I-A 465 Application of Biological-Growth Strain Method on Civil Structures

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Introduction

It is believed that the biological structures usually develop their own adaptation mechanism to all the boundary and loading conditions defined by their environments [1]. The optimal result of the adaptation of those biological structures can be characterized by the state of constant stress on their surface, which results from biological design rules. Hence, this research is motivated to develop an elastic optimal shape design method using the biological design rules, which can be categorized as the optimality criterion approach. In addition, the effect of strength ratio is attempted to be considered in the proposed method.

Description of the Proposed Method

a. optimization procedure

In order to update the design variables, a method called "biological-growth strain analysis (BGSA)" was first proposed here, the concept of which can be regarded the same as the "incremental growth analysis (IGA)", suggested in [2]. Both of the methods are similar to "initial strain method", i.e. the shape updating of the design structure is an iterative process which consists of two stages : (i) generation of fictitious strain by built-in rules (e.g. nonlinear constitutive relationship or the biological growth rules) and (ii) production of fictitious external loads by the given fictitious strain. According to the numerical results of [2], IGA indeed has offered good performance on optimal shape design with effective reduction of stress concentration. However, because the bulk strain introduced in IGA only considers in the form of principal strain without the consideration on shear strain and the consideration on the effect of strength ratio by introducing weigh factor neglects the actual growth direction of structural elements. Hence the idea of "biological-growth strain" is presented in place of the idea of bulk strain for improving the aforementioned insufficiency. In addition, the updating of design structure in BGSA can be the whole domain of the design structures or only part of the design structures by specifying the design domain.

b. biological-growth strain

The concept of biological-growth strain in essence is derived from "stress-ratio method" , the concept of which is based on the assumption that the variation of volume (or area) of design structures has a proportional relationship to the variation of stress. For continuous structures, the concept of "stress-ratio method" may hold for the discretized elements under the state of principal stress. As a result, in stead of the use of equivalent stress , the principal stress is considered for the principal biological-growth strain $\boldsymbol{\varepsilon}_k^{BP}$ which is defined as

$$\boldsymbol{\varepsilon}_k^{BP} = \frac{\sigma_{1,i} - \sigma_{1,mean}}{\sigma_{1,mean}} \left| \frac{\sigma_k}{f_k} \right| h \tag{1}$$

where $\sigma_{1,i}$: maximum principal stress within ith design elements; $\sigma_{1,mean}$: average of maximum principal stress within design domain; f_k: uniaxial compressive or tensile strength; σ_k: the principal stress ; h: constant for search step and $\left|\frac{\sigma_k}{f_k}\right|$ (>0) offers the consideration on the effect of strength ratio.

then by transformation of coordinates , the biological-growth strain $\boldsymbol{\varepsilon}_k^{B}$ can be defined as

$$\boldsymbol{\varepsilon}_k^{B} = \int_{\Omega_e} [A]^T \{\boldsymbol{\varepsilon}_k^{BP}\} [A] d\Omega_e \tag{2}$$

where $[A]$: the transformation matrix between principal strain tensor and local strain tensor; Ω_e : design element.

Numerical Examples

After the brief explanation on this method, the availability of this proposal are illustrated by two numerical examples : (i) The design of optimal shape for mass concrete dam under static water pressure and (ii) the optimal design of notch shape for an infinite plate under biaxial tension. For the first example, the configuration of the original structure is given in Fig.1. By minimizing the stress variation along the inner and outer profile of the dam, the optimized shape of the dam is arch-like dam (as shown in Fig.2). Fig.3 indicates the accepted convergence of the result; however, from Fig.4, the minimization of stress variation is obviously insufficient so that the result obtained here is only considered as local optimum. Along with the optimization process, if the distortion of elements exceeds the default value, remeshing techniques using spline curve and isoparameteric mapping are introduced, the effect of which can be observed in the abrupt variation on value of objective function and maximum principal stress. In addition, in this example, the effect of strength ratio is included by Fc:Ft=160:20. With its possible availability shown in this case and the other cases which are not given here, the performance on the effect of strength ratio can be thought acceptable. And for the second example, the analytical solution of the notch shape by the theory of elasticity is circular due to the biaxial isotension (the FEM model is given in Fig.5). This known result can be verified with the optimized result shown in Fig.6, the shape of which is nearly circular. And the good convergence on the objective function and maximum principal stress is illustrated in Fig.7. Especially, the result of Fig.8 represents the state of constant stress along with the optimized design profile, which effectively affirms the possibility of this method on simulating the biological growth to the design of structures.

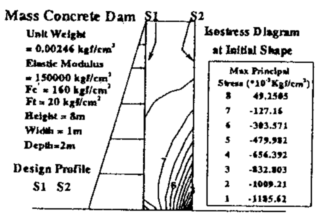

Fig.1 The Configuration of Mass Concrete Dam

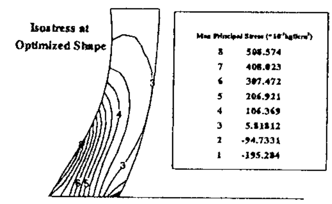

Fig.2 The Optimized Shape of Mass Concrete Dam

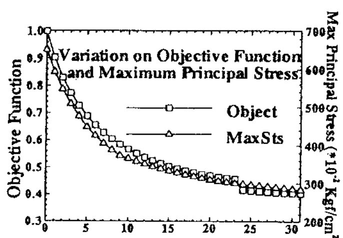

Fig.3 The Convergence of Objective Function and Maximum Principal Stress

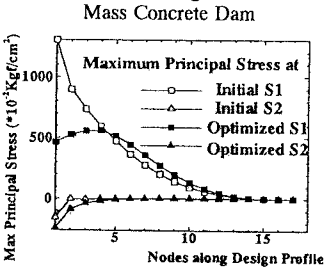

Fig.4 The Minimization of Stress Along the Design Profile

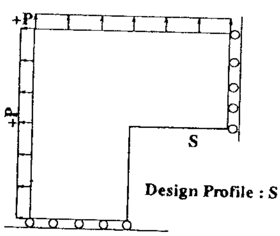

Fig.5 The FEM Model of Infinite Plate Under Isotension

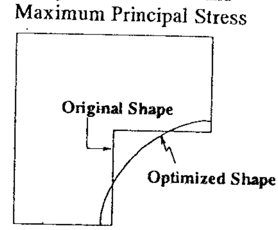

Fig.6 The Variation of Notch Shape

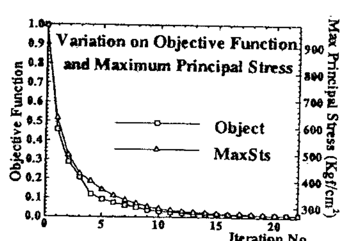

Fig.7 The Convergence of Objective Function and Maximum Principal Stress

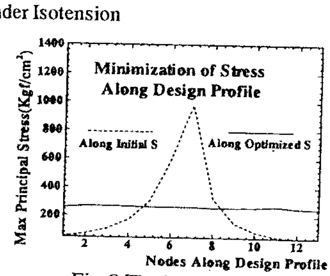

Fig.8 The Minimization of Stress Along the Design Profile

Conclusions

In this paper, only the main feature of Biological-Growth Strain Method - the introduction of biological-growth strain is briefly explained, the form of which considers the existence of fictitious shear strain and the actual element growth under different ratio of strength. And through the above examples, the availability of this newly proposed method is believed to be accepted.

References

[1] Mattheck, C., "Engng. Components Grow Like Trees", Mat.-wiss. u. Werkstofftech. 21, 1990, pp.143-168.

[2] Hsu,K.L. and Taketo UOMOTO, "A Proposal For Optimal Shape Design Of Structures Using Brittle Material (Static Loaded, Two-Dimensional Body)," "SEISAN-KENKYU" - Monthly J. of IIS, Univ. Of Tokyo, Vol.47, No.3, Mar., 1995.