International Journal of Academic Research and Development
ISSN: 2455-4197, Impact Factor: RJIF 5.22
www.academicsjournal.com
Volume 2; Issue 4; July 2017; Page No. 530-539

Blast analysis of liquid petroleum tank

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Abstract

Large petroleum storage tanks are vulnerable to internal pressure due to their sensitivity to imperfections. Blast pressure can cause imperfections, which increases storage tanks vulnerability to collapse. Collapse of tanks can put surrounding area at risk of fire and explosion. Hence, correct load determination and analyses are important. Correct distribution of the blast loading is important for storage tanks containing hazardous materials, as it is the local load acting on structure, especially for thin walled structure. This paper gives results of a series of analysis performed on STAAD-Pro on the distribution of blast pressure on the walls of large storage tank with different liquid filled condition. Using regression analysis, expressions that fit the analysis results very well were derived and critical filled condition of the tank was determined.

Keywords: liquid petroleum tank, blast loading, STAAD-Pro

1. Introduction

Damage to the property, loss of life and social panic are factors that have to be minimized if the threat of explosion action cannot be stopped. A fully blast resistant structure is not an economical and realistic option, however current engineering knowledge can used to improve the new and existing buildings to mitigate the effects of an explosion for a structure.

The main objective of this study is to provide guidance for the design of structure where there is a necessity of protection against the explosions caused by detonation of high explosives. The guidance gives measures for mitigating the explosions effects, therefore protecting human, structure and surrounding environment. The paper includes information about explosives, blast loading parameters and blast resistant structure design. Only high explosives are only considered within the study. Condensed explosives are high explosives which are solid in form, TNT (trinitrotoluene) being the most widely known example. There are many types of high explosive available and every explosive has its own detonation characteristics, the behavior of each blast wave will be different. Hence, TNT is being used as the standard, where all explosions can be expressed in terms of an equivalent charge mass of TNT.

2. Explosion

Major headings are to be column centered in a bold font without underline. They need be numbered. "2. Headings and Footnotes" at the top of this paragraph is a major heading. An explosion occurs when a solid, liquid or gas material goes through a rapid chemical reaction. When the explosion occurs, gas is released caused by chemical reaction leading to very high temperature and pressure at the source. These high pressure gasses expand rapidly into the surrounding leading to formation of blast wave. Blast waves propagate at supersonic speeds and gets reflected from the plane of incidence. As the blast wave continues to expand away from the source of the explosion its intensity decreases and its effect on the objects is also reduces.

Blast loading on liquid petroleum storage tanks may lead to disaster due health hazard owing to the spread of fire and chemical hazard due to the spread of petroleum fuel. Blast load on liquid storage facility containing hazardous chemicals may also be dangerous to the surrounding area. Chang and Lin have given a comprehensive review on storage tank accidents caused by blast and other factors all over the world. One example of blast induced fire hazard is the Bunce field vapour cloud explosion in 2005 which lead to major damage to large diesel storage tanks and the surrounding commercial property. The blast caused fire in the tanks containing diesel and therefore, resulted in large plastic deformation of the tanks on explosion. Another example is an explosion in Adepot of the Indian Oil Corporation in 2009 in Jaipur, India which resulted in fire in the nearby area, leading to damage of buildings lying in a radius of up to 3 kilometres from the centre of blast. Hence, understanding the behaviour of petroleum liquid storage structures under blast loading is of most importance. In the present study, the effect of blast loading on cylindrical tank is investigated. The objectives of the study is to find the (i) the maximum stresses induced in the tank wall when subjected to blast loading, The dynamic analyses of the three dimensional(3D) water storage tanks are performed using the blast formulation in STAAD-Pro software. The blast loading is applied on the tank through an equivalent pressure time history generated using the manual calculations. Parametric studies are performed for the water tanks by varying percentage of liquid filling in the tank, i.e. 100%, 80%, 60%, 40% and 20%, boundary conditions of the tank bottom, i.e. fixed, thickness of the tank wall (tw), i.e. 8mm, 10mm, 15mm, 20mm, 25mm and 30mm and scaled distance(Z) of the explosive material accordingly. The cylindrical tank is made of following parameters.

Table 1: Given data

Sr. no.	Parameters	Symbol	Value	Units
1	Capacity of tank	C	1500	m3
2	Diameter of tank	D	12	m
3	Height of tank	H	14.1	m
4	Level of liquid	H	13.64	m
5	Height of roof	h1	0.7	m
6	Wall thickness	t1	0.008	m
7	Roof plate thickness	t2	0.005	m
8	Bottom plate thickness	t3	0.08	m
9	Mass density of water	P	1000	kg/m3
10	Density of steel plate	$\dot{\rho}$	78.53	kN/m3
11	Youngs modulus	E	2E+11	N/m2

The blast load is applied on the steel tank using a pressure– time history curve.

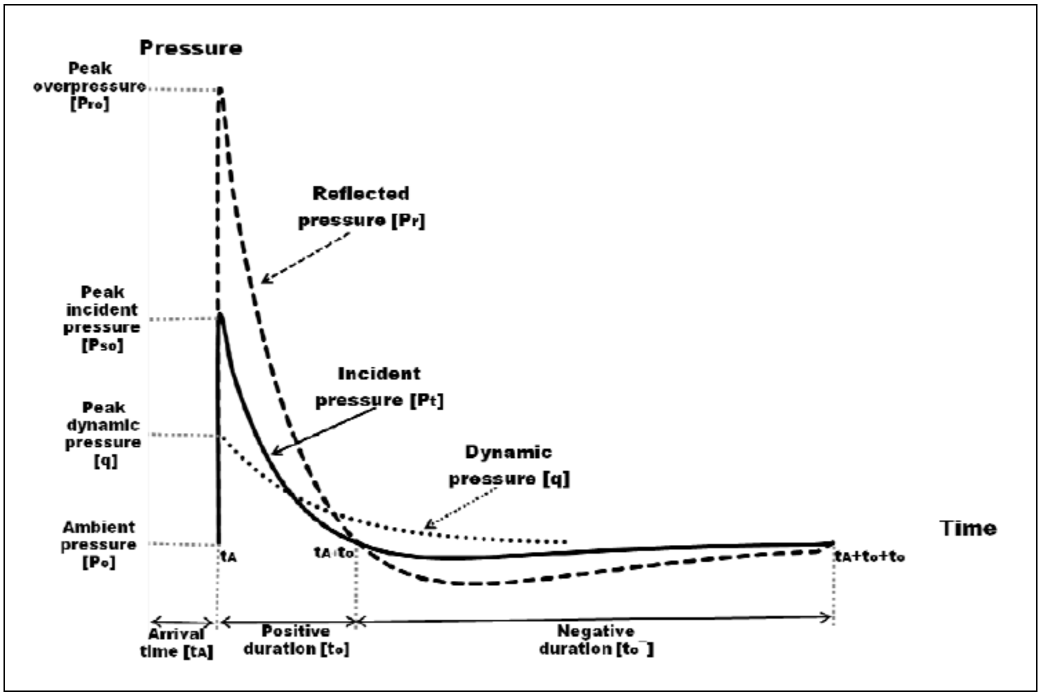

Fig 1: shows an ideal blast wave pressure time history profile.

3. Summary of the blast loads calculation

1. An explosive charge weight, type and detonation distance according to the geometry around the building is calculated as

$$Z = \frac{R}{W^{0.33}}$$

Where,
Z is scaled distance in m/kg0.33,
R is the horizontal distance between the projection of the explosive to the ground and the structure in m,
W is equivalent weight of TNT in kg.

2. The equivalent TNT weight W is computed through Equation as follows and Tables.

$$We = \frac{W_{exp}\ H_{exp}}{H_{TNT}}$$

where,
We is the TNT equivalent weight [kg],
W_{exp} is the weight of the actual explosive [kg],
H_{exp} is the heat of detonation of the actual explosive [MJ/kg], and
H_{TNT} is' the heat of detonation of the TNT [MJ/kg].

Table 2: Heat of Detonation

Name of explosive	Heat of detonation [MJ/kg]
TNT	4.10-4.55
C4	5.86
RDX	5.13-6.19
PETN	6.69
PENTOLITE 50/50	5.86
NITROGLYCERIN	6.30
NITROMETHANE	6.40
NITROCELLULOSE	10.60
AMON./NIT. (AN)	1.59

3. The scaled distances are next determined for every case scenario according to Equation. Depending on the expected type of blast wave (hemispherical from ground burst or spherical from air burst) the parameters, the peak incident Pso and reflected Pr pressures is calculated according to equation as follows

$$P_{SO} = P_O \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\left\{\left[1+\left(\frac{Z}{0.048}\right)^2\right]\left[1+\left(\frac{Z}{0.32}\right)^2\right]\left[1+\left(\frac{Z}{1.35}\right)^2\right]\right\}^{0.5}}$$

$$P_r = \frac{2P_{so} \times (4P_{so} + 7P_o)}{(P_{so} + 7P_o)}$$

4. The stresses on the cylindrical wall is calculated as

$$S = \frac{P_r \times D}{2t}$$

4. Results and Discussion

The blast load is applied on the steel tank using a pressure time history curve. Following tables and graphs shows an stress values for different cases.

1. For change in thickness

CASE 1: 8mm Thickness Tank

Table 3: comparison of analytical and software study of stresses for different tank filled condition for 8mm thick tank

% Filled	Stresses (kN/m2)	
	Study	Software
100	12359.64	12328.1
80	15520.82	15476.2
60	19380	19325.2
40	22956.88	22890.9
20	21681.62	21619.2

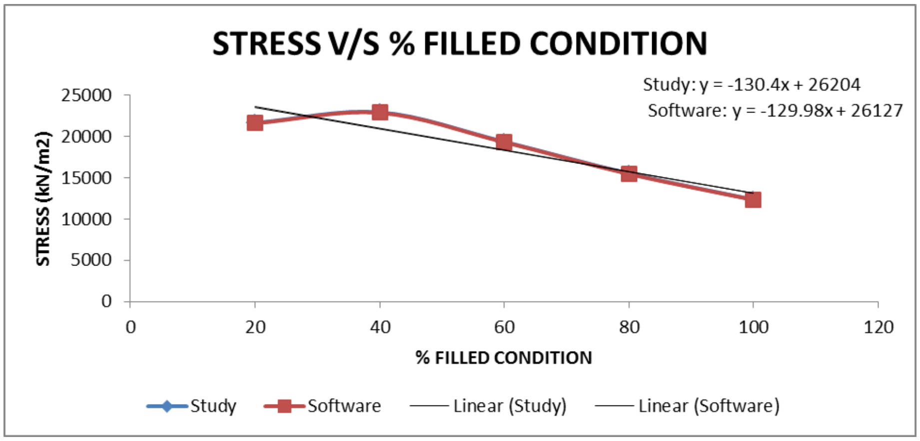

Fig 2: comparison of analytical and software study of stresses for different tank filled condition for 8mm thick tank

CASE 2: 10mm Thickness Tank

Table 4: comparison of analytical and software study of stresses for different tank filled condition for 10mm thick tank

% Filled	Stress (kN/m2)	
	Study	Software
100	9887.716	11285.5
80	12416.66	14167.3
60	15504.78	17690.9
40	18365.5	20955
20	17345.3	19790.9

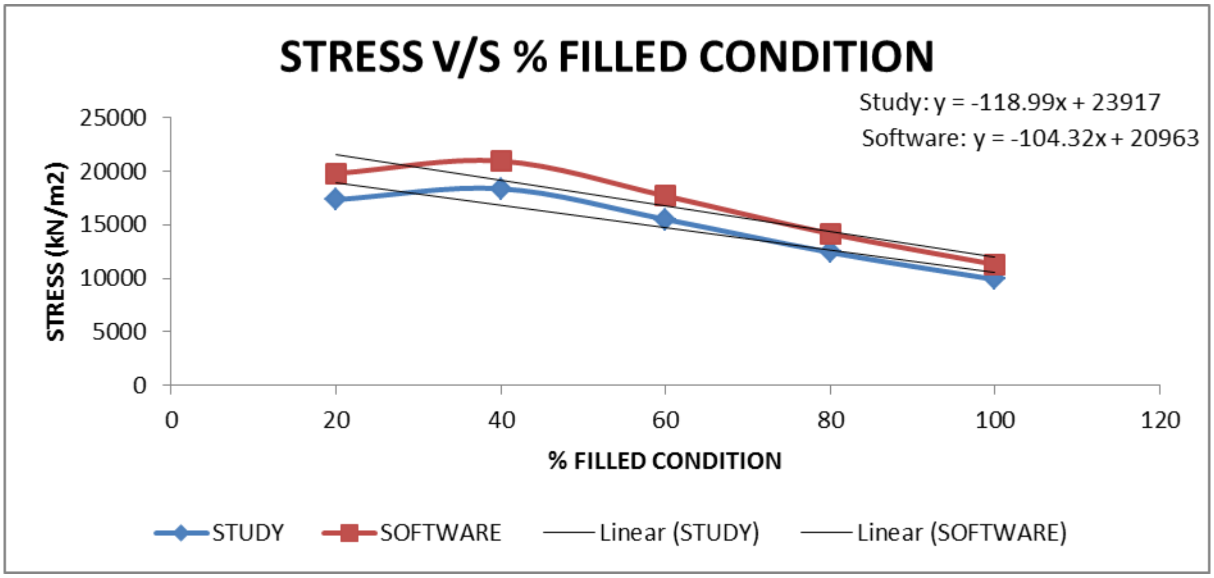

Fig 3: comparison of analytical and software study of stresses for different tank filled condition for 10mm thick tank

CASE 3: 15mm Thickness Tank

Table 5: comparison of analytical and software study of stresses for different tank filled condition for 15mm thick tank

% Filled	Stress (kN/m2)	
	Study	Software
100	6591.81	9279.01
80	8277.77	11648.4
60	10336.52	14545.4
40	12243.67	17229.2
20	11563.53	16272.1

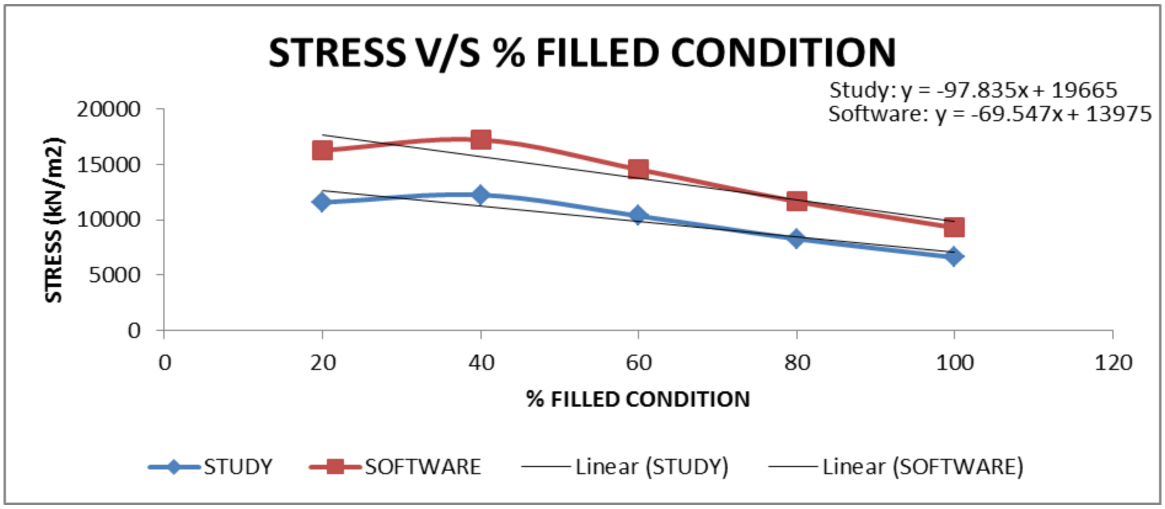

Fig 4: comparison of analytical and software study of stresses for different tank filled condition for 15mm thick tank

CASE 4: 20mm Thickness Tank

Table 6: comparison of analytical and software study of stresses for different tank filled condition for 20mm thick tank

% Filled	Stress (kN/m2)	
	STUDY	SOFTWARE
100	4943.85	7850.65
80	6208.33	9855.24
60	7752.39	12306.3
40	9182.75	14576.9
20	8672.65	13767.2

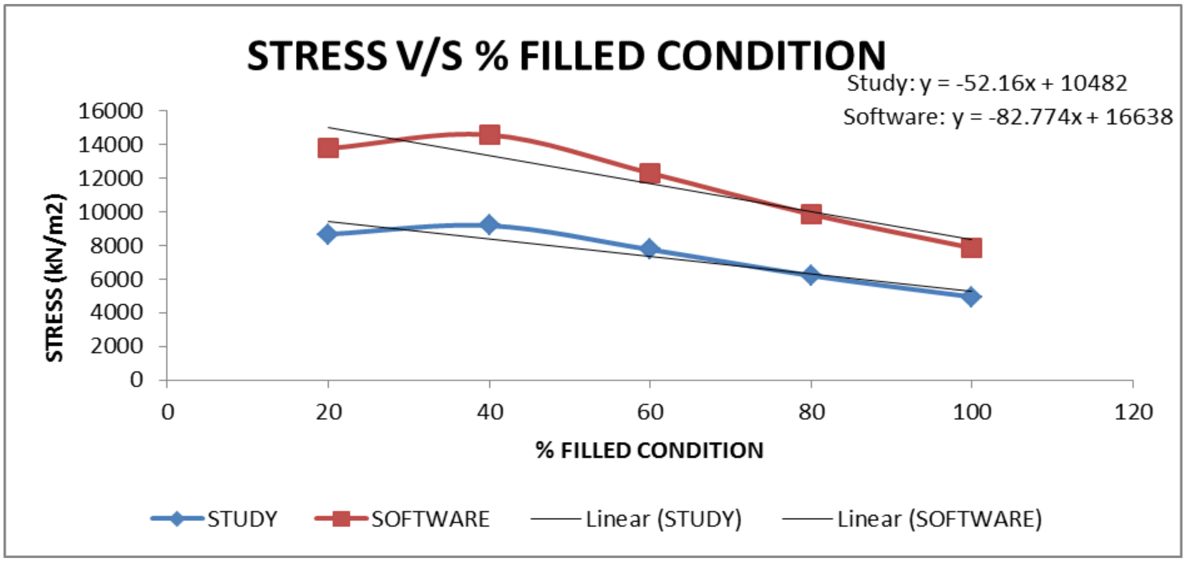

Fig 5: comparison of analytical and software study of stresses for different tank filled condition for 20mm thick tank

CASE 5: 25mm Thickness Tank

Table 7: comparison of analytical and software study of stresses for different tank filled condition for 25mm thick tank

% Filled	Stress (kN/m2)	
	Study	Software
100	3955.08	6792.41
80	4966.66	8526.74
60	6201.91	10647.4
40	7346.2	12612
20	6938.12	11911.3

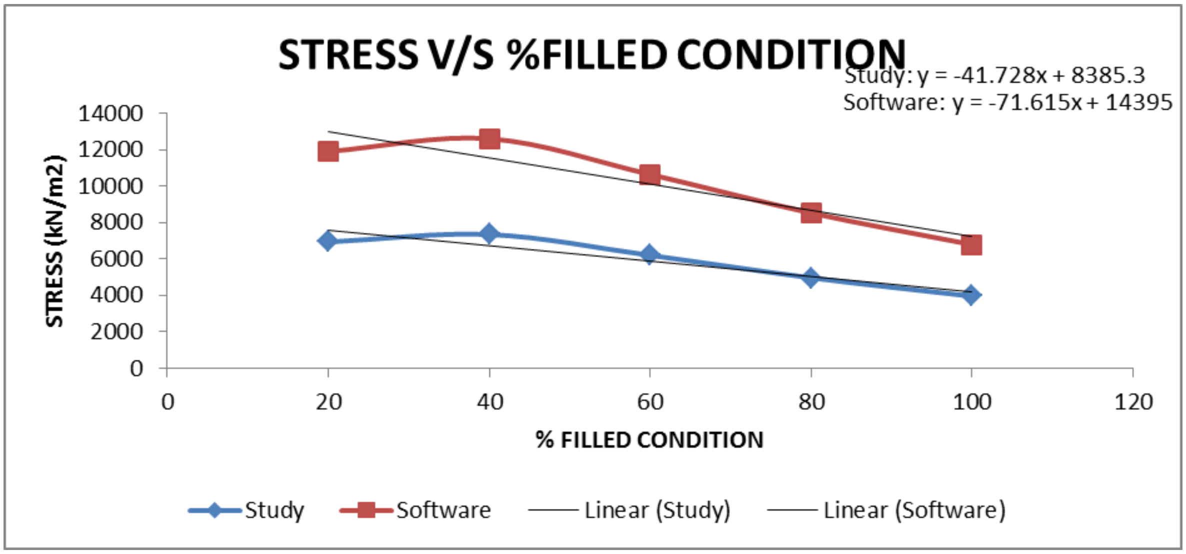

Fig 6: comparison of analytical and software study of stresses for different tank filled condition for 25mm thick tank

CASE 6: 30mm Thickness Tank

Table 8: comparison of analytical and software study of stresses for different tank filled condition for 30mm thick tank

% Filled	Stress (kN/m2)	
	Study	Software
100	3295.9	5982.04
80	4138.88	7509.42
60	5168.26	9377.08
40	6121.83	11107.2
20	5781.76	10490.2

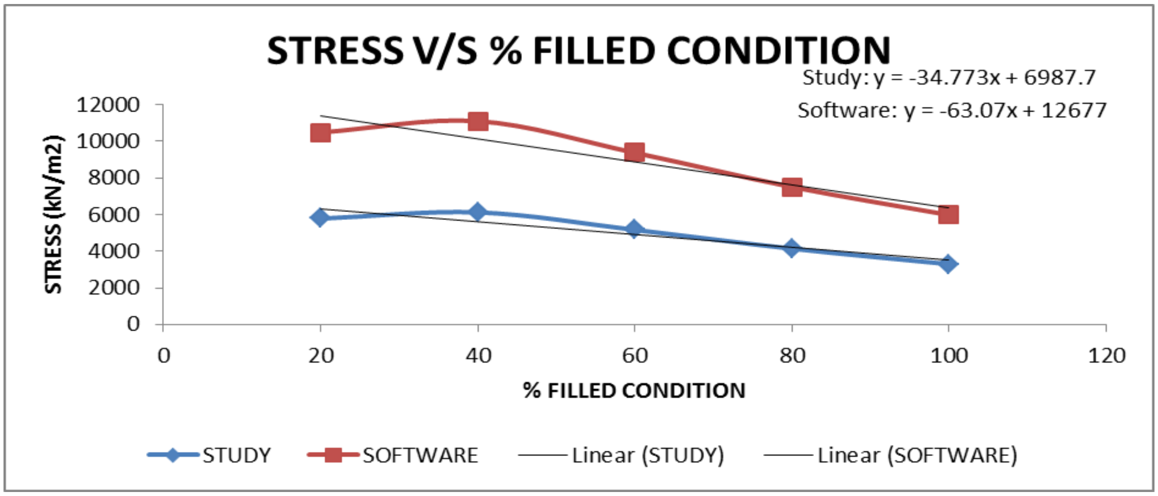

Fig 7: comparison of analytical and software study of stresses for different tank filled condition for 30mm thick tank

2. Variation of stresses with change thickness of tank

CASE 1: 100% Filled tank condition

Table 9: comparison of analytical and software study of stresses for different tank thickness with 100% filled condition.

Tank thickness mm	Stress (kN/m2)	
	Study	Software
0.008	12359.6	12328.1
0.01	9887.72	11285.5
0.015	6591.81	9279.01
0.02	4943.86	7850.65
0.025	3955.09	6792.41
0.03	3295.91	5982.04

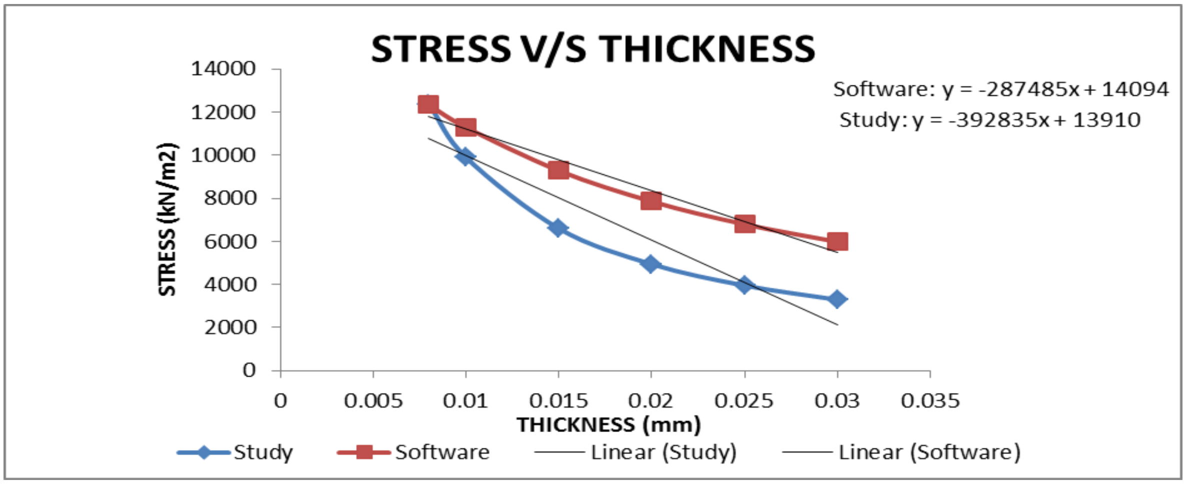

Fig 8: Comparison of analytical and software study of stresses for different tank thickness with 100% filled condition.

CASE 2: 80% Filled tank condition

Table 10: comparison of analytical and software study of stresses for different tank thickness with 80% filled condition.

Tank thickness mm	Stress (kN/m2)	
	Study	Software
0.008	15520.82	15476.2
0.01	12416.66	14167.3
0.015	8277.77	11648.4
0.02	6208.33	9855.24
0.025	4966.66	8526.74
0.03	4138.88	7509.42

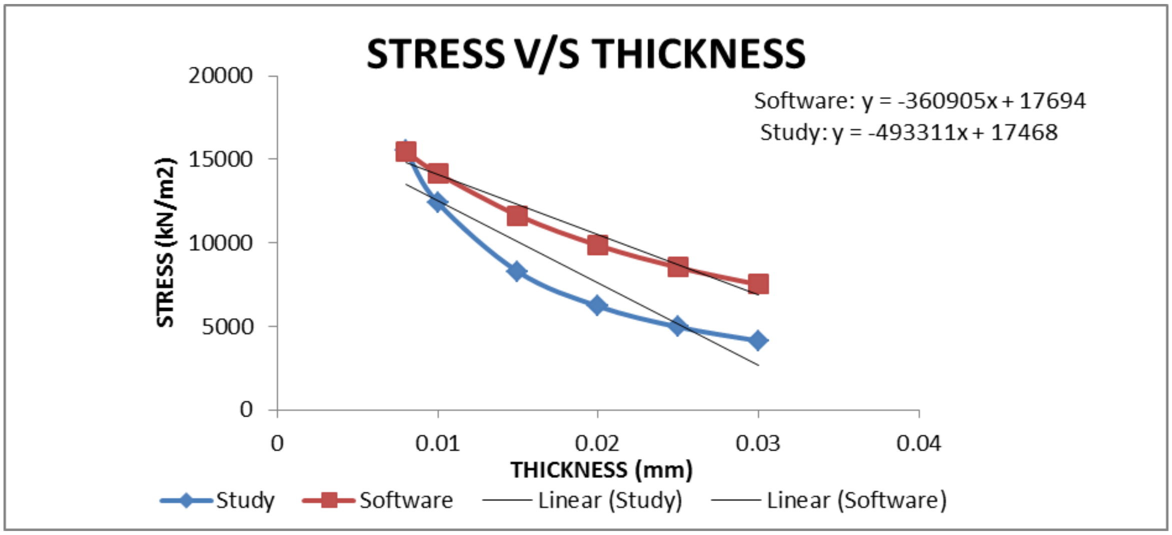

Fig 9: Comparison of analytical and software study of stresses for different tank thickness with 80% filled condition.

CASE 3: 60% Filled tank condition

Table 11: comparison of analytical and software study of stresses for different tank thickness with 60% filled condition.

Tank thickness mm	Stress (kN/m2)	
	Study	Software
0.008	19380.97	19325.2
0.01	15504.78	17690.9
0.015	10336.52	14545.4
0.02	7752.39	12306.3
0.025	6201.91	10647.4
0.03	5168.26	9377.08

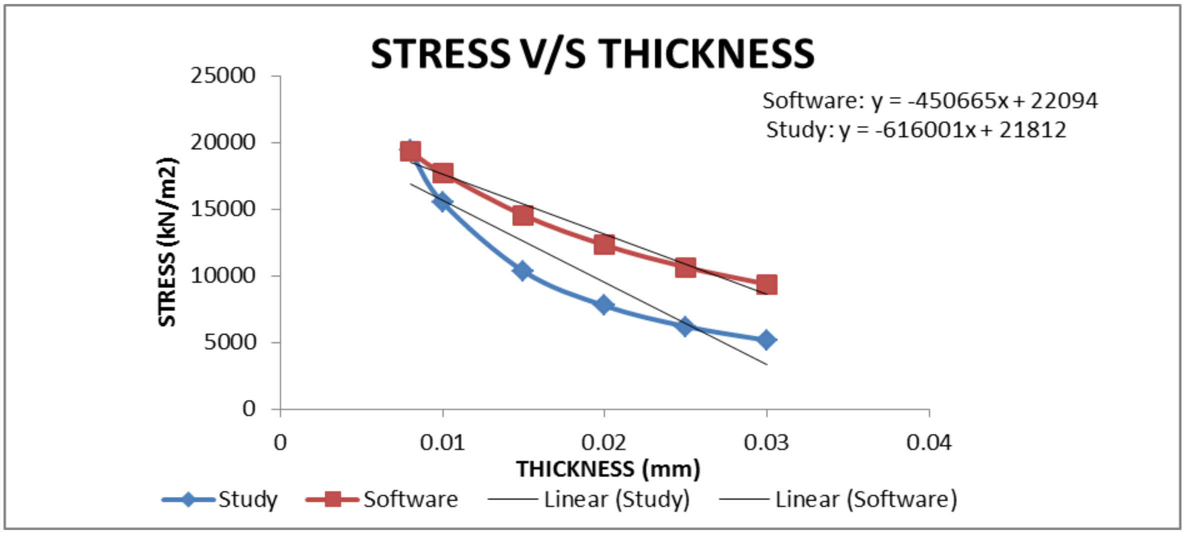

Fig 10: Comparison of analytical and software study of stresses for different tank thickness with 60% filled condition.

CASE 4: 40% Filled tank condition

Table 12: comparison of analytical and software study of stresses for different tank thickness with 40% filled condition.

Tank thickness mm	Stress (kN/m2)	
	Study	Software
0.008	22956.88	22890.9
0.01	18365.5055	20955
0.015	12243.67	17229.2
0.02	9182.75	14576.9
0.025	7346.2	12612
0.03	6121.83	11107.2

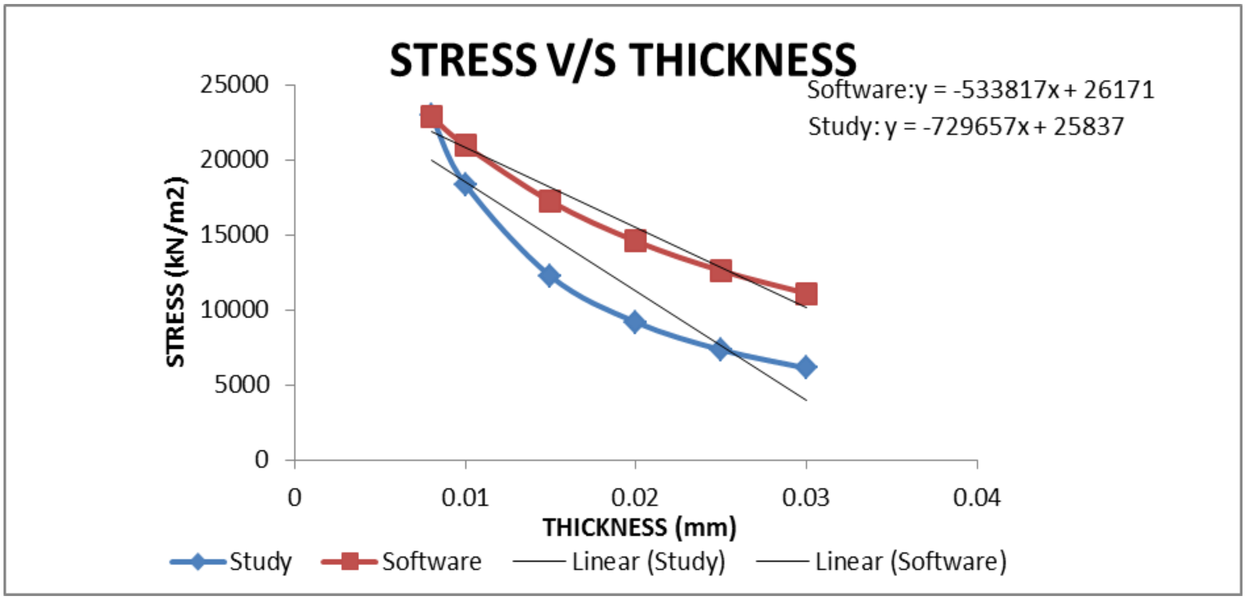

Fig 11: comparison of analytical and software study of stresses for different tank thickness with 40% filled condition.

CASE 5: 20% Filled tank condition

Table 13: comparison of analytical and software study of stresses for different tank thickness with 20% filled condition.

Tank thickness mm	Stress (kN/m2)	
	Study	Software
0.008	21681.62	21619.2
0.01	17345.3	19790.9
0.015	11563.53	16272.1
0.02	8672.65	13767.2
0.025	6938.12	11911.3
0.03	5781.76	10490.2

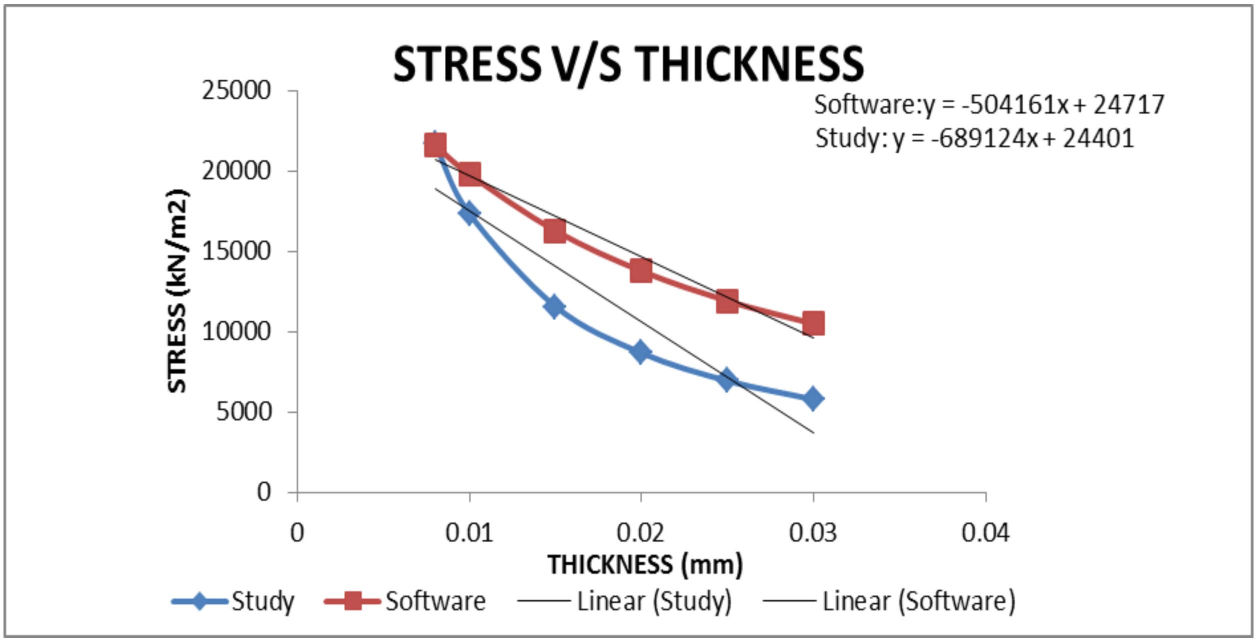

Fig 12: Comparison of analytical and software study of stresses for different tank thickness with 20% filled condition.

3. Critical value of stress obtained for water filled condition

Analysis showed that the critical value of stress obtained for 8mm, 10mm, 15mm, 20mm, 25mm and 30mm thick steel tank is 32%. Thus when the tank is 32% filled with petroleum liquid the stresses acting on the walls on the tank are obtained maximum. The stresses acting on the walls of the tank for 8mm thick tank are as shown in graph 12. Similar graphs are obtained for 10mm, 15mm, 20mm, 25mm and 30mm steel tank.

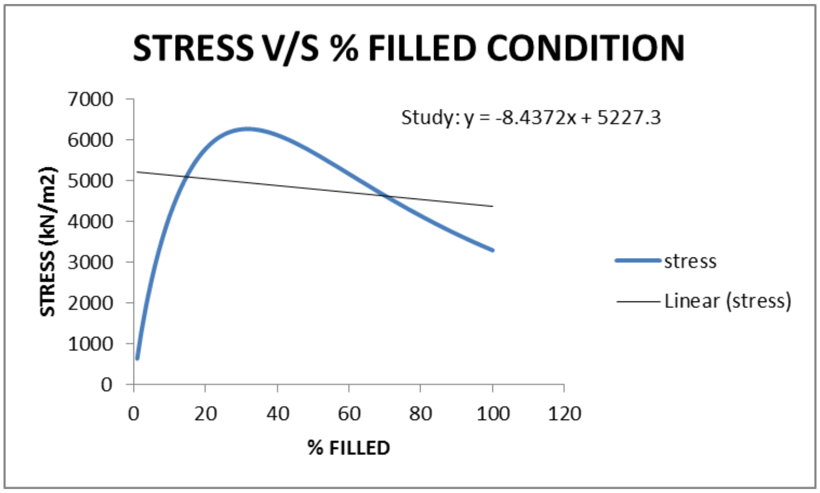

Fig 13: stress acting on walls of tank for different % filled condition for 8mm thick tank The maximum value of stress obtained is at 32% tank filled condition.

4. Comparison of analytical study and software output

CASE 1: For 100% filled condition

Table 14: comparison of analytical and software study of stresses for different tank thickness with 100% filled condition.

tank thickness	Software	study	difference
0.001	13806.515	13517.165	2.095749724
0.002	13519.03	13124.33	2.919588166
0.003	13231.545	12731.495	3.779226084
0.004	12944.06	12338.66	4.677048778
0.005	12656.575	11945.825	5.615658265
0.006	12369.09	11552.99	6.597898471
0.007	12081.605	11160.155	7.626884011
0.008	11794.12	10767.32	8.706033176
0.009	11506.635	10374.485	9.839105872
0.01	11219.15	9981.65	11.03024739
0.011	10931.665	9588.815	12.28403907
0.012	10644.18	9195.98	13.60555722
0.013	10356.695	8803.145	15.00044174
0.014	10069.21	8410.31	16.47497669
0.015	9781.725	8017.475	18.03618482
0.016	9494.24	7624.64	19.69193953
0.017	9206.755	7231.805	21.45109759
0.018	8919.27	6838.97	23.32365765
0.019	8631.785	6446.135	25.32095042
0.02	8344.3	6053.3	27.45586808
0.021	8056.815	5660.465	29.74314292
0.022	7769.33	5267.63	32.19968775
0.023	7481.845	4874.795	34.84501483
0.024	7194.36	4481.96	37.70175526
0.025	6906.875	4089.125	40.79630803
0.026	6619.39	3696.29	44.15965822
0.027	6331.905	3303.455	47.82841815
0.028	6044.42	2910.62	51.84616555
0.029	5756.935	2517.785	56.26518278
0.03	5469.45	2124.95	61.14874439

Analysis showed that the % difference between the analytical study and software study goes on increasing with the increase in the thickness of tank. Therefore, analysis showed for thickness upto 10mm software as well as analytical study shows a difference of upto 10%. Hence, for thickness greater than 10mm, analytical study need to be done than software study, as the values obtained in software are more than the values obtained in analytical study. Due to higher range of values for stresses, the design dimensions obtained are greater leading to uneconomical design.

8. Conclusions

- The maximum value obtained for the stress is when the tank is 32% filled. Thus the value of the blast will be maximum when the tank is 32% filled and not when the tank is 100% filled.

- The stress acting on the walls of the tank will be minimum when the tank is 100% filled
- The linear equations obtained from the graph help is giving an approximate value for stresses for different conditions.
- Analysis showed for thickness upto 10mm software as well as analytical study shows a difference of upto 10%. Hence, for thickness greater than 10mm, analytical study need to be done than software study, as the values obtained in software are more than the values obtained in analytical study thereby making the design uneconomical.

9. References

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