FEA BASED STATIC STRUCTURAL ANALYSIS OF CORRODED EXPANSION BELLOW BASED ON ASME AND RCB 8 CODE

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Abstract: **In process industries heat exchangers are the important element used. It deals with fluids having high temperature and pressure, which results in thermal stresses. So in order to absorb thermal expansion metal bellows are provided over the shell. Expansion Joints are provided on the shell side of heat exchanger. It allows the free expansion of shell relieving tubesheet & tube to tubesheet weld junction. Thus preventing its failure. In this paper the expansion bellow was analyzed for different loading conditions as per TEMA standards using Finite Element Analysis in ANSYS.**

***Keywords*: TEMA, STATIC STRUCTURAL ANALYSIS, EXPANSION BELLOW, ASME, RCB 8 CODE**

1. INTRODUCTION

A. Abbreviations and Acronyms

G	Shell inside Diameter
ts	Shell thickness
K_{FSE}	Stiffness Flexible shell element
Pl	Local membrane stress
Pb	Bending stress
Sm	Allowable stress
Q	Secondary stress

Expansion bellows are basically thin, shell structures and having wide applications in industry for accommodating thermal expansion and for sealing purpose. The pressure changes and temperature variations in heat exchanger, piping or other systems induce stresses. The main purpose to use metallic bellows is to withstand axial thermal deflection and equivalent internal shell side pressure. Expansion joints are provided on shell side of heat exchanger. It allows the free expansion of shell relieving tubesheet and tube to tubesheet weld junction. Thus preventing its failure.

The function of expansion joints is to provide flexibility in various applications. The performance of expansion joint is mainly depends on the design of bellows.
The expansion bellow may consists of one or more convolutions. In the shell and tube heat exchanger, if the tubes are hotter than shell, the tubes want to expand. Relatively, the shell may try to contract, creating bending stress in the tubesheets. Also tensile stresses in the in the shell, and compressive stresses in the tubes. An expansion joint can reduce these stresses.

2. LITERATURE SURVEY

1. A.K. Dureja [1], In this paper study of basic sizing of bellows according to design requirement is done by using EJMA guidelines. Here, In Hot shutdown Passive valves (HSPV) bellows are used. It is analyzed that when stainless steel grade 304L material was used for bellows it requires six plies of 0.5mm thickness to meet the pressure requirement. It results in higher axial stiffness and does not meet intended travel requirement of the valve. Later the material of bellows was replaced by INCONEL-600 with two plies of 0.5mm thickness, and hence it was satisfying both requirements of stresses as well as axial stiffness.

Finite element method was used to evaluate the design of bellows. A methodology was evolved to compute membrane and bending stresses from component stresses resulting from finite element model. Bellows shape plays important role in development of membrane and bending stresses in component. Different shapes of bellows were modeled; meshed, analyzed and found that omega shape bellows performs well compare to U-shaped bellows.

2. S. K. Makke [2], In this paper fatigue life of U-shaped metal expansion bellows is analyzed using analytical and simulation approach. After a limited number of movement cycles the bellows will eventually fatigue. As a design consideration it is important to indicate practical cycle life. In this work study finite number of cycles taken by the bellow of the selected application using analytical and simulation approach. To optimize the bellow design parametric study also performed simultaneously. In the end actual testing performed and results of actual testing compared with simulation and analytical results.

3. J. Prasanna Naveen Kumar [3], This paper describes effect of design parameters on static mechanical behavior of metal bellows. Design of experiment techniques were used for analysis of effect. The required responses for DOE were obtained from a set of Finite Element Analysis (FEA) for various configurations of bellows. Expansion Joints Manufacturing Association standard were used for validation of FEA results of metal expansion bellows. A mathematical relationship between the design parameters and the static mechanical behavior was derived. It was concluded that thickness of metal bellows has great influence on staic mechanical behavior of component. Again design parameters were optimized and validation test was carried out using FEA.

4. S. C. S. P. Kumar Krovvidi [4], In this paper design and analysis of bellows is done which are used for high temperature applications. In this case creep are significant. The bellow was designed using RCC MR code and was validated experimentally. Results were closely related.

5. Bijayani Panda [5], In this paper author has analyzed that bellows with 316L stainless steel material fails under stress corrosion cracking in petroleum refinery applications. Failure was due to the presence of high concentrations of chlorine.

3. PROBLEM STATEMENT

Expansion Joints are provided on the shell side of heat exchanger. It allows the free expansion of shell relieving tubesheet & tube to tubesheet weld junction. Thus preventing its failure. In this work, expansion bellow of heat exchanger will be analyze for a typical industrial application. Expansion bellow will be modeled in FEA, analyze and tested for stresses and stiffness calculations.

4. OBJECTIVES

TEMA guidelines are followed for analysis of expansion bellow.
1.Design parameters & material properties extraction for expansion bellow of the heat exchanger.
2.Preparing FEA Models for different conditions of expansion bellow.
3.Solving all FEA Models for stiffness calculations.
4.Solving geometrical conditions of expansion joint for different loading conditions.

5. EXPERIMENTAL DETAILS

A. Design Data

TABLE I
Design data

Location	**Material**	**Allowable Stress (MPa)**	**Young's Modulus (MPa)**	**Yield Strength (MPa)**
Shell	SA-240 GR. 304	126	1.83E+05	144

Poison's ratio: 0.3

B. Modelling And Meshing

The modeling of the bellow is done as per the guidelines given in Fig. RCB-8.42. In the present analysis modeling, meshing of expansion joint, spring rate determination and stress analysis of expansion joint is carried out. The spring rate is used to calculate displacements because of mechanical as well as thermal loads. This displacement is subsequently used in the stress analysis of expansion joint subjected to specified internal pressure. Structured mesh is generated with Plane 183 element with six elements across the thickness (As per RCB-8.3).

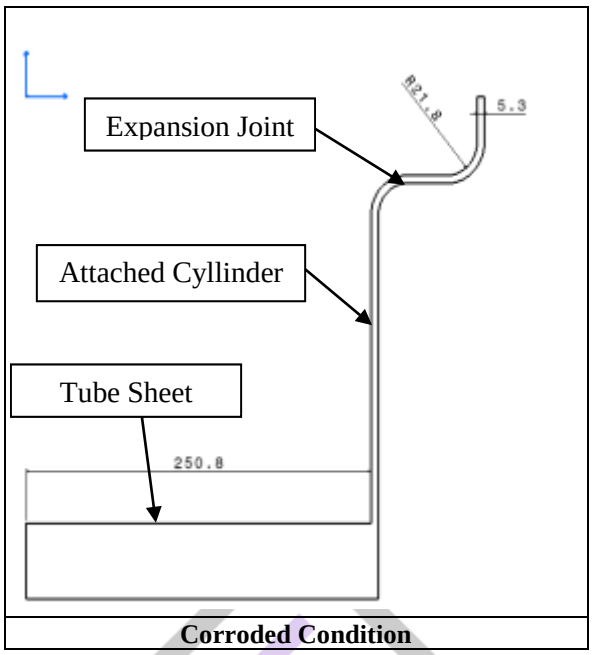

Fig 1. CAD model for corroded condition

C. Finite Element Model

PLANE183 is a higher order 2-D, 8-node or 6-node element. PLANE183 has quadratic displacement behavior and is well suited to modeling irregular meshes. This element is defined by 8 nodes or 6 nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element (plane stress, plane strain and generalized plane strain) or as an axisymmetric element.

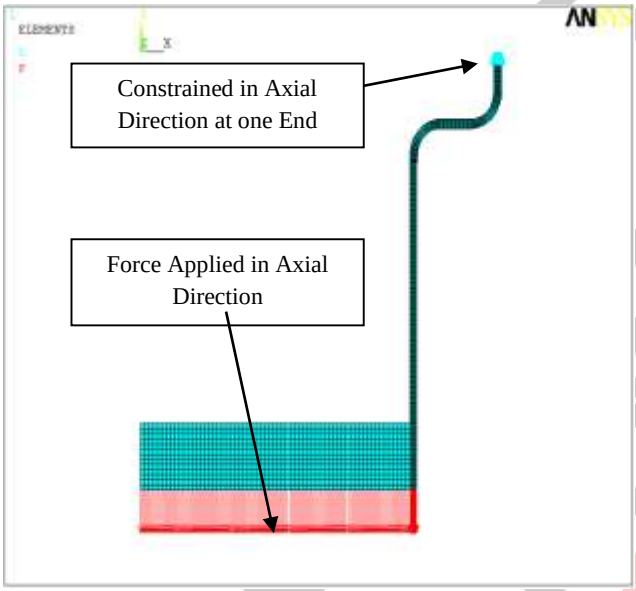

Fig 2: Boundary Conditions For Stiffness Calculations (Corroded Case)

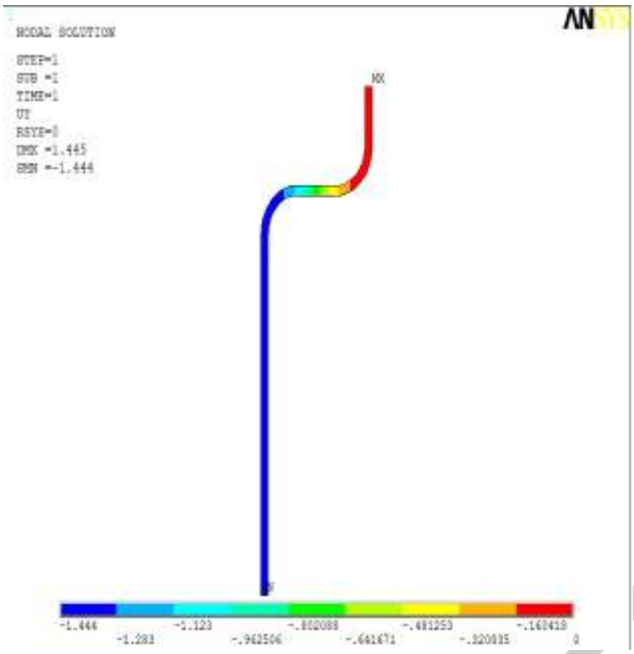

Fig 3: Deflection Plot (Corroded Case)

6. STIFFNESS CALCULATION

A rigid solid end cap for application of axial force and displacement is modeled at the end of cylinder length. From the obtained deflection and applied force the stiffness is calculated. Minimum cylinder length of 3.6*sqrt (G*ts) (As per RCB 8.21, Fig. RCB 8.21) is considered attached to the expansion joint.

A. Corroded (As per RCB 8.5)

TABLE II
Stiffness calculation (Corroded case)

Parameter	Value
Force	1.36E+05 N
Deflection	1.444 mm
Stiffnes (Kas) (half convolution)	9.4353E+04
No of Convolutions/Bellows	1
No of Half Convolutions	2
Stiffnes (Kfse) (full convolution)	4.7177E+04

7. BOUNDARY CONDITIONS

Differential Expansion is applied at the smaller diameter and axial constrain is applied at the larger diameter of the expansion bellow. The internal Pressure is applied at the internal surface of the Expansion Bellow.

A. Corroded case:

Load Case-1 (LC1) - Thermal

1. Differential Expansion (D.E)= 7.2282E-01 mm
2. Internal Pressure = 0 MPa

Load Case-2 (LC2) - Mechanical

1. Differential Expansion (D.E)= 8.6051E-02 mm
2. Internal Pressure = 1.094422 MPa

Load Case-3 (LC3) - Thermal + Mechanical

1. Differential Expansion (D.E)= 7.4003E-01 mm
2. Internal Pressure = 1.094422 MPa

8. CONCLUSIONS

A. Corroded Case:

TABLE III
Comparison of induced and allowable stresses as per ASME code (corroded case)

B. Corroded Case:

TABLE V
Comparison of induced and allowable stresses as per ASME code (Corroded case)

Case Details	Induced Stresses			Allowable Stress Sm (MPa)	ASME Evaluation		
	Pl	**Pl+Pb**	**Pl+Pb+Q**		**Pl (1.5*Sm)**	**Pl+Pb (1.5*Sm)**	**Pl+Pb+Q (3*Sm)**
Differential Expansion Only	-	-	175.1	126	-	-	Ok
Shell Pressure only	51.27	78.76	-	126	Ok	Ok	-
Shell Pressure + Differential Expandion	-	-	199.40	126	-	-	Ok

The induced stresses in the expansion joint have been found to be within the allowable limits. Hence the modelled geometry of expansion joint is adequate for analyzed conditions. Thus, Stress limits of ASME Sec VIII Div.2 are met.

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