Chapter 1

# INTRODUCTION

## Introduction

Nowadays, owing to their architecturally esthetics and economic advantages, cable suspended structures are being used widely to meet the increasing demand of long span structures. Common examples are suspended cable roofs, suspension and cable stayed bridges. In these cable structures, nonlinear response prevails even under working load as a result of large displacements, and it is practically impossible to solve the pertaining governing differential equations for even relatively simple cable nets.

Suspension structures have the unique characteristics that for a given loading condition, finite displacements occur which make the deformed geometry significantly different from the undeformed one. Thus, large errors result when a linear analysis is used since there is interdependence between the internal forces and the resulting geometry necessary to maintain equilibrium. This behaviour leads to mathematical difficulties because of nonlinear load-response characteristics. Iterative methods of analysis are therefore needed to solve the complicated problem.

Many iterative procedures have been presented for nonlinear cable problems. The most frequently used schemes are Newton-Raphson method and its modified versions which are second order iterative methods. Four well known techniques are the Underrelaxation method (1), the average procedure (see e.g. (2)), the Krishna modified Newton-Raphson method (3), and the Kar modified Newton-Raphson method (4). They are designed to accelerate the rate of convergence of the solution. However, in some highly nonlinear cases these schemes may even not converge to a solution, and an incremental load procedure must be applied, demanding more computation time.

## Objectives

The study herein deals with analyses of geometric nonlinear cable structures. The elastic catenary element developed by Jayaraman and Knudson (13) is used to model the cables. The main objectives of the study are:

1. to incorporate the linear elastic catenary element into the well known NONSAP PROGRAM (5) in order to increase its capability of modelling cable structures with curved catenary elements;

2. to present a new iterative technique which effectively improves the rate of convergence and stability of the numerical solutions of highly geometric nonlinear cable problems;

3. to investigate and compare the effectiveness of the proposed iterative technique with some existing schemes in solving cable problems. Emphasis is placed on speed of convergence and stability of the numerical solutions.

Assumptions

The principle assumptions applied in this study are as follows

1. The material is assumed to be linear elastic obeying Hookes' law

2. The cable is slender and highly flexible. Thus, the bending stiffness of cable element is negligibly small so that the cable is virtually a tension member.

3. The cable undergoes large displacement with a state of small strain.

Literature Review

Poskitt (6) presented the difference between the first order and the second order iterative methods and showed how to classify them. He suggested that in small nonlinear cases the first order iterative methods are satisfactory. As the degree of nonlinearity increases, the second order iterative methods are more suitable.

Thornton and Brinstile (7) suggested an analytical procedure for solving three-dimensional suspension structures through a set of nonlinear simultaneous algebralic equations based on a two-node straight element. Two numerical methods were presented. The first method is the method of connectivity that is numerically integrated. The second method is the incremental load method where the equations are solved at each incremental load level.

Baron and Venkatesar (8) studied the nonlinear geometric problems of cable and truss structures based on small deformation and large displacements. The geometric stiffness matrix of a two node straight element was formulated from the changes in geometry resulting from the rotations about the local axes. Four schemes for solving the nonlinear equations, viz., the secant stiffness matrix, a modified secant stiffness matrix, the tangent stiffness matrix and the combination of the secant and the tangent stiffness matrix were presented. They concluded that the use of the tangent stiffness matrix leaded to more rapid convergence of the solution.

Saafan (2) uses the finite deflection theory to obtain the solution of the suspension roof using two-node straight elements. The tangent stiffness matrix was obtained as a partial derivative of the end force vector with respect to each one of the end displacement. A test for the convergence was introduced, in addition. The average procedure was applied to accelerate the convergence rate because the solution during the iteration oscillated around the final nonlinear solution.

Foster and Beaufiat (9) developed a program for analysing the total system of cables with roof panels modelled by two-node truss elements and plane-stress triangular elements, respectively. Also, they commented on the use of the accelerating factors to estimate the deflected shape and demonstrated that computation effort could be reduced when the appropriate factors were used.

O'brien and Francis (10,11) solved for the deflection of a suspension cable under concentrated loads by a process of successive approximation for geometric compatibility. Cable sag was treated in an exact manner because of the use of the catenary element.

Peyrot and Goulois (12) developed a procedure for the determination of the end forces of a cable element by utilizing the flexibility iteration of the catenary element. The local tangent stiffness matrix was obtained by introducing successively small changes in the horizontal and vertical projections of the element chord length and evaluating corresponding equilibrating forces.

Jayaraman and Knudson (13) presented a method to evaluate the local tangent stiffness matrix of a catenary element similar to that of ref. (12), but in an explicit form. Thus, the stiffness matrix could be readily evaluated at each deformation state, leading to more efficient scheme.