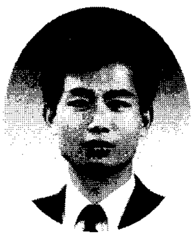
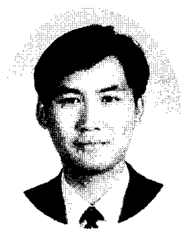
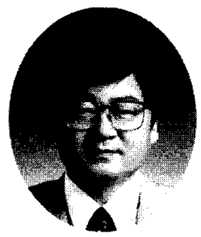
Development of a Computer Program for User-Oriented Analysis and Design of Prestressed Concrete Bridges

Kim, Tae-Hoon* Choi, Jeong-Ho ** Lee, Kwang-Myong *** Shin, Hyun-Mock ****

Abstract

A computer program, named NEO-PCBRG, for the analysis and design of prestressed concrete(PSC) bridges was developed using the finite element method. NEO-PCBRG can predict the response of PSC bridges throughout the various stages of construction and service. NEO-PCBRG has both pre- and post-processing capabilities. Pre-processing refers to all the necessary steps required to prepare a virtual prototype, more commonly termed a varied model for analysis. Post-processing here stands for the step in which the results from the analysis are reviewed and interpreted. In order to allow for the easy and convenient execution of the entire procedure, NEO-PCBRG was developed using computer graphics in the Visual Basic programming language. In conclusion, this study presents a new software architecture for analysis using the user-oriented design technique.

Keywords : PSC bridges, pre-processing, post-processing, user-oriented

* KCI member, Ph.D. Candidate, Department of Civil Engineering, Sungkyunkwan University, Korea.
** KCI member, Lecturer, Department of Civil Engineering, Hankyong National University, Korea.
*** KCI member, Associate Professor, Department of Civil Engineering, Sungkyunkwan University, Korea.
**** KCI member, Professor, Department of Civil Engineering, Sungkyunkwan University, Korea.

1. Introduction

Prestressed concrete bridges have been widely used as an economical and aesthetic solution for medium and long span bridges. Analytical solution for the response of these structures is complicated because of the following reasons(1). First of all, the prestressed concrete bridges are highly indeterminate, and they consist of two different materials, concrete and steel. Therefore, under increasing load, they may experience cracking and material nonlinearities, and the internal forces may be redistributed. Furthermore, the distribution of internal forces is time-dependent because of the creep and shrinkage of concrete.

This study attempts to develop a new computer program, named NEO-PCBRG, for the analysis and design of prestressed concrete bridges using the user-oriented design technique. Finite element method is employed in NEO-PCBRG, based on the assumptions of linear elasticity and static equilibrium. It should be noted that if the deformation of a structure remains small and the material is linearly elastic, the behavior of the structure is linear, and thus the principle of superposition can be applied to both deformation and stress. NEO-PCBRG was designed such that if the computed stresses of a design are not in accordance with the specification limits(2,3), then the numerical analysis procedure is restarted automatically with increased or decreased cross-sectional areas of both tendon and concrete, and is iterated until the specifications are met.

2. Theoretical Background

2.1 Time-dependent Effects

The time-dependent secondary losses must be accounted for as the structure accumulates deformation, either elastic or inelastic such as creep and shrinkage. The assumptions of linearity and elasticity hold in prestressed concrete as long as the material remains in compression. Time-dependent effects are evaluated under these assumptions(4,5). However, the stiffness matrix is kept current in time by updating the modulus of elasticity.

A numerical formulation is used for creep and shrinkage of concrete in which the principle of superposition is assumed to be valid for evaluating the total strain $\varepsilon(t)$ at any time t as expressed by the following equation:

$$\varepsilon(t) = \varepsilon_i(t_o) + \varepsilon_{cr}(t,t_o) + \varepsilon_{sh}(t,t_o) \quad (1)$$

where $\varepsilon_i(t_o)$ = instantaneous strain by a short-time loading; $\varepsilon_{cr}(t,t_o)$ = creep strain at time $t-t_o$; $\varepsilon_{sh}(t,t_o)$ = shrinkage strain at time $t-t_o$. Creep and shrinkage strains are evaluated by ACI 209 Model(6) and CEB-FIP Model(7).

Creep is handled as an internal load case to simulate the effects of restrained long-term strains. Shrinkage is also dealt with as an internal load case although it is independent of the stress level in the material. Relaxation losses are a direct function of the stress level throughout the construction.

Non-linearities that can be accounted for in the developed program are the time-dependent behavior (creep and shrinkage) of concrete, time-dependent behavior (relaxation) of steel and (time-dependent) stiffness non-linearity(8). It is assumed that the creep of concrete is proportional to stress and thus, the superposition of stresses and strains is valid. The assumptions on the time-dependent behavior of concrete are in accordance with the commonly used codes of practice.

2.2 Structural Modeling

The structure is defined in the general system of coordinates (X, Y). The general displacement field is denoted as (x, y, r), where x, y and r are the horizontal, vertical displacements and rotation, respectively (Fig. 1)[4,5].

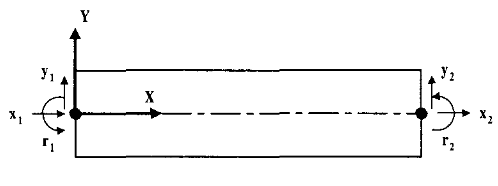


Fig. 1 Analytical model

Various stiffness components may be inserted in the global stiffness matrix (i.e., the support stiffness and restraint stiffness). The stiffness solution uses an optimized banded matrix solution. This study offers a simplistic band optimizer based on the sorted general X and Y coordinates. This method is proved to be sufficient in most cases for bridge girders. Once decomposed, the banded matrix is kept in memory for the back-substitution. Each load case including the time-dependent corrections re-uses the decomposed matrix. The stiffness matrix is re-evaluated at each step. The stiffness method is used to determine the displacement and stress increments of the structure. Various standard load cases constitute a part of the default implementation of the stiffness solution. Users may define additional load cases and load combinations. These standard loads may be used at any time during the construction to simulate the various stress states.

2.3 Construction Specifications

The program was designed such that the construction steps of a prestressed concrete bridge may be simulated in great details[4,5]. Concrete sections may be poured or precast segments may be assembled, tendons and stays may be stressed or de-stressed, and (concentrated or distributed) external loads may be applied at any time and location on the structure to simulate the effect of various construction equipments attached to the structure, moved on various sections or removed. The construction schedule was taken into account in the form of time steps that can be defined and redefined if necessary. This allows for the consideration of the correct concrete age throughout the construction, and the accurate evaluation of time-dependent strains. Support conditions may be introduced and changed at any time.

3. Development of User-Oriented Program

3.1 Scope

It is common these days to utilize computer graphics in performing the pre-processing and post-processing of the finite element analysis. This trend greatly reduces the time and effort required in checking the model geometry, and allows for easy interpretation of the computed results of analysis in the comprehensive graphical form instead of vast amount of printed output. The program, NEO-PCBRG, developed in this study also utilizes computer graphics, generated in the Visual Basic programming language[9].

Any type of finite element program requires the geometry data and attribute data such as boundary conditions, material property data or loading conditions for the analysis. These are usually generated by the pre-processor, and the correctness of the input data is checked by graphical methods before the analysis. Then the analysis is executed through the main program with this confirmed data, and the results such as the deformed geometry; stresses or other parameters from the various load cases are obtained. The files containing these kinds of information are the plot files for the graphic post-processing. During the processes, the plot operation is interactively controlled by the dialogue-type menu panels. The entire procedure of the NEO-PCBRG program is shown in Fig. 2.

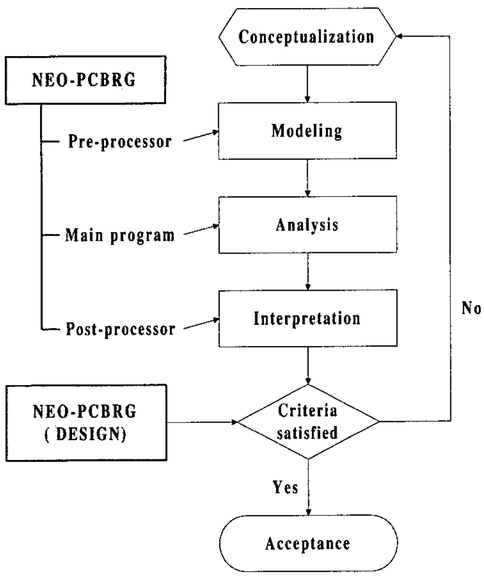


Fig. 2 Procedure of program

3.2 Main Program

The development of the NEO-PCBRG program had begun in 1992[10], and was enhanced for the analytical capability to deal with many structures encountered in practice. A finite element tangent stiffness formulation, coupled with a time step integration scheme, is described which traces the quasi-static response of the structure throughout the load history up to the ultimàte failure. The method uses step-by-step superposition of strains and accounts for time-dependent effects including the creep and shrinkage of concrete, and the relaxation of the prestressing steel. Structural elements comprise the supports, hinge and temporary links as well as the concrete segments, and can be considered in any logical order. Results appear in the chronological order as defined by the stages in the data. The control flow of the main program is shown in Fig. 3.

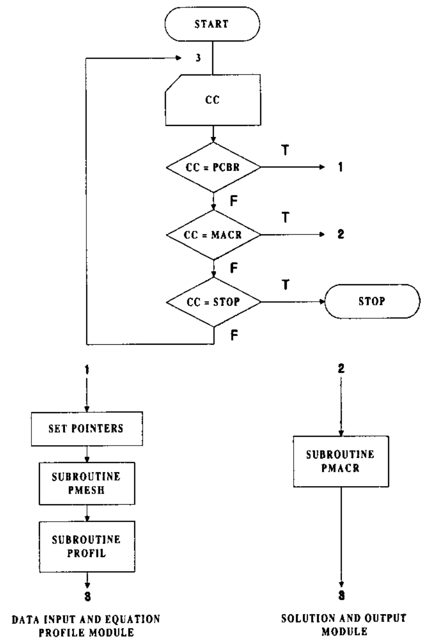


Fig. 3 Flowchart for control program procedure

3.3 Pre- and Post-Processor

Pre-processing refers to all necessary steps required to prepare a virtual prototype, more commonly termed a varied model for analysis[11]. Post-processing denotes the step in which the results from the analysis solution are reviewed and interpreted[11]. The program has a graphical interface for the user input, with options of the field or drop-down box input, all available via the keyboard or mouse pointer movement. As can be seen in Fig. 4, operation is controlled by the menu panels. This dialogue-type input has many advantages as follows: 1) owing to the self-explanatory input descriptions, the user does not need to consult the manual and can interact immediately with the computer, 2) since the input data selections are controlled by the program internally, the user is only allowed to pick only acceptable characters or numbers within the permissible range, which can greatly reduce input errors. The general procedure is to generate a special file, called a plotfile, and to use this as the input to the post-processor, which produces the actual graphics output.

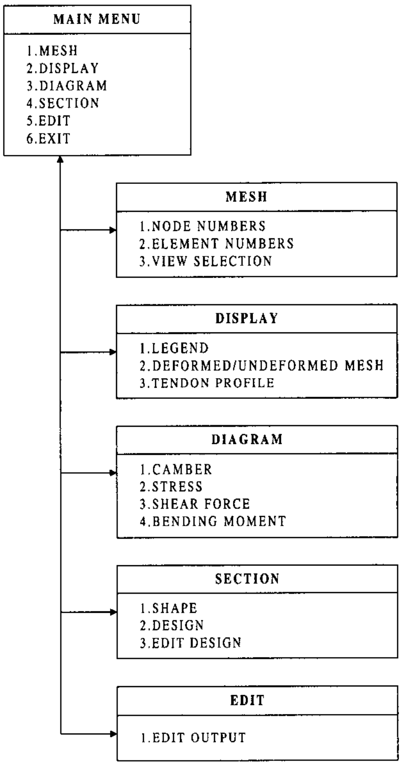


Fig. 4 Simplified schematic of post-processor program

4. Illustrative Example

An example problem is to illustrate how to use the developed computer program. The example problem is a simple three span bridge, as depicted in Fig. 5. Through this example, the usefulness of the developed program will be manifested.

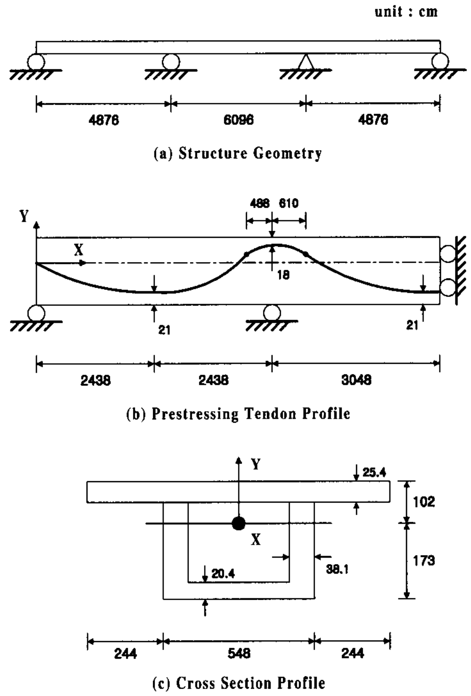


Fig. 5 Three span post-tensioned box girder bridge (Choudhury bridge)[12]

The detailed step-by-step pre-processing for this example is shown in Figs. 6 through 9. The pre-processor defines the structural model in terms of the coordinates, materials properties and describes the construction stages.

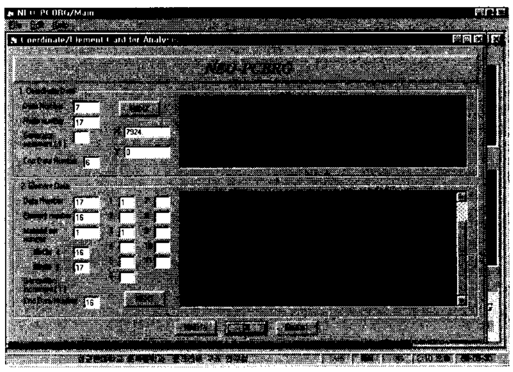


Fig. 6 Coordinate/Element card (Specify the coordinate/element geometry)

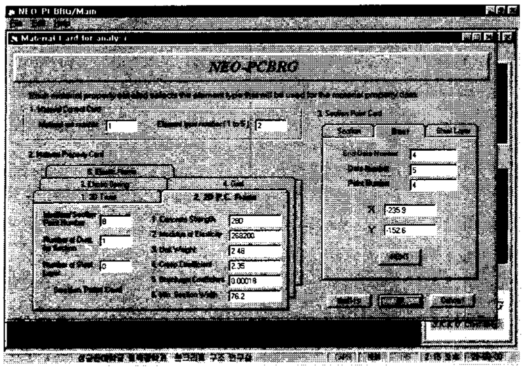


Fig. 7 Material card (Specify the material property)

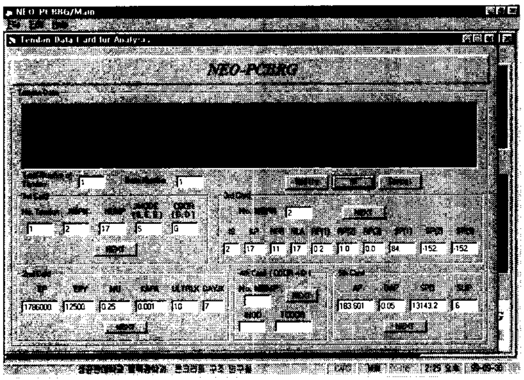


Fig. 8 Tendon data card (Specify the geometry and property of tendon)

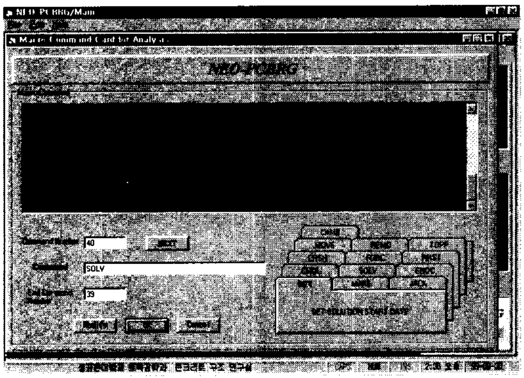


Fig. 9 Macro command card (Solve many type of problems, Describe the construction sequence operation)

In order to demonstrate the use of the program, a three-span continuous post-tensioned box girder bridge was designed and analyzed by SPCFRAME[1]. Present results are compared with results by SPCFRAME and good agreement is obtained as shown in Fig. 10 and Fig. 11.

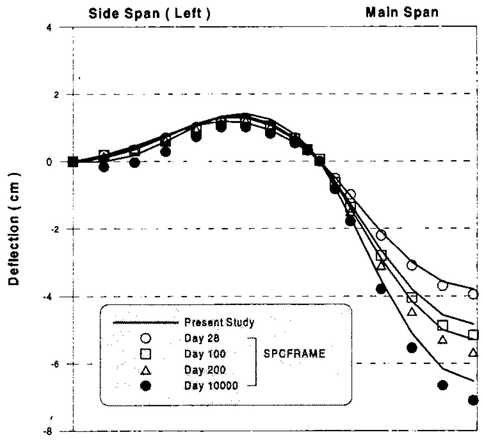


Fig. 10 Deflected shape for different times (without live load)

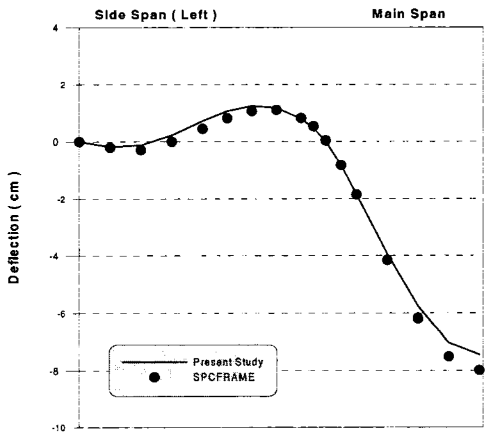


Fig. 11 Deflected shape of load case 1 (Maximum negative moment)

The use of an easily accessible post-processor and its graphic display capability allows for the efficient performance of the designer. Results obtained using such a post-processor are shown in Figs. 12 through 15.

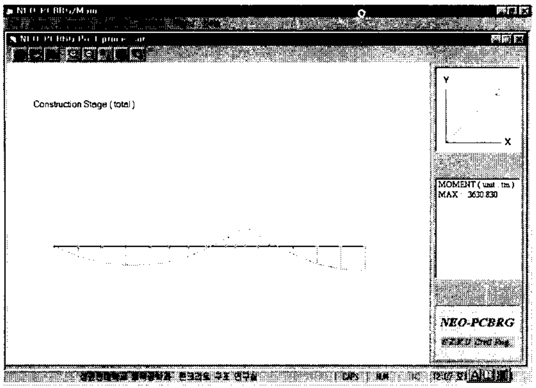


Fig. 12 B.M.D. at the construction stage

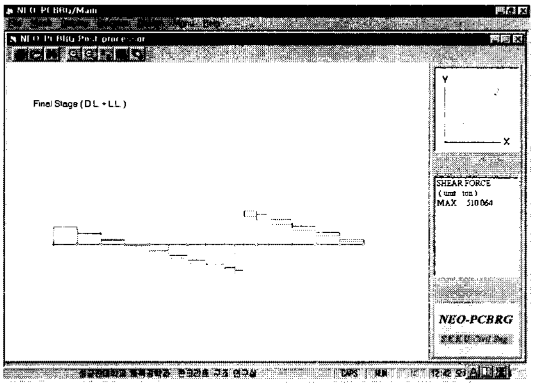


Fig. 13 S.F.D. at the final stage (D.L. + L.L.)

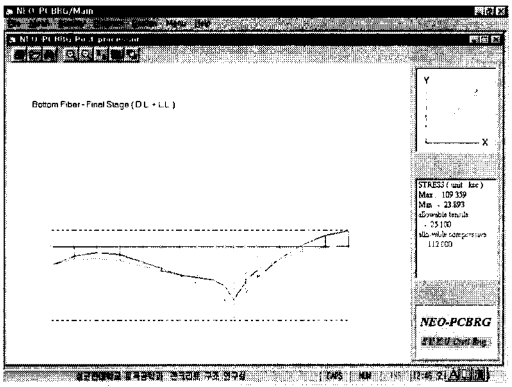
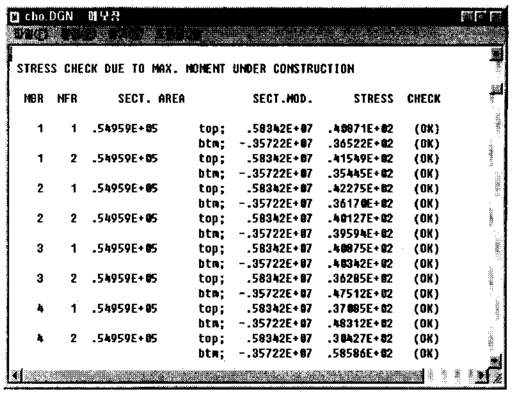


Fig. 14 Stresses at the final stage


STRESS CHECK DUE TO MAX. MOMENT UNDER CONSTRUCTION

MBR	NFR	SECT. AREA		SECT.MOD.	STRESS	CHECK
1	1	.54959E+05	top;	.58342E+07	.40871E+02	(OK)
			btm;	-.35722E+07	.36522E+02	(OK)
1	2	.54959E+05	top;	.58342E+07	.41549E+02	(OK)
			btm;	-.35722E+07	.35445E+02	(OK)
2	1	.54959E+05	top;	.58342E+07	.42275E+02	(OK)
			btm;	-.35722E+07	.36170E+02	(OK)
2	2	.54959E+05	top;	.58342E+07	.40127E+02	(OK)
			btm;	-.35722E+07	.39594E+02	(OK)
3	1	.54959E+05	top;	.58342E+07	.40875E+02	(OK)
			btm;	-.35722E+07	.40342E+02	(OK)
3	2	.54959E+05	top;	.58342E+07	.36285E+02	(OK)
			btm;	-.35722E+07	.47512E+02	(OK)
4	1	.54959E+05	top;	.58342E+07	.37085E+02	(OK)
			btm;	-.35722E+07	.48312E+02	(OK)
4	2	.54959E+05	top;	.58342E+07	.30427E+02	(OK)
			btm;	-.35722E+07	.58586E+02	(OK)

Fig. 15 Design results

5. Conclusions

It should be noted that the ultimate goal of all structural analyses is to aid the engineer in producing a satisfactory design with respect to its functionality, serviceability and ultimate strength. This study has been carried out to develop a computer program, which provides user-oriented guides toward such a satisfactory design of prestressed concrete bridges. The results obtained in this study may be summarized as follows.

(1) The computer program NEO-PCBRG developed in this study has been shown to be a useful tool in the structural analysis and design of prestressed concrete bridges.
(2) The error-preventive dialogue-type input scheme allows users to control the plot operation in a highly interactive manner. Through the pre-processing and post-processing examples, the convenience and usefulness of the program have been demonstrated.
(3) If the stress results are not in accordance with the specification limits, the numerical

analysis procedure is restarted automatically with increased or decreased cross sections of both tendon and concrete, and is iterated until the specifications are satisfied.

(4) Future work should incorporate the capability of handling nonlinear geometry into the structural elements, and also incorporate the nonlinear material constitutive relationships for the concrete and steel structural elements.

References

1. Kang, Y. J., "SPCFRAME-Computer Program for Nonlinear Segmental Analysis of Planar Prestressed Concrete Frames," University of California, Berkeley, UCB/SEMM-89/07, 1989.
2. Ministry of Construction and Transformation, Standard Specifications for Highway Bridges, 1999.
3. Ministry of Construction and Transformation, Standard Specifications of Concrete Structure, 1999.
4. Lee, G. H., Choi, J. H., and Shin, H. M., "Structural Analysis and Design for Segmental Prestressed Concrete Bridges," Proceedings of KSCE, 1994, pp. 317-320.
5. Kim, R. G., Lee, J. H., Choi, J. H., and Shin, H. M., "Structural Analysis and Automatic Design for Prestressed Concrete Bridges," Sungkyunkwan University Journal Science and Technology, Vol. 46, No. 2, 1995, pp. 775-782.
6. ACI Committee 209, Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures, ACI 209R-92, 1992.
7. Comite Euro International Du Beton, CEB-FIP MODEL CODE (DESIGN CODE), 1993.
8. Collins, M.P., and Mitchell, D., Prestressed Concrete Structures, Prentice-Hall Inc., 1991.
9. Stephens, R., Visual Basic Graphic Programming, John Wiley & Sons, Inc, 1998.
10. Choi, J. H., Structural Analysis and Design System for Prestressed Concrete Bridges by the Personal Computer, Master Thesis, Sungkyunkwan University, Korea, 1992.
11. Kim, T. H., Development of General Purpose Finite Element Analysis Program, Master Thesis, Sungkyunkwan University, Korea, 1998.
12. Choudhury, D., "Analysis of Curved Nonprismatic Reinforced and Prestressed Concrete Box Girder Bridges," University of California, Berkeley, UCB/SEMM-86/13, December 1986.