STRUCTURAL OPTIMIZATION OF CLASS-2(METHOD2) TYPE GEODESIC STEEL DOME USING ANSYS® WORKBENCH

[1]Kunjan Bharwad, [2]Satyen Ramani
[1]Post Graduate Student, [2]Associate Professor
Department of Civil Engineering
SAL Institute of Technology and Engineering Research, Ahmadabad

***Abstract*— In this study, optimization of geodesic type steel dome is carried out for 20 m diameter class 2 subdivision method 2 for division frequency 4, 6 and 8. Generation of geometry is carried out using CADREGEO and then imported into STAAD.PRO software. Customized JAVA Scripting is developed further for creating structural geometry in ANSYS® Design Modeler. Primarily the Excel sheet was used to systematically develop the JAVA script from the STAAD geometry data .The static structure analysis is carried out in ANSYS® Workbench. Parametric sets required for various input and output parameter were defined and used in ANSYS® Design Exploration tools. Lastly, Optimization is performed in ANSYS® workbench using Response surface optimization tool. The Optimized weight and the corresponding member sections extracted from this optimization is presented.**

***Index Terms*— Optimization, Geodesic steel dome , JAVA Scripting , ANSYS® Workbench , Response surface ,**

I. INTRODUCTION

A dome is one of the oldest structural forms and it has been used in architecture from earliest times. Domes are of special interest to engineers and architects as they enclose a maximum amount of space with a minimum surface and have proved to be very economical in the consumption of construction materials. A dome is been proved as a most efficient self-supporting structure for a large area due to its two curved direction.

Architect and engineers have been excited about the possibilities of space structures for the past many years. They offer opportunities for variation in plan form and building profile, large uninterrupted spans, and excellent distribution of loads, optimum utilization of materials and prefabrication and mass production of easily transportable components. Now that the computers are readily available to handle the complex calculations, there should be little implement to the widespread use of these interesting structures. Domes and shells have an outstanding role in modern construction.

Domes can be exceptionally suitable for covering sports stadia, assembly halls, exhibition centers, fish farming aqua pods, swimming pools and industrial buildings. For getting large unobstructed areas with minimum interference from internal supports.

A dome is a typical example of a synclastic surface in which the curvature of any point is of the same sign in all directions. The synclastic surfaces are also called surfaces of positive Gaussian curvature and are not developable, that is, a domic surface cannot be flattened into a plane without stretching or shrinking it. This property is one of the reasons why, in practice, domes cannot be built from members of the same length.

Geodesic domes constitute an important family of braced domes offering high degree of regularity and evenness in stress distribution. Data preparation and handling of graphics for geodesic forms are difficult and time consuming tasks and are the stages of analysis where mistakes are most commonly made.

INTRODUCTION TO ANSYS® OPTIMIZATION

1) **Design of experiments.**
2) **Response surface.**
3) **Optimization**

1. Design of experiments:

Design of Experiments (DOE) is a technique used to scientifically determine the location of sampling points and is included as part of the Response Surface, Goal Driven Optimization, and Analysis systems. There are a wide range of DOE algorithms or methods available in engineering literature. These techniques all have one common characteristic: they try to locate the sampling points such that the space of random input parameters is explored in the most efficient way, or obtain the required information with a minimum of sampling points. Sample points in efficient locations will not only reduce the required number of sampling points, but also increase the accuracy of the response surface that is derived from the results of the sampling points. By default, the deterministic method uses a Central Composite Design, which combines one center point, points along the axis of the input parameters, and the points determined by a fractional factorial design.

Once you have set up your input parameters, you can update the DOE, which submits the generated design points to the analysis system for solution. Design points are solved simultaneously if the analysis system is set up to do so; sequentially, if not. After the solution is complete, you can update the Response Surface cell, which generates response surfaces for each output parameter based on the data in the generated design points.

2. Response surface:

The Response Surfaces are functions of different nature where the output parameters are described in terms of the input parameters. They are built from the Design of Experiments in order to provide quickly the approximated values of the output parameters, everywhere in the analyzed design space, without having to perform a complete solution. The accuracy of a response surface depends on several factors: complexity of the variations of the solution, number of points in the original Design of Experiments and choice of the response surface type. ANSYS® Design-Explorer provides tools to estimate and improve the quality of the response surfaces. Once response surfaces are built, you can create and manage response points and charts. These post-processing tools allow exploring the design and understanding how each output parameter is driven by input parameters and how the design can be modified to improve its performances. This section contains information about using the Response Surface:

3. Optimization:

There are two different types of Goal Driven Optimization systems:

Response Surface Optimization: A Response Surface Optimization system draws its information from its own Response Surface component, and so is dependent on the quality of the response surface. The available optimization methods (Screening, MOGA, NLPQL, and MISQP) utilize response surface evaluations, rather than realsolves.

PRESENT STUDY: In this paper an optimization using ANSYS® workbench for 20 m diameter and various frequencies for geodesic steel dome is carried out. Initially using CADREGEO software for the geometry generation of geodesic dome is used. The generated geometry is imported in STAAD.PRO and then using JAVA SCRIPTING import geometry in ANSYS® workbench. Here an Optimization is carried out by minimizing total weight of dome with respect to several constrain condition like Stresses and Deflection using response surface optimization toolbox.

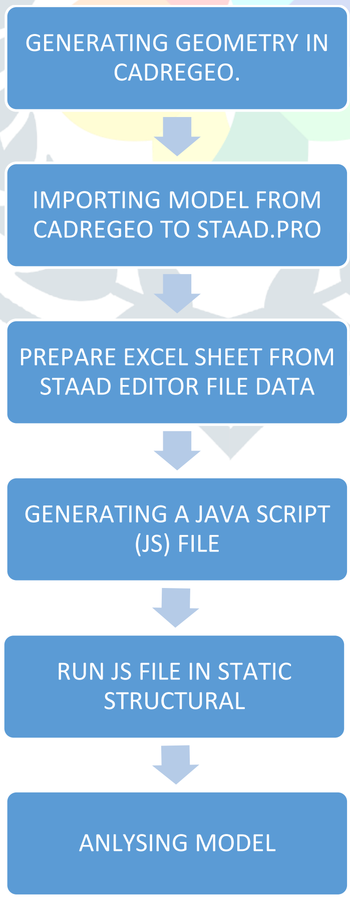
II. PRESENT STUDY:

In this paper an optimization using ANSYS® workbench for 20 m diameter and various frequencies for geodesic steel dome is carried out. CADREGEO software for the geometry generation for geodesic dome is used. The generated geometry is imported in STAAD.PRO and then using JAVA SCRIPTING importing geometry in ANSYS® workbench. Here an Optimization is carried out by minimizing total weight of dome with respect to several constrain condition like Stresses and Deflection using response surface optimization toolbox.

Sr. no.	Models	Diameter(m)	Height(m)	Method	Frequency
1	Model2-2-4-10	20	10	Class 2 Method 2	4
2	Model2-2-6-10	20	10	Class 2 Method 2	6
3	Model2-2-8-10	20	10	Class 2 Method 2	8

Table 1 Generation Details

Where Model2-2-4-10 suggests that it is generated by class 2 method 2 with frequency 4 division having radius 10 meter.



III. LOADING AND GROUPING

Before discussing loading let the clear that we are considering whole structure is covered by covering materials this has no stiffness and can only pass the load into members of the structure. So structure can bear and transfer load easily.

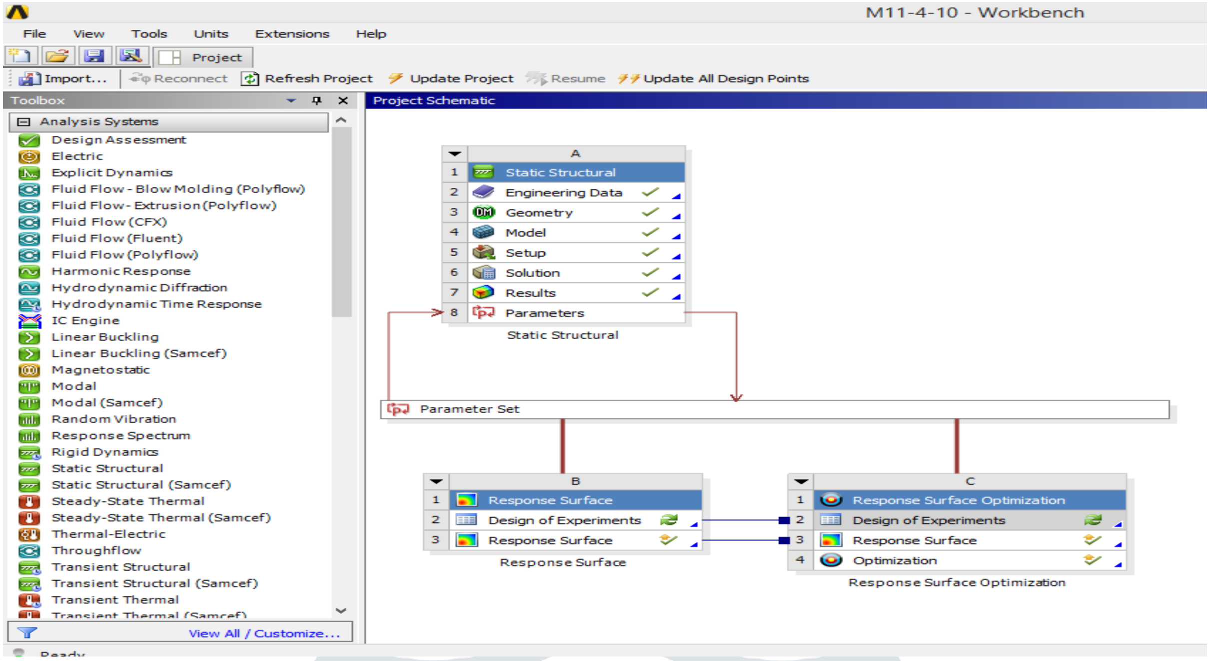


Fig.1 Workbench Static structural home page

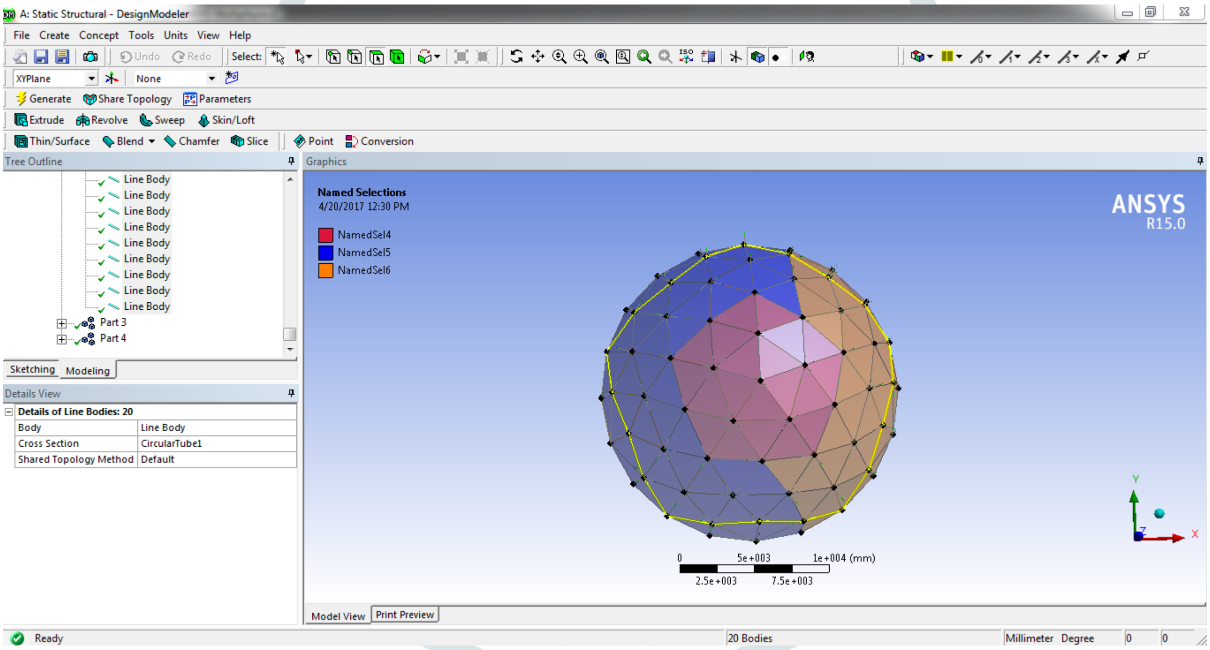


Fig.2 grouping of members RING -1

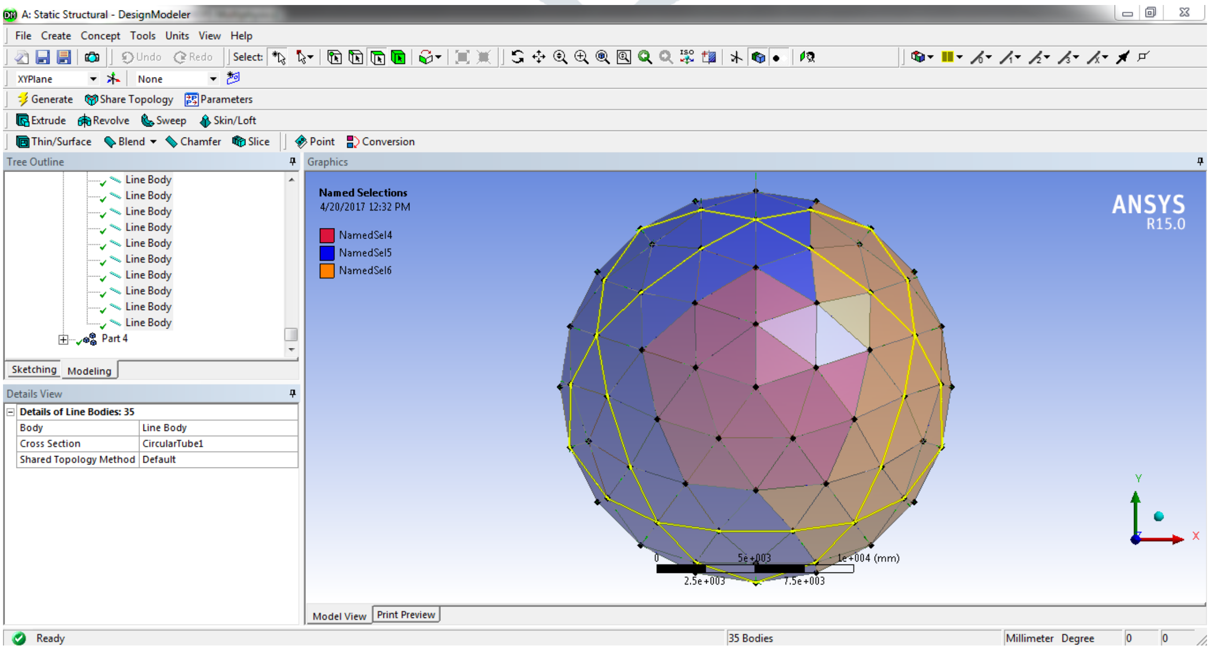


Fig.3 grouping of members RING -2

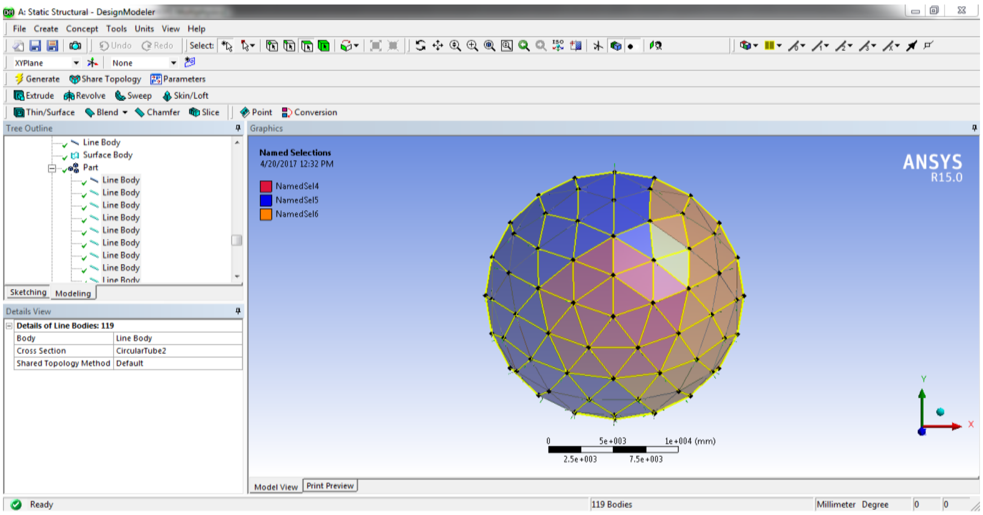


Fig.4 Grouping of Remaining members

Dead Load (Self weight)

Dead load in terms of self weight is considered as weight of members and covering material. Here we are considering covering sheet as a non-structural element, which is only transfer the load to the members.

Live load

A vertical imposed load of 0.5 kN/m^2 is applied and it is taken based on the codal provision IS:875 – part 2.

Wind Load

The wind load case on the structure was calculated by IS- 875(part 3) table 15.

Calculation:

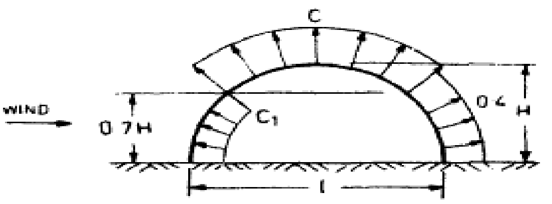
Design wind speed V_Z is given by,

$V_Z = V_b\, k\, k_2\, k_3$ IS: 875 (Part-3)-1987, Clause-5.3

Where, V_b = Basic wind speed,
k_1 = Risk coefficient,
k_2 = Terrain, Height and structure size factor,
k_3 = Topography factor.
Now for Ahmadabad,

Basic wind speed V_b = 39 m/s IS: 875 (Part-3)-1987, Appendix-A
Risk coefficient k_1 = 1.06 IS: 875 (Part-3)-1987, Clause-5.3.1
Terrain, Height and structure size factor k_2 = 1 IS: 875 (Part-3)-1987, Clause-5.3.2
Topography factor k_3 = 1 IS: 875 (Part-3)-1987, Clause-5.3.3
So, $V_Z = V_b\, k_1 k_2\, k_3$ IS: 875 (Part-3)-1987, Clause-5.3
= 39*1.06*1*1
V_z = 41.34 m/s
$P_z = 0.6{*}V_z^{\wedge 2}$
$\mathbf{P_z = 1025.3\ kN/m^2}$

Now, design wind pressure will be calculated by external pressure coefficient for curved roof (IS: 875 (Part-3)-1987, clause 6.2.2.5)



a) Roof springing from ground level

Table 1 **Values of pressure coefficient**

Calculating for dome having Height =10 m and Diameter =20m
Here, H/l =0.5

Values of C, C_1 and C_2

H/l	C	C_1	C_2
0·1	−0·8	+0·1	−0·8
0·2	−0·9	+0·3	−0·7
0 3	−1·0	+0·4	−0·3
0·4	−1·1	+0 6	+0·4
0·5	−1·2	+0·7	+0·7

Table 2 **Values of pressure coefficient**

So the value of C and C_1 as per table.
C = -1.2 & C1 = 0.7
$P_{z1} = 0.7 * P_z$
$= 0.7*1025.3$
P_{z1} = 1.23036 kN/m^2
$P_{z2} = -1.2 * P_z$
$= -1.2*1025.3$
P_{z2} = -0.717.71 kN/m^2
$P_{z3} = 0.4*P_z = 0.4*1025.3$
P_{z3}= -410.12 kN/m^2

RESPONSE SURFACE OPTIMIZATION:
Objective function = To minimize total weight of dome
Constrains = Directional deformation and stresses
The deformation limits are decided based on the codal provision. As per the Florida code the Maximum Vertical Deformation should not be exceed beyond the limit 19.1mm. The Maximum horizontal deformation is as per the IS: 800(2007) and it should not be exceeded beyond the limit Height/200.
The tensile and compressive stresses are as per IS-800(2007) sec.6 and sec.7 respectively.

1) Tensile stress should be less than or equals to minimum of **Fy/1.1 “or” 227.27 N/mm^2**
2) The compressive stress should be less than or equals to design compressive stress as per sec.(7.1.2.1) $\sigma_{c} \leq f_{cd}$

PARAMETER SET:
Here for a model2-2-4-10 the whole procedure for response surface optimization is shown in below figures.
The set of input and output parameter is selected and updated in parameter set.

Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Static Structural (A1)			
4	P13	CircularTube1_Plane.Ri	169.8	mm
5	P15	CircularTube2_Plane.Ri	130.6	mm
6	P35	thick1	8	mm
7	P36	thick2	5.9	mm
8	P21	AREA 1	8731.7	mm^2
9	P22	AREA 2	4948.3	mm^2
*	New input parameter	New name	New expression	
11	Output Parameters			
12	Static Structural (A1)			
13	P5	Geometry Mass	33.867	tonne
14	P10	Directional Deformation-X Maximum	0.23625	mm
15	P11	Directional Deformation-Z Maximum	0.077057	mm
16	P16	Directional Deformation-Y Maximum	0.14563	mm

Fig 6 Input and output parameter

DESIGN OF EXPERIMENT (D.O.E):
In this various methods are available for updating the various sets of design points .we use **CUSTOM method** for updating the design points by applying upper and lower bound limits to input parameter.

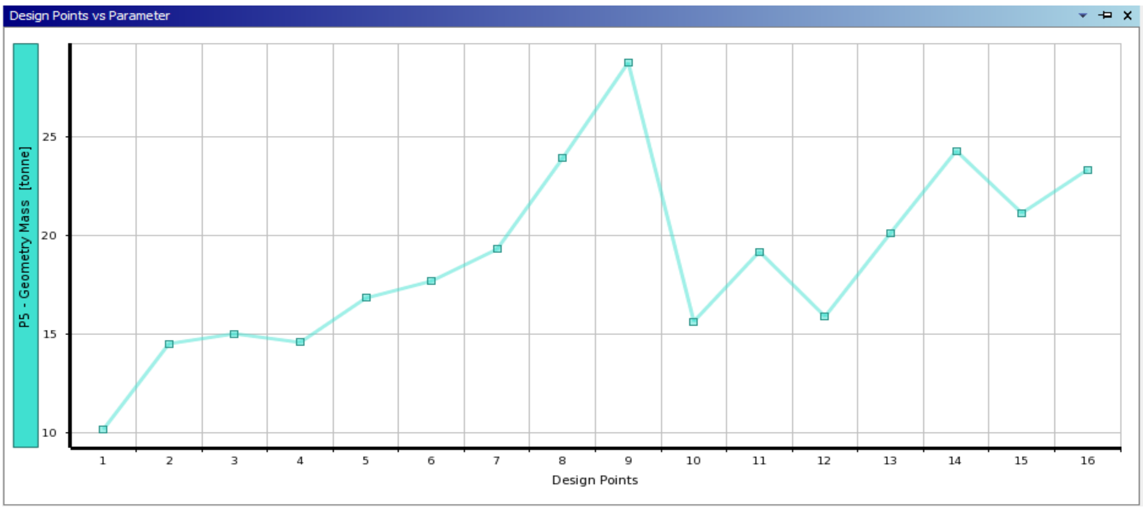


Fig7 Design points vs parameter (Geometry mass)

RESPONSE SURFACE:

Different response surface types are available here **Kriging type** is used. It gives verification and response point from those design points.

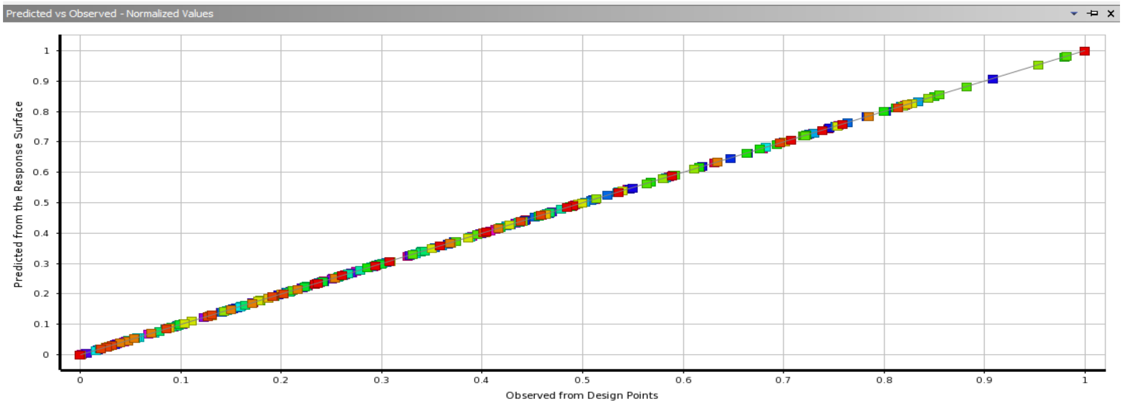


Fig 8 Response surface observed DP

Table of Outline A35: Goodness Of Fit

	A	B	C	D	E	F
1	Name	P5 - Geometry Mass	P10 - Directional Deformation-X Maximum	P11 - Directional Deformation-Z Maximum	P16 - Directional Deformation-Y Maximum	P17 - Axial Force Mini
2	Goodness Of Fit					
3	Coefficient of Determination (Best Value = 1)	1	1	1	1	1
4	Maximum Relative Residual (Best Value = 0%)	0	0	0	0	0
5	Root Mean Square Error (Best Value = 0)	4.8978E-12	1.0934E-10	1.4691E-12	7.7063E-14	1.7197E-07
6	Relative Root Mean Square Error (Best Value = 0%)	0	0	0	0	0
7	Relative Maximum Absolute Error (Best Value = 0%)	0	0	0	0	0
8	Relative Average Absolute Error (Best Value = 0%)	0	0	0	0	0
9	Goodness Of Fit for Verification Points					
10	Maximum Relative Residual (Best Value = 0%)	0	0	0	0	0
11	Root Mean Square Error (Best Value = 0)	4.8978E-12	1.0934E-10	1.4691E-12	7.7063E-14	1.7197E-07
12	Relative Root Mean Square Error (Best Value = 0%)	0	0	0	0	0
13	Relative Maximum Absolute Error (Best Value = 0%)	0	0	0	0	0
14	Relative Average Absolute Error (Best Value = 0%)	0	0	0	0	0

Fig9 Goodness of fit

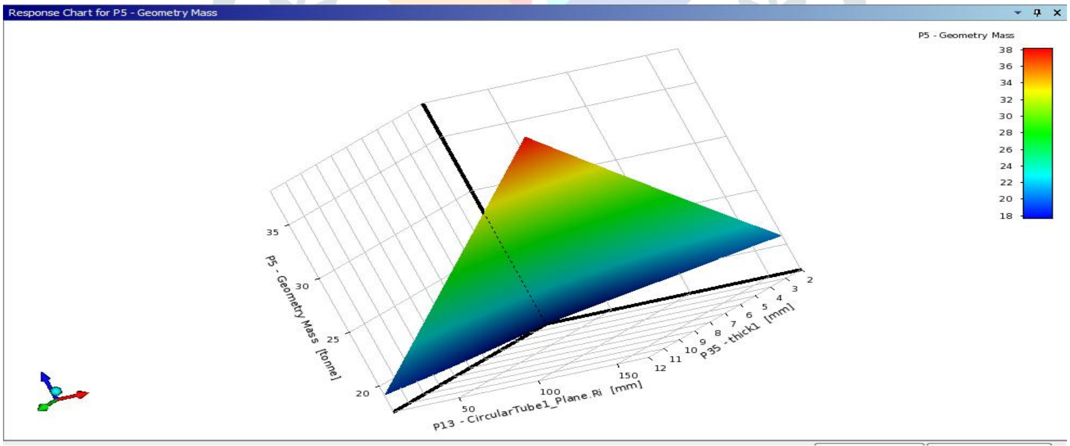


Fig10 . Response chart Input parameter (Ri 1 ,T1) vs Output parameter Geometry mass

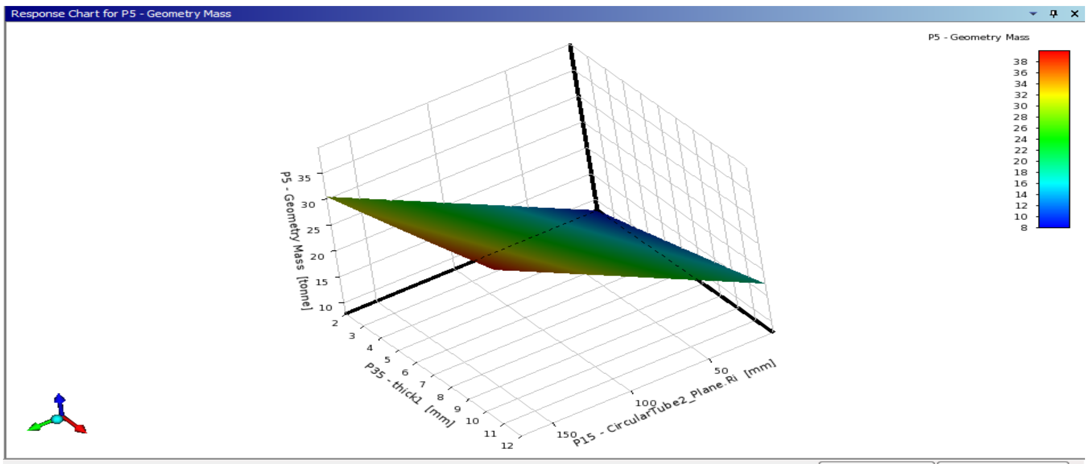


Fig .11 Response chart Response chart Input parameter (Ri 2 ,T2) vs Output parameter Geometry mass

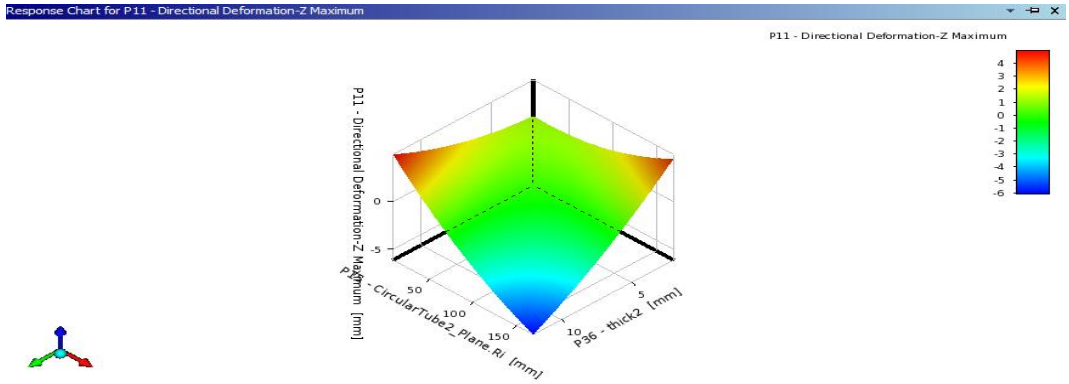


Fig12 .Response chart Response chart Input parameter (Ri 1 ,T1) vs Output parameter Deformation

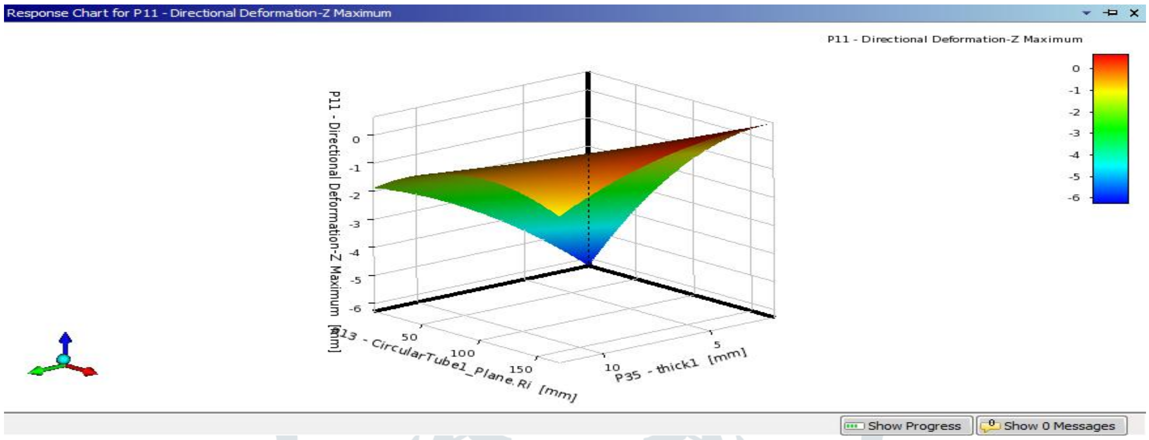


Fig 13 Response chart Response chart Input parameter (Ri 2, T2) vs Output parameter Deformation

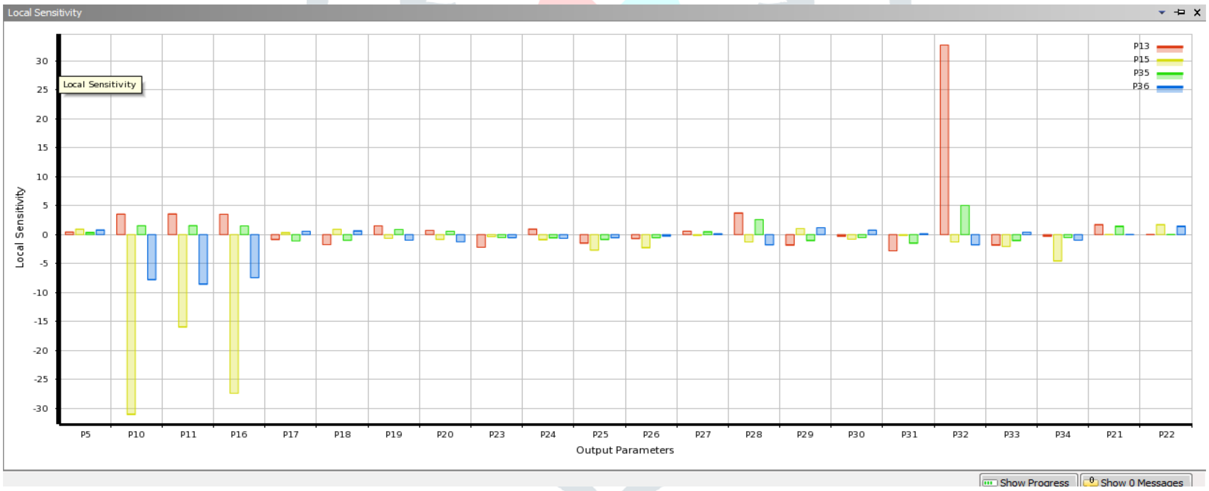


Fig14 Local sensitivity Graph

OPTIMIZATION:

Here a **MOGA method of optimization** is selected for the optimization of design points updated from the response surface by selecting the objective function as weight that is to be minimized and constrain condition as directional deformation and stresses by applying the limits.

18	Candidate Points						
19		didate Point 1	Candidate Point 1 (verified)	Candidate Point 2	Candidate Point 2 (verified)	Candidate Point 3	Candidate Point 3 (ve
20	P13 - CircularTube1_Plane.Ri (mm)	8.682		8.7591		8.7483	
21	P15 - CircularTube2_Plane.Ri (mm)	12.023		12.1		11.975	
22	P35 - thick1 (mm)	2.2753		2.2856		2.2725	
23	P36 - thick2 (mm)	2.0511		2.03		2.0564	
24	P5 - Geometry Mass (tonne)	5.1628	5.1628	5.1629	5.1629	5.1635	5.1635
25	P10 - Directional Deformation-X Maximum (mm)	5.9305	28.932	5.9735	28.805	5.9276	29.138
26	P11 - Directional Deformation-Z Maximum (mm)	1.3527	3.4606	1.3654	3.4611	1.3517	3.4646
27	P16 - Directional Deformation-Y Maximum (mm)	4.1123	16.575	4.1424	16.477	4.1102	16.637
28	P23 - STRESS 1 (mJ mm^-3)	85.712	69.608	84.929	69.281	85.282	69.485
29	P24 - STRESS 2 (mJ mm^-3)	79.707	65.593	79.093	65.292	79.284	65.51
30	P25 - STRESS 3 (mJ mm^-3)	64.823	39.415	64.963	39.469	64.884	39.414
31	P26 - STRESS 4 (mJ mm^-3)	113.85	72.416	113.98	72.451	113.97	72.405
32	P31 - STRESS 5 (mJ mm^-3)	46.833	43.898	46.328	43.59	46.597	43.788
33	P32 - STRESS 6 (mJ mm^-3)	40.579	35.532	40.472	35.371	40.377	35.49
34	P33 - STRESS 7 (mJ mm^-3)	44.855	42.436	44.917	42.439	44.894	42.375
35	P34 - STRESS 8 (mJ mm^-3)	54.973	36.949	55.061	36.967	55.062	37.026

Fig15. Verified candidate points

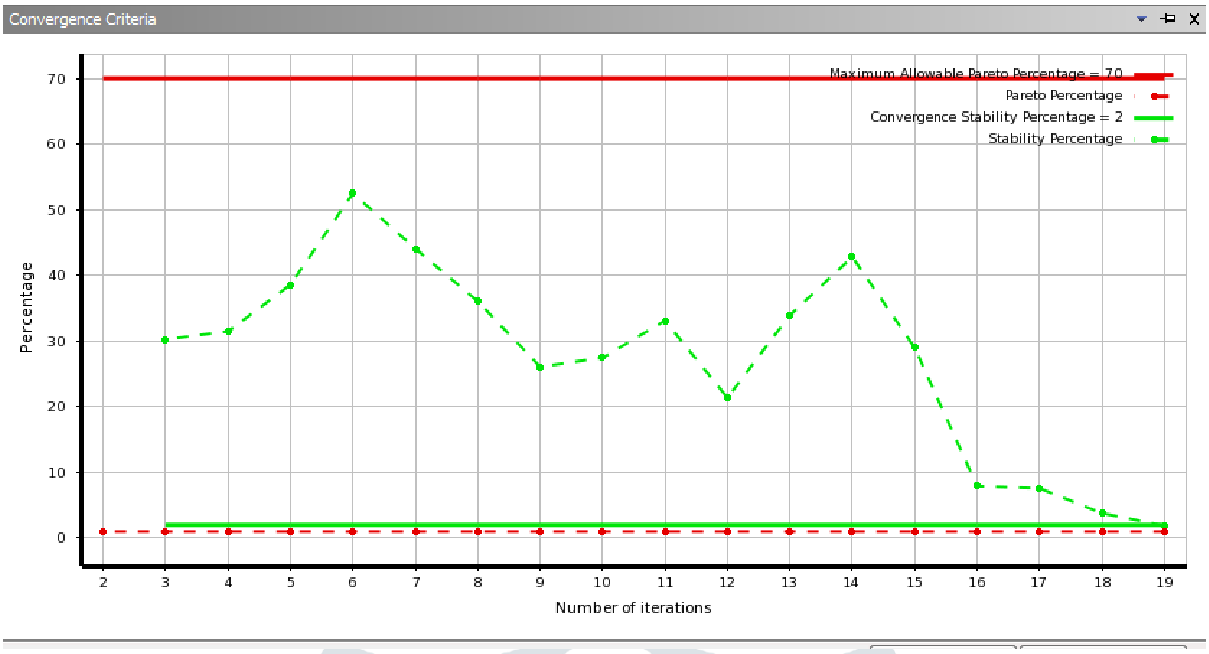


Fig16. Convergence Criteria

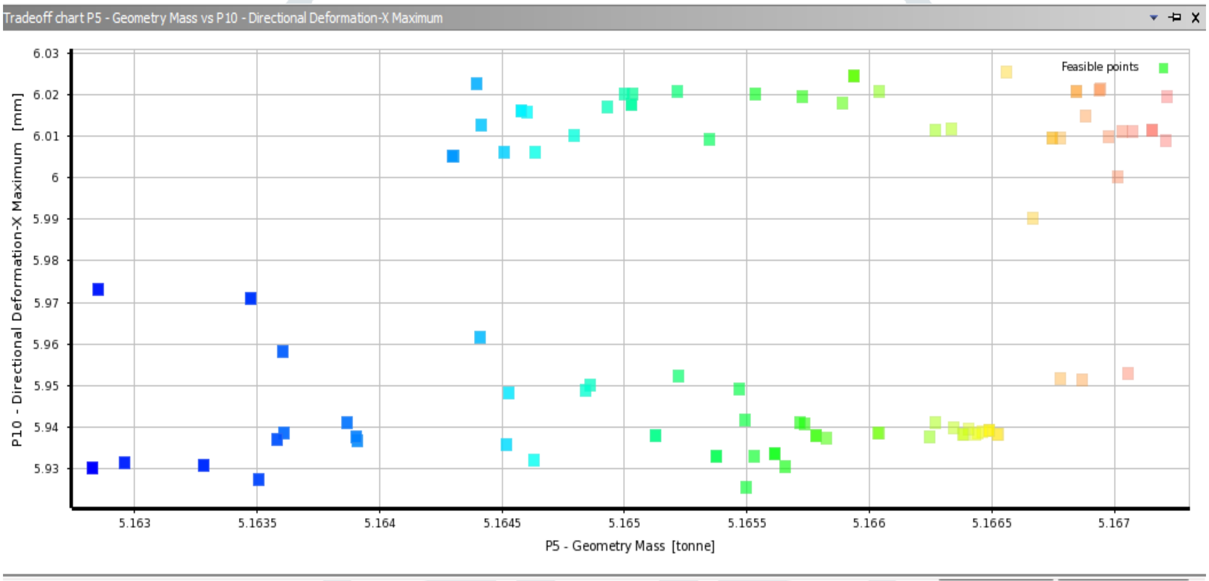


Fig17. Tradeoff

The same procedure is carried out for the MODEL 2-2-610 and MODEL2-2-8-10.

IV. RESULTS:

From the above optimization procedure the results obtained satisfying the constrained criteria. Based on those results the optimum weight of the dome and for that the proposed sections are selected.

Method	Model name	Group Name	Section Size
Class 2 method 2	Model2-2-4-10	Ring 1	PIP28.1×2 CHS
		Ring 2	PIP28.1×2 CHS
		Remaining members	PIP21.3×2 CHS

Table 3 Section obtained for frequency 4

Method	Model name	Group Name	Section Size
Class 2 method 2	Model2-2-6-10	Ring 1	PIP65.1×2.3 CHS
		Ring 2	PIP65.1×2.3 CHS
		Ring 3	PIP44.8×2 CHS
		Remaining members	PIP44.8×2 CHS

Table 4 Section obtained for frequency 6

Method	Model name	Group Name	Section Size
Class 2 method 2	Model2-2-8-10	Ring 1	PIP76.1×3.2 CHS
		Ring 2	PIP76.1×3.2 CHS
		Ring 3	PIP60.3×3.6CHS
		Remaining members	PIP60.3×2.9 CHS

Table 5 Section obtained for frequency 8

MODELS	OPTIMIZED WEIGHT(Tonnage) IN ANSYS® WORKBENCH	FREQUENCY	OPTIMIZED WEIGHT(TONNAGE) IN STAAD.PRO[1]
Model2-2-4-10	5.1628	4	27.72
Model2-2-6-10	6.3525	6	28.32
Model2-2-6-10	7.6422	8	27.42

Table 6 Optimized Weight of Class2Method2 Domes

V. CONCLUSION:-

Results shows the optimized weight obtained in ANSYS® WORKBENCH is better and more reliable than the results obtained in earlier research work[1] .The weight obtained in ANSYS® is optimized successfully for the proposed models by using response surface optimization toolbox satisfying the stresses and deflection criteria. So it has been concluded that the optimization by using response surface optimization toolbox gives more satisfied results than staad.pro and hence it is advantageous to use this for further varieties of various frequency, division methods and diameter .It is also useful for optimization of other structures.

REFERENCES:-

[1] “Divyesh mandali” M.E thesis , “Design of Geodesic domes” GTU - 2016

[2] COMPARATIVE STUDY FOR GEODESIC DOME OF CLASS 1 SUBDIVISIONS Divyesh G. Mandali , Satyen D. Ramani Department of Civil Engineering, SAL Institute of Technology and Engineering Research, Ahmedabad, Gujarat, India , May 2016, Volume 3, Issue 5 JETIR (ISSN-2349-5162)

[3] “S.S.Rao” Engineering Optimization.

[4] Hugh Kenner “Geodesic Math and How to Use It” (1976).

[5] Vijay Krishna “Structural Optimization Using ANSYS® Classic and Radial Basis Function Based Response Surface Models”, Master of Science in Mechanical Engineering Thesis, The University of Texas At Arlington May 2009

[6] K. S. BabuNarayan ,Subhash C. Yaragal, and Yukio Tamura.” SHAPE OPTIMIZATION AND ASSESSMENT OF WIND INDUCED STRESSES IN DOMES” The Seventh Asia-Pacific Conference on Wind Engineering, November 8-12, 2009,Taipei, Taiwan.

[7] Li Shi-feng, Zhang Zhuo-qun, Li Hong-nan and Ren zongdong “Optimal Design of Truss Structures based on the New Improved Ant Colony Optimization Algorithm” Dalian University of Technology, Dalian,China(ICCET 2015).

[8] M. P. SAKA (2007). “Optimum Geometry Design of Geodesic Domes Using Harmony Search Algorithm” *Advance in Structural Engineering* , Vol. 10 No. 6 , 2007.

[9] MallikaAlapati “Discrete Optimization of Truss Structure Using Genetic Algorithm”, VNR VignanaJyothi Institute of Engineering & Technology-Hyderabad ISSN 2347-6435(Online) Volume 3, Issue 1, July 2014.

[10] Mr. MuralimanojVaradharajan, “Shape and weight optimization of structural members”.Researchgate, December 2013.

[11] O. Hasançebi, F. Erdal, M. P. Saka “OPTIMUM DESIGN OF GEODESIC STEEL DOMES UNDER CODE PROVISIONS USING METAHEURISTIC TECHNIQUES” (IJEAS) Vol.2, Issue 2(2010)88-103

[12] Qi WANG,Houan DING, Yuxiang LIN , Yue LUO “Collaborative Optimization Computation Using Improved Genetic Algorithm and ANSYS®”, 5th International Conference on Advanced Design and Manufacturing Engineering (ICADME 2015)

[13] S. Abdel Salam, A.EL-s hihy, A. Eraky, and M. Salah,” Optimum Design of Trussed Dome Structures”. ISSN: 2277-375, (IJEIT) Volume 4, Issue 8,February 2015.

[14] S. Gholizadeh,A. Barzegar and Ch. Gheyratmand “SHAPE OPTIMIZATION OF STRUCTURES BY MODIFIED HARMONY SEARCH” Department of Civil Engineering, Urmia University, Urmia, Iran Int. J. Optim. Civil Eng., 2011; 3:485-494

[15] Vijay Krishna “Structural Optimization Using ANSYS® Classic and Radial Basis Function Based Response Surface Models”, Master of Science in Mechanical Engineering Thesis, The University of Texas At Arlington May 2009

[16] Yanyun “Design of Structure Optimization with APDL”, School of Civil Engineering and Architecture, East China Jiaotong University