

Optimization of Sheet Thickness for CRCA Sheet Metal Panel in a Storage Rack by Experimental Analysis of Deflection under Static Load

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ABSTRACT: This paper focuses on optimization of design parameters such as sheet metal thickness, number of folds used for increasing the strength of sheet metal, raw material selection which ultimately helps in reduction of material and processing cost for 'CRCA- Cold Rolled Close Annealed' sheet metal. Storage rack loading panel is chosen for the analysis. For the analysis work the solver used is ANSYS. Detailed discussion with manufacturer of storage racks gave inputs regarding excessive material cost of the panels as well as the failure data for poorly designed panels. Based on the data input from both manufacturer and literature review, certain cases of the panels are developed and modelled on CAD interface and all the models are analysed in solver to find a value of deflection of panel under a selected load value specified by manufacturer. Out of the cases solved optimized deflection is experimentally validated and suggested for manufacturing the panel.

KEYWORDS: Deflection Analysis, Optimization of design parameters, Sheet Metal Optimization, Material Optimization, storage rack panels, Design of storage rack.

I. INTRODUCTION

The field of storage rack manufacturing is has extensive use of structural steel and sheet metals. Storage racks are the most important components in material handling system. Components and goods in industry are repeatedly stored and retrieved from storage racks in industries. Though there is large importance for storage racks, the design area of these racks is not given enough importance because structural material is readily available in the form of channels, angles, plates, sheet metals etc. The manufacturer is only selecting the material arbitrarily based on the load value to be kept on it specified by the customer. Sometimes these values of loads may not be accurate and wrong data may also transferred by the customer end. So the manufacturer has a chance to overdesign the racks so that it can fit for all the uses. This methodology may add an excessive costing of the material as the sheet metal used of high thickness, grade. As well as structural members are also have overdesign in their size and specifications. Our area of work is more concentrated on the horizontal panels used in storage racks for which the sheet metal thickness is arbitrarily chosen by judging the load value to be kept on it. [2] The problem in sheet metal loading panel design is highlighted and given a solution for helping the manufacturer of these storage racks using the FEA and CAD interfaces. [1][8][12]

II. DATA COLLECTION AND SELECTION OF LOADING PANEL MODEL (CASE)

While working on the problem definition of our study, we visited the manufacturer unit of the storage racks (M/s. Phoenix Technocrafts). We had a discussion with manufacturer about the design of the loading panels for a specific load values. The detailed discussion gave us the inputs such as manufacturer doesn't follow any specific procedure for

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selection of the sheet thickness and fold arrangements for the loading panels and the procedure followed is an arbitrary selection of these parameters. That means for a certain load value deflection or failure mode is not predicted but considering the maximum value for thickness the sheet is selected. This value of the thickness may fall wrong and may be as an overdesigned value which is also undesired. Manufacturer suggested one case that he wanted to design a panel for 250kg of load uniformly distributed over the panel, out of optimum thickness from range 1.0 mm – 3.0 mm with CRCA material. For the load of 250 kg we designed the different cases that he used to manufacture. In each sheet thickness there can 7 panels to be developed. This range of CRCA material is varying with the step of 0.2 mm, i.e. if we consider first thickness value as 1 mm the next will be 1.2, 1.4, 1.6... and so on up to 3.0 mm The CRCA material is standard available sheets in these thickness values. Out of these values we selected the best value for the given load and the suitable arrangement for the folds to be provided on panel for which the deflection of panel is minimum. The thumb rule for deflection is it should be less than 5 mm. The summary of the thicknesses and the dimensions of the panels are shown in next table. [14]

Table 1- Summary of Models to analyse

Sr. No.	Sheet Thickness Steps (t) mm	Load Value	Models made for each Thickness value (LxBxH) and No. of Bends (Cases)	Total Models to be Analysed
1	1.0	250 kg	1000x 500x 45 with 0 Bends 1000x 500x 45 with 2 Lengthwise Bends 1000x 500x 45 with 2 Width wise Bends 1000x 500x 45 with 4 Bends 1000x 500x 45 with 6 Bends (4+2L) 1000x 500x 45 with 6 Bends (4+2W) 1000x 500x 45 with 8 Bends (4+4)	11 Steps x 7 Cases = 77 Models
2	1.2			
3	1.4			
4	1.6			
5	1.8			
6	2.0			
7	2.2			
8	2.4			
9	2.6			
10	2.8			
11	3.0			

The Table 1 shown above gives the data regarding specifications of the loading panel models. There is a thickness range Thickness' column and in each thickness the load is constant, 250 kg. The size and bend arrangement is described in fourth column shown in 'Sheet of the Table 1. In CRCA material we selected above cases for our study, for these cases we generated the CAD models and analysis of deflection is done. The thickness range selected is suggested by the manufacturer for the given load value. This load is applied as UDL on entire panel.

III. CAD MODEL DEVELOPMENT

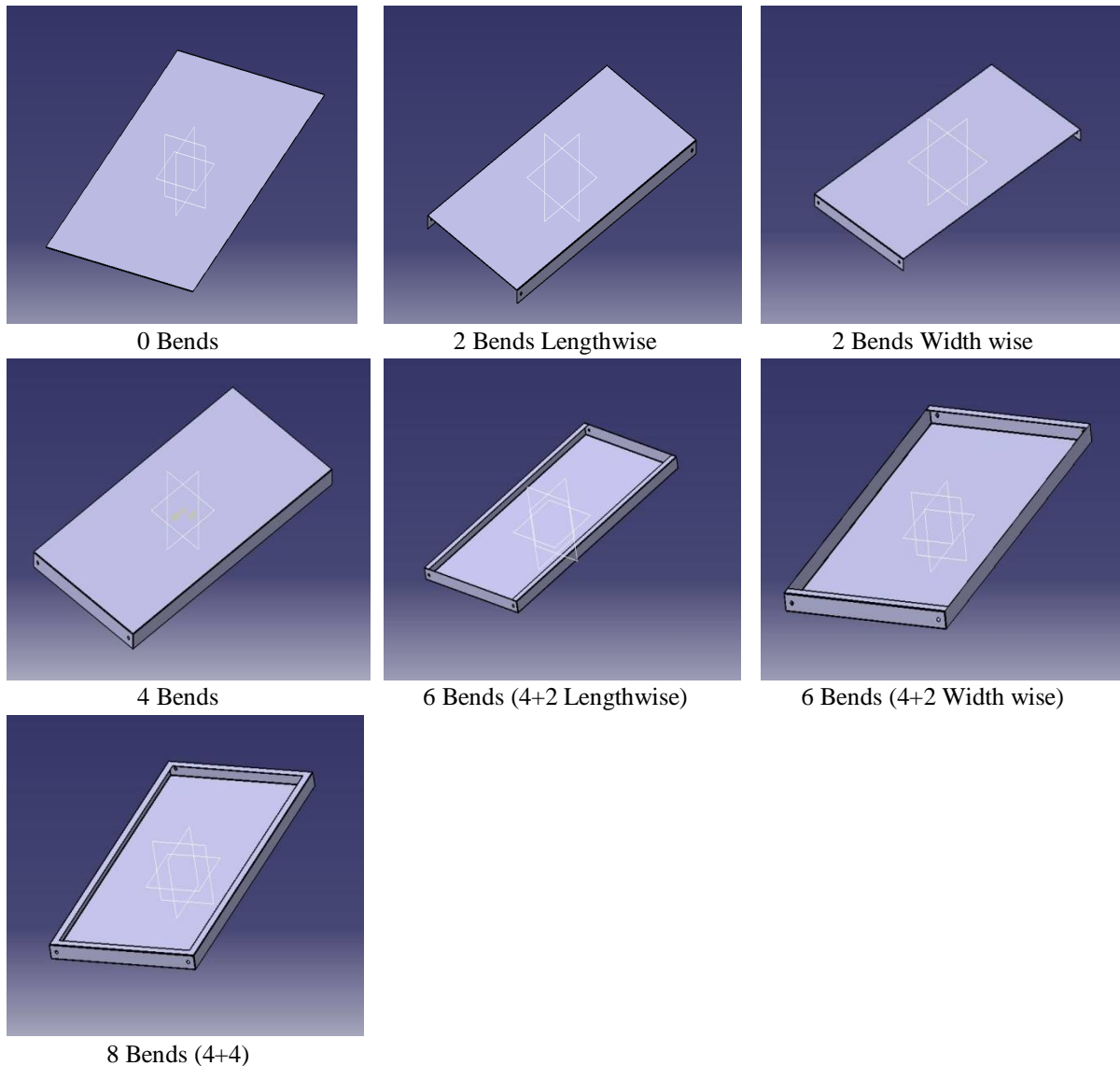
We developed 77 number of CAD models using CATIA V5 as CAD tool. All the models are of same dimensions instead thickness variation. In each of the thickness step there are 7 models with different arrangements for bends. These 7 cases of models are pictorially listed below in Table 2.

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Table 2 – CAD Modelling of Loading Panels



In above Table 2, total 7 number of loading panel designs are shown. There is difference of the bend arrangement in each panel. All the figures in Table 2 are CAD models. For our study we are developing these CAD models for each thickness value. Further, same models will be analysed using structural analysis in ANSYS which is explained in methodology.

IV. METHODOLOGY

a. Finite Element Analysis of the Models

ANSYS is a solver used for analysing all the above cases. The results for deflection are calculated for each model with different bends. The objective for the FEA is to predetermination of the failure mode based on the deflection value. This is type of the simulation which can list the deflection result and help in optimizing the design.

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Though it is not giving the 100% true value, the results are closer to the experimentation results. And FEA can be a suitable supporting tool to predict the deflection. [9][11]

The data used for FEA is as listed below in Table 3-

Table 3 – Material Properties used for FEA

Sr. No.	Material Property	Value
1	Yield Strength of CRCA	410 MPa
2	Young's Modulus for CRCA	2.1e5 MPa
3	Poisson's Ratio CRCA	0.3
4	Load value for 1000x500x45 panel	250 kg
5	Load on Panel in N	2452.5 N

Table 3 is showing the data regarding material properties of CRCA steel which is used in FEA for defining the material. In solver it is taken through 'Material Model'. Analysis and results of deflection are calculated in solver based on this data only.

b. Element and Meshing of the Models

The loading panels analysed are CRCA sheets. There are holes provided on panel width which will fit the panel in storage racks horizontally. The horizontal surface of the panel is used as the loading surface. For sheet metal we used SOLID 187 which is 10 Node Tetrahedron structural elements. This is the most suitable element type for panel model. For this element the mesh size taken is 5. This size can be suitably designed by checking the error in the analysis in ANSYS APDL. The geometry of the element is shown in Fig. 1 below.

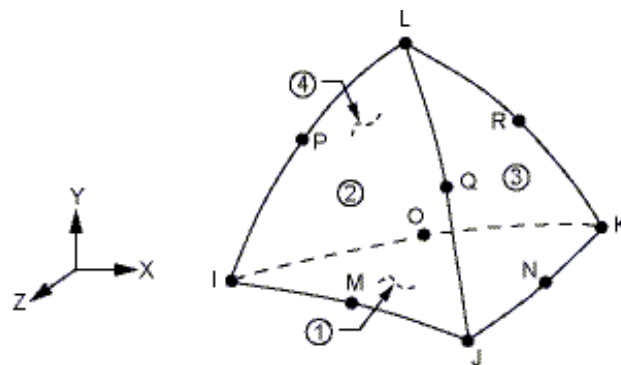


Fig. 1 – SOLID 187 Geometry (10 node tetrahedron)

Fig. 1 shows SOLID187 element which is a higher order 3-D, 10-node element. SOLID187 has quadratic displacement behaviour and is well suited to modelling irregular meshes (such as those produced from various CAD/CAM systems). The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elasto-plastic materials, and fully incompressible hyper elastic materials. Fig. 2 shows a meshed model of loading panel.

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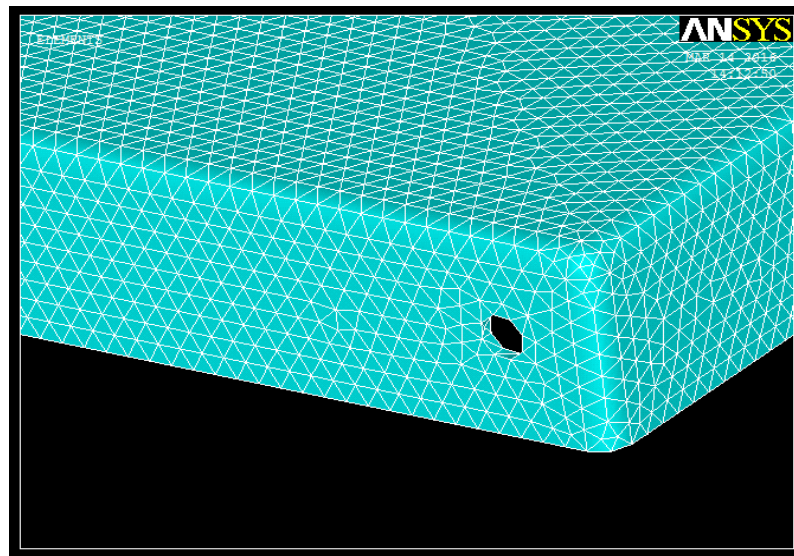


Fig. 2 – Meshing using Free Volume Mesh

in Fig. 2 free meshing is shown, this is a suitable element type for the mesh. The meshing is done as Free Volume Mesh after importing the model and assigning the element to it. Size of the mesh is selected as '5' because as we mesh and solve the entire model we can get a 'Percent error' in the results and this error should be less than 20%. With size 5 this is limited to 12- 16% so size taken is suitable.

c. Setting the Boundary Conditions and Loading Conditions

The loading panels are provided with hole on width are fixed by bolting in a storage rack to the vertical structure. This gives us the boundary condition as all the degrees of freedom are fixed at the areas of these holes and the load is applied on the top surface area as UDL.

Load = 250 kg

Load in newtons = $250 \times 9.81 = 2452.5 \text{ N}$

$$\text{UDL on Top Surface} = \frac{2452.5}{\text{No of nodes attached to area of top surface}} \quad \text{N}$$

With above formula we can apply UDL on the top surface. For setting the boundary conditions we need to select the area of the bolting holes and plot the nodes on them. After plotting the nodes we apply the constraint by restricting all DOF to zero. So the panel is fixed. For application of the load we need to follow the same procedure to select the top surface area and plotting the nodes on it. Then by dividing the load value by the number of nodes we apply the UDL. The area of load application is $1000 \times 500 = 500000 \text{ mm}^2$. For aluminium panels, area is $1200 \times 600 = 720000 \text{ mm}^2$ and the load value is explained as below.

Load = 125 kg

Load in newtons = $125 \times 9.81 = 1226.25 \text{ N}$

$$\text{UDL on Top Surface} = \frac{1226.25}{\text{No of nodes attached to area of top surface}} \quad \text{N}$$

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All the above procedure is shown in next photographs in Fig. 3.

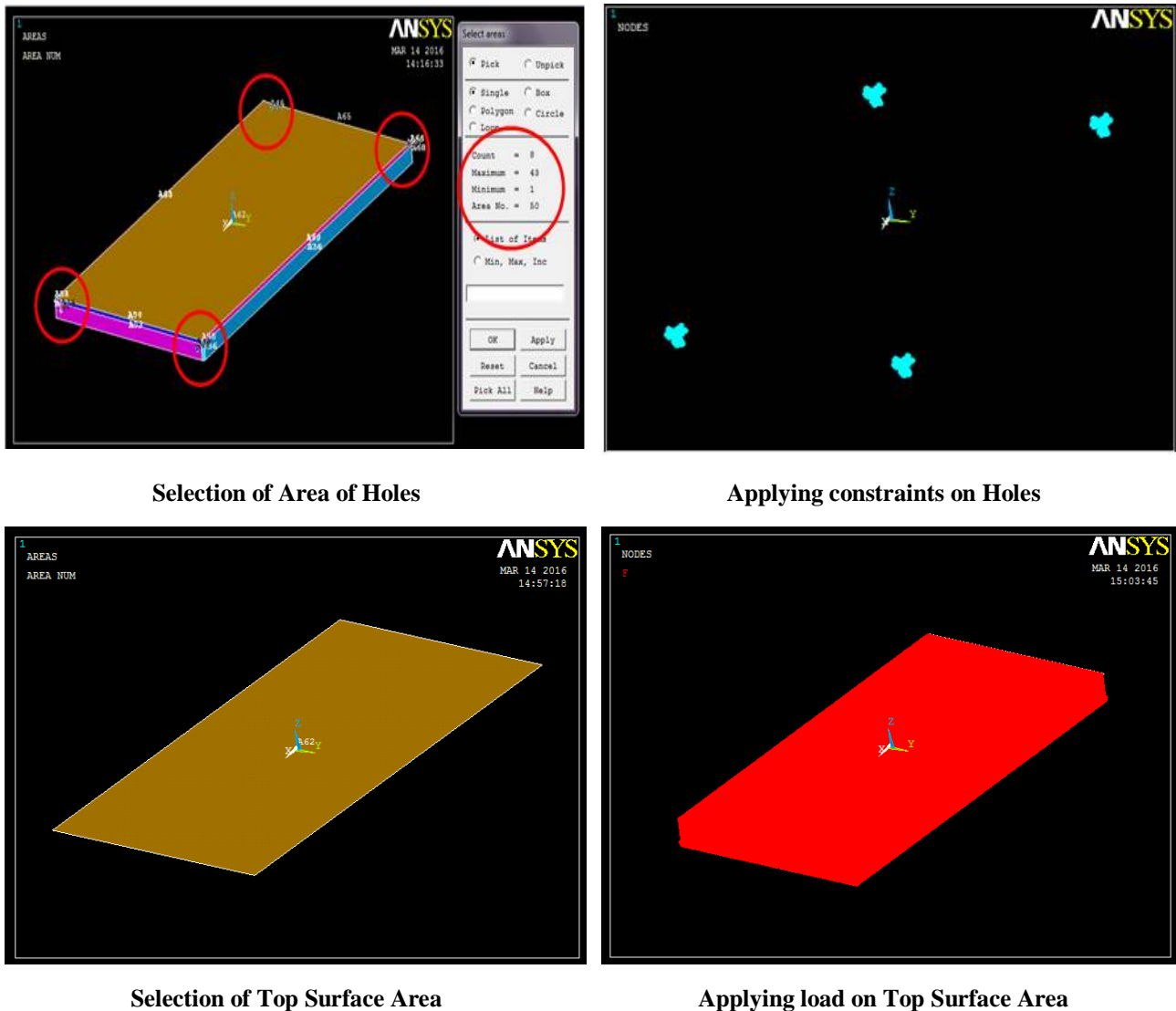


Fig. 3 – Application of boundary conditions and loading conditions

Fig. 3 is showing the sequence to apply the constraints and loading condition on a particular area. Constraint is the fixing condition of panel on rack. Constraints are applied on bolt holes areas. The top surface area is selected using the selection logic, it is plotted. Then using load option load is applied on each node by plotting area nodes.

d. Solution for Deflection

Selected loading conditions are solved and results are plotted using 'Contour Plot'. For deflection Nodal solution is plotted with 'Von Mises Stress'. The procedure is carried out for the given thickness range for all models. A consolidated result sheet for CRCA panels is shown below. We can find out the optimum condition based on deflection value and stress value. The solution for optimum case is shown in Fig. 4 below.

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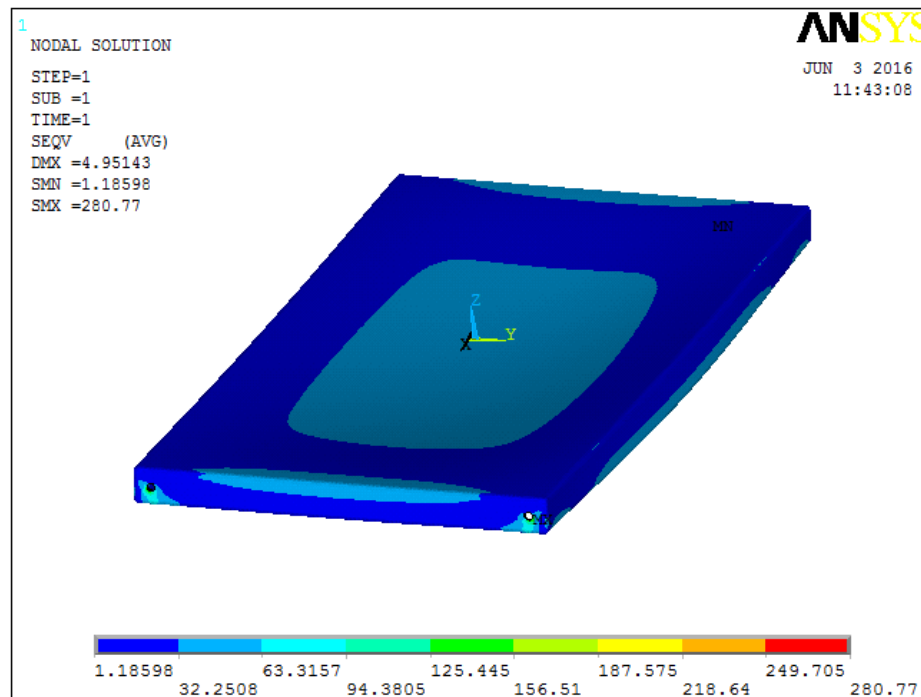


Fig. 4 – Optimum Deflection in Case 1000x500x45 3.0 mm thick 8 bends

Fig. 4 is solution for the optimum case 3.0 mm thick 1000x500x45 mm. For this case the the deflection is having an optimum value of 4.95143 mm which is less than 5 mm. Similarly other cases are solved for the deflection. All the results are listed in Table 4. Listed results are showing the change in the deflection of the panels under the same load. This table gives the idea about the sheet thickness, model of the panel, Maximum and Minimum Stress and Deflection of the panel. All 77 cases of panels are viewed at a glance through this table.

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Table 4 – Deflection calculation by Solver (ANSYS14.0)

Sr. No.	Thickness of Sheet Metal	Model Type → Parameter Measured	1 No Folds	2 2 Folds Lengthwise	3 2 Folds Widthwise	4 4 Folds All Sides	5 6 Folds (4+2 On Length)	6 6 Folds (4 + 2 on Width)	7 8 Folds (4 + 4 All Sides)
1	1 mm	Max Stress	2275.1	2354.69	9024.17	1176.41	3378.92	1506.49	1647.87
		Min Stress	65.5641	14.9164	92.6303	17.7913	8.14911	8.74744	5.98356
		Deflection in Z Direction	721.522	156.764	1106.08	145.395	105.433	132.103	76.2341
2	1.2 mm	Max Stress	1583.45	1607.68	5671.65	793.95	2531.59	1120.69	1245.76
		Min Stress	45.1653	13.1199	61.5035	14.9398	6.78715	3.81609	4.03276
		Deflection in Z Direction	417.62	90.9976	640.821	84.8888	66.6114	77.0424	48.4727
3	1.4 mm	Max Stress	1167.94	1209.29	4851.7	625.483	1967.11	819.63	1051.72
		Min Stress	33.0775	9.94422	27.2277	12.6049	4.89154	3.22576	2.44085
		Deflection in Z Direction	263.016	57.4546	403.933	54.004	44.7996	49.1075	33.1101
4	1.6 mm	Max Stress	895.415	1010.99	3399.8	502.638	1639.71	763.333	886.586
		Min Stress	25.5587	6.42002	24.2898	11.0156	5.37982	3.2104	1.14144
		Deflection in Z Direction	176.213	38.6272	270.799	36.5713	31.6603	33.3133	24.2671
5	1.8 mm	Max Stress	708.969	869.385	2907.72	408.592	1457.59	680.421	727.096
		Min Stress	20.1734	5.52586	16.291	9.54347	4.3946	2.55203	0.168962
		Deflection in Z Direction	123.767	27.2315	190.239	25.9865	23.1228	23.6816	18.071
6	2.0 mm	Max Stress	575.134	740.375	2387.83	358.205	1158.02	609.349	603.017
		Min Stress	16.3277	4.03564	15.8563	8.58894	2.81959	1.90229	1.30335
		Deflection in Z Direction	90.2313	19.9345	138.759	19.1791	17.4142	17.4814	13.8649
7	2.2 mm	Max Stress	474.44	562.951	2026.97	290.797	982.576	560.413	474.696
		Min Stress	13.4474	2.69892	11.3447	7.54196	4.86937	1.61804	1.59794
		Deflection in Z Direction	67.7953	15.0434	104.331	14.598	13.4439	13.2461	10.72
8	2.4 mm	Max Stress	399.324	514.499	1651.53	245.928	808.475	483.426	414.701
		Min Stress	11.3541	2.02949	8.31454	6.79622	2.04419	1.3938	0.743591
		Deflection in Z Direction	52.2219	11.6436	80.3859	11.3985	10.6198	10.3768	8.7416
9	2.6 mm	Max Stress	340.997	449.564	1587.76	246.062	677.368	1027.54	374.375
		Min Stress	9.6495	1.56148	8.16936	5.52509	3.19385	1.31005	0.170137
		Deflection in Z Direction	41.0759	9.20076	63.2773	9.09486	8.53908	11.127	7.13446
10	2.8 mm	Max Stress	293.876	411.49	1298.83	256.138	582.165	418.082	310.762
		Min Stress	8.30172	1.26508	5.58299	4.59885	0.794172	1.34451	0.999574
		Deflection in Z Direction	32.8891	7.40843	50.6775	7.38803	6.98084	6.71017	5.90721
11	3.0 mm	Max Stress	256.471	371.437	1030.7	241.79	498.992	391.041	288.77
		Min Stress	7.27666	1.00876	4.60801	3.89233	0.784573	1.37116	1.18598
		Deflection in Z Direction	26.741	6.0578	41.2324	6.09605	5.78462	5.52939	4.95143

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e. Results and Discussion

After solving all the cases of the loading panels with 250 kg load, the results are obtained for the deflection. All these results are important for mathematical modelling of deflection. After entire analysis we found the case of 1000x500x45 mm with 3.0 mm thick sheet metal and having 8 bends was optimum as it was having the deflection <5 mm. 5 mm is the deflection value which is considered as safe empirically. So, we limited the safe deflection to this value. Comparison of nearby steps of thickness with the optimum thickness is done according to deflection in chart 1 below.

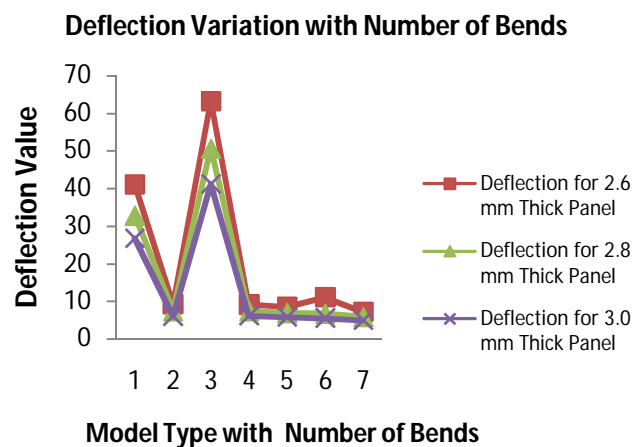


Chart 1 – Deflection comparison (Thickness wise)

Here in chart 1 we can see the decrement in deflection as we increase the thickness of the sheet. So, panel with 3.0 mm thickness are more suitable for the 250 kg load based on this results.

After this analysis we carried the experimental validation of the results for 3.0 mm thick loading panels and compared the results obtained through ANSYS. The cases of 3.0 mm thick panels (1000x500x45) chosen for experimental validation are –

1. 3.0 mm thick with 2 Bends Lengthwise
2. 3.0 mm thick with 4 Bends all over
3. 3.0 mm thick with 6 Bends (4+2 Lengthwise)
4. 3.0 mm thick with 6 Bends (4+2 Width wise)
5. 3.0 mm thick with 8 Bends (4+4)

f. Experimental Validation of Results

The results obtained through the structural analysis of CAD models using ANSYS gives an idea about selection of optimum thickness and selection of folding arrangement of loading panels for given loading specifications by company. Therefore the selected cases from these results have to be cross verified with the actual working environment as per company specifications.

The CAD model prepared for specific loading conditions satisfies the requirement through the simulation. By validating the results, we are checking and comparing the results for actual deflection while loading the panel. For experimental investigation, we manufactured several prototypes of the panel with optimized parameters and tested it with loading conditions specified by M/s. Phoenix Technocrafts for factors such as load carrying capacity, plastic bending, etc. The results achieved with experimentation will then be compared with the results obtained from FEA to validate the optimized parameters.

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g. Manufacturing of Loading Panels for Selected Cases

As discussed above different models of panels are selected for actual manufacturing based on the optimized thickness value and number of fold arrangement. These prototypes are made with CRCA steel sheet. We used hydraulic press brake machine to cut and bend the sheet. We prepared total 05 prototypes. Fig. 5 shows the prototypes of the panels.



Fig. 5 – CRCA Loading Panels for Experimental Validation

In Fig. 5 the prototypes shown are used for the experimental analysis of the deflection. As we got the optimum case in 3.0 mm thickness, we made panels using CRCA sheet of 3.0 mm thickness and practically listed the deflection value.

h. Experimental Set up and Methodology

As per given specific loading condition by company, we are working for 250 kg load which is uniformly distributed over an area of panel. In our experimental set up we are testing single prototype at a time.

We used four angles of mild steel as the panels are fixed using the slotted angles. These MS angles are working as vertical supporting members. Total size can be specified as 40 mm x 40 mm x 5 mm. Length of the angle taken is 1.5 m with holes ϕ 10 mm drilled on both ends it. Slotted angles are used for height adjustment of panels depending on load to be kept and size of the object to be kept.

Panel to be tested for load is fixed on top side and supporting panel is fixed on bottom side. Panels are bolted to the angles bolt size used is M8 x 50. In this set up the important thing is the load of 250 kg which is to be exerted as UDL on top panel. As this is UDL we selected foundry sand as our loading media i.e. we are putting 250 kg of foundry sand on the top panel. As we are loading the panel with bulk load we need some additional construction that will held the entire sand on top area of the panel.

For this we prepared a box with size 1000 x 500 mm in length and width. But height of the box is selected after calculation of volume of sand required for 250 kg depending on the density of refractory sand. Density of this sand is 7.0 gram/cm³. So after calculations height comes to be around 20 inches i.e. around 400 mm. The experimental set up and box for containing sand are shown in fig 6 as below.

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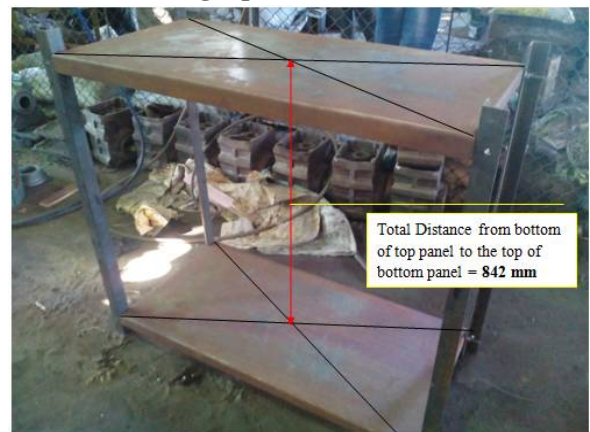
Experimental Set Up



Loading top surface with sand



Loaded Surface area



Deflection Calculation with Change in Distance

Fig. 6 – Experimental Validation of Optimum Thickness

In this we can use a dial gauge for measurement of the deflection. In Fig 6 the distance between two panels is shown which can be an alternative method of counting the deflection. Comparison is done between analytical results and experimental results.

i. Comparison of results for deflection through Experimental Validation

The same procedure is repeated for all the panel prototypes and deflections are calculated. Following table shows the result found by experimental testing and comparison with the ANSYS results for deflection. Following table 5 shows the comparison of results.

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Table 5 – Comparison of Experimental Results

Loading Panel	Fixed Distance (mm)	Measured Distance (mm)	Deflection (mm)	ANSYS Results for Deflection (mm)	% Variation in Results
3.0 mm thick with 2 folds lengthwise	842	835	7.0	6.0578	15.5535
3.0 mm thick with 4 folds all sides		835.5	6.5	6.09605	6.6264
3.0 mm thick with 6 folds (4 all sides + 2 Lengthwise)		835.8	6.2	5.78462	7.1807
3.0 mm thick with 6 folds (4 all sides + 2 Width wise)		836	6.0	5.52939	8.5110
3.0 mm thick with 8 folds		837.5	4.5	4.95143	9.1171

In this table we can see that the experimental results are closer to the analytical results. So the values obtained for all the panels can be used for further work of mathematical modeling and DSS development. See chart 2

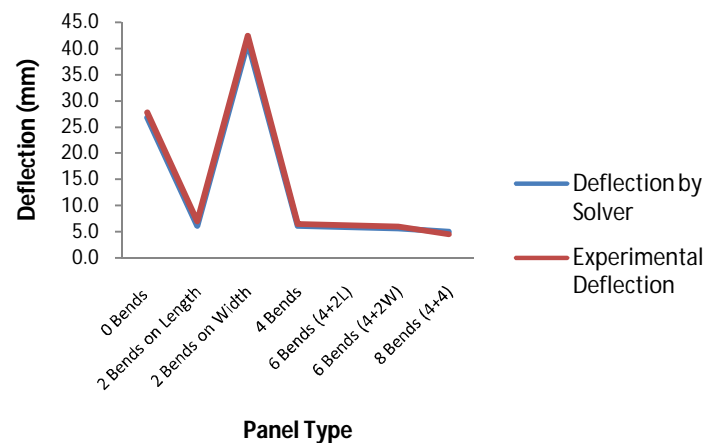


Chart 2 – Comparison of Experimental Results with Solver Results for CRCA sheet Panels

Through this experimental testing we got results which are within tolerable limits of the results obtained through ANSYS. After this validation procedure, results obtained in ANSYS are used for the preparation of Decision Support System and Mathematical Model as further part of our study.

This ends up the validation procedure and thereby the method of finding the optimum case among the entire thickness values of the loading panels. Through this study we suggested the manufacturer an optimum case of 3.0 mm thick sheet with 1000x500x45 size, and with 8 bends. Now, the study doesn't stop here, we are developing the decision support system that would help the manufacturer to predetermine the failure deflection and he could judge the thickness and load values based on prediction of the deflection. This will be based on a mathematical model which will be developed by Regression Analysis in Microsoft Excel based on the deflection data of all these cases.

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V. CONCLUSION

1. Rack manufacturers are having the issue of arbitrary selection of sheet thickness which could be non optimal value for loading panel based on load value which leads to over-design of panels.
2. Experimental validation shows that results obtained through simulation are valid and can be used for further work of development of DSS or an expert system.
3. Through this experimental analysis of deflection of loading panel we developed a data base for development of mathematical model which will be used in development of DSS.
4. Future scope will include work regarding mathematical model and development of Decision Support System.

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