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Design of steam piping system by using ASME B31.1 codes

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Abstract: ***Given paper is about stress analysis as well as design of piping system of given piping flow diagram. The main purpose of this project is to design and analysis of main component of given piping system. Safe thickness calculated from given piping system for operating pressure.0.114 inch thickness calculated for header pipe and stander thickness is 0.285 inch and standard thickness is 2.4 times the calculated values. Thermal load and static loads of all pipes are calculated. Spacing support carried out after the load calculating. After the analysis of static and thermal the result are compare with the ASME Power Piping Code B31.1. circular pipe of 4 inch nominal size design and analyze by manually and on analyze software after all calculation .results of both methods are safe for given load***

Keywords: component; Steam piping; ASME Codes; ANSYS validation;

I.INTRODUCTION

In case of process and power industry design and analysis of Piping System is a very important field. As in human body blood circulating system is use to circulate the blood in same way in industry for circulating the steam, piping system is used. In given paper steam piping is use for supplying the steam at different location for required temperature and pressure. This is one of the major requirements of the plant at the time of installation of the plant. Main purpose of analysis is to provide safety for design. There are many safe designs are available but design engineer select the design which is economical and safe. Stress analysis of piping system is use for:
1) Safety of piping and there components
2) safety of structure which is use for supporting purpose.
Given steam piping system contained 745*295m2 area which includes 48 pipes with 52 junctions. Following figure 1 shows nominal pipe size with pipe no. range from 208 to pipe no. 256, also length of each pipe. Inlet and outlet velocity, pressure and temperature of each pipe are arranged for further calculation.
This paper is about stress analysis as well as design of piping system of given piping flow diagram. The main purpose of this project is to design and analysis of main component of given piping system.
Paper includes the following steps:

a) Design process for complete piping system
b) Manually pipes structure design
c) By using ANSYS stress analysis of the pipes.
d) Structural design for supports manually.[1]

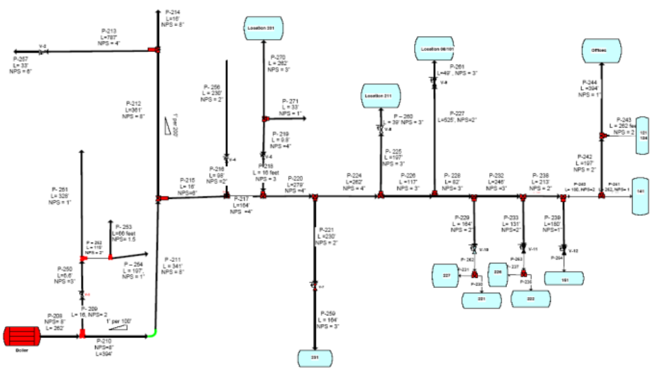

Fig. 1 piping system layout

II. PIPING STANDARD AND CODES

Before selection of codes, historical background of standards and codes of steam piping system is given below.

A. development of piping code

Operating temperature and pressure increases so that ASA B31 code is developed for pressure piping. During the 1950s, the code was developed for different segments piping industry such as power, gas transmission and petrochemical companies. The 1960s and 1970s is development period of requirements, methodologies and standard concepts. Standards and codes are developed to provide manufacturing methods reporting and listing design data [3].

B. B31.1 power piping

This code includes minimum requirement of the design, fabrication, materials, erection, inspection and testing of auxiliary service and power piping systems for industrial institutional plants, central and district heating plants and electric generation stations. External piping is also covered by this code for power boilers and high-pressure, high temperature water boilers. The reason for selecting this code for steam piping system is, this code is used typically for transportation of water or steam under elevated temperatures [5].

C. Requirements of ASME codes

In steam system boiler outlet section is comes under the section of ASME Code B31.1 Power. Code requirements should be fully satisfied in order to ensure the safety of the piping system. This code incorporates different relationships for stress level for different loads as given below.

The effects of the weight, pressure and other sustained loads meet the requirements of the above equation [1].

$S_L = (0.75i \times M_A/Z) + (PD_O/4t)$

Where,

S_L= allowable stress for basic material at design pressure, psi.

M_A=resultant moment because of loading on cross section due to weight and other sustained load, in-lb

Z= pipe section modulus,in^3

P=internal pressure in psi

D_0=pipe outside diameter, in

T=wall thickness, in

.

III. DESIGN PROCEDURE FOR PIPING

A. Process Design

On the requirement of the process variables this process is based. It defines the cross section area & required length of pipe, nature of pipe, rate of flow & the properties of fluid inside the pipe. During lay outing and routing these variables affect the placements and positioning of equipments. From Process & Instrumental diagram (PID) and Process Flow Diagram (PFD) the end of Process Plan Design is created, which are used in the lay outing & designing of the Pipe.

B. Structural Design of Pipe

The design and minimum allowable thicknesses are calculated In piping structural design, according to pressure in pipelines, as per the required codes and standards. for various standards different ASME codes are available, ASME B31.1 is used for process fluid flow.

C. Calculations for Pipe Thickness

Minimum thickness tm including the allowance for mechanical strength shall not be less than the thickness in ASME B31.1 piping code [2].

$t_m = A+(P \times D_O/2 \times S \times E_q + P \times Y)$ (3)

Where,

t_m= thickness in inches

A=additional thickness to provide for material removed in threading erosion or corrosion allowance.

p=internal pressure in psig

D o = pipe outside diameter in inches

S=Allowable hot stress in psi

E_q= factor of quality.

t= thickness for pressure design in inches

Y = coefficient that takes design temperature and material properties into account.

D. Calculations for Sustained Load

The loads which are caused by mechanical forces are called as the Sustained loads and these loads are present in the normal operation of the piping system. These loads include both pressure and weight loadings. Entire weight of the system must be hold by the supports, including that of the fluid **components, insulation, pipe and the support themselves [2].**

Weight of pipe = $(D_O{}^2\text{-}Di^{2)} \times (g/g_c) \times (\pi/4) \times \rho_{steel}$

Weight of fluid = $(Di)^{2)} \times (g/g_c) \times (\pi/4) \times \rho_{fluid}$ (5)

Weight of Insulation =Insulation factor$\times (g/g_c) \times \rho_{insulation}$

Where,

D_0= pipe outside diameter in inches
Di=pipe inside diameter in inches
t=insulation thickness in inches
g=acceleration because of gravity in ft/sec2
g_c=gravitational constant in lbm-ft/ft sec2
ρ_{steel}=steel density in lb/in3
ρ_{fluid}=water density in lb/in3
$\rho_{insulation}$= insulation density in lb/in3

On the thickness of the insulation of the pipe factor of insulation is depend.

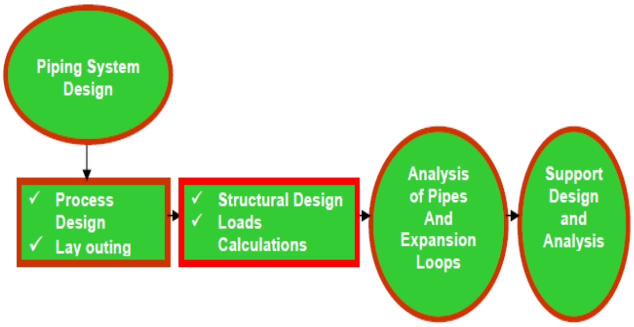

Fig. 2 piping system of complete stage design.

IV. STATIC LOADS CALCULATIONS

Pipe no. 208 is considered For Static loads calculation, section of pipe is taken up to first vertical leg of the expansion loop. This pipe is considered as a straight beam with uniformly distributed load.

A. Specifications for design

Outer Diameter of pipe = 8.625 in

Thickness of Pipe = 0.322 in

Nominal Pipe Size= 8 in =200 mm

Total distributed weight of pipe (Fluid +metal +Insulation) = 50lb/ft = 4.167 lb/in Section Modulus, Z= 16.8 in3
Elasticity Modulus, E = 27.5 Mpsi

Moment of Inertia, I = 72.5 in4

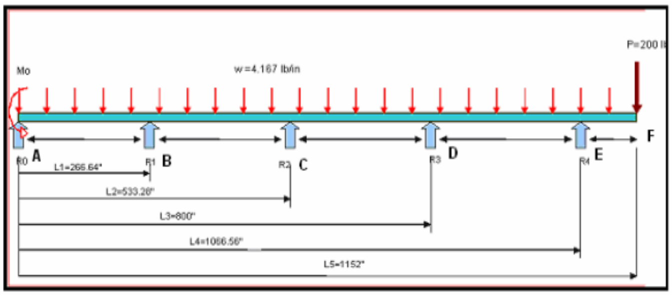

Fig.3 considering header pipe as a beam in symmetry

Solving Segment A-B

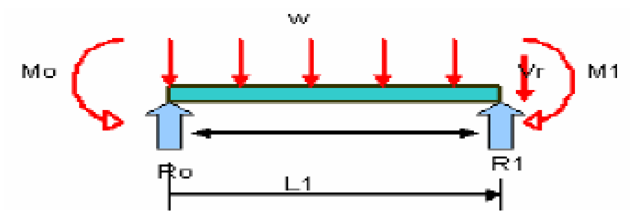

Fig.4 Segment A-B

as shown in Figure For segment A-B, taking the shear force, moment equation & weight and then taking L_1=22.22ft
$V(x) = -M_o(x)^{-1} + R_0(x)^0 - w(x)^1 - R_1(x-a)^{-1} - M_1(x-L)^{-2}$ (6)
$M(x) = -M_o(x)^0 + R_0(x)^1 - w(x)^2 - R_1(x-a)^1 - M_1(x-L)^0$
$W(x) = -M_o(x)^{-2} + R_0(x)^{-1} - w(x)^1 - R_1(x-a)^{-1} - M_1(x-L)^{-2}$
With the boundary conditions integrating the moment equation twice we get,

$EIy(x) = -M_0 (x)^2/2 + R_0(x)^3/6 - w(x)^4/24 = 0$ (7)

Given segement AB,$x=L_1$=266.64 in

$-M_0 (l_1)^2/2 + R_O (l_1)^3/6 - w (l_1)^4/24 = 0$

$-35548.44M_0 + 315945.77R_0 - 877634043.8 = 0$

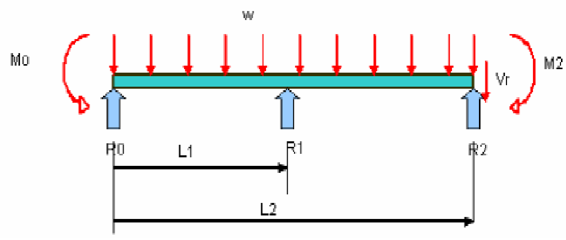

Fig.5 segment A-B-C

$EIy(l_2) = - M_O(l_2)^2 + R_0(l_2)^3/6 + R_1(l_2-l_1)^3/6 - w(l_2)^4/24 = 0$ (8)

$-142193.78M_0 + 252766366.2R_0 + 3159545.78R_1 - 1.404_e^{10} = 0$

Same for segment C-D

$EIy(l_3) = -M_O(l_3)^2 + R_0(l_3)^3/6 + R_1(l_3-l_1)^3/6 - R2(l_3-l_2)^3/6 - w(l_3)^4/24 = 0$ (9)

$-320000M_0 + 85333333.33R_0 + 25287743.4R_1 + 3159545.78R_2 - 7.11e^{11} = 0$

Segment D-E

$EIy (l_4) = -M_O(l_4)^2 + R_0(l_4)^3/6 + R_1(l_4-l_1)^3/6 - R_2(l_4-l_2)^3/6 + R_3(l_4-l_3)^3/6 - w(l_3)^4/24 = 0$ (10)
$568775.12M_0 + 202210929R_0 + 85307735.9R_1 + 252776366.2R_2 + 3156702R_3 - 2.24e^{11} = 0$

Taking summation of moment at left end of right end support

$M_0 + R_0 l_4 + R_1(l_4 - l_1) + R_2(l_4 - l_2) + R_3(l_4 - l_3) - wl_1(l_4 - a) - w(l_2 - l_1)(l_4 - b) - w(l_3 - l_2)(l_4 - c) - w(l_3 - l_2)(l_4 - c) - w(l_4 - l_3)(l_4 - d) - wx^2/2 - P \times x = 0$
(11)
$M_0 + 1066.56R_0 + 800R_1 + 533.28R_2 + 266.64R_3 - 2369952.574 = 0$
Solving the above equation we get
M_o = -24401 lb.in,R_o= 552 lb, R1=1123 lb R_2=1067 lb,
R_3= 1266 lb For R_4,
Taking $R_0 + R_1 + R_2 + R_3 + R_4 = wL + 800$
R_4 = 159 l lb.
Maximum Bending Moment Mmax = -32741.44533 lb-in at x =799.92 in

B. Code Verification

$$SL = \frac{PD_0}{4t} + \frac{0.75ixM_A}{Z} \leq 1.0S_h$$

Where,
D o = pipe Out Side diameter in inches
Z = pipe Section modulus in inches^3
t = wall thickness(nominal) in inches
P = Internal Pressure in psi
S_L= allowable stress for basic material at design pressure, psi.
i =factor of stress intensification
M_A = Resultant moment because of weight and other sustained loads in lb-in

$193.7 \times 8.625 / (4 \times 0.322) + 0.75 \times 1 \times 32700 / (16.8) \leq 1.0 \times 14400$

$2756.92 \leq 14400$

$2.75 \; 10^3 \leq 14.4 \times 10^3$

C. Piping analysis on ANSYS

BY using the following data IN ANSYS analysis was performed for the pipe

Type of element = Beam 3

Properties of Material

Elasticity Modulus= 27.5 Mpsi

Poison's Ratio = 0.283

Flow Density = 0.283 lb/in3

D. Load Types

One all degree of Freedom constrained at the start and Four Vertical constraints in the middle.

Gravity = 9.81(386.22 in/sec2)

Final Meshing = for total length of the beam 96 elements (8 elements for the last section and 22 elements for first four each sections. There is no change found in deformation values and bending moment values after refining the mesh from 24 elements up to 96 elements)

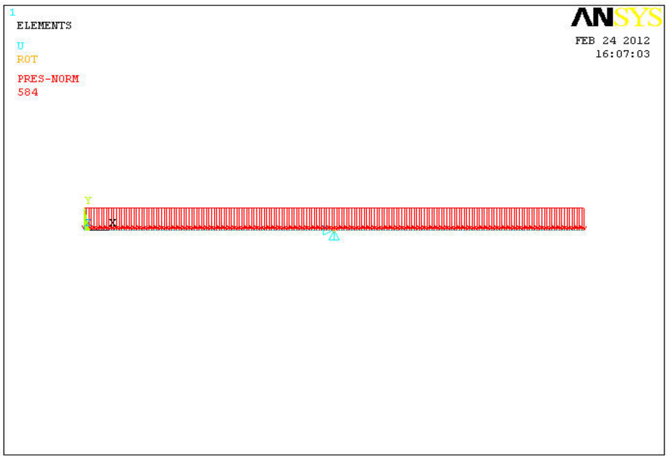

Fig.6 meshed beam loaded view

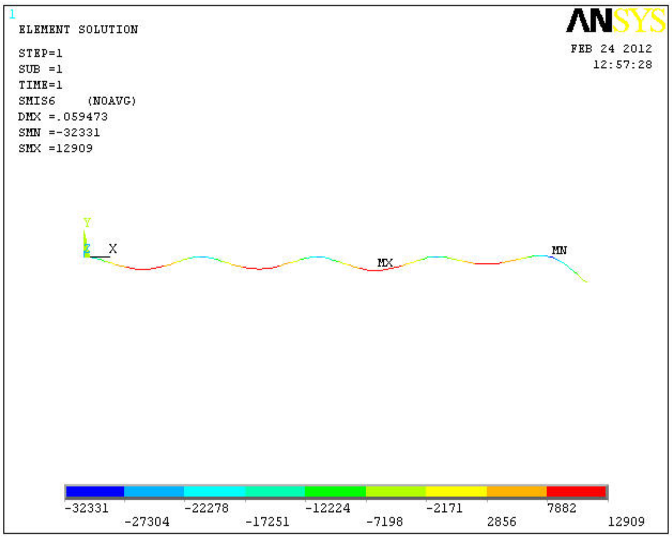

Fig.7 pipe deflection (inch)

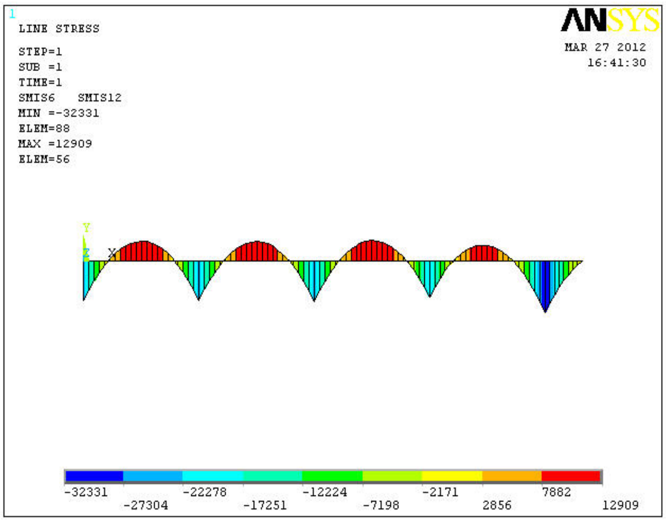

Fig.8 pipe bending stress (psi)

E. Analysis Comparison

The bending moment and maximum deflections values obtained from both methods are arranged below in Table

TABLE I

ANALYSIS COMPARISON OF BEAM

Method	**Max. Deflection (in)**	**Max. Bending (lb-in)**
Manual	0.064	32741.445
ANSYS Results	0.0596	32921.00

DISCUSSION AND RESULTS:

Results obtained from both ANSYS and manually, maximum deflection difference is 6.4% and max. Bending moment difference is 1.35%. Maximum bending stress is 1947.55 psi which is very less than the allowable stress of the pipe and also deformation is less than 0.1 inch.

CONCLUSION

From the analysis of the designed system Following conclusions are made:

1. All the conditions defined by the ASME Boiler and Pressure Vessel code B31.1 are verified from designed pipe. Working pressure and thickness calculated are in the safe limit. Sustained and Thermal analysis results obtained are in the safe limits defined by the Code.
2. Supporting Assembly fulfills all the safety requirements of AISC standards.
3. after verifying results by manual calculations and ANSYS software the analysis shows that the complete system is safe.
4. By the assumptions made during manual calculations make the results slightly differ from the software results but on the positive side of the manual calculations lays the fact that it gives fully basic concept of the piping system.

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