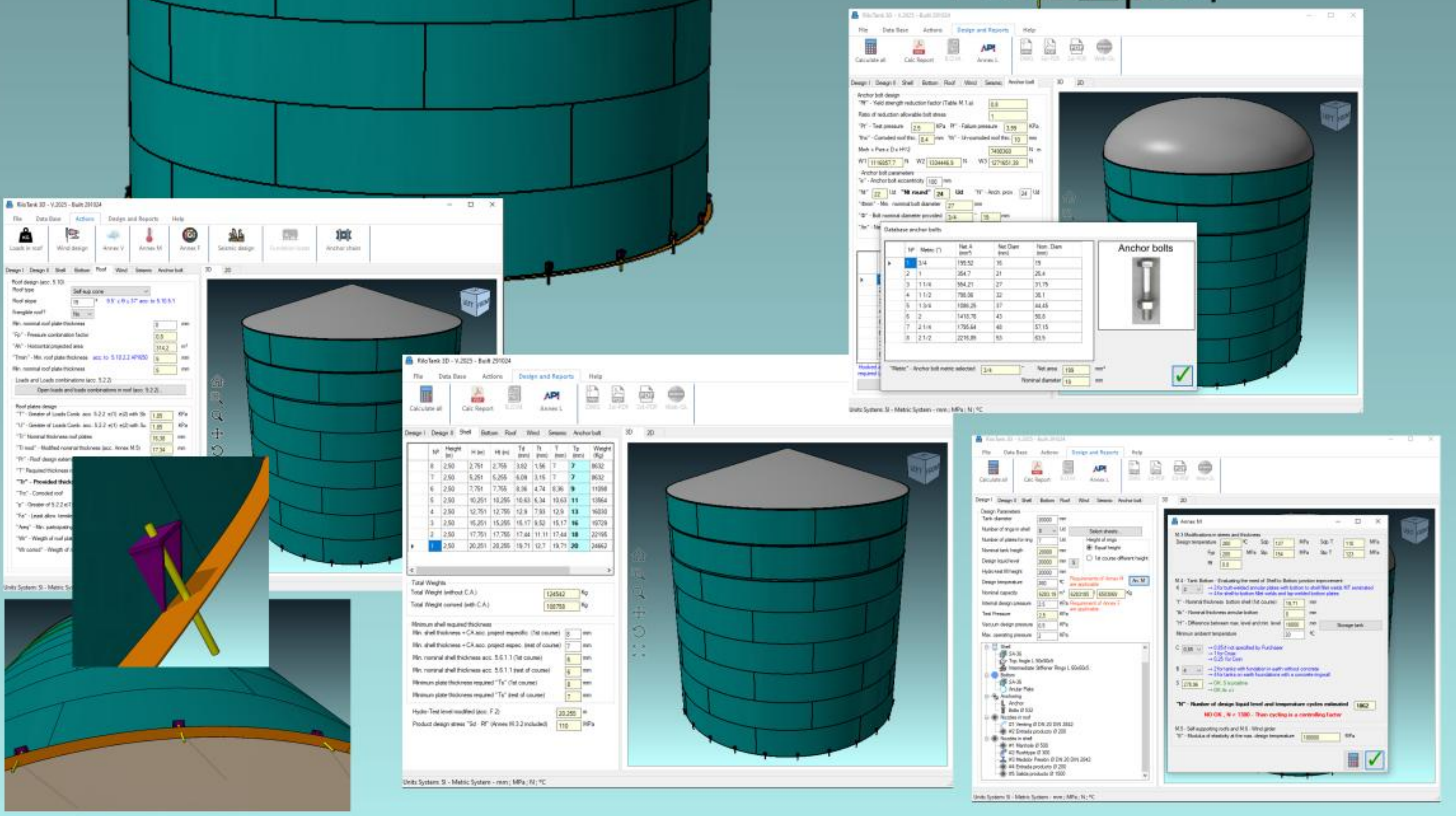

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1. PRESENTATION. STORAGE EQUIPMENT DESIGN STANDARDS

Rilotank 3D is a technical software for the design and calculation of metal tanks (carbon steel or stainless steel), welded (not bolted), vertically oriented (it does not cover horizontal orientation, nor spherical shape), for the storage of fluids (in liquid and/or gaseous state - it does not cover the storage of solids and therefore, neither fluidised solids). The storage of such fluid must meet the following conditions in terms of pressure and temperature:

Pressure: ≤ 18 KPa

Temperature: ≤ 260 ºC

Although a series of considerations must be taken into account with respect to the pressure that will be studied in point 10.- Design at internal pressure according to Annex F of API 650 and to the temperature that will be studied in point 5.- Requirements of Annex M of API 650 due to high temperatures ≤ 260 ºC.

STORAGE EQUIPMENT REGULATIONS, CODES, GUIDELINES AND SUPPORTING DOCUMENTS

The selection of a standard for the calculation of metallic equipment for fluid storage depends on several factors, which will mainly be:

- The volume of fluid to be stored,
- Pressure range at which it must be stored.
- Temperature at which the fluid must be stored

Generally, the standard par excellence for the calculation of fluid storage tanks, especially in the hydrocarbon sector, is API 650, drawn up by the American Petroleum Institute. It is undoubtedly the most widely used standard at international level, even beyond refineries and the gas & oil sector, as it has also been widely used in other sectors such as the agri-food sector, due to the fact that it not only covers carbon steel materials, but also other tank manufacturing materials widely used in the agri-food sector, such as stainless steel.

Alternatively, in the EU, the EN 14015 standard is also widely used, which also covers the design and manufacture of site-built, vertical, cylindrical, flat-bottomed, non-buried, welded, steel tanks for the storage of liquids at ambient temperatures and above. This standard is also beginning to gain acceptance in North African and other Latin American countries.

Likewise, in the case of tanks, if the fluid storage is water, and the tank is made of welded carbon steel, it is possible to use the AWWA D100 standard drawn up by the American Water Works Association.

It should also be noted that there is another standard that has been widely used in recent years, due to the mandatory installation of fire water supply systems, and due to the speed and ease of assembly of bolted tanks, AWWA D103 is also widely used for bolted carbon steel tanks for water storage, supported in turn by the NFPA-22 guide for PCI water tanks. The following figure shows the most commonly used base standards for tank calculations, as well as the other complementary standards on which API 650 is based:

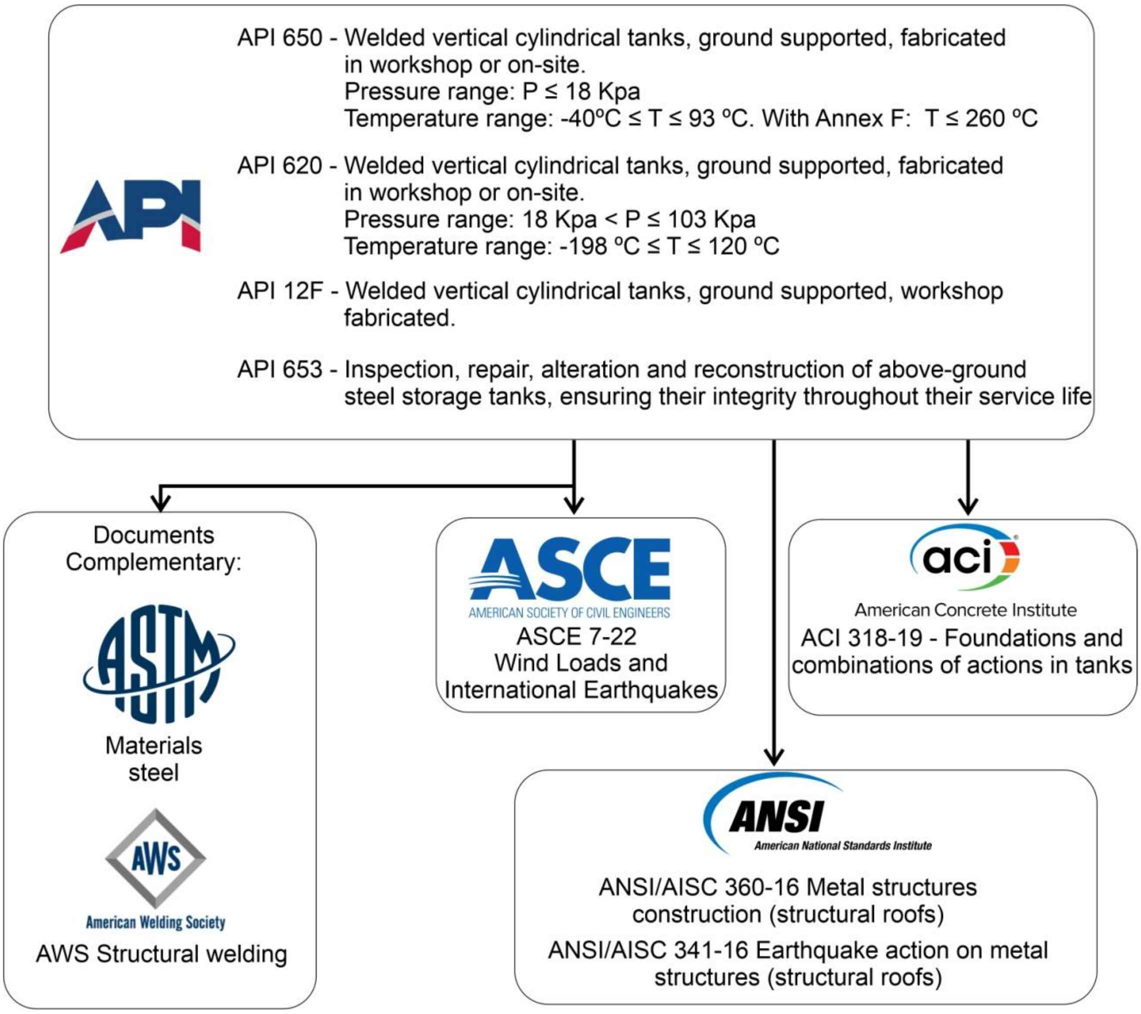


Figure 1.- API 650 standard and other similar reference standards with other pressure and temperature ranges such as API 620, as well as other useful standards such as API 12f for tanks manufactured in the workshop (of small dimensions compared to API 650) and API 653 for the inspection of tanks throughout their useful life. Other standards are also presented in which API 650 is supported for the choice of materials and welds, loads, foundation calculations, etc.

2. TYPOLOGY OF TANKS CALCULATED BY THE SOFTWARE. DATABASES (MODIFICATION, DELETION AND RECORDING OF NEW RECORDS)

The software RiloTank 3D V. 2025 is a software application that performs 3D tank design and calculation according to API 650 13th. It also performs the calculation of wind and seismic loads according to ASCE 7-22, the standard on which API 650 13th is based. The software provides several reports in PDF and WORD with all the calculations performed, list of materials and Annex L filled in according to API 650, which can be used as supporting reports of the calculations performed. It also exports the 3D design of the tank with all the details such as shell plate, roof, bottom (annular bottom if necessary), wind rings, and anchor chairs, see figures 2, 3 and 4.

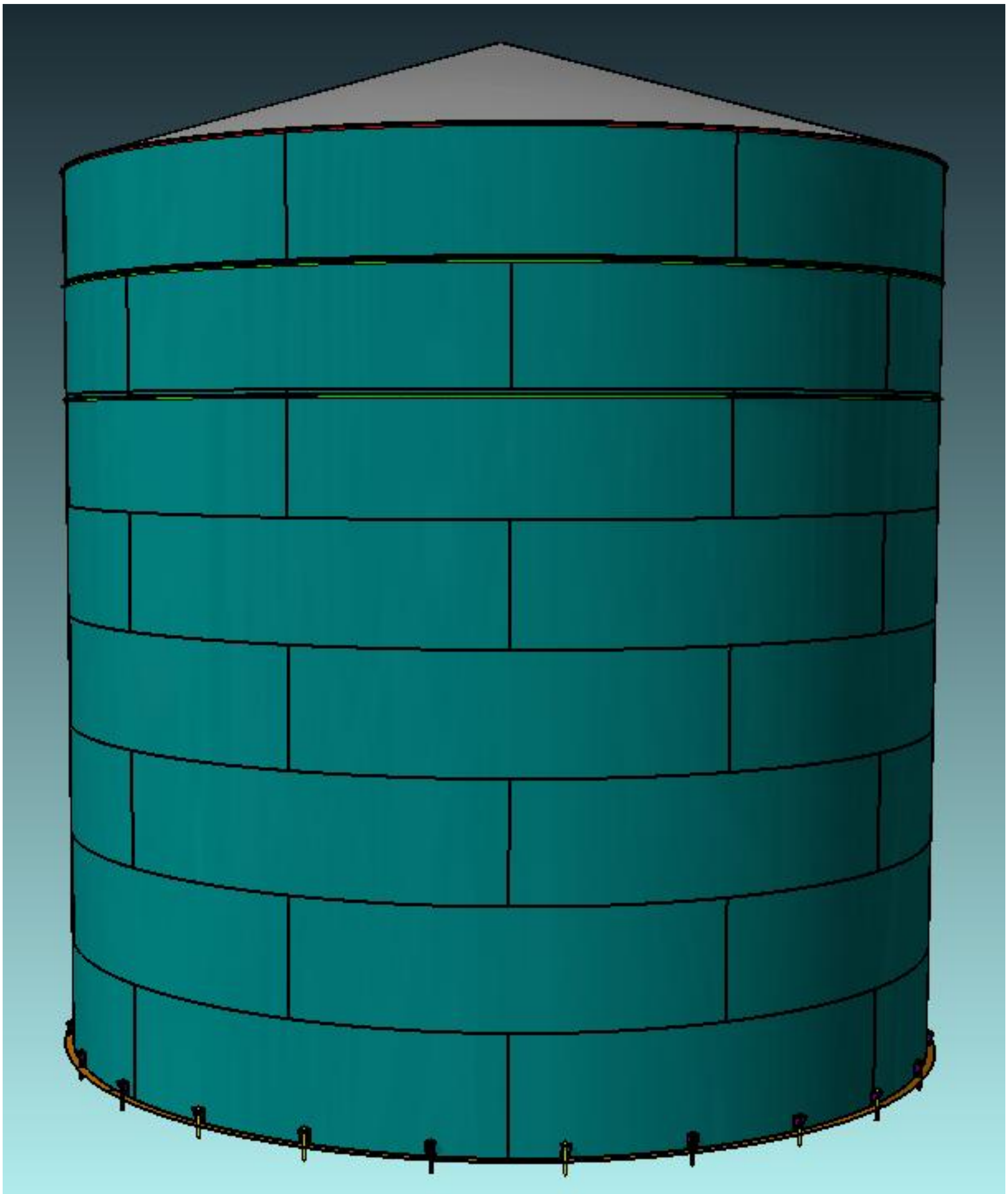


Figure 2.- Detail of the 3d design of a tank with self-supporting conical roof, shell plates in cylinder, top angle, 2 wind rings, bottom, annular bottom, anchor bolts and anchor chairs

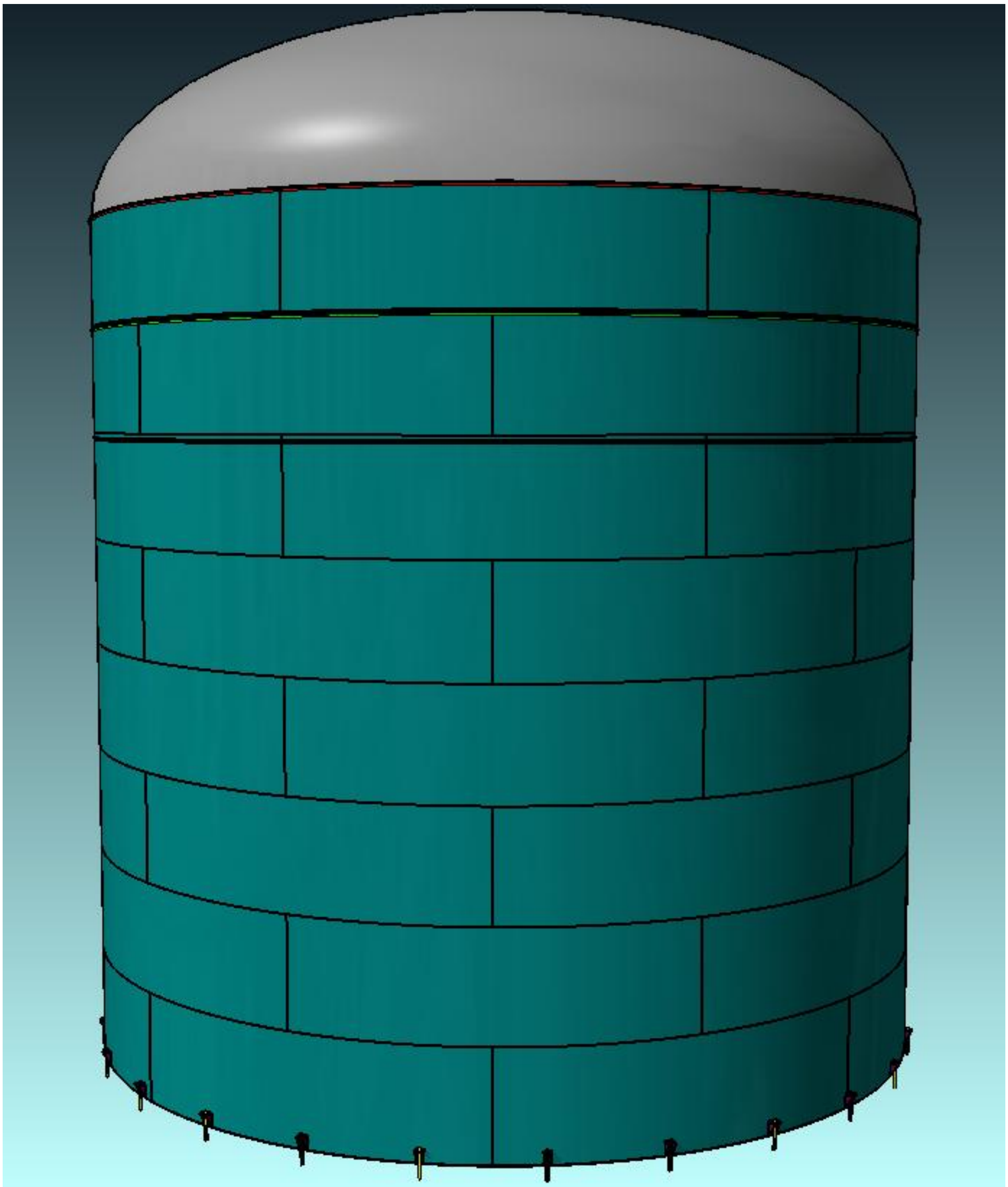


Figure 3.- Detail of the 3d design of a tank with dome roof, cylinder shell plates, top angle, 2 wind rings, bottom, annular bottom, anchor bolts and anchor chairs

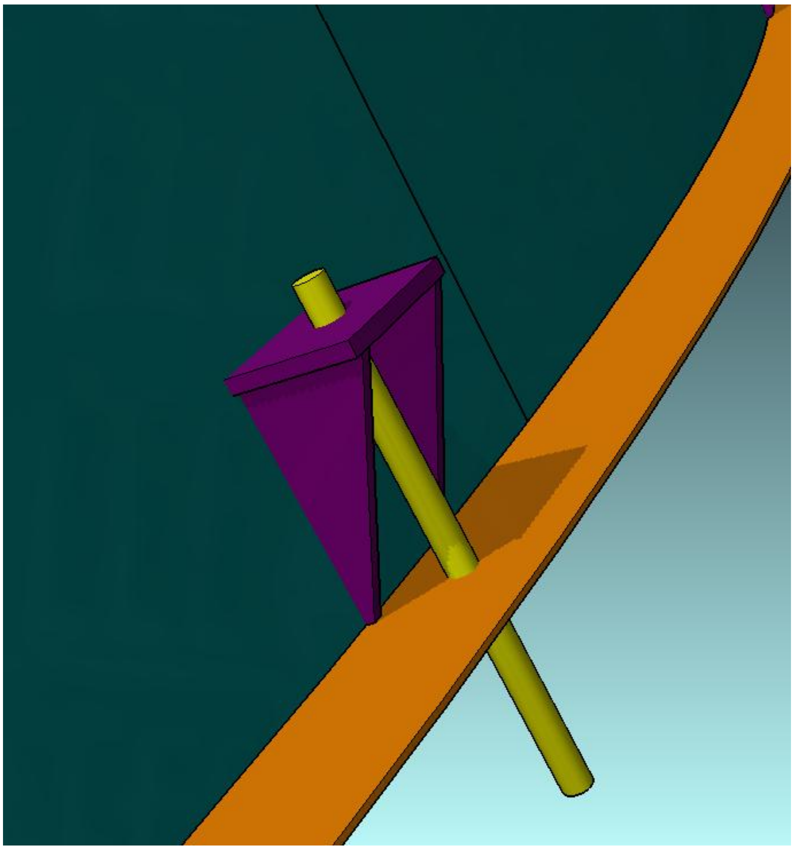


Figure 4.- Detail of the 3d design of anchor chairs with anchor bolt in tank

DATABASES (MODIFICATION, DELETION AND RECORDING OF NEW RECORDS)

The software has several databases where you can select fluids to be stored, tank construction materials, shell plate formats, wind rings in the form of angles, as well as anchor bolts for anchor chairs. All these databases can be accessed by clicking on the corresponding button from the 'Data Base' menu tab located at the top of the main software window, see figure 5:

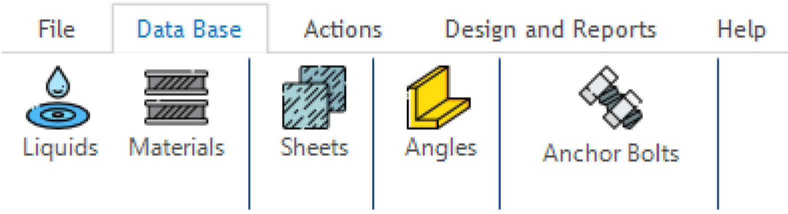
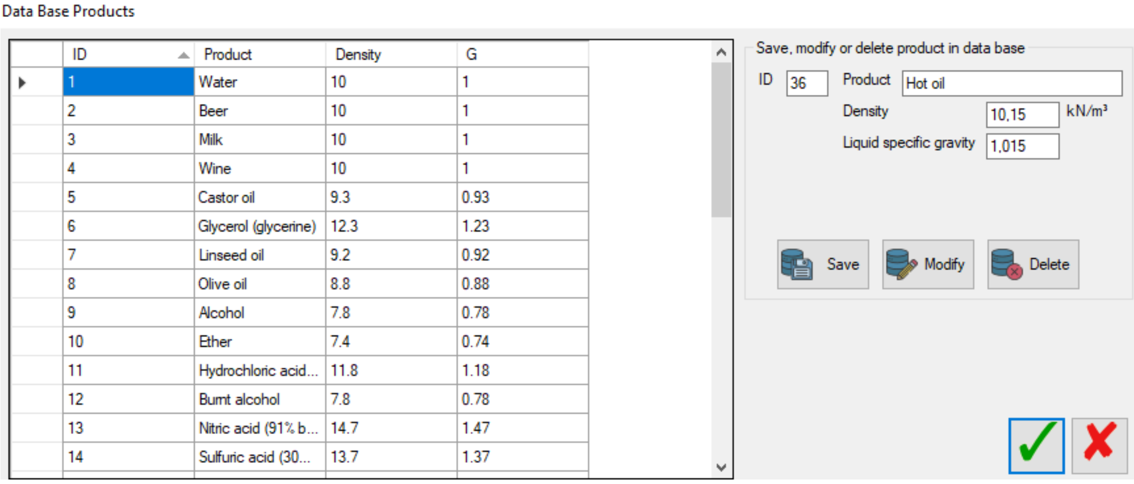


Figure 5.- "Data Base" tab to access the different databases of the software.

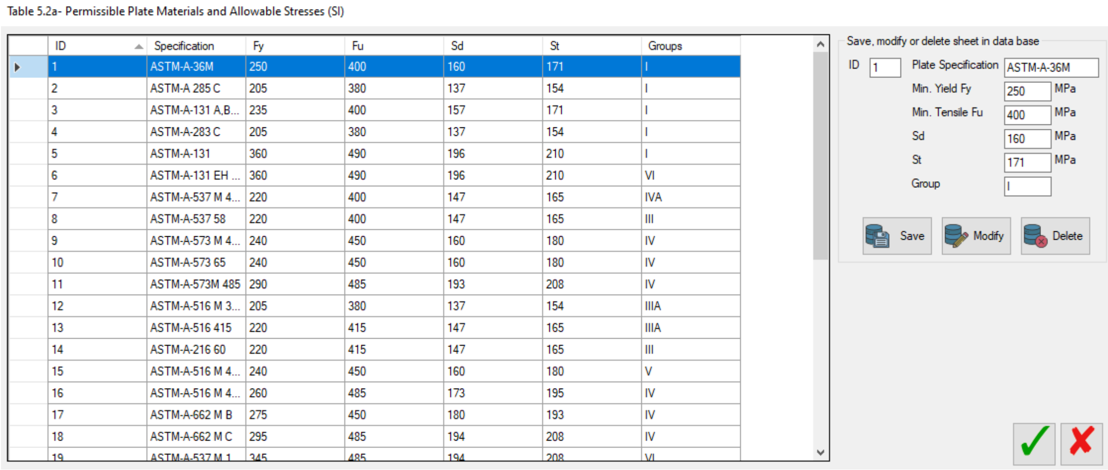
From each database it is possible to select, delete, modify or add any record, and the operation is identical in all of them.

The different windows of the databases are shown in the following figures:



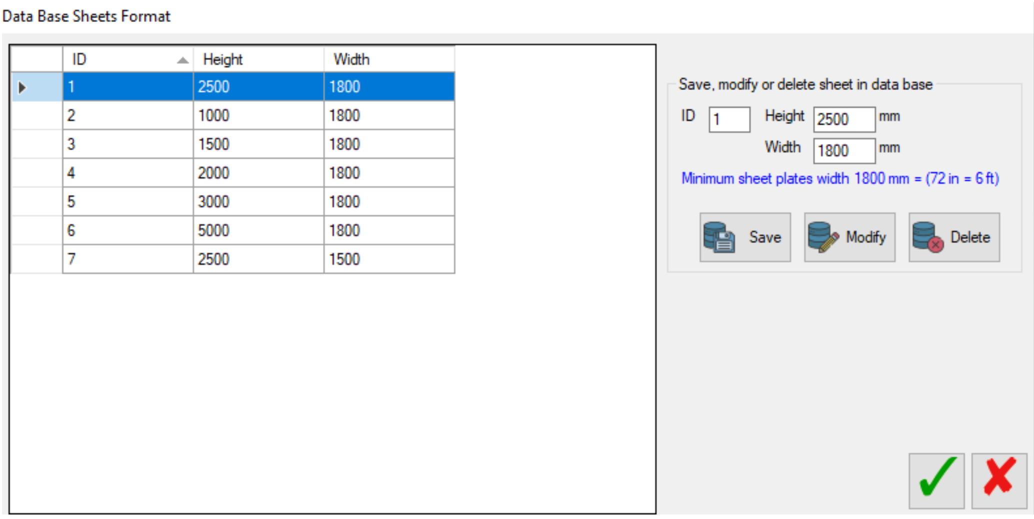
ID	Product	Density	G
1	Water	10	1
2	Beer	10	1
3	Milk	10	1
4	Wine	10	1
5	Castor oil	9.3	0.93
6	Glycerol (glycerine)	12.3	1.23
7	Linseed oil	9.2	0.92
8	Olive oil	8.8	0.88
9	Alcohol	7.8	0.78
10	Ether	7.4	0.74
11	Hydrochloric acid...	11.8	1.18
12	Burnt alcohol	7.8	0.78
13	Nitric acid (91% b...	14.7	1.47
14	Sulfuric acid (30...	13.7	1.37

Figure 6.- Liquid database, i.e. products that can be stored in API 650 tanks, with their identification number (ID column), Product, Density or specific gravity in kN/m³ and G = Specific gravity



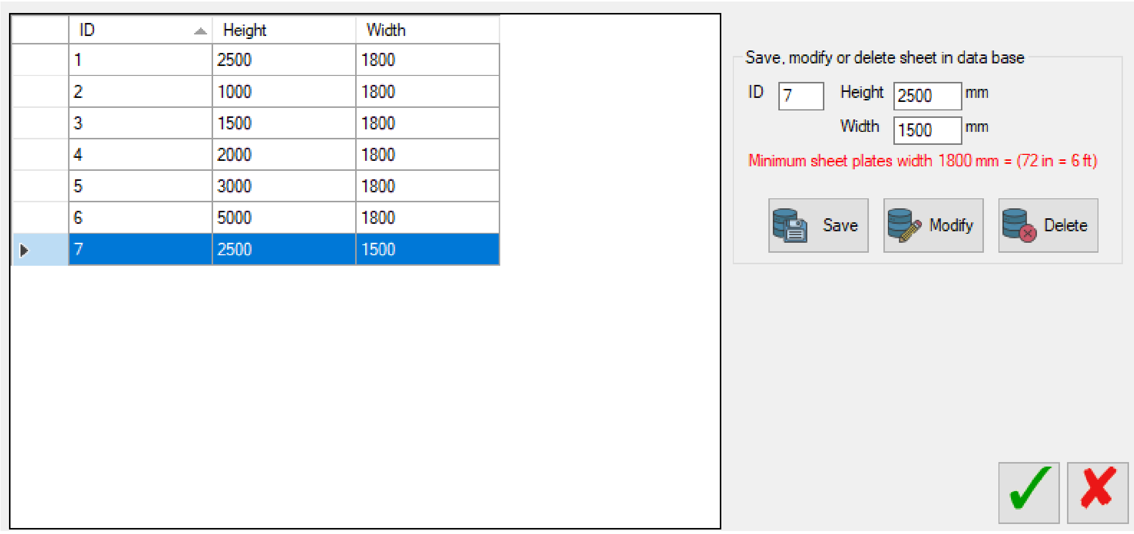
ID	Specification	Fy	Fu	Sd	St	Groups
1	ASTM-A-36M	250	400	160	171	I
2	ASTM-A 285 C	205	380	137	154	I
3	ASTM-A-131 A,B...	235	400	157	171	I
4	ASTM-A-283 C	205	380	137	154	I
5	ASTM-A-131	360	490	196	210	I
6	ASTM-A-131 EH ...	360	490	196	210	VI
7	ASTM-A-537 M 4...	220	400	147	165	IVA
8	ASTM-A-537 58	220	400	147	165	III
9	ASTM-A-573 M 4...	240	450	160	180	IV
10	ASTM-A-573 65	240	450	160	180	IV
11	ASTM-A-573M 485	290	485	193	208	IV
12	ASTM-A-516 M 3...	205	380	137	154	IIIA
13	ASTM-A-516 415	220	415	147	165	IIIA
14	ASTM-A-216 60	220	415	147	165	III
15	ASTM-A-516 M 4...	240	450	160	180	V
16	ASTM-A-516 M 4...	260	485	173	195	IV
17	ASTM-A-662 M B	275	450	180	193	IV
18	ASTM-A-662 M C	295	485	194	208	IV
19	ASTM-A-537 M 1	345	485	194	208	VI

Figure 7.- Database of materials, with the identification data (ID column), specification of the standard according to territories (ASTM -America-, CSA -Canada-, EN -European Union- and ISO -International-), Fy (yield stress in MPa), Fu (yield stress or plastic limit in MPa), allowable stresses Sd and St, in MPa and Group to which the material belongs



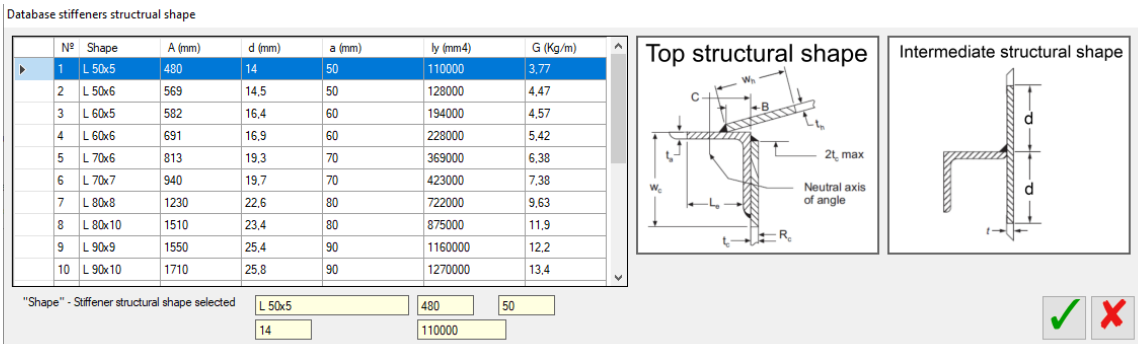
ID	Height	Width
1	2500	1800
2	1000	1800
3	1500	1800
4	2000	1800
5	3000	1800
6	5000	1800
7	2500	1500

Figure 8a.- Database of plates with the identification data (ID column) and their height and width dimensions. In this case a sheet with width dimensions ≥ 1800 mm, as required by API 650, is selected, which is indicated by a blue label "Minimum sheet plates width 1800 mm = 72 inches = 6 feet"



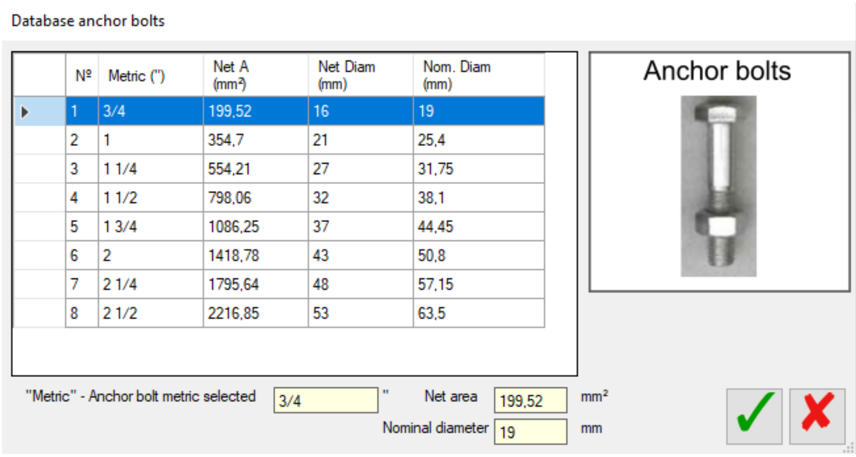
ID	Height	Width
1	2500	1800
2	1000	1800
3	1500	1800
4	2000	1800
5	3000	1800
6	5000	1800
7	2500	1500

Figure 8b.- Plate database with the identification data (ID column) and its height and width dimensions, but note that on this occasion the selected plate has a width dimension of 1500 mm, less than 1800 mm which is a requirement of the API 650 standard in point 5.4.1 for bottom plates, and in point 5.6.1.2 for plates forming part of the cylindrical body. Therefore the software automatically warns with a red label



Nº	Shape	A (mm)	d (mm)	a (mm)	Iy (mm4)	G (Kg/m)
1	L 50x5	480	14	50	110000	3,77
2	L 50x6	569	14,5	50	128000	4,47
3	L 60x5	582	16,4	60	194000	4,57
4	L 60x6	691	16,9	60	228000	5,42
5	L 70x6	813	19,3	70	369000	6,38
6	L 70x7	940	19,7	70	423000	7,38
7	L 80x8	1230	22,6	80	722000	9,63
8	L 80x10	1510	23,4	80	875000	11,9
9	L 90x9	1550	25,4	90	1160000	12,2
10	L 90x10	1710	25,8	90	1270000	13,4

Figura 9.- Database of structural reinforcements with angular profiles used as head angles and wind bracing rings, with all their inertia data, weights, dimensions, areas, etc. On this occasion, this database is not customizable, nor can it be edited, deleted, modified or new elements added, as these are standardised profiles



Nº	Metric (")	Net A (mm²)	Net Diam (mm)	Nom. Diam (mm)
1	3/4	199,52	16	19
2	1	354,7	21	25,4
3	1 1/4	554,21	27	31,75
4	1 1/2	798,06	32	38,1
5	1 3/4	1086,25	37	44,45
6	2	1418,78	43	50,8
7	2 1/4	1795,64	48	57,15
8	2 1/2	2216,85	53	63,5

Figure 10.- Database of anchor bolts, with their metric data (in inches and mm), net area, and nominal and net diameters. This D.B. is not customisable either, as these are standardised bolts

All databases (except for angle shapes and anchor bolts which are standardised products), are open and modifiable (fluids, materials, bolts and sheet metal databases) and the way to add, delete or modify existing records is identical in all of them.

- To **add** a new record to the database, first modify the data in the corresponding boxes:
    - ID: Indicates the record number and should not be equal to an existing number in the database, otherwise it will modify the record with the same number or ID, so, let's suppose that the last number in the database is ID: 35, the ideal would be to enter as the new ID of the new record = 36.
    - Rest of data: Each and every one of the rest of the necessary data must be entered (we must not omit any data, since all of them are necessary to be able to subsequently carry out the corresponding calculations, in case of forgetting to enter any data, the software will start to launch calculation errors, because it does not find the corresponding data to calculate), see figure 11:

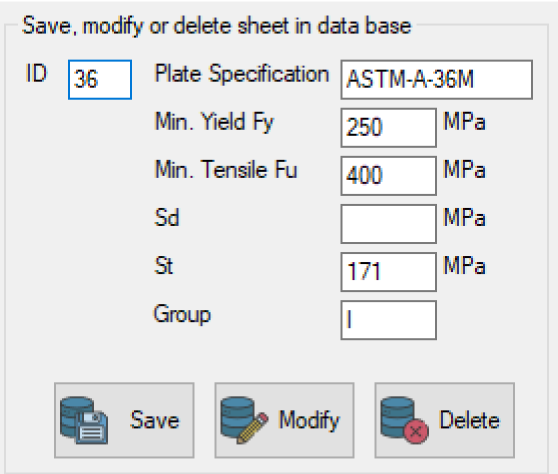
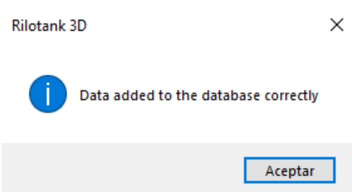


Figure 11.- Let's suppose that we do not enter the 'St' data in MPa, and we press the 'Save' button, the program will launch an error and close, because the 'Sd' box has been left blank and there is no numerical data to save, so it will not be possible to perform the sheet thickness calculations correctly. It is very important not to leave any data blank, or incorrectly entered with values that are not real, as then all the calculations made by the software will be erroneous. Also remember to enter an ID that does not exist as this will rewrite an existing record. On this occasion, as can be seen in the figure, the ID = 36 was entered, since by default there are 35 records in the materials database, so the next new record must have the ID = 36

    - Once all the data have been entered, to add the new record to the DB and save it forever, click on the 'Save' button, see figure:

    - A message will appear on the screen indicating that the record has been successfully added to the DB:



- To **delete** an existing record in the database, select it by left-clicking on the row of the record table (see figure 12):

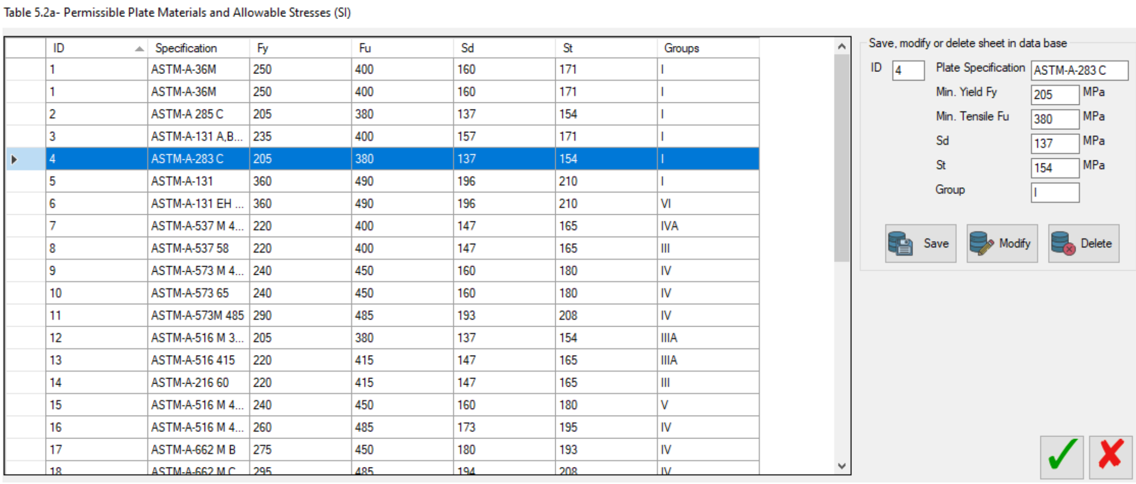
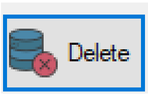


Table 5.2a- Permissible Plate Materials and Allowable Stresses (SI)

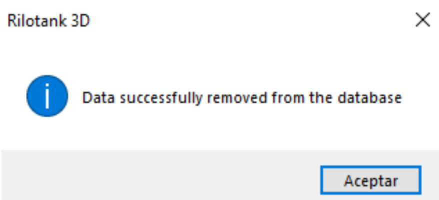
ID	Specification	Fy	Fu	Sd	St	Groups
1	ASTM-A-36M	250	400	160	171	I
1	ASTM-A-36M	250	400	160	171	I
2	ASTM-A 285 C	205	380	137	154	I
3	ASTM-A-131 A,B...	235	400	157	171	I
4	ASTM-A-283 C	205	380	137	154	I
5	ASTM-A-131	360	490	196	210	I
6	ASTM-A-131 EH ...	360	490	196	210	VI
7	ASTM-A-537 M 4...	220	400	147	165	IVA
8	ASTM-A-537 58	220	400	147	165	III
9	ASTM-A-573 M 4...	240	450	160	180	IV
10	ASTM-A-573 65	240	450	160	180	IV
11	ASTM-A-573M 485	290	485	193	208	IV
12	ASTM-A-516 M 3...	205	380	137	154	IIIA
13	ASTM-A-516 415	220	415	147	165	IIIA
14	ASTM-A-216 60	220	415	147	165	III
15	ASTM-A-516 M 4...	240	450	160	180	V
16	ASTM-A-516 M 4...	260	485	173	195	IV
17	ASTM-A-662 M B	275	450	180	193	IV
18	ASTM-A-662 M C	295	485	194	208	IV

Figure 12.- Record ID = 4 selected with the mouse (that is why it appears in blue), pressing the 'Delete' button will delete this record from the database.

  - By pressing the 'Delete' button, the selected record will be deleted from the DB table (in blue), see figure:



  - A message will appear on the screen indicating that the record has been successfully deleted from the DB:



- To **modify** an existing record in the database, select it by left-clicking on the row of the table of records to be modified, this record will be selected and can be modified by entering new data in the corresponding boxes (see figure 13):

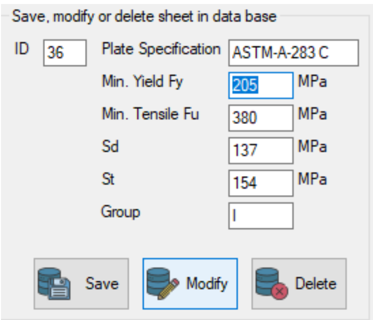
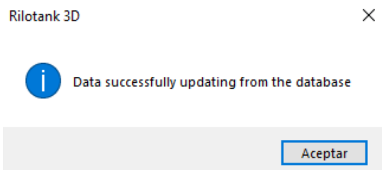


Figure 13.- Record ID = 36 selected, and proceeding to modify the 'Min. Yield Fy' data (this is why it is highlighted in blue, as new numerical data is being entered with the keyboard).

- Onde the desired data has been modified (except for the ID data, since this data indicates the record to be modified), click on the 'Modify' button, see the figure:

- A message will appear on the screen indicating that the record has been successfully modified from the database:



3. DESIGN DATA. MATERIALS. CORROSION ALLOWANCE

When the software is started, the first tab 'Design I' selected for entering the design data 'Design Parameters' will appear in the first instance, see figure 14.

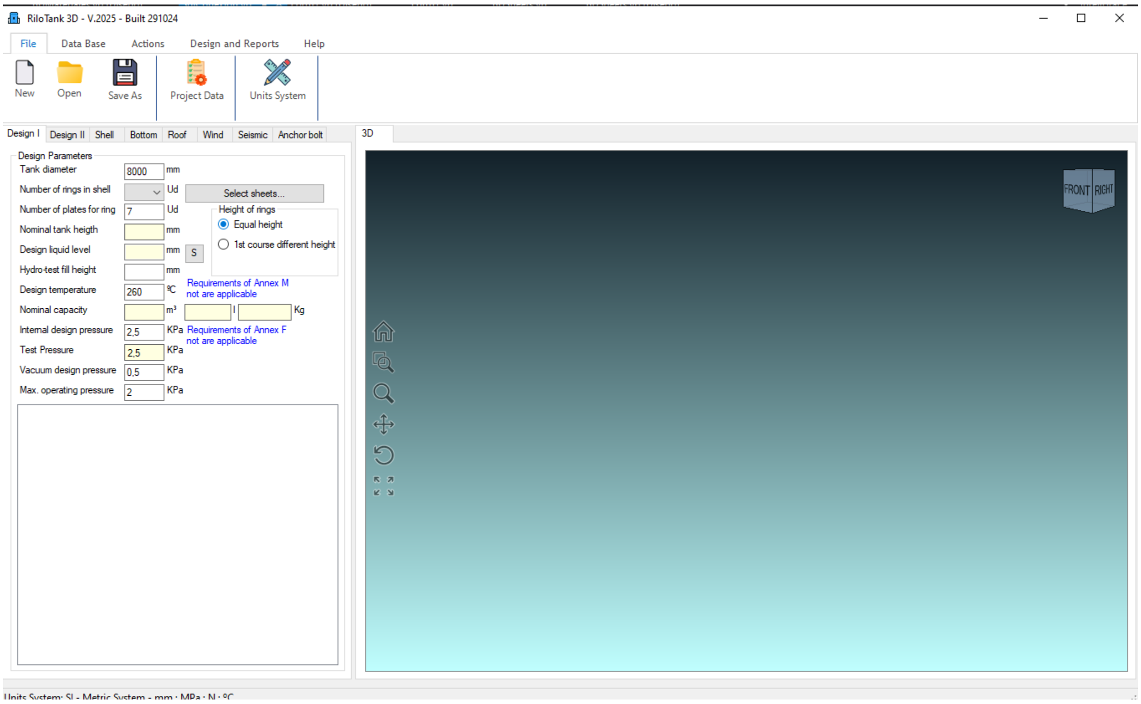


Figure 14.- Initial screen of the software

Figure 15.- "Calculate all"' button, from the menu tab "Design and Reports"

If we proceed directly to the calculation by clicking the "Calculate all" button on the "Design and Reports" menu tab (see figure 15) without entering any data, the software will perform an initial calculation for a tank using the default values that appear when the program is started, i.e., a tank with a diameter of 8000 mm. The missing data, such as the "Number of rings in Shell" to determine the total height of the tank and other data required to perform the calculations, if not entered, the software will use default values, as mentioned above, which it will automatically enter (with 3 rings of plates) (since if any data is missing, the application will obviously be unable to "Calculate all"). The screen will therefore appear with the initial calculation using all the data entered by the software by default, as can be seen in figure 16:

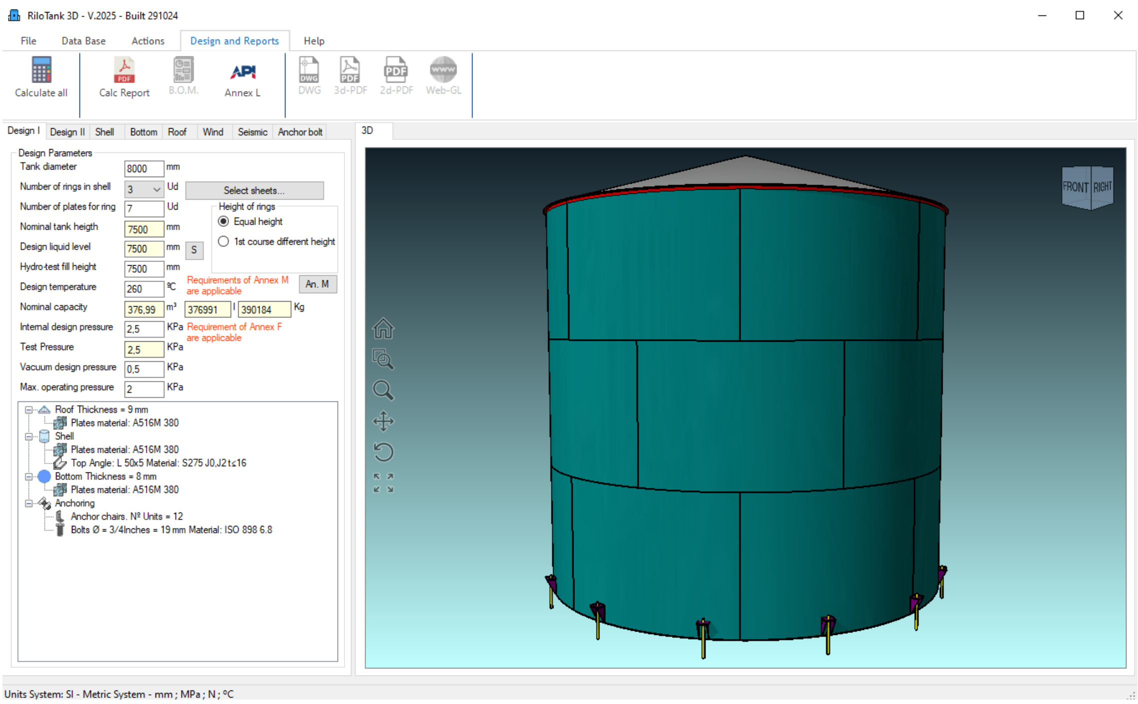


Figure 16.- Initial screen of the software, with calculation made with default data

Obviously, we can change the data at any time and enter our own project data when we wish, such as diameter, number of rings, number of plates per ring, tank design temperature (in case it is necessary to apply Annex M), tank design internal pressure (in case it is necessary to apply Annex F), vacuum pressure and maximum operating pressure of the tank.

It is also interesting to note that the software offers the possibility that all the rings have the same height or that the first of them (the plate ring Nº 1 that will be welded to the bottom) has a different height (lower than the rest of the plate rings) in order to achieve an exact volume (in the Nominal capacity section in m³). This is achieved by simply selecting the option ‘1st course different height’ and entering a certain height in mm in the cell ‘height’, see figure 17a and 17b:

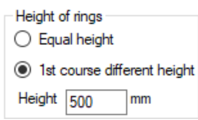


Figure 17a.- Screen where you can select that all the rings have the same height ‘Equal height’ or that the first one has a lower height than the rest with the option ‘1st course different height’

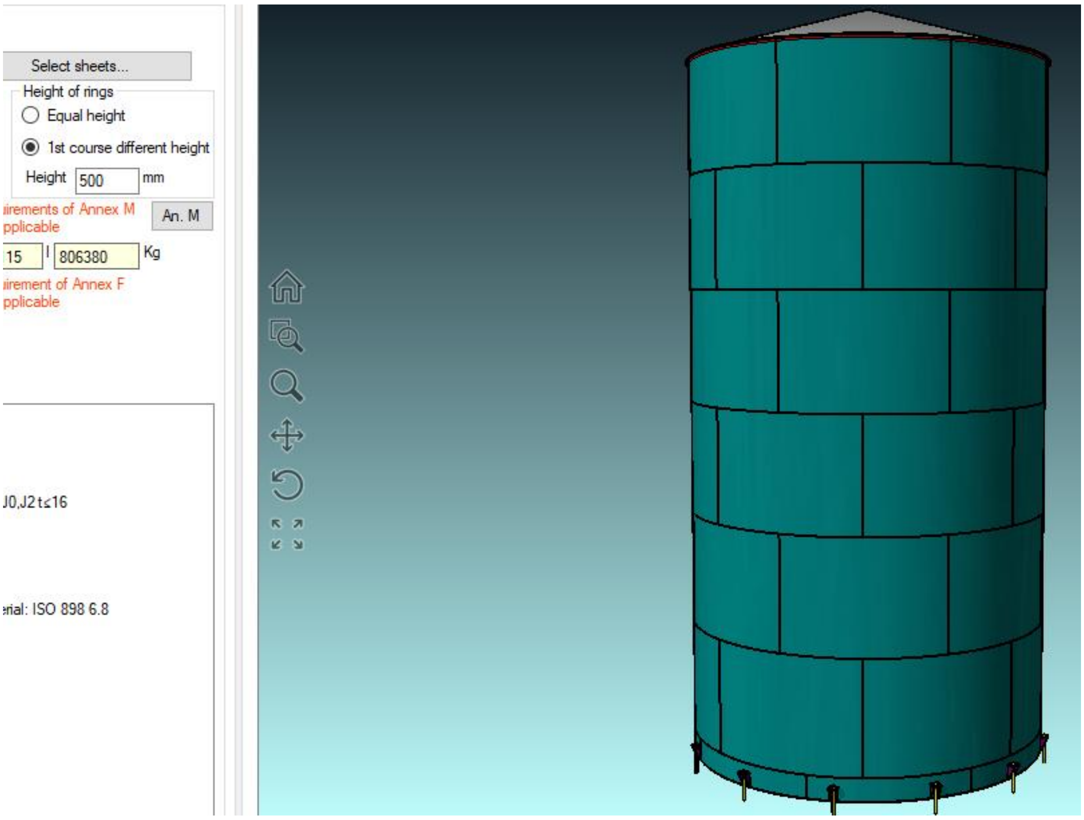


Figure 17b.- Selecting the option '1st course different height' will cause the 3D drawing of the tank to change according to the height of the first ring of plates, which will be of a lower height depending on the measurement entered in the 'Height' cell -in this particular case 500 mm-

It is important to note that there are numerical data that **can be changed by the user in those cells with a white background**. For example in the Tank diameter cell:

However, in the **cells with a yellow background, data cannot be entered by the user, as these are the cells that provide the results calculated by the software**, for example the Nominal capacity cells, see figure 18:

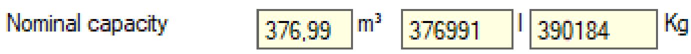


Figure 18.- The cells with yellow background are cells showing results calculated by the software. In the 'Nominal capacity' cell, as is obvious, the software already automatically calculates the tank capacity in m^3, litres and weight in kg of the stored fluid (from the data of diameter, tank height, density of the stored fluid, etc.) and no user intervention is necessary

Likewise, the following tab 'Design II' offers data that can be modified by the user by pressing the corresponding 'Select Liquid' buttons to access directly to the BD of liquids and change the existing default, and of materials, with their corresponding 'Select material...' buttons in plates, structural members and bolts, see figure 19:

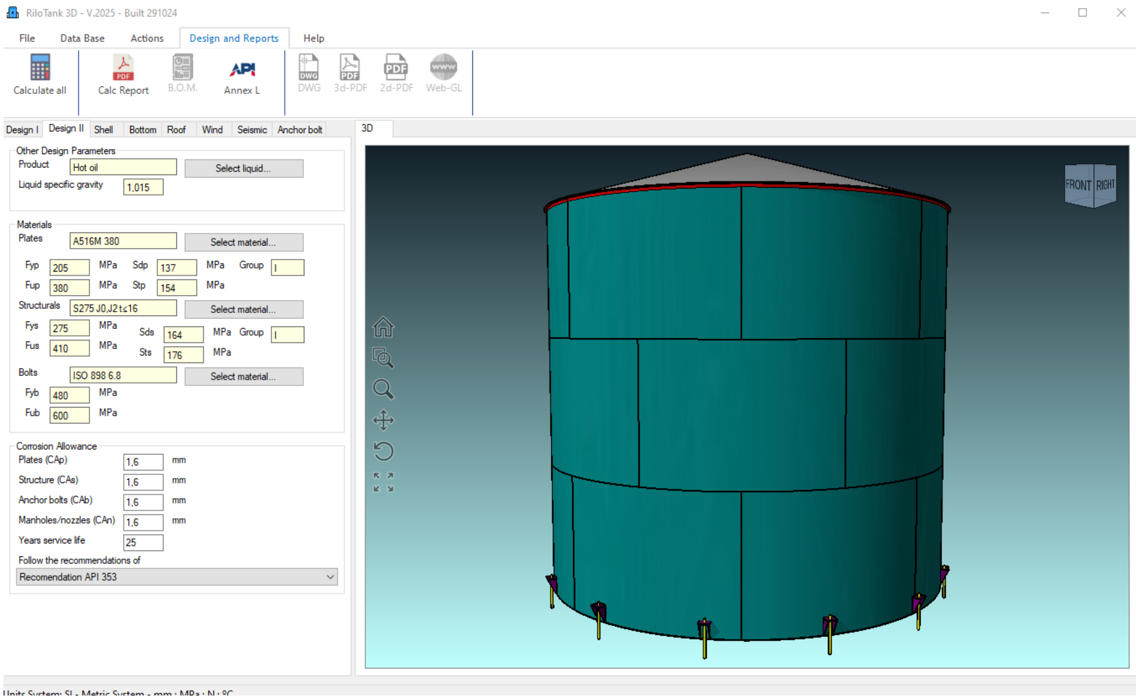


Figure 19.- "Design II" tab, where it can be seen that all the data are entered from the databases, except for the "Corrosion Allowance" section referring to the admissible corrosion to be used in the calculations

As can be seen in figure 20, the section 'Corrosion Allowance' referring to the allowable corrosion, although the background of the cells is white and can be modified directly by the user, in order to change the allowable corrosion with the keyboard in each of the tank components 'Plates, Structure, Anchor bolts...', it is necessary to select in the section 'Follow the recommendations of' the option 'Proposed by the user', so that it is effectively the user himself who enters the thicknesses directly with the keyboard in the section 'Follow the recommendations of'. 'In the 'Follow the recommendations of' section, it is necessary to select the 'Proposed by the user' option, so that the user of the application can enter the desired corrosion thicknesses directly with the keyboard in the calculation for each of the tank components (see figure 20):

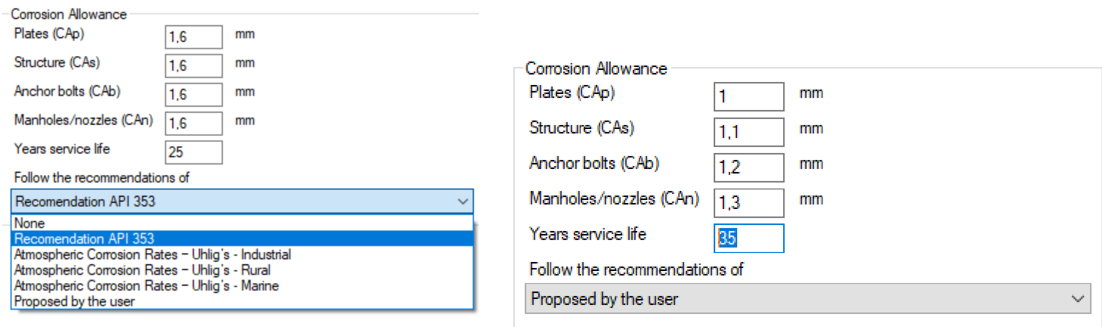


Figure 20.- On the left side, the 'API 353 Recommendation' option is shown by default for the 'Corrosion Allowance' section, where the allowable corrosion according to this standard will be directly selected. The same will occur if the other options 'Atmospheric Corrosion Rates' are selected, which base the choice of corrosion thickness on the paper 'Paper Shell corrosion allowance for aboveground steel tanks' published by 'Debra Tetteh-Wayoe, P.Eng.' in September 2008. If, on the other hand, the user wishes to enter the corrosion thickness directly on the PC keyboard, he must select the option 'Proposed by the user' as shown in the figure on the right, and can also freely select the number of years of service life of the tank

4. SHELL DESIGN. SHEETS

The next tab after 'Design II' is the 'Shell' tab, where the calculation of the thickness of the tank sheets by rings is carried out, depending on the height of each ring of plates, see figure 21:

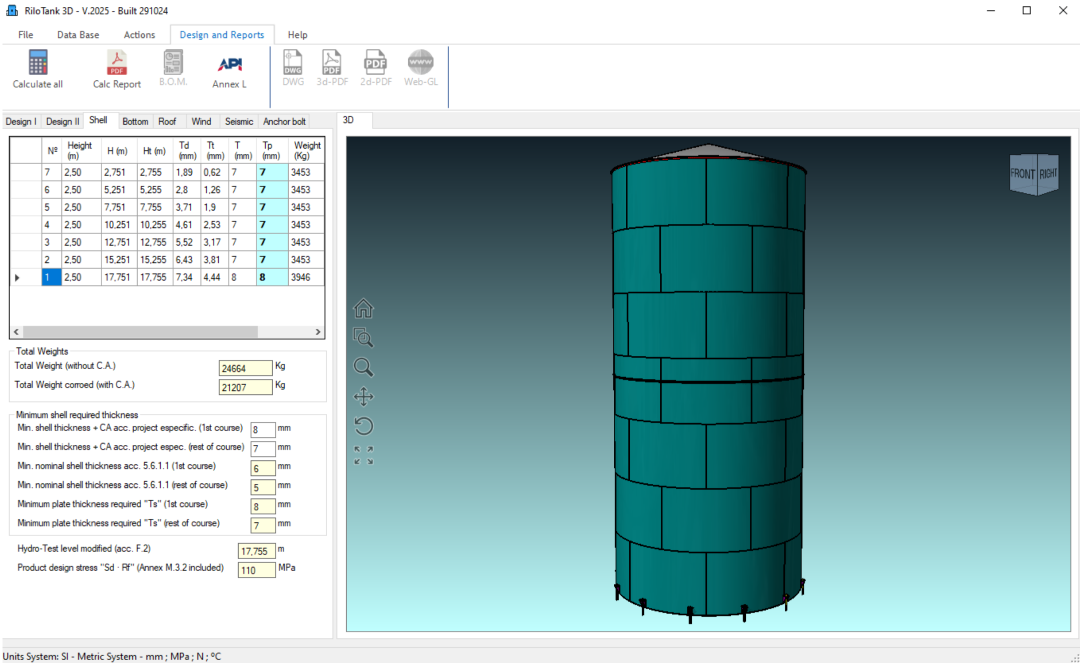


Figure 21.- "Shell" tab where cylinder thicknesses, weights and other factors are automatically calculated

This 'Shell' section is divided into 3 distinct parts, **the first part** is a table where the calculations by heights and all the results by plate ring are presented, see figure 22:

	Nº	Height (m)	H (m)	Ht (m)	Td (mm)	Tt (mm)	T (mm)	Tp (mm)	Weight (Kg)
	7	2,50	2,751	2,755	1,89	0,62	7	**7**	3453
	6	2,50	5,251	5,255	2,8	1,26	7	**7**	3453
	5	2,50	7,751	7,755	3,71	1,9	7	**7**	3453
	4	2,50	10,251	10,255	4,61	2,53	7	**7**	3453
	3	2,50	12,751	12,755	5,52	3,17	7	**7**	3453
	2	2,50	15,251	15,255	6,43	3,81	7	**7**	3453
▸	1	2,50	17,751	17,755	7,34	4,44	8	**8**	3946

	H (m)	Ht (m)	Td (mm)	Tt (mm)	T (mm)	Tp (mm)	Weight (Kg)	Tc (mm)	Weight c (Kg)
	2,751	2,755	2,49	0,62	7	**7**	3453	5,4	2663
	5,251	5,255	3,4	1,26	7	**7**	3453	5,4	2663
	7,751	7,755	4,31	1,9	7	**7**	3453	5,4	2663
	10,251	10,255	5,21	2,53	7	**7**	3453	5,4	2663
	12,751	12,755	6,12	3,17	7	**7**	3453	5,4	2663
	15,251	15,255	7,03	3,81	7,03	**8**	3946	6,4	3157
▸	17,751	17,755	7,94	4,44	8	**8**	3946	6,4	3157

Figure 22.- In the 'Shell' tab, the first thing that appears is the table of results by plate rings, with the data of ring number (where 1 is always the ring welded to the bottom and the last number -in the figure Nº 7- the closest to the roof), 'Height' represents the height of each ring in mm, 'H' the depth in m., 'Ht', the depth in metres of the hydrostatic test that can be modified according to Annex F.2 according to the internal design pressure of the tank, 'Td' the design thickness in mm, Tt' the hydrostatic test calculation thickness in mm, "T" the thickness required in the design as entered by the user in the "Minimum shell required thickness" section in mm, "Tp" the final thickness of the ring of plates in mm, "Weight" the weight in kg of each ring of plates calculated with T(mm), "Tc" the thickness of the corroded plates = T - CA in mm, and "Weight c" the thickness in kg of each ring of plates found with the corroded thickness Tc(mm). It is likely that not all the data will be displayed directly, for this you can use the horizontal and vertical scroll bars that will appear in the table in such a case

The **second part** of the 'Shell' tab is the 'Total Weights' section which simply presents the total weights in kg of all the tank ring plates without corrosion (with thickness T(mm)) and which will be the weight used in the bill of materials as it represents the final weight in the manufacture of the tank, and the total weight of all the tank ring plates with corrosion included (calculated with thickness Tc(mm)), see figure 23:

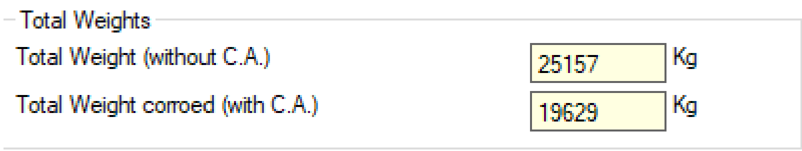


Figure 23.- Obviously, the weight of the cylinder plates without corrosion (without C.A.) is greater than the weight of the corroded plates (with C.A.) because the thickness of the admissible corrosion C.A. has been subtracted.

The **third part** of the 'Shell' tab is the section 'Minimum shell required thickness', which will give value to the column 'T' of the table seen above and which represents the thickness required in the project as entered in this section. It also shows the height of water level to be reached in the hydrostatic test (which may be modified according to Annex F.2 of API 650 due to the value of the internal design pressure), and the factor 'Rf' which may modify the value of the allowable stress 'Sd' in MPa (if the requirements of Annex M.3.2 of API 650 are applicable due to high design temperatures of the tank), see figure 24:

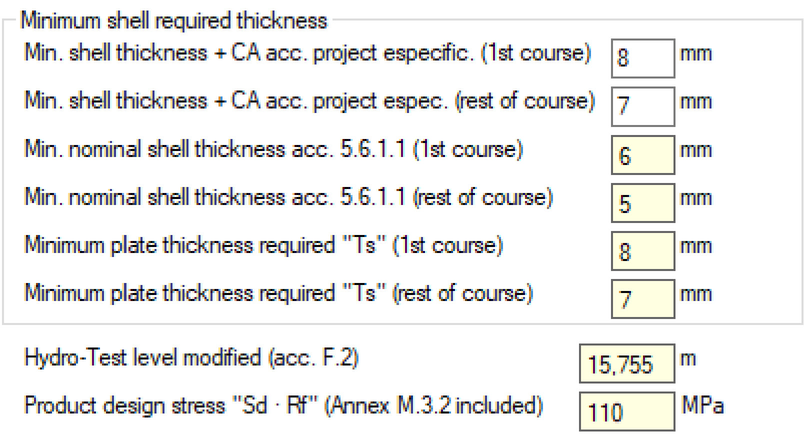


Figure 24.- 'Minimum shell required thickness', whose first 2 rows can be modified at will by the user (that is why the colour of the cells is white according to the project specifications in the first ring (welded to the bottom of the tank) and the rest of the rings. Likewise, the following sections appear in yellow cells, since they cannot be modified because they represent the minimum nominal thicknesses of the first and the rest of the tank rings according to API 650 standard and which are a function of the tank diameter, as explained in point 5. 6.1.1 of API 650. The higher thickness of the 2 options will be the final required thickness in the sections ''Minimum plate thickness required 'Ts' (1s course)' in the first plate ring -welded to the bottom- and "Minimum plate thickness required "Ts (rest of course)' in the rest of the rings

5. REQUERIMIENTS OF ANNEX M – API 650 FOR HIGH TEMPERATURES ≤ 260ºC

- **Temperature:** The maximum design fluid storage temperature shall be in the range of -40ºC ≤ T ≤ 93ºC. In case the temperature exceeds 93ºC, Annex M of API 650 shall be considered, which applies for ranges of 93ºC < **T ≤ 260 ºC***

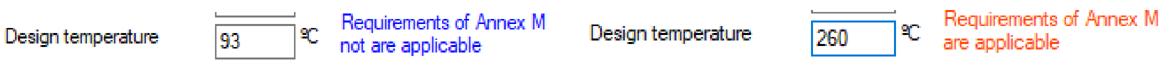


Figure 25.- Notice from the RiloTank 3D software showing the Annex M applicability notice for tanks with temperatures above 93ºC right image. When the range is less than or equal to 93ºC, Annex M does not need to be applied

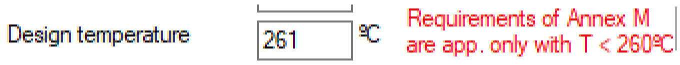
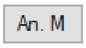


Figure 26.- In case the design temperature of the tank exceeds 260°C, a notice shall be displayed stating that the requirements of Annex M are only applicable for T ≤ 260°C

Although the calculation of the requirements according to Annex M is performed automatically by the software when the design temperature exceeds 93ºC, all the checks can be accessed by clicking on the button 

located in the 'Design I' tab, which will only appear when the temperature exceeds 93ºC. Pressing it will bring up a new screen called 'Annex M'.

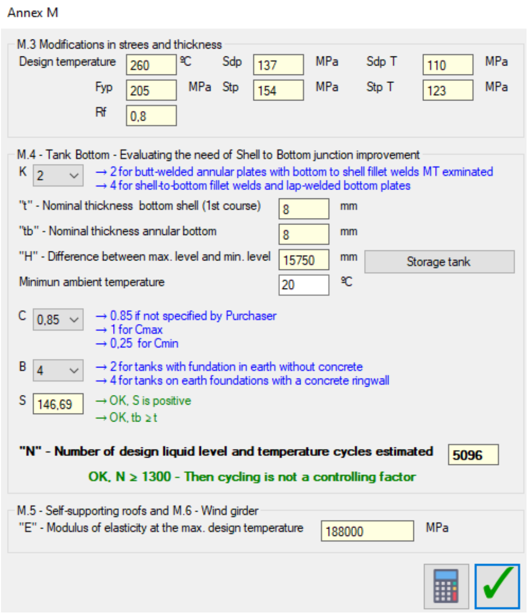


Figure 27.- Screen where Annex M checks are carried out

***T ≤ 260 ºC.-** It is very common that even if the design temperature exceeds 260ºC, the API 650 standard and its Annex M continue to be applied for the calculation of the tank. This has been seen in numerous molten salt thermal storage tank projects that have proliferated in recent years, such as high-temperature thermal energy storage (TES) systems in Concentrated Solar Power (CSP) plants. In these plants, 'cold' molten salt tanks are designed with temperatures of around 290ºC and 'hot' tanks with temperatures ranging from 395ºC to 565ºC depending on the technology used, and in all of them the calculation standard was API 650.

Annex M does not apply to tanks with the following typology:

- Tanks without roof (open)
- Tanks with floating roof
- Tanks with aluminium dome roofs.

Annex M is only applicable at temperatures above 93°C and is divided into 3 distinct parts:

- **M.3. Modifications in stress and thickness.** At this point, modifications are made to the permissible stresses of the cylinder plate material (but not of the bottom or roof plates), so that their thicknesses will be increased. Basically, it consists of multiplying the permissible stresses 'Sd' and 'St' by reduction factors 'Rf', which are obtained from table M.1a and are a function of the design temperature of the tank and 'Fy' of the material, see table M.1a:

Table M.1a—Yield Strength Reduction Factors (SI)

Temperature (°C)	Minimum Specified Yield Strength (MPa)		
	< 310 MPa	From ≥ 310 to < 380 MPa	≥ 380 MPa
94	0.91	0.88	0.92
150	0.88	0.81	0.87
200	0.85	0.75	0.83
260	0.80	0.70	0.79

NOTE Linear interpolation shall be applied for intermediate values.

The equations for calculating cylinder thicknesses will be as follows:

$$t_t = \frac{4{,}9D(H-0{,}3)}{S_{t-corregido}}$$

$$t_d = \frac{4{,}9D(H-0{,}3)G}{S_{d-corregido}} + CA$$

Where:

$S_{t\text{-corregido}}$ = St · Rf y $S_{d\text{-corregido}}$ = Sd · Rf

The factor 'Rf' = Yield Stress Reduction Factor , fluctuates between 0.7 and 0.92, so it will always cause a reduction of the original allowable stresses 'Sd' and 'St', which will increase the thickness of the cylinder plates. Furthermore, as linear interpolations are allowed in the table depending on the exact temperature of the tank design, the software automatically performs a double linear interpolation to find the 'Rf' factor accurately, see figure 27.

- **M.4.- Tank bottom.** At this point, the need to improve the bottom-cylinder joint is evaluated. This is an optional evaluation, not mandatory, but the software performs it as it is recommended especially when large temperature differentials are expected between the bottom and the first ring of plates of the cylinder.

It is known that in tanks with Ø > 30 metres, the use of a butt-welded bottom ring plate is mandatory (according to point 5.1.5.6 API 650). The weld between the first plate ring of the cylinder and the bottom ring plate has to be checked according to the following equations:

$$S = \frac{0.028 D^2 t_b^{0.25}}{t} \times \left[\frac{58 HG}{(Dt)^{0.5}} + \frac{26.2 C T t^{0.5}}{D^{1.5}} - \frac{4.8 B S_y t_b^2}{(Dt)^{1.5}} - G \right]$$

Once the 'S' parameter has been found, the following conditions must be met:

$$\left[\frac{58 HG}{(Dt)^{0.5}} + \frac{26.2 C T t^{0.5}}{D^{1.5}} - G \right] > \frac{4.8 B S_y t_b^2}{(Dt)^{1.5}}$$

tf 'plate thickness of first cylinder annulus' **≥** tbf 'thickness of bottom annular plate'.

Once these 2 conditions are met, the estimated number of liquid level cycles and design temperature 'N' shall be checked, using the following equation:

$$N = \left(\frac{9.7 \times 10^3}{KS} \right)^{2.44}$$

  - In case N ≥ 1300, the cycles are a control factor.
  - In case N < 1300, the cycles are not a control factor, which means that no control is necessary at the Shell-Bottom junction.

All the calculation of the parameters involved in the equations, the checks and the results are performed automatically by the software and are presented on the screen of Annex M (see figure 27).

- **M.5.- Self-Supporting Roofs.** At this point, the longitudinal modulus of elasticity (Young's modulus) - please do not confuse with the transverse modulus of elasticity - of the material of the plates for the manufacture of self-supporting (non-structural) roofs, whether conical or dome-shaped, will be modified. Table M.2a presents the values of the new modulus of elasticity to be used as a function of the design temperature of the tank (the higher the temperature, the lower the modulus of elasticity, which causes a decrease in the strength of the material due to higher temperatures). The software also performs a double linear interpolation to accurately find the modulus as a function of the exact temperature.

Table M.2a—Modulus of Elasticity at the Maximum Design Temperature (SI)

Maximum Design Temperature	Modulus of Elasticity
°C	MPa
93	199,000
150	195,000
200	191,000
260	188,000
NOTE Linear interpolation shall be applied for intermediate values.	

- **M.6.- Wind girder.** At this point, the same test is carried out as in the previous one, with the longitudinal modulus of elasticity being affected by the increase in the design temperature of the tank (Table M.2a), but on this occasion affecting the counter-wind rings that will intervene in Annex V for the internal pressure test. This will also cause the rings to decrease in strength due to the higher temperatures.

6. BOTTOM AND ANNULAR BOTTOM DESIGN

The calculation of the bottom shall be carried out in the 'Bottom' tab (see figure 28), and whenever it is necessary for the tank to incorporate a ring plate it shall also be designed in this tab.

A tank shall be fitted with a ring plate if and when:

- Its diameter > 30 metres (see figure 29)
- If the material of manufacture of the tank plates belongs to groups VI, IVA, V or VI.
- It may also be necessary to use an annular plate due to high temperature requirements according to Annex M.4 or even in exceptional cases of earthquakes, etc

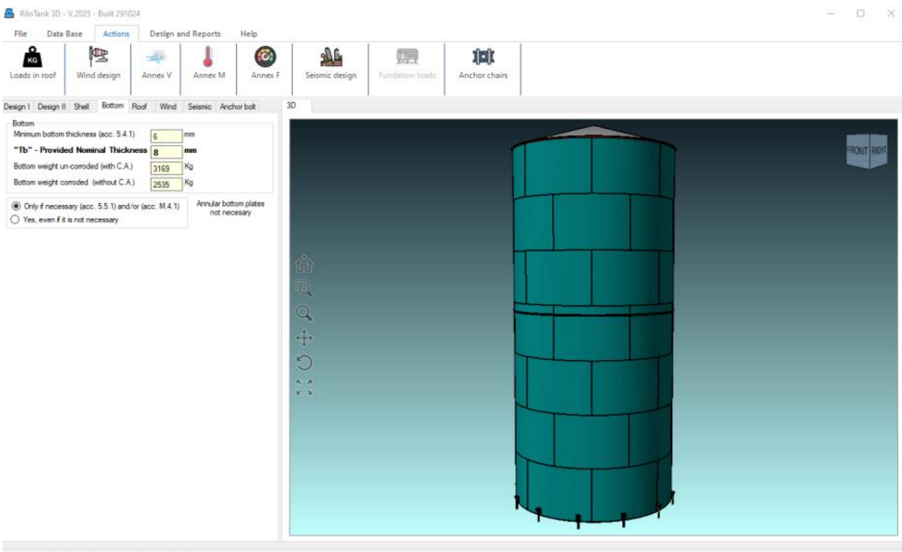


Figure 28.- Calculation of the tank bottom, it is noted that the calculation of the bottom ring plate is not performed as the option 'Only if necessary' is selected.

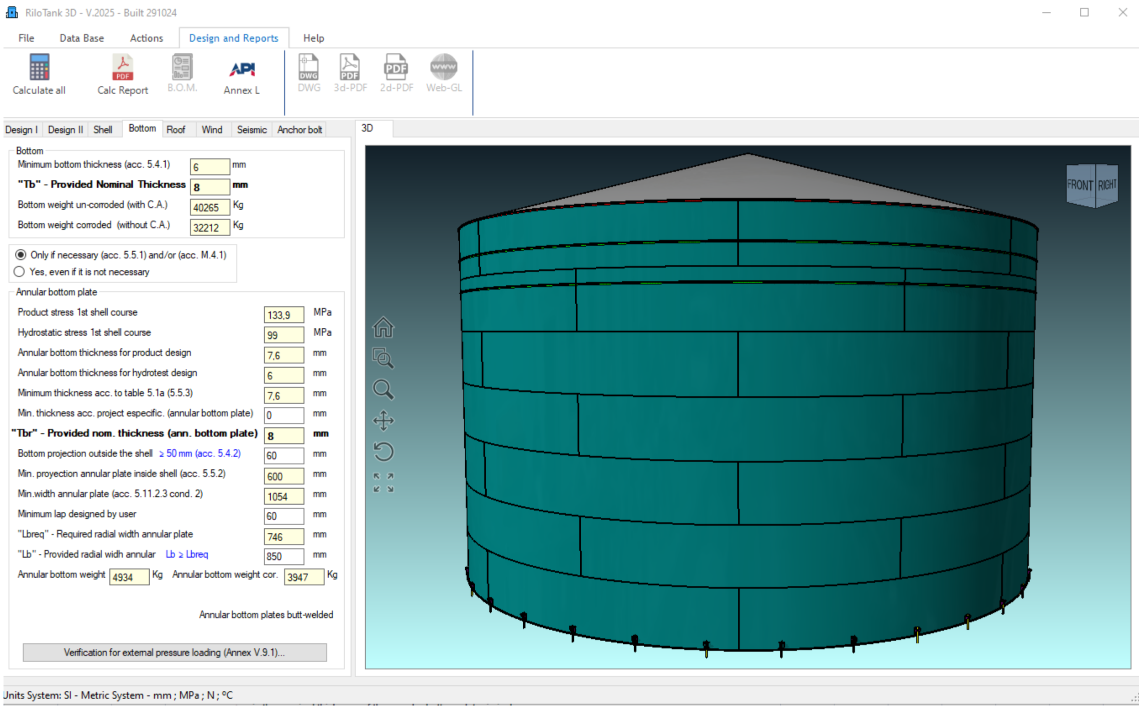


Figure 29.- Calculation of the tank bottom and the annular bottom plate, which is necessary in this case because the tank has a Ø > 30 metres.

However, the software offers the option to incorporate the annular plate calculation (even if it is not necessary) by selecting the option 'Yes even if it is not necessary' by the user, see figure 30:

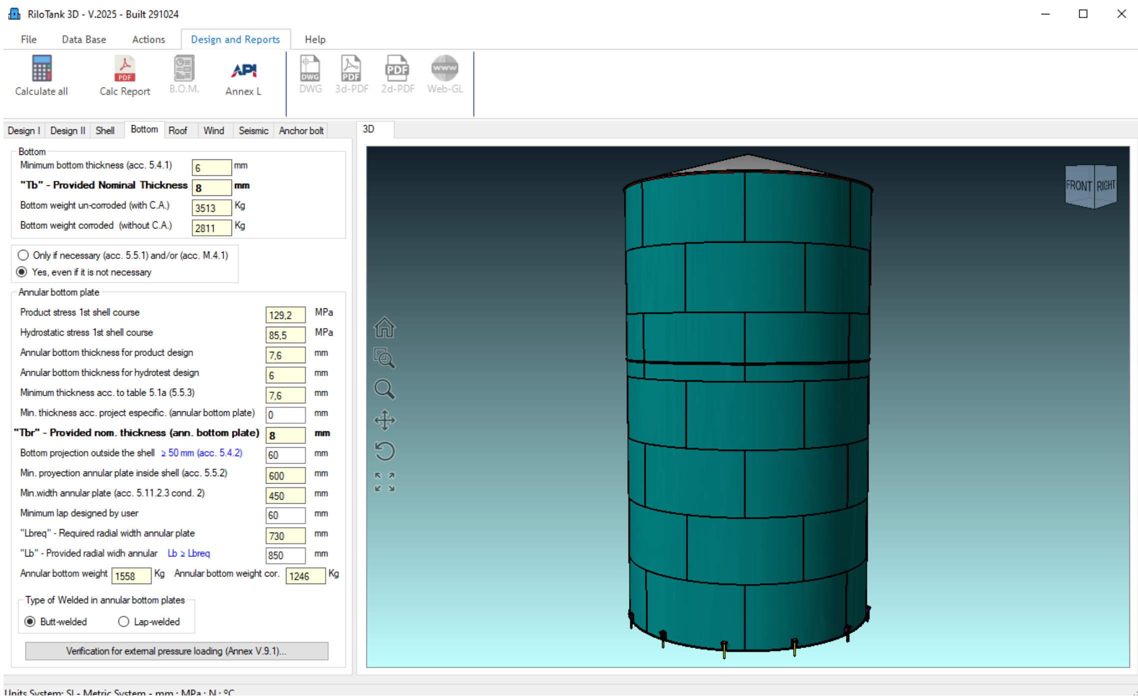


Figure 30.- Calculation of the tank bottom and the annular bottom plate, even if not necessary, but still carried out when the option 'Yes even if is not necessary' is selected

Pressing the 'Verification of external pressure loading' button performs this verification on the screen that appears, which is necessary following the indications in Annex V 9.1. See figure 31:

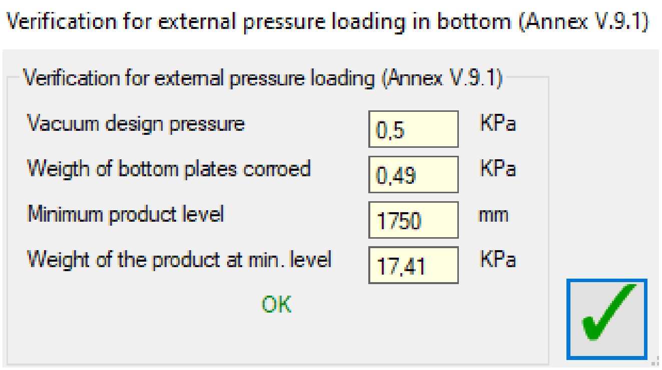


Figure 31.- Test for external bottom pressure loads in accordance with Annex V.9.1.

7. ROOF DESIGN. LOADS AND LOAD COMBINATIONS

The calculation of roofs takes place in the ‘Roof’ tab. Currently the software can calculate 2 types of self-supporting roofs: conical or dome (see figure 32). In the next version 2026, the calculation of structural roofs will be incorporated.

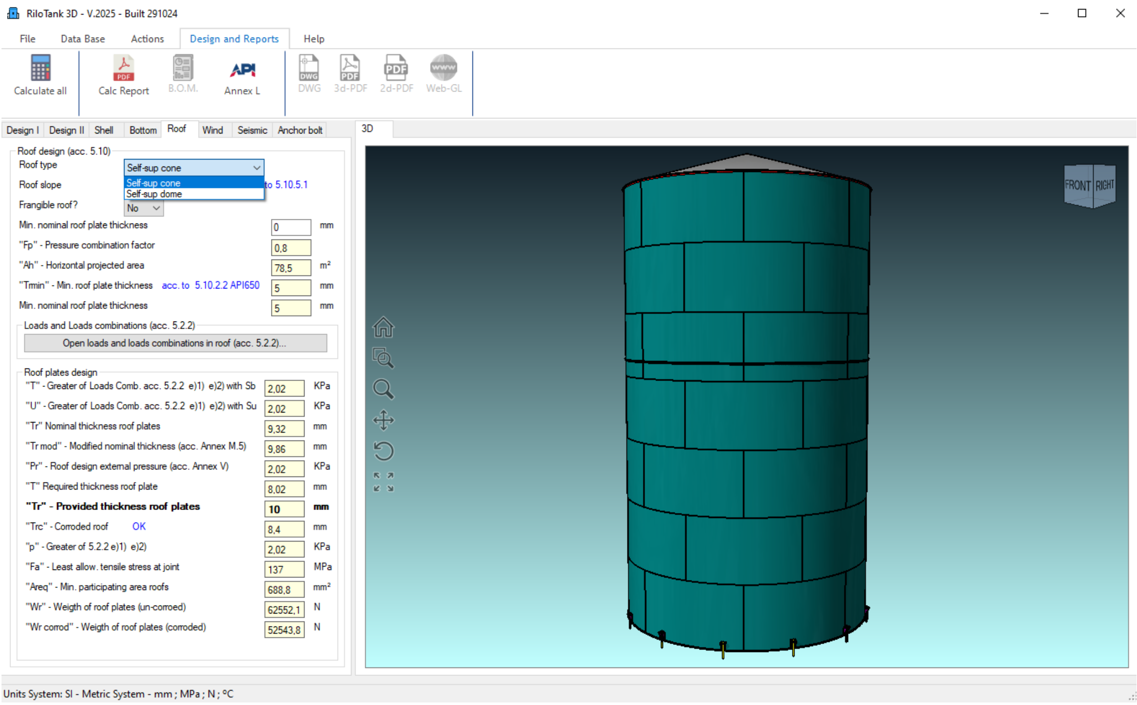


Figure 32.- In the Roof Type section you can select 2 types of self-supported roofs: Self-sup`cone or Self-sup dome roof

If the conical roof is selected, the data requested on this screen (figure 32) will be:

- Roof slope (conical roof pitch angle in degrees) shall be between 9.5° and 37° according to API 650, section 5.10.5.1.

If, on the other hand, the dome roof is selected, the data requested on this screen (figure 32) will be:

- Roof radius (dome roof pumping radius in millimetres), shall be between 0.8 - Tank Diameter and 1.2 - Tank Diameter as per API 650, section 5.10.6.1.

There are other options to be entered by the user, such as whether or not the ceiling should be frangible, or if a minimum ceiling tile thickness in mm is desired.

The rest of the data on this screen are the results of all the checks carried out automatically by the software (that is why the background colour of the cells is yellow, as they are result cells), where the calculated thickness of the ceiling tiles 'Tr', ceiling weights, projected ceiling area and other checks according to point 5.10 of API 650 are presented, see figure 32.

Also, by clicking on the button 'Open loads and loads combinations in roof', the loads and loads combinations screen will appear according to point 5.2.2 of API 650, see figure 33, where the additional loads on the roof, such as access platforms, etc., can be modified. Likewise, the weights of the roof insulation 'Insulation on roof' can also be added in the case of tanks that incorporate it due to high temperatures of the stored fluid, as well as snow loads, or overloads of use to be considered (all these modifiable cells as shown in figure 33 appear with a white background). The rest of the cells with a yellow background show the results of the combinations and actions found automatically by the software.

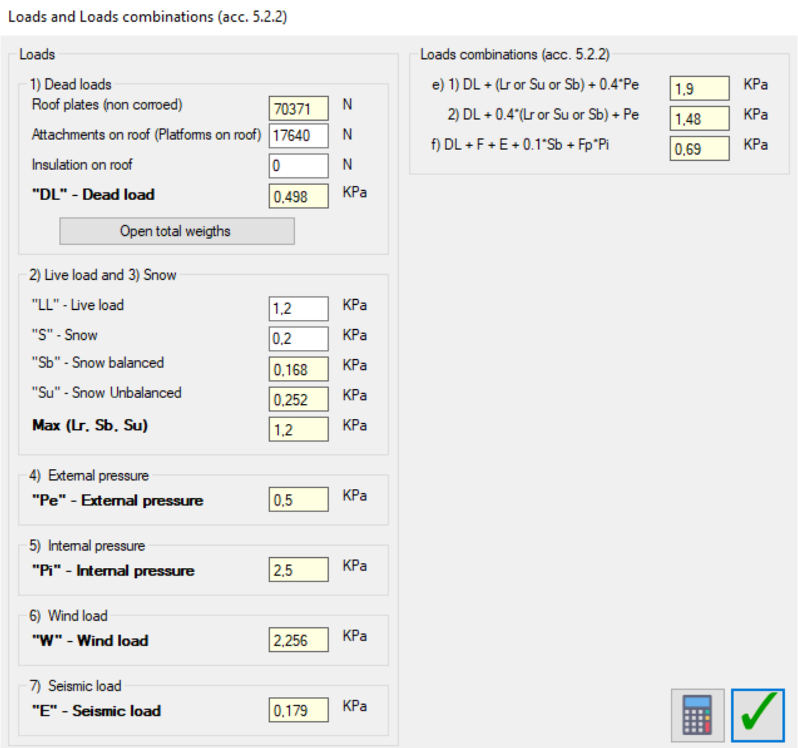


Figure 33.- Screen actions and combinations in ceilings

Also on this screen, by clicking on the 'Open total weights' button, you can access the calculation screen of all the tank weights, data that will be used for the preparation of the calculation report in its section B.O.M. 'Bill of materials' -Summary of tank material weights-. See figure 34.

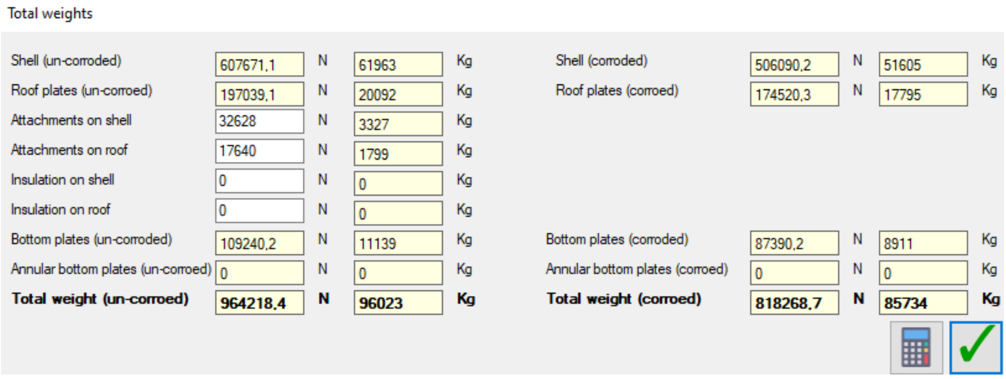


Figure 34.- Screen showing the calculation of all the tank weights in Newtons and Kilograms. Remember that the cells with a white background can be modified by the user and new weights can be added related to structures attached to the cylinder (helical ladders, platforms, nozzles...) or to the roof (platforms, railing...) and insulation in the cylinder and roof, in case they are necessary due to high temperatures of the stored fluid. As we can see in all these screens there is a button with a calculator, in case any data is modified, when pressing this button all the checks will be calculated and carried out again so that the changes made are reflected

8. WIND ACTION AND OVERTURNING STABILITY

In this 'Wind' tab, the entire calculation of the wind action takes place, so that in the first section 'Wind design acc. 5.2 API 650' the calculation of the wind action according to point 5.2 of API 650 as well as the overturning stability check according to point 5.11 API 650 take place.

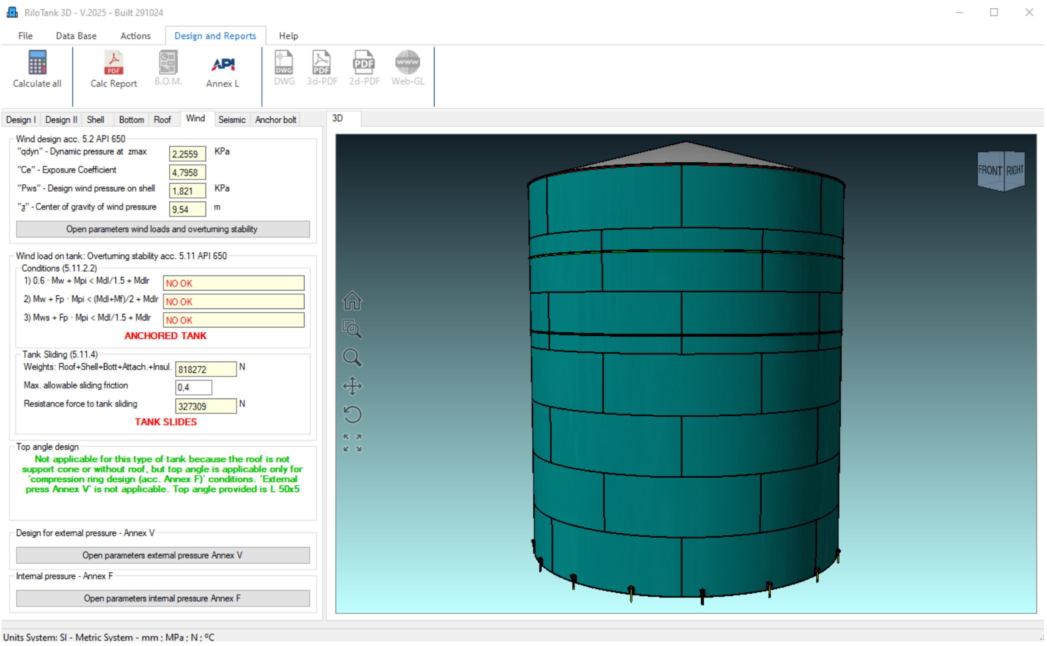


Figure 35.- "Wind" tab where all wind action tests according to 5.2 API 650, overturning stability according to 5.11 API 650, external pressure design according to Annex V and internal pressure design according to Annex F including calculation of the top angle are carried out.

The main screen simply shows the results of the wind load calculation (figure 35). If we want to modify the wind speed data (reference speed in m/s depending on the location of the tank), risk category, air density, topographic coefficient, soil classification and other parameters that influence the wind load calculation, which is performed according to ASCE 7-22 standards, which is integrated in the calculation philosophy of

API 650, the 'Open parameters wind loads and overturning stability' button must be pressed and the 'Wind load' window will appear, see figure 36:

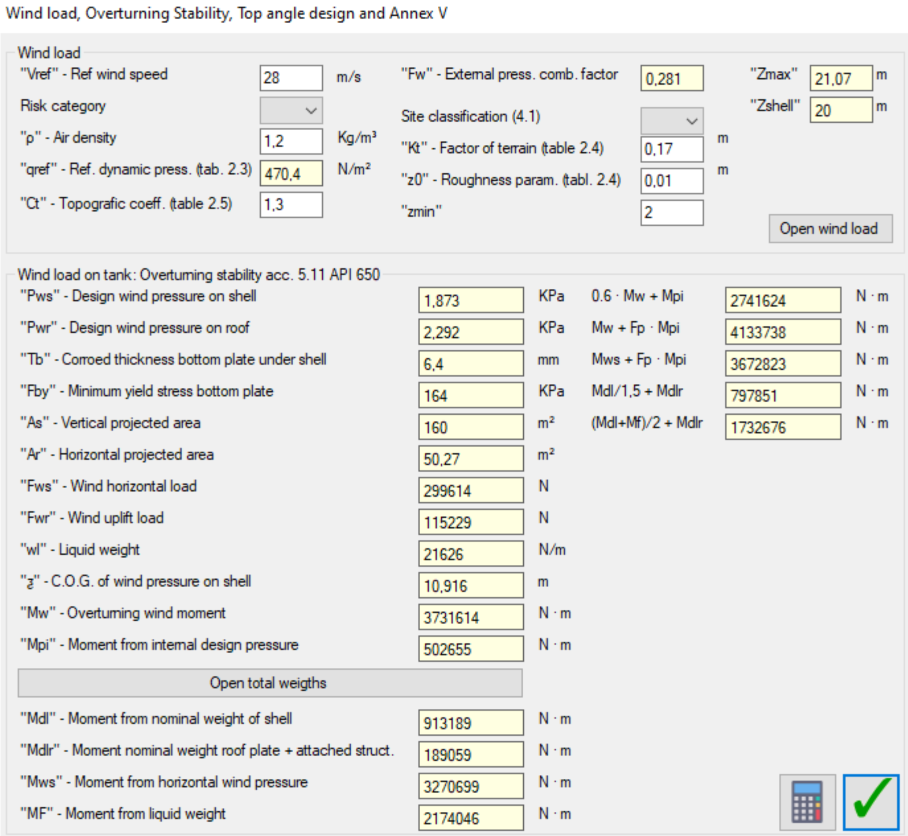


Figure 36.- Wind load, Overturning stability, top angle design and Annex V screen, where you can modify the calculation parameters that appear in white cells. Remember that the yellow cells cannot be modified as they are only for displaying the results calculated by the software

This screen (figure 36) shows all the results of the checks of the stability against overturning due to the action of wind, and from here we can also access the exhaustive calculation of the wind load by heights, by pressing the 'Open wind load' button, which will show us the screen in figure 37 with all the calculations. And by pressing the 'Open total weight' button, the screen shown in figure 34 above can be accessed again to view the total weights of the materials that make up the tank or to modify them if desired.

Wind load

z (m)	Ce	qdyn (kN/m²)	(qi+1 + qi)/2	Δh=(hi+1 - hi)	A (KN/m)	Aacum (KN/m)	pws (KPa)	M (KNm/m)	Macum (KNm/m)	ʒ (m)
0	2,76	1,3004	0	0	0	0	**0**	0	0	0
0,5	2,76	1,3004	1,3004	0,5	0,6502	0,6502	**1,3004**	0,1626	0,1626	0,25
1	2,76	1,3004	1,3004	0,5	0,6502	1,3004	**1,3004**	0,4877	0,6503	0,5
1,5	2,76	1,3004	1,3004	0,5	0,6502	1,9506	**1,3004**	0,8128	1,4631	0,7501
2	2,76	1,3004	1,3004	0,5	0,6502	2,6008	**1,3004**	1,1379	2,601	1,0001
2,5	2,94	1,3835	1,3419	0,5	0,671	3,2718	**1,3087**	1,5097	4,1107	1,2564
3	3,09	1,4531	1,4183	0,5	0,7091	3,9809	**1,327**	1,9501	6,0608	1,5225
3,5	3,22	1,5131	1,4831	0,5	0,7415	4,7224	**1,3493**	2,41	8,4708	1,7937
4	3,33	1,5659	1,5395	0,5	0,7698	5,4922	**1,373**	2,8866	11,3574	2,0679
4,5	3,43	1,6133	1,5896	0,5	0,7948	6,287	**1,3971**	3,3779	14,7353	2,3438
5	3,52	1,6561	1,6347	0,5	0,8174	7,1044	**1,4209**	3,8824	18,6177	2,6206
5,5	3,60	1,6953	1,6757	0,5	0,8379	7,9423	**1,444**	4,3988	23,0165	2,898
6	3,68	1,7315	1,7134	0,5	0,8567	8,799	**1,4665**	4,926	27,9425	3,1756
6,5	3,75	1,7651	1,7483	0,5	0,8741	9,6731	**1,4882**	5,4634	33,4059	3,4535
7	3,82	1,7964	1,7808	0,5	0,8904	10,5635	**1,5091**	6,0101	39,416	3,7313
7,5	3,88	1,8259	1,8111	0,5	0,9056	11,4691	**1,5292**	6,5653	45,9813	4,0092
8	3,94	1,8536	1,8397	0,5	0,9199	12,389	**1,5486**	7,129	53,1103	4,2869
8,5	4,00	1,8798	1,8667	0,5	0,9333	13,3223	**1,5673**	7,7001	60,8104	4,5645
9	4,05	1,9046	1,8922	0,5	0,9461	14,2684	**1,5854**	8,2784	69,0888	4,8421
9,5	4,10	1,9283	1,9164	0,5	0,9582	15,2266	**1,6028**	8,8636	77,9524	5,1195
10	4,15	1,9509	1,9396	0,5	0,9698	16,1964	**1,6196**	9,4554	87,4078	5,3967

Figure 37.- "Wind load" screen with all wind calculations by heights

Continuing with the data provided on the main screen of the software and its 'Wind' tab (figure 35), we can view the results of the 'Overturning stability' check, according to conditions 5.11.2.2 API 650 with the 3 results of the 3 load checks, in such a way that if any of them is not fulfilled, the red warning **'ANCHORED TANK'** will appear, making it necessary to anchor the tank in the wind, as it will not be stable (see figure 28). Likewise, the 'Tank Sliding' tank sliding check is also displayed according to point 5.11.4 API 650, where the user is asked to enter the maximum admissible friction coefficient (0.4 by default friction coefficient). If the tank slides, it will also be necessary to anchor it, and the message **'TANK SLIDES'** will appear in red.

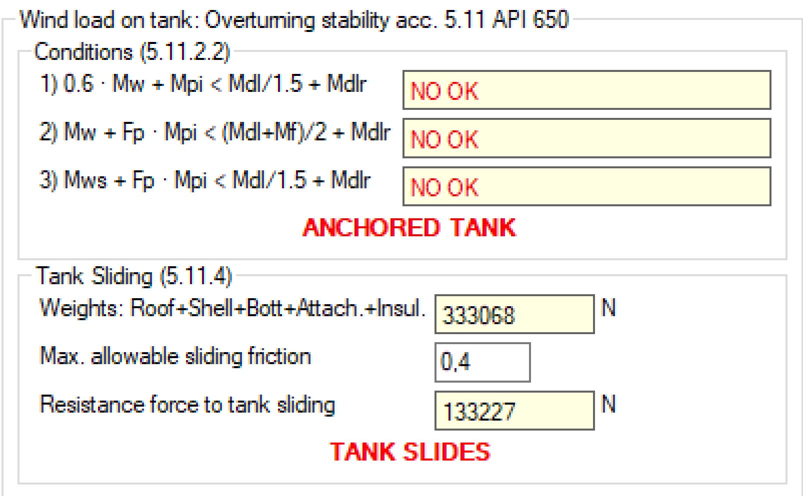


Figure 38.- Results of the Overturning stability and Tank Sliding tests. The detailed data and calculations of these 2 tests (in case you wish to follow the calculation procedure exhaustively), can also be viewed on the 'Wind load' screen seen previously (figure 36), as only the final results and conclusions are shown here. In this case, as can be seen, it does not fulfil any condition, so all the texts are shown in red

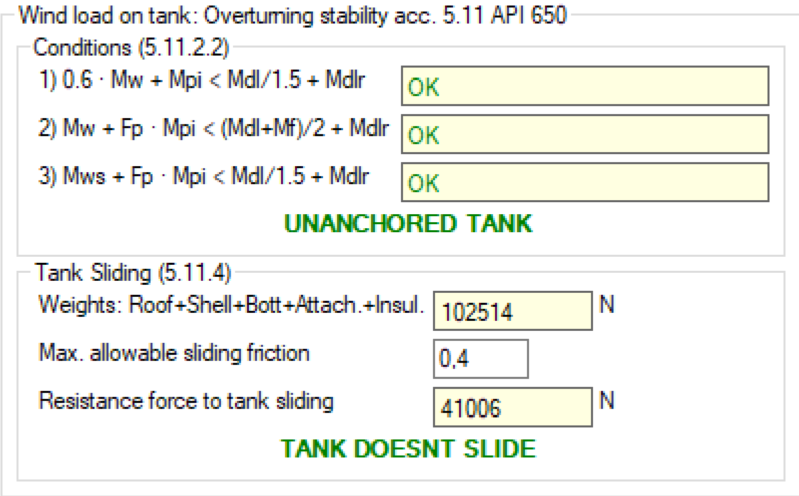


Figure 39.- Results of the Overturning stability and Tank Sliding tests. On this occasion, the tank does meet all the conditions, so the results are shown in green. It is not necessary to anchor the tank due to wind (perhaps due to other subsequent considerations, such as earthquakes, but not due to wind), and the tank will not slide either

9. EXTERNAL PRESSURE DESIGN (ANNEX V – API 650)

In the same tab 'Wind' (figure 35) the external pressure test due to wind load is also carried out according to Annex V API 650, see figure 40 where only the results are shown:

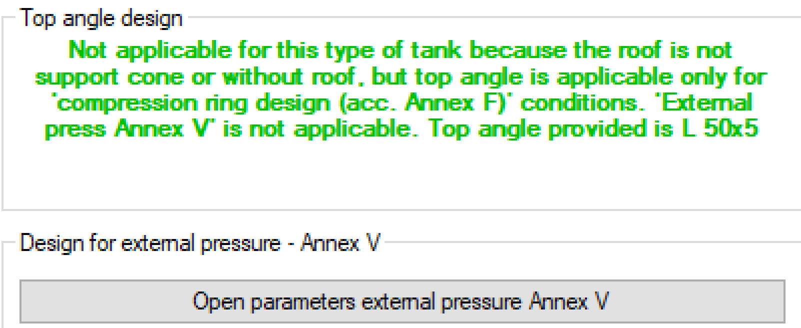


Figure 40.- "Top angle design" check result and button to access all Annex V checks, click on "Open parameters external pressure Annex V"

Pressing the button 'Open parameters external pressure Annex V' will take you to the screen 'Annex V - Design of storage tanks for external pressure' (see figure 41), where the following checks are carried out, by sections:

- Tsmin' Nominal thickness of thinnest Shell course
- You can select whether you want to analyse the buckling of the tank in corroded condition or not (by default the option Yes is checked, so it is recommended to perform this check for the safety of the tank).
- The transformed tank height according to V.8.1.4 API 650 is automatically calculated.
- The V.8.1.1 condition check is performed.
- The maximum external pressure test according to V.8.1.2 is performed and the results of the 2 conditions are automatically provided.

Finally, if stiffener rings are necessary, they are designed according to section V.8.2, finding the number of stiffeners or stiffener rings, their position in the cylinder, and whether or not the selected ring complies (if it does not comply, the selected ring, which by default is an L 50x5 -see figure 41-, will be shown in red **'Not OK'**).

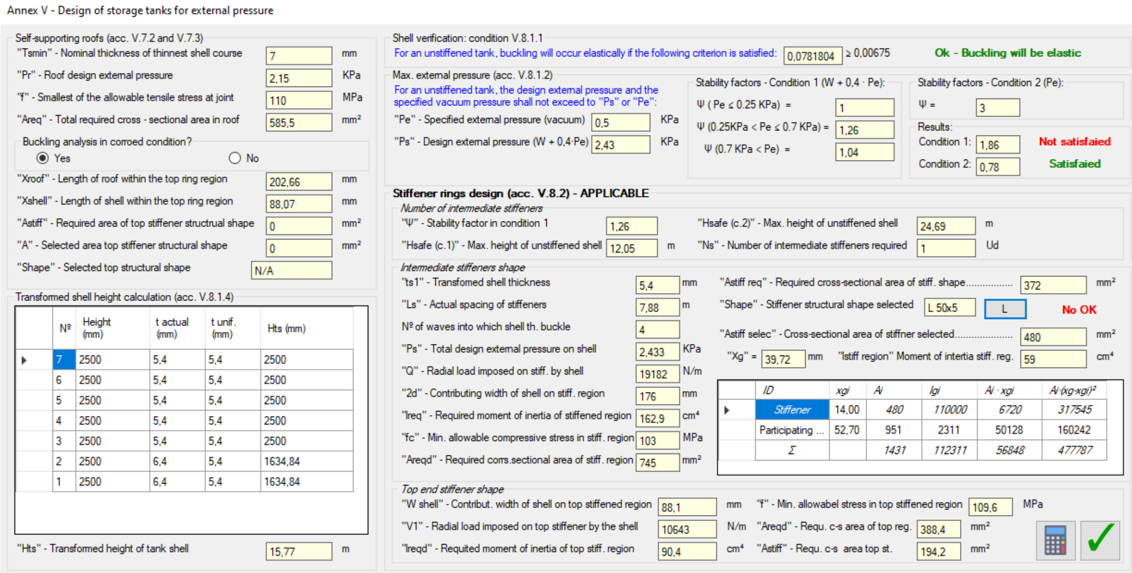
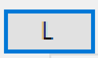


Figure 41.- Screen "Annex V – Design of storage tanks for external pressure"

- To change this wind ring to a larger one in order to comply with the conditions of Annex V, simply click on the button  and the wind ring database will appear (figure 42) where a larger reinforcement has to be selected. In figure 42 the new angle 'L 70x7' has been selected.

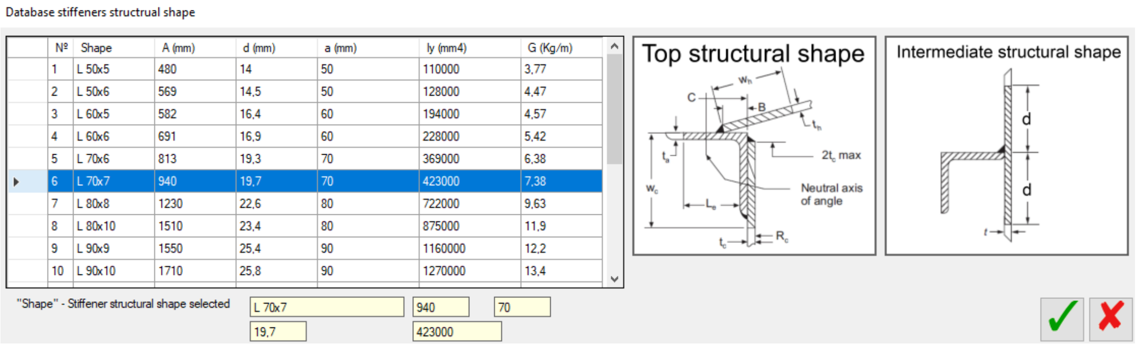


Figure 42.- Database display of angle braces to be used as tank wind rings, and also as a head ring if required (Top structural shape)

Once the new counter wind ring has been selected and the database in figure 42 has been closed by clicking on the button , checks will be automatically performed again to determine whether the newly selected windbreak ring meets the requirements of Annex V.8.2. If so, a green **"OK"** label will appear next to the newly selected ring (see Figure 43).

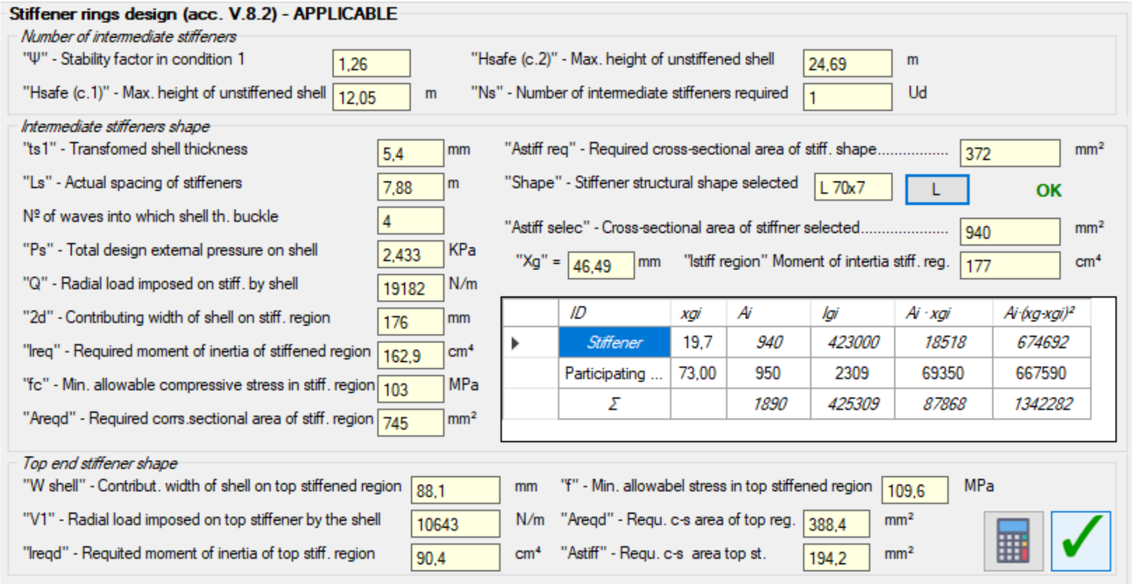


Figure 43.- In this case, the check according to V.8.2 complies with the selection of the new selected wind ring as it is an angle L 70x7, which is why the label 'OK' appears next to it in green

10. INTERNAL PRESSURE DESIGN (ANNEX F – API 650)

To access the Annex F internal pressure check, simply click on the 'Open parameters internal pressure Annex F' button in the 'Wind' tab, see figure 44.

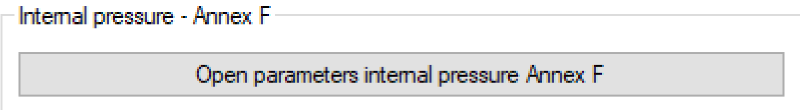


Figure 44.- Button for accessing API 650 Annex F checks

- **<u>Pressure</u>:** The internal pressure shall be ≤ 18 KPa and the following considerations shall be made for this internal pressure as described in Annex F - Design of tanks subjected to low internal pressures:
    - If the internal pressure Pi = 0 KPa a basic tank design is carried out without any considerations
    - If the internal pressure Pi ≤ 2 KPa a basic tank design is carried out without any consideration.
    - If the internal pressure Pi > 2 KPa and in addition Pi < 18 kPa, the considerations of Annex F have to be started. First the liquid level height of the tank 'H' must be modified by increasing it by an amount = Pi (kPa) / (9,8 · G). Being G = Specific gravity of the stored liquid, according to Annex F 2.4 of API 650. Apart from this, as the internal pressure Pi > 2 KPa, the following cases to be considered must also be taken into account, which are summarised below:
        - If the following 2 conditions apply:
            - Pi (kPa) ≤ Weight of ceiling tiles (kPa = kN/m^2) and

- Pi (kPa) ≤ Weight of ceiling tiles (kPa = kN/m^2) + Roof structure (kPa = kN/m^2) + Weight of cylinder plates (kPa = kN/m^2) + Weight of all the structures gravitating on the cylinder (ladder, helicolidal stair…), Nozzles and Accessories gravitating on the cylinder:

  - A design shall be carried out under the considerations described in Annex F from F.1 to F.6 of API 650, which basically consist of:

    - *Limit compression area Cylinder/Ceiling according to F.5.*
    - *Not to exceed the maximum pressure Pmax*
    - *No anchorages will be required in the tank due to internal pressure*

- In the event that Pi (kPa) > Weight of ceiling tiles (kPa = kN/m^2) + Roof structure (kPa = kN/m^2) + Weight of cylinder plates (kPa = kN/m^2) + Weight of all the structures gravitating on the cylinder (ladder, helical stair…), Nozzles and Accessories gravitating on the cylinder:

  - *Anchorages will be required in the tank by internal pressure according to point F.7.*

- If finally Pi > 18 kPa, the considerations in Annex F should be used and in addition another calculation standard for this tank, which is API 620 for Design and Construction of Large, Welded, Low-Pressure Storage Tanks Not Greater Than *15 lbf/in² = 103 kPa*

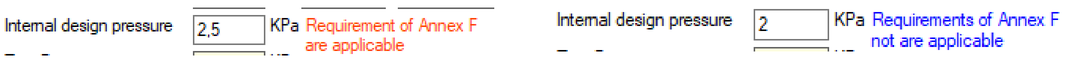


Figure 45.- Screen of the Rilotank 3D software where it automatically warns when it is not necessary to calculate with Annex F (if Pi >2 kPa) in the left image and when it is necessary to consider Annex F (if Pi >2 kPa) in the right image

If it is necessary to consider the calculation with API 650 Annex F, it will be done automatically with all checks in the corresponding screen, this Annex F screen can also be accessed by pressing the menu button: 

from the 'Actions' tab, and the screen shown in Figure 46 will be displayed:

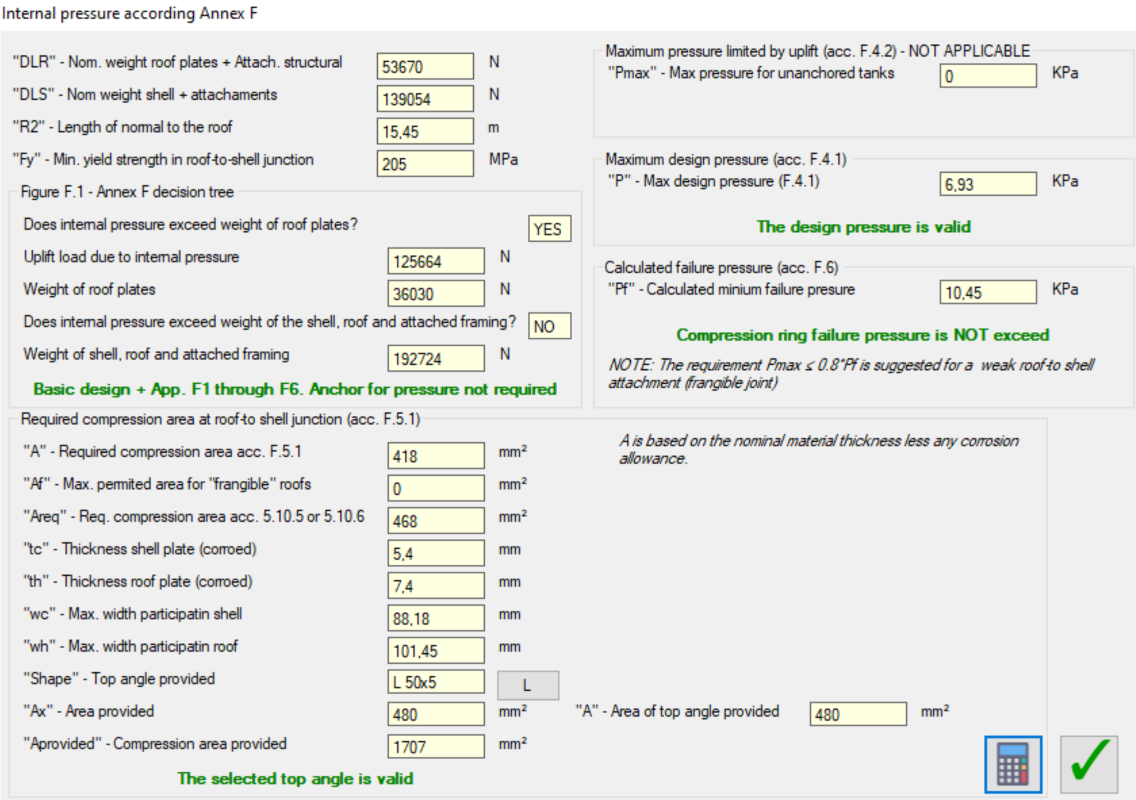


Figure 46.- Automated calculation screen of Annex F according to API 650 in the Rilotank 3D software, where all the checks carried out on Annex F can be seen

In the event that Pi > 18 kPa the message of the need to apply API 620 will be displayed (see figure 47):

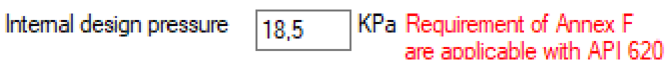
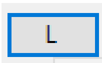
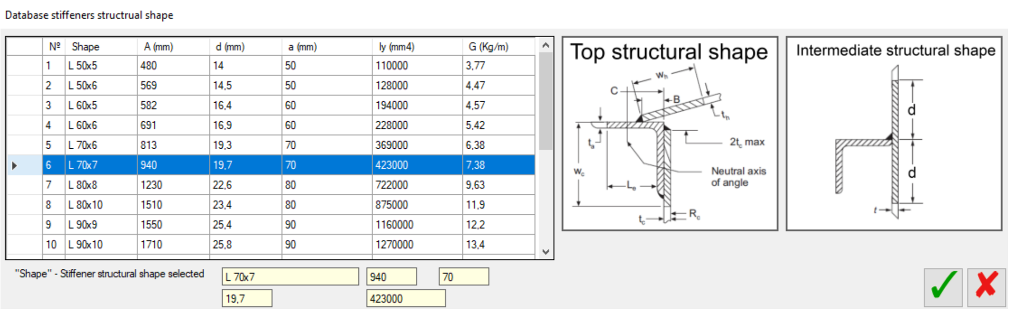


Figure 47.- Notice of the RiloTank 3D where the necessity of the applicability of API 620 is noted

On the screen in figure 46, where all the checks in Annex F are carried out, in point F.5.1 the required compression area in the Cylinder/Ceiling joint is checked, as mentioned above, and a top angle can be selected for this check to be carried out. By default the selected angle is always ‘L 50x5’ (in figure 46, it is valid as the text **‘The selected top angle is valid’** appears in green colour, but in case it is not valid and a red label appears, you can increase this angle by pressing the button , which will give access to the angle database to select another angle, see figure 47:



Nº	Shape	A (mm)	d (mm)	a (mm)	Iy (mm4)	G (Kg/m)
1	L 50x5	480	14	50	110000	3,77
2	L 50x6	569	14,5	50	128000	4,47
3	L 60x5	582	16,4	60	194000	4,57
4	L 60x6	691	16,9	60	228000	5,42
5	L 70x6	813	19,3	70	369000	6,38
6	L 70x7	940	19,7	70	423000	7,38
7	L 80x8	1230	22,6	80	722000	9,63
8	L 80x10	1510	23,4	80	875000	11,9
9	L 90x9	1550	25,4	90	1160000	12,2
10	L 90x10	1710	25,8	90	1270000	13,4

Figure 47.- Database screen of Top structural shape

Likewise, the angle selected as Top angle in the Cylinder/Ceiling joint will be reflected in the main screen of the software in the 'Wind' tab in the 'Top angle design' section, see figure 48:

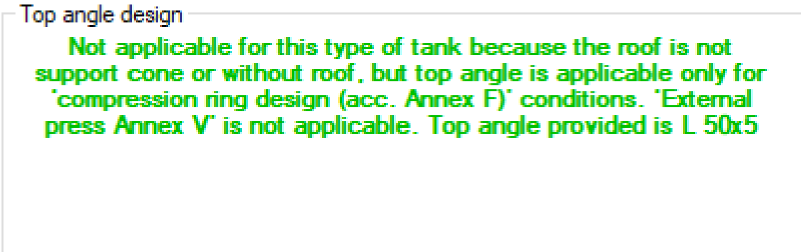


Figure 48.- Main screen of the software, in the 'Wind' tab you will find the 'Top angle design' section where you can see the indications of the calculation made and the angle selected

11. SEISMIC ACTION (ANNEX E – API 650)

The seismic action check according to Annex E API 650 takes place in the 'Seismic' tab of the main screen of the software, see figure 48. These checks according to Annex E API 650 are in accordance with ASCE 7-22

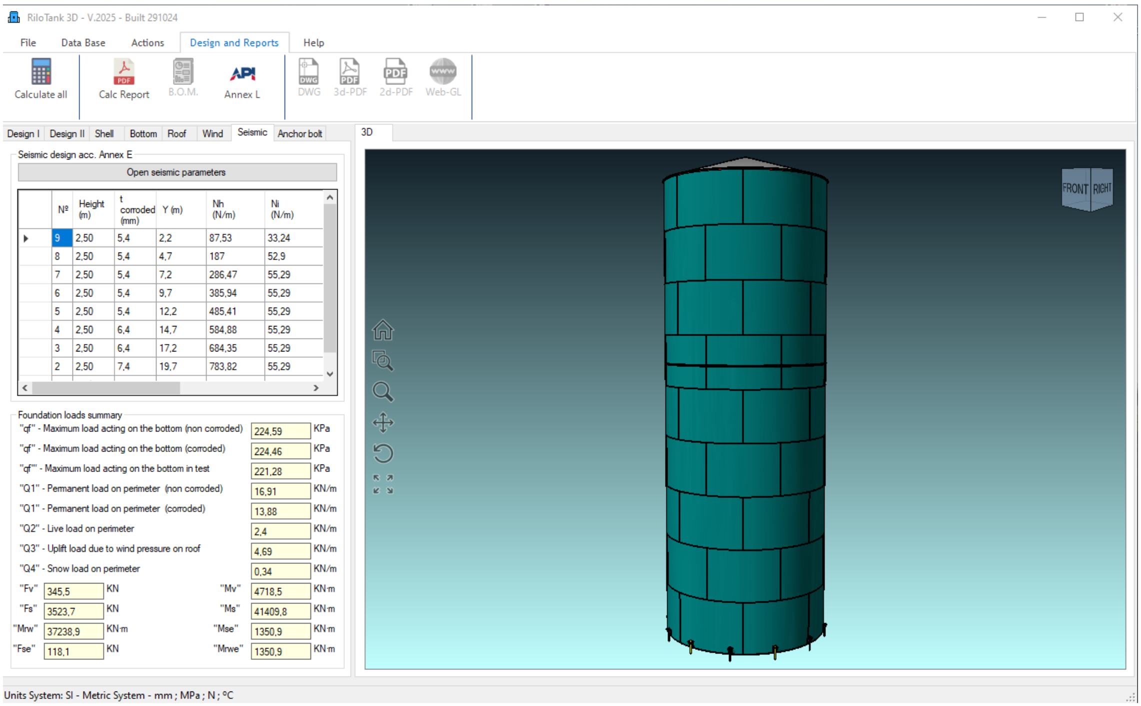


Figure 48.- "Seismic" tab where all API 650 Annex E checks take place

In addition to presenting the results of the seismic design in the table in the section 'Seismic design acc. Annex E', another section called 'Foundation loads summary' is also presented, which, as its name indicates, is the summary of the foundation loads, with which the foundation of the tank in question can be designed. In future versions of the software, the foundation design will be incorporated according to:

- Calculation of foundation ring according to ACI 318-19
- Anchor bolt-concrete cone test acc. to ACI 318-19

Thus, the design of the tank foundation will also be covered within the same software.

Returning to the seismic calculation, although this screen shows a table with all the seismic results, see figure 49, all the detailed calculations can be accessed by clicking on the 'Open seismic parameters' button.

n)	Nc (N/m)	σt (MPa)	σ allow (MPa)	Result
4	8,68	22,98	182,21	OK
	2,75	45,63	182,21	OK
9	0,87	65,81	182,21	OK
9	0,28	85,97	182,21	OK
9	0,09	106,37	182,21	OK
9	0,03	107,1	182,21	OK
9	0,01	124,55	182,21	OK
9	0	122,87	182,21	OK

Figure 49.- Summary table of seismic calculation results on the main screen of the software ('Seismic' tab). Because not all results fit in the table, you may have to scroll through the table to view the rest of the checks with the horizontal and vertical scrollbars.

By clicking on the 'Open seismic parameters' button, the 'Seismic design according Annex E - API 650' screen will appear (see figure 50):

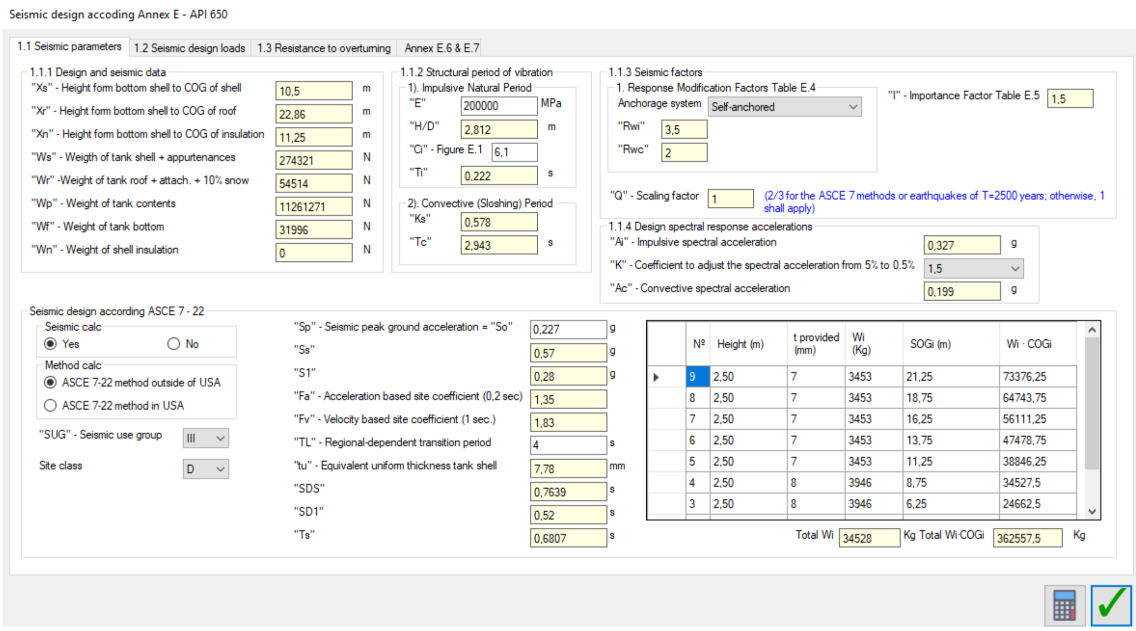


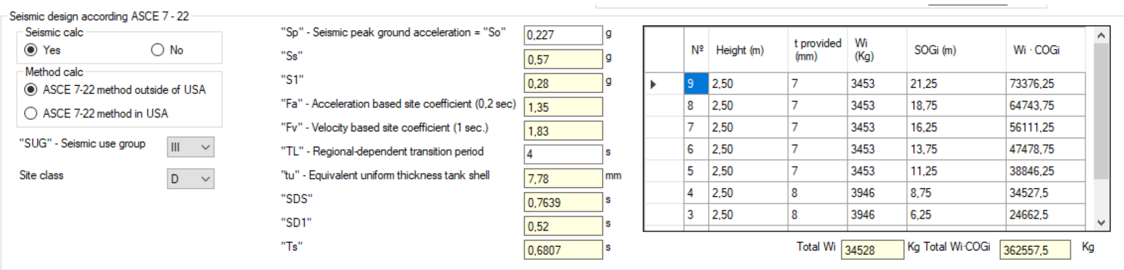
Figure 50.- Screen where all the seismic calculations are carried out in great detail

Several tabs appear on this screen, mainly due to the number of checks to be carried out in the seismic calculation according to Annex E. All the checks are detailed and grouped by tabs.

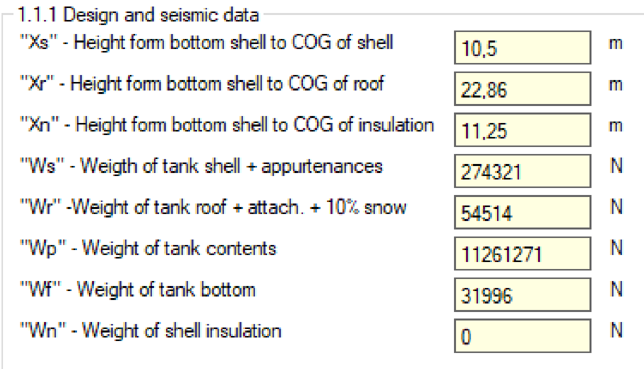
In essence, this screen is divided into the following tabs which incorporate the following checks:

- 1.1. Seismic parameters: It is divided into the following sections:
  - "Seismic design according ASCE 7-22".- In this section, the user enters the data in the white cells, indicates whether or not to carry out the seismic calculation and which

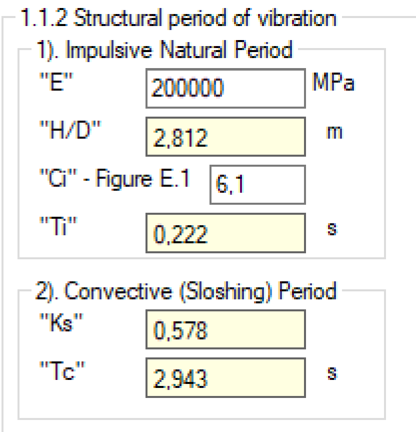
method will be used, and automatically finds the geometric data of the tank (centres of gravity, weights, heights) necessary to carry out the checks.



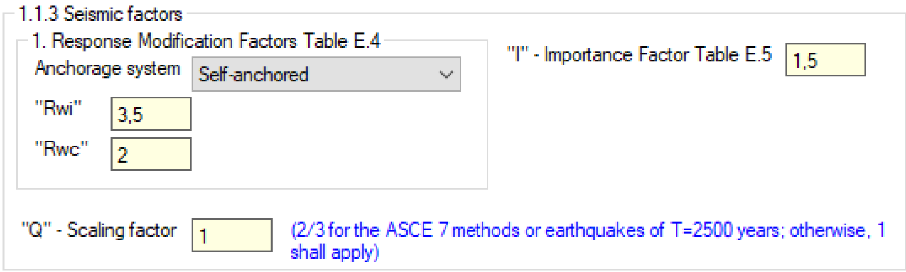
- "1.1.1 Design and seismic data".- It presents the results of heights at centres of gravity and weights, taking into account other loads gravitating in the tank, the user does not have to enter any data as all the results are provided automatically by the software, that is why the cells are all yellow in this section.



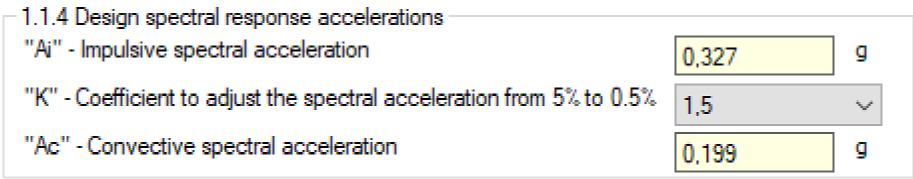
- 1.1.2 Structural period of vibration"



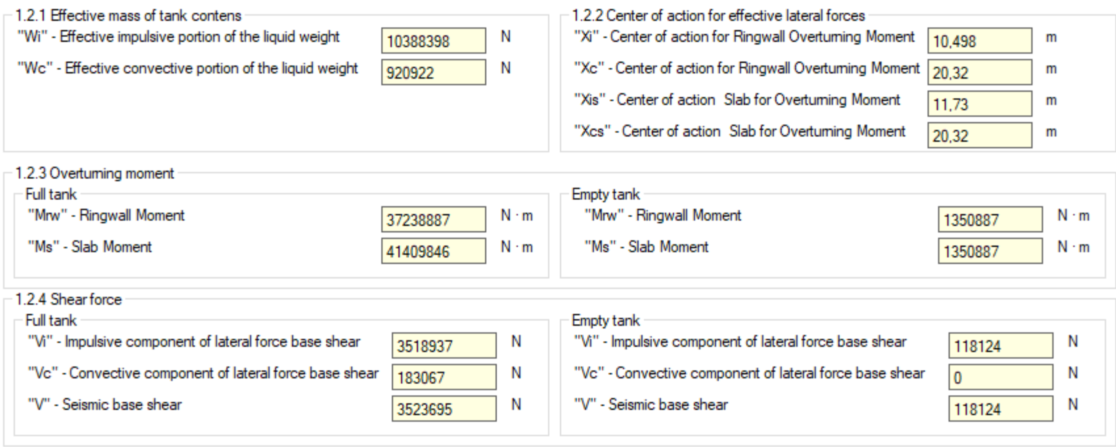
- "1.1.3 Seismic factors"



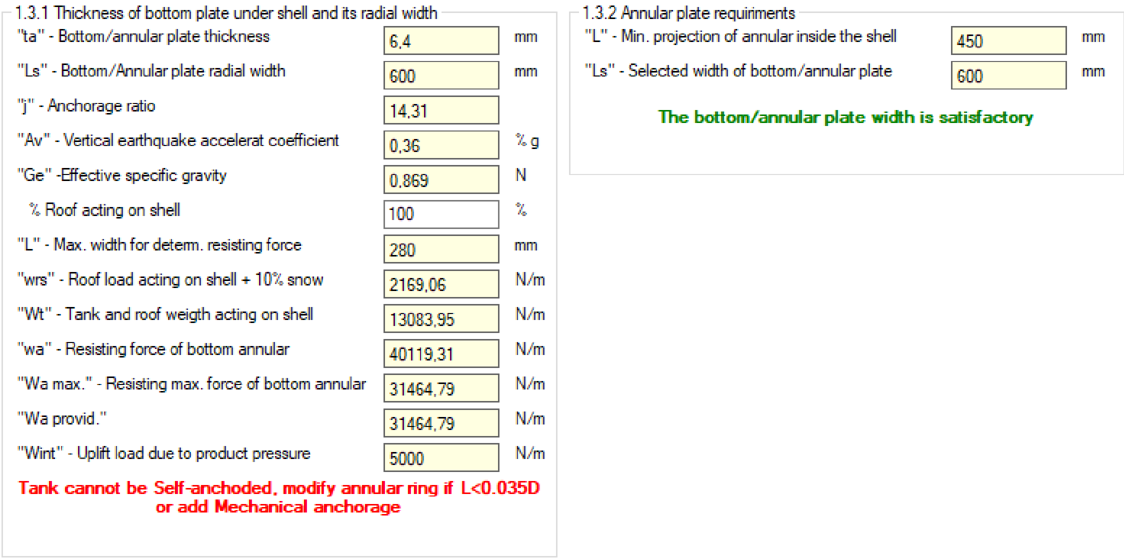
- "1.1.4 Design spectral response accelerations"



- 1.2. Seismic design loads: It is divided into several sections, where the calculation of the effective mass of the tank, the effective centres of action of lateral forces, and the calculation of moments with full and empty tank and shear forces with full and empty tank are performed automatically:



- 1.3. Resistance to overturning: This tab is used to check the overturning resistance of the tank against the action of earthquakes, indicating whether seismic anchorages are necessary and whether it is necessary to use a ring plate in the tank:



1.3.1 Thickness of bottom plate under shell and its radial width

"ta" - Bottom/annular plate thickness	6,4	mm
"Ls" - Bottom/Annular plate radial width	600	mm
"j" - Anchorage ratio	14,31	
"Av" - Vertical earthquake accelerat coefficient	0,36	% g
"Ge" -Effective specific gravity	0,869	N
% Roof acting on shell	100	%
"L" - Max. width for determ. resisting force	280	mm
"wrs" - Roof load acting on shell + 10% snow	2169,06	N/m
"Wt" - Tank and roof weigth acting on shell	13083,95	N/m
"wa" - Resisting force of bottom annular	40119,31	N/m
"Wa max." - Resisting max. force of bottom annular	31464,79	N/m
"Wa provid."	31464,79	N/m
"Wint" - Uplift load due to product pressure	5000	N/m

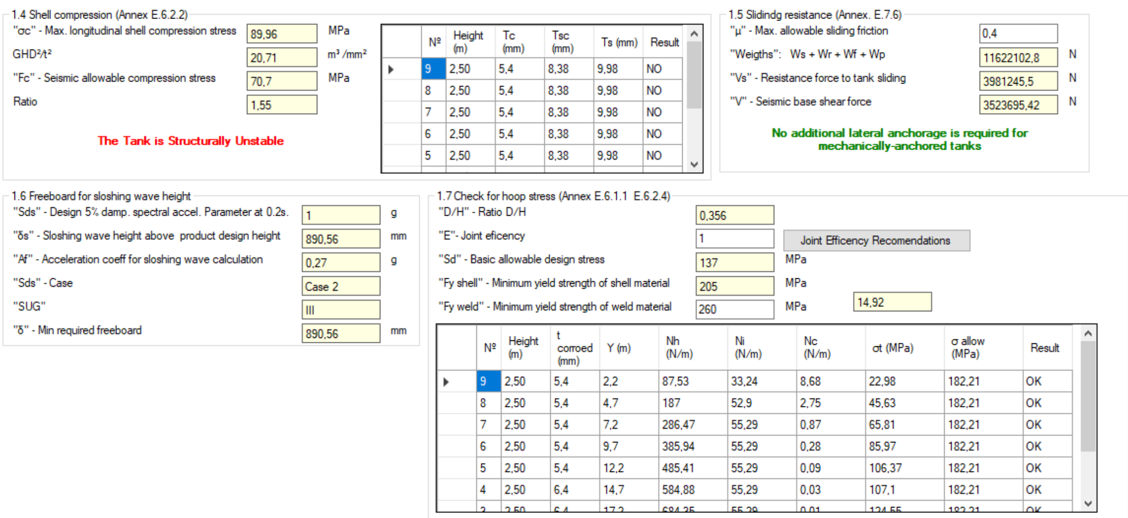
Tank cannot be Self-anchoded, modify annular ring if L<0.035D or add Mechanical anchorage

1.3.2 Annular plate requirements

"L" - Min. projection of annular inside the shell	450	mm
"Ls" - Selected width of bottom/annular plate	600	mm

The bottom/annular plate width is satisfactory

- "Annex E.6 y E.7".- In this last tab there are the checks of the compression of the cylinder due to seismic action, the resistance to tank sliding, possible surge problems in the upper part of the tank due to seismic action for the free edge design and the verification of the circumferential stress 'Hoop stress' which gives rise to instability phenomena in the lower part of the tank cylinder known as 'elephant foot deformation' caused by vertical seismic acceleration.



1.4 Shell compression (Annex E.6.2.2)

"σc" - Max. longitudinal shell compression stress	89,96	MPa
GHD²/t²	20,71	m³ /mm²
"Fc" - Seismic allowable compression stress	70,7	MPa
Ratio	1,55	

The Tank is Structurally Unstable

Nº	Height (m)	Tc (mm)	Tsc (mm)	Ts (mm)	Result
9	2,50	5,4	8,38	9,98	NO
8	2,50	5,4	8,38	9,98	NO
7	2,50	5,4	8,38	9,98	NO
6	2,50	5,4	8,38	9,98	NO
5	2,50	5,4	8,38	9,98	NO

1.5 Slidindg resistance (Annex. E.7.6)

"µ" - Max. allowable sliding friction	0,4	
"Weigths": Ws + Wr + Wf + Wp	11622102,8	N
"Vs" - Resistance force to tank sliding	3981245,5	N
"V" - Seismic base shear force	3523695,42	N

No additional lateral anchorage is required for mechanically-anchored tanks

1.6 Freeboard for sloshing wave height

"Sds" - Design 5% damp. spectral accel. Parameter at 0.2s.	1	g
"δs" - Sloshing wave height above product design height	890,56	mm
"Af" - Acceleration coeff for sloshing wave calculation	0,27	g
"Sds" - Case	Case 2	
"SUG"	III	
"δ" - Min required freeboard	890,56	mm

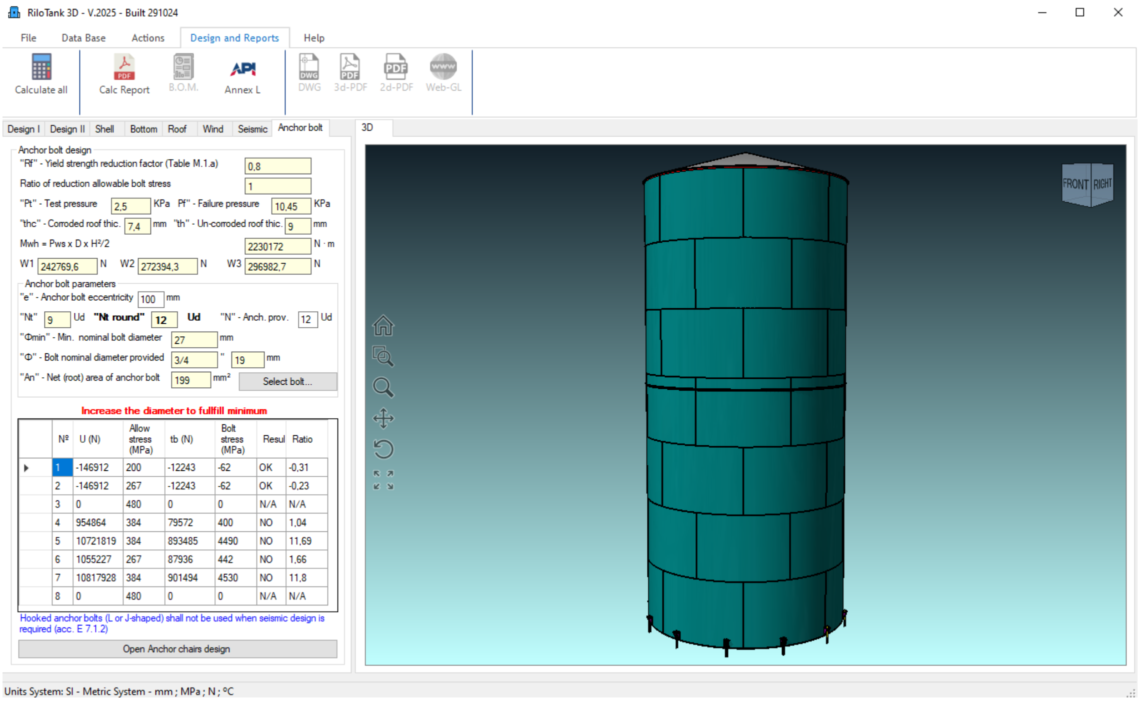
1.7 Check for hoop stress (Annex E.6.1.1 E.6.2.4)

"D/H" - Ratio D/H	0,356	
"E"- Joint eficency	1	Joint Efficency Recomendations
"Sd" - Basic allowable design stress	137	MPa
"Fy shell" - Minimum yield strength of shell material	205	MPa
"Fy weld" - Minimum yield strength of weld material	260	MPa 14,92

Nº	Height (m)	t corroed (mm)	Y (m)	Nh (N/m)	Ni (N/m)	Nc (N/m)	σt (MPa)	σ allow (MPa)	Result
9	2,50	5,4	2,2	87,53	33,24	8,68	22,98	182,21	OK
8	2,50	5,4	4,7	187	52,9	2,75	45,63	182,21	OK
7	2,50	5,4	7,2	286,47	55,29	0,87	65,81	182,21	OK
6	2,50	5,4	9,7	385,94	55,29	0,28	85,97	182,21	OK
5	2,50	5,4	12,2	485,41	55,29	0,09	106,37	182,21	OK
4	2,50	6,4	14,7	584,88	55,29	0,03	107,1	182,21	OK

12. ANCHOR BOLT DESIGN

In the 'Anchor bolt' tab of the main screen, the calculation of the anchor bolt is carried out and a new screen is also accessed by clicking on the 'Open Anchor chairs design' button on the anchor chair, see figure 51:



Nº	U (N)	Allow stress (MPa)	tb (N)	Bolt stress (MPa)	Resul	Ratio
1	-146912	200	-12243	-62	OK	-0,31
2	-146912	267	-12243	-62	OK	-0,23
3	0	480	0	0	N/A	N/A
4	954864	384	79572	400	NO	1,04
5	10721819	384	893485	4490	NO	11,69
6	1055227	267	87936	442	NO	1,66
7	10817928	384	901494	4530	NO	11,8
8	0	480	0	0	N/A	N/A

Figure 51.- Screen where all the calculation of anchor bolts and anchor chairs is carried out.

The first section of this screen, called ‘Anchor bolt design’ presents the automated calculation of the bolt design, in which no user intervention is necessary (hence all cells are yellow), as only results are presented, taking into account the reduction of the permissible bolt stress as a ratio according to Annex M.3.7, the test pressure according to Annex F.4.4 or F.7.5, etc., see figure 51:

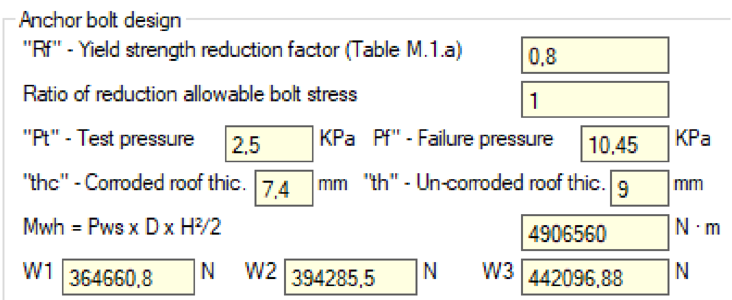


Figure 52.- Anchor Bolt Test Results Section

In the second section, all the parameters used for the calculation of said bolt appear, and the user must indicate the value of the bolt eccentricity “e” (distance from the cylinder to the bolt axis (see figure 53), taking into account that the designed saddle will be the typical one presented by the API 650 standard in its figure 5.28).

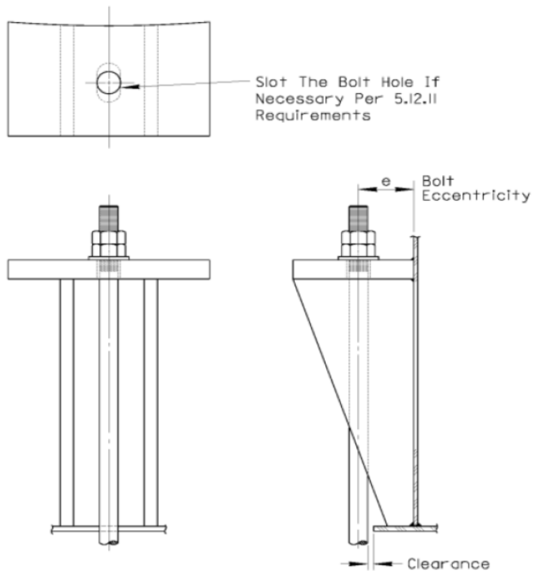


Figure 5.28—Typical Anchor Chair

Figure 53.- Typical figure 5.28 of the API 650 standard, which shows the saddle typology designed by the software and where the distance in mm from the bolt eccentricity "e" must be entered. Other saddle typologies are presented in API 650, in figures 5.29 and 5.30.

The table in this section shows the 8 checks that cause traction and lifting loads on the anchor bolts, carried out and required according to table 5.20.a of API 650.

Table 5.20a—Uplift Loads (SI)

Uplift Load Case	Net Uplift Formula, U (N)	Allowable Anchor Bolt or Anchor Strap Stress (MPa)	Allowable Shell Stress at Anchor Attachment (MPa)
Design Pressure	$[P_i \times D^2 \times 785] - W_1$	$5/12 \times F_y$	$2/3\ F_{ty}$
Test Pressure	$[P_t \times D^2 \times 785] - W_3$	$5/9 \times F_y$	$5/6\ F_{ty}$
Wind Load	$P_{WR} \times D^2 \times 785 + [4 \times M_{WS}/D] - W_2$	$0.8 \times F_y$	$5/6\ F_{ty}$
Seismic Load	$[4 \times M_{rw}/D] - W_2\ (1 - 0.4A_V)$	$0.8 \times F_y$	$5/6\ F_{ty}$
Design Pressure[a] + Wind	$[(F_p\ P_i + P_{WR}) \times D^2 \times 785] + [4\ M_{WS}/D] - W_1$	$5/9 \times F_y$	$5/6\ F_{ty}$
Design Pressure[a] + Seismic	$[F_p\ P_i \times D^2 \times 785] + [4\ M_{rw}/D] - W_1\ (1 - 0.4A_V)$	$0.8 \times F_y$	$5/6\ F_{ty}$
Frangibility Pressure[b]	$[3 \times P_f \times D^2 \times 785] - W_3$	F_y	F_{ty}

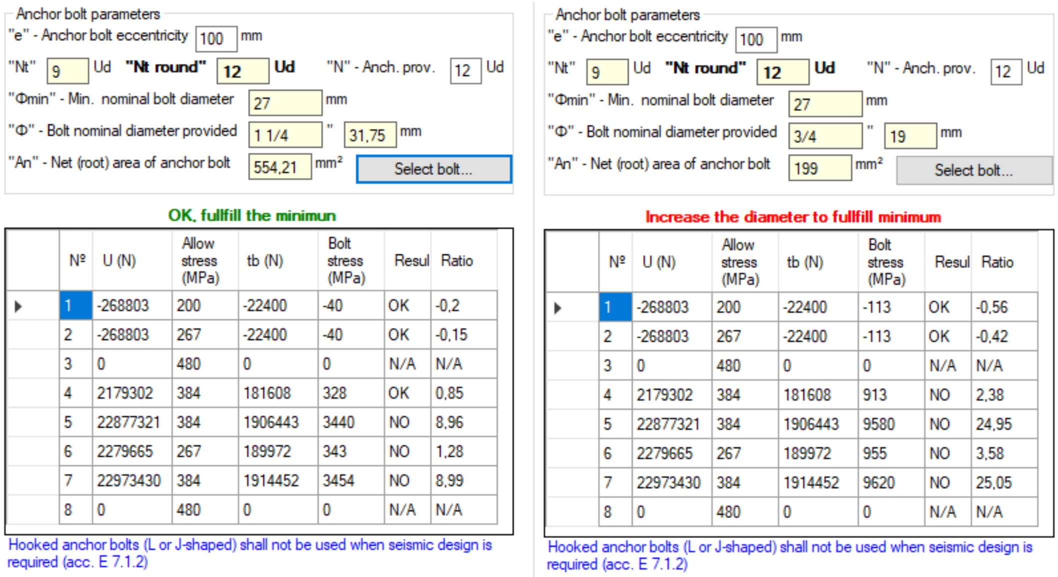
where

- A_v is the vertical earthquake acceleration coefficient, in % g;
- D is the tank diameter, in meters;
- F_p is the pressure combination factor;
- F_{ty} is the minimum yield strength of the bottom shell course, in MPa;
- F_y is the minimum yield strength of the anchor bolt or strap; bolts are limited to specified material minimum yield strength or 380 MPa, whichever is less, in MPa; anchor strap material minimum yield strength shall not exceed the minimum yield strength of the shell;
- H is the tank height, in meters;
- M_{WS} equals $P_{WS} \times D \times H^2/2$, in N-m;
- M_{rw} is the seismic moment, in N-m (see Annex E);
- P_i is the design internal pressure, in kPa (see Annex F);
- P_f is the failure pressure, in kPa (see Annex F);
- P_t is the test pressure, in kPa (see Annex F);
- P_{WR} is the wind uplift pressure on roof, in kPa; for supported cone roofs meeting the requirements of 5.10.4, P_{WR} shall be taken as zero;
- P_{WS} is the wind pressure on shell, in N/m^2;
- W_1 is the corroded weight of the roof plates plus the corroded weight of the shell and any other corroded permanent attachments acting on the shell, in N;
- W_2 is the corroded weight of the shell and any corroded permanent attachments acting on the shell including the portion of the roof plates and framing acting on the shell, in N;
- W_3 is the nominal weight of the roof plates plus the nominal weight of the shell and any other permanent attachments acting on the shell, in N.

[a] Refer to 5.2.2 concerning the pressure combination factor applied to the design pressure.

[b] Frangibility pressure applies only to tanks designed to 5.10.2.6 d.

All of these results can be seen in the table presented in the "Anchor Bolt" tab of the software's main screen, see figure 54. For the selected bolt to comply, a green text should appear above the table: **"OK, fullfill the minimum."** If the selected bolt does not comply, the red text **"Increase the diameter to fullfill minimum"** will appear, see figure 54:

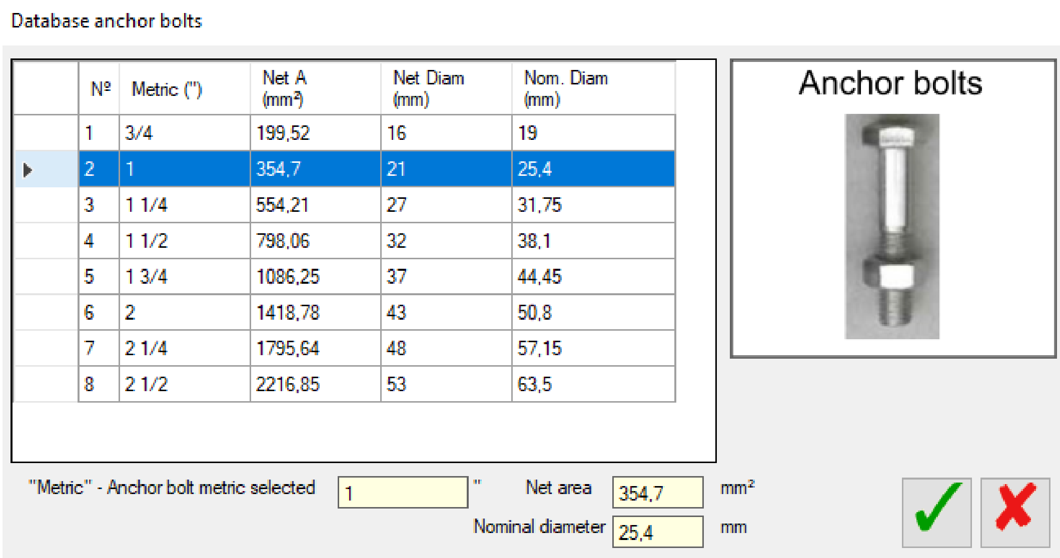


Nº	U (N)	Allow stress (MPa)	tb (N)	Bolt stress (MPa)	Resul	Ratio
1	-268803	200	-22400	-40	OK	-0,2
2	-268803	267	-22400	-40	OK	-0,15
3	0	480	0	0	N/A	N/A
4	2179302	384	181608	328	OK	0,85
5	22877321	384	1906443	3440	NO	8,96
6	2279665	267	189972	343	NO	1,28
7	22973430	384	1914452	3454	NO	8,99
8	0	480	0	0	N/A	N/A

Nº	U (N)	Allow stress (MPa)	tb (N)	Bolt stress (MPa)	Resul	Ratio
1	-268803	200	-22400	-113	OK	-0,56
2	-268803	267	-22400	-113	OK	-0,42
3	0	480	0	0	N/A	N/A
4	2179302	384	181608	913	NO	2,38
5	22877321	384	1906443	9580	NO	24,95
6	2279665	267	189972	955	NO	3,58
7	22973430	384	1914452	9620	NO	25,05
8	0	480	0	0	N/A	N/A

Figure 54.- Anchor bolt calculation results, with the 8 checks performed. On the left, when the selected bolt meets the requirements, and on the right, when it does not meet the requirements, requiring an increase in the bolt diameter.

To select a new bolt with a larger diameter when it does not meet the requirements, simply press the button. Select bolt... , a new window will open with the bolt database so you can select a larger one, see figure 55:



Nº	Metric (")	Net A (mm²)	Net Diam (mm)	Nom. Diam (mm)
1	3/4	199,52	16	19
2	1	354,7	21	25,4
3	1 1/4	554,21	27	31,75
4	1 1/2	798,06	32	38,1
5	1 3/4	1086,25	37	44,45
6	2	1418,78	43	50,8
7	2 1/4	1795,64	48	57,15
8	2 1/2	2216,85	53	63,5

Figure 55.- Anchor bolt database

Once the new anchor bolt has been selected, close the database by pressing the button ✓ and immediately recalculate everything by pressing the button "Calculate all" Calculate all from the "Design and

Reports" tab, as the changes will then not take effect. **It is very important to remember that when making any data changes in the software, you must always immediately press the "Calculate all" button so that these changes are reflected in the new calculation, otherwise the results will not be updated and will be incorrect.**

Please note that the software indicates a minimum bolt diameter in millimeters required to meet all the conditions in the "Ømin Min. Nominal bolt diameter" section (see figure 54). Once a bolt with a larger diameter is selected from the bolt database, as shown in the "Ø Bolt nominal diameter provided" section (see figure 54), all the checks in the table will be met.

13. ANCHOR CHAIRS DESIGN

In the "Anchor bolt" tab and pressing the "Open Anchor chairs design" button you will access the anchor chairs calculation screen where the bolts calculated in the previous section will be screwed in, see figure 56:

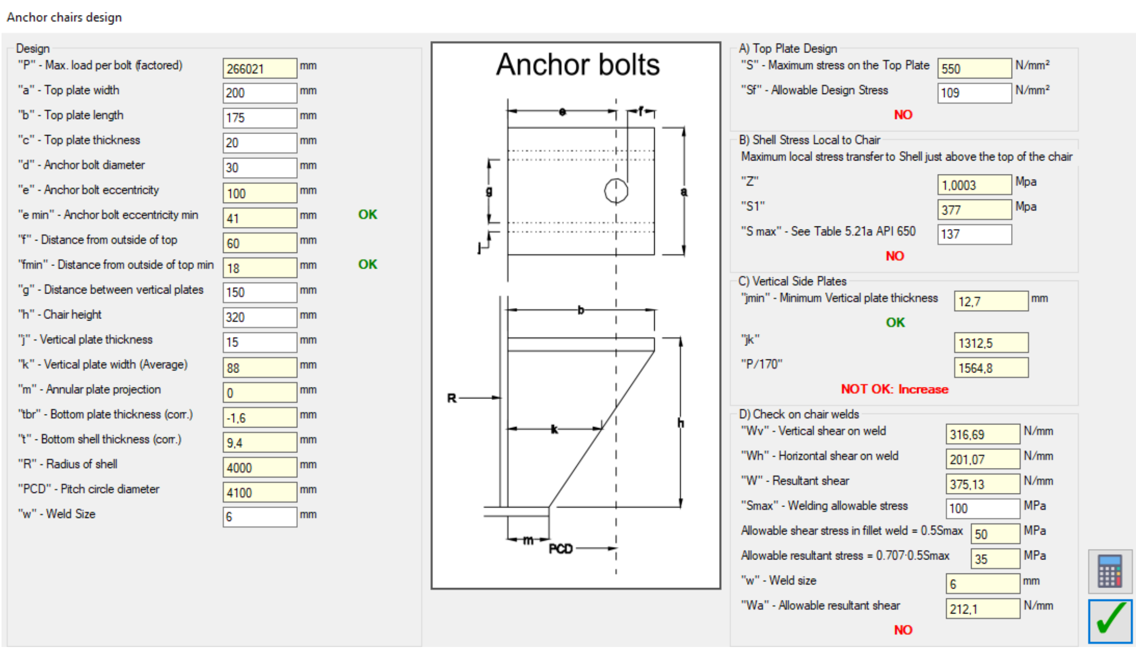


Figure 56.- Screen where the calculation of the anchor chairs is carried out

As we have mentioned, the type of saddle designed is based on Figure 5.28. There are white cells that can be modified by the user and correspond to the measurements and dimensions of the different elements displayed in the figure on the screen. The remaining yellow cells represent the results provided by the calculation software. This calculation and verification of the anchor chair are based on the publication *"Steel Plate Engineering Data Vol. II Part VII"* in addition to the guidelines indicated by API 650. The verifications performed are as follows:

- Top Plate design: Design of the top plate of the saddle
- Shell Stress Local to Chair
- Vertical Side Plates

- Check on chair welds

As usual, when any of these checks are not met, texts will appear in red **"NO"**, and when they are met, they will appear in green **"OK"**. It is most likely that some check is not met and the measurements of the anchor chair must be modified and the "Calculate" button that appears on the same screen must be pressed. , until all checks appear with a green label **"OK"**, see figure 57:

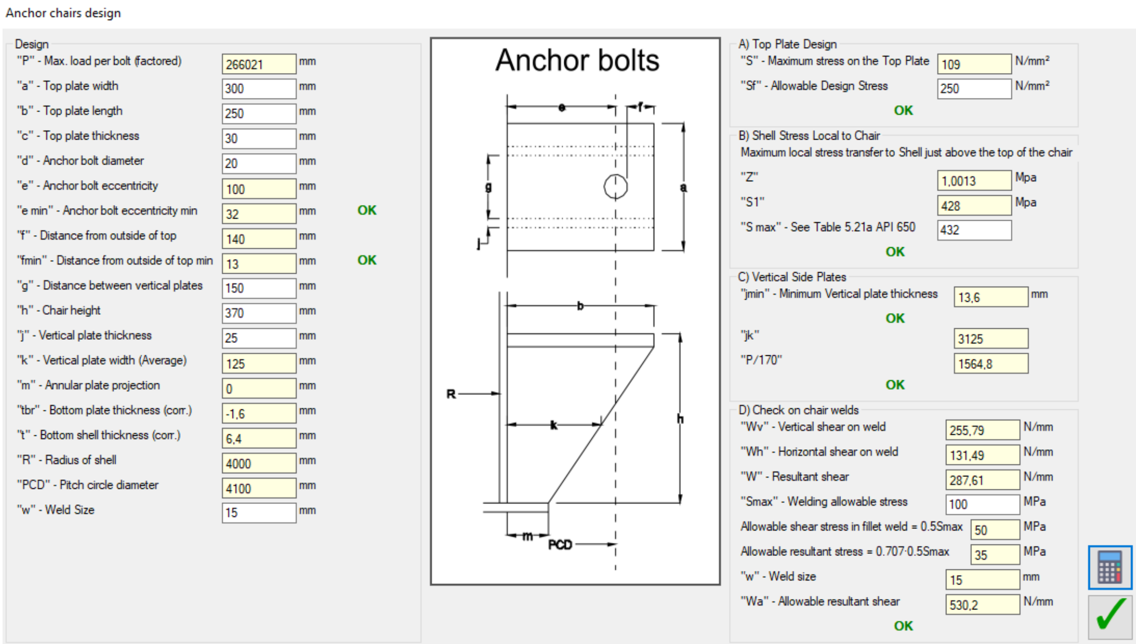


Figure 57.- Screen where the calculation of the anchor chair is carried out, with all checks "OK"

14. GENERATION OF CALCULATION REPORTS AND ANNEX L - API 650

In the "Design and Reports" menu tab (see figure 58), there is a "Calc Report" button. Clicking it will issue the full calculation report with all the checks and results performed by the software. Obviously, it is best to first perform the calculation for the entire tank by clicking the "Calculate All" button before launching the calculation report. If some data has been modified and the "Calculate All" button is not clicked again, the results will not be updated with the new data entered, resulting in an erroneous report. Therefore, it is essential to always click the "Calculate All" button before clicking the "Calc Report" button to ensure that all calculations have been updated.

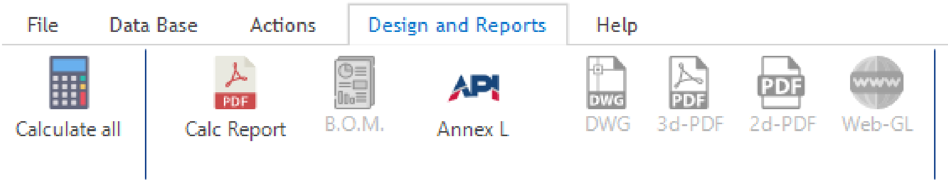


Figure 58.- "Design and Reports" menu tab where you can calculate the tank and present the calculation reports, and the completed report of Annex L API 650. The rest of the buttons are deactivated, but in future versions they will be active to print the detailed report of the bill of materials 'B.O.M.', as well as the export of the 3D drawing in PDF-3D and other formats such as Web-GL, among other possibilities.

The "Calc Report" button allows you to view a report with approximately 50 pages on screen (see figure 59) and print it directly, or export it to PDF or WORD formats for later editing (see figure 60).

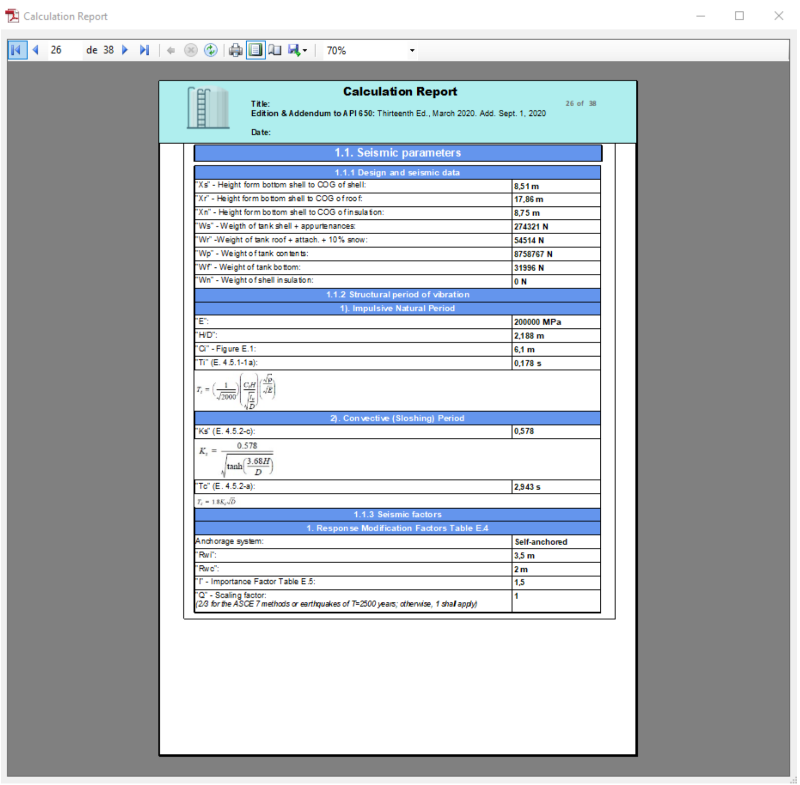


Figure 59.- Report presented on screen, for printing or exporting in PDF or WORD

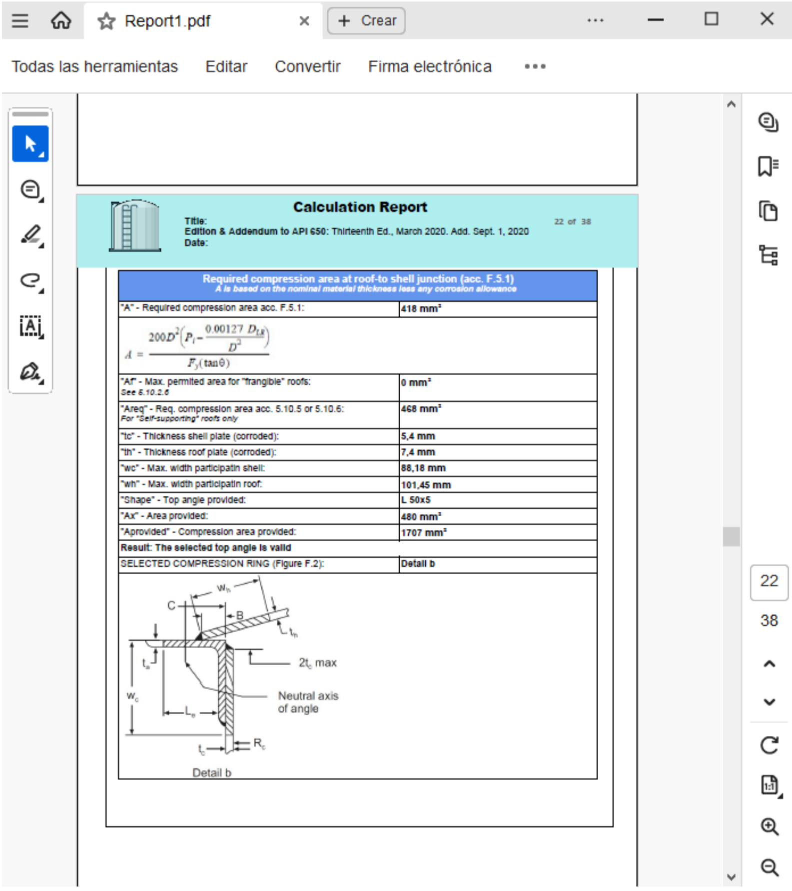


Figure 60.- Report presented on screen, for printing or exporting in PDF or WORD

By clicking the "Annex L" menu button, a new screen will appear with all the project data according to Annex L in its various sections. Some of the sections from the calculations will be filled in (thicknesses found, tank construction materials, etc.). See figure 61:

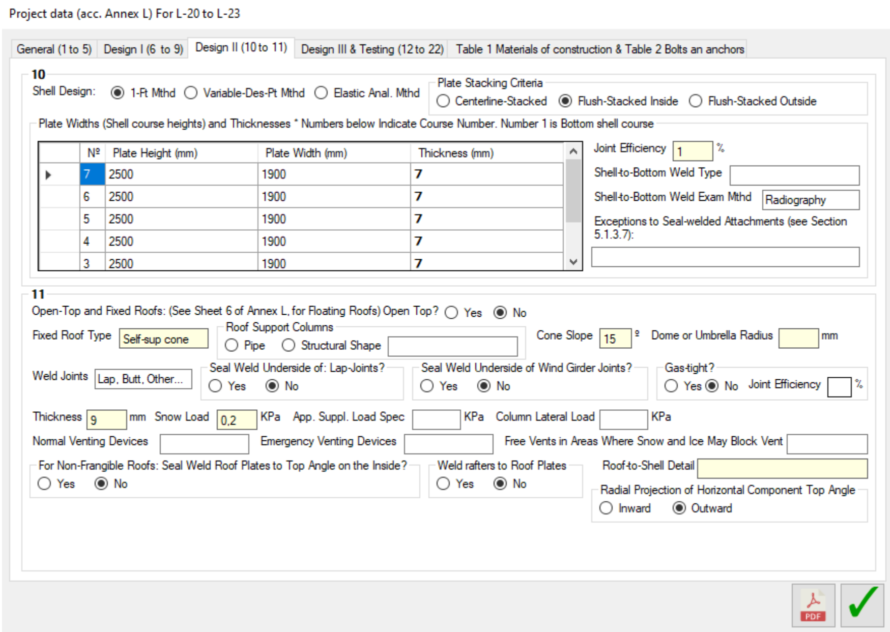


Figure 61.- Annex L screen, with the sections from the calculation automatically filled in

Other sections, however, must be filled out on this screen (such as Manufacturer, Purchaser, Address, etc.), see figure 62:

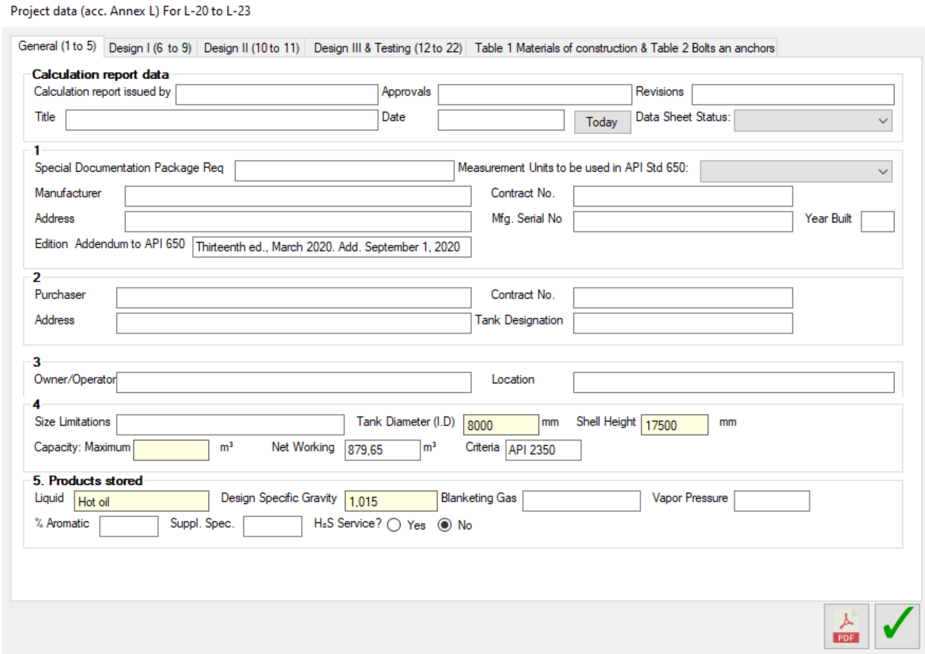


Figure 62.- Calculation report exported in PDF

By pressing the button [PDF] from this screen a new window will appear to print, or export to PDF or WORD Annex L as it appears in the API 650 standard, see figure 63.

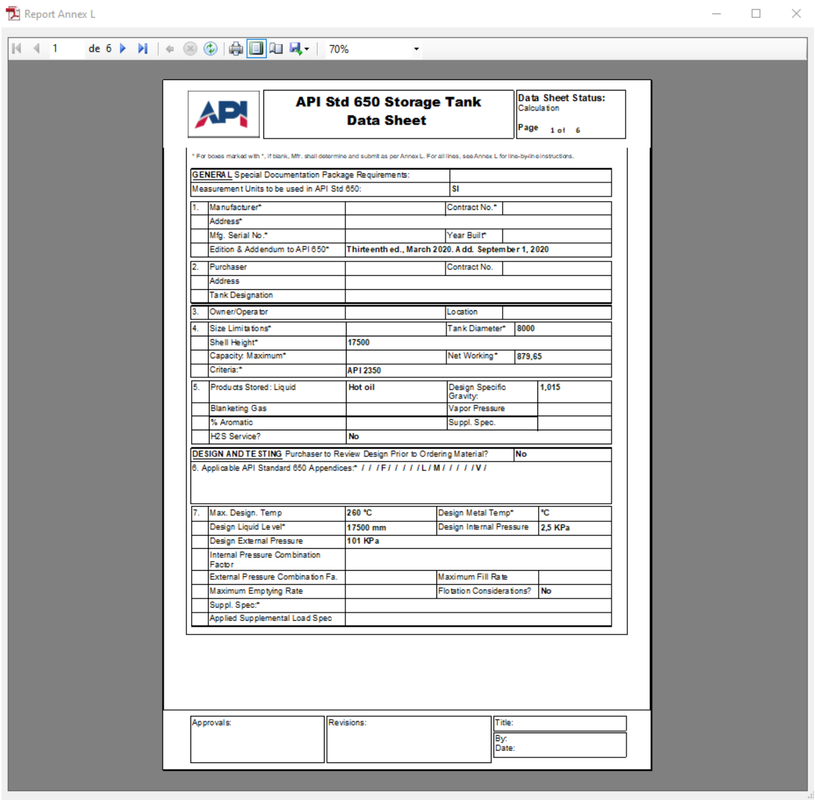


Figure 63.- API 650 Annex L ready for printing or exporting to PDF or WORD

15. HELP AND SUPPORT

To access help, in the “Help” menu tab, you can directly open the PDF manual by clicking on the “Manual” button, see figure 64:

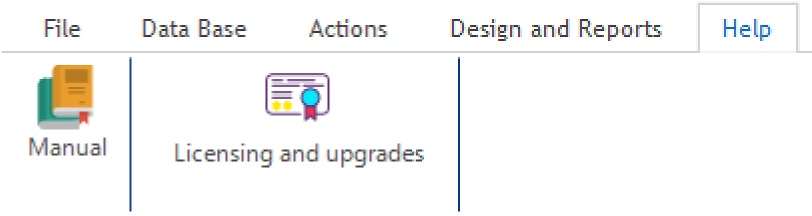


Figure 64.- Access to program manual

Additionally, our YouTube channel features numerous videos specifically designed for easy learning, explaining step-by-step each and every one of the procedures for using the different parts of the software. In addition to quickly learning how to use the application (which is very simple), the videos are also rich in information, presenting the equations, articles, and calculations of the API 650 standard. These videos also provide a wealth of information for learning how to use this standard. These videos include recommendations and links to other sources of information such as articles, presentations, etc.

Therefore, we encourage you to visit our YouTube channel regularly:

https://www.youtube.com/@Rilotank

YouTube

16. NEXT VERSION 2026 PROFESSIONAL

The next version of Rilotank 3D, which will be version 2026 and is already being worked on, will incorporate the following improvements:

- Structural conical roof calculations
- Saving and opening internal calculation files with an *.api extension will be allowed in the application
- Detailed generation of BOM reports
- • Generation of 3D drawings exportable to 3D PDF, Web-GL, etc
- Design and verification of cylinder and tank roof openings (nozzles) and direct addition to the 3D drawing

- Vent calculations for atmospheric and low-pressure storage tanks according to the 7th edition of API 2000

- Design of retaining wall foundation design according to ACI 318-19 and API 650 Annex B, E, F, and I

- Saving and opening internal software calculation files

- Generation of detailed BOM reports and new manufacturing materials: stainless steel, duplex...

- Generation of 3D drawings and export in PDF, DWG... formats

- And many more calculations

Visit https://www.rilotank.com regularly to stay up to date with new updates to our software.

For more info: rilotank3d@gmail.com