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Analysis of Dent on Cylindrical Pressure Vessel Using FEA

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Abstract

Stress and strain estimation in structures is very important in predicting and preventing the prior failure of the members. The earlier stress based failure theories are slowly moving towards strain based theories due to the advances in material technology.

In this paper, FE analysis is done for the structure with dent. A dent is formed in the pressure vessel system accidentally. So it is important to estimate the stress and plastic strain for doing acceptance study of the problem, as immediate rejection of the system involves higher investments. Due to the advances in computer and finite element techniques, this type of study is possible and avoids unnecessary inventory loss. So analysis will be carried out on the system to find theoretical stresses and finite element stresses for the calculated operating loads. All the steps involved in analysis will be carried out on the model, using Ansys plastic shell elements.

I. INTRODUCTION

Vessels carry, store, or receive fluids are called pressure vessels. A pressure vessel is defined as a container with a pressure difference between inside and outside. The inside pressure is usually higher than the outside, except for some isolated situations. The fluid inside the vessel may undergo a change in state as in the case of steam boilers, or may combine with other reagents as in the case of a chemical reactor. Pressure vessels often have a combination of high pressures together with high temperatures, and in some cases flammable fluids or highly radioactive materials. Because of such hazards it is imperative that the design be such that no leakage can occur. In addition these vessels have to be designed carefully to cope with the operating temperature and pressure. It should be borne in mind that the rupture of a pressure vessel has a potential to cause extensive physical injury and property damage. Plant safety and integrity are of fundamental concern in pressure vessel design and these of course depend on the adequacy of design codes.[1]

Pressure vessels are used in a number of industries; for example; the power generation industry for fossil and nuclear power, the petrochemical industry for storing and processing crude petroleum oil in tank farms as well as storing gasoline in service stations, and the chemical industry (in chemical reactors) to name but a few. Their use has expanded throughout the world. Pressure vessels are in fact, essential to the chemical, petroleum, petrochemical and nuclear industries. It is in this class of equipment that the reactions, separations, and storage of raw materials occur. Generally speaking, pressurized equipment is required for a wide range of industrial plant for storage and manufacturing purposes.

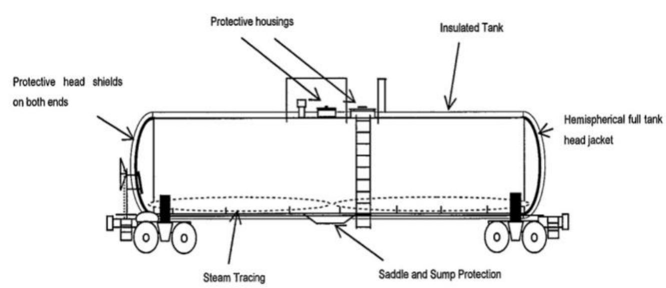

Fig.1 Pressure vessel[16]

The size and geometric form of pressure vessels vary greatly from the large cylindrical units for aircraft. Some are buried in the ground or deep in the ocean, but most are positioned on ground or supported in platforms. Pressure vessels are usually spherical or cylindrical, with domed ends. The cylindrical vessels are generally preferred, since they present simpler manufacturing problems and make better use of the available space. Boiler drums, heat exchangers, chemical reactors, and so on, are generally cylindrical. Spherical vessels have the advantage of requiring thinner walls for a given pressure and diameter than the equivalent cylinder. Therefore they are used for large gas or liquid containers, gas-cooled nuclear reactors, containment buildings for nuclear plant, and so on. Containment vessels for liquids at very low pressures are sometimes in the form of lobed spheroids or in the shape of a drop. This has the advantage of providing the best possible stress distribution when the tank is full.

II. SCOPE OF THE PRESENTSTUDY

The present analysis is to determine the effect of accidental dent formation on the pressure vessel system. Since pressure vessels are costly and immediate replacement involves lot of investment and time. So Finite Element Analysis is carried out to check the safety of the system as per ASME standards.

The vessel has been met with an accident and a dent has been formed. The maximum depth of the dent is 27mm and different depth of dent at different positions spreading for an arc length of 450mm and around 550mm height. This deformation may result into local plastic condition of the cylindrical vessel and sometimes stresses may exceed the yield stress of the structure and resulting into plastic strains causing residual stresses. This residual stresses may result into crack formation and eventual failure of the system. To avoid the probable damage, results are compared with the standard material properties either to accept or reject the vessel.

III. MODEL DEVELOPMENT USING CATIA

A. Material Properties [6]

The material used to manufacture above pressure vessel is stainless steel and its properties used for design and analysis is as follows.

Table 1:Material properties [2]

Material	SA 204 TP 304
Young's Modulus	210GPa
Poison's Ratio	0.29
Tangent Modulus	1388 N/mm^2
Yield Stress at weld	121 N/mm^2
Yield Stress of parent Material	205 N/mm^2
Ultimate Tensile Strength	515 N/mm^2
Density	7850 Kg/m^3

B. Other Specifications:

S_T- Allowable membrane stress at the pressure test condition 138 N/mm^2

S - Allowable membrane stress for the design temperature 138 N/mm^2

P - Internal and external maximum allowable working pressure =2.2 bar

D - Dead weight of the vessel =65000 kg

Wpt - Wind test Pressure (Value of zero is considered for analysis)

Ps - Static head from liquid or bulk materials (zero value is assumed)

De - Static load for erection calculations = 35000Kgs

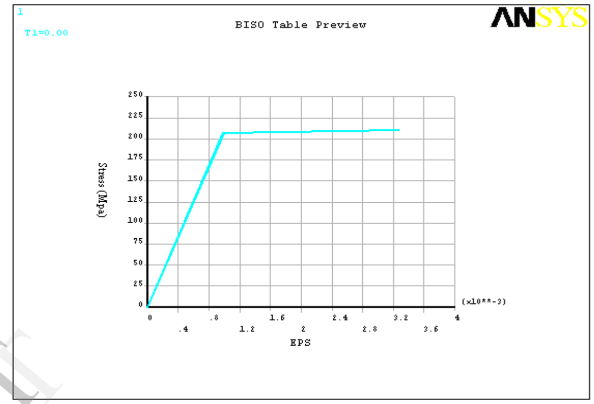

Fig.2 Bilinear Material Property

The Figure 2 shows variation of material properties above the yield point of the problem. Up to the yield point of 210Mpa, the curve is linear and later sloping down representing more deformation under yield conditions. The tangent modulus is calculated from the slope as 1388 Mpa.

The Pressure vessel is modeled using Catia V-5 R-19. The dimensions of the vessel are taken as per the ASME standards. A dent on the vessel is created with a depth of 27mm using Hypermesh. Meshing of the model and internal pressure is also applied in Hypermesh. Theresults are studied using Ansys13 and compared with the material properties, stating whether the vesselis suitable for further use or not.

IV. GEOMETRY OF MODEL

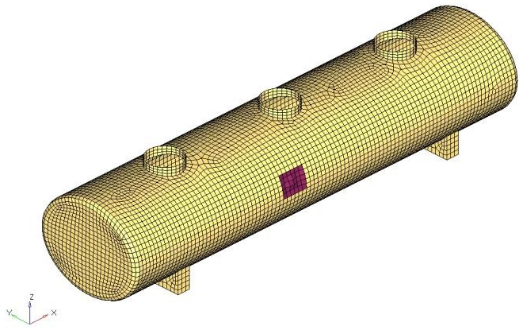

Fig. 3 Dent Area plot

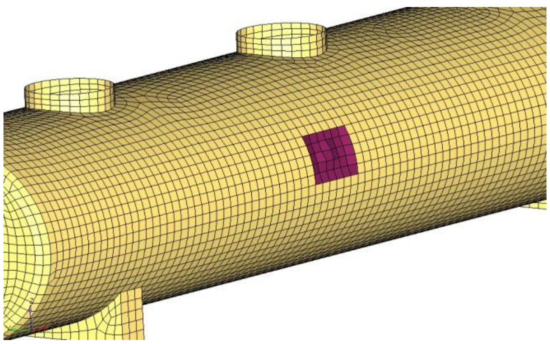

Fig. 4 Element plot of the problem

Fig. 3 shows area plot of the problem. The cylinder has been modeled using CATIA v5R19.The geometry is split into more number of areas with 4 sides to ease map meshing. Each area is represented by different color. Hypermesh is used to mesh the structure. Also this representation helps in applying different thickness across the geometry. The dimensions for the tank are considered as per the ASME standards.

Fig 4 shows geometrical and real (thickness) properties, the fluid pressure is acting inside the member. It is supported locally at the bottom section. The pressure vessel is having 5 mm thickness.

V. METHODOLOGY OF THE PROBLEM

Initially, the vessel is modeled as fabricated without the dent in CATIA.

The model has been meshed using SHELL 63 element. This element is well suited to model linear, warped, moderately thick shell structures. The element has six degrees of freedom at each node: translations in the model X, Y and Z directions and rotational about the modal X, Y, and Z axes. The element has plasticity, creep, stress stiffening, large deflection and large strain capabilities.

Now, on this meshed model the following load steps have been applied.

- Displacement constraints are applied at the given region by inputting the different displacement values.
- VonMises stress and the three principal stresses are recorded without the formation of dent.

- The constraint is removed and again with this condition, displacement, Vonmises stress and the three principal stresses are recorded, at the depth of dent 27mm.

VI. ASSUMPTIONS

- The material assumed to be linear isotropic upto yield point and later bilinear in the plastic region.
- All approximation applied to Finite Element Methods are applied for analysis.
- Shell63 element is used for analysis

VII. RESULTS

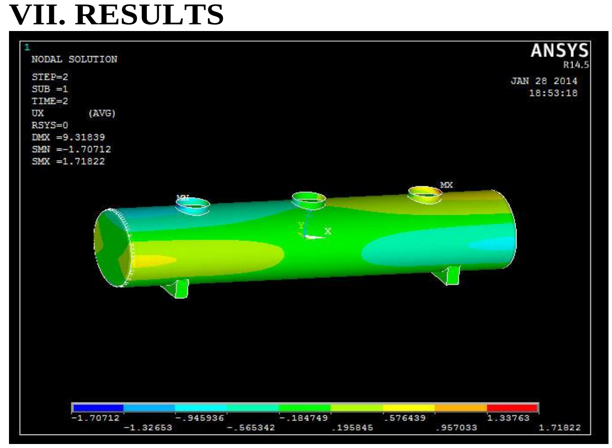

Fig.5 Displacement plot at load case without dent in x-direction

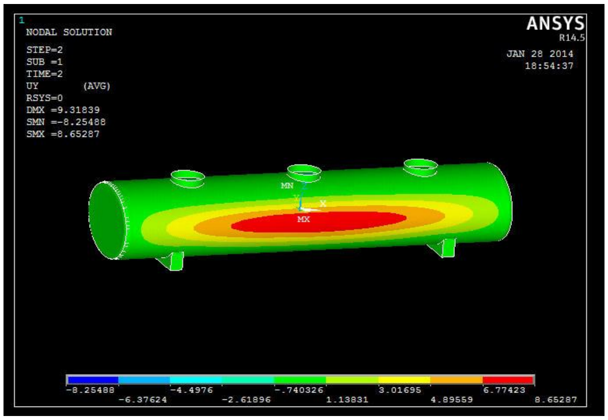

Fig.6 Displacement plot at load case without dent in y-direction

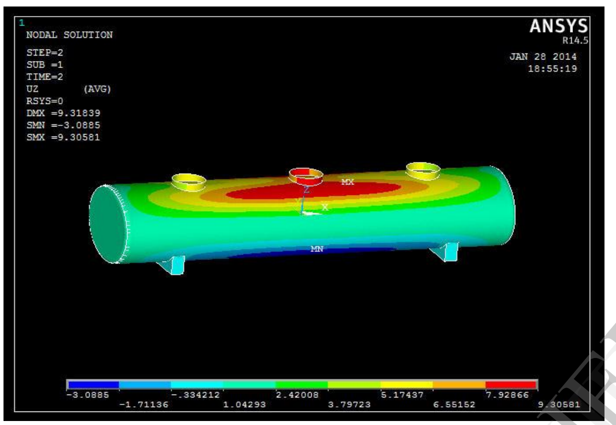

Fig.7 Displacement plot at load case without dent in z-direction

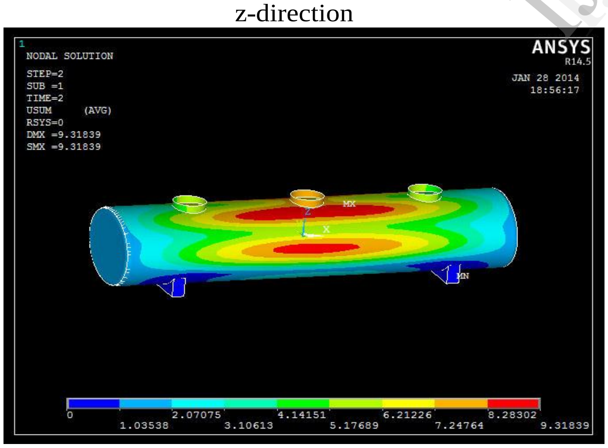

Fig.8 Displacement vector sum at load case without dent

Stress formation without dent:

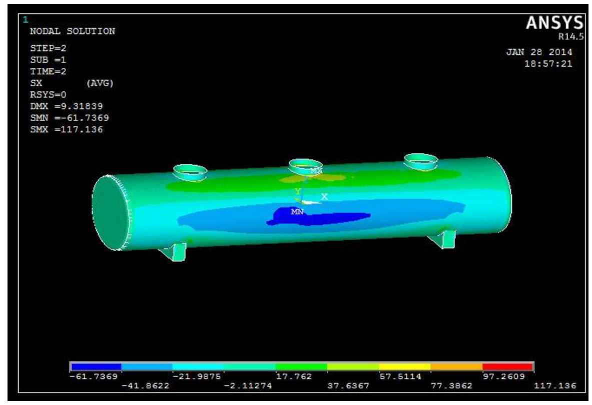

Fig.9 Stress plot at load case without dent in x-direction

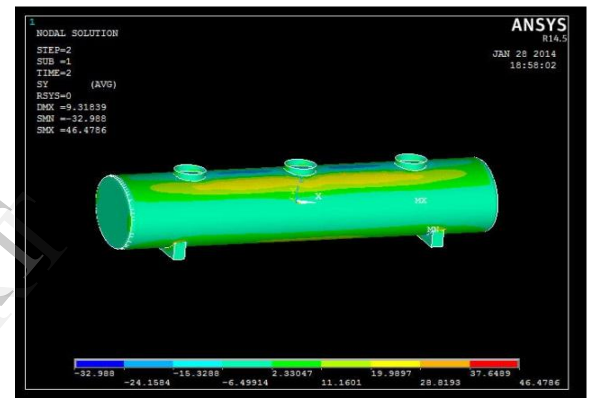

Fig.10 Stress plot at load case without dent in y-direction

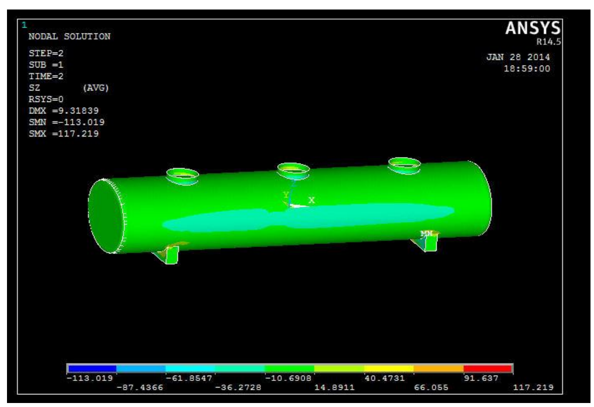

Fig.11 Stress plot at load case without dent in z-direction

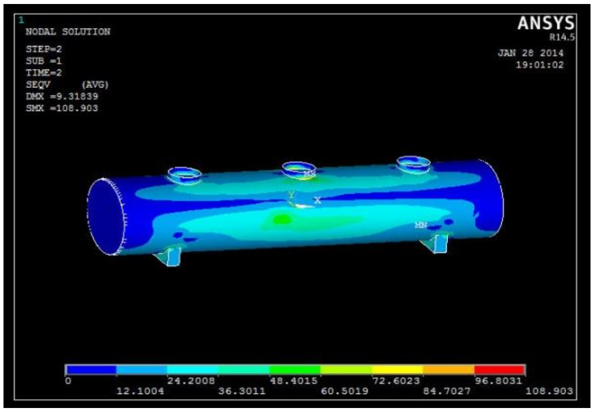

Fig.12Vonmises Stress plot at load case without dent

The dent nodes are shown above to apply the displacement loads. Maximum displacement location is represented by red color circle.

The nodes are identified from the center of lifting pad to the top of the cylindrical vessel.

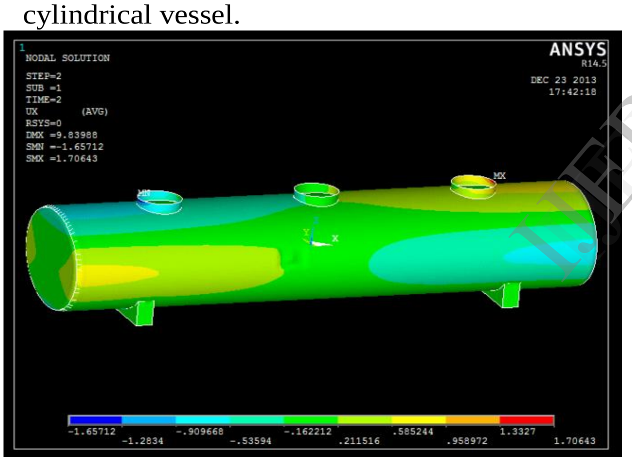

Fig.13 Displacement plot at load case with dent in x-direction

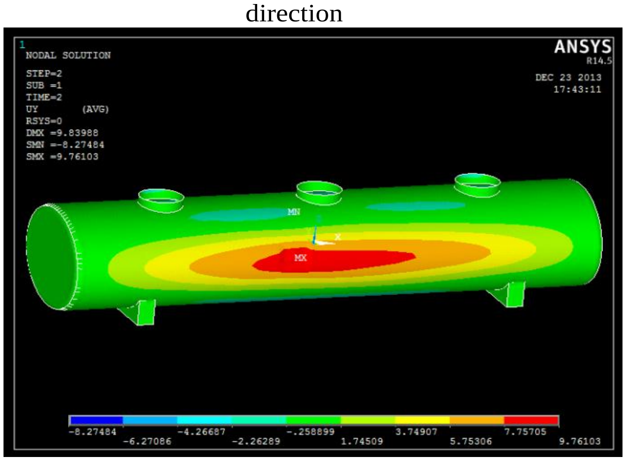

Fig.14 Displacement plot at load case with dent in y-direction

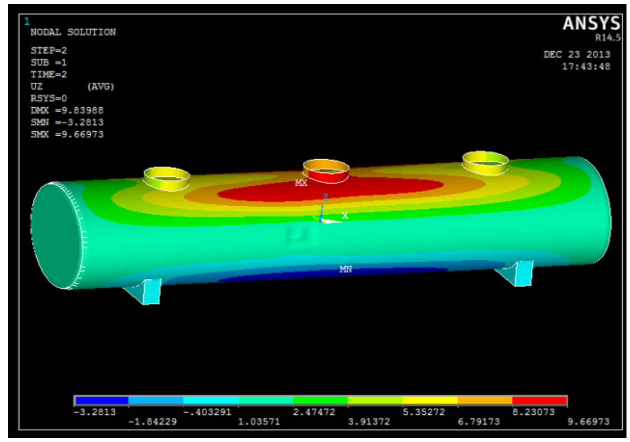

Fig.15 Displacement plot at load case with dent in z-direction

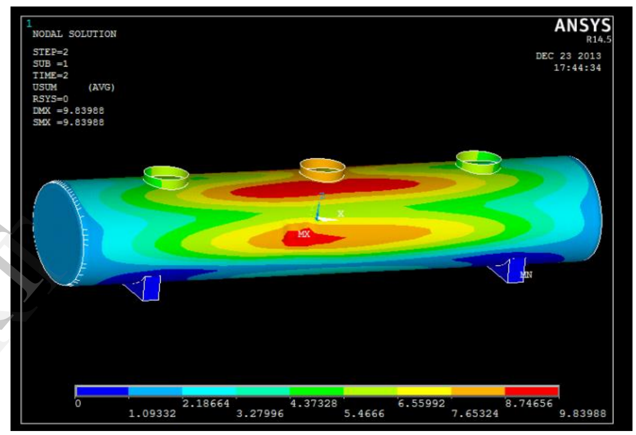

Fig.16 Displacement vector sum at load case with dent

Stress formation due to dent formation:

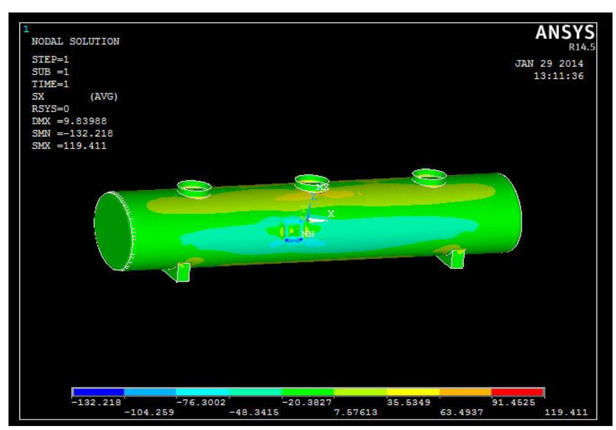

Fig.17 Stress plot at load case with dent in x-direction

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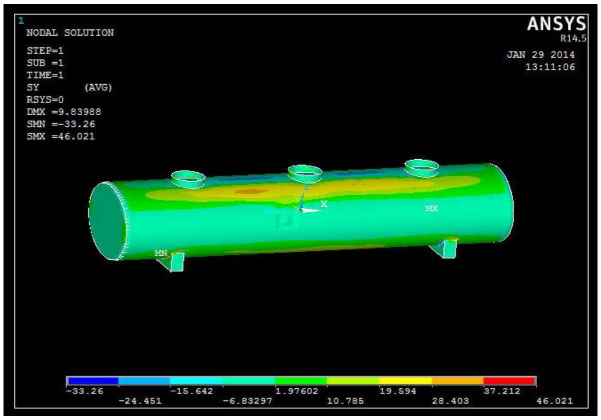

Fig.18 Stress plot at load case with dent in y-direction

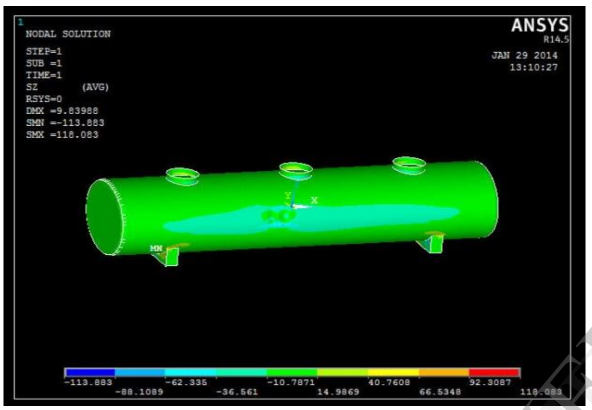

Fig.19 Stress plot at load case with dent in z-direction

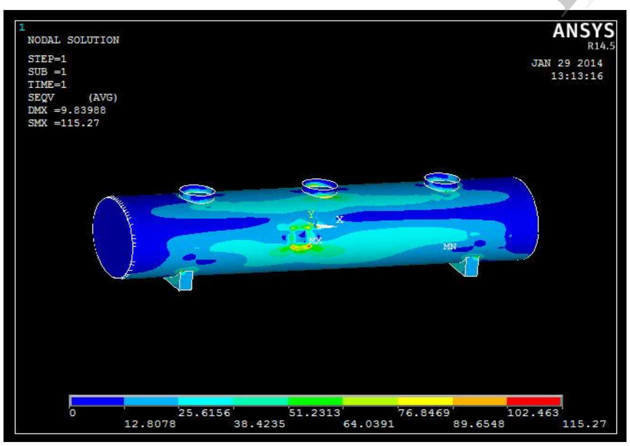

Fig.20Vonmises stress plot at load case with dent

The Figure12 shows maximum vonmises stress developed without the dent formation. Maximum vonmises stress is around 108.903 N/mm^2. The stress value is less than the yield stress of the material.

The Figure 17 shows maximum vonmises stress developed due to the dent formation. Maximum vonmises stress is around132.218N/mm^2 which is taking place at the maximum dent position.

VIII. CONCLUSIONS

The analysis results are summarized as follows.

- The model is imported to Ansys after applying an internal load of 1.75 bar inHypermesh. The results are studied using Ansys13.
- The model is applied with displacement to create a virtual dent formation on the structure using Hypermesh. From the center of rest pad, nodes are applied with gradual increasing displacement up to maximum dent depth of 27mm.
- An internal pressure load of 1.75bar is applied along with the residual stress formation. This model with a virtual dent created is again studied in Ansys13.
- In both the cases Vonmises stresses are recorded and compared with the yield stress of the material.
- All the results are presented with necessary pictures (Vonmises, principal and displacements).
- Finally acceptance calculations are carried out using ASME standards for analysis to check the safety of the local stress and plastic strain development due to the dent formation. The results shows, the acceptable permissible stress is much more than the developed maximum stress. So structure is safe in design for working conditions.

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