Structural analysis and Design modification of The Compressor Skid of Helium Liquifier Plant

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Abstract

Now days, Compressors are widely used in gas gathering, gas processing, and gas storage, chemical and refining applications. Compressors are mounted on the its support structure(skid) to carry its weight, to maintain its alignment and to assist in carrying the different static and dynamic loads . So, maximum stress, maximum shear stress and deflection are important criteria for the design of the skids. This report is the work performed towards the optimization of the compressor skid with constraints of maximum shear stress, equivalent stress and deflection of skid under maximum load. . This paper represents a case study of the compressor skid of Helium Liquifier/Refrigeration(HRL) plant In IPR(Institute of Plasma Research) on which high speed, oil injected, rotory, single stage gas compressors are mounted. By using FEA tool approach is made for the investigations of critical stresses.

Structural systems like the skid can be easily analyzed using the finite element techniques. A sensitivity analysis and taguchi method is is carried out for Higher life span and weight reduction. So a proper finite element model of the skid is to be developed. The skid is modeled in Solid works2011. FEA is done on the modeled chassis using the ANSYS11 Workbench ,and validates all result by structrural software STAAD.ProVi8, which include, Indian and global codes.

***Keywords:-*Compressor skid Design , Static and Dynamic loading, Sensitivity analysis , Taguchi's optimization , STAAD –ProVi8 validation.**

1. INTRODUCTION

The skid frame consists of the space frame with I channel Section,and eight support strut with hollow square section,placed at the equal span. Stress analysis using Finite Element Method (FEM) can be used to locate the critical point which has the highest stress. This critical point is one of the factors that may cause the fatigue failure. The magnitude of the stress can be used to predict the life span of the skid. So,it shoud be reduced .

A.J. Smalley et.al. has given the idea about various loads coming on the compressor base frame . John P. Harrell has given the idea about the advantages of the skid mounted compressor. The primary advantage of skid mounting is portability and the ability to perform all the necessary integration of engine and compressor.Kishor D.Jadhav et. al. give brief idea for compressor skid of reciprocating compressor,and Patel Vijaykuamr V.et.al give idea about the optimization and reduction in stress,deformation.[6][7][8]

2. Arrangement of component ,material property and Load calculation of skid

A. Arrangement of component

HRL plant have three compressor and motors are placed parallel on main skid,and oil pump,oil cooler is placed on the base frame,For higher capacity plant , it should keep the same arrangement and same position of exsisting one.

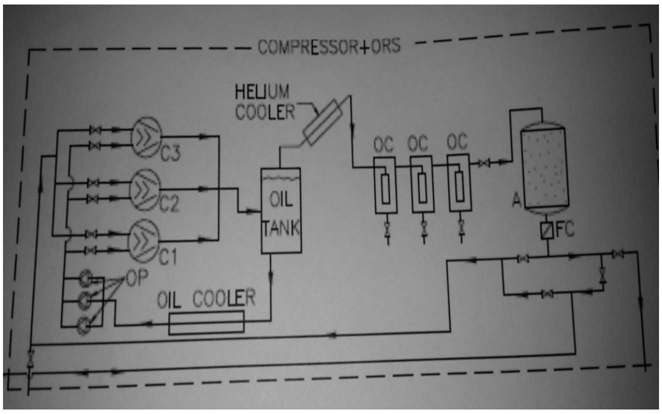


Fig. 1 Line dia.of Compressor and oil removal system (ORS) system of IPR

B. Material of skid

Material is given as a input parameter is A36 Carbon Steel.

TABLE I Physical and Mechanical Property of A36 Carbon steel[2]

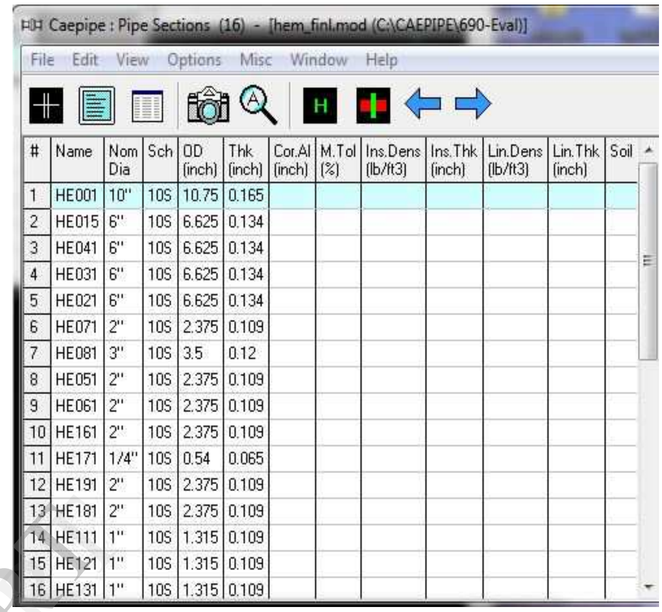
Properties	Metric	Comment
Density	7.85 g/cc	
Tensile Strength, Ultimate	400 - 550 MPa	
Tensile Strength, Yield	250 MPa	
Elongation at Break	20.0 % 23.0 %	in 200 mm In 50 mm.
Modulus of Elasticity	200 GPa	
Compressive Yield Strength	152 MPa	Allowable compressive strength
Bulk Modulus	140 GPa	Typical for steel
Poissons Ratio	0.260	
Shear Modulus	79.3 GPa	

C. Load calculations

TABLE II Weights of different components of skid

Component name	specification	Weight(kg)
compressor	C100A,B,C	1200
Electric moter	Fimet,315kw	1850
pump	C160A,B,C	50
Filter	F140A,B,C	50
Oil cooler	E170	850
Oil cooler	E120	500

All above equipment weight is taken from the Ipr, Here 3 compressor and 3 motors is running on the skid, for piping weight is measured by CAE-PIPE software is 450 kg including other equipments.Here pump,filter,and oil cooler is placed on the base frame ,So,As taken the base frame is fixed,it not include into calculation. All the equipments are evenly distributed all over the area,So consider here the UDL load.



#	Name	Nom Dia	Sch	OD (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Thk (inch)	Lin.Dens (lb/ft3)	Lin.Thk (inch)	Soil
1	HE001	10"	10S	10.75	0.165							
2	HE015	6"	10S	6.625	0.134							
3	HE041	6"	10S	6.625	0.134							
4	HE031	6"	10S	6.625	0.134							
5	HE021	6"	10S	6.625	0.134							
6	HE071	2"	10S	2.375	0.109							
7	HE081	3"	10S	3.5	0.12							
8	HE051	2"	10S	2.375	0.109							
9	HE061	2"	10S	2.375	0.109							
10	HE161	2"	10S	2.375	0.109							
11	HE171	1/4"	10S	0.54	0.065							
12	HE191	2"	10S	2.375	0.109							
13	HE181	2"	10S	2.375	0.109							
14	HE111	1"	10S	1.315	0.109							
15	HE121	1"	10S	1.315	0.109							
16	HE131	1"	10S	1.315	0.109							

Fig. 2 CAE-PIPE software evaluation of Different Pipe Section

On this skid Mainly three forces is acting on it:

(1)Static weight of the component and piping=(3*1200)+(3*1850)+(450)=9600kg*9.81m/s^2=94176N.

(2)Standard gravity force is apply On the whole body=9.81m/s^2 on whole body .

(3)Dynamic load is acting on the skid=942KN.

Here compressor and motor are running at the 3000rpm. As per the ACI Report,

Dynamic force amplitude,$F_0=m_r * Q * w_0^2\ s_f$ N

Where, m_r=rotating mass~100kg, Q=normal balance quality=2.5mm/s, $w_0^2=2\pi n/60$=314rad/s, s_f=service factor=2.

By calculating F_0=157KN,Here 3 compressor and 3 motor is running on skid,So F_0=942KN.

3. FE ANALYSIS OF EXISTING SKID

For carrying out the FE Analysis of skid as per standard procedure first it requires to create merge part for assembly to achieve the connectivity and loading and constraining is required to be applied also idealization of parts is done on structure this will lead to faster analysis since the connected structure will not be physical but it will be a sketch with mechanical properties of mechanical structure. Procedure is followed in this section.

A. Cross Section of Main Frame

h = 205 mm, b = 200 mm, tw = 10 mm , tf=15mm

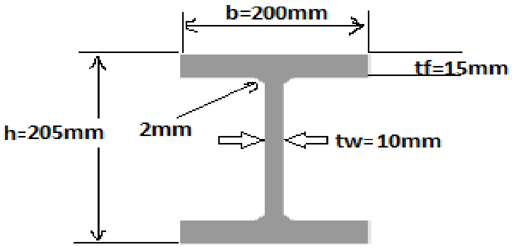


Fig. 3 Cross section of existing skid

B. Loading And Boundary condition

The skid model is loaded by the Static forces of the 3 Compressors,3 motors, and piping and other equipment load of 94176N and Dynamic force when the plant is running is 942KN,Here also considered the standard earth gravity on whole skid body.

Here base frame is given the fixed support boundry condition.

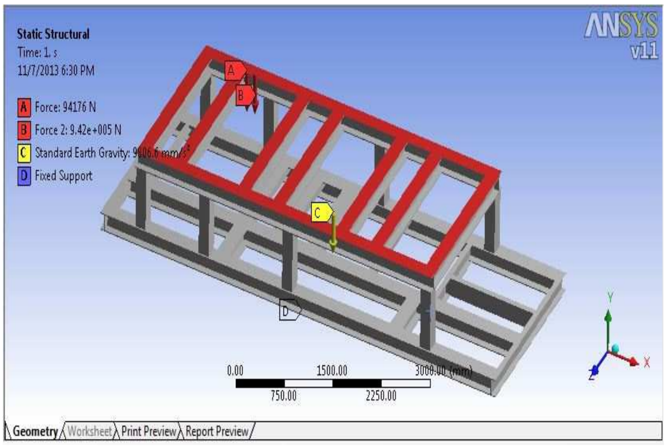


Figure 4 Structural load and boundry condition

C. Results

Maximum principle stresses on the existing skid is 87.336Mpa Max. shear stress is 59.059Mpa and Max.Deflection is 2.5773mm.

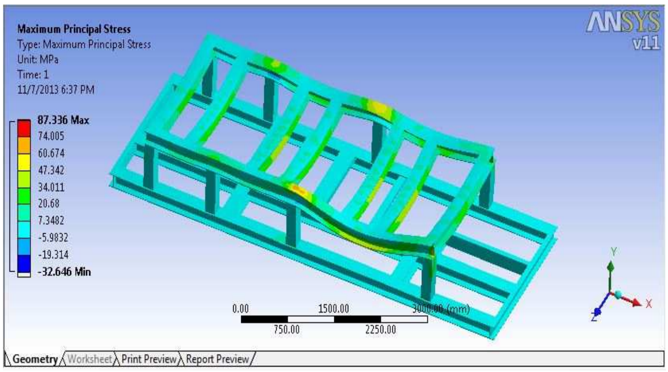


Fig.5 Maximum principle stresses on the existing skid

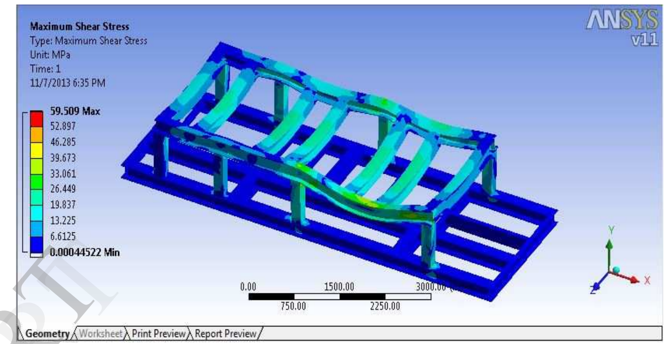


Fig. 6 Maximum shear stresses on the existing skid

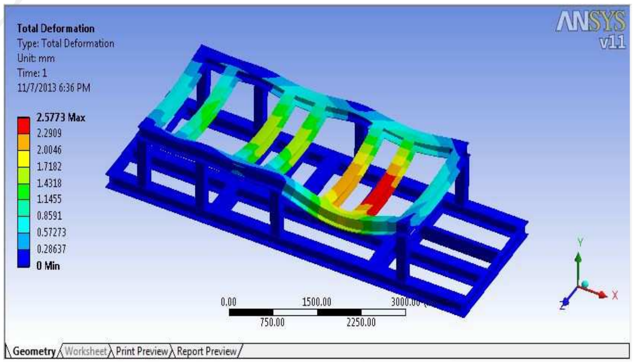


Fig. 7 Maximum deformation on the existing skid

4. DESIGN MODIFICATION

Exsiting skid is designed by taking into consideraton of two compressor is run at a time and other one is used as a stand by,Our aim is to Modify or Design same skid with Three compressor run at a time(i.e.High capacity) .

Constrain:The Space constrain is given that skid should be within space volume(lxbxh) of 6855x 2400x1175 mm.

Assumption: By appling 16186.5N force on base frame in Ansys,The result is almost same with only 0.02% error in stress and shear stress.There is no any change in deformation value because it is fixed with the ground,So,Consider here the base frame is fixed,for further analysis.

A. Modification with changing the strut position

Position of Strut is kept at the equal span.and check the result with the Ansys and Staad pro.The stresses and deformation reduce effectively.Here Each strut reaction is checked and verify that to the johnson's formula to make it wihin safe stress limit. So,By Johnson's straight line formula for columns and strut P= $A\left[\sigma c - n\left(\frac{Le}{k}\right)\right]$;

P=safe load on column/strut,A=Area of the column cross section=6600mm^2, 6c=allowable compressive stress in the column=320Mpa, n=constant,for steel material is 0.0053,Le/k=slenderness ratio=2.268 ;By calculating the safe load By Johnson's formula, is 2111.9KN.

B.Modified model by changing cross section

1) *Sensitivity analysis*

To analyze the sensitivity of frame web height to the change in thickness and vice-versa for the approximately same section modulus and flange width. Here,Section modulus z=(bh^3-b$_1$^{3}h$_1$^{3})/6h; and web hight h=t(dh/dt);This concludes that With increase in web height and decrease in thickness or vice versa.Here there is talking three variable for optimization is flange thickness(tf), web thickness(tw)and height(h),Bykeeping flange with constant.

2) *Design of Experiment using Taguchi's L9 orthogonal Array*

TABLE III DOE Taguchi's L9 Orthogoal Array

Va riab le tw	Vari Able h	Vari Able tf	Max .Principle stress	max. shear stress	max. defl ection
10	200	12	63.532	50.736	1.9868
10	203	14	63.315	48.258	1.7923
10	205	15	56.884	45.101	1.6872
11	200	15	60.737	47.215	1.6424
11	203	14	64.776	46.281	1.7584
11	205	12	91.266	50.187	1.8447
12	200	12	78.903	46.765	1.73
12	203	15	55.754	34.834	1.6703
12	205	14	61.567	45.914	1.6908

where the maximum rection in Ansys is 165.06KN,So strut is safe .Also it cross checked by staad pro.So,By changing the strut position at equal span,the design remain in safe state.

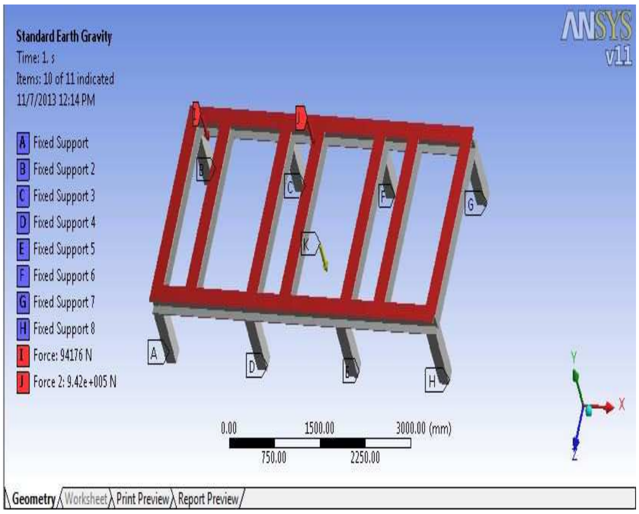


Fig. 8 modified strut position and Reaction

All of above model is created in Solid works2011 and done the analysis individually in Ansys,The below result obtained in Ansys

3) *Cross Section of Modified Main Frame*

H=203mm,b=200mm,tf=15mm,tw=12mm

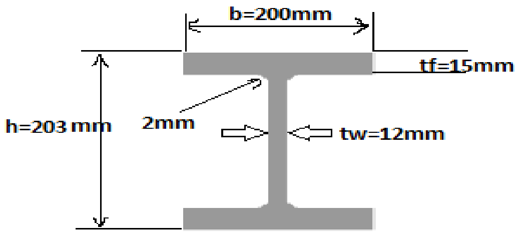


Figure 9 .Modified cross section

4). *Loading And Boundary condition*

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Here base frame is given the fixed support boundary condition.

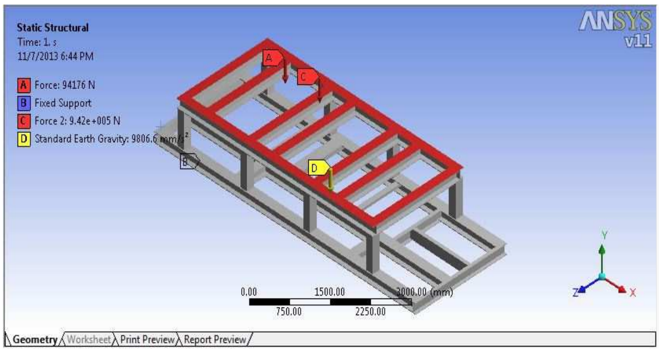

Fig. 10 Structural load and boundry condition

C .Results

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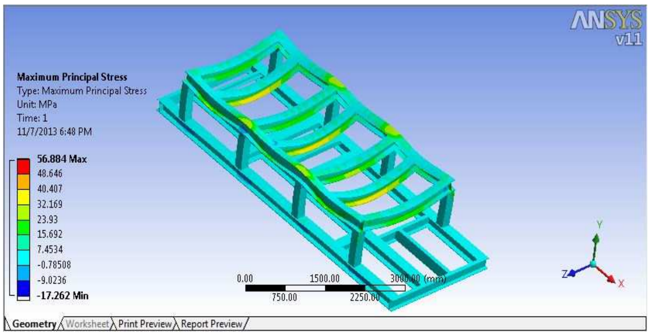

Fig. 11 Maximum principle stresses on the existing skid

5..Result discussion

TABLE IV Stress,Deformation,Weight reduction result

Sr. no.	section	Max.principle stress(MPa)	Shear Stress (MPa)	Max. Displacement (mm)	Weight (kg)	F.o.s.
1	Existing skid model	87.336	59.509	2.5773	3986.797	1.74
2	Modified after changing strut position	56.884	45.101	1.6872	3986.797	2.67
3	Final Modified by changing cross section	55.754	34.834	1.6703	3780.03	2.72

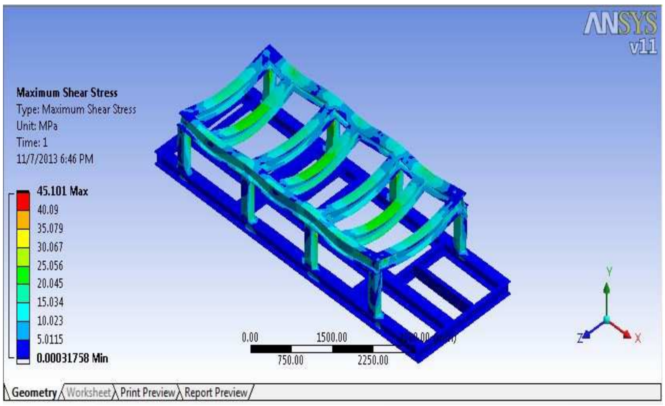

Fig. 12 Maximum shear stresses on the existing skid

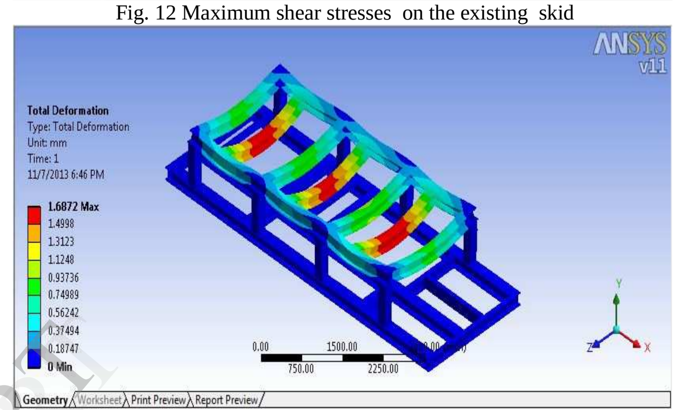

Fig. 13 Maximum deformation on the existing skid

A. Stress analysis,Deformation and weight Reduction

From above result,we can say that,In Modified skid the max. stress,Max.Shear stress,And Deformation is effectively Reduce than the existing one, Also the Weight is Reduced as 5.18% of Exsisting skid,It is clear From F.O.S.,the Modified Design is Safe.

B.*Modal analysis:*

Operating frequency is 50-60 HZ ,provided by manufacturer.

TABLE V Different natural frequency of skid

sr no.	mode	frequency(HZ)
1	1	78.828
2	2	89.212
3	3	89.379
4	4	109.14
5	5	120.51
6	6	123.1

The above table shows the first six natural frequencies is far/away from the operating frequency while plant is running, So minimum vibration is produced and it is safe .

C. Minitab Results

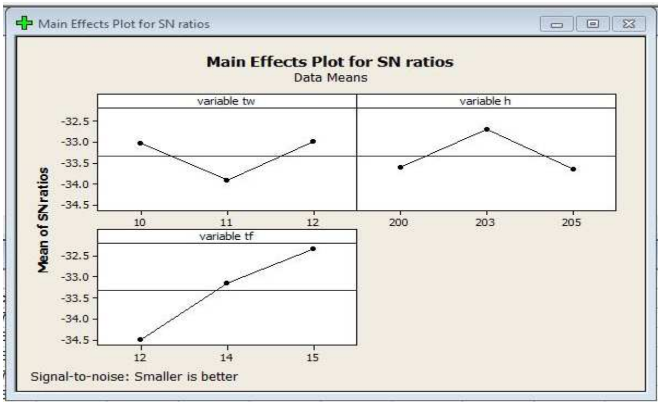

Fig. 14 S-N Ratio graph From Minitab

By Performing DOE,Taguchi's design in Minitab 15 with given input variable the Predictade value is get as a result of the Mean & S-N ratio Graph.

6. VALIDATION USING STAAD-PRO Vi8

In the staad pro software each element is descre atized ,By giving different beam and node numbers ,And analyzed the result of each and every element. The same dimentions ,loading and boundry conditions is applied to the STAAD-PRO Vi8 and get max.stress,max.shear stress,and deflection.

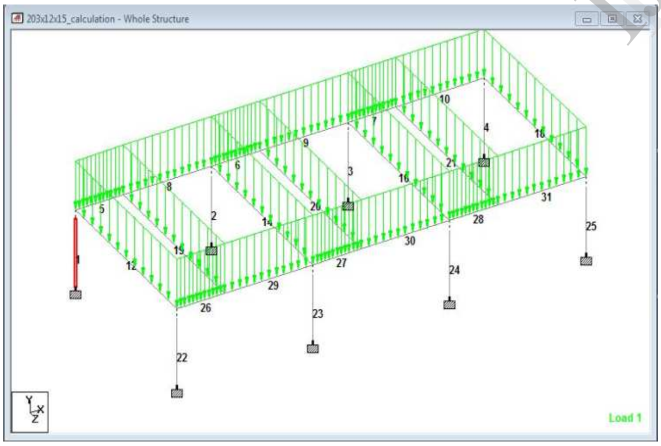

Fig. 15 Staadpro Loading condition

Accordingly structrural software Staad pro vi8 ,The maximum principle stress is 55.784Mpa,Maximum shear stress is 34.834Mpa,and Maximum deflection is 1.6703mm, The result is Almost same with 4-5% error with Ansys result,So,it validate the modified compressor skid design .

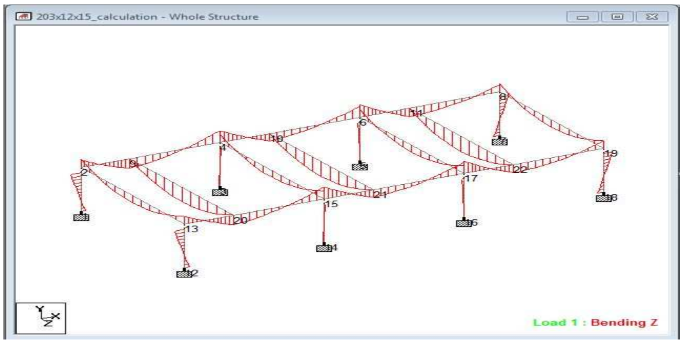

Fig. 16 Staad pro_Bending moment dia. of each element of beam and strut.

7. CONCLUTION

From the above results it can be concluded that:

1. The analytical(Staadprovi8) and the FEA(Ansys) results are almost same.
2. The vibration of the Modified Compressor skid is within Safe limit.
3. By varying the Web thickness & Height of the I-channel section we can increase the load Capacity of the Compressor skid.
4. By performing design of experiments in Taguchi method using sensitivity analysis, we can get the optimum set of values for variables.
5. The maximum stress generated in the Compressor skid, total deformation of the Skid and weight of the Compressor skid can be minimized through shape modification.

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