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REVIEW ON FORM FINDING FOR DYNAMIC LOADS

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ABSTRACT

Form Finding is followed by choosing the best suitable solution in terms of various design parameters having a high level of performance in terms of spaces, people, cultures and knowledge. It is process of finding the geometry in terms of load carrying capacity of a particular structure and choosing the best design in terms of its behavior against various loading conditions. It is therefore necessary to have a command over the flow of forces governing a design. The design could be made economical and environmental sustainable by using the sections which provides us minimum bending moment and shear forces. This all process involves a form to be justified and which in turn leads to form finding methods which depends on various forces, function, geometry and material. The aim is to design a structure in such a way that it should be able to sustain an impact during any structural changes or dynamic loading without losing the structural integrity. The strategy involves a good choice of design parameters which could be the shape of the structure, the location of the beams, columns and frames. Dynamic forces are those forces whose magnitude and position changes with time. The loads due to earthquake, wind and explosion activities such as blasting are categorized as dynamic loads. Due to these dynamic loads the building vibrates and gives rise to the dynamic responses. These dynamic responses are measured in terms of deformations, velocity and acceleration. A dynamic load is something that changes with time quickly as compared to structures natural frequency. Therefore, the dynamic analysis could be done manually for simple structures, but requires various techniques such as finite element method when it comes to complex engineering problems for finding various mode shapes and frequencies.

KEYWORDS: Optimization of structure, Form Finding, Dynamic loads, Finite Element Method.

INTRODUCTION

OPTIMIZATION

Optimization is a kind of mathematical programming which can be used as a technique to solve various engineering problems related to the structures.

For an optimization problem to be solved we need to check the feasibility of the problem solution. Then the objectives of the problem are compared such as cost, profit etc. and then the best solution is obtained. It does not uses any empirical formula for the computation whereas it uses certain design procedures governing the standard definition and these procedures vary as the design problem changes. Basically, while solving for a particular design during the optimization we need to minimize the cost function or tend to maximize the efficiency part i.e (overall weight of the structure can be reduced or the life of the structure can be treated as an objective function) of the design problem for which we use some iterative processes by comparing various solutions until an optimum solution satisfying the problem statement is found and an algorithm is prepared.

With the use of these optimization techniques one could easily find the optimal design procedures which could be the logical decisions in terms of arithmetic algorithms.

OPTIMIZATION PROBLEM IN MATHEMATICAL FORM

a) *Objective function*- A design can be represented in terms of objective function which determines the actual form of the structure and which proves the required design criteria and for these objective function or merit function the design variables are choosen.

b) *Design variables*- Design variables are those on which the design depends i.e they are varied during the optimization process. The parameters could be sensitive or they may remain fixed during the design process. After choosing the design variables the procedure could be checked and if needed the formulation could be revised. These are the parameters on which a particular design is to be satisfied and under various limits known as constraints.

c) *Constraints*- These are the moves which proves the various design parameters and the design variables thereby satisfying the physical conditions and proving a functional relationship between the various parameters. For ex. Maximum stress is a constraint of a structure. Constraints could be categorized as inequality type or equality type. In equality constraint there should be a resource value which should satisfy a functional relationship. The equality constraints are difficult to handle and hence these could be replaced using inequality constraints.

d) *Variable bounds*- The final task is to set the variable bounds that is the upper and the lower limits of the chosen design variables. For 'n' design variables we can write it as-

$$X_i^{(L)} < X_i < X_i^{(U)}, \quad \{ \text{for } i = 1, 2, 3, \dots, n. \}$$

The formation of the algorithm is then checked for the upper and the lower bounds that is the maximum and the minimum bounds and the optimum solution is reached as a result of programming procedure.

As a result the procedures can be written in a special format like as in Non Linear Programming format which is termed as non linear programming.

- Denoting the design variables as a column vector

$$X = (x_1, x_2, x_3, \dots, x_n)^T$$

- The objective function as a scalar quantity $f(x)$;

- Q inequality constraints as $g_q(x) \geq 0$;

- R equality constraints as $h_r(x) = 0$; we can write the non linear programming problem as, we will minimize $f(x)$ subject to

$$g_q(x) \geq 0 \quad q = 1, 2, 3, \dots, Q;$$

$$h_r(x) = 0 \quad r = 1, 2, 3, \dots, R;$$

$$x_i^{(L)} < x_i < x_i^{(U)} \quad i = 1, 2, 3, \dots, n.$$

NUMERICAL METHODS OF OPTIMIZATION

a) *Linear programming*- This is used where the objective function (f) is treated as a linear quantity & which varies with a set (A) which is specified according to linear equalities and inequalities.

b) *Integer programming*- It involves the calculation of the best solution in terms of a mathematical expression that is the variables are constrained to take on the integer values.

c) *Quadratic programming*- This also involves the calculation using mathematical expression but this uses the quadratic terms to reach the desired solution.

d) *Non Linear programming*- The NLP is used where the objective function as well as the concerning constraints both of them contains non linear part to be solved.

e) *Stochastic programming*- This uses the technique where the constraints used depends on random variables and this way the solution is reached.

f) *Dynamic programming*- The programming uses the case in which the design problem is splitted into smaller parts and the solution is reached step by step.

g) *Combinatorial programming*- These are the methods used where the set of feasible solution is discrete or where it can be reduced to discrete.

h) *Constraint satisfaction*- This method can be said to exist where the objective function (f) is constant. This technique is used in the processes of artificial intelligence, particularly in automated reasoning.

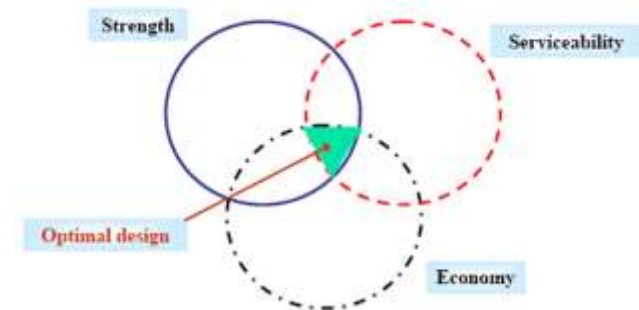


Fig: 1 Optimal Design

OPTIMIZATION IN STRUCTURES

The structures could be designed according to the maximum permissible stresses or considering various load conditions where the weight of the structure plays a very important role in optimal design and choosing the various parameters, constraints and the objective function which are to be optimized. The parameters chosen could be dependent or independent of the design variables. These are selected considering the computational time of the process or from past experiences. These could be stresses, deflections, natural frequency, buckling loads etc. As we move further the merit function governing the design is formed by proper choice of the design parameters which is then maximized or minimized with respect to the design requirements.

If there exist a linear relationship between the design variables, various constraints and the objective function they are treated as linear programming

problems and the results are calculated. But if these design parameters does not follow the linear relationship then the problem is treated as non-linear programming problem and then we require a set of procedures for the design criteria to be followed and through these procedures the optimum solutions are obtained.



Fig: 2 Types of Optimization

SIZE OPTIMIZATION –

It simply means to optimize a given structure keeping in mind the size of its members and its member properties and defining an optimal solution by optimizing its size. Sizing of member plays a very important role in the field of optimization. The size of the members and its properties governs a particular design which needs to be designated using this design procedure.

SHAPE OPTIMIZATION –

It is done to find out the shape function which could prove out to be optimal or which could satisfy various constraints related to the shape of the structure and its modeling. Here the connectivity of the system is not changed keeping in mind the structural integrity of the system and no extra members could be added to the present system i.e new boundaries are not formed during the process. For example, the process can be explained as the size of a conventional frame could be adjusted to take the load of the structure by using a tapered member in place of the full section which was used earlier and required large steel which can be reduced using a tapered section. The overall weight as a result can be reduced by using this process of shape optimization where the section properties governing the design are changed according to the load conditions and the moment produced in the section which determines their shape.

TOPOLOGY OPTIMIZATION –

This is concerned with the various topological outcomes in terms of the structures node distribution system or various boundary conditions which needs to be satisfied and governs a set of procedures to be followed. For a standard condition it can be achieved for truss assembly using their members as the design variables and then choosing them in terms of their load bearing capacity and omitting or replacing those members having the zero value of load. The members which are having the values zero those bars could be removed from the assembly of the truss and their connectivity could be changed or the location of the nodes will be treated as variable and we can see that the topology of the truss changes. The shape optimization and the topology optimization are interrelated and the first could be treated as a sub class of the later but their practical applications uses different techniques for the purpose of finding out a solution, therefore sometimes they are uses as two different things.

Whereas in case of size and topology optimization they are practically related to each other but differs when from fundamental point of view. For example if we talk about the solution of a differential equation the shape optimization governs a control over the domain of the differential equation and the sizing and topology optimization are concerned with the related parameters of the design procedures.

DYNAMIC LOADS

Dynamic loads could be considered to be acting on simple structures as well as on the complex structures. The analysis for the simple structure could be done manually whereas for the complex ones the finite element analysis needs to be done for calculation of various mode shapes and frequencies and thereby the nature of the structure can be studied. The forces concerned with the inertial forces which are developed by the structure when it is excited due to dynamic loads such as earthquakes, blasts, explosions needs to be studied using the dynamic analysis techniques.

REVIEW OF PAPERS

Feng TT, Arora J S, et al; discussed that the transformation of dynamic loads into equivalent static loads(ESLs) has been studied in civil engineering for the analysis and design under

earthquake loads [1-2-3] Andres Guerra; Panos D. Kiouisis; programmed member sizing and the cost evaluation, in MATLAB (Mathworks, Inc.) including the structural FEA, the ACI-318-05 and obtained the minimum cost design using the SQP algorithm implemented in MATLAB's intrinsic optimization function fmincon.[7]. M.Ramu; V.Prabhuraja, et al (2010);discussed that statistical techniques are widely used in engineering design to construct approximate models of the costly analysis codes which are referred as meta-models to address expensive computational cost.[8] Andrej Cherkaev; et al; showed that the bi-stable structure can absorb more energy in comparison to the conventional structure by distributing the damage along its length to design a structure which is capable of sustaining an impact of a dynamical load (collision or blast) by absorbing and redistributing the energy of the collision and keeping the structural integrity. [9] V.B. Hammer and N. Olhoff; presented a generalization of Topology optimization of continuum structures subjected to pressure loading which can be solved by successive iterations based on a fixed-point optimality criterion algorithm. D. Veenendaal; compared existing form finding methods for discrete networks and identified key distinctions and presented a single mathematical formulation and implemented in the computational framework.[10] John Harding et al; described a new method for form finding of funicular structures in 2 or 3 dimensions using a zero length spring system with dynamic nodal masses.[11] S. Amstutz and A.A. Novotny; discussed that the topological asymptotic analysis provides the sensitivity of a given shape functional with respect to an infinitesimal domain perturbation, so that sensitivity can be naturally used as a descent direction in a structural topology design problem.[12] Colby C. Swan, et al; discussed optimizing concept designs of structures featuring inelastic material behaviours by using topology optimization and described the aid of spatial distributions of volume fraction design variables throughout a prescribed design domain.[13] Thadeu A. Senne, et al; discussed that when the external loads applied to the structure are large, the displacements also become large, so it is necessary to suppose that there is a nonlinear relation between strains and displacements.[14] Jeffrey Smith, et al; discussed that truss structures are ubiquitous in the industrialized world, appearing as bridges, towers, roof supports and building

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exoskeletons, yet are complex enough that modeling them by hand is time consuming and tedious and presented a method for designing truss structures, using non-linear optimization.[15]

CONCLUSION

By the use of computer programming the algorithms can be formulated accordingly so as to check the structural performance of the structure depending on the use of the material and various parameters such as weight, force, moment, cost, deflection etc. which will govern the design and is capable of performing billions of instructions per second. As a result the performance of a particular design or a structure could be enhanced using the form finding technique in a better way and introducing many ways so as to increase the bending capabilities of the elements.

From the above literature review we have seen that so many work has been done on optimization of structures which involves techniques to optimize a structure which can be done by using various form finding methods.

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