DESIGN AND FINITE ELEMENT ANALYSIS OF MOUNDED BULLET

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ABSTRACT

The storage of highly inflammable, toxic and pressurized gases such as LPG is of prime challenging task and there is a need to design storage facilities for such gases with safety of the personal in and around, the locations, where it is situated. The safety is of prime importance, because it not only leads to the loss to the industry but also to the lives of the people.

In the present work an attempt is made to design a MOUNDED BULLET with a huge capacity of 851.5 m^3 LPG at a pressure of 1.697 Mpa. The MOUNDED BULLET which is nothing but a pressure vessel, being buried underground, the chances of explosion and consequent throwel of debris is almost nullified.

The vessel has been designed considering various parameters such as internal pressure, hydro test pressure etc., based on ASME codes. For the required quantity of gas to be stored, the length and diameter of the MOUNDED BULLET have been chosen according to the codes.

The designed vessel has been analyzed for stresses using FINITE ELEMENT TECHNIQUE. In additional to the internal pressure of the vessel, mound load, earthquake load. Uneven displacement/settlement of the sand bed, weight of the vessel, test conditions have been considered for the analysis.

INTRODUCTION

The storage of dangerous gases became a challenging problem, which posed a question mark on safety of surroundings, as well as to the lives of the people. Moreover the property of the industry, which is handling it is also lost. The accident that occurred in 1984, which cause disaster in MEXICO City depot, is an unforgettable and unrecoverable accident, where 16000 m^3 of LPG was stored in 6 spheres and 48 horizontal vessels. A leak occurred in 8” fill line to one of the spheres and within in 15 minutes of leakage, a series of BLEVES occurred producing a fire ball of 350m diameter which engulfed all the remaining spheres and horizontal vessels whose debris flew up to 1200m distance killing 500 people and injuring 7000 people. A good majority of the were within 300m of the depot. A similar accident has occurred in HINDUSTAN PETROLUM CORRORATION LIMITED, VISAKHAPATNAM, where nearly 30 lives were lost. The main cause of this accident was found to be the leakage occurred in the fill line. Due to this leakage a fire accident occurred to a sphere thus spreading to all other spheres.

It appears that the main causes of these accidents is due to the unavailability of proper storage facilities and also close spacing of the spheres and horizontal vessels.

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In these project an attempt has been made to design a Mound Bullet that falls under the category of pressure vessel, for the storage of LPG. The design has been done as per ASME (AMERICAN, SOCIETY OF MECHANICAL ENGINEERS)

The purpose of mound is to protect the vessel against external events, such as radiation in case of fire, flying objects and sabotage and hence the thickness of cover should be at least one meter. The slope of the mound shall not exceed the natural slope of fill material by 1:1.5 maximum.

DESIGN OF MOUNDED BULLET

Design Parameters and Material Specifications

The MOUNDED BULLET is designed with the following design parameters and material specifications.

Table1: Design parameters of MOUNDED BULLET

Fluid Handled	LPG LIQ./VAP
Design Pressure kg/cm^2	17/(FV+WEIGHT OF MOUND)
Design Temperature ^0C	70/-27
Working Pressure kg/cm^2	10
Working Temperature ^0C	40
Pneumatic Test Pressure kg/cm^2	NIL
Hyd. Test Pressure kg/cm^2	21.6(AT TOP)
Corrosion Allowance mm	3
Weld Joint Efficiency SHELL/HEAD	100%
Radiography SHELL/HEAD	FULL
Insulation	NIL
Lining	NIL
P.W Heat Treatment (Stress Reliving)	YES
Minimum Design Metal Temperature:^0C	-27

Volume (Capacity) m^3	851.5
Liquid Density (kg/ m^3)	531.2
APPROXMATE WEIGHTS (kgs).	
Erection Weight kg.	282000
Operation Weight kg	671000
Hydro Test Weight kg	1139000

Material Specification

Sa 516 Gr. 6	:	SHELL, D'END FAB. NOZZLES. & RF PADS .
Sa 266 Gr. 2	:	Nozzle Necks.
Sa 105	:	W.N. Flanges.
Sa 106 Gr.B	:	Int. Pipes

The above materials are nonferrous and structural steels.

Selection of materials

Selection of material plays a major role in design and reduction in cost of Vessel. Selection of materials for the vessel depends on the following.

1. Mechanical resistance i.e. strength and toughness at the operating temperature.
2. Chemical resistance under operating conditions with regard to corrosive media, concentration, temperature, foreign substance, flow behaviour etc.,
3. There should be no detrimental interference by the material on the process.
4. Availability of material in market within time.
5. Good workability.
6. Low cost.
7. Steel is one of the most versatile material. Carbon steel can be used for pressure vessels for a life of 20 years and even more.
8. Yield strength drops with increase in temperature and below room temperature, temper embrittlement occur, which can be found by notch impact tests, by increasing the carbon content, the tensile strength and hardness increases while the ductility and weldability decreases.
9. The mechanical and physical properties at low temperature i.e. tensile strength, yield strength and modulus of elasticity of carbon steels increases, where as the elongation, reduction in area and impact strength gets decreased.

Various components of Pressure Vessels

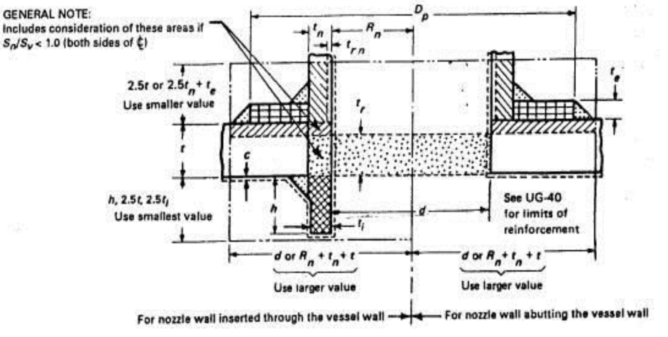
Shells: Most of the shells of pressure vessels are made of cylindrical sections. Cylindrical shells have all the metal area located at maximum distance (*for a given diameter) n of the neutral axis, the section modulus is maximum and induced stresses are minimum for the metal involved. Also square and spherical shells are used.

Flat Ends: These are used as closures for small diameter and low-pressure vessels. These flat ends will be connected to the shell by direct welding or bolting

Dished ends: In general, all cylindrical vessels are provided with dished ends. The use of formed heads as closures is usually more economical than the use of flat plates. The formed end with a gradual change in shape reduces the local discontinuity stresses at the junction.

Reinforcement Pads: It is circular plate with a circular hole of nozzle size to which reinforcement is required. Due to weakening effect on shell and because of opening made in the shell for nozzle etc. and where compensations are required, normally, reinforcement pads are provided by welding another plate around the hole to add sufficient metal to compensate for the weakening effect of the opening. The reinforcement prevents local over stressing of shell around the opening.

Fig1: Placing of Reinforcement pads



Flanges And Fittings: Flanges are used for closures of openings (nozzles) and for joining shells. Flanges are used on the shells of a vessel to permit disassembly and removal and cleaning of internal parts. When the diameter of vessel is too small for providing a manhole for a man to go in to the vessel for cleaning and maintenance, usually shell flanges are provided. A great variety, types and sizes of standard flanges are available for various pressure and services.

Fasteners: Any process equipment consisting of various piping i.e. fluid inlet, fluid outlet, drain etc for manufacturing and maintenance convenience these pipes are provided with flanged joints near the equipment. Studs are generally used to fasten the flanges and these are tightened by hand where for low pressure service, for high-pressure service hydraulic stud tightening devise is used.

Platform and ladder supports: The process equipment is requiring platform and manholes in order to make easy to fit the internals through the manhole or to repair if any damage occurs during the process. Platforms are provided near the manholes. For holding these platforms and ladders, there should be some supports required on to the vessel. The platform supports are channels or angles welded to the outer surf races of the vessel.

Manhole Davit: Manholes are provided with hinged circular covers so that the cover may be opened or closed very easily in position. The hinge consists of pipes, hook lifting lug etc. The whole part is called as davit.

Stiffening Rings: A cylindrical vessel under external pressure has an induced circumferential compressive stress equal to twice the longitudinal compressive stress because of external pressure effects alone. Under such a condition the vessel is opt to collapse because of elastic instability. The collapsing strength of such vessel may be increased by the use of uniformly spaced internal or external circumferential stiffening rings.

Fig 2: Internal Stiffener ring

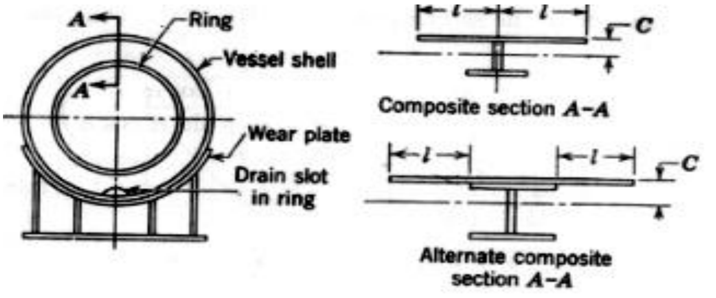
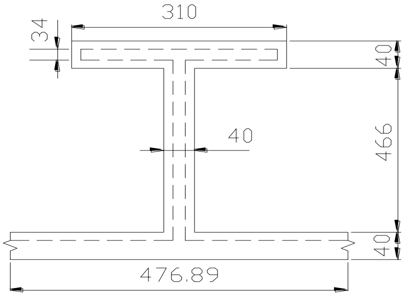


Fig 3: Cross sectional view of stiffener rings



Nozzles: Nozzles are connections through which the vessel is connected to the piping, instrumentation and other control equipment. These are welded to the shell. Nozzles can be made from seamless pipes, forged hollow bars or can be fabricated from plates depending upon the size and thickness. The nozzles are connected to piping, instrumentation etc., by means of flanges, screwed type connections or direct welding.

Shell Design of Large Storage Tanks

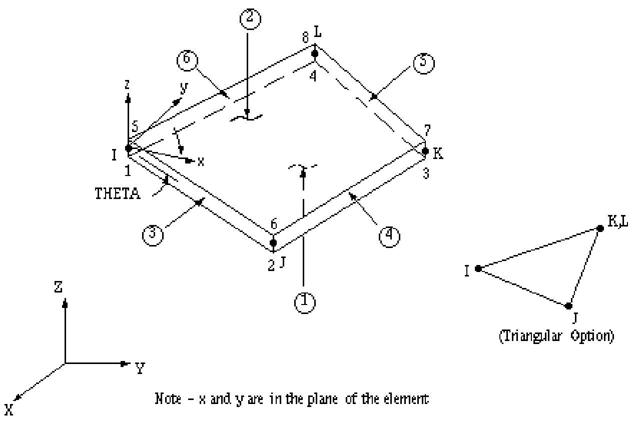
The majority of tanks and vessels are cylindrical because a cylinder has great structural strength and is easy to fabricate. Several types of stress may occur in a cylindrical shell. These may be recognized as:

1. Longitudinal stress resulting from pressure
2. Circumferential stress resulting from pressure
3. Residual stress resulting from localized heating
4. Stresses resulting from superimposed loads such as wind, snow, and ice, auxiliary equipment, and impact loads;
5. Stresses resulting from thermal differences;
6. Others, such as may be encountered in practice.

SHELL 63 ELEMENT

SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses.

Fig 4: Shell 63



SHELL 63 Input Summary

Element Name: SHELL 63
Nodes: I,J,K,L
Degrees of Freedom : UX,UY,UZ,RTOX,RTOY,RTOZ
Real Constants : TK(I), TK(J), TK(K), TK(L), EFS,THETA.
Material properties:
Material Specification : SA516 Gr.60
Young's modulus : 200192.67 N/mm^2 at design temperature
: 202203.72 N/mm^2 at test temperature
Poisson's ratio, NUXY : 0.31
Density, DENS : 7.70085 E^{-05}

Design Calculations of Mounded Bullet

Calculations of static head, hydro test pressure and external pressure

(a) INTERNAL PRESSURE:

Static pressure due to liquid head = ρgh.
Where
ρ : Density of liquid =531.2 kg/m^3
g : Acceleration due to gravity = 9.81m/sec^2
h : Height of liquid = 4000(HLL) mm
= 4 m

Static pressure = ρgh.
= 531.2×9.81×4 N/m^2

= (531.2×9.81× 4) ÷ (9.81×100^2) kg/cm^2

= 0.213 kg/cm^2

Total pressure at bottom=internal design pressure+ pressure due to Static head of liquid

= 0.213+17.3

= 17.213 kg/cm^2

Considered pressure at bottom = 17.3 kg/cm^2

= 1.697 Mpa

(b) HYDRO TEST PRESSURE:

Static pressure due to liquid head = ρgh.

Where

ρ = Density of water = 1000 kg/m^3

g = Acceleration due to gravity = 9.81m/sec2

h = Height of liquid = 6920 mm

= 6.92 m

(Water level at top face of Nozzle in Dome-1)

Static pressure = ρgh.

= 1000×9.81×6.92 N/m^2

= (1000×9.81×6.92) ÷ (9.81×1002) kg/cm^2

= 0.692 kg/cm^2

Test pressure =1.25×(design pressure × Stress ratio) +Static pressure

$$S.R = \frac{\text{Allowable stress at test temperature}}{\text{Allowable stress at design temperature}}$$

= 1.25×(17 ×1406/1385.78)+0.692=22.26

Hydro test pressure at bottom = 22.26 kg/cm^2

= 2.183 Mpa

(c) CALCULATION OF EXTERNAL PRESSURE

Considered 15 PSI = 1.055kg/cm^2

External pressure due to mound as per shell guide lines = 0.603 kg/cm^2

Considered External pressure due to mound = 0.708 kg/cm^2

Total external pressure = 1.055+0.708

= 1.763 kg/cm^2

= 0.1729 Mpa

ANALYSIS OF MOUNDED BULLET

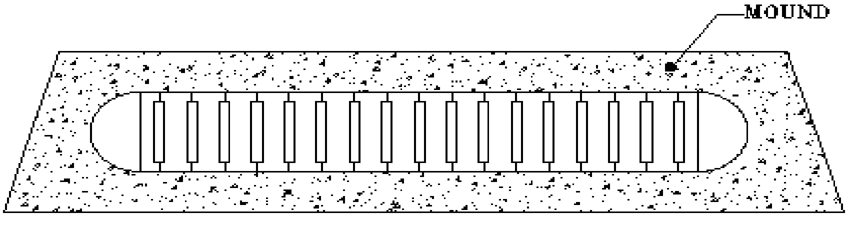
FEA Modeling

- Complete bullet along with internal stiffeners was modeled with the Shell63 elements with different real constants.
- Corroded thicknesses were considered for analysis during operating condition and uncorroded thickness were considered for analysis during hydro test condition.
- The elastic foundation stiffness is generally uniformly distributed and in the range of 10 to 15 MN/m^2 per meter as indicated in IS 2911(Part-1/Sec.2 Appendix-C)Table-1 for medium to dense sands. Both the values have been conservatively considered using configurations of distribution as shown in the fig 4.

Settlement of soil foundation is considered as displacement along the negative Y-direction considering two independent cases .

- Weight of mound on the bullet is considered .
- Earthquake load is applied as pe**r F.MANG** guidelines.
- Total number of elements = 11356
- Total number of nodes = 11487
- Aspect ratio = 6 (Max.).Aspect ratio is used for modeling of domes only.
- Domes are modeled up to a distance of √RT for analyzing the discontinuity stresses at the junction. Towards the end of the domes a pressure equivalent to the internal/external pressure has been applied to the tip of the domes.

Fig 5: Evaluation of the bullet



Loads & boundary conditions

The following loads and load combinations are considered for analysis.

Loads

A. Weight of empty vessel = 2766420 N

B. Weight of stored liquid = 3816090 N

C. Internal design pressure = 1.697 Mpa

D. Pressure by mound on the domed ends Pm

$$Pm = 2Q/\pi RL$$

Where, Q = Density of mound x $[(2RH-\pi R\spadesuit/2) + H^2/3]$ x L

R: Out side radius of the bullet = 2.54 m

H: Height of mound = 3.54 m

L: Total length of bullet = 45.06 m

$Q = 2000 \times [(2\times2.54\times3.54-\pi(2.5)\spadesuit/2) + (3.54)^2/3] \times 45060$

= 1084000 Kgs.

$P_m = 2\times1084000/\pi\times2520\times45060$

= 0.00603 kg/m

= 0.059154 N/mm^2.

E. Weight of mound on the vessel

$= [(2RH-\pi R\spadesuit/2) + H^2/3] \times 2000$ Kg/m.
= 24050 Kg/ m
= 235930.5 N/m.

= 235930.5 N/m.

F. Axial load due to change in vessel length (Stress due to friction).

The change in length of bullet due to the variation of temperature & Pressure is almost negligible. However due to the small change in length of bullet, the surrounding soil will exert a frictional force in a direction opposite to the direction of change of length which is advantageous in this case.

G. Loads due to uneven support of the vessel (Differential settlement)

The following settlement values are considered.

- Immediate settlement value = 5 mm.
- Long term settlement value = 15 mm.
- Max. differential settlement value between center and ends =10 m

Two independent cases are considered

i. Settlement of midpoint with respect to end points.

ii. Settlement of ends with respect to mid point.

H. Supporting pressure by the compacted sand bed.

I. Earthquake load.

Earthquake load is calculated as per IS 1893-1984 considering the following.

Seismic Zone = **V** (as per IS1893-1984)

Soil foundation factor, $\boldsymbol{\beta}$ = 1.2

Importance factor, **I** = 2.0

Basic Horizontal seismic co-efficient, αo = 0.08

Horizontal seismic co-efficient, $\alpha h = \boldsymbol{\beta I \alpha o}$

$= 1.2 x 2 x 0.008 = 0.192$

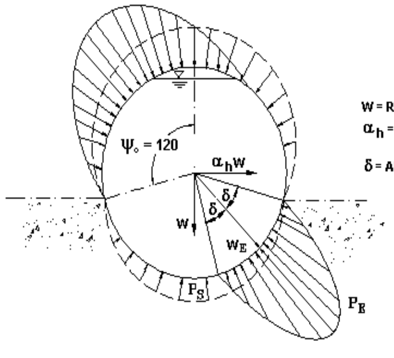
Earthquake load = Wo X αh

= 671000 X 0.192 ≈ 129000 Kgs.

= 1265490 N

Where Wo is the operating weight of the bullet = 671 MT.

Fig 6: Assumption of Earth cover and Bearing pressure in case of earth quake



J. Weight of hydro test water =1139000 kg

= 11173590 N

K. Hydro test pressure = 2.183 Mpa

L. Live load = 250 Kg/m²

Live load is considered as a uniformly distributed load in analysis.

Live load = (⅔H + 2R) X 250 Kg per meter

= 1860 Kg /m = 18246.6 N /m

M. Internal vacuum.

N. Loads due to external explosion pressure

Fe = (2R + ⅔H) x L x (Cr x Pe)

Where Cr is the reflection co-efficient = 1.5

L is the overall length of bullet = 45060 mm

Pe is the explosion pressure = 0.15 bar(g) (max.)

Fe = (2x2.54 + ⅔X3.54) x45060 x (1.5 x0.15x1.01325)

≈ 769200 Kgs = 7545852 N

Explosion and earthquake loads are assumed not to occur simultaneously.

Fig 7: Mound & Live load on top of Bullet and Soil Reaction Pressure distribution

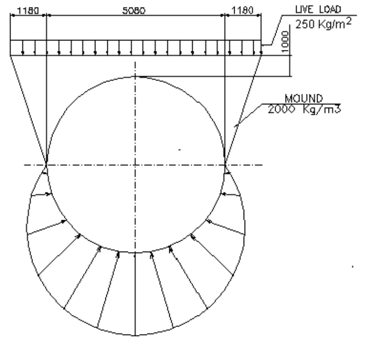
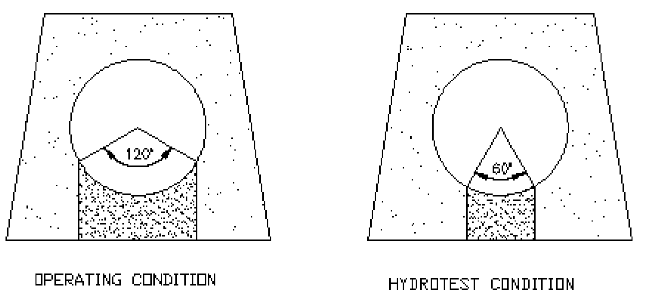


Fig 8: Support consideration



LOAD COMBINATIONS

I. Operating Condition

Without internal pressure & without earthquake

a) (A) + (D) + (E) + (F) + (G)(i) + (H) + (L) + (N)
b) (A) + (D) + (E) + (F) + (G)(ii) + (H) + (L) + (N)

With internal pressure & without earthquake

c) (A)+ (B) + (C) + (D) + (E) + (F) + (G)(i) + (H) + (L) + (N)
d) (A) + (B) + (C) + (D) + (E) + (F) + (G)(ii) + (H) + (L) + (N)

Without internal pressure & with earthquake

e) (A) + (D) + (E) + (F) + (G)(i) + (H) + (I) + (L)
f) (A) + (D) + (E) + (F) + (G)(ii) + (H) + (I) + (L)

With internal pressure & earthquake

g) (A) + (B) + (C) + (D) + (E) + (F) + (G)(i) + (H) + (I) + (L)
h) (A) + (B) + (C) + (D) + (E) + (F) + (G)(ii) + (H)+ (I) + (L)

With internal vacuum & earthquake

i) (A) + (D) + (E) + (F) + (G)(i) + (H) + (I) + (L) + (M)

j) (A) + (D) + (E) + (F) + (G)(ii) + (H)+ (I) + (L) + (M)

II. Test Condition

Without test pressure

a) (A) + (G)(i) + (H) + (J)

b) (A) + (G) (ii) + (H) + (J)

With test pressure

c) (A) + (G)(i) + (H) + (J) + (K)

d) (A) + (G) (ii) + (H) + (J) + (K)

RESULTS AND DISCUSSIONS

The finite element analysis is carried out for different loading combinations indicated in chapter loads. Loading combinations – I(b), I(c), I(f), I(g), I(i), II(b) and II(c) are found to be governing. A case sheet for each of the governing loading combination has been prepared that includes details of the Stress intensities, maximum principal stresses and Von-mises stress. Maximum stress intensity of 206.088 N/mm^2 is found at the shell to Dome-3 junction and maximum stress intensity of 124.142 N/mm^2 is found in shell away from the junctions during operation condition (Load combination-I(g)). Stress intensity at the junctions within 1T are ignored while comparing with the allowable stresses as per code. Linearized stresses are plotted for the severely stressed region of bullet considering stress intensity (**σ s**) as indicated below.

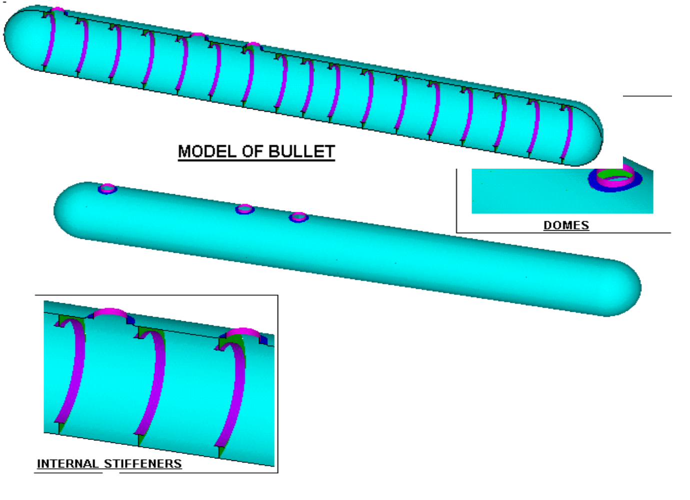
$$\sigma 1,2 = \sigma x + \sigma y/2 \pm \sqrt{((\sigma x + \sigma y)/2)^{♠} + \tau xy^{♠}}$$

In this case, principal stress σz is equal to $\sigma 3$

Stress intensity (SINT) is calculated from the three principal stresses $\sigma 1$, $\sigma 2$ and $\sigma 3$.

SINT = | (σ 1-σ 2), (σ 2-σ 3), (σ 1-σ 3) |

Fig 9: Mounded bullet with domes and internal Stiffeners



Sa – Maximum stress intensity at a (should be < 3Sm = 415.71 N/mm^2)

Sb– Maximum stress intensity at b(should be < 1.5Sm = 207.86 N/mm^2)

Sc – Maximum stress intensity at c (should be < Sm = 138.57 N/mm^2)

Load Combination 1(b):

	Sa	Sb	Sc
Stress in N/mm^2	163.37	109.92	83.09

Load Combination 1(C):

	Sa	Sb	Sc
Stress in N/mm^2	129.56	97.18	64.79

Load Combination 1(f):

	Sa	Sb	Sc
Stress in N/mm^2	110.4	98.13	61.34

Load Combination 1(g):

	Sa	Sb	Sc
Stress in N/mm^2	297.91	196.0	128.99

Load Combination 1(i):

	Sa	Sb	Sc
Stress in N/mm^2	84.2	74.85	56.15

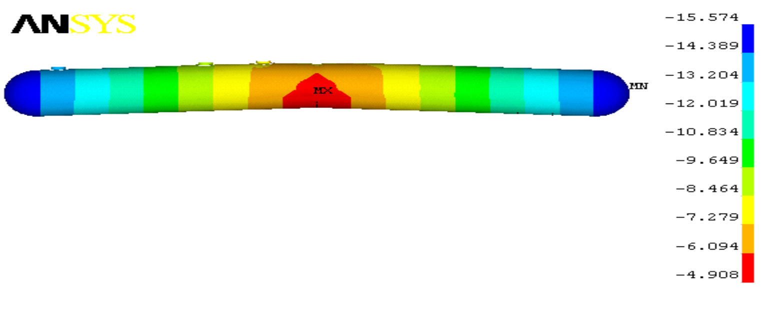
Load Combination 2(b):

	Sa	Sb	Sc
Stress in N/mm^2	71.45	54.12	51.56

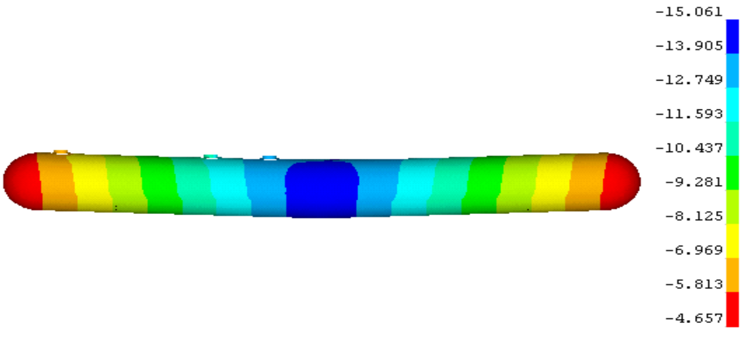
Load Combination 2(c):

	Sa	Sb	Sc
Stress in N/mm^2	231.71	185.36	185.36

DEFORMATION OF BULLET



15 mm DISPLACEMENT AT ENDS



15 mm DISPLACEMENT AT CENTERS

CONCLUSIONS

In additional to the internal pressure of the vessel, mound load, earthquake load, uneven displacement/settlement of the sand bed, weight of the vessel, test conditions have been considered for the analysis. The analysis reveals that the design stresses are within the limit and the design is safe.

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