# CHAPTER-1

# INTRODUCTION

## 1.1 Slab Bridges of Arbitrary Planforms:

The development of modern highway system in major cities has led to the construction of an increasing number of curved slab bridges at complex interchanges and grade separations in order to cope with the increasing volume of highway traffic. Currently the bridges are curved to accommodate highway alignments laid out from various considerations and are designed to follow the natural course of the road. From several architectural and aesthetic criteria, planners have been adopting any angle of intersection between new and existing roads. To furnish design for these complex situations, structural engineers find no alternative but to use skew, curved and continuous slab bridges. In many cases, the geometric planform for the deck may be diverging or bifurcating with individual spans either rectangular or annular sector. The support lines may be right or skewed or in the form of discrete columns. In view of the extensive use of slab bridges of arbitrary planform in practice, the present investigation has been taken up to develop computer oriented analyses and to predict their structural behaviour through model studies.

## 1.2 Scope of the Present Investigation:

The analysis of continuous orthotropic bridge decks with panels of rectangular or annular sector planform of different radii with variation in thickness has been taken up. The study is also extended to diverging and bifurcated decks characteristic of motorways in modern cities.

The principal contributions made in the thesis may be studied under the following major sections, namely -

1) Finite Difference Energy method (FDE).
2) Isoparametric Finite Difference method (IFD).
3) Discrete Energy method (DE).
4) Experimental Investigations.

These methods are explained in detail as below :

### 1.2.1 Finite Difference Energy Method:

The method is primarily based on the plate bending energy equation instead of differential equation of equilibrium. The method of analysis was introduced by Houbolt (1)[*] for the calculations of deflection and bending moment of variable thickness plate of trapezoidal shape used in aircraft wing. His concept has been extended in the present thesis using plate bending energy expression in cylindrical co-ordinate system with a view to tackle complicated curved bridge deck configurations. This approach makes it possible to handle following types of decks :

i) Curved slab bridges radially supported.
ii) Continuous curved slab bridges with right, skew or discrete column supports.

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[*] No. in bracket indicates reference cited at the end.

iii) Curved slab bridges with intermediate line hinges.

The bridge slab may have cylindrical orthotropic properties with varying stiffness from region to region.

Fig.1.1 shows the planforms of various slab bridges amenable to this approach.

The common types of loading that are generally encountered in practice have been incorporated in this analysis. The following loading cases arise :

i) Patch load at any location to simulate wheel loads.
ii) Ideal point load at any location.
iii) Uniformly distributed load to simulate the self-weight of the bridge.

FDEBEN, a FORTRAN IV medium capacity computer program, has been developed to tackle the above mentioned bridge deck configurations subjected to various types of loading systems.

In order to estimate the accuracy and reliability of the present formulation several examples of curved plates are solved and the results are compared with the theoretical and experimental results of Coull and Das (2) and Heins and Hails (3). The example of curved bridge with intermediate line hinge reported by Cheung et al (4) has also been considered for comparison.

### 1.2.2 Isoparametric Finite Difference Method:

The concept of isoparametry is now well established in the field of finite element analysis and inherent merits of the technique are amply demonstrated for the stress analysis of various problems of practical interest especially the planforms of bridges with curved boundaries. The similar concept of isoparametry is independently proposed by Frey (5) and Lau (6,7) in the domain of finite difference analysis by using conventional approach, utilising governing differential equations of the system. In this thesis, isoparametry concept is merged with finite difference energy method to make it more powerful and versatile to tackle complex plate bending problems with curved edges.

The approach is closely related to isoparametric finite element displacement method since the variational technique is followed in both the cases along with specification of coordinates and displacements by using the same interpolation function defined with respect to a set of nodal points in the local orthogonal curvilinear co-ordinate system. Although the local curvilinear co-ordinate system varies from region to region in the plate, to provide close fit to the boundaries, it can be related to the global co-ordinate system by co-ordinate transformation relationships. By means of difference equations the total potential energy of plate is written in terms of grid point deflections defined in curvilinear co-ordinate system. The energy expression is then minimised with respect to each of grid point displacements to obtain the required set of equations. Since the variational approach is employed, only the geometric boundary conditions need be satisfied.

Fig.1.2 shows the slab bridges of different planforms that could be tackled by this method. All types of boundary conditions and loadings stated in the previous section can be incorporated in the analysis without any difficulty.

One of the most important phases of this investigation is the development of the ISO FDM computer program written in FORTRAN IV which takes care of the automatic generation of the mesh, co-ordinates of the grid points and the computation of area around the grid points. It takes advantage of symmetry and banded nature of the coefficient matrix and finally gives the design parameters such as moments in the radial and circumferential directions.

In order to test and evaluate the present numerical procedure and the validity of the related program several examples of isotropic plates with a variety of planforms are solved and the results are compared with the existing analytical and numerical solutions.

### 1.2.3 Discrete Energy Method or Discrete Element Method:

The method proposed by Buragohain (8) presents an alternative formulation of the element stiffness matrix for plate bending problems, where the finite difference expressions are used in the form of shape functions. The close similarity with FDE led to its inclusion in the present thesis and to utilise this method as a check on various problems investigated. In this method lateral deflections at all the interior grid points in the plate are considered as unknown, and slope of the normal to the boundary of the plate is taken as an additional unknown. This slope facilitates the application of boundary conditions.

It is possible to join two adjacent panels of a bridge deck by using slope compatibility.

Consequent to the similarities in formulation, it is seen, that at times, one obtains the identical sets of equations both by DE and FDE.

The method was applied so far for the analysis of slab bridges having single sector panel. In this thesis the inherent potentiality of this method is fully exploited by extending it for the analysis of bridges with changing curvature, with intermediate line hinge and for bifurcating decks. The restriction of this method is that in case of complex slab bridges which can be divided into several distinct sub-structures each one must be expressible in polar coordinates.

The FORTRAN IV program DEBEND incorporating these elements contains special features, such as automatic generation of mesh and connectivity table and the transformation to tackle reversed curvature. It also provides facilities to accommodate rectangular, annular sector and skew plates. It can analyse the continuous slab bridge decks with all types of support conditions. Fig.1.3 shows various bridge decks amenable to this program.

### 1.2.4 Experimental Method:

It appears that a limited amount of test data is available for radially supported bridge deck models (2,3,9,10). Experimental investigation of slab bridges with complicated shapes such as curved slabs with variable curvature and reversed curvature are not available in literature. Hence, it is justified to conduct the model studies of these types of slabs.

Two models of Asbestos cement sheet, one with panels of different curvatures and other with reversed curvature, with approximate scale ratio 1:25 were studied (Fig.6.4). Both the models were tested under uniformly distributed load and concentrated load at various positions. The experimental results have shown good correlation with the theoretical results.

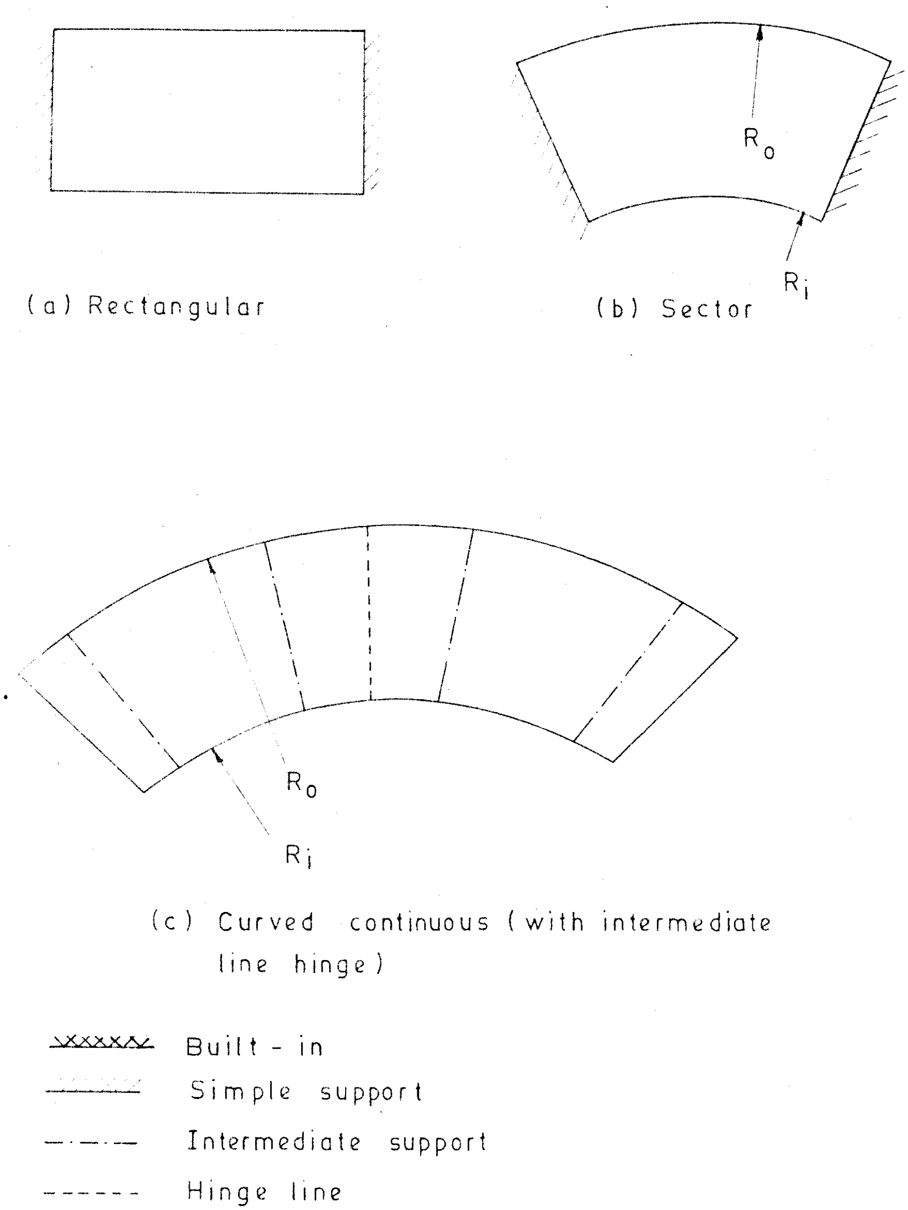


Fig.1.1 Slab bridges amenable to finite difference energy method

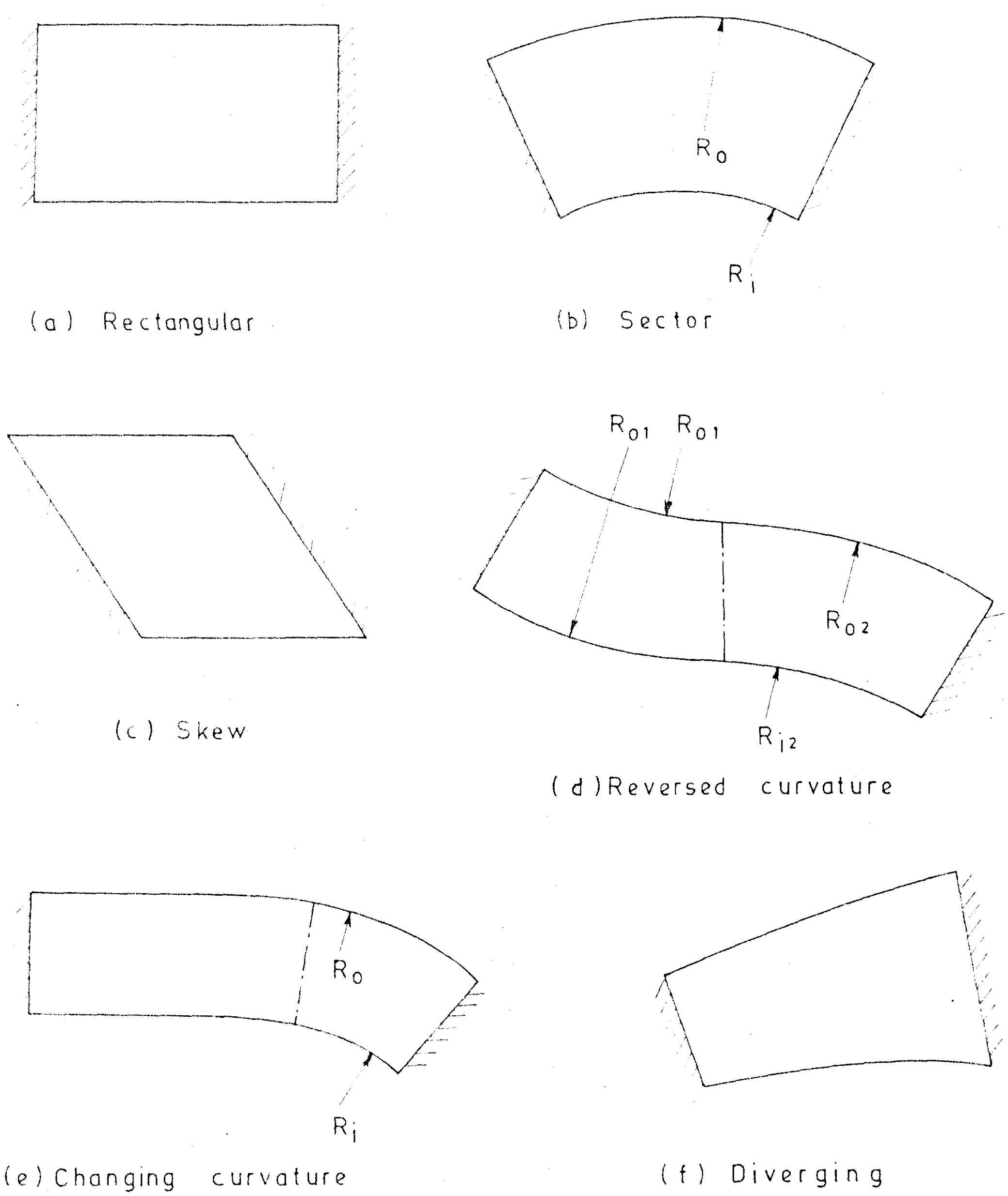


Fig.1.2 Slab bridges amenable to isoparametric finite difference method

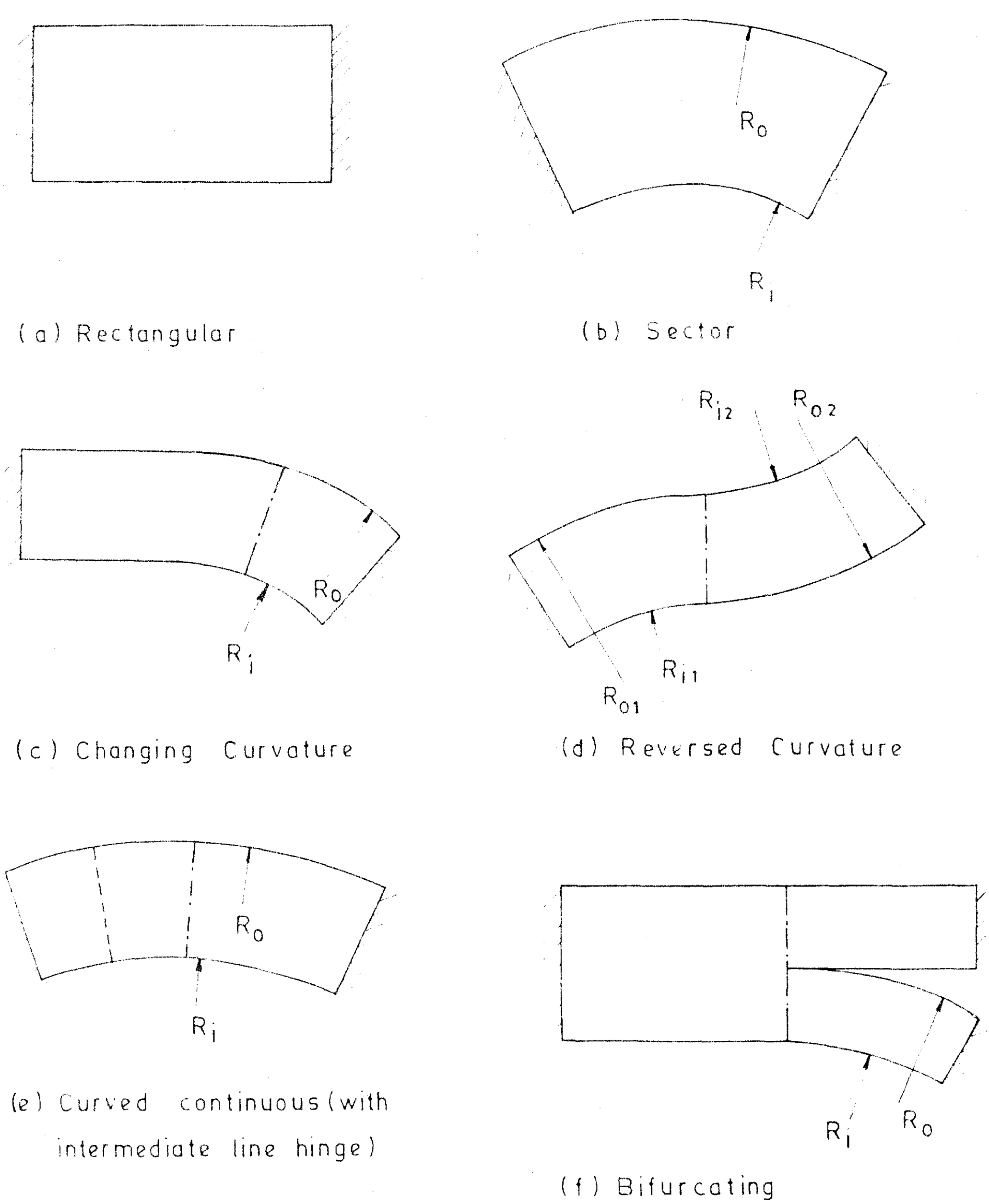


Fig. 1.3 Slab bridges amenable to discrete energy method