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The Study Of The Behaviour Of Bolted Flanges With Gaskets

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Abstract

Gasketed flange joints are very common in pressure vessel and piping systems. Flanges are primarily used where a connecting or dismantling joint is needed. These joints may include joining pipe to fittings, valves, equipment, or any other integral component within the piping system. The performance of joint is characterized mainly by its strength and sealing capability. However, recommended design procedures for bolted flange joints are available in international codes and standards. In this paper, bolted flange connections are analysed by implementing the design method of ASME Boiler and Pressure Vessel Code. The results of a parametric study of the behaviour of flanges and stresses in bolts are analysed by varying the flange thickness, bolt preload and number of bolts, at the same time maintaining other flange dimensions constant. Theoretical results obtained using ASME design approach is compared with results obtained by an analytical method.

1. Introduction

Bolted flange joints forms a part of pressure vessels and piping components, and are used extensively in the chemical and nuclear power industries. They are simple structures and offer the possibility of disassembly, making them attractive for connecting pressurized equipment and piping. There are many different designs of flanged joints to perform a particular application. They can be designed to sustain a pressures and variety of fluids with a range of temperatures and can be made to operate successfully under many conditions. Earlier attempts to design flanges were based on a variety of crude and simple assumptions. In 1927, Waters and Taylor initiated a method for calculating stresses and deflections in flange joints, the results will have good agreement with experimental results. **Waters et al. [1]** further refined the analysis in 1937, and named as the 'Taylor and Forge method'. This is the basis for ASME and BS5500 code of flange design. In a flange joint assembly, initially bolts are tightened and create tension and bolt-up stress in bolts in order to prevent leakage of the fluid from system. The initial bolt-up stress should be large enough for efficient sealing of the joint, but it should not large so as to allow the possibility of scratching and damaging the flange and gasket surface. The tightness of flange joints depends on the contact stress between the flange surfaces and gasket surface. Performances of gasketed flange joints are characterized mainly by its strength and sealing capability. However, ASME Boiler and Pressure Vessel Codes recommended design procedures for flange joints [**2**].

Based on plate theory **Hichem Galai et al. [3]** proposed an analytical model of metal-to-metal contact flange joints beyond the bolt circle. It provides additional considerations compared to the other method developed by them while designing flanges. Besides being more comprehensive, the model based on the plate theory gives more confidence on its ability to predict flange separation and increase in the bolt load during operation. **Koji Kondo et al. [4]** focused their study on the tightening coefficient developed by the impact of wrenches and bolt preload. A finite element analysis approach was used to determine the gasket stress during bolt tightening and results are compared with fundamental gasket characteristics. The experiments were conducted and bolt forces are measured during tightening process and evaluated the sealing performance using the bubble leak testing.

G. Mathan et al. [5] conducted experiments on gasketed flange joint and analysed bending loads in flange joints through FEA considering the nonlinear properties of the gasket. The contact stress distributions observed has significant variation along the gasket width and also in bolts under bending load and results were well compared with the experimental studies. **Tan Dan Do et al. [5]** proposed an analytical approach to determine the effect of bolt spacing and its impact on flange design based on the theory of circular beam. The model was tested for different bolted joints by varying number of bolts, flange and gasket stiffness. The analytical results were compared with FEA and suggested that the thickness of the flange and the stiffness of the gasket have a great effect on stress distribution. In this paper, a parametric study of the behaviour of flanges and stresses in bolts are analysed and results were discussed.

2. Gasket joint configuration

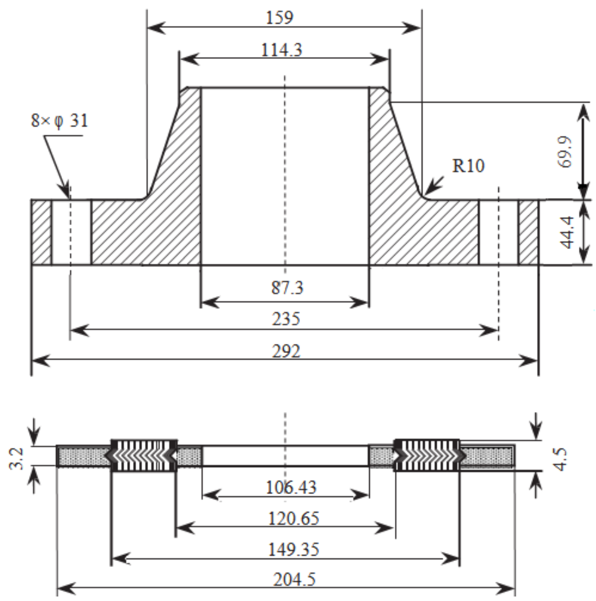


Figure 1: 2D Geometry of Flange Joint

A 2D model of a gasketed flange joint with nominal dimensions is as shown in Figure 1 as per the ASME Boiler and Pressure Vessel Code, washer is not included in the present work and gasket was modelled as a solid ring. A 3D model of bolted flange joint analysis require more space and time to solve the problem, hence 1/8th part of the model is used to study the entire behaviour of the component as shown in Figure 2.

3. Material property

Components of pipe flange joints are homogenous, isotropic and elastic in nature different properties and materials are listed in Table 1 and the material as per ASTM standards and these properties are used for finite element analysis.

The flange subjected to an internal pressure of 15.32 MPa as per the pressure rating recommended for ASME Class 900# with a flange size of 4 inch

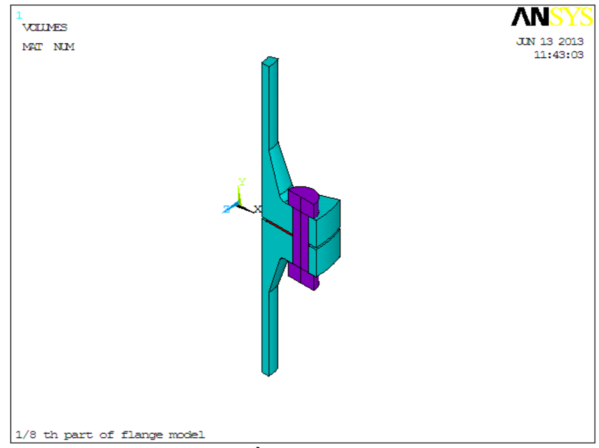


Figure 2: 1/8th Part of Flange Model

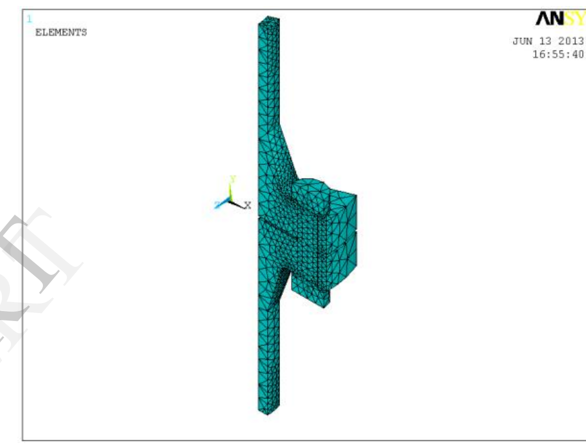


Figure 3: Finite Element Mesh for the Flange Joint

. Table 1: Material Properties of Flange Joint

Items	Young's Modulus , E (MPa)	(υ)	Allowable stress (MPa)	Material
Flange	173,058	0.3	248.2	ASTM A350 LF2 or A105
Bolt	168,922	0.3	723.9	ASTM SA193 B7
Gasket	164,095	0.3	206.8	ASTM A182 F316

4. Finite element formulation

A three-dimensional FE model has been developed for bolted flange connections with gaskets. For flange, gasket and bolts SOLID187 a higher order 3-D, 10-node element is used. Figure 3 show finite element mesh for the joint. In this model there is a contact between bottom of the flange and top of the gasket surface and top of the flange and bottom of the bolt surface to predict the exact physical behaviour, a 3D surface-to-surface CONTA174 and TARGE170 elements are used to simulate contact.

5. Boundary conditions

Following boundary conditions are used to perform finite element analysis using ANSYS software

- The flanges are free to move either in radial (X) or tangential (Z) direction, this provides flange rotation and the exact behaviour of stress in flange and bolt.
- Symmetry conditions are applied on both sides of the gasket, bolt cross-sectional area, both sides of the flange ring and the attached pipe.
- A nominal preload i.e. 35% of the yield strength of the bolt was chosen to perform stress analysis.

6. Results and Discussion

The FEM results mainly consist of axial, radial and tangential stresses these stress components are using finite element software ANSYS 11.

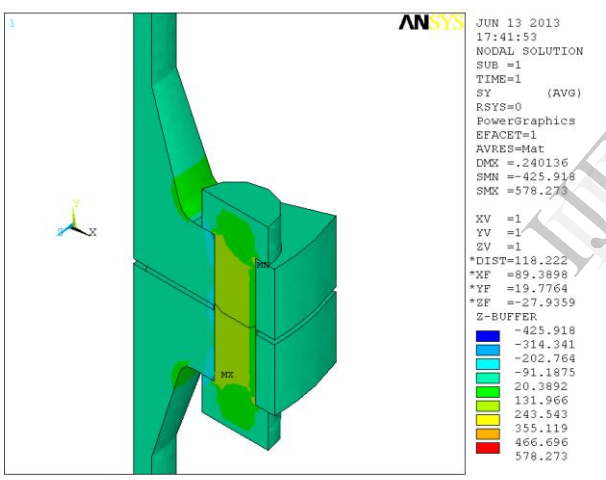
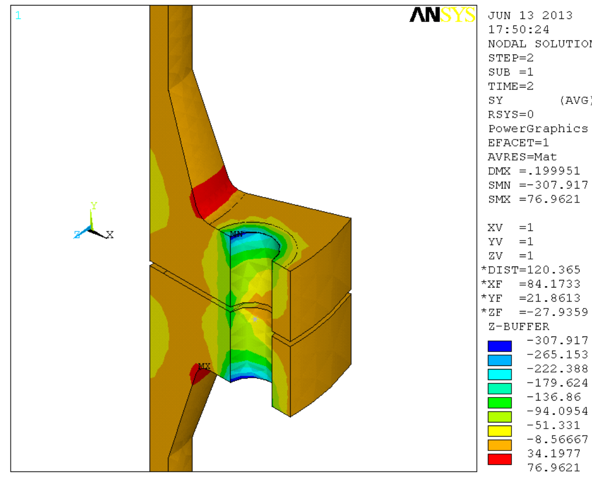


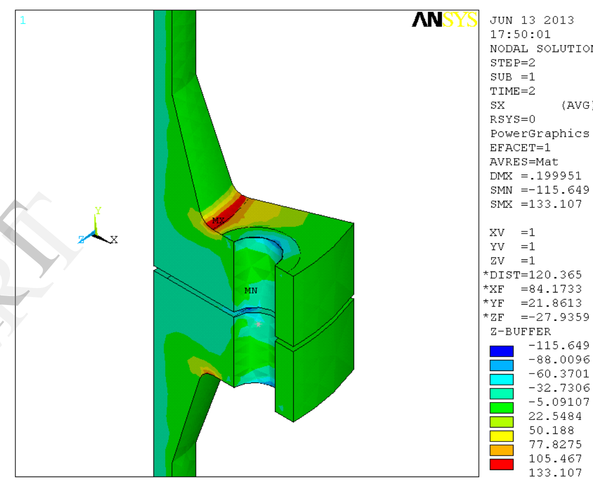
Figure 4: Pre-stress in the Bolt for 35% Preload

Figure 4 shows the pre-stress in the bolt for minimum flange thickness of 44.4 mm with eight bolts subjected to nominal preload which is 35% of the yield strength of the bolt, it is observed that an average pre-stress of 319.68 MPa using ANSYS software.

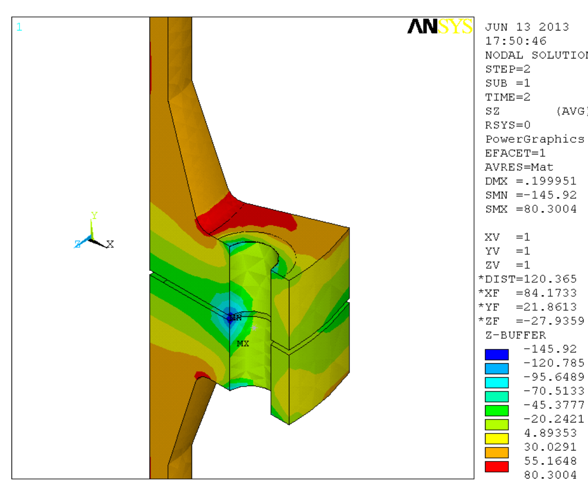
Similar model and boundary conditions used for calculation of flange stress based on ASME code. Figure 5 & 6 shows axial, radial and tangential stress in the flange obtained from FEA and theoretical results were closely compared.



Axial stress



Radial Stress



Tangential Stress

Figure 5: Stresses in the Flange

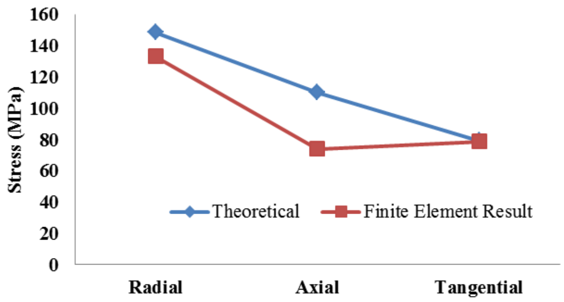


Figure 6: Comparisons of ASME Code and FEA Results

Hence the results obtained from finite element analysis using ANSYS software are within the acceptable variations 10-20% when compared to theoretical solutions obtained by ASME Boiler and Pressure Vessel code calculations. These variation can be reduced by using more number of elements, this can be happened only when higher configuration computer are used.

Similar analyses were carried out by varying flange thickness, bolt preload and number of bolts to study the effect of pre-stress in the bolts, radial, tangential and axial stress components in the flange.

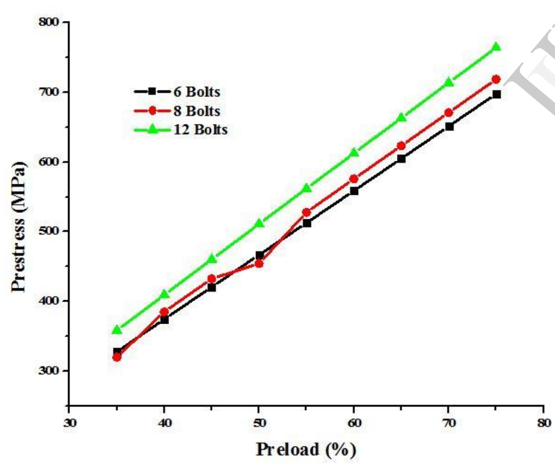


Figure.7: Effect of Pre-stress by Varying Preload and Number of Bolts

Figure 7 shows the distribution of pre-stress when bolts are subjected pre load, As the pre-stress increases with increase of preload by varying number of bolts. It is evident that resisting area deceases with increase in number of bolts hence pre-stress in the bolt increases because of reduction in the cross sectional area.

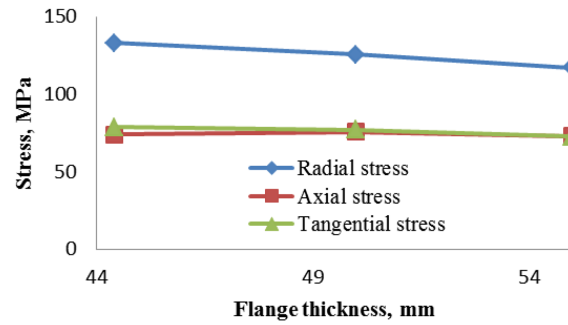


Figure 8: Stress Variation in Flange for Different Thickness

Variation of radial, tangential and axial stresses are as shown in Figure 8. As the flange thickness increases all stress were decreased because of increase in the resisting cross sectional area of the flange.

7. Conclusions

Bolted flange connections are analyzed by implementing the design method for gasketed bolted flanged connections as per ASME Boiler and Pressure Vessel Code and results were validated with finite element analysis software ANSYS. A parametric study of the behavior of flanges and bolts stresses are analyzed by varying the flange thickness, bolt preload and number of bolts, at the same time maintaining other flange dimensions constant.

Axial, radial and tangential stresses are obtained by varying flange thickness from 44.4 mm to 55 mm; bolt preload is varied from 35 % of yield strength to 75% in step of 5% and to obtain uniform stress numbers of bolts are varied from 6, 8 and 12 bolts.

8. References

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