Buckling Analysis of Solar Panel Supporting Structures

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Abstract

Cell phones become an essential part of our day to day life. The working of mobile phones requires cell phone towers for transmitting and receiving signals from mobile phones. These tower system consume about 2 billion litres of diesel every year for operating the generators. Which will affects economy and also the environmental problems. Thus any change in the power generation method of cell phone tower would make tremendous impact in terms of resource saving and reduction in carbon emissions. Now diesel generators in India are being challenged by clean , renewable energy source such as sun. So solar powered cell phone towers arises. To collect the solar energy effectively from sun there is a necessity of proper alignment of solar panels. This study investigated the stability analysis of solar panel supporting structure and also the factors which affects the strength and stability in economic manner. Mainly buckling analysis can be performed in two methods such as, Eigen value buckling analysis and Non linear buckling analysis . Eigen value buckling analysis predicts the theoretical buckling strength of a structure. Non linear buckling analysis is more accurate than Eigen value analysis. Because it employs non linear, large deflection, static analysis to predict buckling load. In this work, CATIA which is a drawing software used for the modelling, and ANSYS software which is a finite element software used for the analysis of solar panel supporting structure. From this thesis work it is concluded that the stability of a structure depends on several factors such as sectional properties , sectional arrangements , modelling of the structure etc., and also find that the non linear buckling stress is less than that of the linear buckling stress.

Keywords— *buckling, Eigen value buckling analysis, Non linear buckling analysis, solar panel.*

I. INTRODUCTION

Since the development of technology, mobile phones changed the way of communication. Because of this increased use of mobile phones energy consumption of mobile towers also increases day by day. This needs high powered diesel generators, but it make tremendous amount of polluted gases and also it is a costlier method. So now a day's solar powered cell phone towers are generated. Solar panels are attached to the cell phone towers by means of supporting structures. Efficient utilization of solar energy is possible only by means of proper alignment of solar panels, it is possible only by means of properly arranged supporting structures. So the structural features of solar panel supporting structure is of quite important. Due to increased loads the supporting structure may leads to mathematical instability, which may cause difficulties in the functioning of the cell phone towers. So the stability analysis of supporting structure is an important task in the case of solar powered cell phone towers. The mathematical instability of supporting structure is called as buckling . Before the alignment of solar panels buckling analysis of supporting structure is necessary. Buckling proceeds either in stable, unstable or in equilibrium state. Stable and equilibrium buckling states are permitted because it do not collapses the structure i.e., in this case displacements increase in a controlled manner as loads are increased but the unstable state of buckling is not permitted because in this case deformations increase instantaneously, the load carrying capacity vary steeply and the structure collapses catastrophically. Stability analysis or buckling analysis can be done in different ways mainly as linear and non linear buckling analysis. Linear buckling analysis or Eigen value buckling analysis gives a buckling load which ma over predicts the real situation. So for a complete buckling study , Non linear buckling analysis is more preferable. Material non linearity and non linearity due to boundary condition are also investigated if it is necessary. A nonlinear buckling analysis can be performed on the original structure either without imperfection, or by incorporating an initial imperfection based upon a deformed shape obtained from a linear buckling analysis. Material nonlinearity during buckling is due to yielding or boundary nonlinearity. One major characteristic of non-linear buckling, as opposed to linear buckling (bifurcation buckling), is that non-linear buckling (snap through buckling) phenomenon includes a region of instability in the post-buckling region whereas linear buckling only involves linear, pre-buckling behavior up to the bifurcation (critical loading) point. The linear buckling load is larger than that of the non-linear buckling load, the comparison of linear and non-linear buckling stresses is carried out in the present thesis work

In this present thesis work, linear and non linear buckling analysis of solar panel supporting structure is carried out for the efficient and effective utilization of solar energy by means of proper alignment of solar panels on this supporting structures. Here the supporting structures are modeled by using a CAD software CATIA V5R20, then buckling analysis is carried out by using ANSYS. Different models are created then all of this is subjected to linear and non linear buckling analysis, and then the results are compared. Also study is extended to different cases of models by taking changing the alignment of sectional properties

II. METHODOLOGY AND ANALYSIS OF SOLAR PANEL SUPPORTING STRUCTURES

A. Solar panel supporting structure

Developing countries like India, has been slowly installing the solar panels for converting the solar energy to source of energy in the case of cell phone towers. The project started in 2010 with a goal of 50 percent of rural towers running on renewable energy by 2015, then going up to 75 percent of rural towers and 33 percent of urban towers green powered by 2020.

Fig.2.1 Solar Powered Cell Phone Towers (Source : Wikipedia)

Solar panel supporting structures can be designed in a variety of ways , and it depends on the wind velocity , loading etc. These support structures should be light in weight, durable, and flexible. Different supporting structures are available based on the structural arrangements. A key design decision is whether or not to mount the panels as "flat" or "sloped".

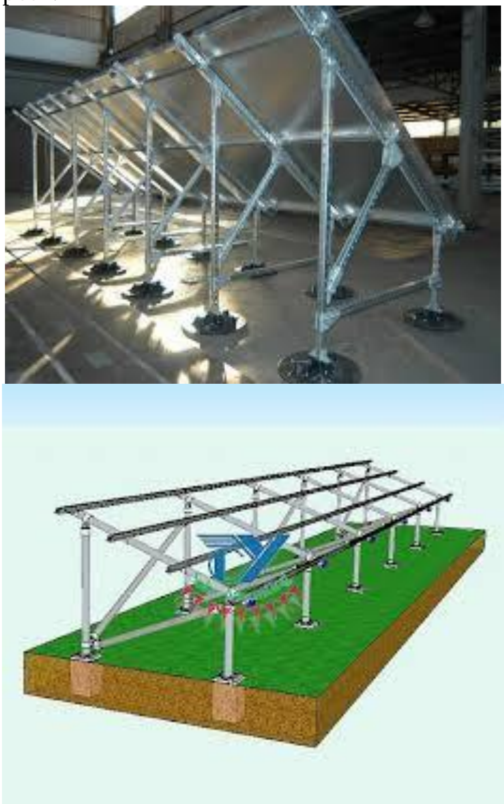


Fig.2.2 Solar Panel Supporting Structure (Source: Wikipedia)

When designing a new solar panel installation, wind, seismic and snow loads must be considered and efforts made to minimize their impact on the existing structure. In this present study, the seismic effects is not considering.

B. Methodology

There are two primary means to perform a buckling analysis

1. Eigen value buckling analysis
2. Non linear buckling analysis

1.Eigen value buckling analysis

This method predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural eigenvalues for the given system of loading and constraints. This is known as classical Euler buckling analysis. In real life, structural imperfections and non linearities prevent most real world structures from reaching their eigen value predicted buckling strength. that is it over predicts the expected buckling load. This method is not accurate for real world buckling prediction analysis.

2. Non linear buckling analysis

Non linear buckling analysis is more accurate than eigen value analysis. Because it employs non linear, large deflection, static analysis to predict buckling load. Its mode of operation is very simple. The modeling of geometric imperfections , load patterns, material non linearity's and gap is permitted in non linear buckling analysis.

In this project **Finite element procedure** is carrying out. In which the body is sub divided into small discrete regions known as finite elements. These elements are defined by nodes and interpolation functions. Governing equations are written for each element and these elements are assembled in to a global matrix. Loads and constraints are applied and the solution is then determined. ANSYS software which is a finite element software has been used for this study.

3. Finite element analysis

The basic concept of finite element method is discretization of a structure into finite number of elements, connected at finite number of points called nodes. The properties and governing equations are considered over these elements and expressed in terms of nodal displacement at nodes. Assembly of these nodal characters gives a set of equations. Solutions of these equations give the response of the structure. The accuracy of this method depends on the selection of proper number of finite elements such as by taking higher order elements can increase the accuracy of solution obtained by finite element method.

4. ANSYS Methodology

Typical ANSYS program includes three stages such as,

1. Pre- Processor
2. Solution
3. General Post processor

Pre processing is for defining the problem such as key points/lines/area/volumes , defining element type and material/geometric properties, and creating Mesh lines/area/volumes as required. In the solution stage we can assign the loads, constraints and solving . Here we specify the loads (point or pressure), constraints (translational and rotational), deformations. Further processing and viewing the results are in the post processing stage.

C. Modeling and analysis

The modeling and analysis of supporting structure is based on some assumptions such as:

1. Assumptions:

1. The wind load is acting in horizontal direction
2. Wind load is acting with a constant velocity
3. Only wind force and weight of the panel are acting on the structure. Other force are out of scope of this study.
4. The ends of the supporting structure is fixed to the tower system

2. Model specifications are;

Length of roof : 2927.765 mm
Inclination : 23 degrees
Braced frame structure is adopted

3. Material properties :

Modulus of elasticity along x direction= 19305.320 N/mm^2
ydirection=12672.5639 N/mm^2
z direction = 8873.552 N/mm^2

Poisson's ratio along x direction = 0.295
y direction = 0.275
z direction = 0.260

Modulus of rigidity along x direction = 4447.1185 N/mm^2
y direction = 2992.3246 N/mm^2
z direction = 2833.745 N/mm^2

4. Load calculations :

The arrangement of solar panels in structure is similar to double sloped roof trusses, for which the expression for wind pressure according to IS 875 part 3 is given by ,

$$P_{wind} = 0.6 \times V^2$$

Wind force = Wind Pressure x Effective area of panel

$$F_{wind} = P_{wind} \times A_e$$

A_e = Total area of sloped roof x Sine of angle of inclination

sin α = Projected area line / Total area line

$$A_e = A \times \sin\alpha$$

$$F_{wind} = P_{wind} \times A \times \sin\alpha$$

Design velocity, V can be calculate by using the equation

$$V = k_1.k_2.k_3.V_b$$

k_1 =Risk coefficient or probability factor. For all general building and structures = 1

k_2 = Terrain, height and structure size factor = 1

k_3 = Topography factor. Its value is taken as unity, if the slope of ground is $< 3^0$.

It is assumed that the tower is located in zone IV. and wind load is assumed as 170km/hr that is 47m/s also assume that the panel is made of aluminum alloy of weight 750kg which is acting in vertical direction.

V_b = Basic wind speed of zone IV = 47 m/s

V = 47m/s

$P_{wind} = 0.6 \times V^2 = 0.6 \times 47^2 = 1336.7$ Pa

$F_{wind} = P_{wind} \times A_e = 1336.7 \times 42.64 = 57$kN

This wind force is resolved in to vertical and horizontal components

$F_V = 59825.9$ N and $F_H = 2271.67$ N

Table 2.1 Wind Zone

Wind zone	Basic wind speed (m/ s)
VI	55
V	50
IV	47
III	44
II	39
I	33

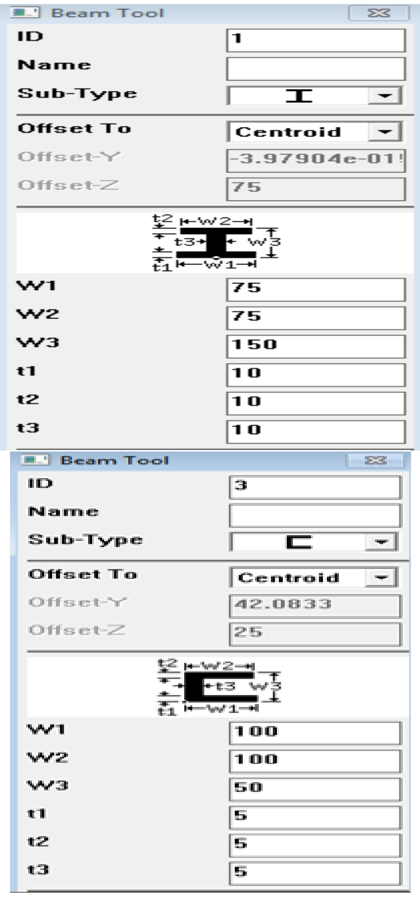
III. EXPERIMENTAL MODELS

In this present thesis work, four models are created and also each model consist of eight cases.

A. Model 1

This model is generally implemented in the industries . So the datas are collected from a popular company in India, but considering the privacy of this company the name is not revealed here. The collected sectional properties are as follows.

Here I, C and L sections are adopted and studied the buckling behaviour according to their positions which is adopted by the 'X' named company. The properties of these sections are illustrated below:



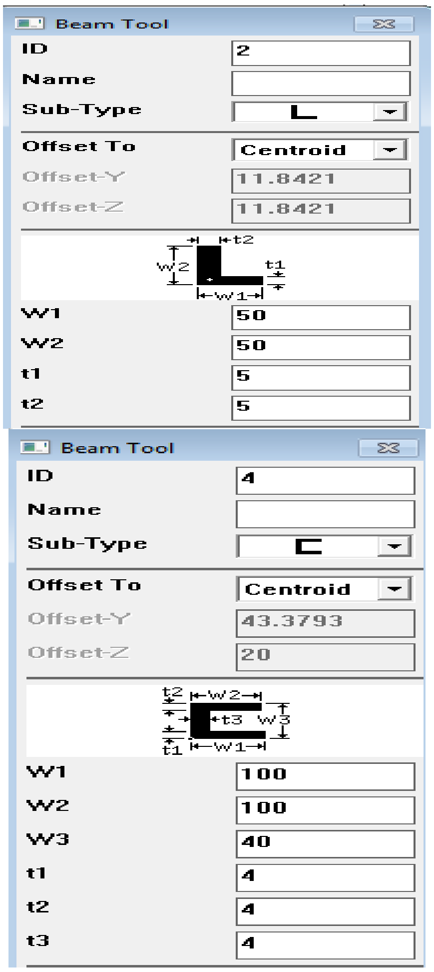


Fig.3.1 Specifications Of I, C ,L Sections

Solar panel supporting structure is modeled by using the software CATIA V5R20 . It is computer aided 3D interactive application used for modeling purpose. Here the supporting structure is modeled in xy plane and the dimension of the structure as below.

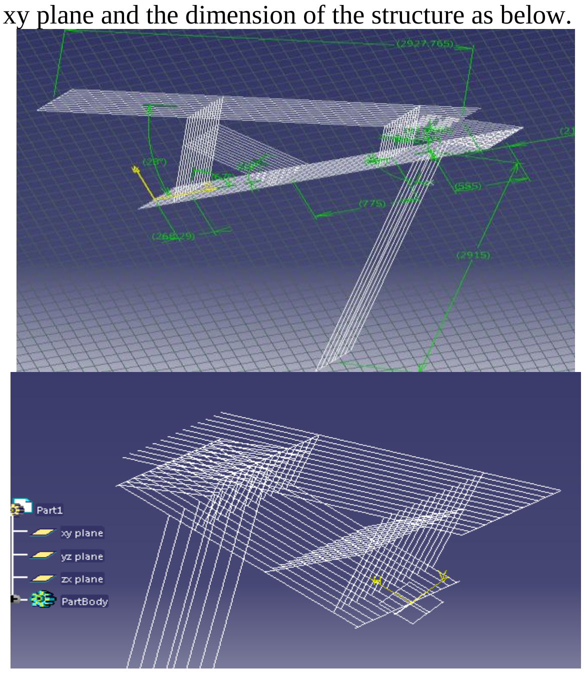


Fig.3.2 Solar Panel Supporting Structure Model

These models are imported in to ANSYS and then it is analyzed with above properties and sections

1. CASE 1 : Base I, Panel roof C, and bracings L and C

Here base is provided with I and C sections , roof is made of C section , and the bracings are of L and C sections.

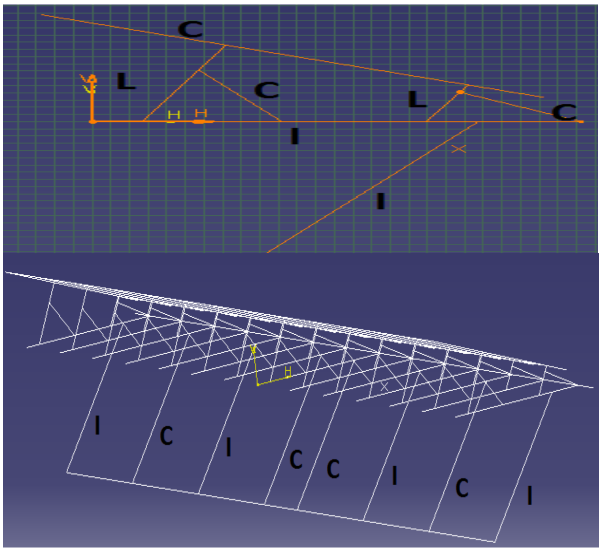


Fig.3.3 Sectional Arrangements For Case 1

Analysis of solar panel supporting structure with sectional and other properties given by the company in the industry is completed . By changing the sectional arrangements to improve the stability of the structure is included in this thesis work.

2. CASE 2 : Base I, Panel roof C, and Bracings C

First the analysis is carried out with the sectional arrangement given by the company. Now the arrangements of sections are varied , in this case the angle sections (L) in the bracings is changed to channel sections (C), but the sectional properties are similar to that of the original case given by the company.

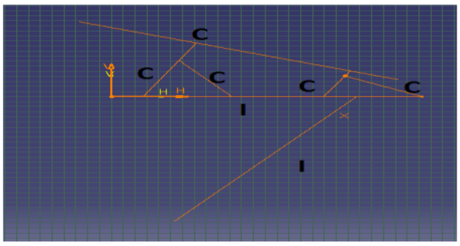


Fig.3.4. Sectional Arrangements For Case 2

3. CASE 3 : Base I, Panel roof L and Bracings L and C

From the previous cases we obtained that more buckling occurs in the panel supporting roof structure, so it must be more strengthen, by changing the sectional arrangements to achieve the stability is carried out. Here the channel section in the roof is replaced by angle section .

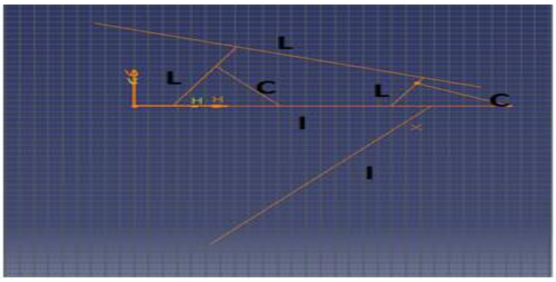


Fig.3.5 Sectional Arrangements For Case 3

4. CASE 4 : Panel L, Supports C , and Base I

From the above case we can conclude that angle (L) section is more suitable in the panel roof. Here roof is provided with L , and the bracings are changed to C , to check the stability.

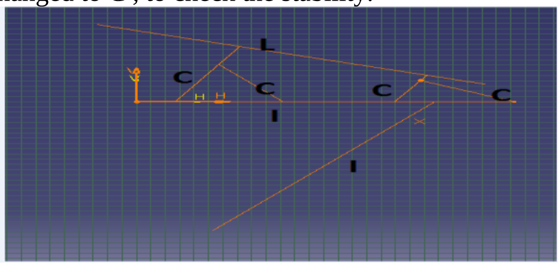


Fig.3.6. Sectional Arrangements For Case 4

5. CASE 5 : Base I, Panel roof L, and Bracings L

From the above cases we got an idea that the more stable structure have L sections on the roof , and also on the bracing supports. So here the structure is constructed with L sections on the panel roof , bracings, and the base supports are provided with I sections.

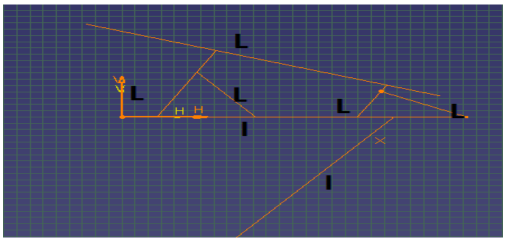


Fig.3.7. Sectional Arrangements For Case 5

By considering the cost factor , we can check the stability of this structure with other arrangements also such as ;

6. CASE 6 : FULL C

Here the entire structure is provided with channel section. That is the panel roof, bracings and the base supports are provided with the C sections of given specifications

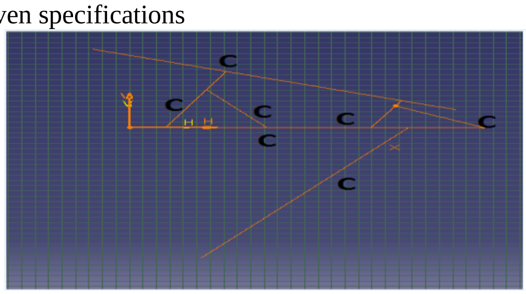


Fig.3.8. Sectional Arrangements For Case 6

7. CASE 7 : FULL L

Here the entire structure is provided with L section.

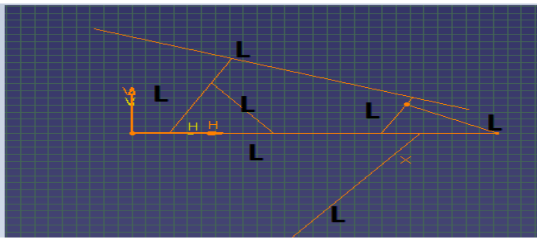


Fig.3.9.Sectional Arrangements For Case 7

8. CASE 8 : FULL I

We know that I section has more strength than any other sections, so here we provide entire structure as I section.

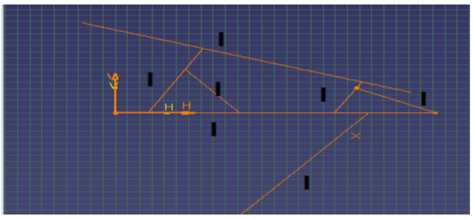


Fig.3.10. Sectional Arrangements For Case 8

B. MODEL 2

In the previous analysis, the I, L, and C sections provided is given by the company. Same model is analyzed with standard I, L, and C sections such as I section of 300x300x140 having thickness of flange as 12.4 mm and thickness of web as 7.5 mm. L sections are of ISA 130x130x8 and C section of ISMC 150x150x75 . Similar to the above sectional arrangements , these sectioned models also carried out for linear and non linear buckling analysis . Here the analysis is carrying for all the above eight cases .

C. MODEL 3

In the previous cases the solar panel supporting structure with sectional properties and arrangements used by a known company in the industry is analyzed. Here the modeling of that supporting structure is changed to obtain the more stable structure. The positioning of bracings is varied and its linear buckling analysis is included in this thesis work.

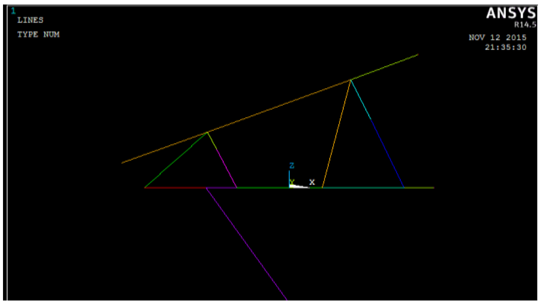


Fig.3.11 Model 3

The different sectional arrangements are worked out and the linear buckling analysis of these different models are carried out similar to that of the previous cases.

D. MODEL 4

In the above case we can see that the buckling load that means the stability of the structure depends on the positioning of bracings, and the previously taken model has better stability than the other one. It is necessary to check the other models also to get the better result and conclusion. Here x shaped bracing is adopted at the centre of the base structure.

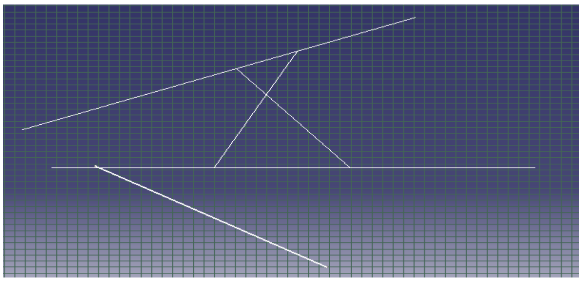


Fig.3.12 model 4

IV. RESULTS AND DISCUSSIONS

The linear and non linear buckling analysis of all the above models and cases are completed , the results are compared and it is summarized in this chapter. From the obtained results we can conclude the effects of various parameters on buckling stresses and the comparative study of linear and non linear buckling analysis is as follows ;

A. Linear buckling analysis

The linear buckling analysis of all the selected structural models are carried out in this chapter. The results obtained from this analysis is illustrated below.

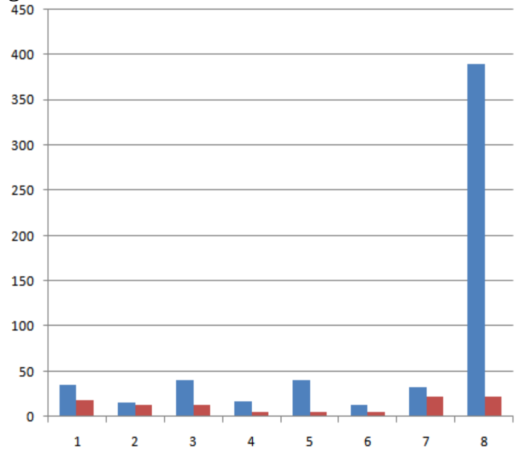
1. MODEL 1 :

The linear buckling analysis of all the eight cases of model 1 is completed and the values are compared here to find the effect of sectional arrangements on buckling and also the non linear buckling analysis is carried out and the results are shown in table.

Table: 4.1 . Comparison Between Linear & Non Linear Buckling Stress

Cases	Linear buckling stress	Non linear buckling stress
Case1	210.116	137.99
Case 2	295.746	64.828
Case 3	111.199	66.7203
Case 4	131.946	32.998
Case 5	110.332	65.3935
Case 6	469.399	145.937
Case 7	560.265	464.699
Case 8	6.58897	6.49839

The linear buckling analysis of model 1 solar panel supporting structure with different cases are completed and the results obtained shows that the buckling load factor depends up on the arrangement of different sections within the structure. From the obtained results it is clear that the many of the above structure buckled with the given loading condition. More buckling occur when the structure is completely made up of C sections and its buckling load factor is 0.198143 , so it cannot be used as the supporting structure. The structure which is entirely made up of I section shows better stability against buckling , but considering the economy this structure is not generally adopted. By considering the strength, stability and cost most suitable structure is the one which is similar to that of original case but the roof of the panel is replaced by L , which is having a BLF 0.624373 and it is preferred as the solar panel supporting structure for the given conditions.



Graph: 4.1 Comparison B/W Linear And Non Linear Buckling Load

2. MODEL 2

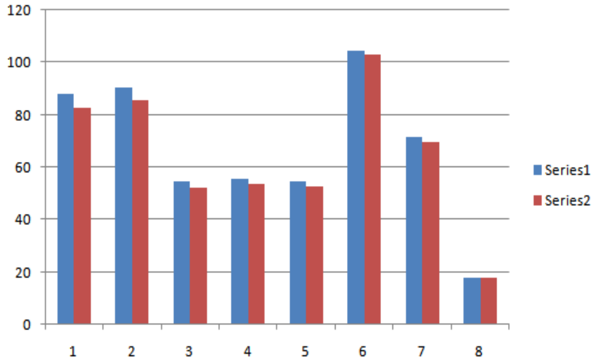
Table: 4.2 . Comparison Between Linear & Non Linear Buckling Stress

Cases	Linear buckling stress	Non linear buckling stress
Case1	87.1459	53.136
Case 2	88.76	84.2682
Case 3	52.0152	49.6375
Case 4	51.4072	49.3381
Case 5	50.14	45.7
Case 6	107.588	105.198
Case 7	72.5684	68.8087
Case 8	16.087	15.9293

Here the structure is more stable than that of the model 1, because all the cases have BLF greater than 1 , so there is limited buckling occurs. Here also I section is more better , but it is not adopted for the supporting structure because of the increased cost. The structure which is entirely provided with L section have better stability , but considering the strength criteria the base supports must be an I section, so more suitable case for solar panel supporting structure is the one which is similar to that of original case but have panel roof as L sections, and have BLF 1.41248 and buckling load is 90.903kN.

From this obtained result we can see that the non linear buckling stress is always lesser than that of the linear buckling stress.

This results can be graphically shown as:



Graph: 4.2 Comparison B/W Linear And Non Linear Buckling Load

Here blue bars indicates the linear buckling stress and the red bar indicates the non linear buckling stress. Here it can be easily seen that the non linear buckling stress is less than that of linear buckling stress

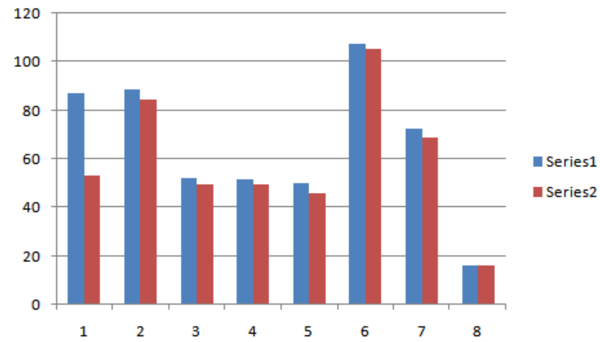
3. MODEL 3

From the linear and non linear buckling analysis of all the cases of model 3 is tabulated here as follows:

Table: 4.3 . Comparison Between Linear & Non Linear Buckling Stress

Cases	Linear buckling stress	Non linear buckling stress
Case1	87.9578	82.6796
Case 2	90.69	85.929
Case 3	54.4583	52.3236
Case 4	55.542	53.4752
Case 5	54.7925	52.7074
Case 6	104.347	102.846
Case 7	71.6098	69.6374
Case 8	17.899	17.805

Here also obtained results prove that the linear buckling stress is greater than that of non linear buckling stress. Graphical representation is as follows:



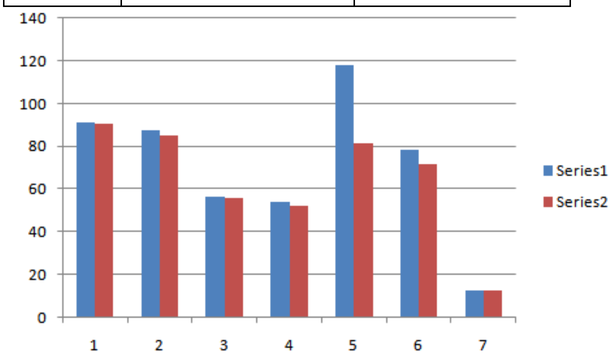
Graph: 4.3 Comparison B/W Linear And Non Linear Buckling Load

4. MODEL 4

Table: 4.4 . Comparison Between Linear & Non Linear Buckling Stress

Graphical representation of obtained result is:

Cases	Linear buckling stress	Non linear buckling stress
Case1	91.44	90.48
Case 2	87.66	85.3
Case 3	56.77	55.862
Case 4	54.393	52.281
Case 5	118.272	81.5739
Case 6	78.5005	71.63
Case 7	12.55	12.50



Graph: 4.4 Comparison B/W Linear And Non Linear Buckling Load

V. CONCLUSION

From this work it is concluded that the stability of a structure depends several factors such as sectional properties, sectional arrangements, modeling of the structure etc. Above results can be concluded as standard sections improve the stability of the structure, the arrangements of I, C, and L section affect the buckling behaviour of the structure. Among these sections I section have more stability but it is not economical ,and the C section are less stable during buckling. During loading such as due to the weight of the panel and the effect of wind, more stress occurring at the roof of the panel supporting structure, the L section is more suitable at the place of maximum stress. The inclination of bracings affect the buckling behaviour, that is the angle of panel supporting roof and the angles of bracings affect the stability, so analysis should be carried out for a properly aligned models, model 2 and model 3 are much better than other two structures. Also case 3 and case 5 gives better results. From the result obtained from the above work, we can conclude that the non linear buckling stress is lesser than that of the linear buckling stress. So another conclusion is the nonlinear buckling analysis is more accurate than linear buckling analysis.

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