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# BASIC COMPARISON OF SELECTED STRUCTURAL STEEL STRENGTH INFLUENCE ON TOTAL WELDING FABRICATION COSTS OF OIL STORAGE TANKS

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## ABSTRACT
*Uses of lighter, stronger, reliable and cheaper welded steel structures are constant trends. There is a various industrial application where structural steels with higher strength replace conventional low strength structural steels. This paper will outline basic comparison of three type of structural steel selection influence on total welding fabrication costs of atmospheric oil storage steel tanks (design and fabrication according to API 650). However, there are a number of parameters which may influence welding fabrication costs, as well as different company's experiences, and therefore provided calculation assumptions in this paper do not have any intention to underestimate them.*
*While considering typical types of structural steels, i.e. S235, S275 and S355 (acc. to EN 10025) the basic parameters which influence its selection on total welding fabrication costs are described. In particular, paper will outline selection influence related to size of oil storage tank. In addition, only one particular type of tank shall be evaluated, i.e. oil storage tank with fixed roof within its size limits applicable for oil industry.*
*While considering minimum required thickness of shell structure as defined in API 650 according to selected structural steel, and almost non-affected thickness of roof and bottom, the main influencing parameter, i.e. sizes of tank shell butt weld joints shall be evaluated. In all cases, the same possibly applied welding technology shall be considered, while considering appropriate filler material strength class.*
*Finally, range of total welding fabrication costs savings due to the use of stronger structural steel shall be outlined in relation to oil storage steel tank size, as well as used spreadsheet calculation.*
**Keywords:** structural steel, strength, welding fabrication, costs, oil storage tank, API 650

## 1. BASIC ELEMENTS OF OIL STORAGE TANK AND USED MATERIALS
Atmospheric oil storage tanks represent a welded steel structure for temporary storage or processing of petroleum products or crude oil. Design and fabrication of those tanks is defined in accordance to various international standards, while the most used is American Petroleum Institute standard – API 650. The main components of tank welded structure are shown on Figure 1. Particularly, tank bottom, shell and roof are the basic parts. The most used material for their fabrication are low carbon structural steel. However, other types of structural steels as low-alloy steel, stainless steel or aluminium may be used for particular components in accordance to design specification.
For purpose of this paper, the oil storage tank with fixed roof shall be evaluated. Allowed range of sizes of this type oil storage tank is from 3 to 60 meters in diameter. In addition, height of tank may be in range from 1 to 22 meters. Therefore, nominal capacities of atmospheric oil storage tanks may be from 7 to 62.200 $m^3$. However, particular size and type of oil storage tank must be carefully considered due to flash-point class of stored petroleum product.
For evaluation of structural steel strength influence on welding fabrication costs of oil storage tank, the steels S235, S275 and S355 - strength class shall be used. Typical weld joint details of basic tank

components, i.e. bottom, shell and roof, are shown on Figure 2, in accordance to various material thicknesses.

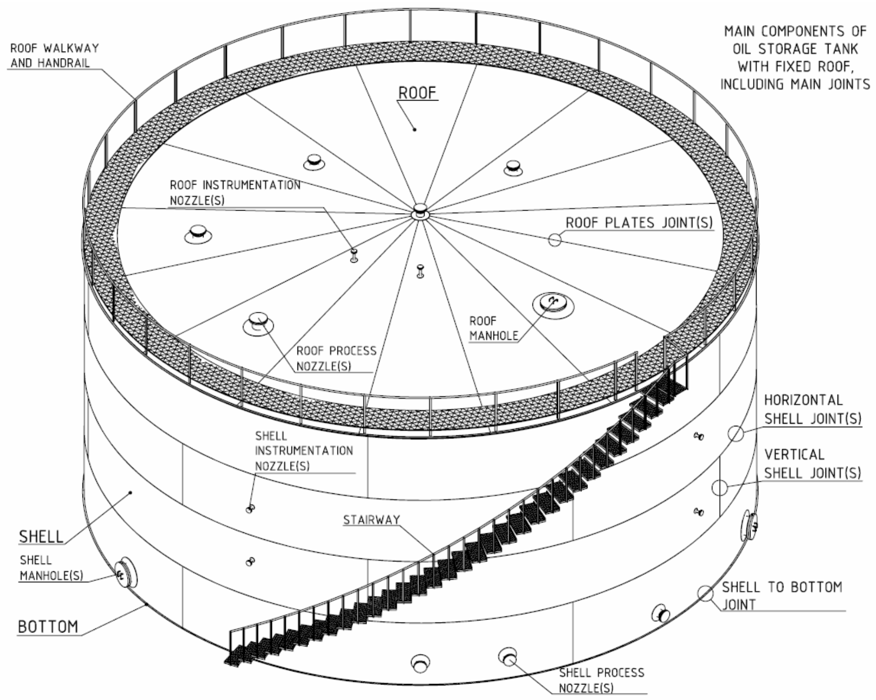



*Figure 1. Basic parts of oil storage tank with fixed roof [3]*

While bottom and roof thickness are mostly non affected by structural steel strength, a tank shell depends, according to following formulas [1]:

$$t_d = \frac{4.9D(H-0.3)G}{S_d} + CA$$

$$t_t = \frac{4.9D(H-0.3)}{S_t} \quad ...(1)$$

where, $t_d$ and $t_t$ [mm] are design shell thickness and hydrostatic test shell thickness, respectively; $D$ [m] is nominal tank diameter and $H$ [m] is design liquid level; $G$ is design specific gravity, and $CA$ [mm] is corrosion allowance.

In formulae(s) (1) variables $S_d$ and $S_t$ [MPa] represent allowable stress for the design condition, and allowable stress for the hydrostatic test condition [MPa], respectively [1].

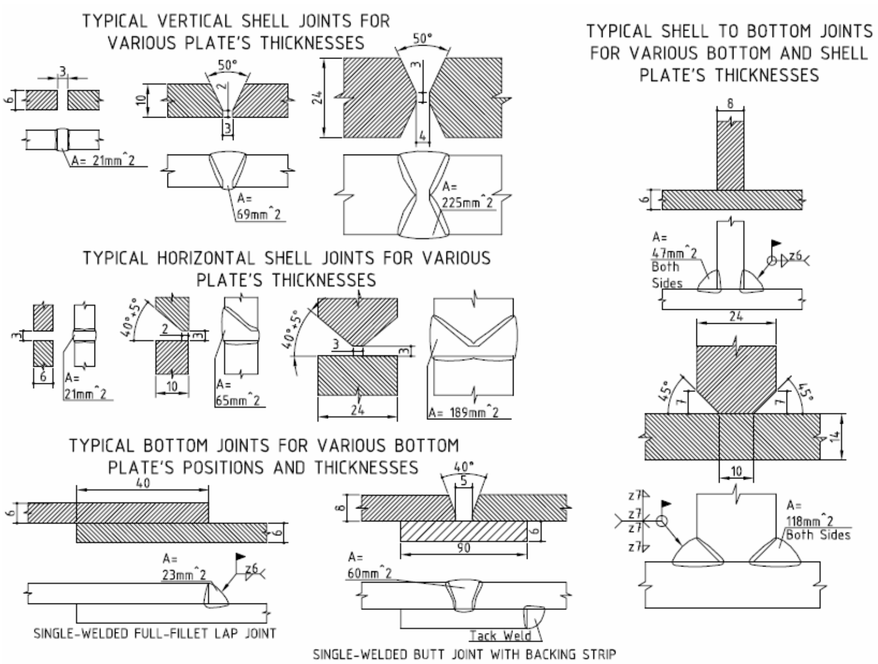



*Figure 2. Typical weld joints of oil storage tank according to various material thicknesses - API 650 and good engineering practice [1,2,3]*

For fabrication welding of oil storage tank a various arc welding processes are allowed, as SMAW, GMAW, FCAW, SS-FCAW [2], SAW. However, use of particular welding process is strongly dependent on company's experiences, welding positions, shielding possibilities, and finally on client's approval.

For the simplification purposes of this paper, a common arc welding process shall be selected for fabrication, i.e. SS-FCAW – *Self Shielded – Flux Cored Arc Welding*.

However, there are a number of parameters which may influence welding fabrication costs, as well as different company's experiences, and therefore provided calculation assumptions in this paper do not have any attention to underestimate them.

Basic data of structural steels used for this evaluation are presented in following table.

*Table 1. Basic data of structural steel used for evaluation*

| Structural steel | acc. to. EN 10025 | | acc. to. API 650 | |
|---|---|---|---|---|
| | $R_{p(0,2)}$ [MPa] | $R_m$ [MPa] | $S_d$ [MPa] | $S_t$ [MPa] |
| S235JR | min 235 | 360-510 | 137 | 154 |
| S275JR | min 275 | 410-560 | 164 | 175 |
| S355JR | min 355 | 470-630 | 196 | 210 |

Five (5) different sizes of fixed roof oil storage tank are used for evaluation. Chosen sizes are: 400m$^3$, 2000m$^3$, 10000m$^3$, 25000m$^3$ and 56500m$^3$. Main dimensions (diameter x height in metres) of selected tanks are: 8x8, 16x10, 30x14, 42x18 and 60x20 respectively.
While taking into consideration experiences in design of similar tank sizes, as well as requirements of design standard [1], thickness of bottom plates does not depend on selection of structural steel strength. Therefore, for all tank sizes, common steel for bottom shall be considered, i.e. S235. In addition, steel S235 shall be in all cases selected material for stairway, handrail and walkway structure. Finally, higher grade structural steel, i.e. S275 and S355 shall be selected for shell, shell accessories, roof, roof accessories, roof structure and wind girder while comparing selection of structural steel strength influence on total welding fabrication costs.

Example of selected shell thicknesses according to design calculation [1,3] for one typical selected tank size are presented in following table (including 1 mm of corrosion allowance).

*Table 2. Example of selected shell thicknesses and corresponding weights for 10.000m$^3$ tank size*

| Course (Section of Shell) | ***S235*** | | | ***S275*** | | | ***S355*** | | |
|---|---|---|---|---|---|---|---|---|---|
| | $t_S$ [mm] | plates [kg] | welds [kg] | $t_S$ [mm] | plates [kg] | welds [kg] | $t_S$ [mm] | plates [kg] | welds [kg] |
| 1-bottom | ***16*** | 23.675 | 125 | ***14*** | 20.716 | 94 | ***12*** | 17.756 | 69 |
| 2 | ***14*** | 20.716 | 97 | ***12*** | 17.756 | 74 | ***10*** | 14.797 | 61 |
| 3 | ***12*** | 17.756 | 69 | ***10*** | 14.797 | 61 | ***8*** | 11.838 | 31 |
| 4 | ***10*** | 14.797 | 61 | ***8*** | 11.838 | 31 | ***8*** | 11.838 | 25 |
| 5 | ***8*** | 11.838 | 25 | ***8*** | 11.838 | 25 | ***7*** | 10.358 | 23 |
| 6 | ***7*** | 10.358 | 23 | ***7*** | 10.358 | 23 | ***7*** | 10.358 | 23 |
| 7-top | ***7*** | 10.358 | 23 | ***7*** | 10.358 | 23 | ***7*** | 10.358 | 23 |
| # | total | **109.497** | **468** | total | **97.660** | **376** | total | **87.302** | **300** |

According to experience in design of similar oil storage tanks [3], the following approximation of partial weight (in percentage) of main tank components are used: for roof plates 102% of bottom weight, for roof structure 9% to 35% of shell weight (higher values for larger tank sizes). In addition, wind girder, shell accessories, roof accessories, handrail and walkway, and stairway are approximated as 2%, 6%, 4%, 1,5% and 1% of shell weight respectively. Corresponding welds weights are approximated from 0,5 to 2,0% of total material weight. All weld joints weights for bottom, roof and shell plates are designed and calculated according to effective area of fusion zone as indicated in typical weld joint details in figure 2, using AutoCAD command Area-Inquiry.

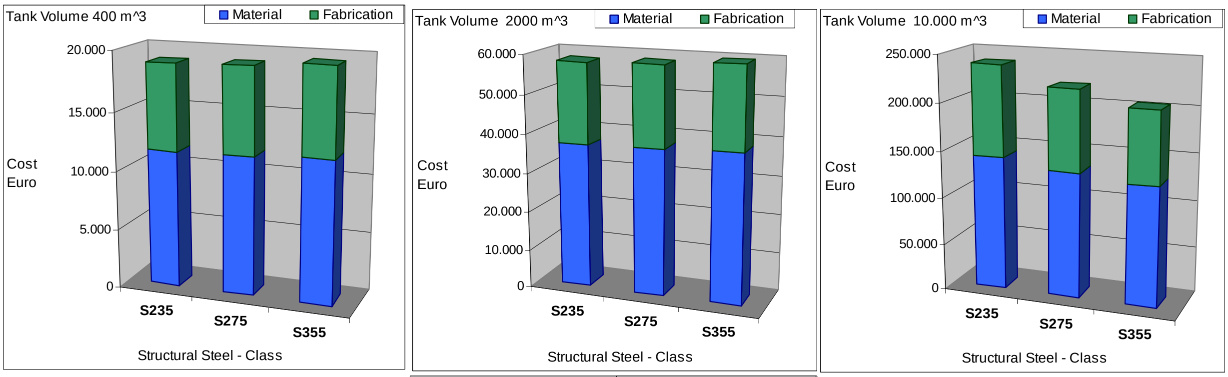
## 2. COST CALCULATION PARAMETERS

The following are used main parameters approximation for calculation purposes [2,3,4]:

- Price of base material – structural steels: 645, 655 and 675 Euro/ton, for steel S235, S275 and S355 respectively.
- Price of filler material: 7,0 to 7,5 Euro/kg for corresponding filler material grade according to selected structural steel strength.
- Deposition rate: 2,2 to 3,4 kg/h for corresponding welding positions.
- Welding process efficiency (operating factor): 0,4 or 40% and filler metal efficiency: 0,8 or 80%.
- Labour rate: 40 Euro/h, while total labour time was approximated as double (two times) of total welding fabrication time. Total labour time may vary significantly due to available man power and used tools, i.e. general company's experiences. However, for purposes of this paper it does not include time and cost of various prefabrication work (steel plates cutting and bending).
- Due to selected welding process, i.e. SS-FCAW, there is no any shielding gas costs.
- Power costs are approximated as 0,2% of total Labour costs.

## 3. INFLUENCE OF STRUCTURAL STEEL SELECTION ON COSTS PARAMETERS

The following are general charts of costs due to selected structural steel strength.



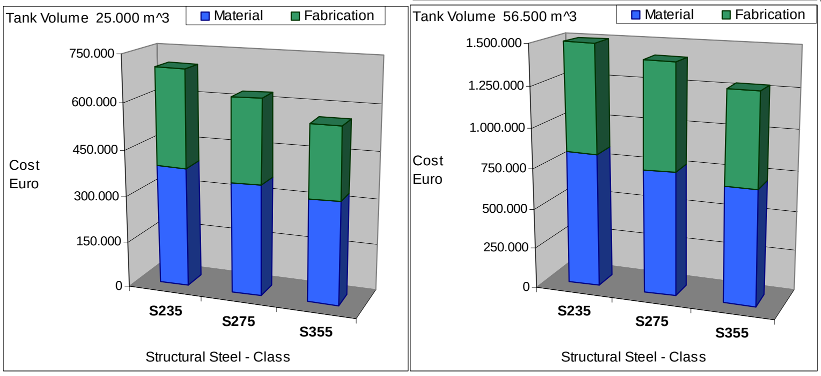
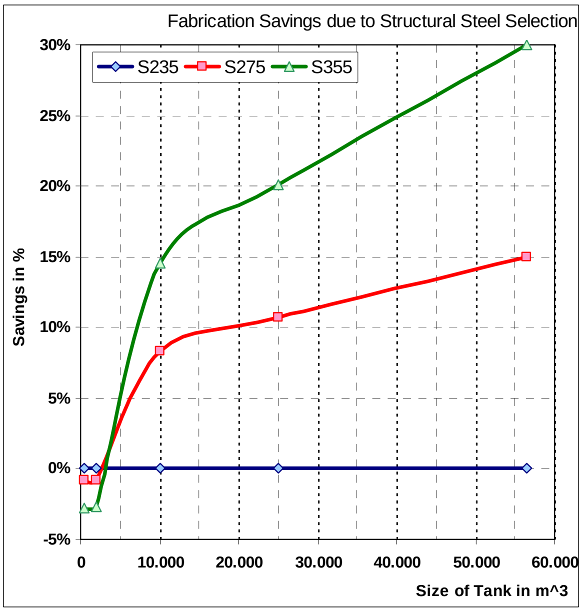




*Figure 3. General charts of costs comparison due to selected structural steel strength – results for five (5) typical oil storage tanks sizes.*

Finally, total costs saving and therefore "economically critical" tank size are presented in following figure.




It is obvious that there is no economical reason to select higher strength structural steel for small size tanks. Yet, for larger size tanks there is economical reason to select higher strength structural steel. Particularly, while considering range of tank sizes from 10.000m$^3$ to 56.500m$^3$ total cost saving for selected steels S275 and S355 are from 7% to 15%, and from 15% to 30% respectively. Therefore, an "economically critical" tank size for selection of higher strength structural steel is approximately 5.000m$^3$ in size. Finally, once more, those facts are based on approximation of a number of parameters which may influence significantly welding fabrication costs, as well as different company's experiences, and therefore provided conclusions do not have any attention to underestimate them.

*Figure 4. Fabrication saving(s) due to structural steel selection*

## 4. REFERENCES

[1] API 650 - Welded Steel Tanks for Oil Storage, American Petroleum Institute Standard, 2005.

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