Flexibility and Stress Analysis of Piping System using CAESAR II- Case Study

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***Abstract*— Process Plant can be operated safely and efficiently with the help of good design of equipments and piping systems connecting to the various equipments like tanks, heat exchangers, pumps etc. Design of piping system includes the pipe and fitting sizing, thickness calculation, equipment layout, pipe routing, support type, support location finalization and stress analysis. This study explains the stress analysis of piping system as per process piping code ASME B 31.3 using 3D software tool CAESAR II. Major requirements in piping stress analysis are to provide adequate flexibility for absorbing thermal expansion, code compliance for stresses incurred in piping system, safe nozzle loads and displacement. The design is said to be safe if all these are in allowable range as per code. In this study, the criterion of selection of piping system for flexibility analysis is explained analytically. The two piping systems are stress analyzed, compared and the effect of flexibility of piping system on nozzle loads and stresses developed are observed. The software output is discussed and safer piping system is identified.**

Keywords*— *Code compliance, Nozzle Loads, Piping Flexibility, Stress Analysis, ,

I. INTRODUCTION

Piping system is the heart of any process plant. The performance of the plant depends on the pipe line sizing, Equipment layout, Pipe routing with minimum possible pressure drop, considering all mechanical and operational safety.

Piping system comprises of pipes, fittings like elbows, tees, reducers, sockets, half couplings, unions, flanges and valves. These all are used to transfer the fluid from one point to another through straight pipes, changing the direction with most economical means- elbow [11], branching through tees, size variation through reducers or reducing tee at branches, connecting each other or to the instruments through flanges, union, sockets, half couplings and on-off conditions or fluid control through different types of valves.

This study is emphasis on the process piping code ASME B 31.3. As the piping temperature changes from installation condition to operating condition, it expands or contracts. Both expansion and contraction is known as thermal expansion. When a system tries to expand in a rigid piping system, a large amount of stresses are generated leading to failure of system. Flexibility analysis plays a major role in designing the piping system. Flexibility analysis is a part of stress analysis. Stress analysis of piping system is performed to verify the compliance with the Design Code, to calculate pressure vessel nozzle loads, displacements due to thermal expansion, selection of support type and support location on piping system etc. The aim of this study is to analyze the stresses in the piping system.

II. PIPE LAYOUT AND ROUTING

Flexibility of piping system is mainly dependent on the Equipment Layout. While finalizing the location of equipments, the connecting piping flexibility is also to be considered alongwith the process flow, accessibility to valves, instruments, equipment maintenance, cleaning, operational safety, headroom clearance and aesthetics. The piping layout designer has to undergo number of iterations to reach to a final layout. Pipe Routing is always decided based on the Equipment layout. The best possible pipe routing is achieved by knowing the process flow and the above criterion for layout.

Pipe Data:
Pipe Size: DN 200
Pipe Schedule: Sch 5S
Pipe Material: A312 TP 316L
Max. Operating temperature: 110^0c
Max. Operating Pressure: 1.5 bar (g)
Fluid density: 1100 kg/m^3
Ambient Temperature: 25^0c

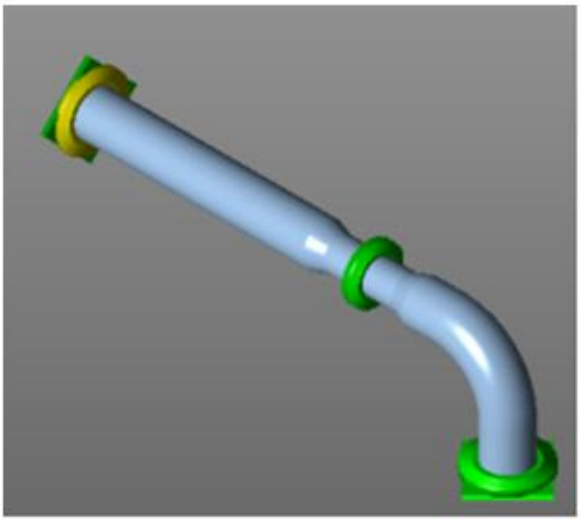

Fig: 1- 3D view of piping System 1 to be designed

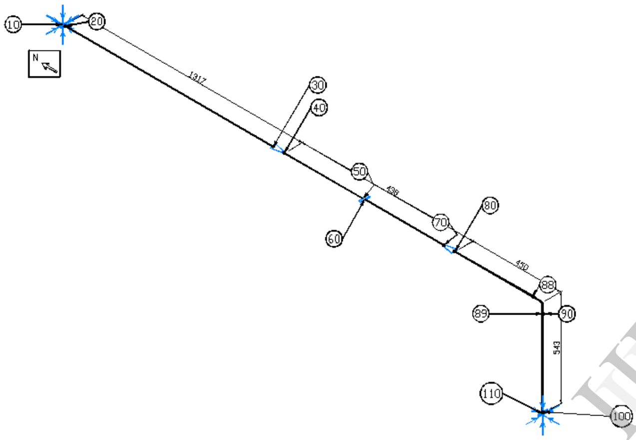

Fig. 2- Isometric view of piping system 1 to be designed

III. FLEXIBILITY ANALYSIS CRITERION

Once the piping layout is fixed, the nearest possible routing of piping system is done.

As per ASME B 31.3 [2], No formal analysis of adequate flexibility is required for a piping system which

a) Duplicates or replaces without significant change, a system operating with successful service record.

b) Can readily be judged adequate by comparison with previously analyzed systems

c) is of uniform size, has no more than two points of fixation, no intermediate restraints, and falls within the limitation of empirical equation:

$$((D \times y)/ (L-u)^2) \leq k_1 \qquad (1)$$

Where,

D = outside diameter of pipe in mm (inch)

y = Resultant of total displacement strains in mm (inch), to be absorbed by the piping system

L = developed length of piping between anchors in m (ft)

u = anchor distance, straight line between anchors, in m (ft)

$k_1 = 208000 \times S_A / E_a$ (mm/m^2) or $30 \times S_A / E_a$ (in. / ft^2)

Ea = Reference Modulus of Elasticity at 21^{0}c in MPa (ksi)

S_A = Allowable displacement stress Range in MPa (ksi)

Sc = Allowable stress at cold operating temp. in MPa (ksi)

Sh = Allowable stress at hot operating temp. in MPa (ksi)

For the piping system I, calculated value of k_1=

$$((D \times y)/ (L-u)^2) = 2.21$$

$k_1 = 30 \times S_A / E_a$ (in. / ft^2)

S_c for 40^{o}c = 16.7 ksi (As per Table A-1 Basic Allowable stresses in Tension for metals- for A312-TP 316L)

S_h for 110^{o}c = 16.7 ksi (As per Table A-1 Basic Allowable stresses in Tension for metals- for A312-TP 316L)

Allowable Stress Range S_A= f (1.25 S_c + 0.25 S_h)

f = 1 for 10^4 cycles (Table 302.3.5 Stress Range Factor,f)

S_A = 1((1.25x16.7) + (0.25x16.7)) = 25.05 ksi

E_a = Reference modulus of elasticity at 21^{0}c (70^{0}F) = 28.3 x 10^3 ksi (Table C-6- Modulus of Elasticity for metals- For Austenitic steels)

$k_1 = 30 \times S_A / E_a$ (in. / ft^2)

Limiting value of k_1= $((D \times y)/ (L-u)^2) = 0.027$

IV. STRESS ANALYSIS 3D MODELLING

Piping stress analysis is a term applied to calculations, which address the static and dynamic loading resulting from the effects of gravity, temperature changes, internal and external pressures. The purpose of stress analysis is to ensure safety of piping and piping components as well as the safety of connected equipments and supporting structure [7]

Flexibility as well as stress analysis for this piping system is done through CAESAR II software.

Operating loads are calculated using self weight, operating pressure and temperature for the piping system, Sustained loads are by using self weight and operating pressure and Expansion loads are due to temperature differences.

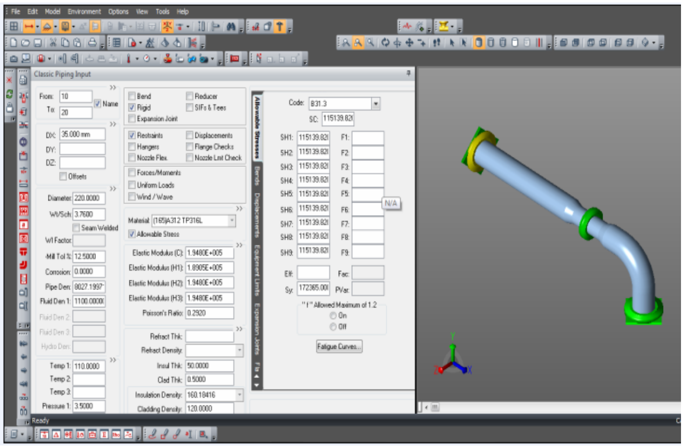

Fig. 3- Modeled piping system 1 in CAESAR II software

1: Code compliance and Nozzle loading for piping system

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LOAD CASE DEFINITION KEY

CASE 2 (SUS) W+P1


Piping Code: B31.3      = B31.3 -2008, December 31, 2008

***  CODE COMPLIANCE EVALUATION PASSED  ***

Highest Stresses: (lb./sq.in.)
CodeStress Ratio (%) is 6.3 at Node 20 LOADCASE: 2 (SUS) W+P1
Code Stress:          1058.3  Allowable:     16700.0
Axial Stress:          673.4  @Node     30  LOADCASE: 2 (SUS) W+P1
Bending Stress:        384.8  @Node     20  LOADCASE: 2 (SUS) W+P1
Torsion Stress:          0.0  @Node     90  LOADCASE: 2 (SUS) W+P1
Hoop Stress:          1434.4  @Node     30  LOADCASE: 2 (SUS) W+P1
3D Max Intensity:     1511.0  @Node     30  LOADCASE: 2 (SUS) W+P1
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Table 1- Nozzle Load on Tanks for the piping system 1 to be designed- CAESAR output

NODE	Load Case	FX lb.	FY lb.	FZ lb.	MX ft.lb.	MY ft.lb.	MZ ft.lb.
Tank (10)		Rigid ANC					
	1(OPE)	-20624	2171	0	-0.0	-0.0	8252.0
	2(SUS)	-124	-225	0	0.0	-0.0	-289.4
	3(EXP)	-20500	2397	0	-0.0	-0.0	8541.4
	MAX	-20624/L1	2397/L3	0/L1	-0.0/L3	-0.0/L1	8541.4/L3
tank (110)		Rigid ANC					
	1(OPE)	20624	-2673	-0	-0.0	0.0	-27834.6
	2(SUS)	124	-277	-0	0.0	0.0	-109.5
	3(EXP)	20500	-2397	-0	-0.0	0.0	-27725.1
	MAX	20624/L1	-2673/L1	-0/L1	-0.0/L3	0.0/L1	-27834.6/L1

Table 2- Nozzle Load on Tanks for the modified piping system 2 - CAESAR output

NODE	Load Case	FX lb.	FY lb.	FZ lb.	MX ft.lb.	MY ft.lb.	MZ ft.lb.
10		Rigid ANC					
	1(OPE)	-733	123	-847	-625.1	3777.0	904.1
	2(SUS)	1	-290	-18	-42.2	93.2	-692.2
	3(EXP)	-734	413	-828	-582.9	3683.8	1596.3
	MAX	-734/L3	413/L3	-847/L1	-625.1/L1	3777.0/L1	1596.3/L3
130		Rigid ANC					
	1(OPE)	733	-724	847	1923.3	-1558.4	-1788.7
	2(SUS)	-1	-311	18	-43.5	13.4	-18.4
	3(EXP)	734	-413	828	1966.7	-1571.8	-1770.4
	MAX	734/L3	-724/L1	847/L1	1966.7/L3	-1571.8/L3	-1788.7/L1

Another piping system with same size and same operating pressure and temperature connecting with the same equipments can be routed as follows, as the equipment layout is different.

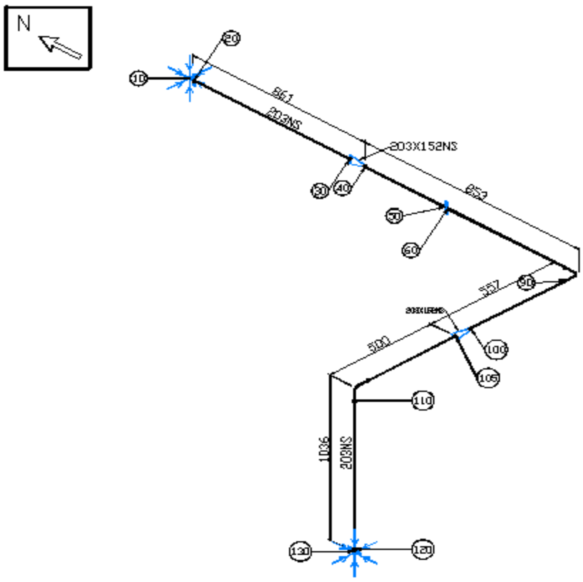

Fig. 4- Isometric view of piping system 2 to be designed

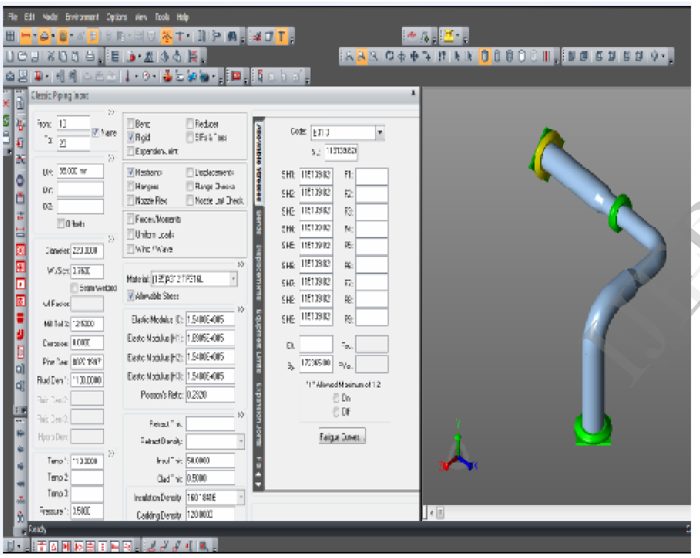

Fig. 5- Modeled piping system 2 in CAESAR II software

2: Code compliance and Nozzle loading for piping system

The reports for code compliance and nozzle loads from CAESAR II software are generated.

Calculated value of k_1= ((D x y)/ (L-u)^2) for piping system 2 is 0.025

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Piping Code: B31.3      = B31.3 -2008, December 31, 2008

***  CODE COMPLIANCE EVALUATION PASSED  ***

Highest Stresses: (lb./sq.in.)
CodeStress Ratio (%) is 34.6 at Node 90 LOADCASE: 3 (EXP) L3=L1-L2
Code Stress:          8657.7  Allowable:    25050.0
Axial Stress:          705.1  @Node     30  LOADCASE: 2 (SUS) W+P1
Bending Stress:       8777.1  @Node     90  LOADCASE: 1 (OPE) W+T1+P1
Torsion Stress:       1138.3  @Node    110  LOADCASE: 3 (EXP) L3=L1-L2
Hoop Stress:          1434.4  @Node     30  LOADCASE: 1 (OPE) W+T1+P1
3D Max Intensity:     9801.1  @Node     90  LOADCASE: 1 (OPE) W+T1+P1
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V. RESULTS

Piping flexibility empirical equation is solved for the piping systems to be designed. The values found for k_1 are 2.21 and 0.025 for piping system 1 and Piping system 2 respectively. The limiting value calculated for the mentioned pipe data is 0.027.

CAESAR II output for Piping system 1 and Piping system 2 is observed. Code compliance evaluation for both the piping systems is passed i.e. the maximum stresses developed in the piping systems is less than the allowable stress mentioned by the process piping code ASME B 31.3. The code stress ratio is 6.3% for piping system 1 and 34.6% for piping system 2.

Table 3-Maximum nozzle loads on the connecting tanks at Node No. 10 and 110 for piping systems

Piping System 1	**F_x (lb)**	**F_y (lb)**	**F_z (lb)**	**M_x (lb.ft)**	**M_y (lb.ft)**	**M_z (lb.ft)**
Node No. 10	-20624	2397	0	-0	-0	8541.4
Node No. 110	20624	-2673	-0	-0	0	27834.6
Piping System 2	**F_x (lb)**	**F_y (lb)**	**F_z (lb)**	**M_x (lb.ft)**	**M_y (lb.ft)**	**M_z (lb.ft)**
Node No. 10	-734	413	-847	-625.1	3777.0	1596.3
Node No. 110	734	-724	847	1966.7	-1571.8	-1788.7

VI. CONCLUSION

The analytical study of piping systems is done using the process piping code ASME B 31.3 and 3D software tool CAESAR II is used for piping system modeling and stress analysis purpose. The analytical and software output is observed. The flexibility analysis requirement for the piping system is checked analytically using the design code ASME B 31.3 and also the system is stress analyzed using CAESAR II software. The results are analyzed and found that

i) Piping system 2 is safer than the Piping system 1.

ii) Piping system 2 is more flexible than the piping system 1

VII. DISCUSSION

The flexibility, code compliance and Nozzle loads on connecting equipments are observed. The empirical equation limiting factor (k_1) for the pipe design data provided is 0.027. Analytically, for piping system 1, the observed factor is 2.21 which is beyond the limiting factor. So flexibility analysis for piping system 1 is must. While for piping system 2, the observed factor is 0.025 which is less than the limiting value. So, flexibility analysis for piping system 2 is not required analytically.

When the software output is observed for these systems, the nozzle load force in X direction (F_x) and moment in Z direction (M_z) for piping system 1 are very high as compared to allowable nozzle loads. This may lead to failure of the system at nozzles (Node No. 10 and 110).To avoid the failure, either the equipment thickness is to be increased or some reinforcement has to be provided at nozzle, depending on the severity of nozzle loads developed. This increases the cost of the system which is not acceptable. But the nozzle loads for the piping system 2 are within the allowable loads on equipment.

The stresses developed in both the pipe system are in code stress limit and hence can be accepted.

This study reveals that more the flexibility, lesser are the nozzle loads on the equipments. Hence the piping system 2 is preferred to piping system 1.

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