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Design and Analysis of Piping System with Supports Using CAESAR-II

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***Abstract*—**A steam power plant is housed with various types of equipments like boiler, turbine, heat exchanger etc. These equipments are mainly connected with piping systems. Such a piping layout design depends mainly on stress analysis and flexibility. It will vary with respect to pipe geometrical properties, pressure, temperature, and supports. The present paper is to analyze the presence and effect of hangers and expansion joints in the piping layout/routing using CAESAR-II software. Main aim of piping stress analysis is to provide adequate flexibility for absorbing thermal expansion, code compliance for stresses and displacement incurred in piping system. The design is said to be safe if all these are in allowable range as per code. In this study, a sample problem is considered for analysis as per power piping ASME B31.1 code and the results thus obtained are compared.

***Keywords*—**ASTM B31.1, hanger, expansion joint, CAESAR-II.

I. INTRODUCTION

PIPING stress analysis is a method which is highly reciprocal with piping layout and support. In piping system, the layout should be performed with the concern of the piping support and stress in mind. It shows sufficient flexibility for thermal expansion in pipe routing so that various simple and economical pipes can be build using various piping materials & section properties which includes pressure, temperatures & loading. The required layout should be perfectly balance between stresses so that layout efficiency is achieved. After piping layout is made, piping support system is determined. Various support locations & types should be repeatedly iterated until all the stress requirements were satisfied with piping allowable (e.g., nozzle loads, valve accelerations, and piping movements).

The piping supports are designed based on the selected locations, types and the applied loads. The discussion is heavily weighted to the stress analysis of piping systems in thermal power plants, since this type of piping has the most stringent requirements.

Basavaraju [1] has carried out research on piping systems, supports, materials used, fittings, insulation properties, operating medium in pipe line and analyzed the main Stream line of thermal power plant. Hanger is mainly used in the analysis of the piping systems.

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A significant research on piping systems, span length, number of supports, and cost of the piping layout had been studied by [2] using CAESER-II software. He optimized the number of supports by changing temperature and pressure within operating medium, density of pipe material and the span length between the supports. It was reported by [3] that by modifying the layout of steam piping system, the pressure drop can be minimized and hence power can be minimized in thermal power stations. Due to the layout changes, the hanger supports position also changed. A research on pipelines with an aim of maximizing the distance between supports, minimizing the number of supports and reducing the total cost of erecting these pipe supports was done by [4] with mathematical calculation. Shweta Bisht et al. [5] have given the basic ideas about the piping analysis software CAESAR II. The design and analysis of piping systems using software was explained elaborately in this work. The benefits of using FRPC and interaction between the different stresses on the pipe walls were analyzed by [6]. It was reported that carbon composites pipes improved ultimate internal pressure capacity of pipes. The possibilities and disadvantages of finite elements methods in steam pipeline stress analysis were founded by [7]. The basic concept of flexibility such as flexibility characteristics, flexibility factor and stress intensification factor (SIF) for any code using CAEPIPE software was explained by [8].

A. Need of Pipe Supporting

The objective of the pipe supports design phase is to prevent the following:

- maximum stress occurring in the piping
- excessive forces on equipment
- excessive interference with thermal expansion
- excessive pipe sag
- excessive heat flow, exposing support to temperature outside their limits.

Emphasis was given in the literatures only on piping systems and its layout and there were no report giving emphasis to piping supports. As for as steam piping is concerned, there are so many supports that can be used in the piping system and it should be selected based on the position and as per ASTM codes. In this paper, the piping supports mainly used in industries such as hanger, expansion joints and restraints were considered with an objective of better flexibility and reduced stress. The analysis is performed using CAESAR II software [10]. Among the various types of hangers, variable supports are preferred for use in power plants [11].

The displacement in the expansion joint is restricted by guide rod when it exceeds the design value in the case of employing single expansions joints. When the displacement is large, double joints are preferred. Normally the thrust force produced by the displacement reaction and internal pressure will react at the fixed point of the expansion joint. By fixing a guide rod at that fixed point, the possible damage can be avoided since it enables sufficient strength against the generated thrust force.

II. Modeling

In the piping systems various failure modes is to affect the overall function of the power plant [9]. Mainly the pipe engineer is to consider the stress analysis according to the piping codes. It depends upon the material, supports and loads. The major stress categories are primary, secondary, and peak. The pipe stress depends upon structural integrity, operational integrity and optimal design. These codes contain basic reference data, formulas, and equations necessary for piping design and stress analysis. ASME B31.1 Power Piping Code concerns in this piping system. Design requirements of this code cover those for pipe, flanges, bolting, gaskets, valves, relief devices and fittings. It includes supports, hangers and other equipment items necessary to prevent overstressing the pressure-containing components.

A. Piping Routing Parameters

- Design pressure: 210 bar
- Working medium: Sh steam
- Working temperature: 540°C
- Pipe size: D219.1x8.17
- Pipe material: SA 335 P22
- Pipe density: 0.0078 kg/cc
- Insulation: 100 mm
- Insulation density: 240 kg/m^3

The geometric properties of piping system are directly given to the software. The material is to be selected from the material library. In piping system SA335 P22 is selected from the material library available in the CAESAR software. For piping stress analysis, piping layout is to be modeled first. Fig. 1 is the piping layout available in literature [1] which is considered for the analysis of piping stress with supports.

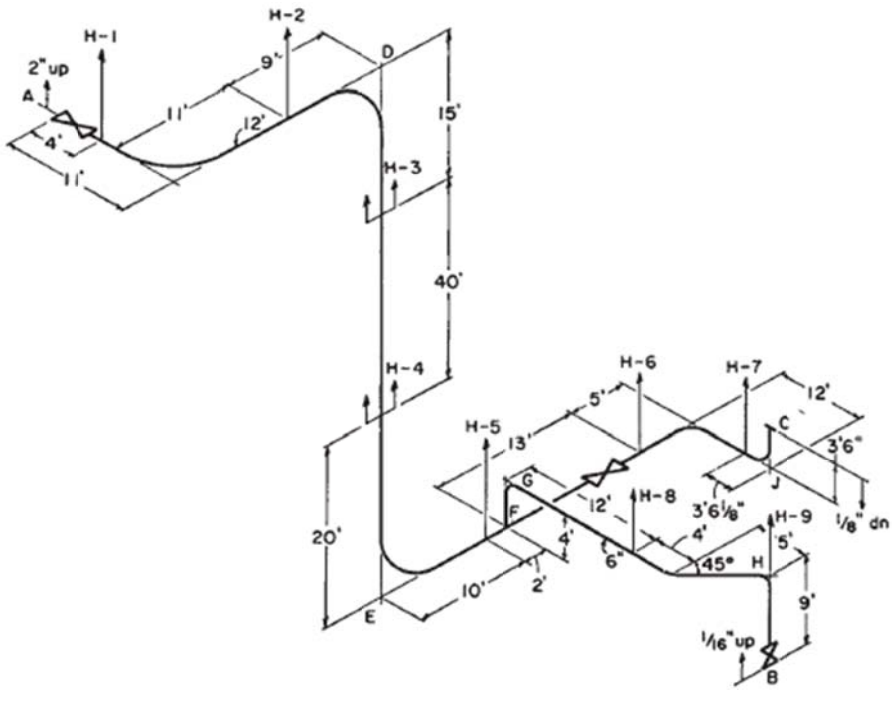

Fig. 1 Piping Routing with Hanger Supports

ASTM A335 P22 Pipe (ASME S/A335, Chrome-Moly) is a seamless ferritic Alloy-Steel Pipe for high temperature service. Pipe of this specification shall be suitable for bending, flanging (vanstoning), and similar forming operations, and for fusion welding. Usually chrome moly pipes are referred as “P Grade” pipes and few popular categories are P5, P9, P11, P22, and P91.

Molybdenum increases the strength of steel as well as the elastic limit, resistance to wear, impact qualities, and hardenability. Molybdenum increases the resistance to softening, restrains grain growth.

TABLE I
PROPERTIES OF PIPE ROUTING

Material	COMPOSITION						
	C	Mn	P	S	Si	Cr	Mo
SA335 P22	0.05-0.15	0.30-0.60	0.025	0.025	0.50 max	1.90-2.60	0.87-1.13

The properties of pipe routing material are presented in Table I. The size of the material to be used commonly is NPS 1/4" to NPS 48". The wall thickness is considered as scheduled 40.

B.Pipe Stiffness Calculation for Expansion Joints

Pipe stiffness is calculated using:

PS = El/0.149r3

PS = Pipe Stiffness, psi; E = Modulus of Elasticity, psi; I = Moment of Inertia of pipe per Unit; L= Length of Pipe, in 4/Lin; r = Mean Radius of Pipe, in. D = Mean Diameter of Pipe, in.

E= 3.06E7, I=72.49 in, R=4.232 in

$$PS = \frac{3.06 * 10^7 * 72.49}{0.149 * 4.232^3}$$

$$PS = 19.64 * 10^7$$

The pipe stiffness equation is common for any pipe lines. For analyzing the piping layout with expansion joint information such as stiffness value for axial, bending, torsion, rotational and mean radius are to be fed into the software.

The design of piping layout is modeled using CAESAR-II software. The starting of the piping system is connected with nozzle. It is divided into two branches and one end is with the Translational Directional (y+) and other end connected with anchor.

III.RESULT AND DISCUSSION

A.Piping System with Hanger Support

Fig. 2 is a piping layout incorporating nine hangers which is modeled using CAESAR II software. The model is then simulated with sustained type of loading system and the output parameters such displacement at various points, stresses and nozzle loads were observed. Moment and force at hanger locations were also analyzed. Main aim of the analysis is to reduce the flexibility and the stress in the pipe layout.

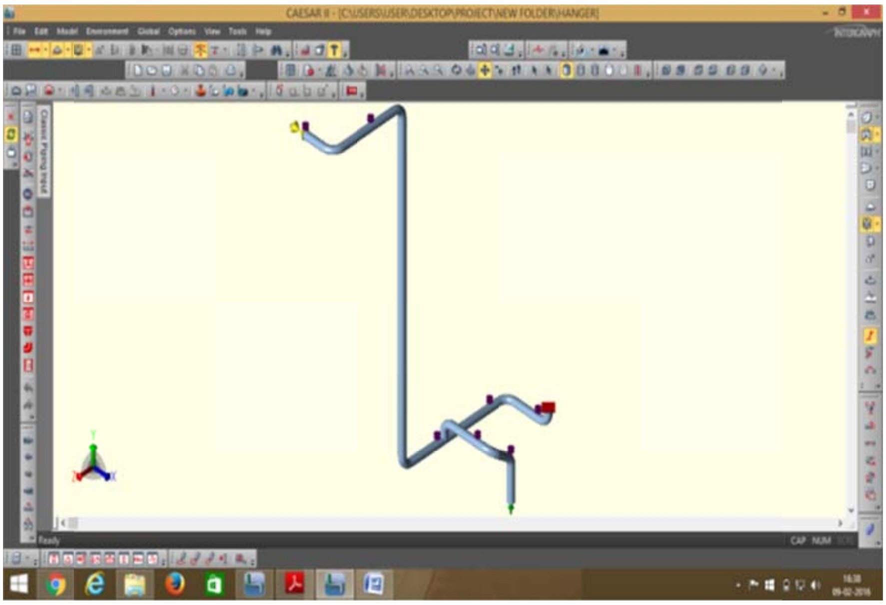

Fig. 2 Modeled Piping Systems with Hanger Support in CAESAR II Software

The output of the piping analysis is detailed below.

- Piping Code: B31.1= B31.1 -2016, Jan 29, 2016
- Code Stress Check Passed: Loadcase 4 (SUS) W+P1+H
- Highest Stresses: (lb./sq.in.)
- Ratio (%): 31.7@Node 20
- Code Stress: 5262.4
- Allowable Stresses: 16600.0
- Axial Stress:1285.6@Node 30
- Bending Stress: 4195.5@Node 18
- Torsion Stress: 837.0@Node 20
- Hoop Stress: 2602.5@Node 14
- Max Stress Intensity: 7850.0@Node 18

Based on the pressure and temperature, the stress values were changed at every node in the routing. The ratio of the pipe routing obtained in the analysis was 31.7% at Node 20. Ratio of the pipe routing is defined as

$$Ratio = \frac{codestress}{\text{allowable stress}}$$

The allowable stress is the maximum force per unit area that may safely be applied to a pipe. Allowable stress of material is an important parameter in the stress analysis of piping system. Working stress (code stress) in the piping system should not exceed an allowable stress of the material for the selected code and standard. Nodal displacement (DX_{in}, DY_{in}, DZ_{in}) and rotation (RX_{deg}, RY_{deg}, RZ_{deg}) in all the three directions obtained from the analysis of piping system using CAESAR-II software are presented in Table II.

Force/Load and moment at hanger locations can also be obtained from CAESAR-II software and are presented in Table III.

TABLE II
NODAL DISPLACEMENT AND ROTATION OF PIPING SYSTEM WITH HANGER SUPPORT – CAESAR II OUTPUT

Node	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
10	0.709	0.938	-1.311	-0.255	0.021	-0.113
11	0.709	0.907	-1.316	-0.255	0.021	-0.113
19	0.707	0.821	-1.329	-0.254	0.021	-0.112
20	0.704	0.776	-1.33	-0.253	0.021	-0.111
21	0.689	0.587	-1.33	-0.252	0.021	-0.109
22	0.201	0.391	-0.303	-0.194	0.019	-0.092
29	0.667	0.406	-1.315	-0.241	0.02	-0.106
30	0.651	0.391	-1.28	-0.232	0.019	-0.104
31	0.538	0.391	-1.031	-0.223	0.019	-0.101
38	0.062	0.391	-0.014	-0.182	0.019	-0.089
39	0.048	0.38	0.012	-0.172	0.018	-0.086
40	0.04	0.356	0.022	-0.159	0.018	-0.085
41	0.028	0.253	0.022	-0.15	0.018	-0.083
42	0.025	0.227	0.022	-0.147	0.018	-0.082
48	0.001	0.052	0.022	-0.111	0.018	-0.066
49	-0.001	0.034	0.021	-0.08	0.018	-0.053
50	-0.002	0.023	0.019	-0.066	0.018	-0.034
51	0.005	0.078	0.022	-0.117	0.018	-0.068
59	-0.001	0.078	0.003	-0.032	0.009	-0.015
60	-0.001	0	0.003	-0.003	0	-0.001
61	-0.002	0.005	0.008	-0.045	0.018	-0.028
70	0	0	0	0	0	0
99	0.037	0.227	0.002	-0.147	0.018	-0.083
100	0.05	0.222	-0.021	-0.15	0.019	-0.092
101	0.056	0.208	-0.033	-0.151	0.02	-0.098
102	0.056	0.145	-0.046	-0.154	0.02	-0.101
109	0.056	0.131	-0.048	-0.154	0.02	-0.102
110	0.051	0.108	-0.046	-0.156	0.019	-0.104
111	0.04	0.082	-0.034	-0.158	0.019	-0.105
121	0	0.082	0	0	0	0
131	0	0.082	0	0	0	0
139	0.018	0.044	-0.007	-0.158	0.019	-0.105
140	0.009	0.034	0.004	-0.158	0.019	-0.105
141	-0.002	0.03	0.02	-0.158	0.019	-0.105
151	-0.072	0.03	0.126	-0.158	0.019	-0.105

TABLE III
LOAD AND MOMENT ON PIPING SYSTEM WITH HANGER SUPPORT- CAESAR II OUTPUT

Node	Load Case	FX lb.	FY lb.	FZ lb.	MX ft.lb.	MY ft.lb.	MZ ft.lb.
11	ProgDesign VSH 4(SUS)	0	-792	0	0	0	0
21	ProgDesign VSH 4(SUS)	0	-381	0	0	0	0
22	ProgDesign VSH 4(SUS)	0	-902	0	0	0	0
31	ProgDesign VSH 4(SUS)	0	-798	0	0	0	0
41	ProgDesign VSH 4(SUS)	0	-385	0	0	0	0
51	ProgDesign VSH 4(SUS)	0	-315	0	0	0	0
61	ProgDesign VSH 4(SUS)	0	-226	0	0	0	0
70	Rigid ANC 4(SUS)	0	10	0	-1607	0	-643.9
102	Rigid ANC 4(SUS)	0	-280	0	0	0	0
141	Rigid ANC 4(SUS)	0	-190	0	0	0	0
151	Rigid +Y 4(SUS)	0	0	0	0	0	0

B.Piping System with Expansion Joint and Restraints

Piping system incorporating two expansion joints and five restraints are modeled to the same geometry and simulated with same operating pressure and temperature. Fig. 2 is the pipe routing with hangers and restraints modeled in CAESARII software. There are three types of analysis available namely thermal run, weight run and final run. Thermal run will be useful to study the displacements which will consider linear direction of flow. In linear directional flow, normally the displacement will be high and the stress will apparently be low. Stress will be more at the flow where it is diverged into two branches. Output of the pipe routing for sustained load condition from CAESAR II software is detailed below.

- Piping Code: B31.1 = B31.1 -2012, June 29, 2012
- Code Stress Check Passed: Loadcase 2 (SUS) W+P1
- Highest Stresses: (lb./sq.in.)
- Ratio (%): 20.8@Node 60
- Code Stress:3451.4
- Allowable Stress: 16600.0
- Axial Stress: 1323.1@Node 22
- Bending Stress: 2934.1@Node 60
- Torsion Stress: 573.5@Node 50
- Hoop Stress: 2602.5@Node 19
- Max Stress Intensity: 6089.6@Node 60

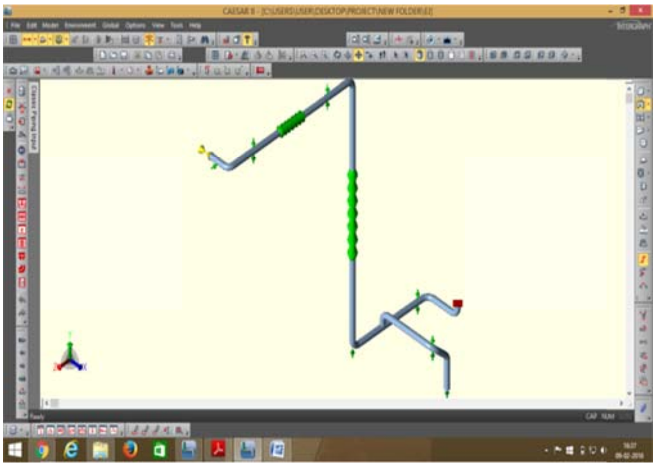

Fig. 3 Modeled Piping System with Expansion Joint and Restraints Support in CAESAR II Software

Force / Load and moment at hanger locations can also be obtained from CAESAR-II software and are presented in Table IV.

TABLE IV
NODAL DISPLACEMENT AND ROTATION OF PIPING SYSTEM WITH EXPANSION JOINT AND RESTRAINTS SUPPORT – CAESAR II OUTPUT

Node	Load Case	FX lb.	FY lb.	FZ lb.	MX ft.lb.	MY ft.lb.	MZ ft.lb.
15	Rigid +Y 2(SUS)	0	-1305	0	0	0	0
21	Rigid Y 2(SUS)	0	350	0	0	0	0
31	Rigid Y 2(SUS)	0	-983	0	0	0	0
40	Rigid +Y 2(SUS)	0	-1800	0	0	0	0
51	Rigid Y 2(SUS)	0	-518	0	0	0	0
70	Rigid ANC 2(SUS)	0	-152	0	-1.6	0	16.8
111	Rigid Y 2(SUS)	0	-325	0	0	0	0
131	Rigid +Y 2(SUS)	0	-188	0	0	0	0

Nodal displacement (DXin, DYin, DZin) and rotation (RXdeg, RYdeg, RZdeg) in all the three directions obtained from the analysis of piping system using CAESAR-II software are presented in Table V.

TABLE V
LOAD AND MOMENT ON PIPING SYSTEM WITH EXPANSION JOINT AND RESTRAINTS SUPPORT - CAESAR II OUTPUT

Node	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
10	-0.317	-0.08	0.028	-0.042	-0.01	0.122
11	-0.317	-0.037	0.031	-0.042	-0.01	0.122
14	-0.317	-0.012	0.033	-0.042	-0.01	0.12
15	-0.317	0	0.034	-0.042	-0.01	0.117
17	-0.317	0.012	0.035	-0.042	-0.01	0.115
18	-0.317	0.019	0.035	-0.042	-0.01	0.114
19	-0.317	0.028	0.036	-0.045	-0.01	0.102
20	-0.316	0.027	0.037	-0.043	-0.01	0.1
21	-0.309	0	0.037	-0.027	-0.01	0.093
23	-0.301	-0.009	0.037	0.004	-0.01	0.084
26	-0.292	-0.005	0.037	0.004	-0.01	0.084
28	-0.277	-0.002	0.037	-0.005	-0.01	0.069
29	-0.272	-0.003	0.037	-0.004	-0.007	0.065
30	-0.262	-0.003	0.037	-0.004	-0.005	0.058
31	-0.284	0	0.037	0.002	-0.01	0.075
33	-0.164	-0.003	0.032	0.006	-0.005	0.042
36	-0.072	-0.003	0.02	0.006	-0.005	0.042
38	-0.005	-0.002	0.003	0.012	-0.005	0.027
39	-0.001	-0.001	0.003	0.013	-0.002	0.019
40	-0.001	0	0	0.004	0	0.016
41	-0.001	-0.003	0	-0.002	0	0.007
42	-0.001	-0.003	0	-0.004	0	0.013
43	-0.001	0	0	0.004	0	0.015
44	-0.001	0.004	0	-0.003	0	0.014
48	0	0.004	0	0.003	0	0.002
49	0	0.004	0	0.004	0	0.004
50	0	0.004	0	0.004	0	-0.001
51	0	0	0	0.004	0	0.002
58	0	0	0	0	0	0.002
59	0	0	0	0	0	0.002
60	0	0	0	0	0	0
70	0	0	0	0	0	0
99	0	-0.003	0	-0.002	0	0.007
100	-0.002	-0.003	0	-0.001	0	0.001
101	-0.002	-0.003	0	-0.001	0	-0.001
109	-0.002	-0.001	0	-0.001	0	0.004
110	-0.001	-0.001	0	-0.001	0	0.007
111	-0.001	0	0	-0.001	0	0.007
119	0.001	0	0	0	0	0.007
120	0.002	0	0	-0.001	0	0.007
121	0.002	0	0	-0.001	0	0.007
131	0.007	0	0	-0.001	0	0.007

When sustained type of loading is given to the piping system, stress value was recorded with a ratio of 20.8%.

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 31.1. The code stress ratio is 31.7% for piping system with hanger support and 20.8% for piping system with expansion joints and restraints.

IV. CONCLUSION

The analytical study of piping system is done using the power piping code ASME 31.1 and the piping system is modeled and analyzed using CAESAR II platform. From the analysis it can be concluded that displacement in the piping systems with expansion joints are comparatively lower than the piping system with hangers. Hence an expansions joint plays a major role in decreasing the displacement in the linear direction of the pipe routing. It is also observed that when a restraint is connected at the branches of the pipe routing, stress developed is significantly reduced. Since more number of supports may lead to the complication of the pipe routing, it is suggested to use expansion joints and displacements can be reduced significantly. Even though allowable stress in both the cases is within the limits.

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