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A study on the optimization of rectangular steel storage tanks

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Abstract
The rectangular steel storage tanks placed above ground are extensively used in various sector at different stages of the manufacturing, storage etc. Due to the large number of similar tank structures the desire to automate the design and manufacturing process was imminent. This can be met by optimizing these tanks by adopting different structural arrangements, optimal load distribution and more economically by developing different structural sections for main structural frame of the tanks. Also the cost optimization study for these tanks is taken up by considering the fabrication and installation stages involved.

Keywords: cost optimization, fabrication, installation**,** rectangular storage tank, optimal load distribution

Introduction
The major challenge in civil engineering is to design and build an economically competitive structure of suitable strength performance which would satisfy the purpose of the structure built and all the requirements for durability, maintenance, ecological sustainability and architecture appearance. The need for the most efficient cost design solution has led to the need to carry out accurate cost estimation and a structural cost optimization

Optimization can be defined as finding solution of problems where it is necessary to maximize or minimize a real function within a domain which contains the acceptable values of variables while some restrictions are to be satisfied. There might be the large amount of set of variables in the domain that maximizes or minimizes the real function while satisfying the described restrictions. They are called as the acceptable solutions and the solution which is the best among them that satisfy constrains are obtained as the optimum solution of the problem

Analogously the definition given above, the aim of the optimum structural design methods is to minimize the size of the structural elements considering their load carrying capacity in order to reduce the total cost by reducing the material necessary for construction.

A.*Structural Optimization*
The increasing interest in this structural optimization is due to the availability of cheap and powerful computers, along with rapid developments in methods of structural analysis and optimization. Weight optimization of structures plays a major role in many engineering fields. In some aspects it can be associated with cost optimization, since it obviously leads to an optimal material usage. Globally, over 1.3 billion tons of steel are manufactured and used every year and it is predicted there will be continuing strong growth in the volume of steel produced. Hence the optimized use of structural steel got much attention. Nowadays, with the escalating fuel prices and awareness of environmental changes more attention is focused on order to develop sustainable products.

At the same time, this trend adds more pressure on the original equipment manufacturers (OEM) to not only come up with new solutions to minimize the environment impact through the usage of more efficient processes that preserve resources, but also to develop quantitative metrics to assess such impact and gauge improvement efforts. Reducing the amount of material used over the product life cycle is an effective method of reducing its environmental impact.

The particular problem of interest here is the minimum cost design of a welded open rectangular steel storage tank.The task of the optimization is to find the minimal structure's material and labour costs, the optimal topology with the optimal number of portal frames and purlins as well as the optimal standard cross-sections of steel members.

i. Rectangular Tanks in Automobile Sector

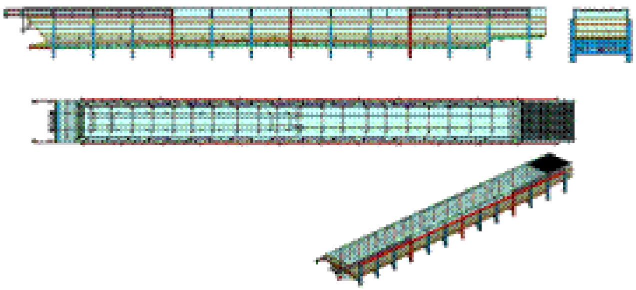


Fig 1 Typical 120m^{3}capacitytank – views

A typical tank of capacity 120m3 is shown in the above Fig 1.These tanks are used to store different type of liquids viz. water collected from rinsing the automobile bodies either in hot temperature or with normal conditions, chemical mixed solutions utilized in process of automobile manufacturing. They are generally above ground open storage tanks, rectangular shape in cross section. These tanks are then anchored to ground or fixed on the structural platforms at different levels based on the requirement of the automobile plant. Since these are used in the cleaning and application of base coat for the automobile bodies, these are positioned in the early stages of automobile manufacturing process.

The tank is fabricated with main the structural frame arrangement, normally of MS rolled sections with tank sheet either MS of SS welded together with the frame along with the stiffeners, usually of rolled steel angles or channels spaced depending on the hydro static loads and other parameters of the tank as shown below

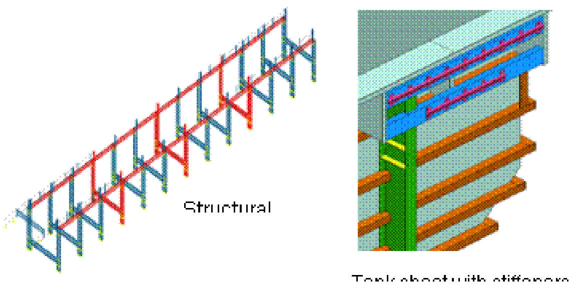


Fig 2 Typical tank frame arrangement and its structural elements

Depending on the tank size, the modular units of steel construction shall be adopted. The interface of the modular unit is generally channel section with back to back section is used and the same is highlighted in the above Fig.2 By combining the frames and the wall for the decided length depending on the transportation and installation requirements, the modular units of tanks are fabricated. The hydrostatic loading pattern and the different structural sections proposed for the study of structural optimization is shown in Fig 3 mentioned below.

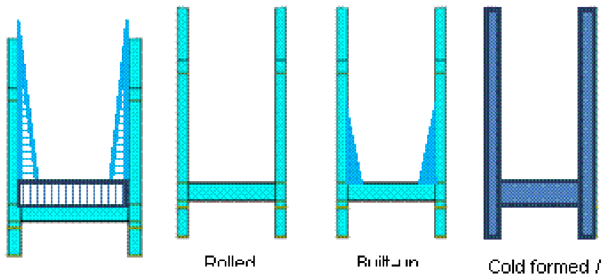


Fig 3 Typical tank frames with hydro static loading and different structural sections of study

ii. Design Optimization

There are two design - optimization tendencies to achieve more economical solutions as mentioned below

- ➢ Optimize material
- ✓ Structural optimization
- ○ Reduce material weight
- ○ Structural arrangement – members and supports
- ○ Optimal Load distribution
- ➢ Optimize cost
- ✓ Cost Optimization
- ○ Fabrication Cost
- ○ Installation Cost

By using the above two optimization methodologies, the best possible structural frame arrangement with tank sheet along with stiffener spacing along with cost studies shall result in the optimal rectangular steel tanks.

B.Scope and Objective

i. Objective

The objectives of this project work are to study the optimal design of rectangular steel tanks used in the automobile industry with the following

- ✓ To analyse and design the rectangular steel storage tanks based on conventional codal designs and using Structural software packages like STAAD Pro V8i.
- ✓ To study the behaviour of rectangular steel storage tanks with structural frames as rolled steel sections, built-up sections and Cold formed sections.
- ✓ To compare the rectangular steel storage tanks with different materials of tank wall and different wall thickness.
- ✓ To compare the overall cost for the alternatives chosen from the weight, fabrication and installation activities.

ii. Scope

The scope of this project work involves

- ✓ To Optimize and provide a cost effective rectangular steel storage tank.
- ✓ To Compare the behaviour of structural frames in tank due to rolled sections, built-up sections and cold formed sections.
- ✓ To study the structural behaviour of stiffeners using different tank wall materials.

Materials and Methodology

A. General

Characterization is the art of determining the distinctive characteristics of the materials used. It is a salient activity undertaken to completely understand the related properties the materials with reference to particular application. The basic properties of the materials influence the final behavior of the tank structure. Studies have been carried out to investigate the behavior of different materials used in this investigation. This comprised of study of material behavior with MS and SS graded of tank material used for tank wall.

B.Materials

Tank wall is of sheet in Mild Steel (MS), Stainless Steel (SS304). The stiffeners used in holding the tank sheet to the structural frame are of Mild steel sections. The mild steel is of grade Fe250 and the stainless steel with SS304. The structural tank frames of Rolled sections, Hollow sections and cold formed section profiles. The entire tank frame with the tank wall and stiffeners are welded together as modular unit.

C.Software

The structural engineering software package, STAAD Pro v8iis used for the study in the analysis and design of tanks. In addition to the above structural engineering software package, MS- Excel is used for the design calculations and cost optimization studies.

D.Data for Storage tanks

The input information for the optimization of rectangular steel tanks is based on the following parameters

- ✓ Type of the tank to be studied.
- ✓ Dimension and Capacity of the tank.
- ✓ Spacing of tank frames considering the user requirement.
- ✓ Process area for selection of material for tank wall depending on the nature of liquid stored.
- ✓ Restriction on Height and width of tanks based on the feedback from the user.
- ✓ Storage Liquid information
- ✓ Additional Loads on the tank

E. Planning of Analysis and Design

The Structural Optimization of the steel tank based on the input requires the additional following parameters for the planning of the analysis and design studies.

- ✓ The Shape of the tank influence the force acting on the frames
- ✓ Height of the tank
- ✓ Column / Frame position
- ✓ Process stages in the automobile industry
- ✓ The following loads have to be included
- ▪ Storage Liquid used in the process, their chemical nature.
- ▪ The Conveyor loads which is acting on the tank by carrying the automobile bodies from one process stage to other
- ▪ Additional Loads, if any.

F.Methodology

The study of the optimization of rectangular steel storage tank include the following stages as shown in Fig 4 below Fig.2. Recharging Framework

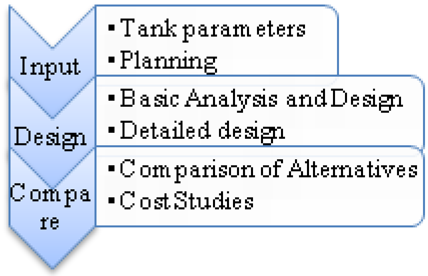


Fig 4 Stages involved in the optimization study

a)Input stage:

The input data with planning and analysis parameters are collected for study in the initial stage to start the basic analysis and design of tanks.

b) Design Stage:

- ➢ Basic Analysis of tank walls and stiffeners with assumed values based on previous project references leading to actual sizing of structural tank frames.
- ➢ Detailed and Final analysis for the tank wall, stiffeners.
- ➢ Use of different sections for the tank frame profile like rolled sections, built-up sections, Hollow sections and cold formed sections for the strength and deflection criteria.
- ➢ Cost studies of each combination of tank wall and stiffener with different section profiles.

c) Comparison Stage:

- ✓ Comparison of the studies for the optimal tank based on different cost studies.

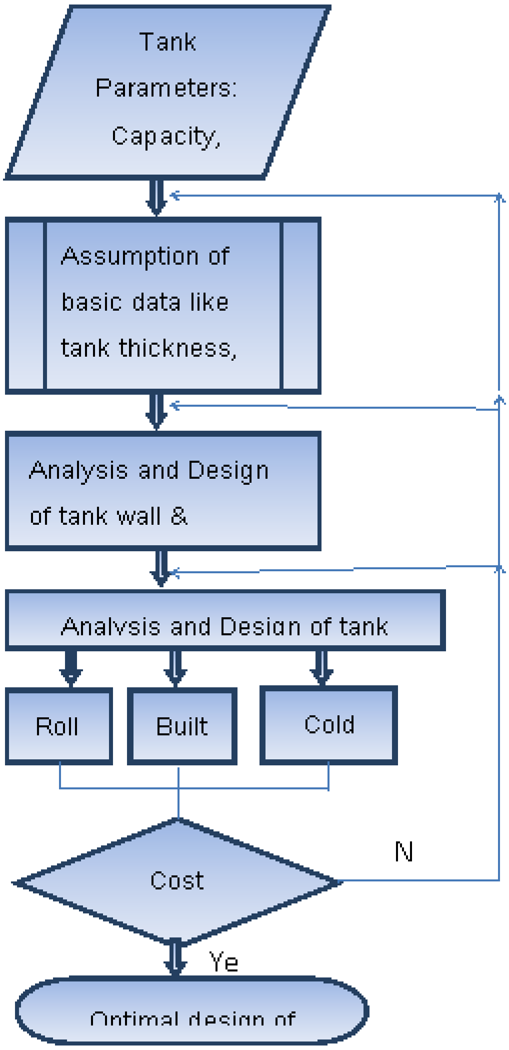
After the comparison stage, the optimized rectangular steel storage tank shall be arrived.

The above items are mentioned in the flowchart as shown in Figure 3.2. This flow chart gives the detailed process involved in the structural optimization of steel storage tank with the following steps.

(i) Software Analysis for the structural study of the behavior of rolled steel sections with built-up section and cold formed steel sections. These sections are taken for the tank frame and the calculated for the strength criteria and the deflection criterion.

(ii) Cost Estimation Studies have been calculated for the each solution obtained from the analysis and design.

(iii) Calculation of tank wall thickness and stiffener sizing with spacing using Excel work sheets



i. ***Cost Optimization***

The following parameters are studied for all the structural options obtained.

- Engineering cost will be the soft cost and have more effect on the finite element calculations.

Fabrication cost will be varying based on the material and the connection design and the installation requirement.

- Material cost - structural steel, electrodes, fire protection and top coat painting and gas consumption
- Power consumption cost - sawing the steel sections, edge grinding, drilling, welding
- Labour cost - metal cutting, edge grinding, preparation, assembling and tacking, welding, steel surface preparation and protection.

Results And Discussions

A. General

The goal to determine the optimized rectangular steel storage tank is taken up by considering the two tanks viz. Tank A and Tank B with capacities 70m^{3}and 33m^3 respectively. The tank frame members are considered for the optimization study than the tank sheet and the stiffeners. It is achieved by comparing the different tank frame sections viz. rolled sections, tapered sections and cold formed built-up sections. Also the behavior of the stiffeners with different material for tank wall is studied.

B.Analytical Study

The analytical study is taken up for tanks with the consideration of all parameters except the tank frame are assumed for the optimization of the tank frame. The assumed inputs are used in the structural engineering software package STAADPro V8i for the analysis of tank frames with different section for comparative study.

C.Weight optimization study

i Analysis and Design of Tank -A -70m^3

The following information is considered in the analysis and design of rectangular steel tank A – 70m^3

Dimensions

Length = 6.6m, Breadth = 3.3m, Depth = 3.4m;
Liquid level, H = 3.2m, Specific gravity = 10kN/m^3;
Tank sheet = MS/SS = 5mm thickness;Stiffener spacing = 0.5m;
Frame Spacing = 2.6m;Deflection Criterion = H/400;

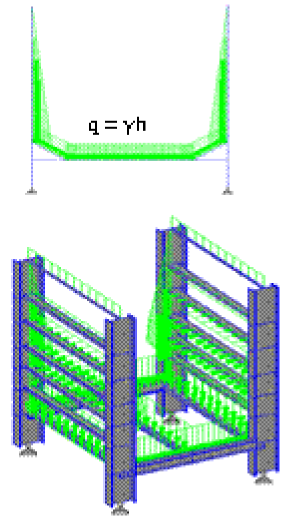


Fig 6 Analysis and Design results of Tank A -70 m^3

Table 1 Weight optimization results for Tank A (70 m^3)

Parameters	**Rolled Steel Sections**	**Tapered sections**	**Cold formed / built-up Tubular sections**
Maximum Stress ratio	0.574	0.598	0.714
Maximum Horizontal Deflection (mm)	7.5	10.3	9.5
Permissible Deflection (mm)	10.3	10.3	10.3
Member details			

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Tank frame	ISMB400	ISMB400/ ISMB300	Tube 350x350x5
Beam	ISMB150	ISMB150	Tube 120x60x4.5
Tank sheet stiffener	ISMC150	ISMC150	Tube 120x60x4.5
Total weight of Structure excluding tank wall (kg)	4283	4001	3344
Percentage weight optimization	-	7%	22%

ii Analysis and Design of Tank -B -33m^3

The following information is considered in the analysis and design of rectangular steel tank B -33m^3

Dimensions

Length = 11m, Breadth = 1.8m, Depth = 3.1m;
Liquid level, H = 2.7m, Specific gravity = 10kN/m^3;
Tank sheet = MS/SS = 6mm thickness;
Stiffener spacing = 0.5m;
Frame Spacing = 2m;
Deflection Criterion = H/400;

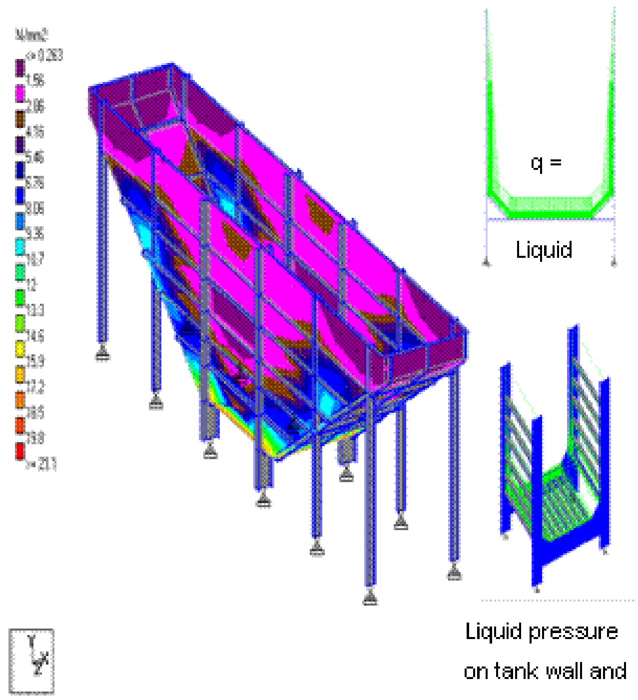

Fig 7 Analysis and Design results of Tank B -33 m^3

Table 2 Weight optimization results for Tank B (33 m^3

Parameters	Rolled Steel Sections	Tapered sections	Cold formed / built-up Tubular sections
Maximum Stress ratio	0.539	0.598	0.714
Maximum Horizontal Deflection (mm)	7.1	7.5	7.7
Permissible Deflection (mm)	7.8	7.8	7.8
Member details			
Tank frame	ISMB300 ISMB150	ISMB400/ ISMB300 ISMB150	Tube 260x260x5
Beam	ISMB150/ ISMC150	ISMB150/ ISMC150	Tube 72x72x4
Stiffener	ISMC150	ISMC150	Tube 72x72x4
Total weight of Structure excluding tank wall (kg)	2369	2294	2350
Percentage weight optimization	-	3%	1%

iii Cost optimization study

Weight of the structural members from design result are considered in addition to the weight of the connection plates such as base plate, stiffeners, end plates, washers etc. in the process of fabricating the tanks.

Table 3 Cost optimization results for Tank A(70 m^3)

Parameters	Rolled Steel Sections	Tapered sections	Cold formed / built-up Tubular sections
Weight of the structural Members (kg)	4283	4001	3344
Rolled Sections (kg)	4283	2667	1922
Tapered sections (kg)	-	1334	-
Cold formed/ built up sections (kg)	-	-	1422
Connection plates @ 5% (kg)	214	200	167
Weight of the tank sheet (kg)	2584	2584	2584
Fabrication costing (INR/kg)			
Material cost			
Rolled sections @ INR55/kg	235565	152019	109554
Plate works @ INR58/kg	162293	238847	242046
Fabrication process cost			
Rolled sections @ INR15/kg	64245	40005	28830
Plate works @ INR22/kg	61559	61249	91810
Total fabrication cost(INR)	523662	492120	472240
overhead cost @ 5%	26183	24606	23612
Total cost of fabrication (INR)	549845	516726	495852
Percentage cost optimization	-	6%	10%

Cost optimization of Tank -B -33m^3

The cost optimization study of tank B 33m3 results are produced for the different tanks frames with the comparison is presented in Table 4. Due to higher fabrication cost incurred in the frames of tapered sections and cold formed sections than rolled section frames, these results are shown as negative values in the table. Rolled section tank frame is effective than other section frame as they are found to be costlier due to more fabrication of plate works

Table 4Cost optimization results for Tank B (33 m^3)

Parameters	Rolled Steel Sections	Tapered sections	Cold formed / built-up Tubular sections
Weight of the structural Members (kg)	2369	2294	2350
Rolled Sections (kg)	2369	1776	1010
Tapered sections (kg)	-	518	-
Cold formed/ built up sections (kg)	-	-	1340
Connection plates @ 5% (kg)	118	115	118
Weight of the tank sheet (kg)	2097	2097	2097
Fabrication costing (INR/kg)			
Material cost			
Rolled sections @ INR55/kg	130295	101232	57570
Plate works @ INR58/kg	128496	158323	206161
Fabrication process cost			
Rolled sections @ INR15/kg	35535	26640	15150
Plate works @ INR22/kg	48740	60053	78199
Total fabrication cost	343066	346248	357080
over head cost @ 5%	17153	17312	17854
Total cost of fabrication	360219	363560	374934
Percentage cost optimization	-	-1% (No savings)	-4% (No savings)

iv Load Optimization Study

The tanks of the study in the automobile industrial structures are generally placed in the ground or sometimes at the structural platform depending on the function usage. Hence the optimized tanks on the weight optimisation criteria generally reduce the load on the anchored ground surface or the supporting platforms.The results of tank A -70m3 and tank B-(30m3) on load optimization criteria is produced in Table.5 ana Table 6 respectively are shown below.

v Tank wall -stiffener study

The tank wall is attached to the tank frame by means of stiffeners running around the tank wall at different height. The stiffeners act as the boundary for the tank wall. The tank wall at the top row will have different boundary condition compared to other areas of the tank wall. Since the top edges of these tanks are normally restrained or supported by many interface equipment supports, the other area plates with four sides fixed are of design concern.

As the liquid pressure increases near the bottom of the tank, the plates at these areas are critical compared to other locations. Hence the plates at the bottom level and the side plates near the bottom plate are taken up for study for both tanks. Also the different grades of material with different thickness are considered with constant boundary conditions and dimension of the plate. The detailed analysis was done and design results is provided as follows

Table 5 Load optimization results for Tank A(70 m^3)

Parameters	Rolled Steel Sections	Tapered sections	Cold formed / built-up Tubular sections
Weight of tank structure with connection plates (kg)	4497	4201	3511
Weight of the tank sheet (kg)	2584	2584	2584
Total weight of the tank (kg)	7081	6785	6095
Plan area of tank (m^2)	21.16	21.16	21.16
Weight of tank structure per unit area (kg/m^2)	335	321	288
Percentage Load optimization	-	4%	14%

Table 6 Load optimization results for Tank B (33 m^3)

Parameters	Rolled Steel Sections	Tapered sections	Cold formed / built-up Tubular sections
Weight of tank structure with connection plates (kg)	2487	2409	2468
Weight of the tank sheet (kg)	2097	2097	2097
Total weight of the tank (kg)	4584	4506	4565
Plan area of tank (m^2)	19.8	19.8	19.8
Weight of tank structure per unit area (kg/m^2)	232	228	231
Percentage Load optimization	-	1.7%	0.4%

Table 7 Design results for tank wall with different grade of material

Parameters	Tank A 70m^3		Tank B 33m^3	
	MS Fe250	SS304	MS Fe250	SS304
Thickness of tank wall considered, t(mm)	5	6	6	6
Thickness of tank wall required (mm):				
Bottom plates	2.4	2.7	4.3	5.3
Side plates	4.9	5.7	4.1	4.5
Deflection of tank wall (mm):				
Bottom plates	0.3	0.2	2.2	2.8
Side plates	2.1	1.5	1	1
Permissible Deflection of tank wall, t/2 (mm)	2.5	3	3	3

The design results of the tank are presented in Table 7.The thickness of tank wall at the bottom location in the stress calculation is the critical criteria in the tank B 33m^3 due to less width of the tank for both the cases of grade of material used. The tank A 70m^3 has critical criteria due to liquid pressure acting on the bottom plates and hence the different thickness for both MS and SS material tank wall are required. The side of tank walls deflected more for the tank A 70m^3 and the bottom plates have more deflection for tank B 33m^3.

Conclusions

From the study, the following information can be inferred from the interpretation of optimization results. The summary of the optimization results are presented below

- Tank frames with built-up tubular sections of tank A (70m^3) result in higher savings than rolled steel or tapered sections.
- Even though 22% optimization is achieved in weight for cold formed tank frame, the fabrication process influences the total optimization thereby bringing down to 10% shows the importance of fabrication process and the cost factor involved in the tank design.
- The cold formed tank frame having better structural efficiency and load distribution compared to other frame sections considered.
- The use of SS304 grade of material results in higher tank wall thickness leading to increase of weight in tank wall. If the change in stiffener spacing is modified, the stiffener weight will increase by introduction of new row in the tank wall stiffener arrangement will increase the weight and fabrication process.
- Tank frames with rolled steel of tank B (33m3) result in higher savings than built-up tubular sections or tapered sections.
- The tanks with capacity of 33 m^3 or less results in better with tank frames of rolled sections alone. No savings by using cold formed tubular sections and tapered sections shall be achieved due to higher fabrication cost.
- The bottom plates of smaller tank with less width are critical in stresses which have to be taken care by introduction of stiffeners.

The engineering cost and the installation cost will have influence in the total optimization as they were considered constant in the study

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