Behaviour of prestressed concrete bridges considering construction stages

Behaviour of Prestressed Concrete Bridges Considering Construction Stages

Comportement de ponts précontraints en fonction des étapes de construction

Verhalten von Spannbetonbrücken unter Berücksichtigung des Bauzustandes

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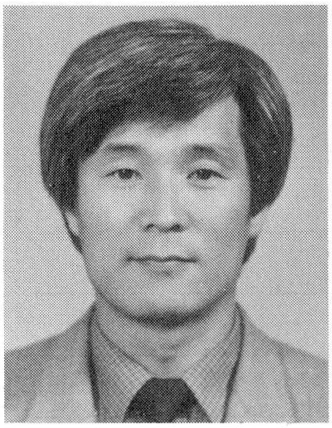

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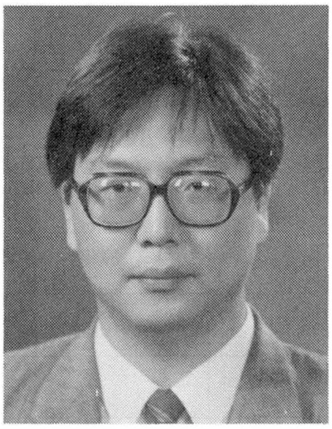

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SUMMARY

A numerical procedure is presented for 3-dimensional prestressed concrete frame structures with stay cables considering construction stages. A finite element type is developed including the warping and flexural-torsional effects of arbitrary cross sections. The geometric nonlinear analysis during construction and linear dynamic analysis at any construction stage are incorporated. The ultimate load of the structure is not studied. The effects of creep, shrinkage and prestressing are considered by nonconservative equivalent loads.

RÉSUMÉ

Une procédure numérique est présentée dans le cas de cadres tri-dimensionnels à haubans avec prise en compte des étapes de construction. Une procédure basée sur les éléments finis est développée; elle tient compte des effets de gauchissement et de torsion-flexion de certaines sections-types. L'analyse géométrique non-linéaire effectuée durant la construction, ainsi que l'analyse dynamique linéaire y sont également incluses. Le charge ultime de la structure n'est pas étudiée. Les effets du fluage, du retrait et de la précontrainte sont pris en considération sous forme de charges équivalentes non-conservatives.

ZUSAMMENFASSUNG

Ein Berechnungsverfahren für die dreidimensionale Rahmenstruktur aus Spannbeton mit Schrägkabeln unter Berücksichtigung des Bauzustandes wird vorgestellt. Ein finites Element wird entwickelt, welches die Effekte der Verwölbung und Biegedrillung eines beliebigen Querschnittes enthält. Die Traglast des Tragwerkes wird nicht untersucht. Die geometrisch nichtlinearen, statischen Analysen während des Bauzustandes und die linearen dynamischen Berechnungen für jeden Zeitpunkt der Konstruktion sind inbegriffen. Die Effekte des Kriechens, des Schwindens und der Vorspannung werden durch nicht-konservative Gleichgewichtskräfte berücksichtigt.

1. INTRODUCTION

In general, prestressed concrete bridges with long spans are constructed by carefully selected construction methods. Most of these construction methods consist of a number of construction steps which normally mean a number of different structural systems during construction. Moreover creep and shrinkage of concrete cause stress redistribution which makes the behaviour of structures more complicated. During the past two decades, a series of efforts to simulate complicated construction methods were made as shown in Table 1, where this study is listed together and compared. [1,2,3,4,5]

The purpose of this paper is to describe the geometric nonlinear analysis procedure of prestressed concrete bridges with flexural-torsion and warping effects implemented in the program SNUBR and present several examples for the validity and applicability.

ANALY-SIS / PRO-GRAM	Used Element		Additional degree of freedom		Shape of section	Segmental Creep & Shrinkage Analysis	Geomatric Material nonlinear
	Frame d.o.f	Stay Cable	warping	distorsn			
R M	6	Used				*	
B C	3	Used				*	
SEGAN	8		*	*	1 cellbox	*	
SFRAME	3					*	
SPCFRAME	3					*	G + M
present SNUBR	7	Used	*		arbitrary	*	G

Table 1 Computer Programs for Prestressed Concrete Bridge

2. FINITE ELEMENT ANAYSIS

2.1 General Remarks

A numerical procedure for the geometric nonlinear analysis considering feasible construction stages and linear dynamic analysis at any construction time of three dimensional prestressed concrete frames is presented. This study includes not only the time dependent effects due to load history, creep, shrinkage and aging of concrete and relaxation of prestressing tendons and stay cables but also the flexural-torsional effects including warping in structures with nonsymmetric sections. In the present study tangential stiffness matrices of the elements are obtained using updated Lagrangian formulation based on finite element method. The following assumptions are based.

(1) All materials are linear-elastic.
(2) It is assumed that the shape of a cross section varies only with warping.
(3) Nonlinear terms in shear strains of a frame element are neglected.
(4) Large displacements and rotations and small strains are assumed.

2.2 Stiffness and Mass Matrix

The frame element has two nodes and each node has 7 degrees of freedom including warping and flexural-torsional effects as shown in Fig.1. The cross section of a frame element has an arbitrary shape which is represented by 7 sectional constants and shear center position. The 14 x 14 tangential stiffness matrix is derived from the virtual work theorem and 14x14 mass matrix based on consistent mass is derived from the energy principle and variational method. Stay cable elements are included in the present nonlinear analysis as truss elements using Ernst's equivalent elastic modulus. Stiffness and mass matrix are also derived by a simillar method with frame elements.

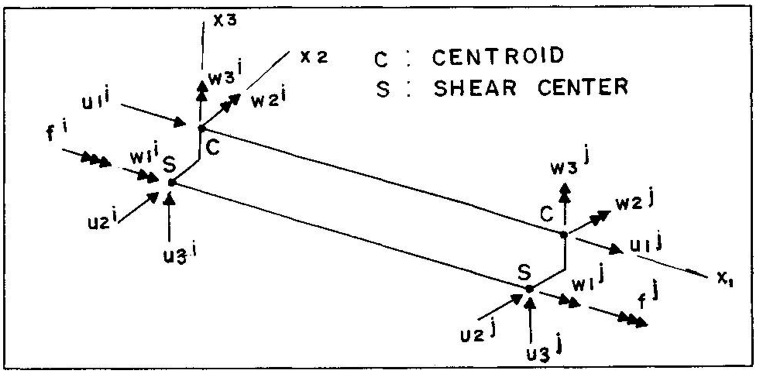

Fig.1 Displacements of a frame element

2.3 Time Dependent Effects in Concrete Members

The typical time dependent charcteristics of concrete, i.e. creep, shrinkage and aging are considered in the present study. It is assumed that creep and shrinkage influence axial deformation, bending deformation, pure torsion deformation and warping deformation at same time. As creep and shrinkage models CEB/FIP and ACI model are used which define their own strain behaviour with time due to loading-unloading stress condition.

The time dependent analysis is based on the superposition principle. The mathmatical forms of the strain and curvature increments are obtained using DIRICHLET series using the previous time interval. So equivalent load vector at each time interval is obtained from the general equilibrium equation of intitial strains.

2.4 Prestressing Force of a Tendon

The geometry of a tendon within an element is defined by two profiles, i.e. a cubic curve in the vertical projection plane and a straight line in the horizontal projection plane as shown in Fig.2.

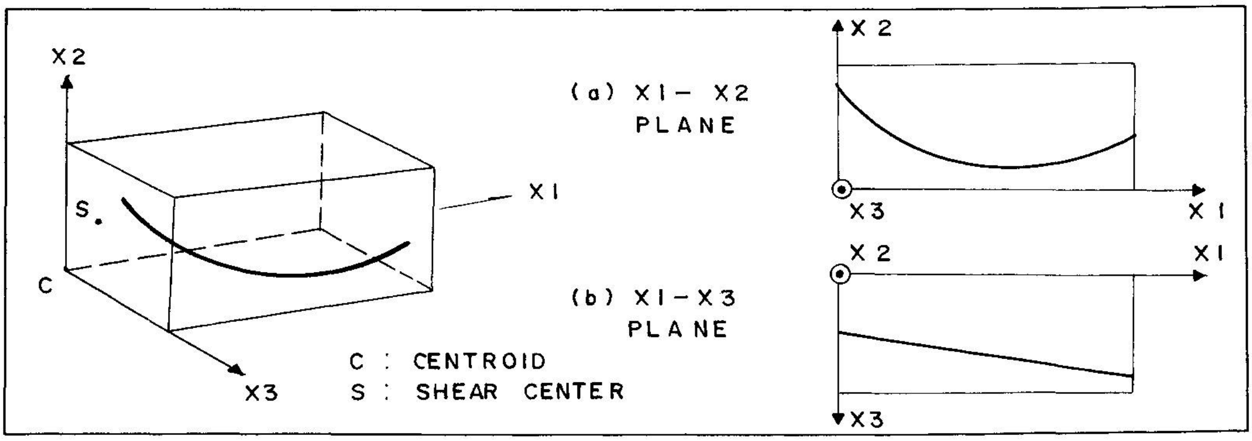

Fig.2 Profiles of a prestressing tendon

The effects of prestressing are considered by the form of equivalent loads. At the jacking stage, the loads are derived from self-equilibrium equations. The equivalent loads by the change of the tendon force due to deformation after jacking are calculated based on the strains of the prestressed members.

The geometric stiffness of the prestressing tendons are considered in the geometric nonlinear analysis. The geometric stiffness of tendons are derived from the deformation and shape functions of main concrete members because the grouted tendons do not have independent shape functions of deformations but are subject to concrete members. After tendons are stressed, the geometric stiffness of tendons are added to the geometric stiffness of a current structure. And then the geometric stiffness of the total structure is not continuous immediately after stressing of tendons because geometric stiffness of a member is embodied from the total sectional resultants.

2.5 Conservative and Nonconservative Loads

In our presentation, the effect of creep & shrinkage and prestressing tendon forces are considered in the form of equivalent loads. The total external loads acting on a structure which are resulted from the prescribed equivalent loads do not keep consistent in the global coordinate system, because the loading directions of these forces would vary according to the relocation of structural members followed by the resulting deformations. Therefore, these forces can be said to be non-conservative. On the other hand, the self-weight of a structure and ordinary loads can be defined as conservative loads because the total external load of them would always keep consistent in spite of structural deformation.

In the case of nonlinear analysis, the unbalanced loads which result in the incremental displacement are found from the difference between the total external loads acting on a structure and the total internal resisting load upto current time-step. Therefore, for the non-conservative forces the total external loads are revised in accordance with the corresponding displacement.

3. DESCRIPTION OF COMPUTER PROGRAM

Program named 'SNUBR' was developed in order to analyze the three dimensional prestressed concrete frame structures according to the presented manner. For the simulation of construction steps, the following "Construction Commands" are defined and directly used for user's input data for the help of a free field interpreter adopted in this program. [6]

(1)	Time	(2)	Erect
(3)	Stress/Remove Tendon	(4)	Stress/Remove Cable
(5)	Load	(6)	Move/Remove Load
(7)	Support	(8)	Change/Remove Support

Static analysis is carried out according to the successive construction steps simulated by several "Construction Commands" which represent unit construction works and time in days. Each constuction command defines structural system and/or produces unbalanced loads at any time. Tangential equilibirum equations are solved by the combined method, i.e. the tangent stiffness method with the iterative method.

In the case of dynamic anaysis at any construction time, a linear analysis is carried out based on the strucrural geometry and tangential stiffnesses transfered from the current stage. Then the assembled mass matrix of frames and stay cables are calculated. Frequency analysis and/or forced vibration analysis due to a moving concentrated load and general time function loads are carried out. For free vibration analysis, Subsapce iteration method is used and for forced vibration analysis, Mode superposition method and Newmark direct integration method are used.

4. NUMERICAL EXAMPLES

4.1 Natural Frequencies of Thin Walled Beams

To verify the validity of the present stiffness matrix and mass matrix, ten natural frequencies of a thin walled beam with a nonsymmetric section are calculated. The results are compared with the analysis of P.O.FRIBERG who calculated the natural frequencies of thin walled cantilever as shown in Fig.3 including warping derived from VLASOV's differential equations. The difference is about 1.0% as shown in Table 2. [7]

Compression P= 0		Mode	Compression P=1790 N	
By FRIBERG	Present	No	By FRIBERG	Present
31.80	31.80	1	25.01	25.01
63.76	63.77	2	61.28	61.31
137.5	137.8	3	136.0	136.3
199.0	199.1	4	192.4	192.4
278.2	278.6	5	274.9	275.3
483.9	484.6	6	478.5	479.3
556.3	556.4	7	550.7	550.9
657.3	658.3	8	654.8	655.9
767.5	769.2	9	760.8	762.6
1075.	1078.	10	1067.	1070.

Table 2 Natural Frequencies(Hz) of Thin Walled Cantilever

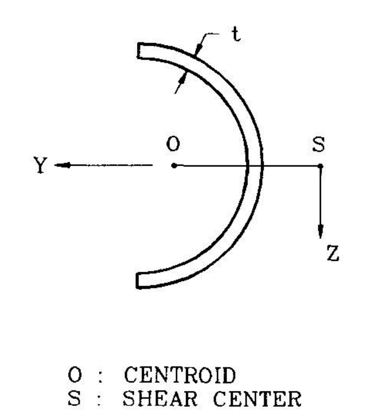

Fig.3 Half Circle Cross Section

4.2 Dynamic anaysis of P.C. Cable Stayed Bridge

In this example, a cable stayed bridge 80 + 150 + 80 = 310 M long is analysed considering construction steps. Pylon is 40m high above deck and 20m long below deck. For constuction method, free cantilever method is used. And then the influence on natural frequencies and forced vibration are investigated. The change of natural frequencies as time passes are shown in Table 3, where it is found that 1st natural frequency is increased 4 % as time passes and 6 % error can happen in case of neglecting construction steps.

Construction steps	day	NATURAL FREQUENCIES in Hz				Remarks
		1st	2nd	3rd	4th	
Considered	200	0.2414	0.3205	0.5697	0.6624	4%small
	6000	0.2512	0.3251	0.5866	0.6784	1.000
Neglected	200	0.2560	0.3248	0.5818	0.6730	6 % err
	6000	0.2581	0.3275	0.5860	0.6810	3 % err

Table 3 Natural Frequencies of Cable Stayed Bridge (Hz)

For the effect on forced vibration, a moving concentrated load with the speed of 20m/sec (72km/hr) is applied. As shown in Fig.4, dynamic load factor is increased about 3.5% at the center of the bridge.

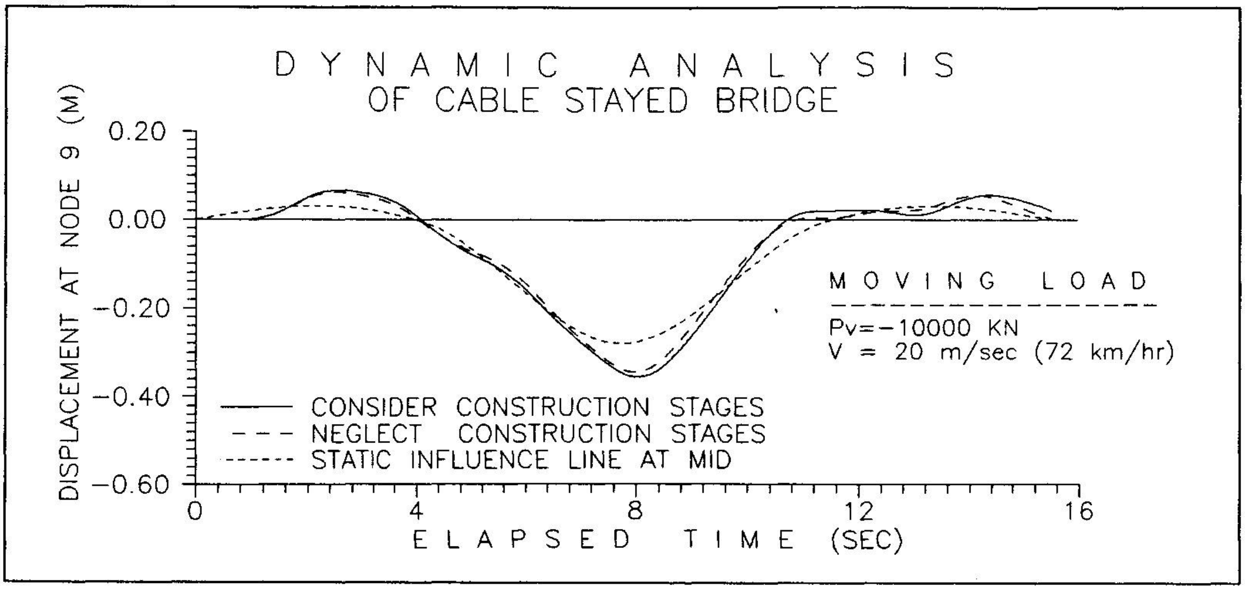

Fig.4 Effect of Moving Load on Cable Stayed Bridge

5. CONCLUSION

A numerical procedure and a computer program SNUBR for the geometric nonlinear analysis considering feasible construction stages and linear dynamic analysis at any construction time of three dimensional prestressed concrete frames are presented. This study includes not only the time dependent effects due to load history, creep, shrinkage and aging of concrete and relaxation of prestressing tendons and stay cables but also the flexural-torsional effects including warping in structures with nonsymmetric sections. Capabilities of the program has been demonstrated by several examples. It can be concluded that the program SNUBR can be useful tool for the analysis and design of segmentally erected prestressed concrete bridges with stay cables.

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