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FLEXIBILITY ANALYSIS OF BOILER FEED DISCHARGE PIPING FOR SUPER CRITICAL BOILER USING CAESAR II

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ABSTRACT:A steam power plant is housed with various types of equipment like boiler, turbine, heat exchangers etc. These equipment are mainly connected with piping systems. The piping layout design depends upon flexibility analysis (Stress analysis). The title is concerned with design and flexibility analysis of BFP piping system using the software CAESAR II. It mainly deals with effect of flexible supports and material change to ensure the safety of the piping system in supercritical boiler. In this static analysis are carried out and verified with ASME Power Piping Code B31.1. Also thickness calculations are carried out for two materials. The supports are designed and spaced for the proposed system and compared with existing layout.

KEYWORDS:CAESAR II software, flexibility analysis, pipe material and supports, ASME code B31.1.

I. INTRODUCTION

Pipe is conduit that used to transmit medium from one equipment to another equipment. It is used in power plants, petro-chemical industries, and oil and gas industries. The basic types of loads acting on piping system can be as follows:

1) Sustained Loads: These are typically steady or sustained types of loads such as gravitational forces acting on the pipe such as weight of pipe and fluid,dead load and imposed load which causes "failure by collapse".The stress due to this load is called sustained stress.
2) Occasional Loads: This type of loads is imposed on piping systems by occasional events such as earthquake, wind or a fluid hammer. The stress due to this load is called occasional stress.
3) Expansion Loads: These are due to temperature differences in maximum operating and normal ambient temperature which causes "failure by fatigue". The stress due to this load is called thermal stress.

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 and section properties which includes pressure, temperatures and 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.

II. LITERATURE REVIEW

BASAVARAJU (2014) has carried out research on piping systems, supports, materials used, fittings, insulation properties, operating medium in pipe line and analysed the main Stream line of thermal power plant. Hanger is mainly used in the analysis of the piping systems. **M.BALAJI (2016)** researched on piping systems, span length, number of supports, and cost of the piping layout had beenstudiedbyusing CAESER-II software. He optimized the number of supports by changing temperature and pressure within operating medium, density of pipe material and thespan length between the supports.

D.M.AWZE et al studied that by modifying the layout of steam piping system, the pressure drop can be minimized and hence power loss can be minimized in thermal power stations. Due to the layout changes, the hangersupports position also changed.

D.P.VAKHARIAETALresearched 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 with mathematical calculation.

RAMANATHAN et al. (2016) mainly considered the piping supports in industries such as hanger, expansion joints and restraints with an objective of better flexibility and reduced stress.

III. PROBLEM IDENTIFICATION

There is a need for a different boiler technology, which is the critical requirement in the adoption of supercritical pressure. Pressure required in the inlet of the boiler is more than outlet (from boiler to turbine). This is because of consideration of piping major and minor losses. To overcome this losses pressure should be increased by Boiler feed Pump. So the stresses in this BOILER FEED DISCHARGE PIPE line is more. To withstand this stress at the same time providing flexibility to the boiler is a serious issue. Because currently these pipes are supported by bottom load supports. This supports are not flexible in practice and it results in increased stress in the working condition of the pipe. Without periodic maintenance the pipe will fail. To avoid this problem Flexible supports are required with change in material properties.

IV. SOLUTION

The identified flexibility problem is rectified by two techniques

1. Provision of Flexible supports (Hangers)
2. Change of Material

4.1Supports

Supports are a type of elements provided to the piping to resist various loads which are primary, secondary, occasional loads. If the piping is not provided with adequate supports, it will be over-stressed and excessively deform. Over-stressing will cause premature failure. Excessive deformation will impair the performance of the piping. The purpose of support are to:

1) Absorbs system weight
2) Reduce pipe sag
3) Control or direct thermal movement

4.2 Flexible supports

Flexible supports are used where loads are to *be* carried, at the same time, accommodate movement. The movements may be due to the thermal expansion of the piping or connected equipment movements.There are two types of flexible support, they are VLH and CLH.

4.2.1Variable Load Hanger:

Variable load hanger is a special type of hanger, which accommodate the vertical thermal movements, while carrying the vertical load. Usually variable load hangers are made of helical springs. The load varies from cold condition to hot condition. The load variation in the variable load hanger from cold to hot be usually limited to 25%.

Fig 4.1 Variable load hanger

4.2.2 Constant Load Hanger:

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Constant load hanger is a special type of hanger, similar to the variable load hanger. There are several types of constant load hangers. The load variation in the constant load hanger from cold to hot is usually limited to greater than 25%.

Fig 4.1constant load hanger

Flexibility:

Flexiblity is quality of bending easily without breaking.It is inverse of stiffness. Flexibility analysis is the process of checking forces and moments, movements of piping system at the nodal points. This helps the designer to balance the system by adjusting support points on trial and error.

Flexibility $=\delta / P$ (mm / kg)

Where,

P = Load and $\delta = (P \times L^3) / (E \times I)$

Thumb rule for flexibility Analysis:

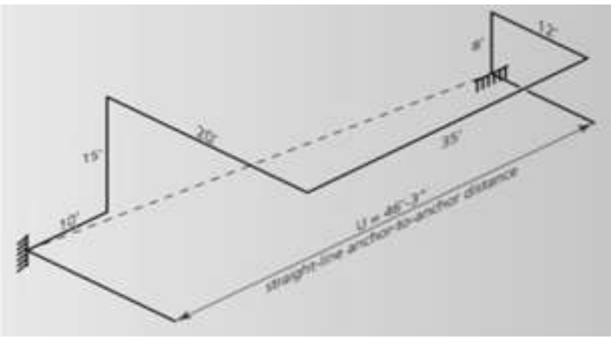


Fig 4.3 Example of flexibility analysis

a) English units:

$$\frac{DY}{(L-U)^2} \leq 0.03$$

If a piping system satisfies the above formula then in it is said to be Flexible.

4.3 Change of material:

The materials used in the project are SA106GrC and SA335P36 which has composition of several elements as per ASME standards listed in the following table

Material	C	Si	Mn	P	S	Ni	Cu	Mo
P36	0.17	0.50	1.20	0.03	0.03	1.30	0.80	0.40
GrC	0.35	0.10	1.06	0.03	0.03			

Table 4.1 Composition of materials

1. Reduction in weight

From the below figure, the pipe geometry requirement for 106GrC is more than P36 when keeping outer diameter as constant. Hence the weight reduction gained for P36 is 30%.

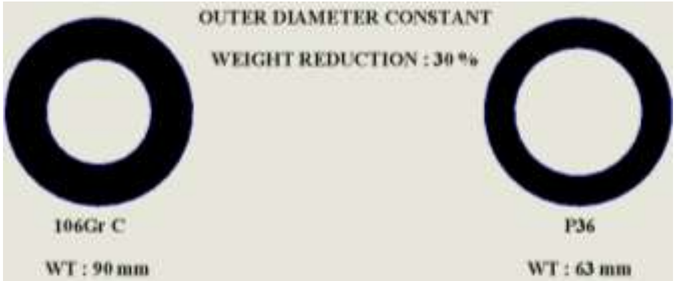


Fig 4.2 Scope of P36

2. Yield strength comparison

From the below graph it clears explains that the yield strength is high for P36 and lower for 106GrC as temperature varies. This increase in yield strength reduce failure by strain providing more flexibility. Hence it is chosen for the BFP pipe line.

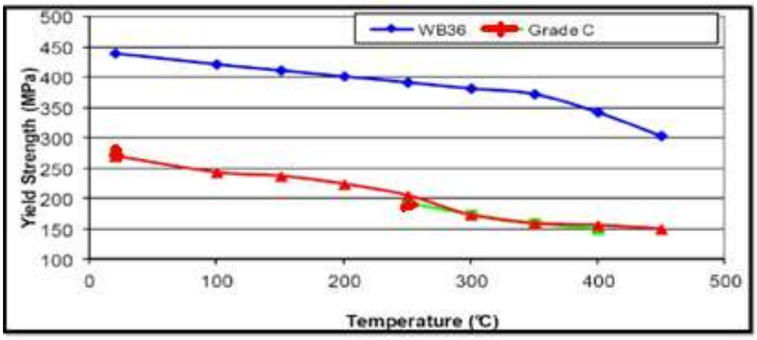


Fig 4.3 Yield strength comparison

V.METHODOLGY

The piping stress analysis is carried out using piping software CAESAR II which is user friendly and easy in inclusion of new material properties. CAESAR II is a computer pipe stress finite element program. This program is used to model pipe systems for electric power, petrochemical, and process industries.

5.1 Analysis Mode in CAESAR:

1. Static analysis (Here the piping system is analysed with the assumption that fluid is static. The analysis is very much useful to check the safety of piping system in both cold and hot condition through the following analysis)
2. Dynamic analysis (In dynamic analysis, flow characteristics of fluid are also given as input and behavior of the system during start-up, shut-down, opening and closing of valves etc are studied. Normally this is done for mainstream and hot reheat lines)

In this paper Static analysis is carried out. Because weight and thermal analysis is highly essential for a safe routing of pipe.

5.2 Existing material:

In the existing system SA106GrC medium carbon steel is used. The displacement and flexible properties are low in that material

5.3 Proposed material:

In this project SA335P36 material is proposed for the boiler feed discharge pipe. We are selecting the material since Low AlloySteel, More Flexibility and less hardness, Welding is easy due to less carbon content(0.17%C), Corrosion resistance is more due to Mn,Si and other Deoxidizing elements, Mo, 0.5%, strength at high temperature 900 °F(482 °C).

5.5 Inclusion of new material in CAESAR II:

The nickel alloy which we selected is not available in CAESAR II package. So we are adding this new material into the material database. Steps to insert a new material in CAESAR II are shown below as images.

Step 1:

Select the tools and then go to material database.

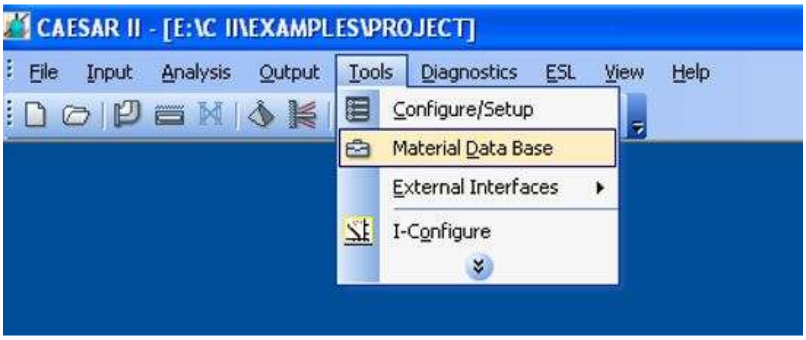


Fig 5.1 New material inclusion step 1

Step 2:

Type the required material property and save the material and then use in CAESAR II for modelling and analysis purpose.

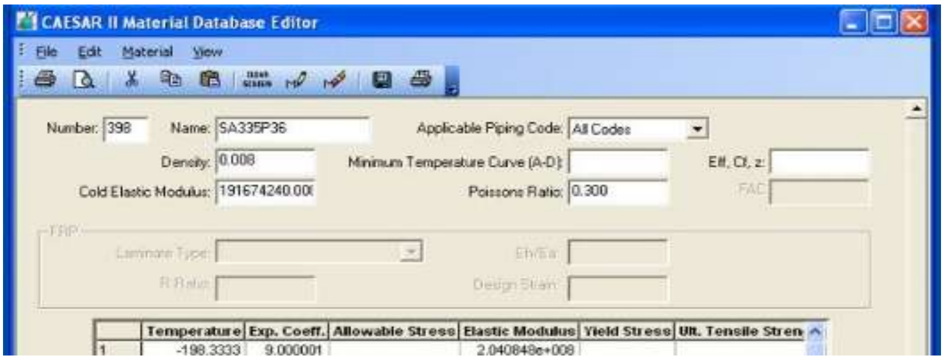


Fig 5.2 New material inclusion step 2

5.4 Design of Hanger support:

5.4.1 Hanger Load calculation

Diameter = 323.9 mm

Thickness = 39 mm

Density of SA335P36 = 0.00775 kg/cm^3 = 7750 kg/m^3

Cross sectional Area of the pipe A= $\pi(D - 1.125t) * 1.125t$

A=$\pi(323.9 - 1.125 * 39) * 1.125 * 39$ = 38597.91168 mm^2

A= 0.03859791168 m^2

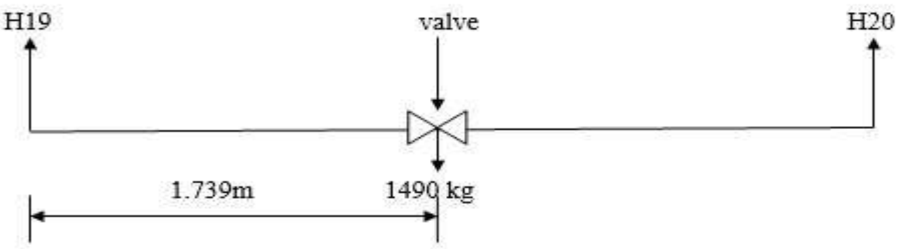
Steel weight $w = Area * Density$

w = 0.03859791168 * 7750 = 299.13381 kg/m.

Hanger Load for Hanger 19

Theoretical Load = L * weight per meter

L= 3.28 m



$H19^{I}$ = 3.28 * 299.13381 = 981.15889 kg.

Total weight of the pipe =299.13381 * 3.380 = 1011.0722 kg,

Total length of the pipe = 3.38 m,

Centre of gravity of the pipe = 1.690 m.

Taking moment about H19 ∑H20 = 0

(H19*3.380) – (1.641*1490) – (1.690*1011.0722) = 0

$H19^{II}$ = 1228.9355 kg.

Total Hanger Load H19 = $H19^{I}$ + $H19^{II}$ = 2210.094 kg.

5.4.2 Thermal movements

According to ASME II Part D,

Coefficient of thermal expansion for low alloy steel at 200^{0}C = 0.0033mm/mm ^{0}C

Thermal Movement = 0.0033 * 3380 =10.84mm.

According to Hanger Table

For Load group 80

Travel of hanger 15 mm, stiffness = 39.38 kg/mm.

Difference of theoretical and actual load Δw = 39.38 * 10.84 = 426.8792 kg.

Δw/w = 426.8792 / 2210.094 = 18 .02 %.

As obtained percentage is less than 25 %, VLH selected.

5.5 THICKNESS CALCULATION

Pressure, P = 46091.0156 Kpa
Efficiency of weld, E = 1

Table 9.4 Dimensionless factor varies with temperature

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VALUES OF y

Temperature, °F	900 and Below	950	1000	1050	1100	1150	1200	1250 and Above
Temperature, °C	482 and Below	510	538	566	593	621	649	677 and Above
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
Nickel Alloys UNS Nos. N08800, N08810, N08825	0.4	0.4	0.4	0.4	04	0.4	0.5	0.7

Dimensionless factor, y = 0.4(from the above ASME section II, Part A)
Allowable stress, S = 120658.2 Kpa (for SA106 GrC)
Allowable stress, S = 301990.3 Kpa(for SA106 P36)
t = (P*D) / (2SE+Py) As per ASME B31.1
SA106 GrC
t = (46091.0156*323.9) / (2*120658.2*1+46091.0156*0.4) = 55.47mm
SA335 P36
t = (46091.0156*323.9) / (2*301990.3*1+46091.0156*0.4) = 38mm
Therefore weight reduction achieved is 31.5% , hence it is used for BFP line.

5.6 Design of Boiler Feed Discharge pipe in CAESAR:

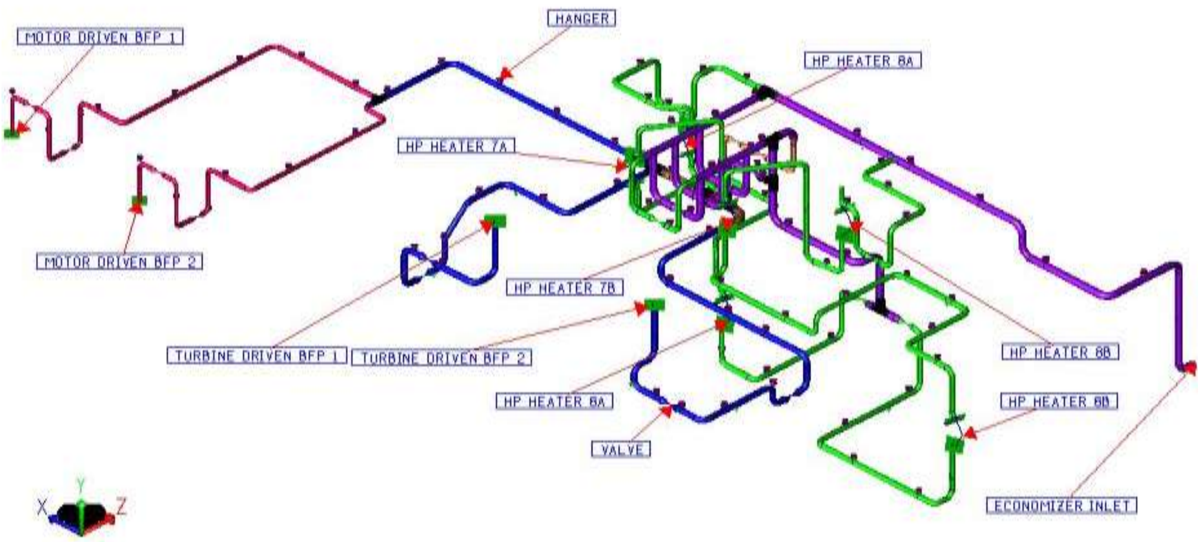

Fig 5.3 Design of BFD pipe

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5.6.1 Parameters used for designing the layout in CAESAR II:
Pipe
Geometric properties: Dia x thickness

NOTATION	EXISTING PARAMETER (Dxt) mm	PROPOSED PARAMETER (Dxt) mm
	Φ 323.9x56	Φ 323.9x39
	ϕ 350x64	ϕ 350x45
	Φ 400x56	Φ 400x39
	Φ 450x82	Φ 450x57
	Φ 550x70	Φ 550x49
	Φ 650x116	Φ 650x81

Material of the pipe:

EXISTING MATERIAL	PROPOSED MATERIAL
SA106 GrC	SA335 P36

Bend and elbow radius: 1.5D
Pipe density:

SA106 GrC	SA335 P36
0.00783 kg/cm^3	0.00775 kg/cm^3

Poisson's ratio: 0.300
Fluid and operating parameters
Working pressure: 470 kg/cm2
Working temperature: 2000 C as per IBR
Hydro Test Pressure: 705 kg/cm2 (g)

VI.CAESAR II REPORT

6.1 Existing Method report

The displacements , stress reports are being listed below and taken for comparison

6.1.1 Displacement report

NODE	DX mm.	DY mm.	DZ mm.	RX deg.	RY deg.	RZ deg.
10	0.000	-0.000	-0.000	-0.0000	-0.0000	-0.0000
18	0.445	6.439	-0.579	-0.0119	-0.0035	-0.0085
19	0.182	7.193	-0.648	-0.0083	-0.0039	-0.0054
20	-0.545	7.518	-0.688	-0.0034	-0.0036	-0.0010
30	-2.193	7.482	-0.717	0.0069	0.0006	0.0054
40	-4.743	7.377	-0.706	0.0070	0.0006	0.0054
48	-6.168	7.306	-0.637	0.0159	0.0133	0.0081
49	-6.882	6.949	-0.583	0.0212	0.0237	0.0106
50	-7.120	6.185	-0.654	0.0253	0.0358	0.0128

6.1.2**Code compliance report: code stresses on elements**
CASE 4 (OPE) W+T1+P1+H
CASE 5 (SUS) W+P1+H
CASE 6 (EXP) L6=L4-L5
Piping Code: B31.1 -2004, August 16, 2004

***** CODE COMPLIANCE EVALUATION PASSED *****
Highest Stresses: (Kpa)
Code Stress Ratio is 55.3 at Node 1490 LOADCASE: 5 (SUS) W+P1+H
Code Stress: 66678.3 Allowable: 120658.2
Axial Stress: 58733.4 @Node 1470 LOADCASE: 5 (SUS) W+P1+H
Bending Stress: 31774.9 @Node 750 LOADCASE: 6 (EXP) L6=L4-L5
Torsion Stress: 9953.5 @Node 1690 LOADCASE: 6 (EXP) L6=L4-L5
Hoop Stress: 134980.4 @Node 1280 LOADCASE: 4 (OPE) W+T1+P1+H
3D Max Intensity: 207581.3 @Node 1450 LOADCASE: 4 (OPE)

6.2 Prosed method report:

The displacements , stress , hanger support table reports are being listed below and taken for comparison.

6.2.1 Displacement report

NODE	DX cm.	DY cm.	DZ cm.	RX deg.	RY deg.	RZ deg.
10	0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000
18	0.0368	0.5782	-0.0441	-0.0083	-0.0028	-0.0070
19	0.0124	0.6455	-0.0484	-0.0036	-0.0025	-0.0028
20	-0.0534	0.6730	-0.0502	0.0011	-0.0012	0.0032
30	-0.2014	0.6647	-0.0504	0.0101	0.0022	0.0082
40	-0.4303	0.6486	-0.0461	0.0102	0.0023	0.0082
48	-0.5582	0.6393	-0.0386	0.0180	0.0127	0.0096
49	-0.6217	0.6058	-0.0332	0.0215	0.0245	0.0125
50	-0.6411	0.5365	-0.0399	0.0250	0.0348	0.0153

6.2.2Code compliance report: code stresses on elements
CASE 4 (OPE) W+T1+P1+H
CASE 5 (SUS) W+P1+H
CASE 6 (EXP) L6=L4-L5
Piping Code: B31.1 -2004, August 16, 2004
*** **CODE COMPLIANCE EVALUATION PASSED** ***
Highest Stresses: (KPa)
Code Stress Ratio is 37.3 at Node 1490 LOADCASE: 5 (SUS) W+P1+H
Code Stress: 112823.6 Allowable: 301990.3
Axial Stress: 97112.6 @Node 1470 LOADCASE: 5 (SUS) W+P1+H
Bending Stress: 26302.5 @Node 750 LOADCASE: 6 (EXP) L6=L4-L5
Torsion Stress: 7686.1 @Node 1690 LOADCASE: 6 (EXP) L6=L4-L5
Hoop Stress: 212582.6 @Node 1280 LOADCASE: 4 (OPE) W+T1+P1+H
3D Max Intensity: 284026.1 @Node 1450 LOADCASE: 4 (OPE)

6.2.3 Hanger table:

NODE	NO REQD	FIG. NO.	SIZE	VERTICAL MOVEMENT (mm.)	HOT LOAD (N.)	THEORETICAL INSTALLED LOAD (N.)	ACTUAL INSTALLED LOAD (N.)	SPRING RATE (N./cm.)	HORIZONTAL MOVEMENT (mm.)
BFPD-H19	1	0080	10	0.673	19901.	21551.	0.	2452.	0.073
BHEL					LOAD VARIATION =	8%			
BFPD-H20	2	0080	9	0.323	15690.	16185.	0.	1533.	0.618
BHEL					LOAD VARIATION =	3%			
BFPD-H21	2	0080	8	0.458	11795.	12245.	0.	981.	0.471
BHEL					LOAD VARIATION =	4%			
BFPD-H22	1	0080	10	0.862	21484.	23598.	0.	2452.	0.585
BHEL					LOAD VARIATION =	10%			
BFPD-H23	1	0080	9	1.316	17267.	19283.	0.	1533.	3.562
BHEL					LOAD VARIATION =	12%			
BFPD-H24	1	0080	9	1.465	15296.	17542.	0.	1533.	7.264
BHEL					LOAD VARIATION =	15%			
BFPD-H25	1	0080	9	1.473	15918.	18176.	0.	1533.	8.613
BHEL					LOAD VARIATION =	14%			
BFPD-H26	1	0080	8	1.336	8685.	9995.	0.	981.	7.958
BHEL					LOAD VARIATION =	15%			

VII.COMPARISON OF RESULT

Fig 7.1 Code stress ratio

Code stress is reduced to 1/3rd of its allowable stress by SA335P36 which is far lesser than allowable stress of SA106GrC.

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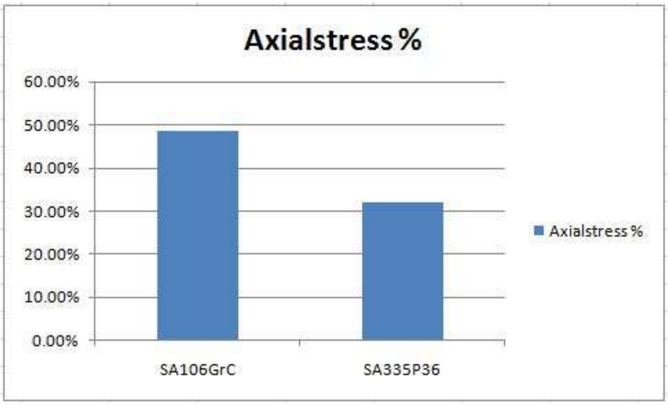

Fig 7.2 Axial stress

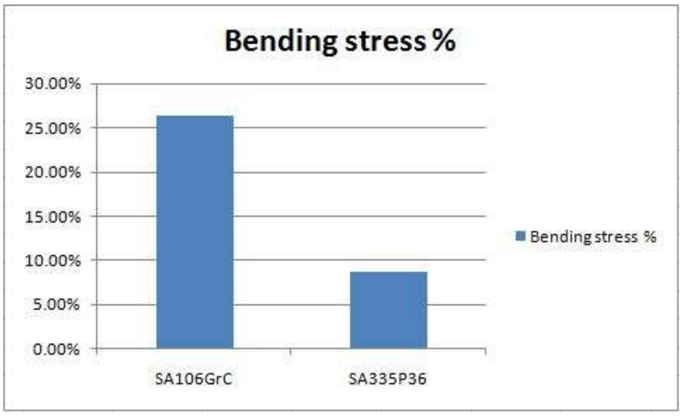

Fig 7.3 Bending stress

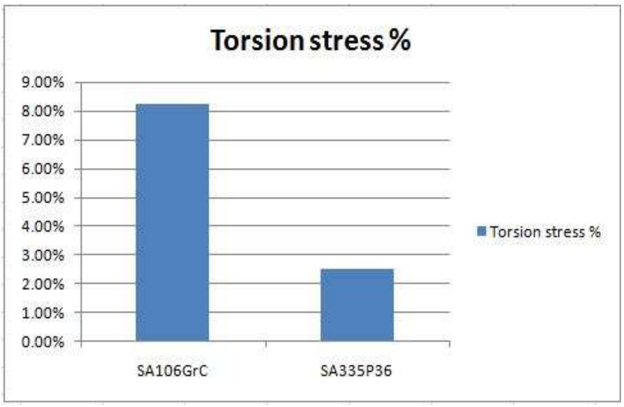

Fig 7.4 Torsion stress

The axial, bending, torsional stresses are also given the same result.

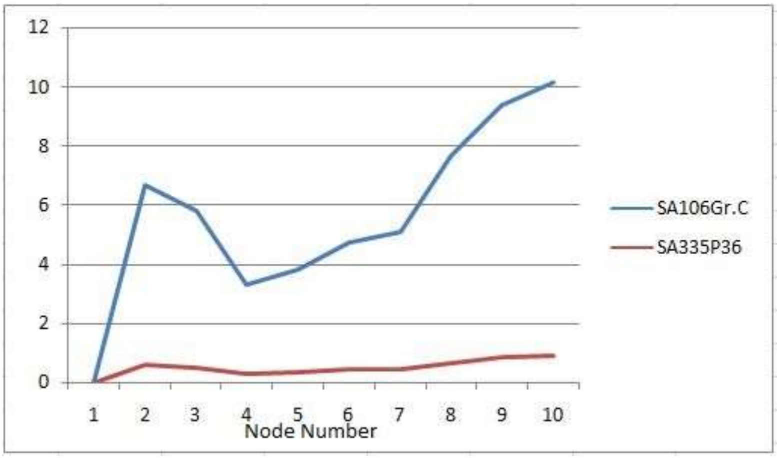

Fig 7.5 Displacement result

The displacement report shows a drastic change in movement of pipes. For the SA106GrC the displacement is more because of rigid supports with lower flexible material. SA335P36 attained a good movement resisting property with flexibility at the same time.

VIII.CONCLUSION

Thus the flexibility analysis for the given design of the boiler feed discharge piping system for the supercritical boiler is performed in CAESAR II with two materials and support and the results are tabulated. The code stresses in the system are within the allowable limits as per ASME B31.1 power piping code for static load cases also verified. The restraint summary report, displacement report and hanger report are attached above. It is found from the analysis that stress induced in piping system due to pressure rise are reduced to 1/3rd of allowable stress for P36 when compared to 106GrC. This stress reduction is due to thickness variation of pipe. Therefore the stress reduction enhances the safety piping and effectiveness of system which is achieved by the provision of flexible support. From the result it clearly explains us for supercritical boiler BFP line P36 material is superior to 106GrC in all the way.

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