Where F - coordinate of the next point of the i-th element strain diagram break; n - number of elements in the bearing system. By the defined increment of parameter P_k the values of internal forces, strains and loads at the stage and are determined.

Realisation of the above algorithms in the design process is ensured by the elaborated recommendations on buildings design as well as strain diagrams of structural elements and joints. A set of applied computer programs allows to automate both individual stages of design and integrated testing of safety of the building's spatoal bearing system over all limit state groups.

Computerization of Engineering Calculations in Studying Structures

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KEYWORDS

Computer-Aided Scientific Research, Calculation of Structures, Boundary Problem, Design Model.

ABSTRACT

The examination of qualitative characteristics of building structures dictates a certain mathematical formalization of their physical and engineering properties. The formalization is generally described by boundary problems for diffrential equations in partial derivatives. Conditions imposed upon the solution of the problem are formalized as equalities and inequalities. The resultant relationships do not always correspond to the "typical" problems realized in software, e.g., on the basis of the finite element method.

On the other hand, the experience of numerical solution of boundary problems allows the most suitable form to be chosen for their description - variational expression realizing a concrete physical or mathematical concept.

In this case, problem formulation is reduced to putting down an integrand and additional conditions imposed upon the solution of the problem. It is, therefore, reasonable to develop a universal algorithm for computer-aided study of building structures wherein mathematical formulation as well as geometrical cinditions and engineering requirements are set forth at the level of formal parameters. Software developed on the basis of such algorithms make it possible to obtain numerical results in solving non-standard boundary problems of structural mechanics in a short period of time. It is very important, e.g., in studying new structures at the development stage or in investigating into a prompt engineering intervention into operating conditions of existing structures.

A number of variants of such an approach the the computer-aided design of structures have been developed in the USSR.

Automatisation des calculs d'ingéniuer pour l'étude des structures

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MOTS CLEFS:

Automatisation des Etudes Scientifiques, Calcul des Structures, Problème aux Limites, Model de Calcul.

Sommaire:

L'étude des caractéristiques qualitatives des structures prédétermine une certaine formalisation mathematique de leurs propriétes physiques et techniques. En général, elle est décrite à l'aide des problèmes aux limites pour équations différentielles à dérivées partielles. Les conditions appliquées à la solution de ces problèmes sont formulées sous forme d'égalités et d'inégalités. Les dépendances obtenues en fin de compt ne correspondent pas souvent aux problèmes-"types", qui sont réalisés dans les programmes d'après la methode des éléments finis. D'autre part, l'expérience de la solution des problèmes aux limites a demontre une forme qui convient le plus pour leur description, celle de notation variationnelle qui réalise le principe physique ou mathématique concret.

La definition de travail dans ce cas consist en enregistrement d'une fonction sous l'integral et des conditions complémentaires appliquées à la solution.

Donc, il est conseillé d'utiliser la possibilité d'établir un algorithme universel pour l'étude des structures à l'aide des ordinateurs, où la formulation mathématique aussi bien que les conditions géometriques et techniques sont déterminées au niveau des paramètres formels.

Les programmes développés sur la base de ces algorithmes permettent de fournir dans le plus court délai des résultats numériques pur résoudre les problèmes aux limites non normalisès dans la mécanique des constructions. C'est très important pour l'étude de nouvelles structures ou pour l'analyse des possibilités d'intervention opérative dans le conditions de leur travail. En URSS sont élaborées plusieurs méthodes de calcul des structures a l'aide des ordinateurs.

1. INTRODUCTION

Computerization of scientific studies in the design of structures mainly consist of computerizing numerical investigations of new design models and engineering theories.

New engineering theories and improved design models come to life with the advent of new structural concepts, building materials, operating conditions of structures and new requirements imposed upon reliability and strength of structures. Thus improved engineering theories are developed, e.g., in studying shells taking into account shear characteristics, non-linear factors, reinforcements, etc. New design models are created in calculating structures of composite materials such as with polymer fibers, granular aggregates, and the like, or as a result of continualization of discrete systems. Improved models are now used in studying structures of reinforced concrete, asbestos cement, stonework and non-compressible materials. Taking into account unilateral constraints, slits and cracks in structures results in non-standard boundary conditions giving birth to new design techniques.

A problem arises before a reaserch worker, how efficient, if necessary, is a revised or new theory as applied to a real-life structure? Computerization of investigations is aimed at finding a prompt answer to such questions, and one cannot do without computer here.

The existing commercial software for design of structures is mainly based on approved models and can be used by a design engineer who is not familiar with the mathematical formulation of the original problem. Constructing a new model with the employment of such software would take much time, and it would be nonsensical to make trial of an inadequately tested model or theory in this manner. Special software for computer-aided numerical study of new engineering theories, mathematical models ans structures is, therefore, necessary, which could be used by a research worker familiar with the mathematical formulation of a problem he faces and with elements of program compilation.

To bring a solution to these problems, variants of software for computer-aided numerical study of structures based on new theories, models and structural features have been developed at the Central Research Institute for Building Structures and Moscow Civil Engineering Institute.

2. FORMULATION OF A PROBLEM

Almost any theory or design model is formulated either in the form of a boundary problem for differential equations or in the form of boundary integral equations or variational problem. The latter is the simplest and most versatile one since it includes, in a compact form, both geometrical characteristics and boundary conditions and facilitates approximation of the problem. A typical variational formulation of a problem of structural mechanics is represented by a functional:

$$\Phi(u) = \int_{\Omega} F\left(x, u, \frac{\partial u_k}{\partial x_q}\right) dx$$

for a set of vector functions $\bar{u} = \bar{u}(x)$, wherein $x\ (x_1, \ldots, x_i)$ are the three-dimensional coordinates; Ω is the area taken by a structure in space; F is the function being integrated. The functions u comply with certain additional boundary conditions associated with various supports of structures. A function u^{*} for which the functional $\Phi(u)$ has minimum value taking into account additional limitations, will describe the state of stress/strain of a structure.

3. FORMULATION OF PROBLEMS USING THE STANDARD AREA METHOD

Let us consider a boundary problem in a preset area Ω:

$$Lu = F,\ x \in \Omega\ ,\ \ lu = f,\ \ x \in \partial\Omega\ ,$$

wherein L and l are the differential operators. Let us place the area Ω into a standard area ω (Fig.1). It can be shown that the original boundary problem may be formulated also within ω. Thus the Poisson formula (Neumann problem) will take the form:

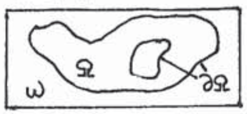

Fig. 1

$$\sum_{i=1}^{N} \frac{\partial}{\partial x_i}\left(\theta \frac{\partial u}{\partial x_i}\right) = \theta F + \delta(p)\cdot f,\ \ x \in \omega,$$

wherein $\theta(x)$ is the characteristic function of the area Ω; $\delta(p)$ is the function concentrated at the boundary [3] ; F and f are known functions set forth within, and at the boundary of the area, respectively. It can be seen that no additional boundary conditions are necessary. The corresponding variational formulation has the following form:

$$\Phi(u) = \int_{\omega} \left[\frac{1}{2}\theta \sum_{i=1}^{N} \left(\frac{\partial u}{\partial x_i}\right)^2 - (\theta F + \delta(p) f) \right] dx.$$

Let us give similar formulations, within a standard area, for:

a problem of the elasticity theory:

- operator $\displaystyle\sum_{j=1}^{N} \frac{\partial \theta \sigma_{ij}}{\partial x_j} = \theta F_i + \delta(p) f_i\ ,\ \ x \in \omega,\ i = 1, 2, \ldots, N$

wherein $\sigma_{ij} = 2\mu \varepsilon_{ij} + \delta_{ij}\lambda\varepsilon\ \ ;\ \ \varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right); \varepsilon = \sum_{i=1}^{N} \varepsilon_{ij}$

- functional $\displaystyle\Phi(u) = \frac{1}{2}\int_{\omega} \theta \sum_{i,j} \sigma_{ij}\, \varepsilon_{ij} dx = \int_{\omega} \sum_i (\theta F_i + \delta(p) f_i) u_i dx;$

and a problem of slab bending:

- operator $\displaystyle\frac{\partial^2 \theta M_{11}}{\partial x_1^2} + \frac{\partial^2 \theta M_{22}}{\partial x_2^2} - 2\frac{\partial^2 \theta M_{12}}{\partial x_1 \partial x_2} = F(x),\ \ x \in \omega,$

wherein $M_{11} = -D\ (\varkappa_1 + \nu\varkappa_2)$, $M_{22} = -D(\nu\varkappa_1 + \varkappa_2)$, $M_{12} = -D(1-\nu)\varkappa_{12}$.

$$\varkappa_i = \frac{\partial^2 w}{\partial x_i^2}\ \ ;\ \ i = 1, 2; \varkappa_{12} = \frac{\partial^2 w}{\partial x_1 \partial x_2}$$

wherein D and ν are the cylindrical rigidity and Poisson's ratio, respectively

- functional $\displaystyle\Phi(w) = \frac{1}{2}\int_{\omega} \theta(M_{11}\varkappa_1 + M_{22}\varkappa_2 + M_{12}\varkappa_{12}) dx - \int_{\omega} \theta F \cdot w dx\ .$

Solving a problem within a standard area may be physically explained as adding to a structure occupying an area Ω (Fig.1) a zero-rigidity structure of an area ω/Ω . In another variant of the method, the design area Ω is supplemented up to a standard area ω (Fig.2) so that its real physical characteristics be preserved within ω and that a step of the function being sought occur within $\partial\Omega$ (in other words, a slit is set around the original area Ω). Solution of the problem is reduced to minimizing the functional within the standard area in the class of discontinuous functions.

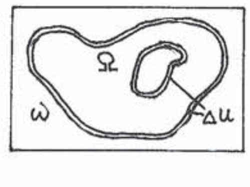

Fig.2

The additional unknown variables are steps of the function being sought at the boundary, and minimization is carried out not only for nodal unknown variables within Ω and $\partial\Omega$ (this is an averaged value of unknown variables on the sides of discontinuity), but also for unknown values of steps of the function within $\partial\Omega$. This approach is physically meaningful with an actual partial cut through a structure (crack, slit or the like) and in this case its use would be undoubtedly broader than that of the preceding variant.

The opportunities offered by the second variant of the standard area method are enlarged within the framework of a so-called "two-step algorithm". In this case steps of the function being sought Δu_s are first considered as a parameter, and the solution is found in the form $\bar{u} = \bar{u}(\Delta u)$. Further solution of the problem involves a detailed representation of the function being sought in the original functional and its minimizing by the parameter Δu. This approach is easily realized in the discrete variant. The second step of the "two-step algorithm" is the discrete analog of the method of boundary integral equations, the resolving system of equations being always symmetrical and positively determinate.

Realization of the "two-step algorithm" proved very effective in solving problems involving unilateral constraints owing both to algorithmic simplifications and reduction of unknown variables taking part in the non-linear calculation.

4. APPROXIMATION

The approximation begins with setting forth a discrete grid in a standard area which is topologically equivalent to a rectangular grid with the unity step.

Formulation of a problem (integral in the standard area) is regarded as a sum of integrals in unit squares

$$\int_\omega F(\quad)dx = \sum_i \int_{\Diamond_i} F(\quad)dx = \sum_i \int_{\Box_i} F(\quad)Jdx,$$

wherein $\Diamond$ is the grid mesh, i is the mesh number, $\Box$ is the unit square, J is the Jacobian.

The functions that are part of the original functional are determined by their values at nodal points of the grid. Discrete values are then supplemented at all other points, e.g., by polynomials. The research worker may take part in the whole process or intervene in individual steps if necessary. At any rate, such participation would prove useful as it can help assess correctly the calculation results. At the same time, representing the discrete analog of the mathematical formulation of the problem, which actually involves representation of the original functional as a set of functions supplementing discrete values, as well as other calculations, are performed automatically, without participation of the research worker.

5. BASIC RELATIONSHIPS INVOLVED IN SOFTWARE

The function u is sought in the form $u = \sum_i u_i e_i$, wherein e_i are the unit basic functions; u_i is the element of vector of discrete values $\bar{u}=(u_1,\ldots,u_m)$.

The general path for finding minimum of the functional $\Phi(u)$ is written in the form of the Newton-Routh procedure

$$\bar{u}^{k+1} = \bar{u}^k - \tau A_k^{-1}\bar{F}^k \text{ with } \bar{u}^0=0.$$

Elements of the matrix A_k and vector $\bar{F}^k$ are calculated by the formulae:

$$a_{ij}^k = \frac{\partial^2\Phi}{\partial u_i \partial u_j}\Big|_{\bar{u}=\bar{u}^k} \approx \frac{1}{\varepsilon^2} \sum_{t_1=0,1} \sum_{t_2=0,1} (2t_1-1)(2t_2-1)\cdot\Phi(\bar{u}^k + t_1\varepsilon e_i + t_2\varepsilon e_j)$$

$$f_i^k = \frac{\partial\Phi}{\partial u_i}\Big|_{\bar{u}=\bar{u}^k} \approx \frac{1}{2\varepsilon} \sum_{t=1,-1} t\cdot\Phi(\bar{u}^k + t\varepsilon e_i).$$

If the problem is linear, the above formulae are simplified. Since $\bar{u}^k=0$ in this case,

$$a_{ij} \approx \sum_{t_1=0,1} \sum_{t_2=0,1} (2t_1-1)(2t_2-1)\cdot\Phi(t_1e_i+t_2e_j)$$

$$f_i = \frac{1}{2} \sum_{t=1,-1} t\cdot\Phi(te_i)$$

and $\tau=1$.

6. PRACTICAL APPLICATION IN SCIENTIFIC RESEARCH

Studies of various three-dimensional structures, design models and engineering theories have been conducted based on the above techniques and software.

Structures such as shells with various reinforcements such as ribs and the like, multilayer shells, underground structures and massive structures have been studied; problems involving oscillations of tunnels and machine foundations have been solved and reinforced concrete slabs design using N.I. Karpenko model and asbestos cement structures using G.A.Geniev model were studied. Numerical studies of errors of optical simulation (models of non-compressible materials), structures of rubber products and non-compressible polymers were designed, and a continuous dependence of the solution on Poisson's ratio has been shown. Studies and calculations of structures were conducted based on revised shell theories taking into account shear characteristics, non-linear factors and layered design. Structures in permafrost areas with varying freezing boundary influencing physical characteristics of the structural materials were calculated and numerically studied. Non-stationary problems are also solved using the software.

Computerization of numerical studies with the employment of the proposed algorithms results in a reduction of total effort and acceleration of the studies as compared to the employment of standard software based on finite element method and individual program compilation by 7-8 times on the average, the total time necessary for studying new models and structural concepzs being 2-3 times shorter.

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TITLE OF THE PAPER: EXPERIMENTAL CONFIRMATION OF A COMPUTER MODEL OF RACKING BRACING FOR A STEEL-FRAMED BUILDING

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KEYWORDS: Computer Program, Racking Bracing, Light Steel-Framed Buildings

SUMMARY

USG Corporation, Research Department, has developed a computer program, DSCSRACK, for designing racking bracing in cold-formed steel-framed buildings.

The program uses as input the building geometry, wind loading condition, and member specifications. From these data, using finite element analysis, the loads and stresses on the braced panel components are calculated. The bracing is then sized and the fastening specified.

To verify the computer program, a full-scale load test simulating wind conditions was conducted on a 1-1/2 story cold-formed steel-framed building, 3.66 meters by 7.32 meters in plan, having screw-attached, gypsum sheathing.

The computer program modeled the behavior of the building within 10%. These test results verified experimentally that the computer program is adequate for analyzing and designing racking bracing and connections in cold-formed steel-framed buildings.