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AN INTRODUCTION TO OPTIMIZATION IN STRUCTURAL DESIGN

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Abstract:Structural optimization is examined from the viewpoint of structural design office practice. The costs and benefits of optimization are considered, as are the special requirements which practical design processes impose. Several design aid computer applications which use optimization methods are examined including simple structural element design, whole structure configuration and sizing for trusses and frames and some specialist applications for concrete bridge decks and small industrial buildings. Practical considerations such as the discreteness of the variables and the use of design aid programs within iterative design processes are considered. Appropriate optimization methods are suggested for each group of applications, emphasis in choice of method being placed upon the practicality of the resulting design. It is concluded that optimum design aid programs are now practicable for many design offices, speeding up the design time for a project and thus repaying capital and software costs. The writing of appropriate software is a vital element at present receiving too little attention**.**

IndexTerms ***-****Requirements and design process of structural optimization etc*

I. Introduction

Concept design is followed by 'detailed structural design' (sometimes called 'design development' or 'developed design') during which the design develops to describe all the main components of the building and how they fit together.Concept design is the first design stage. Feasibility studies and options appraisals that the consultant team or independent client advisers may have previously carried out do not involve 'design' as such. They are preliminary studies whose purpose is to establish whether the project is viable, to assist in the development of the project brief and to aid the identification of feasible options.

The preferred option is then be developed into a concept design which is a response to the project brief. The project brief will continue to develop as the concept design is prepared, but is then frozen at the end of the concept design stage and change control procedures are introduced. **Structural optimization** is a discipline dealing with **optimal** design of load-carrying mechanical **structures**. The objective might be to minimize the total weight of the **structure** subject to constraints on displacements and stresses in the **structure** under the given loads.

II. Requirements for Structural Design

The basic requirements for an efficient structural design is that the response of the structure should be acceptable as per various specifications, i.e., it should at least be a feasible design. There can be large number of feasible designs, but it is desirable to choose the best from these several designs. The best design could be in terms of minimum cost, minimum weight or maximum performance or a combination of these. Many of the methods give rise to local minimum/maximum. Most of the methods, in general give rise to local minimum. This, however, depends on the mathematical nature of the objective function and the constraints.

III.Methods of Structural Optimization

Structural optimization is now targeting area of mechanical product development & design phase of any structure or component which are subjected to loads. The design engineer is focused with the rigorous task of designing a structure by considering various objectives that are like minimizing total weight (mass)or volume, minimizing stress (fluctuating or static), maximizing stiffness, homogenizing distribution of stress, minimizing production costs, etc. Structural optimization implies finding the optimum geometry of selected design space each targeting different types of parameters .It can be divided in three distinct branches,. Size, shape and topology optimization. The techniques generally target either size, or shape, or topology, sometimes integrated approach is followed. It is easy to control a structure's shape and size as the design variables are the coordinates of the boundary (shape optimization) or the physical dimensions (size optimization), but more exercisers needed to control the topology of the structure. Various method of structural optimization are discussed and reviewed as:

3.1 **Sizing optimization**

Sizing optimization is the simplest form of structural optimization. The shape of the structure is known and the objective is to optimize the structure by adjusting sizes of the components. Here the design variables are the sizes of the structural elements, for example the diameter of a rod or the thickness of a beam or a sheet metal. As in size optimization where the diameter of the rods are the design variables in a sizing optimization problem, the design variables are usually geometrical parameters such as length, width or thickness of the part being optimized.

3.2 Shape optimization

Shape optimization is performed similarly as the topology optimization. The main difference is in how the design variables are defined. Design variables are the coordinates of the boundary. The process of shape optimization consists of three modules [19]: geometrical representation, structural analysis, and optimization algorithms. To select a geometrical representation is the first step in the shape optimization process, thenodal coordinates are chosen as design variable because it is very simple by using ANSYS.Considering the architectural or structural requirements, and the initial design model is constructed. The design model is converted into an analysis model. So the past researches focus on the objective function i.e. lowest cost or minimum weight .As mature analysis software, ANSYS &can be analyzed almost all the structures, and has been used in many practical engineering.Yunliang Ding develop numerical model for analysis of shape optimization of various structures. Described the several steps in the shape optimization process. According to him , the steps of shape optimization are model description, selection of the objective function and shape variables, representation of boundary shape, finite element mesh generation & refinement , sensitivity analysis and solution methods. These steps are reviewed in detail in their work. X. Duane et.al.. Discussed the procedure of shape optimization on V-shaped anvil using Finite Element (FE) analysis interface. A FEA software MARC is used for this type of parametric optimization procedure.

3.3 Topology optimization

Topology optimization is the most general structural optimization technique and it is mainly considered in a conceptual design stage. The Greek word topos, meaning landscape or place, is the origin of the word topology optimization. Topology optimization is perhaps the most difficult of all three types of structural optimization. The optimization is performed by determining the optimal topology of the structure. Optimization therefore occurs through the determination of design variable values which correspond to the component topology providing optimal structural behavior. In topology optimization a fixed finite element mesh is used and one design variable is connected to each element. The design variable determines if the corresponding element will represent structural material or a hole. The connectivity of the structure, while connecting the applied loads to the given boundary conditions, is thus changed such that the objective function is minimized subjected to the specified constraint Applying topology optimization to structural design typically involves considering quantities such as weight, stresses, stiffness, displacements, buckling loads and resonant frequencies, with some measure of these defining the objective function and others constraining the system. Topology optimization rapidly expanding a new research field, which has interesting theoretical implications in the field of mathematics, mechanics, multi-physics and computer science, but also important practical applications in product development (particularly car and aerospace) industries, and is likely to have a significant role in micro and nanotechnologies. A century ago, the first paper on topology optimization is published by the Australian inventor Michell (1904), who derived optimality criteria for the least weight layout of trusses. After seven decades, authors and his research group extended Michell's theory to grillages (beam systems) which are quoted in many papers (starting with Rozvany 1972). Based on these applications, Prager and Rozvany (1977) formulated the first general theory, "optimal layout theory" of topology optimization (for a review, see Rozvany 1993 or Rozvany et al. 1995). They applied this primarily to exact analytical optimization of grid-type structures, but it has also important implications for numerical methods and continuum-type structures. Many papers deal with extensions of this theory and discussed the exact solutions of popular benchmark problems (Lewinski and Rozvany 2007-08) The development of topological optimization can be attributed to Bendsoe and Kikuchi (1988).They presented a homogenization based optimization approach of topology optimization. They assumed that the structure is formed by a set of non-homogenous elements which are composed of solid and void regions and obtained optimal design under volume constraint through optimization process. In their method, the regions with dense cells are defined as structural shape, and those with void cells are areas of unnecessary material. At the World Congress, Seoul(2007) many papers were discussed on application and approaches of topology optimization In the Hyper works Technology Conference (HTC), Varun Ahuja et al. (2012) presented paper and discussed about Optimization Techniques in Reducing the Weight of Engine Mounting Bracket and concluded 15 % weight saving of the bracket using Opti-Struct Software tool. In this conference some other papers on topology optimization is discussed.M.V.Aditya Nag(2012) in HTC Conference showed the result how the weight of engine mounting bracket is reduced up to 60% without compromising the strength of the bracket. DheerajGunwant et.al Misra (2012) compared The results of ANSYS based Optimality

Criterion which was a gradient based method, were compared with those obtained by Element Exchange Method which was a non-gradient based method.

IV. Optimization of Structures

Prior to considering existing optimization methods, it is useful to define the framework associated with structural design optimization. This section presents a classification of the design tasks themselves and is followed by a discussion of the typical phases of the structural design process. In increasing order of complexity, structural design optimization tasks are generally considered to be: Optimization of size (and shape) of cross-section for discrete structural members, such as beams and columns, or thickness of continuous material, such as panels or floor slabs. This is often referred to as size optimization. - Shape Optimization, varying positioning of nodes or connections and definition of lines, curves and surfaces that describe structural form. - Topology Optimization, varying the configuration and connectivity of members or material. These tasks, noting the trend in the stage of the design process at which the tasks are addressed. Whilst it is possible to assign a fixed set of variables in defining an optimization model for size and shape optimization, this is generally not the case for topological optimization, hence an infinite number of solutions may exist. The requirement for modelling member connectivity in topology design is a significant barrier to application of many classical optimization methods, as noted by Deb (2001). Shape optimization is often considered to include cross-sectional size optimization; in turn topology optimization may include both shape and cross-sectional size optimization. It is possible to define shape and topology optimization tasks parametrically, for example by defining control points on a curve or varying the number of columns on the perimeter of a building, although this obviously places restrictions on the search space. Additionally, it is possible to consider optimization of plan layout, for example for maximizing potential letting revenue, type of structural system or material selection. The field of structural design optimization includes a number of unique characteristics and corresponding methods. Many structural design tasks are ill-structured, especially those in the earlier stages of the design process, where decisions carry the greatest influence on final efficiency. A crucial part of a potential optimization process in the building industry is the evaluation of structural designs, generally by finite element analysis, which often carries a significant time cost.

V.The Design Process for Building Structures

It is vital to the successful implementation of optimization in structural design that the optimization tasks detailed above are linked to the appropriate phase of the design process. The structural design process essentially follows the same progression as any other design task. However, the interdisciplinary nature of building design, with input from clients, architects and structural and building services engineers, serves to complicate the process and may lead to a large number of iterations and revisions, even revisiting earlier design phases. With reference to design of topology and form and section allocation, it is useful to consider the corresponding stage in the design process for each of these tasks. Structural systems and topologies are developed earlier in the design process, with the optimization problem less well-defined, the design space larger and hence a greater range of possible solutions. Section sizes are not finalized until the latter stages of the design process. Although section-size optimization is a much more straightforward task, a strong driver for optimization prior to this stage is provided by estimates suggesting that up to four-fifths of the total resources in an engineering project are committed in the early design stages (Deiman 1993). The classical design process follows the following stages: In the conceptual design stage, a set of initial concepts is generated in an attempt to satisfy the broad design requirements prescribed, in the case of design of buildings, by the architect or client. The preliminary design stage further develops one (or more) conceptual design(s). At this point, the general building system functionalities that were determined previously will be subject to further refinement in order to furnish a more accurate cost estimate for the project. The detailed design stage finalizes all information required for construction. In these latter stages, member-sizing, joint-detailing and similar well-defined tasks are undertaken in structural design. Whilst these design stage definitions are widely used throughout the design community, the Plan of Work Stages 1999 as described by the Royal Institute of British Architects (RIBA 1999), (Phillips 2000) is recognized and implemented throughout the construction industry. Stages A to L include tasks undertaken both before and after the design stages described above, e.g. tendering, construction and completion. However, the following stages roughly correspond to those detailed above: "B: Strategic Briefing Preparation of Strategic Brief by, or on behalf of, the client confirming key requirements and constraints. Identification of procedures, organizational structure and range of consultants and others to be engaged for the project. [Identifies the strategic brief (as CIB Guide) which becomes the clear responsibility of the client.] C: Outline proposals. Commence development of strategic brief into full project brief. Preparation of outline proposals and estimate of cost. Review of procurement route. D: Detailed proposals. Complete development of the project brief. Preparation of detailed proposals. Application for full development control approval. E: Final proposals. Preparation of final proposals for the Project sufficient for coordination of all components and elements of the Project."

VI. Guidelines for Practical

Use Referring back to the original research question relating to improving the usefulness of ESO for the building industry and the proposals subsequently put forward, we can state the following: – Consideration of appropriate constraints is essential to successful use of any optimization or pseudo-optimization tool, including ESO and its variants. In this case, maximum lateral displacement at the highest point of the structure is likely to govern, but the user should be aware that it is possible that displacement may 64 actually be greater elsewhere. Further, other forms of constraints, such as strength and buckling may be relevant, both in the bracing domain and the orthogonal framework. These are difficult to consider in the ESO process itself, but should be included in optimization of the corresponding discrete structure. – BESO offers the ability to start from alternative configurations to that with all elements active. Running the process from different configurations, in the optimal thickness region (for this problem approximately between 3 and 10mm) most designs are similar (generally based on a double chevron), but consistent convergence to a single optimum is not observed. This may be beneficial in creating different design options and since performance of discrete and continuous design interpretations is often different. BESO yields higher performance and more regular designs than unidirectional ESO. – Defining all elements to be equal size and shape permits the use of a single element stiffness matrix. Different thicknesses are readily accommodated by linear factoring. – Simultaneous topology and thickness optimization gives a reasonable indication of what material volume is likely to be required, providing there is an obvious discrete interpretation. This technique ensures appropriate thickness is used and provides a means of assigning different thicknesses to different regions of the structure, thus promoting structural efficiency. – Defining symmetry conditions with corresponding thickness grouping allows tailoring of designs to preconceived aesthetic requirements, whilst retaining high performance. Further noteworthy observations: – Using a "film" of very thin elements in place of inactive elements will stabilize the ESO process, eliminating the possibility of singularities in the global stiffness matrix causing the computational process to crash. However, this does require additional analysis time due to the extra elements. – In considering the results of an ESO process with thickness optimization, it is valuable to inspect topologies generated throughout the history, alongside a chart of the form shown in figure 3.9. This offers the option to trade-off structural 65 efficiency, as indicated by the bracing volume required, against interpretability of the design as a discrete structure. – A number of ESO solutions should be given discrete interpretation since performance of continuous and discrete solutions may vary. This also allows strength and buckling constraints to be considered.

VII. Conclusions

In this paper general idea regarding Structural optimization had discussed and also methods of Structural optimization discussed in detail.

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