ISSN (e): 2250 – 3005 || Vol, 04 || Issue, 4 || April – 2014 ||
International Journal of Computational Engineering Research (IJCER)

Finite Element Analysis of a Tubesheet with considering effective geometry properties through design methodology validated by Experiment

Ravivarma.R[1], Azhagiri. Pon[2,]

[1] M.E Thermal Engineering (Part Time), University College of Engg., BIT campus, Tiruchirappalli-24
[2] Assistant Professor, Department of Mechanical Engg., University College of Engg., BIT campus, Tiruchirappalli -24
[1, 2] Anna University: Chennai 600 025, Tamil Nadu, India

ABSTRACT

The Tubesheet, in any heat exchanger is a very important component as it provides a firm support to tubes and in the process gets exposed to thermal and pressure gradients. Various analyses required to assess integrity of Tubesheet are analysis for operating pressure loads and transient thermal analyses together with mechanical loads. The present investigation is in two parts; first one is linear Static analysis of conventional equivalent Modulus of elasticity & Poisson's ratio method, which is recommended by ASME (American Society of Mechanical Engineers) Sec. VIII, Division-1. Second is a new and realistic approach of linear Static analysis by considering the perforations of tube holes in the Tubesheet with pressure acting at inside tubes. The methodology and procedure of Finite Element (FE) method for linear Static analysis in FE method is validated through experiment. Based on the results obtained from two different approaches, the design will be validated and the optimum approach for design will be chosen.

KEYWORDS: *ANSYS, Tubesheet, Finite Element Analysis, Linear Static analysis.*

I. INTRODUCTION

The Tubesheet is a very crucial component of shell-tube type Heat Exchangers, a typical Tubesheet is shown in Fig.1. The number of tubes employed to achieve the required heat transfer is usually very large (in thousands). The tubes run either horizontally or vertically and the lengths are also quite large. The tubes, in general, belong to 'Slender' type of members and hence need firm supports at the ends. The Tubesheet provide these supports. Apart from providing support the Tubesheets also demarked two main components of Heat Exchangers which are usually called as Hot Side (Tube Side) and Cold Side (Shell Side). The basic purpose of Heat Exchanger is to extract heat from one (Hot Side) and provided to other (Cold Side). Owing to this the thermal conditions of Hot Side and Cold Side vary a great deal. Apart from thermal conditions even flow conditions (pressure, velocity) are quite different. Hence tube sheets are subjected to quite severe thermal and mechanical loads. As the Heat Exchanger tubes have to necessarily pass through the Tubesheets, the Tubesheets have very large number of perforations (equal to the number of Tube passes).

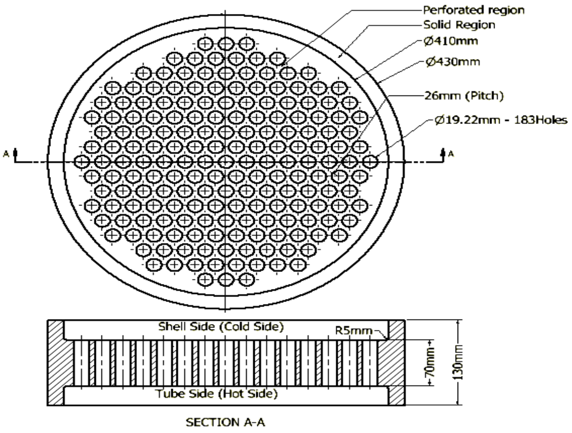


Fig. 1: A Typical Tubesheet Geometry

From these functional requirements Tubesheets are very critical structural components and their mechanical design is very crucial in the whole design of a Heat Exchanger. Tubesheets belong to a category of thick perforated plates subjected to pressure and temperature differentials. As the tubes which pass through perforations handle fluids under pressure the perforations are also subjected to internal pressure. As result, failure of a Tubesheet would result into a very big catastrophe. Hence importance of assessing structural integrity of Tubesheet against various operating conditions needs no emphasis whatsoever.

II. PRESENT INVESTIGATION:

In the mechanical sense, Tubesheet belongs to a category of perforated thick plates. Due to presence of holes in Triangular pattern, (considerable amount of material is removed) the stiffness of the tube sheet gets reduced. Reduction of stiffness in case of perforated plates is well known and analysts represent this using equivalent approach. The reduced stiffness is represented by reduction in Modulus of elasticity and Poisson’s ratio. The reduction is related to hole diameter, pitch and pattern of holes. This type of approach is sufficient if the perforations are free boundaries and loading is only mechanical, i.e., say, a pressure differential.

In case of Tubesheet of large Heat Exchanger, the perforations carry tubes which have pressurized fluid. Thus the perforations are subjected to internal pressure, i.e., the boundaries are not free. Apart from this; the perforations are also subjected to thermal loads. There are gradients along the length (through tube sheet thickness) of perforations. With these two conditions, it is not sufficient to merely replace the Tubesheet by its equivalent solid plate i.e., with modified (reduced) values of Modulus of elasticity and Poisson’s ratio.

The earlier practice of design of Tubesheets used to be with the help of Standard Codes [1-2] . With advent of Finite Element Method the design of Tubesheets is now possible with Finite Element Analysis. Applying Finite Element Technique to Tubesheets or rather perforated plates in general has certain issues involved. These issues are well known and have been a matter of research. Though the subject matter is available in literature [3-9] , the finer aspects of analysis are not available and the analysts would need to develop their own approaches. This precisely is the subject matter of this investigation. The present investigation is in two parts, first one is conventional equivalent Modulus of elasticity & Poisson’s ratio method, which is recommended by ASME (American Society of Mechanical Engineers) Sec.VIII, Division-1. Second is a new & realistic approach of analysis by considering the perforations of tube holes in the Tube Sheet (exact model) under various operating loads like pressure differential, internal pressure at Tubes and temperature gradients. For Analysis, the Element type selection in ANSYS are based on Experimental result comparison with ANSYS output.

III. DESIGN METHODOLOGY VALIDATION BY EXPERIMENT:

3.1 Experiment

Four Carbon Steel Tensile test specimens (IS-2062), in which one specimen without holes that is shown in Fig.2a and other three specimens with holes in 14mm pitch at different diameters say 4mm, 6mm and 8mm that are shown in Fig.2b to 2d, These specimens are undergone a tensile test in Universal Testing machine. The Experimental set-up with test specimen is shown in Fig.3. The tensile tested specimens are shown in Fig.4 and Force Vs elongation plots are obtained from Universal Testing machine indicator that is shown in Fig.5. These plots are used for a reference value for Element Type (ET) selection in ANSYS-14.

a. Without Holes

b.Pitch-14mm; Hole dia.-4mm

c.Pitch-14mm; Hole dia.-6mm

d.Pitch-14mm; Hole dia.-8mm

Fig.2: Tensile test specimens -Before testing

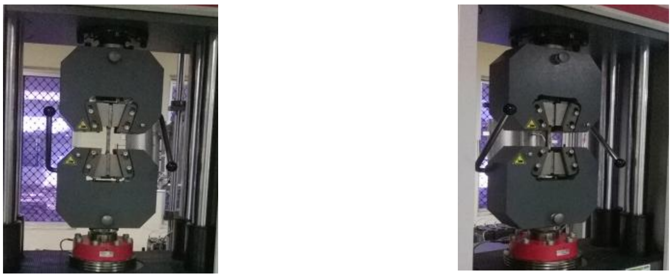
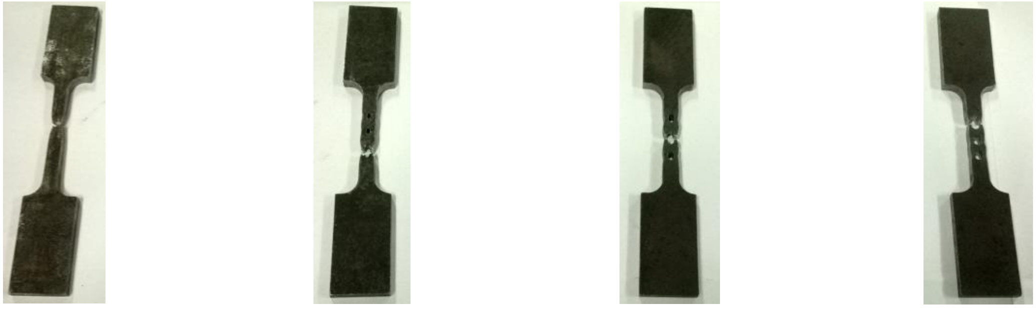
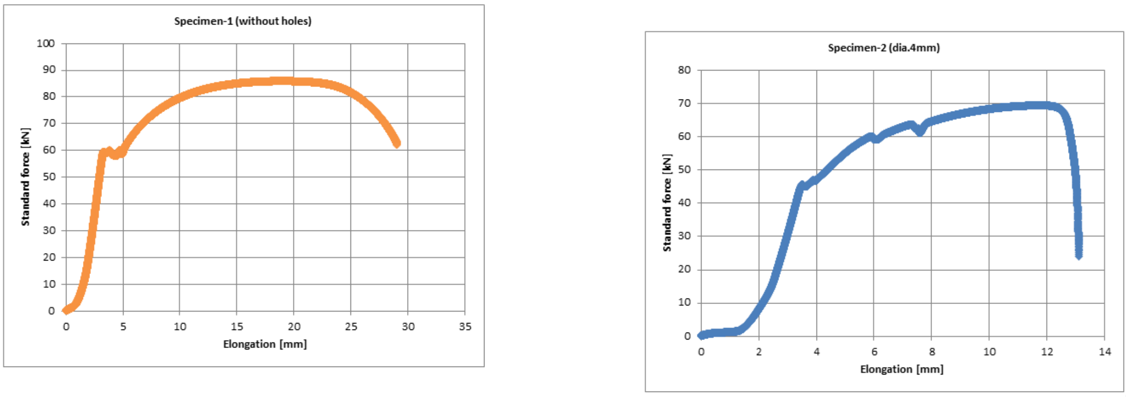


Fig.3: Experimental Set-up

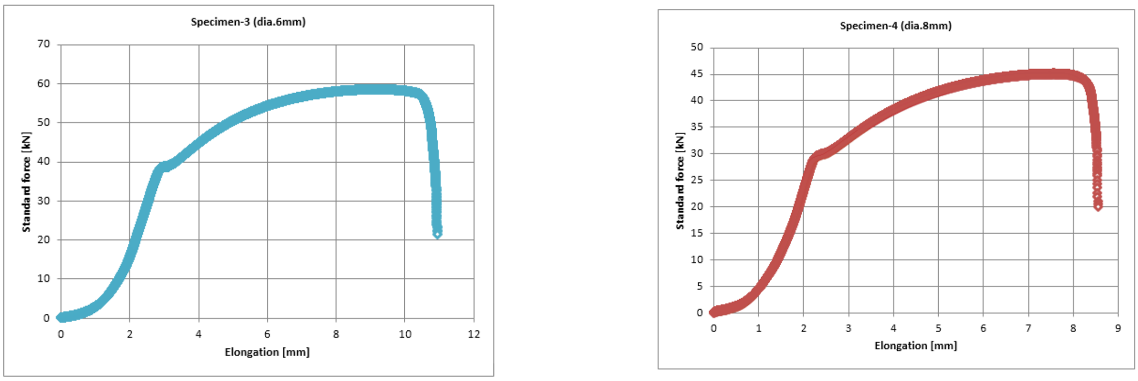


a. Without Holes b.Pitch-14mm; Hole dia.-4mm c.Pitch-14mm; Hole dia.-6mm d.Pitch-14mm; Hole dia.-8mm

Fig.4: Tensile test specimens -After testing



a. Without Holes b.Pitch-14mm; Hole dia.-4mm

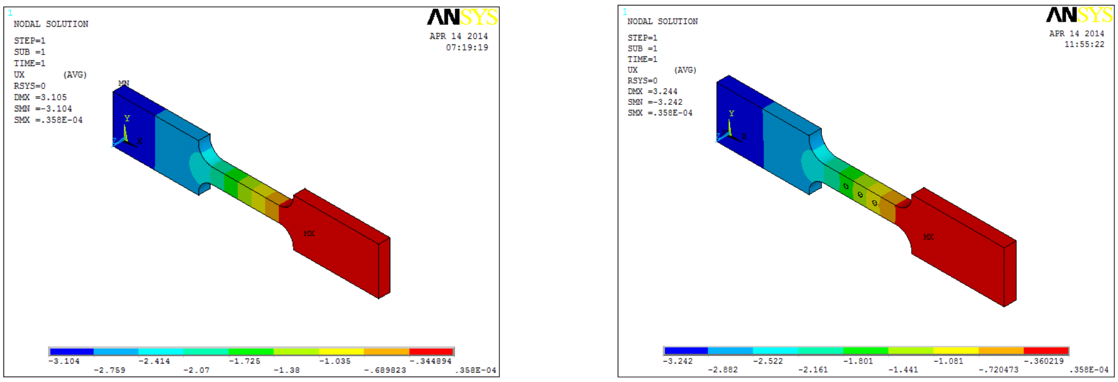


c. Pitch-14mm; Hole dia.-6mm d.Pitch-14mm; Hole dia.-8mm

Fig.5: Tensile test plots for Specimens

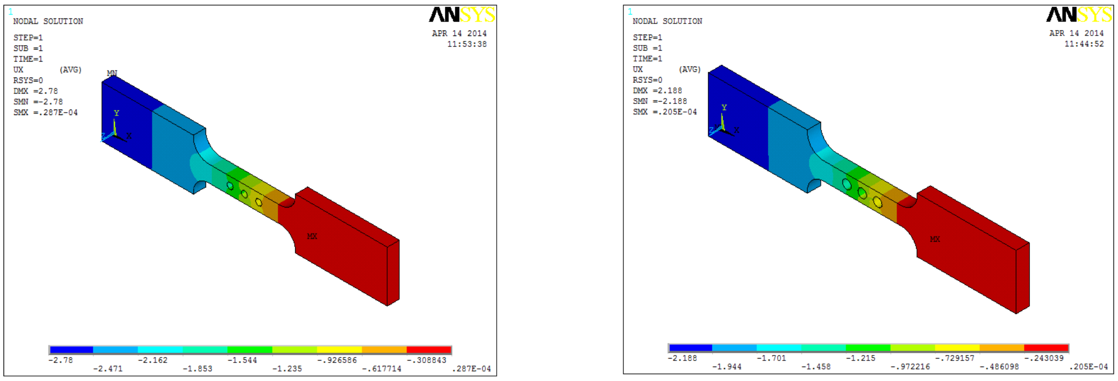
3.2. Analytical Approach through ANSYS-14:

The Tensile test specimen with same geometry is made as volume in ANSYS-14 and meshing is done at different Element Type (ET) such as SOLID45, SOLID73, SOLID185, and SOLID186. Each Element Type have eight nodes and six degree of freedoms. The Static analysis is done in ANSYS-14 with same boundary conditions which are applied in the tensile test experiments. The predicted values of deflection for SOLID45 Element Type result for four types of specimens are shown in Fig.06. This analysis is repeated for different other Element Types of SOLID73, SOLID185, and SOLID186. The predicted values of elongations are shown in Table-I.



a. Elongation of specimen without holes

b. Elongation of specimen in 4mm diameter holes



c. . Elongation of specimen in 6mm diameter holes

d. . Elongation of specimen in 8mm diameter holes

Fig. 6: Predicted result from SOLID45 Element Type.

3.3 Simulation of Analysis result with Experimental values:

The Finite Element values are compared with Experimental values shown in Table-I.

TABLE-I : Temsile Test Specimen Elongation

Specimens type	Elongation from Experiment value	Elongation form Analysis			
		SOLID 45	SOLID 73	SOLID185	SOLID186
Without holes	3.09 mm @ 55kN	3.105	3.105	3.105	3.111
4 mm	3.29 mm @ 40 kN	3.284	3.247	3.241	3.279
6 mm	2.72 mm @ 35kN	2.780	2.486	2.779	2.817
8 mm	2.06 mm @ 25kN	2.185	2.197	2.186	2.226

Based on the above results, SOLID 45 Element Type may be chosen as a compatible element for performing the structural analysis and the procedure and methodology followed in the analytical method through ANSYS may be extended for the static analysis of Tubesheet.

IV. FINITE ELEMENT ANALYSIS:

4.1 The FE Model:

The Tubesheet is symmetric in the parts of interest here with regard to two meridional planes, and is considered to be symmetric with regard to a cross-section in the middle between the Tubesheet. Pre-checks with a model representing one fourth of the Tubesheet is made in ANSYS-14 as per Fig.1 and same taken for linear Static analysis. The Full model of this FE model is made in ANSYS, to be too time consuming. The Tubesheet is made in two methods. The Method-1 is shows equivalent geometry properties method. In this method a model is generated in two volumes such as perforated region made as one volume and unperforated region made in another volume with 3D structural elements SOLID45, which is shown in Fig.8. This FE model consists of 36136 elements and 40327 nodes.

The Model-2, one fourth of Tubesheet (with holes) 3D model is made for analysis. This FE model consists of 237888 elements and 292323 nodes. The part of Shells, Tubesheet and a part of the tubes are modelled with 3D structural elements SOLID 45 that shown in Fig.9. All nodes at the meridional sides of the Tubesheet and Shells are assigned with symmetry boundary conditions.

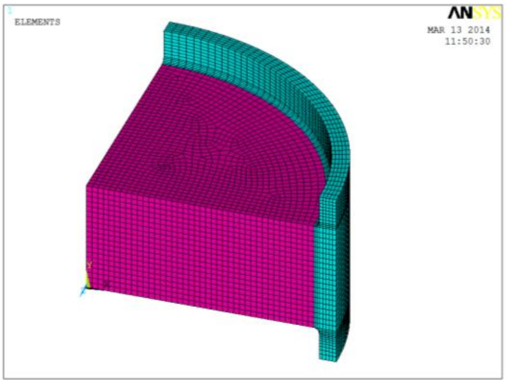


Fig.8: Equivalent of FE Model

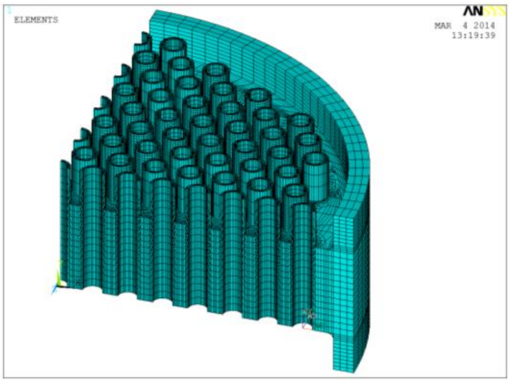


Fig.9: Tubesheet with tubes FE Model

The present investigation on Method-1 & 2 is applied for linear Static analysis approaches. The Tubesheet is subjected to three types of loads. They are; i) pressure differential across the thickness, ii) Pressure inside the holes and iii) thermal gradients which are shown in Fig.10.

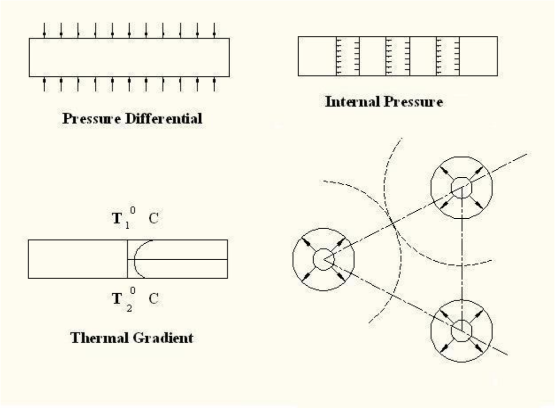


Fig.10: Types of load acting on Tubesheet

4.2 Design Parameter & Geometry Properties:

The Design parameters and Geometry Properties [10] are considered for linear Static analysis of Tubesheet is shown in Table-II and Table-III respectively.

TABLE-II: Design Parameter

Description	Values	
	Tube Side	**Shell Side**
Design Pressure (N/mm^2(g))	1.29	2.16
Design Temperature,T2&T1(°C)	400	200
Hydro Test Pressure(N/mm^2 (g))	1.77	3.24

TABLE-III: Geometry Properties at 25°C & 400°C [10].

Description	Values
Material for Tubesheet	SA-204 Gr.B
Moduls of elasticity, E(N/mm^2) at 25°C	202000
Poisons ratio, µ	0.3
Equivalent Modulas of elasiticity ,E*(N/mm^2) at 25°C	101000
Equivalent Poisons ratio, µ*	0.3
Moduls of elasticity, E(N/mm^2) at 400°C	171000
Equivalent Moduls of elasticity, E**(N/mm^2) at 400°C	85500

4.3 Linear Static Analysis of Tubesheet:

a. Equivalent geometry properties methods:

The linear Static analysis are done for Design conditions as well as in Hydro test condition. The differential pressure is applied on Tubesheet. The equivalent geometry properties are applied as per Table-III. The constrained are made at top and bottom of Shells. The predicted results are shown in Fig.11, 12, 13 and 14 for von Mises stress, and displacement patten for Design conditions and Hydro test condition respectively.

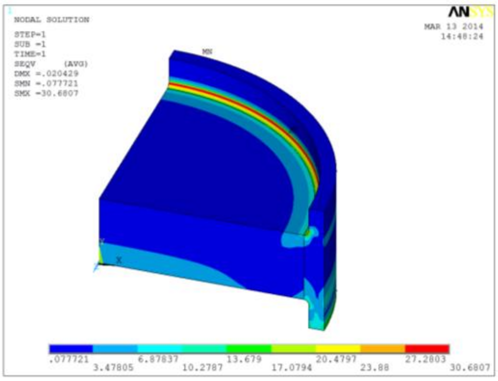


Fig.11: Von Mises Stress value at Design conditions

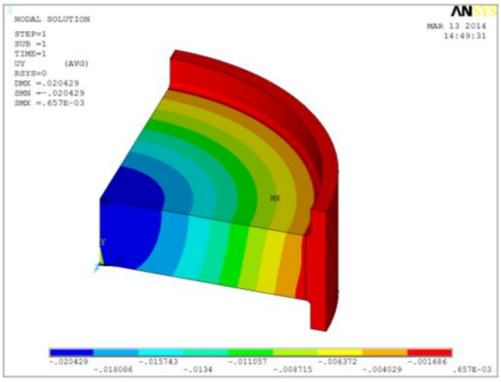


Fig.12: Displacement Patten at Design conditions

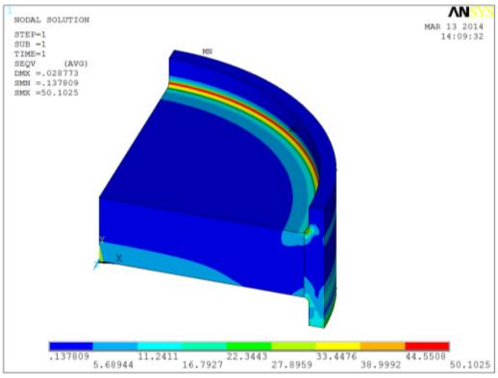


Fig.13: Von Mises Stress value at Hydro test conditions

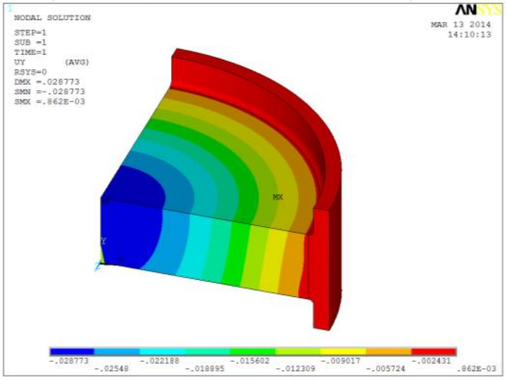


Fig.14: Displacement Patten at Hydro test conditions

b. New and realistic actual Tubesheet geometry methods:

In this method also, the linear Static analysis are done for Hydro test condition as well as in Design conditions. The differential pressure is applied on Tubesheet and tube side pressure is applied at tubes inside which same as per Table-II. The geometry properties are applied as per table-III. The predicted results are shown in Fig.14, 15, 16 and 17 for von Mises stress, and displacement patten for Design conditions and Hydro test condition respectively.

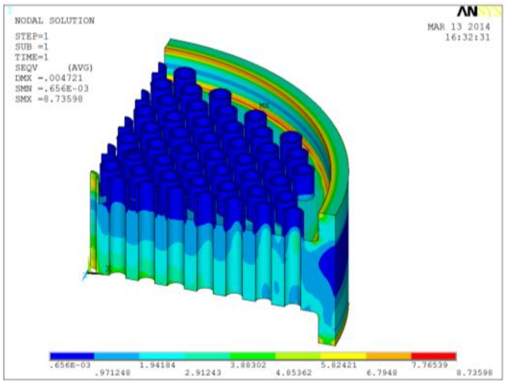


Fig.14: Von Mises Stress value at Design conditions

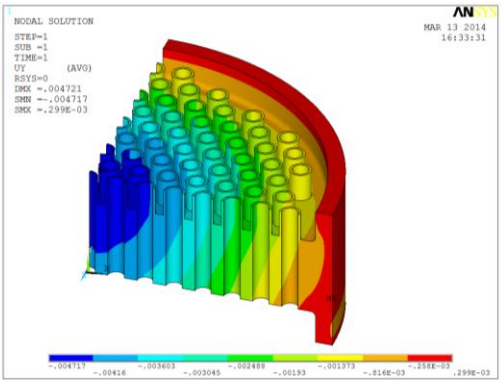


Fig.15: Displacement Patten at Design condition

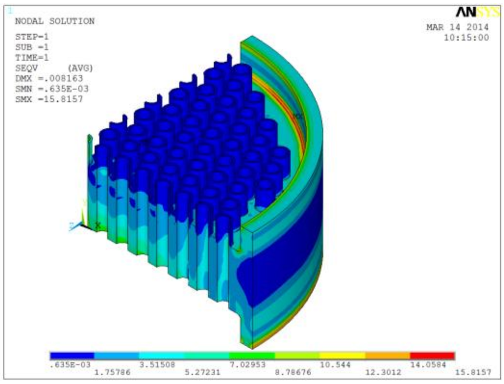


Fig.16: Von Mises Stress value at Hydro test conditions

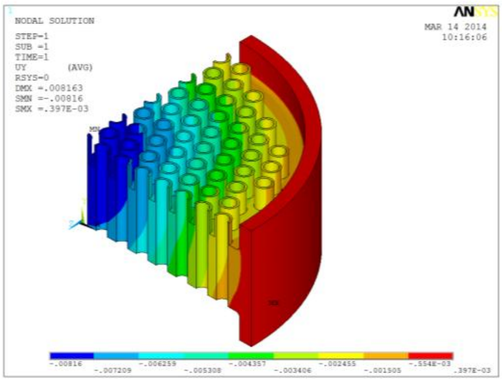
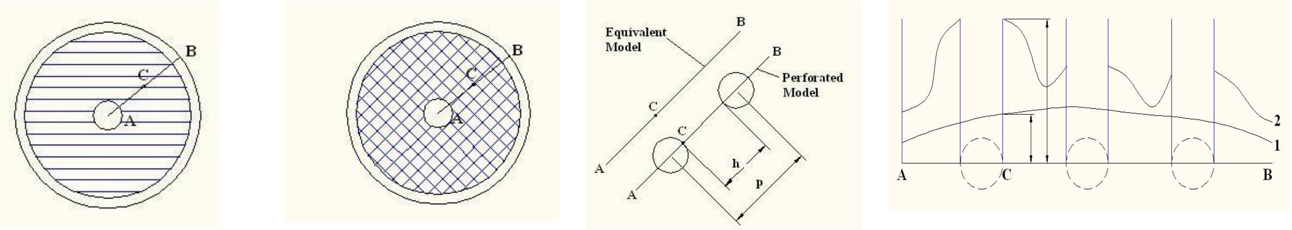


Fig.17: Displacement Patten at Hydro test conditions

V. RESULT AND DISCUSSION

The commonly followed approach for analysis is to replace the perforated part by an equivalent region and carry out axi-symmetric analysis or equivalent solid plate methods.

The axi-symmetric or equivalent solid plate results are then appropriately modified to account for the effect of holes. When loads are applied on an axi-symmetric or equivalent solid body (i.e. holes are not present in the model) the stress distribution obtained would be a continuous one. When these loads are applied on a perforated plate then the distribution would get perturbed and the ligament region, is likely to show enhanced values. This is shown schematically [11] in Fig.18.



(a) Path in Equivalent model

(b) Path in Perforated Model

(c) Geometry of Two Paths

(d) Comparison of Stress Distribution

1 - Distribution in continuous plate

2 - Distribution in perforated plate

Fig. 18: Effect of Holes

At a certain point C on line AB, is the stress obtained by axi-symmetric analysis with perforated region replaced by equivalent material. At same location, would be the stress obtained at the holes boundary in the ligament region. Two types of loads are shown in Fig.10, the pressure differential can be applied on equivalent solid plate and, the pressure differential and internal pressure can be applied on perforated plate. Whereas, it is not possible to apply, pressure inside the holes in an equivalent solid plate. Its effect is computed using thickness of the tubes and the perforation attributes (p, the pitch and h, the ligament). With this, the values obtained from axi-symmetric analysis are appropriately modified.

The developed FE results for linear Static analysis from equivalent geometry properties method and new and realistic actual Tubesheet geometry methods results are generated at various Stress Categorization Lines as per Fig 19 and 22. The maximum von Mises stress, and displacement paten for Design conditions and Hydro test condition at maximum concentrated locations are shown in Fig.20, 21, 23 and 24 respectively. The predicted values at various Stress Categorization Lines which is shown in Tale-IV and V. Based on these values, the new and realistic methods von Mises stress is 36 to 75 % lesser than equivalent geometry properties method.

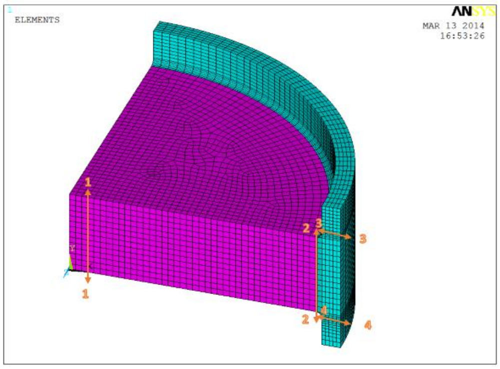


Fig. 19: Stress Categorization Lines (SCL)for equivalent geometry method

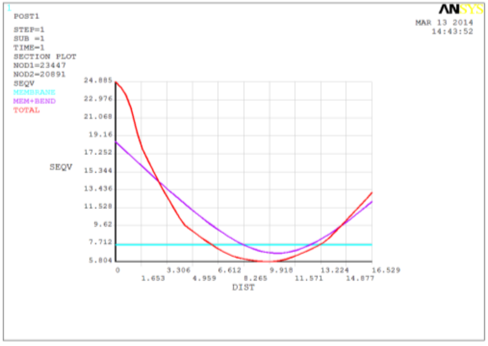


Fig. 20: von Mises plots along SCL No. 3-3 at Hydro test condition

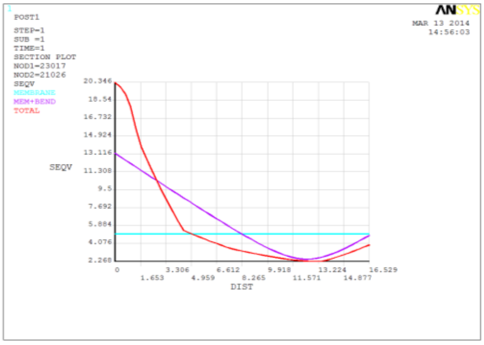


Fig. 21: von Mises plots along SCL No. 3-3 at Design Condition

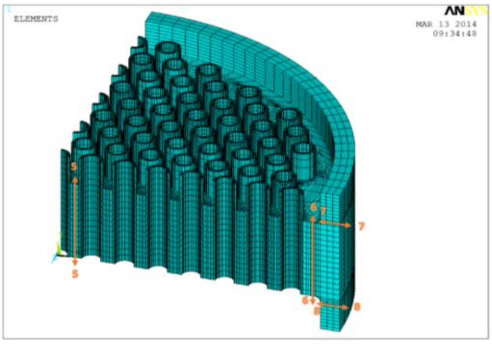


Fig. 22: Stress Categorization Lines (SCL) for actual geometry method

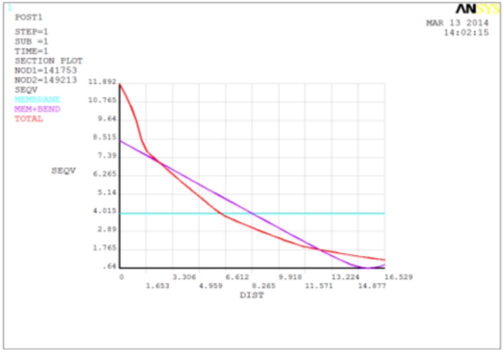


Fig. 23: von Mises plots along SCL No.7-7 at Hydro condition

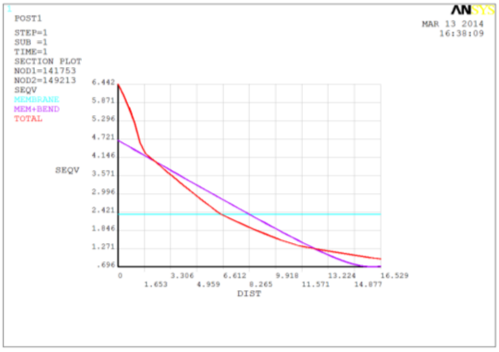


Fig. 24: von Mises plots along SCL No.7-7 at Design condition

TABLE-IV: Comparison of Max.von Mises stress (Total Stress):

SCL No	Maximum von Mises stress in N/mm^2	
	at Design condition	at Hydro test condition
Equivalent geometry method		
1-1	6.662	10.776
2-2	12.39	20.707
3-3	20.343	33.864
4-4	14.805	24.885
New and realistic actual Tubesheet geometry methods		
5-5	3.923	6.837
6-6	5.195	9.024
7-7	6.442	11.892
8-8	3.633	7.729

TABLE-V: Comparison of deflections:

Description	Deflection in mm	
	at Design condition	at Hydro test condition
Equivalent geometry method	0.0204	0.0288
New and realistic actual Tubesheet geometry methods	0.0047	0.0088

VI. CONCLUSIONS:

Various analyses required to assess integrity of Tubesheet are analysis for operating pressure loads and transient thermal analyses together with mechanical loads. The present investigation is done in two parts; first one is linear Static analysis of conventional equivalent Modulus of elasticity & Poisson's ratio method, which is recommended by ASME (American Society of Mechanical Engineers) Sec. VIII, Division-1. Second is a new and realistic approach of linear Static analysis by considering the perforations of tube holes in the Tubesheet with pressure acting at inside tubes. This linear Static Analysis, the Element Type (ET) selection in ANSYS-14 is selected based on Experimental result. Based on this investigation, the results obtained from two different approaches, design of Tubesheet for any Heat Exchanger, better to do analysis in realistic actual Tubesheet geometry methods for the selection of optimum required material.

REFERENCES

[1] ASME. ASME Boiler and Pressure Vessel Code, Section VIII Divi.1", 2013 Edition, the American Society of Mechanical Engineers - New York, 2013, 274 -283.

[2] TEMA, "Standard of Tubular Exchanger Manufactures Association" 9th Edition, Tubular Exchanger Manufactures Association, 2007, 5.7.1 – 5.7.4.

[3] Wengen Peng, Yanwei Hu, Yuanchun Liu, Guangri Jin and Yurong He "Analytical Modeling of the Strength of Tubesheet for Steam Surface Condensers", Journal of Pressure Vessel Technology, October 2013, Vol. 135 / 051206-1 to 9.

[4] Weiya Jin, Zengliang Gao, Lihua Liang, Jinsong Zheng, Kangda Zhang"Comparison of two FEA models for calculating stresses in shell-and-tube heat exchanger", International Journal of Pressure Vessels and Piping, 2004, 563–567.

[5] K. Behseta, S. Schindler, "On the design of the tubesheet and the tubesheet-to-shell junction of a fixed tubesheet heat exchanger", International Journal of Pressure Vessels and Piping, 2006, 714–720.

[6] C. F. Qian, H. J. Yu & L. Yao, "Finite Element Analysis and Experimental Investigation of Tubesheet Structure", Journal of Pressure Vessel Technology, February 2009, Vol.131/011206-1 to 4.

[7] Ricky Chana, Faris Albermanib and S. Kitipornchaic, "Stiffness and Strength of Perforated Steel Plate Shear Wall", the Twelfth East Asia-Pacific Conference on Structural Engineering and Construction; Procedia Engineering, 2011, 675–679.

[8] Masanori Ando, Hideki Takasho, Nobuchika Kawasaki & Naoto Kasahara, "Stress Mitigation Design of a Tubesheet by Considering the Thermal Stress Inducement Mechanism", Journal of Pressure Vessel Technology, December 2013, Vol. 135 / 061207-1 to 10.

[9] Khosrow Behseta, Donald Mackenzie, Robert Hamilton, "Plastic load evaluation for a fixed tube sheet heat exchanger subject to proportional loading", International Journal of Pressure Vessels and Piping, 2012, 11 – 18.

[10] ASME, "ASME Boiler and Pressure Vessel Code, Section II Part-D", 2013 Edition, the American Society of Mechanical Engineers - New York, 2013, 738 and 744.

[11] John F.Harvey,P.E, "Theory and design of pressure vessels", CBS publishers & Distributors, 4596/1A, 11 daryaganj, New Delhi-110 002 (India), 1987,136-148.