

Design and Optimization of Power and Process, Refrigeration and Oil Piping with Respect To the Failures of Piping by Final Run, Weight Run and Thermal Run

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ABSTRACT:The work is to optimize the types and number of hangers and restraints of the piping layout by classifying the various piping as thermal run, weight run, and final run using CAESAR-II. The geometrical properties such as diameter, thickness, and span length were kept constant during the design and analysis of the piping layout. The type of restraint is optimized by studying the report of each type of piping namely thermal-run, weight-run, and final-run. The variation of the pipe material density with respect to the change of pressure and temperature of the operating medium, which leads to the linear and lateral deformation and stress development in the piping, was used to vary the type of restraint between the supports. The number of supports is optimized by the CAESAR-II, and STADD-PRO reports. The material chosen is verified by the ASME (SECTION II) formula and X-STEEL package.

KEYWORDS: Thermal run, Weight run, Final run, Operating Medium, Pressure, Temperature, CAESAR-II.

I. INTRODUCTION

Piping is the engineering related to a structure which transfers a vast amount of fluid from one place to another through pipes made of alloy steel, non-ferrous alloys or composites. The transferring pipe carrying the fluid is subjected to many loads such as thermal load, shock load due to bend or mixing, structural load or it may be loaded due to the fluid density. The parameters involved in the piping engineering (other than the pipe dimensions) are material properties of the pipe, fluid pressure, temperature and density, flow properties of the fluid, all types of loading acting on the pipe and fluid, number and type of supports and restraints provided to the piping.

II. PROBLEM DEFINITION

The failures occurring in various piping can be classified as:

1. Failure by Thermal-Run
2. Failure by Weight-Run
3. Failure by Final-Run

The thermal-run is the piping which fails due to thermal load acted on the pipeline by the fluid. The flow of the fluid in a thermal run piping will be one dimensional, and the temperature of the flowing media is higher than the atmospheric temperature due to the increase in fluid velocity through bends in piping leading to rising in temperature by the fluid collision. Such piping is common in all petrochemical, oil and gas industries where diameter, thickness and insulation thickness of the piping is very low compared to the length of piping. Also, the thermal conductivity of the piping is very high compared to the tensile strength and Young's modulus.

The Weight-run is the piping which may fail due to the weight of the fluid being abnormal to the structure and support of the piping. The routing will be two dimensional, and there will be more branches instead of a long piping

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structure. The flow will be lateral and transverse in direction. A weight run failure may be observed as the cracking at the supports due to overloading the piping. Weight run piping is common in refrigeration piping.

The Final run-piping is the one which may fail due to any of the reasons mentioned above, i.e., thermal load or weight or both. In final-run piping, there will be three-dimensional fluid flows in lateral, linear and transverse directions. Therefore final run piping is found in process industries and power industries.

III. DESIGN STEPS FOR PIPING

Any piping design involves the following processes in general:

- (i) The first step is the material selection. The material for the required piping is selected with the help of X-STEEL software. Also, the ASME Section II provides a formula for calculating the ultimate strength of steels,
 - a. For carbon steel,
Ultimate tensile strength= $19.1[15.4 + (1.8\%Mn) + (5.4\%Si) + (0.25\%pearlite) + (0.5d^{1/2})]$
(Where d is the grain diameter of the material)
 - b. For alloy steel,
Ultimate tensile strength= $90 + 1000[(\%C) + (45\%Mn) + (75\%Si) + (31\%Cr) + (30\%Ni)]$

Thus the material selection is assured with help of X-STEEL software and ASME (SECTION II) formula.

- (ii) The next step is the piping design. For this step, CAESAR-II software is used. CAESAR-II is the software which enables the design and analysis of systems with more number of elements having a very high length w.r.to cross-section. Hence it is preferred for piping design and analysis. For study purpose the version has some restrictions, so the dimensions of piping are 114mm diameter, 4.5mm thick (for oil piping) and 9.5mm thick (for power and process piping). Also, for study version, the number of routings is limited with 20.
- (iii) The third step is piping design for supports. Based on the given piping diagram a piping engineer optimizes the location of the supports using STADD-PRO software so that no excess money is wasted by providing unwanted supports. This software is used to find the ideal place to fix the supports, i.e., the points where excess/failure load acts. Thus the determination of an ideal number of supports is proved by STADD-PRO software.
- (iv) The final step is to prove the selection of welding method. For this, ANSYS 14.5, well-known software for analysis, is used. From the ANSYS report if any welding defects were found, then it should be rectified. For hot cracking defect, uniform heating with asbestos sheet on top is employed; For loss of alloying element while welding, stabilizing elements like Ti, Zr, Nb and Be are added along with welding rod; For shrinkage defect, hammering and peening should be done once in 400 mm of the weld; While welding copper, Si and Ph are to be added to avoid oxidation of Cu. Also, a preheating of the weld zone to 150-2000C is recommended for welding Cu and Cu alloys.

Thus, in the piping design, each and every process is proved and satisfied to the client and then only fabricated.

IV. SOLUTION TO THE PROBLEM

IV.I. THERMAL RUN

For the thermal run failure, an expansion joint is provided along the length of the piping, and no anchor is provided on the route where the expansion joint is provided. If in the route of the expansion joint, an anchor is provided, then its expansion will be arrested by the anchor and thereby the pipe crack and fail. An expansion joint is the sub-element of the route which is a different material than that of the piping. Normally low thermal expansion and high thermal conducting material like copper and its alloys in the form of bellow tube act as the expansion joint. Its selection is verified by CAESAR-II. Further, restraints like Y, +Y, GUIDE, etc. are provided to withstand the weight of piping and the fluid. Depending upon the load acting on the piping, the choice of restraint is made. Nozzle and anchor should be provided only at the end of piping, if required.

For the piping shown below, the code is **B31.4 (Oil piping)**. The material chosen is SA 106 B, whose strength is verified by ASME (SECTION II) formula and the selection is made with the help of X-STEEL package. The arrowed

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image is used for support notation, a square plate for anchor and green or yellow bellow like an image for expansion joint.

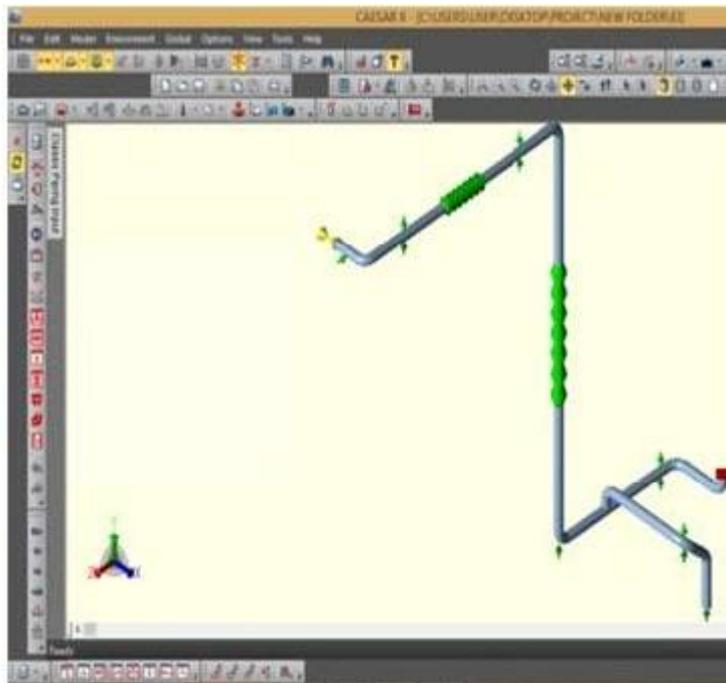


Fig 1: Thermal-Run piping

For the above pipe routing, the report was obtained, and the results are satisfactorily found to be ok and the CAESAR-II report is shown below.

TABLE 1: Thermal-Run report

Node	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
10	0	0	0	0	0	0
20	0	0.0022	0	0	0	0
28	0	0.0124	-0.0002	-0.0006	0	0
29	0	0.0876	-0.019	-0.0975	0	0
30	0	0.1846	0.0022	-0.0894	0	0
38	0	0	0.0046	-0.893	0	0
39	0	0	0.0655	0.0072	0	0
40	0	0	0.0379	0.1188	0	0
48	0	0	-0.2384	0.1168	0	0
49	0	0	-0.2455	-0.0479	0	0
50	0	0	-0.1651	-0.1366	0	0
55	0	0	-0.1502	-0.1364	0	0
58	0	0	-0.0931	-0.1348	0	0
59	0	0	-0.0192	-0.0384	0	0
60	0	0	0.0068	0.0053	0	0
70	0	0	0	0	0	0
80	0	0	0	0	0	0

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IV.II. WEIGHT RUN

For weight run piping, we have to reduce the various displacements, forces and moments, acting on the piping due to either fluid movement or the weight of fluid and piping. So restraints and anchors are the best suitable for weight run piping. Common restraints available in CAESAR-II for weight run piping are X, Y, Z, +X, +Y, +Z, 2X, 2Y, 2Z, X/2, Y/2, Z/2 (where X, Y, and Z denote the direction to be arrested) and anchor. The support location is optimized using both STADD-PRO and CAESAR-II. For weight run piping showed below, the pipe code is **B31.5 Refrigeration piping, and the material is SA 213 TP 301.**

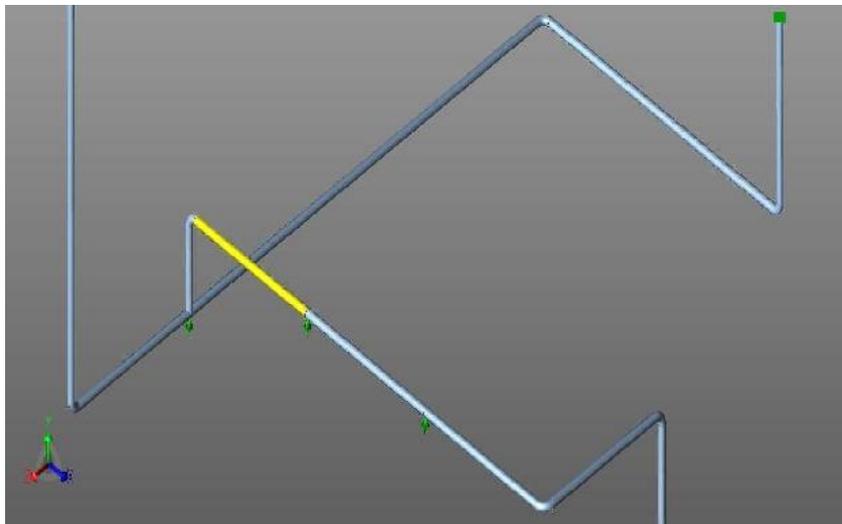


Fig 2: Weight Run piping

To reduce bend in very long piping horizontal and vertical guides may also be used. The CAESAR-II report for the above weight run piping is as below:

TABLE 2: Weight Run report

Node	fx N	fy N	fz N	mx N.m	my N.m	mz N.m
12	61	-208	-1982	471	-3835	-356
14	61	-208	1783	471	5364	437
14	4540	165	5	95	21	-528
25	122	-65	-1621	545	-3025	-137
198	-2065	-166	-5	-95	-59	1770
210	-165	5	-2175	-60	-2677	30
220	-10595	-165	5	30	71	1547
298	-2063	-164	2	37	61	1755
299	-1547	-2	1315	70	-1682	18
300	-164	-2	1984	62	-1473	-36
310	-164	-2	-2176	62	-2677	-13
320	-10597	-164	-2	-13	14	1491

Only at two nodes namely 220 and 320, there is a high force of about 10600N in the negative X direction which is rectified by providing a '+X' restraint.

IV.III. FINAL RUN

For a final run piping where displacement, stress, and forces all the three have to be reduced. Thus apart from the supports mentioned above, restraints and anchor a hanger is needed to allow displacement up to a limited value

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(obtained from STADD-PRO and CAESAR-II reports) and thereby reduce piping stresses. For the final run piping, the piping code is **B31.1 Power piping (Boiler), and Process piping** and the material chosen is alloy steel: SA 335 P22.

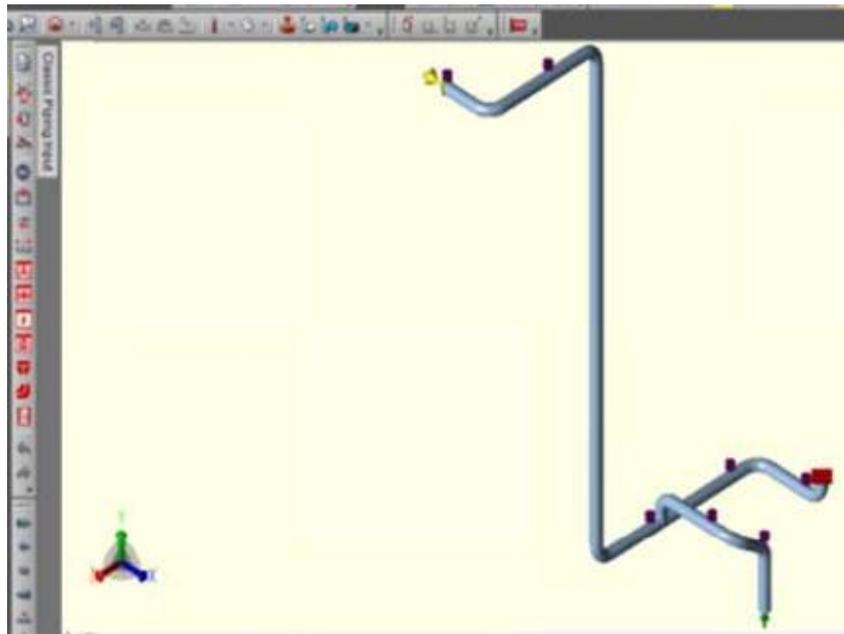


Fig 3: Final run piping

In the above piping, the hanger is indicated by the violet colour spring like image (Standard notation for hanger in CAESAR-II). For final run piping we have to get three reports namely stresses, local element forces and the displacements, since we have to make the piping ok by reducing all the three values to a negligible value.

CAESAR II 2011 Ver.5.30.0, (Build 101122) Date: AUG 31, 2017 Time: 16:13
Job: Z:\CAESAR II\HANGER EXAMPLE
Licensed To: Demonstration Version -- ID #0
LOCAL ELEMENT FORCES REPORT: Forces on Elements
CASE 4 (SUS) W+P1+H

TABLE 3: Final Run report 1

NODE	DX mm	DY mm	DZ mm	RX deg.	RY deg.	RZ deg.
10	-89.406	-4.154	0.000	0.1902	-0.0001	-0.2853
18	-108.566	-4.150	-12.776	0.1902	-0.0001	-0.2853
19	-109.102	-4.372	-13.134	0.1902	-0.0001	-0.2863
20	-109.326	-4.914	-13.281	0.1902	-0.0001	-0.2923
25	-109.326	-21.157	-13.275	0.1902	-0.0001	-0.6036
28	-109.326	-55.502	-13.269	0.1902	-0.0001	-0.9979
29	-109.326	-57.288	-13.269	0.1753	-0.0001	-1.0499
30	-109.326	-57.800	-13.269	0.1641	-0.0001	-1.0692
35	-109.320	-49.259	-13.269	0.2770	-0.0001	-1.2989
37	-109.317	-43.916	-13.269	0.1914	-0.0001	-1.2989
38	-109.314	-41.124	-13.269	0.1212	-0.0001	-1.2989
39	-110.325	-40.904	-13.359	0.1151	-0.0001	-1.2989
40	-112.768	-40.815	-13.574	0.1142	-0.0001	-1.2989
50	-199.997	-40.819	-21.243	0.1142	-0.0001	-1.2989
349	-65.191	-49.261	-1.600	0.4467	-0.0001	-1.4380
350	-62.435	-48.111	-0.695	0.5062	0.0174	-1.4952
351	-61.255	-45.242	-0.238	0.5305	0.0350	-1.5539

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NODE	DX mm	DY mm	DZ mm	RX deg.	RY deg.	RZ deg.
355	-61.255	-0.000	0.738	0.7212	0.0350	-1.6933
359	-61.255	17.941	1.103	0.7926	0.0350	-1.7479
360	-59.857	21.292	1.807	0.8169	0.0525	-1.8198
361	-56.362	22.729	3.446	0.8764	0.0701	-1.8919
369	-15.707	22.729	22.872	0.9862	0.0701	-2.0060
370	-11.921	23.534	24.789	1.0553	0.0519	-2.0678
371	-10.376	25.586	25.629	1.1230	0.0336	-2.0930
379	-11.371	60.500	25.629	1.2144	0.0336	-2.3034
380	-13.251	62.790	24.680	1.2192	0.0519	-2.3286
381	-17.734	63.740	22.385	1.2199	0.0701	-2.3904
389	-90.852	63.744	-13.709	1.2199	0.0701	-2.5522
390	-95.716	65.770	-15.949	1.2199	0.0701	-2.6232
391	-97.778	70.770	-16.767	1.2199	0.0701	-2.6876
395	-97.778	106.099	-15.853	1.2199	0.0701	-2.7147
400	-97.778	148.711	-14.751	1.2199	0.0701	-2.7122

CAESAR II 2011 Ver.5.30.0, (Build 101122) Date: AUG 31, 2017 Time: 16:13

Job: Z:\CAESAR II\HANGER EXAMPLE

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LOCAL ELEMENT FORCES REPORT: Forces on Elements

CASE 4 (SUS) W+P1+H

TABLE 4: Final Run report 2

NODE	fx N	fy N	fz N	mx N.m	my N.m	mz N.m
10	-0	0	-0	-0	0	0
18	-666	-0	0	0	0	0
19	-485	-0	485	0	30	-0
20	-0	-0	707	0	105	-0
20	0	-0	707	-0	105	-0
25	-0	0	-1113	0	-2242	0
25	0	-0	-865	-0	2242	-0
28	-0	0	459	0	-689	0
29	-0	438	-0	467	0	439
30	0	-0	-417	-621	-66	-0
35	540	0	-0	-0	758	621
349	-220	0	-0	0	758	621
350	-141	-0	141	-536	630	-536
351	-0	-0	179	-758	651	-0
355	-0	-0	-97	-758	716	0
359	-0	-0	57	-758	781	0
360	-26	0	-26	-536	-786	536
361	-16	0	0	-0	-787	758
369	191	0	-0	-0	758	787
370	150	0	-150	557	749	557
371	0	-0	232	-787	-725	-0
379	-0	0	-525	787	82	0
380	-386	0	-386	557	25	-557
381	-567	0	-0	-0	-0	-787
389	-860	0	0	-0	-0	-787
390	-623	0	623	-0	-748	0
391	0	-0	902	0	-652	-0
395	0	0	-156	0	70	-0
400	0	-0	-0	-0	-0	-0
35	0	0	-529	0	-189	0
37	-0	0	-745	-0	-986	0
38	0	-0	-707	0	105	-0
39	-485	-0	-485	0	30	-0
40	-666	-0	-0	0	0	0

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NODE	fx N	fy N	fz N	mx N.m	my N.m	mzN.m
50	0	0	0	0	0	0

CAESAR II 2011 Ver.5.30.0, (Build 101122) Date: AUG 31, 2017 Time: 16:13

Job: Z:\CAESAR II\HANGER EXAMPLE
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STRESSES REPORT: Stresses on Elements

CASE 4 (SUS) W+P1+H

```

Piping Code: B31.1 = B31.1 -2008, June 9, 2008
CODE STRESS CHECK PASSED : LOADCASE 4 (SUS) W+P1+H
Highest Stresses: (N/mm2)
CodeStress Ratio (%): 94.1 @Node 25
Code Stress: 110.9 Allowable: 117.9
Axial Stress: 56.4 @Node 40
Bending Stress: 55.4 @Node 361
Torsion Stress: 9.7 @Node 371
Hoop Stress: 116.7 @Node 18
3D Max Intensity: 196.7 @Node 371
    
```

TABLE 5: Final Run report 3

NODE	Bending Stress N/mm2	Torsion Stress N/mm2	SIF In Plane	SIF Out Plane	Code Stress N/mm2	Allowable Stress N/mm2	Ratio %	Piping Code
10	0.00	-0.00	1.000	1.000	55.94	117.90	47.44	B31.1
18	0.00	-0.00	2.068	2.068	55.94	117.90	47.44	B31.1
19	1.54	0.00	2.068	2.068	57.09	117.90	48.42	B31.1
20	5.35	0.00	2.068	2.068	59.95	117.90	50.85	B31.1
25	54.98	0.00	1.000	1.000	110.92	117.90	94.08	B31.1
28	34.93	-0.00	2.068	2.068	82.14	117.90	69.66	B31.1
29	22.25	5.72	2.068	2.068	80.31	117.90	68.11	B31.1
30	3.34	7.62	2.068	2.068	79.70	117.90	67.60	B31.1
35	53.81	-0.00	2.239	2.239	96.30	117.90	81.67	B31.1
349	24.03	0.00	1.000	1.000	79.97	117.90	67.83	B31.1
350	41.96	-6.57	2.068	2.068	93.44	117.90	79.25	B31.1
351	33.00	-9.29	2.068	2.068	93.94	117.90	79.67	B31.1
355	17.56	-9.29	1.000	1.000	81.51	117.90	69.13	B31.1
359	19.15	-9.29	1.000	1.000	82.63	117.90	70.08	B31.1
360	48.26	-6.57	2.068	2.068	97.48	117.90	82.68	B31.1
361	55.44	-0.00	2.068	2.068	97.52	117.90	82.71	B31.1
369	26.80	-0.00	1.000	1.000	82.74	117.90	70.18	B31.1
370	47.33	6.83	2.068	2.068	97.28	117.90	82.51	B31.1
371	36.76	9.66	2.068	2.068	96.65	117.90	81.98	B31.1
379	2.02	9.66	1.000	1.000	75.36	117.90	63.91	B31.1
380	28.27	6.83	2.068	2.068	85.91	117.90	72.87	B31.1
381	39.94	-0.00	2.068	2.068	85.90	117.90	72.85	B31.1
389	39.94	0.00	2.068	2.068	85.90	117.90	72.85	B31.1
390	37.97	0.00	2.068	2.068	84.41	117.90	71.59	B31.1
391	16.00	0.00	1.000	1.000	71.94	117.90	61.01	B31.1
395	1.72	0.00	1.000	1.000	57.66	117.90	48.90	B31.1
400	0.00	-0.00	1.000	1.000	55.94	117.90	47.44	B31.1
35	10.39	0.00	2.239	2.239	63.74	117.90	54.06	B31.1
37	24.17	-0.00	1.000	1.000	80.11	117.90	67.95	B31.1
37	24.17	0.00	1.000	1.000	80.11	117.90	67.95	B31.1
38	2.59	-0.00	1.000	1.000	58.53	117.90	49.64	B31.1
38	5.35	0.00	2.068	2.068	59.95	117.90	50.85	B31.1
39	1.54	-0.00	2.068	2.068	57.09	117.90	48.42	B31.1
40	0.00	0.00	2.068	2.068	55.94	117.90	47.44	B31.1
50	0.00	0.00	1.000	1.000	55.94	117.90	47.44	B31.1

For final run piping alone the number of nodes has been increased by splitting the pipe for every 1m length to get a better result and thereby increase the safety of piping. A hanger is capable of reducing the displacement by deforming itself (spring action) and thereby the stress in the piping due to the displacement is reduced to a very negligible value.

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Thus with the help of hanger, the stress is far reduced than the allowable stress value as evident from the above CAESAR-II report, and the piping is made completely ok for manufacturing.

V.CONCLUSION

Thus the piping can be broadly categorized as thermal run, weight run and final run corresponding to the oil piping, refrigeration piping and power and process piping respectively. By this kind of classification, we can easily apply the respective supports, hangers, and restraints only for the corresponding piping. By this optimization work, it is evident that use of support is sufficient for weight run and thermal run piping instead of using a hanger which is highly expensive one. For final run piping alone a hanger may be used to reduce stress, displacement and forces. Thereby the cost of the piping is also optimized to an economic one. This kind of optimization by the combination of four softwares namely CAESAR-II, STADDPRO, X-STEEL, and ANSYS will be error-free, and it ensures satisfaction to the client of piping.

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