

**OPTIMUM DESIGN OF STRUCTURES UNDER
TRANSIENT DYNAMIC LOADS**

By
ARUN CHANDRA PAUL

DEPARTMENT OF APPLIED MECHANICS

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CERTIFICATE

This is to certify that the thesis entitled 'Optimum Design of Structures Under Transient Dynamic Loads' being submitted by Sri Arun Chandra Paul to the Indian Institute of Technology, Delhi for the award of the Degree of Doctor of Philosophy in Applied Mechanics is a record of bonafide research work carried by him under our supervision and guidance. The thesis work, in our opinion, has reached the requisite standard fulfilling the requirement for the Doctor of Philosophy Degree.

The results contained in this thesis have not been submitted in part or in full, to any other University or Institute for the award of any degree or diploma


(Dr. D.K.Sehgal)
Assistant Professor,
Deptt. of Applied Mechanics,
Indian Instt. of Technology
New Delhi- 110 016


(Prof. C.V.Ramakrishnan)
Professor,
Deptt. of Applied Mechanics,
Indian Instt. of Technology
New Delhi- 110 016

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(A.C.Paul)

ABSTRACT

With the development of finite element analysis, the dramatic increase in speed and capacity of computers and the advances in computational science and optimization algorithms available, the interest in structural optimization has been steadily on the increase. As such structural optimization and smart structural design has become an active field of research on account of its extensive application in economic and safe design. The three modules associated with the efficient optimization of structure are an analysis module, a design derivative module and an optimization module. Finite element method plays an important role in the structural analysis as even a very complicated structure can be analyzed accurately and multiple loading conditions can be handled with ease. In the context of present state of knowledge of finite element analysis an efficient module with compatibilities for automated mesh generation and domain error estimation is an essential prerequisite in a structural optimization package. The two types of problems concerned with the structural optimization are (i) member sizing problems which involves a fixed geometry and (ii) shape optimization problems, wherein a few variable can define the profile to be optimized but the analysis could be complex. For the optimization of structure it is essential to obtain the derivatives of the objective function and constraint functions with respect to design variables. In case of a structural optimization problem the calculation a design sensitivity is a complicated one:

particularly in the context of transient dynamic loading. The numerical errors in the computation of design derivatives and their estimation constitute another dimension to the problem. The third important step concerned with the structural optimization is the choice of a suitable optimization algorithm.

The analysis and design sensitivity computation is simple in case of static loading but for dynamic loading the presence of inertial forces and the time dependent load makes it a very complex one. The finite difference approach on the discretized problem is a common technique for computing the design sensitivity but it takes a large amount of computing time. Apart from the computing effort the accuracy of these have to be ensured. For optimization problem a number of mathematical algorithms based either on transformation methods or direct approaches are available. In the present investigation the improved move limit method of sequential linear programming is employed.

An attempt has been made to compute the design derivatives by solving an adjoint system and it has been tested for trusses with a small number design variables and a 2-D cantilever with one or two design variables only. Since the accuracy of these sensitivity values has not been found satisfactory, finite difference derivative computations have been recommended and utilised in all the applications. However a detailed analysis of error measures has been taken up for study later.

A general purpose optimization package for structures under dynamic loads has been developed to handle both sizing and shape optimization problems. This has been tested on a cantilever beam under the dynamic load such as a suddenly applied load and harmonic load. Some design variables are chosen to define the profile of the beam and constraints are imposed on the

stresses at the boundary. The minimization of the weight of the structure or a function of stresses is taken as the objective function. The dynamic analysis has been carried out by using by finite element method and the design sensitivities are obtained by using finite difference approach. By using the improved move limit method of sequential linear programming the acceptable optimized shape of the structures are obtained

Practical structures like a steel chimney under earthquake or blast load and a dam under reservoir full condition have been chosen for the size and shape optimization study respectively. The analysis has been performed for both the static and dynamic loads. All the practical design considerations and other technological constraints have been taken care of in the design. In these cases also the constraints are imposed on the stresses at the boundary and the objective function is either on weight minimization or a function of stresses. In case of chimney the thickness of the steel plates used at different heights are chosen as design variables and the width of the dam structure at different heights are chosen as design variables in case of dam. The structure-foundation interaction and structure-fluid interaction effects are fully accounted for. However the fluid compressibility effects have not been considered. The investigation leads to very practical dimensions for the chimney sizing problem and reasonably acceptable shapes for the dam optimization problem.

A systematic procedure for accounting the numerical errors in design sensitivity computations using the adjoint problem approach is presented. It is shown that for truss/frame problems, accurate control of modal truncation errors is the key for obtaining extremely accurate design derivatives for structures under transient dynamic loading conditions. Using appropriate error

measures for discretization error control and the choice of an optimal mesh for a given number of basis modes and combining it with suitable modal truncation error control measures, it is shown that one can obtain accurate design sensitivities in the context of F.E. based computations also. This is a very significant conclusion.

The conclusions of the present research have been summarised and suggestions for further research have been outlined.

CONTENTS

	Page No
Certificate	i
Acknowledgements	ii
Abstract	iii
List of Figures	viii
List of Tables	xiv
Nomenclature	xvii
CHAPTER 1	1 - 26
INTRODUCTION AND LITERATURE SURVEY	
1.1 Introduction	2
1.2 Definitions and Classifications of Optimum Design	5
1.3 Modules of Design Optimization	6
1.3.1 Analysis	6
1.3.2 Evaluation of Design Derivatives	8
1.3.3 Optimization	8
1.4 Review of Methods for the Computation of Design Derivatives	9
1.5 Mathematical Programming Techniques Relevant to Structural Optimization	11
1.6 Review of Structural Optimization	16
1.6.1 Sizing or Shape Optimization	17

1.6.2	Classification Based on Primal/Dual Formulations and Numerical Optimization Techniques	21
1.6.3	Classification Based on the Type of Structural Analysis	23
1.7	The Present Investigation	24
1.8	Organization of the Thesis	25

CHAPTER 2

27 - 64

PROBLEM FORMULATION AND MATHEMATICAL THEORY

2.1	Introduction	28
2.2	Structure of Optimization Problems	28
2.3	Formulation of Design Optimization Problem	30
2.4	Dynamic Analysis of 2-D Structures	31
2.4.1	Equation of Motion	31
2.4.2	Eigen Values and Eigen Vectors	33
2.4.3	Modal Superposition Method	34
2.4.4	Subpolynomial Iteration for Determining Eigen Values and Eigen Vectors	35
2.4.4.1	Basic Approach	36
2.4.4.2	Isolation of Eigen Values	37
2.4.4.3	Computation of Shift Using Lagrangian Sub Polynomial	37
2.4.4.4	Inverse Iteration with Shift	38

2.4.5	Duhamel Integral for Finding Dynamic Response	39
2.4.5.1	Numerical Evaluation of Duhamel Integral	42
2.4.6	Response Under Earthquake Loading	45
2.5	Analysis of Displacement and Stresses by Finite Element Method	
2.5.1	Nodal Displacement	47
2.5.2	Stresses and Their Extrapolation to the Boundary	47
2.6	Design Sensitivity	48
2.6.1	Finite Difference Approaches for Finding the Design Derivatives	48
2.6.2	Design Derivative of 2-D Isoparametric Finite Elements	49
2.6.2.1	Derivative of Jacobian Matrix	50
2.6.2.2	Derivative of Jacobian Inverse Matrix	50
2.6.2.3	Derivative of B Matrix	52
2.6.2.4	Derivative of Strain and Stresses w r t Design Variables	53
2.6.2.5	Derivative of Stiffness Matrix	54
2.6.2.6	Derivative of Mass Matrix w r t Design Variables	54

2.6.3	Design Sensitivity for Truss and Beam Elements	55
2.6.3.1	Truss Elements	55
2.6.3.2	Beam Elements	57
2.7	Need of Automated Mesh Generation	58
2.8	Sequential Linear Programming (SLP) With Improved Move Limit Method	58
2.9	Closure	64

CHAPTER-3 65 - 93

NUMERICAL COMPUTATION OF DESIGN DERIVATIVES

3.1	Introduction	66
3.2	Computation of Design Derivatives	66
3.3	Computational Algorithm	71
3.4	Numerical Examples - Truss Problems	73
3.5	Discussion of Results - Truss Problems	80
3.6	Numerical Examples - F.E. problems	83
3.7	Discussion of Results - F.E. problems	87
3.8	Possible Errors in Numerical Computation	92
3.9	Conclusion	93

CHAPTER-4 94 - 147

DEVELOPMENT OF AN OPTIMAL SHAPE DESIGN SYSTEM

4.1	Introduction	95
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4.2	Description of the General Purpose Structural Optimization Problem	96
4.2.1	Structural Optimization Module	96
4.2.2	Computer Program	100
4.3	Formulation for Cantilever Shape Design Test Problem	105
4.3.1	Analysis Details	107
4.3.2	Objective Function and Constraints	107
4.4	Numerical Studies	110
4.5	Results for the Test Problem	110
4.5.1	Results of Optimization with First Objective Function	110
4.5.2	Results for Optimization with Second Objective Function	110
4.6	Discussion of Results	110
4.7	Optimal Design of a Two Metre Long Cantilever Beam	110
4.7.1	Description of Problem	110
4.7.2	Results and Discussion	146
4.8	Conclusion	147
CHAPTER-5		148 ~ 291
OPTIMUM DESIGN OF A STEEL CHIMNEY UNDER TRANSIENT DYNAMIC LOADS		
5.1	Introduction	149
5.2	Loads on Chimney	150

5.3	Design Load Conditions	154
5.4	Scope for Optimization Under Seismic Load	161
5.4.1	Static Analysis Under Dead and Wind Loads	161
5.4.2	Dynamic Analysis Results Under Earthquake Loading	167
5.4.3	Sizing / Shape Optimization	171
5.5	The Design Optimization Problem	171
5.5.1	Objective Function	171
5.5.2	Constraints	172
5.5.3	Design Variables	173
5.5.4	Initial Design	173
5.5.5	Detailed Results	174
5.5.6	Progress of Optimization and Analysis of Results	174
5.5.7	Results with Alternate Starting Points and Progress of Optimization	174
5.5.8	Choice of Different Objective Function	201
5.5.9	Detailed Discussion	202
5.6	Scope for Optimization Under Blast Load	212
5.6.1	Dynamic Analysis Results Under Blast Loading	217
5.6.2	Sizing / Shape Optimization	217
5.7	The Design Optimization Problem	217
5.7.1	Objective Function	217
5.7.2	Constraints	217
5.7.3	Design Variables	218
5.7.4	Initial Design	218

5.7.5	Detailed Results	218
5.7.6	Progress of Optimization and Analysis of Results	218
5.7.7	Results with Alternate Starting Points and Progress of Optimization	219
5.7.8	Choice of Different Objective Function	220
5.7.9	Detailed Discussion	221
5.8	Conclusion	251
CHAPTER 6		252 - 299
	OPTIMUM DESIGN OF A GRAVITY DAM UNDER TRANSIENT DYNAMIC LOAD	
6.1	Introduction	253
6.2	Scope of Optimization	254
6.3	Design Requirements of a Gravity Dam	256
6.4	Static Analysis of the Dam Under Combined Loading	257
6.5	Transient Dynamic Loads	262
6.6	Hydrodynamic Effects on Dam	
6.6.1	Computation of Added Mass	262
6.6.2	Mesh Refinement	272
6.6.3	Numerical Computation of Wet Modes for Test Problem	272
6.6.4	Modelling for the Dam-Reservoir Interaction Problem	275
6.7	Dam Structure Parameters	275
6.8	Dynamic Analysis of the Dam	278
6.9	Optimization of the Dam with Full Reservoir Under Static and Transient Dynamic Loads (Earthquake Excitation)	282

6.10	Results and Discussion	297
6.11	Conclusion	298
CHAPTER-7		300 - 315
	ESTIMATION OF ANALYSIS ERRORS AND ACCURATE COMPUTATION OF DESIGN DERIVATIVES	
7.1	Introduction	301
7.2	Sources of Numerical Errors in Design Derivative Computations	301
7.3	Accurate Design Sensitivity Computation for Truss Problem	305
7.4	Design Sensitivity Computations for 2-D F.E. Dynamic Analysis Problems	309
	7.4.1 Error Estimation	309
	7.4.2 Overall Strategy	312
	7.4.3 Results and Discussion	313
7.5	Conclusion	314
CHAPTER 8		316 - 321
	CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH	
8.1	Introduction	317
8.2	Analysis of Results and Summary of Conclusions	317
8.3	Significant Contribution of the Present Research	319
8.4	Suggestions For Future Research	320
REFERENCES		322
APPENDIX		333
BIODATA		336
PAPERS FROM THIS INVESTIGATION		337