A Numerical Approach for Dynamics of Flexible Structures(構造部材の動的大変位問題の一数値解法)

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号	1861
発行年	1995
URL	http://hdl.handle.net/10097/7134

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授与学位	博士（工学）
学位授与年月日	平成8年3月26日
学位授与の根拠法規	学位規則第4条第1項
研究科，専攻の名称	東北大学大学院工学研究科 （博士課程）土木工学専攻
学位論文題目	A Numerical Approach for Dynamics of Flexible Structures （構造部材の動的大変位問題の一数値解法）
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論文内容要旨

1. Introduction

Research of the flexible structures has been a subject of great interest in civil engineering. A considerable research have been carried out in the field of nonlinear dynamic analysis of planar flexible beam, but a limited studies are available in the field of nonlinear dynamic analysis of spatial flexible beams. Some dynamic analyses are available in the area of spatial flexible multibody systems.

The main objective of this study is to develop a numerical formulation for the nonlinear dynamic analysis of spatial flexible structures undergoing finite-displacements which is derived by physics-based consideration without any computational technique.

Finite element approach is used to model the beam but no energy approach nor variational principle is employed. A co-rotational method is employed in this study where the nodal coordinates, velocities, accelerations, relative displacements and rotations are defined in terms of fixed global coordinates, while the total strains in the beam element are measured in an element coordinate system using the small deflection beam theory. Virtual work expression is used to obtain mass matrices in the beam element but it is not a variational principle but a weak form. Both stiffness and mass are represented by conventional matrices in the linear theory in the local coordinates because of small deformation assumption. They are then transformed into the global coordinate system using the standard procedure. Since the objective of this research is to develop a physics-based numerical method, no fancy technique is employed, but the numerical algorithm used here is an incremental iterative method based on the Rung-Kutta-Merson's integration method.

2. Kinematics and Stiffness of Finite Element

Basic preliminaries required for the development of the motion equations expressed in this chapter. Displacement fields are obtained based on the basic assumptions. Transformation matrix is obtained to transform the stiffness and mass matrices of the element coordinate systems to the global coordinate systems. Also the physically meaningful transformation technique is employed to transform the infinitesimal components of the Eulerian angles corresponding to the global coordinate systems. This chapter deals also about numerical formulations to solve the motion equations. Relative nodal displacement equations are obtained using the nodal displacement vectors.

3. Discretized Equations of Motion

Nonlinear equations of motions for the flexible structures due to internal forces, inertia forces and external forces are presnted in this chapter.

However there are several methods available for solving transient problem by direct integration, well known Runge-Kutta-Merson's method is chosen in this study primarily because of its stability and accurracy under a wide range of element size and time step variations.

4. Numerical Check of Accuracy

In this chapter comparison is made with analytical solutions and numerical solutions by other methods in order to show feasibility of the present method.

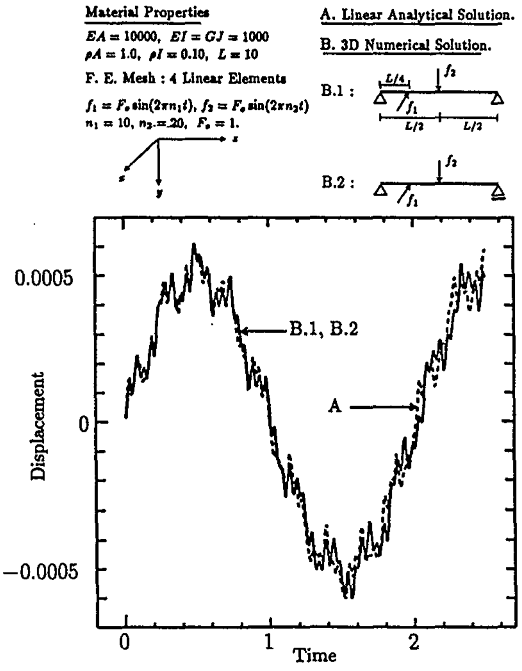

Fig. 1 Time history of midpoint y-dir. displacement at amplitude= 1.

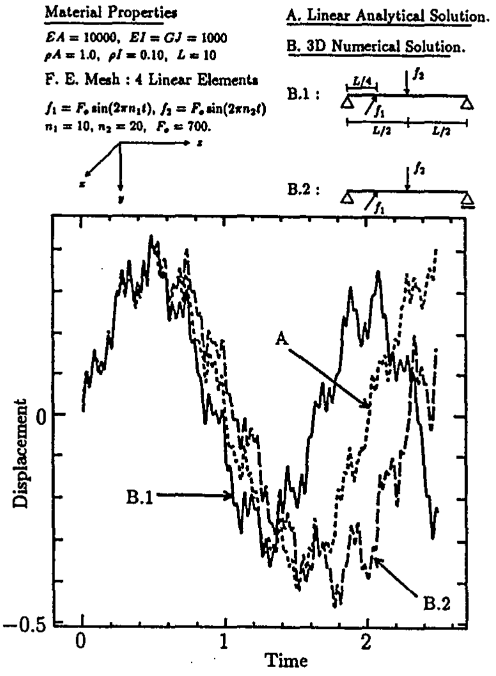

Fig. 2 Time history of midpoint y-dir. displacement at amplitude=700.

First of all a comparison is made with linear analytical solution in Fig. 1. Both the numerical and analytical solutions coincide with each other when the magnitude of responces kept small enough. Fig. 2 shows the check of the effect of nonlinearity qualitatively at finite displacement. A flexible beam as shown in Fig. 3 is subjected to a force and torque is solved by present method and compared with the results of the other researchers and found very close results. The displacements of gravity center of this beam are calculated by present method and analytic method as shown in Fig. 4 and found almost same results.

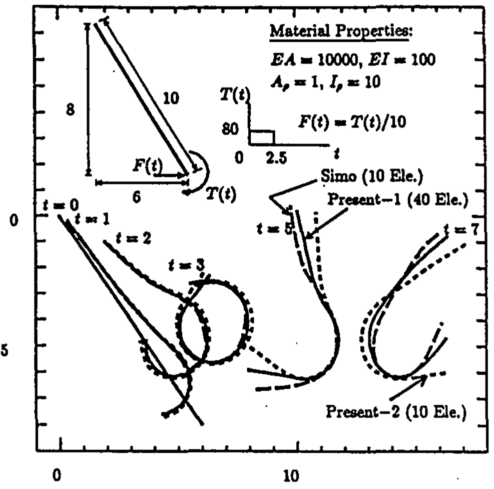

Fig. 3 Free flight of spaghetti.

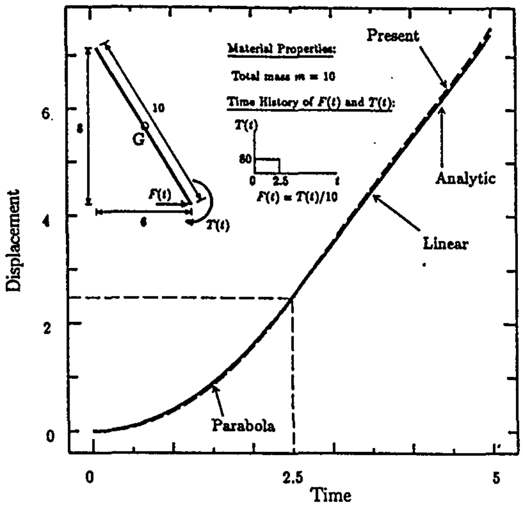

Fig. 4 Displacements at gravity center of free flight beams.

5. Cable Structures

Recently most challenging tasks under severe conditions have to be accomplished by civil engineers. Particularly in the case of the bridge construction over the deep sea, it is so difficult to obtain rigid foundation bases and the strucutre becomes costly. Huge types of structures also affects on the aesthetic sense of the environment. Considering such circumstances, introduction of submerged but stiff floating foundations may also remove such difficulties and extend the valuable contribution in the civil engineering fields.

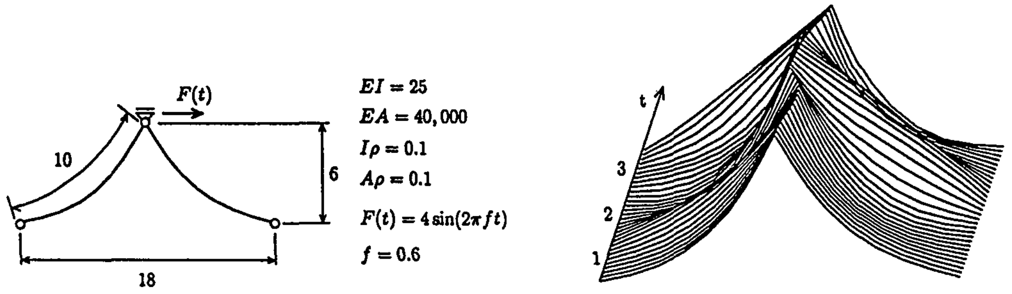

Fig. 5 Cable system : Deformation with time.

Floating bodies are generally moored by cables, they are sensitive to the dynamic effects of wave and tidal current and show nonlinear mechanical behavior. The applicability of the present formulation in the simple cable system of the mooring structure is presented in this chapter is shown in Fig. 5.

6. Conclusions

This study describes a numerical method for the nonlinear dynamic analysis of the spatial flexible structures undergoing finite-displacement which is derived by physics-based consideration without any computational technique. It has been demonstrated by few examples that the present formulation and procedure are applicable to nonlinear dynamic analysis of spatial flexible structures undergoing finite displacements and rotations. This finite element formulation is very useful and highly accurate solutions can be obtained. It is also hoped that this numerical method can be a valuable engineering tool for the dynamic alaysis of spatial flexible structures.

審査結果の要旨

橋梁構造をはじめとする柔な長大鋼構造物では，その架設段階の不完成系におけるケーブルの挙動等，幾何学的非線形性による不安定の可能性が高いが，特に三次元構造解析における不安定解析はまだ十分な精度で解を得ているとは言えない。

本研究は，静的な三次元大変位構造解析と動的な二次元大変位解析とを結び付け，離散運動方程式を定式化する新アプローチを提案し，数値解析によって三次元構造挙動のシミュレーションと安定解析を行なった結果をまとめたものであり，全6章からなる。

第1章は序論であり，研究の背景や既往の研究について述べることによって，本研究の意義と位置付けを明らかにしている。

第2章では，幾何学的非線形運動場と，離散運動方程式を誘導している。新しい局所座標と三次元的な回転角の表現を用いた三次元梁要素の離散運動方程式の誘導を行なっているが，鋼部材等の場合には，いわゆる線形解析における剛性・質量行列を用いて最終的な離散運動方程式を誘導できることを示したことは，三次元問題でははじめてであり，有用な知見である。

第3章では，前章で求まった離散運動方程式の数値解法としてRunge-Kutta-Merson法を用いた場合について詳細している。

第4章では，宇宙構造部材の飛翔問題をも含めて，既往の研究や線形解析との比較を行ない精度を議論している。従来の解析より少ない要素数で同程度の精度が得られる場合があることを示し，本定式化および数値解法の有用性を具体的に示すことができている。

第5章では，橋梁の水中係留基礎やケーブルの三次元動的解を解析しており，数値的な不安定が応答の不安定性を示唆することを例示している。一般的で複雑な構造物を対象とした三次元的動的安定問題を比較的簡単な離散運動方程式をもとに解析し，その解の安定性を解析したことは，重要な成果である。

第6章は結論である。

以上要するに，本論文は三次元的な離散運動方程式を開発し，それによって各種長大柔構造の安定解析をする手法を提案したものであり，構造力学および構造工学の発展に寄与するところが少なくない。

よって，本論文は博士（工学）の学位論文として合格と認める。