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Optimum Design of Stiffened Plate-Structure Subjected to Static Loading

Dr. Hatem H. Al-Taee **Dr. Adil A. Al-Moosawy**
Mohammed A. Al-Shojary
University of Babel / College of Engineering/ Departement of Mechanical Engineering

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Abstract

The field of structural optimization (optimal design) has grown rapidly over the past decades with many different optimization methods that could be used to produce a structure of minimum weight. This research deals with two aspects, in the first, a general numerical technique based on the finite element analysis and it suggests to investigate the preliminary behavior of metal stiffened plate under action of static load environment. The technique was included a finite element model of the structures using high- order isoparimetric plate elements to be used to create a certain models to obtain their optimum design. The models are characterized such that, each model is builded using different types of stiffener configuration. The second aspect was concerned with the investigation of the optimum design configuration of the structures. The optimization techniques used is called Morphing Evolutionary Structural Optimization (MESO). The Morphing ESO was examined in this research to be applied on stiffened plate structures. The Morphing ESO is based on the simple concept that by slowly removing efficient material from a structure, the residual shape evolves in the direction of making the structure better. The mathematical representation of this method is accomplished in this thesis with full programming and modification required being applicable to a new structure with a new condition. Where the thickness of the plate and stiffeners, and the stiffener height are the design variable. While the objective of the optimization is the structure weight and inequality constraints are the maximum Von Misses stress required for each structure.

Keywords: Static Analysis, Bending , Evolutionary Structural Optimization, Stiffened Plate, ANSYS.

Introduction:

Structural optimization has received ever increasing in civil, chemical and especially aeronautical engineering with the advent of high speed computers; the tools of structural optimization are no longer resituated to the classical differential calculus and variation calculus. Indeed, various numerical search techniques have been developed over the past three decades.

The optimization problem is classified on the basis of nature of equations with respect to design variables. If the objective function and the constraints involving the design variable are linear then the optimization is termed as linear optimization problem. If even one of them is nonlinear it is classified as the non-linear optimization problem. In general the design variables are real but some times they could be integers for example, number of layers, orientation angle, etc. The behavior constraints could be equality constraints or inequality constraints depending on the nature of the problem.

The structural optimization problem can be posed as:

Minimize or Maximize

$F = F(x_1, x_2, x_3,\ldots\ldots, x_n)$

Subject to:

$$C_1=C_1 (x_1, x_2, x_3,\ldots\ldots,x_n)$$
$$C_2=C_2 (x_1, x_2, x_3,\ldots\ldots,x_n) \qquad ...(1)$$
$$C_n=C_n (x_1, x_2, x_3,\ldots\ldots,x_n)$$

And

$$\phi_1= \phi_1(x_1, x_2, x_3,\ldots\ldots\ldots,x_n) \geq 0$$
$$\phi_2= \phi_2(x_1, x_2, x_3,\ldots\ldots\ldots ,x_n) \geq 0 \qquad ...(2)$$

$\phi_n = \phi_n(x_1, x_2, x_3, \ldots, x_n) \geq 0$ $x_1, x_2, x_3, \ldots, x_n$ are the design variables ,$C_1, C_2, \ldots, C_n$ are equality constraints and $\phi_1, \phi_2, \ldots, \phi_n$ are inequality constraints. The nature of the mathematical programming problem depends on the functional form of F, C, and ϕ, if these are linear function of design variables, and then the mathematical programming problem is treated as linear programming problem. On the other hand if any one of them is a nonlinear function of the design variable, then it is classified as nonlinear programming problem.

There are three main classes of structural optimization problems depending on the type of the design variables used: sizing, shape, and topology. In sizing optimization problems, the aim is usually to minimize the weight of the structure under certain behavioral constraints on stresses and displacements. The design variables are most frequently chosen to be dimensions of the cross-sectional area of the members of the structure. In structural shape optimization problems, the aim is to improve the performance of the structure by modifying its shape. The design variables are either some of coordinates of the key points in the boundary of the structure or some other parameters that influence the shape of the structure. Structural topology optimization assists the designer to define the type of structure that is best suited to satisfy the operating conditions for the problem at hand.

During the past three decades, many numerical methods have been developed meet the demands of structural design optimization. These methods can be classified in two general categories [1]:

1. Deterministic (Gradient based method).
2. Probabilistic (Heuristic based method).

The research work dealing with the optimum design of stiffened plate structures is an issue that has not yet been addressed adequately by the scientific community. Haftka, R. T [2] solved a material topology optimization problem where the design model is adapted during the optimization process. Marcelin et al [3] determined optimum hat-stiffened compression panel designs by using a structural synthesis technique. Effects of simplifying assumptions made in the bending analysis for the optimization program are investigated using a more accurate analysis, which is a linked plate element program. Optimization results for an aluminum panel are compared with available results. Optimization results for hat-stiffened graphite-epoxy panels show a 50-persent weight savings over optimized aluminum panels. Using the structural synthesis technique, composite panels are shown to posses a variety of proportions at nearly constant weight. Patnaik. and Sannaran. [4] Presented the optimum design of stiffened cylindrical panels weight as the objective function and constraints or the frequencies in the presence of initial stresses by using unconstrained minimization techniques of mathematical programming problem. The interaction between the buckling constraints and the frequency constraints in the presence of initial stresses is inclined in the following. Loss of load carrying capacity due to imperfection and due to suddenly applied load is included in the buckling analysis. Ding,Y.[5] treated with finite element analysis and the optimization problem of sandwich construction. The thickness of the faceplates and the core are used as design variables. In 1992, a new method of structural optimization was developed by (XIE and Steven.,1998) [1] called the Evolutionary Structural Optimization (ESO) method. Evolutionary Structural Optimization (ESO) is a design method based on the simple concept of gradually removing inefficient material from a structure as it is being designed. Through this method, the resulting structure will evolve toward its optimum shape. An engineer must specify the design domain and loads and kinematics constrains. The past research has shown that the ESO method could be successfully applied to all types of elements, i.e. beam, plates and bricks, structural with multiple load cases, to structural dynamic problem and to structure with non-linear properties. However, the ESO method so far, does not allow to incorporate any non- structural constraints to be incorporated during its process [6].

The initial stages of development of the ESO method were employed in verifying the classical single load problems to demonstrate its applicability. Once the method had been shown to work accurately and efficiently [7], it was then extended to structures with multiply load cases.

2. Analysis of stiffened structures:

The use of stiffened structural elements in most branches of structural engineering began in the nineteenth century with the application of steel flat or curved plates for hulls of ships and subsequently with the development of steel bridges and aircraft structures and other situations where the reduction of self-weight is an important design objective for satisfying the requirements of increased stiffness and reduced weight.

Stiffened plate and cylindrical structures have found widespread in a variety of engineering structures such as steel chimneys, pipes and conduits, missile bodies, side shells of ships, its deck and superstructures, submarines and offshore structures because it can achieve economy in weight with no sacrifice of strength. Stiffened cylindrical structure are very common in engineering practice because they combine high stiffening characteristic with low material volume [7]. Plates stiffened by longitudinal and transverse members are one of the most common structural components. Use of stiffeners makes it possible to resist highly directional loads, and to introduce multiple load paths that many provide protection against damage and crack growth under both compressive and tensile loads. The biggest advantage of the stiffeners though, is the increased bending stiffness of the panel with a minimum of additional material.

Stiffened plates have been considered for used in these weight-sensitive structures, where high strength-to-weight and stiffness-to-weight ratios are required. Besides their high strength and stiffness, stiffened plates are usually thin. Thus, bending is a critical consideration for the optimum design of structures made of such plates. These plates are fabricated as an assembly of individual plates. This allows the designer to select the most effective disposition of material in the cross section to carry the specified loading. Figure (1) shows types of honeycomb core.

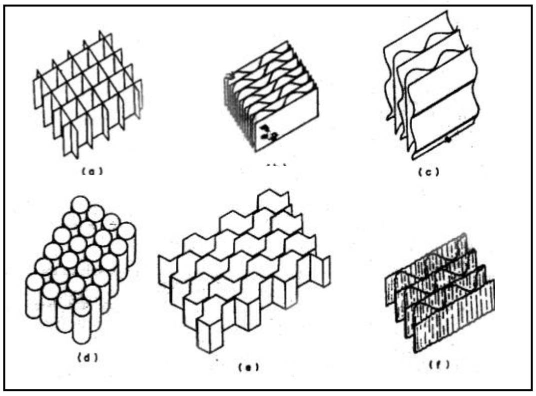

Fig. 1. Types of Honeycomb Core.

2.1. Stress-Strain Relation-Ship:

The stress- strain relations in coordinates aligned with principle material directions are given by:[3].

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \tau_{xy}\\ \tau_{xz}\\ \tau_{yz}\end{Bmatrix}=\begin{bmatrix}c_{11} & c_{12} & 0 & 0 & 0 & 0\\ c_{21} & c_{22} & 0 & 0 & 0 & 0\\ 0 & 0 & c_{33} & 0 & 0 & 0\\ 0 & 0 & 0 & c_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & c_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & c_{66}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_z\\ \gamma_{xy}\\ \gamma_{xz}\\ \gamma_{yz}\end{Bmatrix} \quad ...(3)$$

From the usual thin plate assumption, the normal stress σ_z is assumed small enough to be neglected and the corresponding ε_z is eliminated (plane stress problem is assumed) [8]. Therefore, the equation (3) becomes:

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\\ \tau_{xz}\\ \tau_{yz}\end{Bmatrix}=\begin{bmatrix}c_{11} & c_{12} & 0 & 0 & 0\\ c_{21} & c_{22} & 0 & 0 & 0\\ 0 & 0 & c_{44} & 0 & 0\\ 0 & 0 & 0 & c_{55} & 0\\ 0 & 0 & 0 & 0 & c_{66}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\\ \gamma_{xz}\\ \gamma_{yz}\end{Bmatrix} \quad ...(4)$$

or

$$\{\sigma\}=[E]\{\varepsilon\}$$

Where:

$c_{11}=c_{22}=(1-\nu)/A$, $c_{12}=c_{21}=(\nu)/A$, $c_{44}=G$, $c_{55}=fG$, $c_{66}=fG$,

$$A=\frac{(1-\nu)(1-2\nu)}{E},\quad G=\frac{E}{2(1+\nu)}$$

Where f is the shear factor for homogeneous plate should be given a value of 1.2 in order to account for the fact that the transverse shearing stresses produce too little strain energy [6].

2.2. Element Parameters:

All above finite element models have been created using linear four- node quadrilateral plane elements. This type of elements is used for plate and shell structures for both membrane and flexure load conditions. In this section, the parameters that are concerned with the selected element are discussed. These parameters are basically included; the element property parameters include the material properties and the thickness of the element at each node. For the rectangular- honeycomb finite element models, the material properties for all elements are specified as isotropic material. The ration of thickness value to the smallest element dimension must be equal or less than (0.1) in order to maintain the element to be thin [3].

The element degrees of freedom are assigned at each node along the element coordinate system Figure (2) shows the element degrees of freedom of any point located on the element is function of that of all element nodes ,as:-.

$$\begin{Bmatrix} u(\xi,\eta) \\ v(\xi,\eta) \\ w(\xi,\eta) \end{Bmatrix} = \sum_{i=1}^{4} N_i(\xi,\eta) \begin{Bmatrix} u_i \\ v_i \\ w_i \end{Bmatrix} + z \sum_{i=1}^{4} N_i(\xi,\eta) \begin{Bmatrix} \theta_{xi} \\ \theta_{yi} \\ 0 \end{Bmatrix} \quad \ldots(5)$$

where:

- $z = -\frac{t}{2} \rightarrow \frac{t}{2}$

N_i=Shape functions.

z = nodal thickness

u_i , v_i , w_i= global nodal displacements.

θ_{xi} , θ_{yi} = global nodal notations

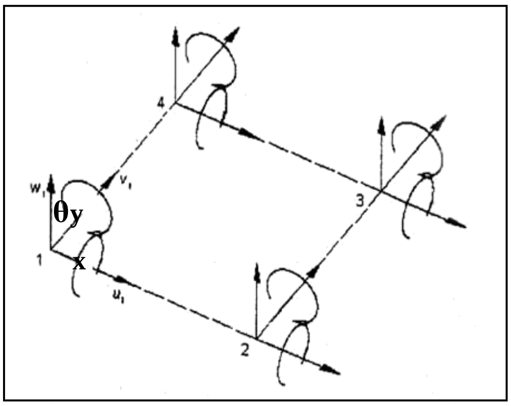

Fig. 2. The Element Degrees of Freedom.

It is obvious that each node has five degrees of freedom, and then the element is of twenty degrees of freedom. Not all but some of the element degrees of freedom are considered at each of the finite element models, depending upon the function (boundary conditions) of that model.

2.3. Static Analysis

Static analysis is achieved on each of the finite element models for each function with their corresponding boundary conditions and load sets. Static analysis solution has been included the calculation of the effects of the applied static distributed loads on each model for each function with the corresponding boundary conditions. These effects included displacements, strains, and stresses that are induced in the structure due to the applied loads. The static analysis is governed by the following equilibrium equations (in matrix notation):

$[K].\{u\}=\{F\}$ ...(6)

where:

$[K]=\sum_{e=1}^{N}[K]_e$:the assembled stiffness matrix.

and

$$[k]_e = \int_A [B]^T[E][B]dA = \int_{-1}^{1}\int_{-1}^{1}[B]^T[E][B]|J|d\xi d\eta \quad ...(7)$$

$$[F]_e = \int_A [B]^T[p]dA = \int_{-1}^{1}\int_{-1}^{1}[N]^T[E][p]|J|\,d\xi d\eta \quad \ldots(8)$$

ANSYS package solve the above equilibrium equations to obtain the following results:

- Displacements of each node along their free degrees of freedom.
- Strains, and stresses at each element along element coordinate axis.
- Von Misses stresses and the maximum shear stresses.

3. Morphing Evolutionary Optimization

In this section the work presented deals with the Morphing Evolutionary Structural Optimization (MESO) method. The Morphing ESO method lies somewhere between a heuristic and a gradient based optimization method. This means that MESO can search through the structural domain, locating both local and global minimal [2].

Because of its evolutionary characteristics, it does not stop when an apparent minimum has been located; instead, the evolution process continues to evolve the structure in search for a better one. Compared with ESO, instead of removing an element totally, Morphing ESO can remove the element gradually. The reason for this was that when an element satisfied the ESO inequality constraints, instead of removing it, it was change to another element of either less strength, thickness or smaller density, thus morphing that element instead of removing it.

3.1 Morphing ESO Procedure:

The principles and procedure that define Morphing ESO are as follows [8].

1- Set up a dense finite element mesh that fully covers the maximum design domain of the structure.

2- Apply all kinematics boundary constraints, loads, materials, element properties, etc.

3- Specify the criteria used to optimize the structure, for example Von Mises stress required.

4- Specify the ESO driving parameter, for example the maximum, or mean Von Mises stress of the structural domain.

5- Define a set of allowable discrete volumes in decreasing order of the strength that each original element of the structure is made. The discrete set could be a set of plate thickness, modulus of elasticity or density or others.

This set could be written in the following:

$x_e = \{A_1, A_2, A_3, A_4,.., A_n\}$ …(9)

or
$x_e = \{t_1, t_2, t_3, t_4, .., t_n\}$ …(10)
or
$x_e = \{E_1, E_2, E_3, E_4, .., E_n\}$ ...(11)
where:
A is the beam cross sectional area with $A_1 > A_2 > A_3 > A_n$.
E is the material modulus of elasticity $E_1 > E_2 > E_3 > E_n$.
t is the material thickness with $t_1 > t_2 > t_3 > t_n$
6. Carry out a linear static finite element analysis of structure.
7- Using the following ESO inequality, determine if there are any elements in the structure that satisfies it. If an element satisfies this equation, the elements discrete value which is allowed to the next discrete value in the set. Since the set is arranged in decreasing order of strength, this new value will be weaker than the one it replaces.

$$\sigma_{VM,e} \leq RR * \sigma_{VM,Max} \quad ...(12)$$

where:
$\sigma_{VM,e}$ =Von Misses stress or selected criterion of element e.
$\sigma_{VM,Max}$ =Maximum von Misses stress or selected criterion of the structure.
and:
RR=Rejection Ratio, used to control the element removal process.

$$RR = a_o + a_1 * ss + a_2 * ss^2 + a_3 * ss^3 \quad ...(13)$$

where:
ss Steady state number. (Equal to the iteration number)

$$0 \leq RR \leq 1$$

a_o, a_1 are coefficients, determined from experience with Morphing ESO method, usually the first two forms are considered.

This can be explained in the following fashion. If at iteration k, the element eth has a discrete value x_{ei}^{k}, then in iteration k+1, if the equation above is satisfied, the discrete value of element becomes x_{ei+1}^{k+1}
where:
$x_{ei}^{k} > x_{ei+1}^{k+1}$
e is the element.
i is the i^{th} position in the discrete set.
k is the k^{th} iteration in the evolution cycle.
x_{ei}^{k}: is the discrete value i of element e in iteration k.
7- If a state is reached where no element of the structure satisfies the above equation a steady state and local optimum has been reached. The steady state number is then incremented by (1) and steps (7) and (8) are repeated.
8- Step(6) through (9) are repeated until the minimum value of the performance index is reached, or until the desired minimum volume or weight of the structure has been reached.

3.2. Mathematical Representation of the Morphing

From the description of the Morphing ESO method, it can be seen that Morphing is a discrete optimization problem similar to the classic ESO definition, but with a discrete set of variables instead of the {0,1} binary set of classic ESO [6].

The mathematical representation for Morphing ESO is as follow:

$$\text{Minimize} \quad f(x)=PI=\frac{\sum_{e=1}^{N} \sigma_e \cdot v_e}{FL} \quad ...(14)$$

Subject to,

$$y_e \ (ye * \sigma_{VMe} - RR * \sigma_{VM\max}) \geq 0 \quad ...(15)$$

$$x_e = \{d_1, d_2, d_3, \ldots, d_i, d_{i+1}, \ldots, d_N\} \quad ...(16)$$

$$y_e \in Y_e = \{1, \frac{d_{i+1}}{d_i}\}$$

where:
PI is performance index (substantial number of optimization methods available for designer /engineer to use as an aid to the design of the structure).
e is the element.
x_e is the set of allowable elements in the structure.
N is the number of elements in the structure.
di is the discrete value at location i in the set.
ye is the Morphing Multiplier where $d_i > d_{i+1.}$
Ye is the set of Morphing Multiplier values.

Initially the inequality constraint has a morphing multiplier magnitude of 1. However, if the stresses in the element cause the constraint to be violated, the second Morphing Multiplier is selected and the discrete value of the element is changed to the value d_{i+1}.

Although by doing this the inequality constraint may remain violated, the Morphing Multiplier will reduce the amount of the violation. Carrying out another finite element analysis will reveal the true effect of the discrete value change and the amount by which the inequality criterion is now violated.

4. Results and Discussion:

Optimization results for stiffened plate are presented in this section. The plate material is Aluminum which is assumed as an isotropic material. The properties are shown in Table (1) [4].

Table 1
Properties of Material.

Material	Aluminum
Young's Modulus(E)	70.3 Gpa
Poisson's ratio(υ)	0.33
Density	2712.64 kg/m3

4.1 Flat Plate Structure:

The optimal model of flat plate with all kinematics boundary conditions is presented. The plate is exposed to uniformly distributed load [see Appendix]. Since the structure is required to optimize. Therefore, the Morphing Evolutionary Structural Optimization is used to carry out the optimization of this structural. Total number of elements are ninety six (8*12) elements, each side element is square of dimension (5*5) cm^2. The length of the flat plate is 60 cm and the width is 40 cm shown in Fig.3. Thickness of element was proposed to be the design variable of this model. Initially for each element the thickness is set the maximum value (6.5mm). Von Misses criterion was used as an optimization criterion while the maximum Von Misses criterion was used as driving criterion. The ANSYS package is used to do the analysis of the structure. For each element if the optimization criterion is satisfied, the thickness of each element is set in to the lower value using Morphing Evolutionary Structural Optimization. The objective of the optimization is the structure weight and the inequality constraints are the maximum Von Misses stress required in this structure.

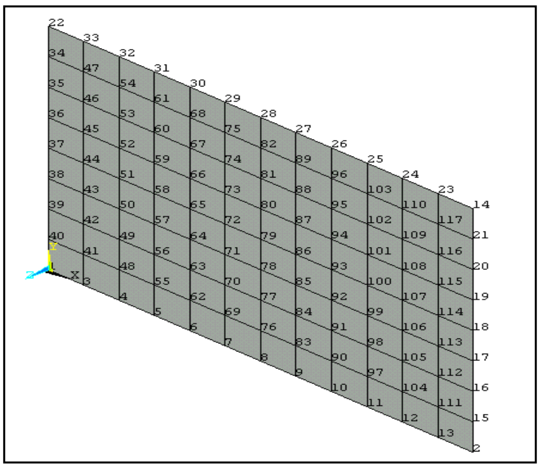

Fig. 3. Flat Plate Finite Element Model.

The evolution process starts with initial rejection ratio RR_o=0% and evolutionary rate ER=0.25%.The stress distribution (Von Misses contour) for each element at steady number SS=0 (no optimization is performed). The mean value of stress about 116.32 N/mm^2 and the maximum value about 232 N/mm^2shown in Fig. (4).

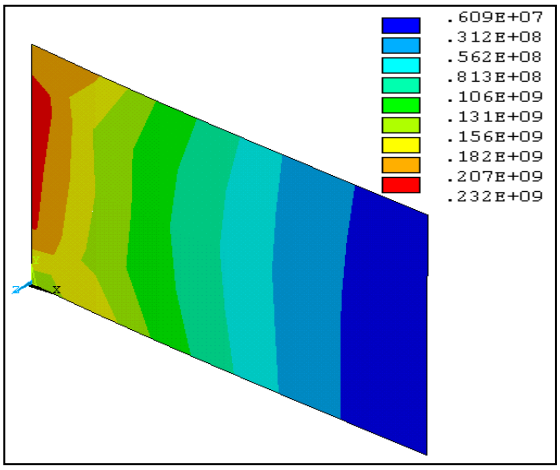

Fig. 4. Element VON MISES Contour at SS=0.

The Performance Index (PI) versus steady state number is plotted as in Fig.(5). The weight index (w/wo) is plotted versus the steady state number as shown in Fig (6). From Fig.(5) shown that the best set are no.43 where the minimum value of performance index (PI=2.09) and weight index (w/wo)= 76.3% from Fig.(6). The stress distribution versus steady state number for mean and maximum Von Misses stress is shown in Fig.(7). It is shown that the mean stress is increased with increasing the steady state number but the maximum stress is still with the same range. Figure (8) show that the Von Misses contour for this steady state (no.43).It is shown that the maximum Von Misses stress is(234 N/mm^2), and the mean Von Misses stress is (153.67 N/mm^2).

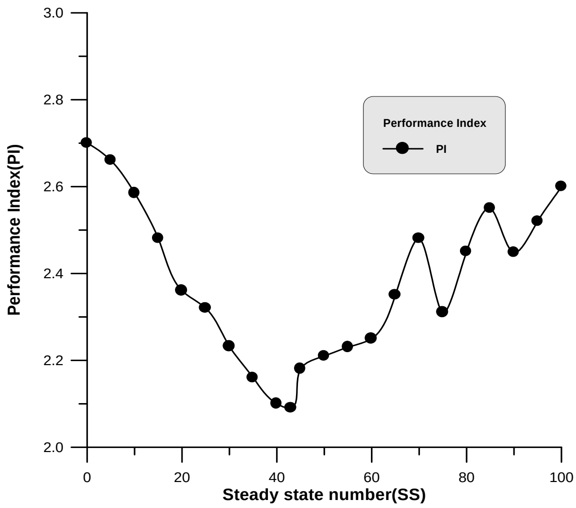

Fig. 5. Performance Index Versus Steady State Number.

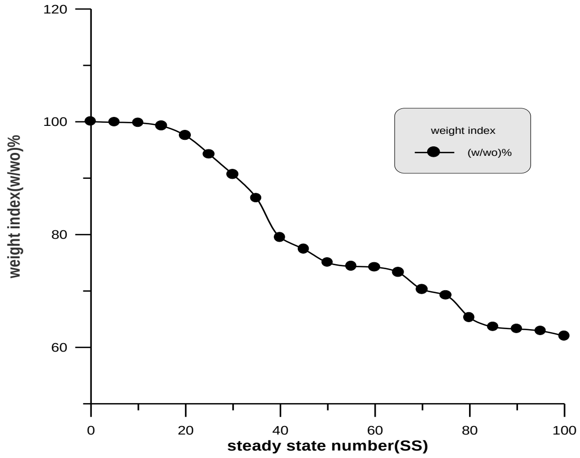

Fig. 6. Weight Index versus Steady State Number.

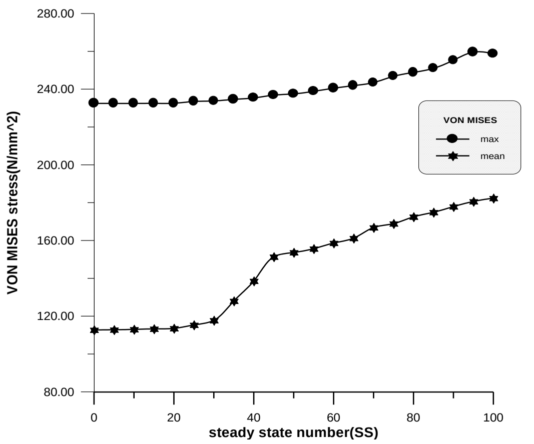

Fig. 7. Element VON MISES Contour versus Steady State Number.

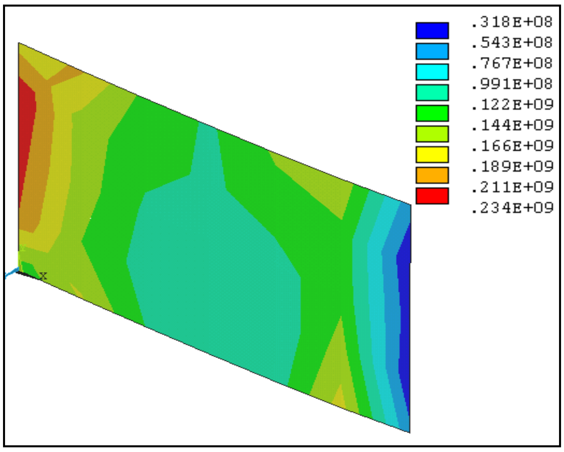

Fig. 8. Best Topology (VON MISES) Contour.

The Von Misses stress distribution for the flat plate is illustrated in Fig. (9). It is note that the maximum Von Misses stress occurs at the distances of 0-15% from the plate constraint because of bending moment. It is notice the maximum thickness occurs at the element closed to the plate root due to the maximum Von Misses stress, and decreasing along the length of plate in the direction of the tip in which a minimum thickness is attained.

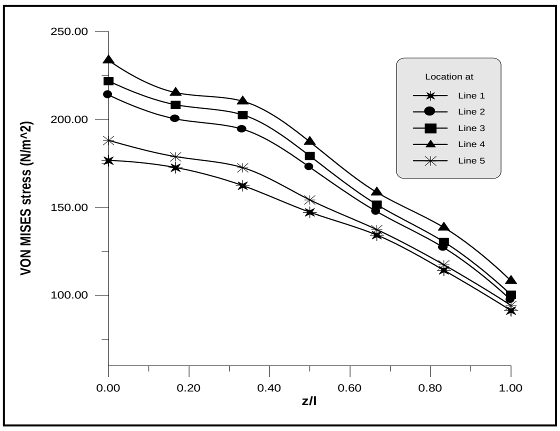

Fig. 9. Distribution of VON MISES Stress on the Finite Element Model.

4.2 Rectangular-Honeycomb Structures:

The same load, material properties and dimensions for flat plates are applied in the optimal design of rectangular- honeycomb plate structures. The objective of the optimization is the structure weight and the inequality constraints are the maximum Von Misses stresses required in this structure. Initially the thickness of the skin plate is (2mm) and the thickness of stiffeners is (4mm), and the height of the stiffeners is (5cm). The structure at the initial stage where no optimization occur (SS=0) have maximum Von Misses stress of (165.09 N/mm^2), and the mean Von Misses stress is (73.68 N/mm^2) shown in Fig. (10).The Performance Index (PI) versus steady state number is plotted as in Fig.(11). The weight index (w/w_o) is plotted versus the steady state number as shown in Fig. (12).

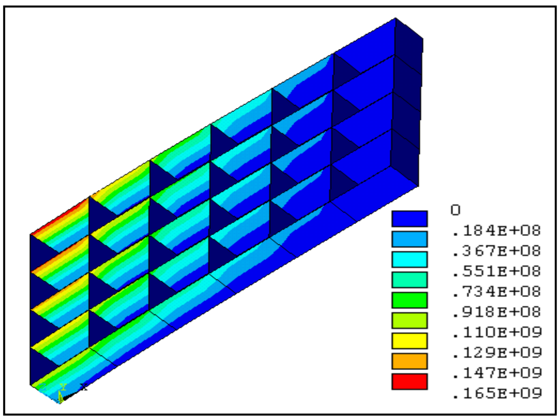

Fig. 10. Element VON MISES Contour at SS=0.

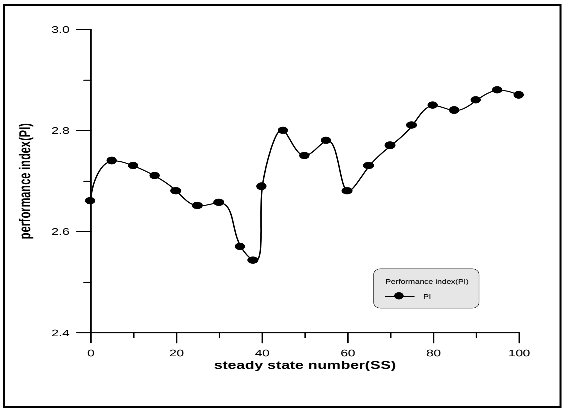

Fig. 11. Performance Index versus Steady State Number.

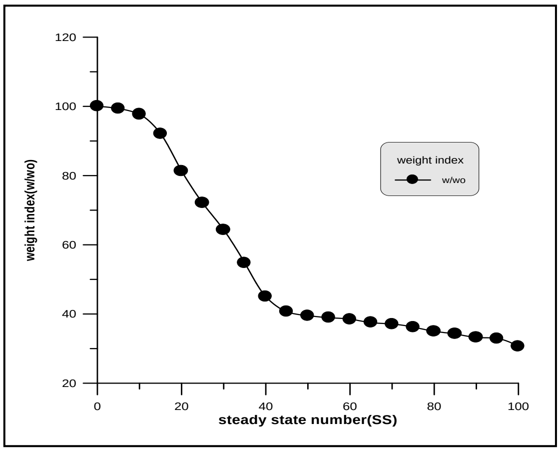

Fig. 12. Weight Index versus Steady State Number.

Von Misses stress distribution for the rectangular-honeycomb model is shown in Fig.(13). It is noted that the maximum Von Misses stress occurs at the root of the plate because of maximum bending moment. So that the location of maximum Von Misses stresses will be of maximum thickness value and the same for minimum Von Misses stresses that occur at the tip and attain a minimum thickness values.

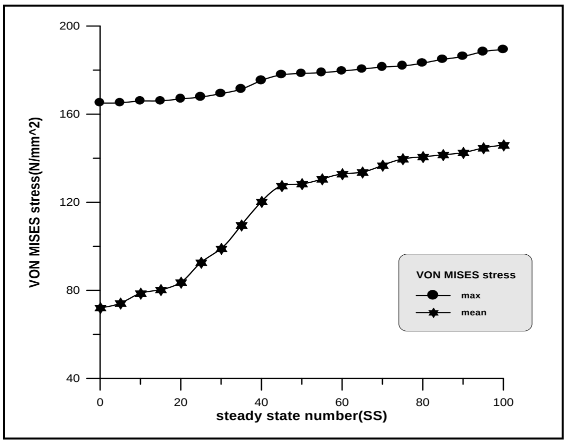

Fig. 13. Element VON MISES Contour versus Steady State Number.

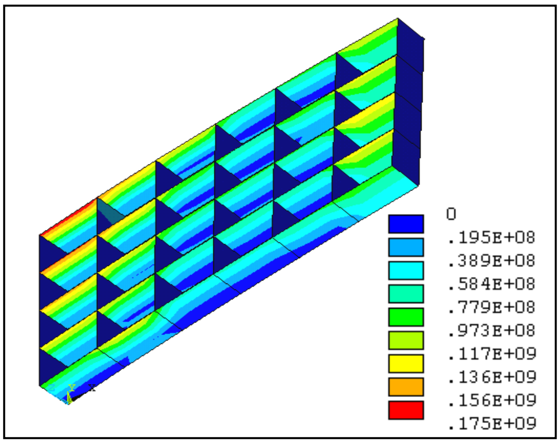

Fig. 14. Best Topology (VON MISES) Contour.

The Von Misses stress distribution for the flat plate is illustrated in Fig. (15). Figure (16) shows that the weight index for stiffeners versus the steady state number (SS) from this figure show that the removing material from stiffener no.1 is greater than the other stiffeners, while the stiffener no.5 is less than the other stiffeners because higher Von Misses stress at the stiffener no.5, in the other word the lower Von Misses stress at the stiffener no.1.

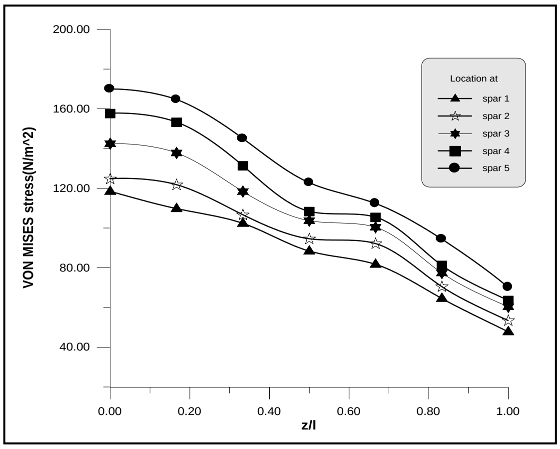

Fig. 15. Distribution of VON MISES Stress on the Finite Element Model.

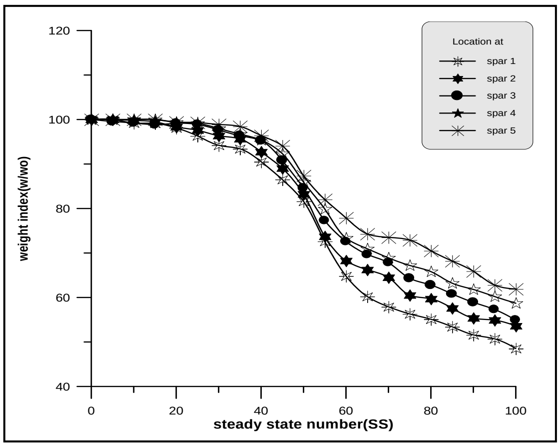

Fig. 16. Weight Index versus Steady State Number (SS) for Spars.

4.3 Diagonal-Honeycomb Structures:

Replacing the longitudinal and transverse stiffeners by the diagonal stiffeners and the same loads and material properties of rectangular-honeycomb model, the diagonal- honeycomb model is presented. The design variable in this structure was the thickness of each element in the skin plate structure, and the thickness of the diagonal stiffeners structural. While the objective of the optimization in the structure are the weight and the inequality constraints are the maximum Von Misses stress required in this structure. Initially the thickness of the skin plate is (2.5mm) and the thickness of the stiffeners is (4.5mm) and the height of the stiffeners is (5 cm). At the initial stage for steady state number SS=0 (no optimization is performed), the value of mean stress about 72.8 N/mm^2 and the maximum value about 189 N/mm^2 as shown in Fig.17. Figure (18) shown that the performance index (PI) versus the steady state number (SS). Figure (19) shown that the weight index (w/w_o) versus the steady state number (SS).

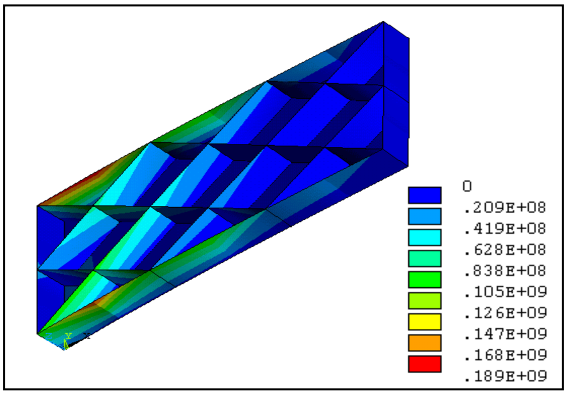

Fig. 17. Element VON MISES Contourat SS=0.

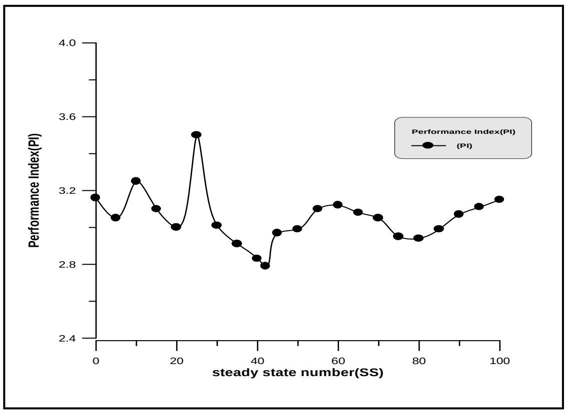

Fig. 18. Performance Index versus Steady State Number.

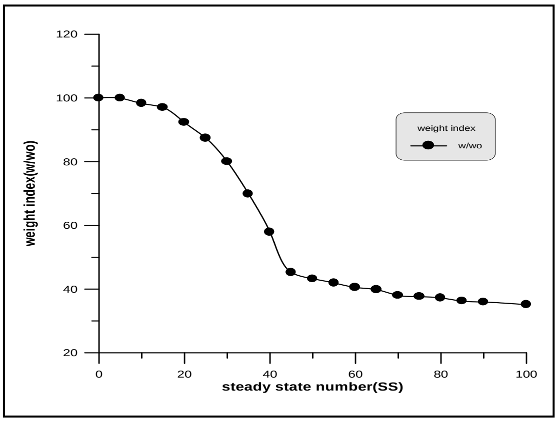

Fig. 19. Weight Index versus Steady State Number.

The maximum and mean element Von Misses stress is plotted versus the steady state number (SS) for the set 0 to 45 as shown in Fig. (20), from this figure shown the mean stress is increased with increasing the steady state number but the maximum stress is still with the same range.

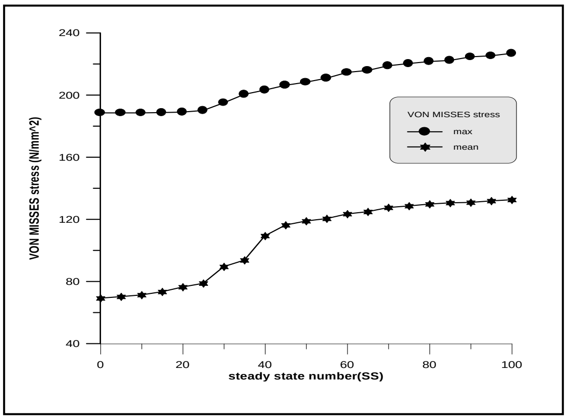

Fig. 20. Element VON MISES Contour versus Steady State Number.

4.4 Comparison of results with theoretical study

4.4.1 Michell type structure with fixed supports

Michell type structure was modeled and optimized using 2D-plane plate element as shown in Fig. (21). The force applied was 200 N in the centre of the structure. The mesh used was 40*20 plate elements. The problem had been solved by (Ostwald, M.1996) [7], using Intelligent cavity creation algorithm. The maximum Von Misses stress was as the ESO driving criterion. The rejection ratio was a_1=0.01. The optimal design is displayed in Fig. (22). Table (2) presented the weight index and performance index. There are good agreements with the results shown in table (2) for Michell structure with fixed supports.

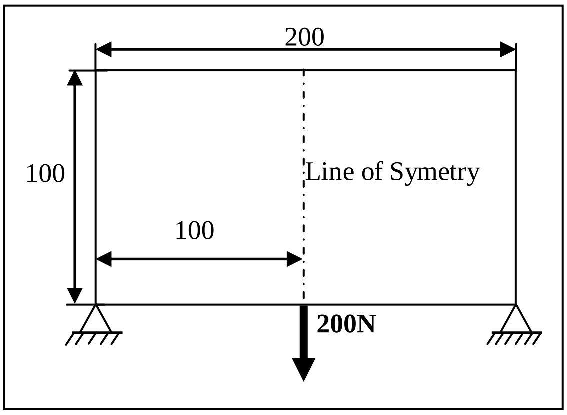

Fig. 21. Design Model for Michell Structure with Fixed Supports.

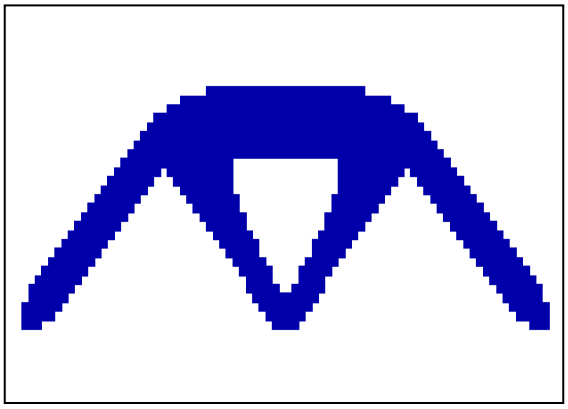

Fig. 22. Optimal Topology for Michell Structure with Fixed Supports at SS=64.

Table 2
Comparison of Results With Theoretical Study

	Weight index	**Performance index**
Ostwald, M.	52.36%	2.528
Present work	49.68%	2.542

4.5 Effect of height of stiffeners
4.5.1 Rectangular-Honeycomb Structures

When the minimum thickness (ts=1.37mm) is constant for each element of the stiffeners, and change the height of the stiffeners to obtain the optimal case of rectangular-honeycomb models. Table (3) shown that the effect of the stiffeners. It is shown that optimal design occur at h=6.09 cm with $\sigma_{VON})_{max}$=183.365, PI=2.56 and u_z=3.897 mm.

Table 3
Effect of the Height of Stiffeners.

h (cm)	$)_{max}$ σ_{VOM} (Mpa)	Deflection (mm)	Volume ($10^{-2}m^3$)
5.0	176.67	4.55	4.852
5.0	276.23	6.31	4.264
5.2	252.25	5.644	4.358
5.4	236.16	5.1292	4.452
5.6	216.38	4.656	4.546
5.8	193.64	4.244	4.642
6.09	173.365	3.897	4.734

4.5.2 Diagonal-Honeycomb Structures

Table (4) shown that the effect of height of stiffeners on the diagonal- honeycomb models, at (ts=1.461 mm) constant for each element of the stiffeners. It is shown that the optimal case occurs at h=6.19cm. At this height the Von Misses stress is (191.36 N/mm2), PI= 2.79, and normal deflection (u_z=4.4625 mm).

Table 4
Effect of the Height of Stiffeners.

h (cm)	$\sigma_{VOM})_{max}$ (Mpa)	Deflection (mm)	Volume ($10^{-2}m^3$)
5.0	202.59	4.732	5.944
5.0	302.35	7.295	5.568
5.2	282.16	6.525	5.651
5.4	250.78	5.621	5.675
5.6	233.46	5.152	5.729
5.8	217.37	4.813	5.783
6.0	207.43	4.646	5.837
6.19	191.36	4.462	5.891

5. Conclusions

The optimum design of a general stiffened plate structure by Morphing Evolutionary Structure Optimization method can be obtained. So any parameter of the stiffened plate can set it in to the best value with easy procedure. When using the Morphing ESO method with isotropic stiffened plate, the optimization by Morphing ESO is able to produce a very good smooth plate thickness variation. The difference between the upper and lower bound of the applied stresses is decreased in to a minimum value using this method. The ratio of the stiffness/weight is increased in to the maximum value using this method. From the results a design optimization for rectangular-honeycomb plate structure gives the best result than the other models.

Nomenclature:

A	Cross section area
E	Elasticity modulus of isotropic material
{F}	Overall load vector
G	Shear (rigidity) modulus of isotropic material
h_s	Height of stiffeners
[K]	Element stiffness matrix
l_s	Side length of rectangular or diagonal cell
$N_i(\xi,\eta)$	Shape function at node i
PI	Performance index
RR	Rejection ratio
S.F	Safety factor
SS	Steady state number
{F}	Overall load vector
G	Shear (rigidity) modulus of isotropic material
t	Thickness
t_p	Thickness of plate
t_s	Thickness of stiffeners
X,Y,Z	Global coordinate system axis
x,y,z	Nodal coordinate system axis
u_i	Linear displacement along element x-axis
v_i	Linear displacement along element Y- axis
σ_i	Normal stress in i-direction
ε_i	Normal strain in i-direction
τ_{ij}	Shear stress component through ij-plane
v	Poisson's ratio of isotropic material
ξ,η,ς	Intrinsic coordinate system

Appendix

Applied Load for Plate Structure:

Load will be applied on nodes (as nodal force). Nodal force that corresponding to each node is illustrated in Table (6).

Node numbe r	Force type	Force (N)	Node numbe r	Force type	Force (N)	Node number	Force type	Force (N)
4	Fz	-31.762	51	Fz	-47.642	32	Fy	-63.52
6	Fz	-42.35	65	Fz	-63.525	32	Fz	-63.52
8	Fz	-52.935	79	Fz	-79.406	30	Fy	-84.7
10	Fz	-63.52	93	Fz	-95.287	30	Fz	-84.7
12	Fz	-74.11	107	Fz	-111.16	28	Fy	-105.8
2	Fz	-84.7	18	Fz	-127.05	28	Fz	-105.8
2	Fx	84.7	18	Fx	127.05	26	Fy	-127.0
49	Fz	-39.702	53	Fz	-55.584	26	Fz	-127.0
63	Fz	-52.937	67	Fz	-74.112	24	Fy	-148.2
77	Fz	-66.171	81	Fz	-92.64	24	Fz	-148.2
91	Fz	-79.406	95	Fz	-111.16	14	Fy	-169.4
105	Fz	-92.640	109	Fz	-129.58	14	Fz	-169.4
16	Fz	-105.87	20	Fz	-148	14	Fx	-169.4
16	Fx	105.87	20	Fx	148			

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التصميم الأمثل لتراكيب الصفائح المقواة المعرضة الى حمل ساكن

د. حاتم هادي الطائي د. عادل عباس الموسوي محمد علي صيهود
قسم الهندسة الميكانيكية/ كلية الهندسة/ جامعة بابل

الخلاصة

أخذ مجال الامثلية الهيكلية (التصميم الأمثل) يتطور بسرعة خلال العقود الماضية مع العديد من طرق الامثلية المختلفة التي يمكن استعمالها للحصول على هيكل يتميز بوزن أقل ومقاومة مقبوله. يتضمن البحث جزئين، الجزء الأول يتضمن اقتراح تقنيه عدديه اعتمدت طريقه العناصر المحددة كأساس لها لتوضيح سلوك الصفائح المقواة تحت تأثير ظروف الأحمال الساكنة. التقنية تضمنت نمذجة (صياغة) طريقه العناصر المحددة باستخدام عناصر ذات خواص متجانسة(isotropic) ربطت لخلق نماذج بغيه أيجاد التصميم الأمثل لها. أن هذه النماذج سوف تتميز بذلك وان كل نموذج يستعمل أنواع مختلفة من التقويات. الجزء الثاني يتضمن توضيح التصميم الامثل للموديل المقترح باستخدام تقنيه الامثلية (MESO). هذة الطريقة طبقت في هذا البحث لتطبيقها على الصفائح المقواة وتعتمد هذه الطريقة على فكره بسيطة وهي بالأزاله البطيئة للمادة الغير المؤثرة من التركيب، بحيث ان الشكل المتبقي يتجه نحو تركيب أفضل. ان التمثيل الرياضي لهذه الطريقه تامة في هذا البحث بالبرمجة الكاملة والتعديل المطلوب بحيث تكون قابله للتطبيق على تراكيب أخرى وبشروط جديدة. يمثل سمك الصفيحة وسمك التقويات (honeycomb stiffeners) وارتفاعها متغيرات التصميم ، إما هدف تحقيق الامثلية فسيمثل بوزن التركيب بينما تتمثل القيود بإجهاد الفون مايسز (Von Misses).