STRUCTURAL BEHAVIOR OF MULTICELLULAR HIGH RISE TUBULAR STRUCTURES OF ARBITRARY PLAN SHAPE

A Thesis
by
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DECLARATION

I hereby declare that the research reported in this thesis was performed by me and that the work has not been submitted anywhere else for any other purpose.

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ABSTRACT

A method for approximate lateral load analysis of high rise tubular structures of arbitrary shape and having any number of interconnected cells is presented in this thesis.

In this method, the structure is idealized by replacing the spandrel beams with a continuous medium of equivalent stiffness. The computational effort is greatly reduced by taking the shear force in the continuous medium as the primary unknown.

A computer program in FORTRAN has been developed on the basis of the approximate theory and it has been used to analyze two tubular structures, one with four rectangular cells and the other with three cells of different shape and size, both under the action of two types of lateral loads viz. a point load at the top and a uniformly distributed load. Both the structures were then analyzed using a computer program (STAAD-III/ISDS) for analyzing space frames. The results of the approximate method of analysis have been compared with those obtained using the space frame analysis program. The forces and deflections predicted by the approximate method, in general, agree with space frame analysis values.

NOTATION

A_i	cross-sectional area of ith wall/column
$A_{p,i}$	cross-sectional area of spandrel beams in ith band of openings
b_i	clear span of spandrel beams in ith band of openings
$b_{x,i}$	x projection of b_i
$b_{y,i}$	y projection of b_i
d_i	depth of spandrel beams in ith band of openings
E	modulus of elasticity
F_i	axial force in ith wall/column
G	shear modulus
H	height of the building
h	story height
$I_{c,i}$	reduced moment of inertia spandrel beams in ith band of openings
$I_{p,i}$	moment of inertia of spandrel beams in ith band of openings
$I_{x,i}$	moment of inertia of ith wall/column about x-axis
$I_{y,i}$	moment of inertia of ith wall/column about y-axis
i,j,k	integer variables
$L_{x,i}$	x projection of the distance between centroidal axes of two neighboring walls/columns
$L_{y,i}$	y projection of the distance between centroidal axes of two neighboring walls/columns
m	total number of walls/columns per story
$M_{x,i}$	bending moment about x-axis in ith wall/column
$M_{y,i}$	bending moment about y-axis in ith wall/column
n	total number of lines of openings
P_x	x component of the point load applied at top
P_y	y component of the point load applied at top

q_i	intensity of shear force in the connecting medium in ith band of openings
S'_{f10}	10 story equivalent stiffness factor
t_i	thickness of the spandrel beam in the ith band of opening
T	integral of shear force
T'	dT/dz; T'' = d2T/dz2
U	total strain energy of tube
U_1	strain energy due to bending and shear deformation of beams
U_2	strain energy due to axial deformation of walls/columns
U_3	strain energy due to bending of walls/columns
w_x	intensity of uniformly distributed horizontal load applied in the x-direction
w_y	intensity of uniformly distributed horizontal load applied in the y-direction
y_x	horizontal deflection in x-direction
y_y	horizontal deflection in y-direction
z	distance of any horizontal section from top of the structure
ν	Poisson's ratio

CONTENTS

CHAPTER ONE
INTRODUCTION

1.1 GENERAL

Throughout the recorded history of building, perhaps nothing is more captivating than the human aspiration to create increasingly tall structures. Pride seems to have been the prime motivation for the building of such ancient structures as the Tower of Babel, Colossus of Rhodes, the Pyramids of Egypt, the Mayan temples of Mexico, and the Kutub Minar of India. Ego and competition still play a part in determining the height of a building, but various other social and economic factors, such as increases in land values in urban areas and higher density of population, have led to a great increase in the number of tall buildings all over the world. What was once considered to be an American urban phenomenon can now be seen in many small towns and even in open country. The skylines of the world's cities are continually being pierced by distinct and identifiable tall buildings as impressive as mountain ranges, and reaching upward continues to be the challenge and goal.

It is only in the last 30 years that reinforced concrete has found increasing use in the construction of tall buildings. In its initial development in the early parts of the twentieth century, reinforced concrete buildings were limited to only a few stories in height. The structural type used was the traditional beam-column frame system which made the construction of taller buildings relatively expensive. In the early fifties the introduction of shear walls opened up the possibility of using concrete in apartment and office buildings as high as thirty stories. Taller buildings remained economically unattractive because the shear walls, which were mostly used in the core of the building, were relatively small in dimension compared to the height of the building, leading to insufficient stiffness to resist lateral loads. It was obvious that the overall dimensions of the interior cores were too small to economically provide the stability and stiffness for buildings over thirty to forty stories.

The natural tendency then was to find new systems of structures that would utilize the perimeter configurations of such buildings rather than to rely on the core configurations alone (26). The development of the spatial wall frame i.e. perforated wall structure known as rigid tube was, therefore a logical outcome of this challenge. The modifications of the rigid tube system into a tube-in-tube, framed tube and other variations are indeed known to offer certain advantages in planning, design and construction.

The rigid tube system manually relies on "hull-core" i.e. tube-in-tube type configuration for its basic layout; this has formed the structural backbone of almost all the tallest buildings constructed in recent years. The exterior enclosure tube or "hull" usually consists of closely spaced columns connected together with deep spandrel beams at each floor level to form a multi-story multi-bay box frame. For apartment buildings this tube alone or the hull with cross-walls provides the necessary stiffness against lateral loads. For office buildings, the exterior hull is usually combined with an internal service "core" through the floor system. The resulting "hull-core" system is extremely efficient in resisting all kinds of horizontal loads viz. winds, earthquakes or blasts.

1.2 DEFINITION OF A TALL BUILDING

It is difficult to distinguish the characteristics of a building which categorize it as tall. After all, the outward appearance of tallness is a relative matter. In a typical single-story area, a five-story building will appear tall. In Europe, a 20-story building in a city may be called as high rise, but the citizens of a small town may point to their skyscraper of six floors. In large cities, such as Chicago or Manhattan, which are comprised of a vast number of tall buildings, a structure must pierce the sky around 70 to 100 stories if it is to appear tall in comparison with its immediate neighbors. Tall building cannot be defined in specific terms related to height or number of floors. There is no consensus on what constitutes a tall building or at what magic height, number of stories, or proportion a building can be called tall. Perhaps the dividing line should be drawn where the design of the structure moves from the field of statics into the field of structural dynamics.

From the structural point of view, it is simpler to consider a building as tall when its structural analyses and design are in some way affected by the lateral loads, particularly sway caused by such loads. Sway or drift is the magnitude of the lateral displacement at the top of the building relative to its base. As building heights increase, the forces of nature begin to dominate the structural system and take on increasing importance in the overall building system. Structural systems have to be developed around concepts associated entirely with resistance to turbulent wind. Over the past two decades, remarkable improvement has been achieved in the structural engineer's ability to develop appropriate building systems. Equally important, the structural engineer has developed a far more complete understanding of those forces of nature, particularly atmospheric wind.

1.3 LATERAL LOAD DESIGN PHILOSOPHY

In contrast to vertical load, lateral load effects on buildings are quite variable and increase rapidly with increases in height. For example, under wind load the overturning moment at the base of a building varies in proportion to the square of the height of the building, and lateral deflection varies as the fourth power of the height of the building, other things being equal.

There are three major factors to consider in the design of all structures: strength, rigidity, and stability. In the design of tall buildings, the structural system must also meet these requirements. The strength requirement is the dominant factor in the design of low-height structures. However, as height increases, the rigidity and stability requirements become more important, and they are often the dominant factors in the design. There are basically two ways to satisfy these requirements in a structure. The first is to increase the size of the members beyond and above the strength requirements. However, this approach has its own limits, beyond which it becomes either impractical or uneconomical to increase the sizes. The second and more elegant approach is to change the form of the structure into something more rigid and stable to confine the deformation and increase stability. If design for lateral load, be it due to wind or earthquake, is of importance in tall buildings. What then are the criteria for the design of these loads ? Let us consider designing for wind loads.

It is significant that there are no reports of completed tall buildings having collapsed because of wind load (26). Analytically, it can be shown that a tall building under the action of wind will reach a state of collapse by the so-called P-effect, in which the eccentricity of the gravity load increases to such a magnitude that it brings about the collapse of the columns as a result of axial loads. Therefore, an important stability criterion is to assure that predicted wind loads will be below the load corresponding to the stability limit. The second consideration is to limit the lateral deflection to a level that will ensure that architectural finishes and partitions are not damaged. Although less severe than the collapse of the main structure, the floor-to-floor deflection, normally referred to as the interstory drift, nevertheless has to be limited because of the cost of replacing the windows and the hazard to pedestrians of falling glass.

Slender high-rise buildings should be designed to resist the dynamic effects of vortex shedding by adjusting the stiffness and other properties of the structure such that the frequency of vortex shedding does not equal to the lateral frequency of the structure. Lateral deflections of buildings should be considered from the standpoints of serviceability and comfort. The peak acceleration at the top floors of the building resulting from frequent windstorms should be limited to minimize possible perception of motion by the occupants.

In earthquake-resistant designs it is necessary to prevent outright collapse of buildings under severe earthquakes while limiting the nonstructural damage to a minimum during frequent earth tremors. The building should be designed to have a reserve of ductility to undergo large deformations during severe seismic activity.

1.4 CONCEPT OF PREMIUM FOR HEIGHT

If there is no lateral loads such as wind or earthquake, any high-rise building could be designed primarily for gravity loads. Such a design would not impose any premium for height. Since there is no way to circumvent the gravity loads resulting from dead and live loads, the minimum possible material for a building of any number of stories cannot be less than that required for gravity loads alone. Qualitatively, from the structural point of view, this corresponds to the most efficient or optimum system. Ideally, the structure needs to be designed for gravity loads only, whereas the stresses caused by lateral loads will automatically be limited to the 33 percent overstress allowed in most codes.

When the structure for a low or mid-rise building is designed for gravity loads, it is very likely that the structure can carry most of the lateral loads. In general, this is not so for high-rise buildings because resistance to overturning moment and lateral deflection will almost always require additional material over and above that required for gravity load alone. Assuming equal bay sizes, the material quantities required for gravity floor framing in low and high rise structures are essentially identical; it makes no difference in the required quantities whether the floor being framed is at the 70th level of a high-rise building. The material required for floor framing is a function of the column-to-column span and not the building height. However, the material required for the vertical system, such as columns and walls, in a high-rise structure is substantially more than that for a low-rise building. The material increases in the ratio (n+1)/2, where n is the number of floors, because the vertical components carrying the gravity load will need to be strengthened for the full height of the building, requiring more vertical steel than a one-story structure having the same floor area.

The quantity of materials required for resisting lateral loads is even more pronounced and would soon outstrip all other structural costs if rigid frame action where employed in very tall buildings. The graph shown in Fig.1.1 illustrates how the unit weight of a structural material such as steel increases as the number of floors increases. Wind begins to show its dominance at about 50 stories and becomes increasingly important with greater height. For example, in a steel building using rigid frame action, the total weight of, say, 24 psf of structural steel is split evenly at about 8 psf for each of three subsystems, namely, (1) floor framing, (2) gravity columns, and (3) wind bracing system. Above 50 stories, wind bracing ingenuity often makes the difference between economical solution and an expensive one. The objective is to arrive at a wind bracing system that keeps the additional material required for lateral loads to a reasonable quantity.

The material quantities needed with reinforced concrete buildings also increase as the number of stories increases. The increase in material for gravity load is more than for steel,whereas the additional material required for lateral load is not as high as

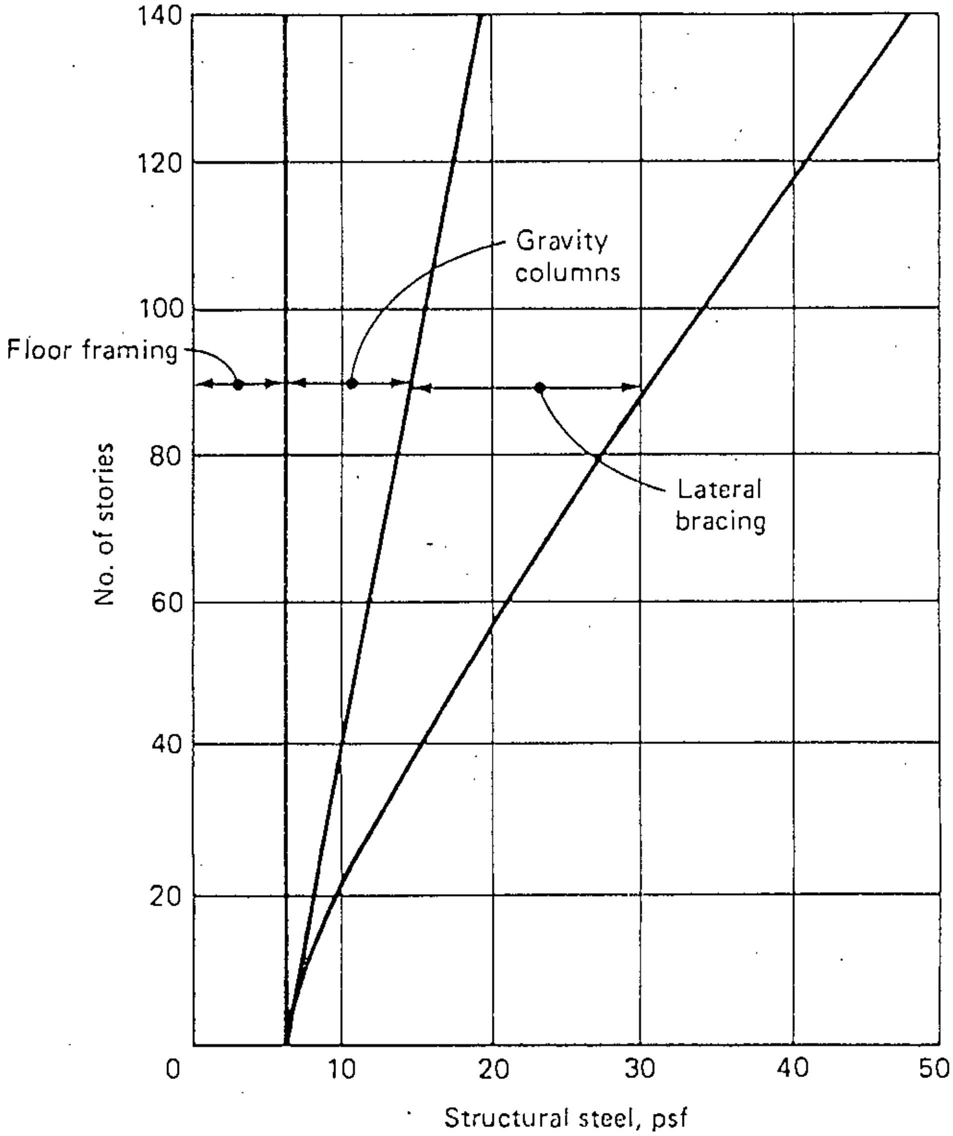


Figure 1.1 Structural steel quantities for gravity and wind systems. (26)

for steel, since weight of additional gravity loads helps to resist the lateral deflection and overturning moment. The additional gravity load, on the other hand, can aggravate the problem of designing for earthquake forces.

1.5 LATERAL LOAD RESISTING SYSTEMS

Traditionally, the primary concern of the structural engineer designing a building has led the provision of a structurally safe and adequate system to support vertical loads. This is understandable, since the vertical load-resisting capability of a building is the reason for its existence. Any calculations undertaken to check the adequacy of the design with regard to lateral loads were often cursory in nature and more as an after thought than as an essential and integral part of the total design effort. This attitude did not appear to affect the resulting designs significantly, as long as the building involved were not too tall, were not in seismic zones, or were constructed with adequate built-in safety margins in the form of substantial nonstructural masonry walls and partitions.

The need to resist large lateral forces is one of the major distinguishing characteristics of tall buildings. The normal lateral loads are those due to wind and earthquake. The lateral load resisting system of a tall building must be able to resist these loads and at the same time must prevent excessive deflections or accelerations and must help to provide stability. However, the lateral load resisting elements must not be too large, and must conform with the architectural, structural and mechanical schemes, or vice versa. A lateral system is generally considered to be efficient if the provision for lateral load resistance does not increase the floor and column sizes beyond those required for gravity loads.

Although there are as many concepts of structural systems , it is possible to classify these systems into categories. Each category render to be most efficient for a certain height range or a certain type of occupancy.

1.5.1 Lateral systems: steel buildings

Today there are innumerable structural steel systems that can be used for the lateral bracing of tall buildings. It would be an exercise in futility to try to classify all these systems into distinct categories. However, for purposes of presentation, the different structural system that are currently being used in the design of tall steel buildings are broadly divided into the following categories:

1. Semirigid frames
2. Rigid frames
3. Braced frames
4. Rigid frame and braced frame interaction
5. Belt and outrigger truss systems
6. Framed tube structures with regularly shaped tubes
7. Framed tube structures with irregular shapes
8. Exterior braced tubes with regular shapes
9. Exterior braced tubes with irregular shapes
10. Cellular tube structures
11. Megastructures (ultimate high-efficiency structures)

1.5.2 Structural systems for concrete buildings

Fig.1.2 shows 14 different categories of structural systems, starting with the most elementary system consisting of floor slabs and columns. At the other end of the spectrum is the bundled tube system, which is appropriate for very tall buildings and for buildings with large plan aspect ratio.

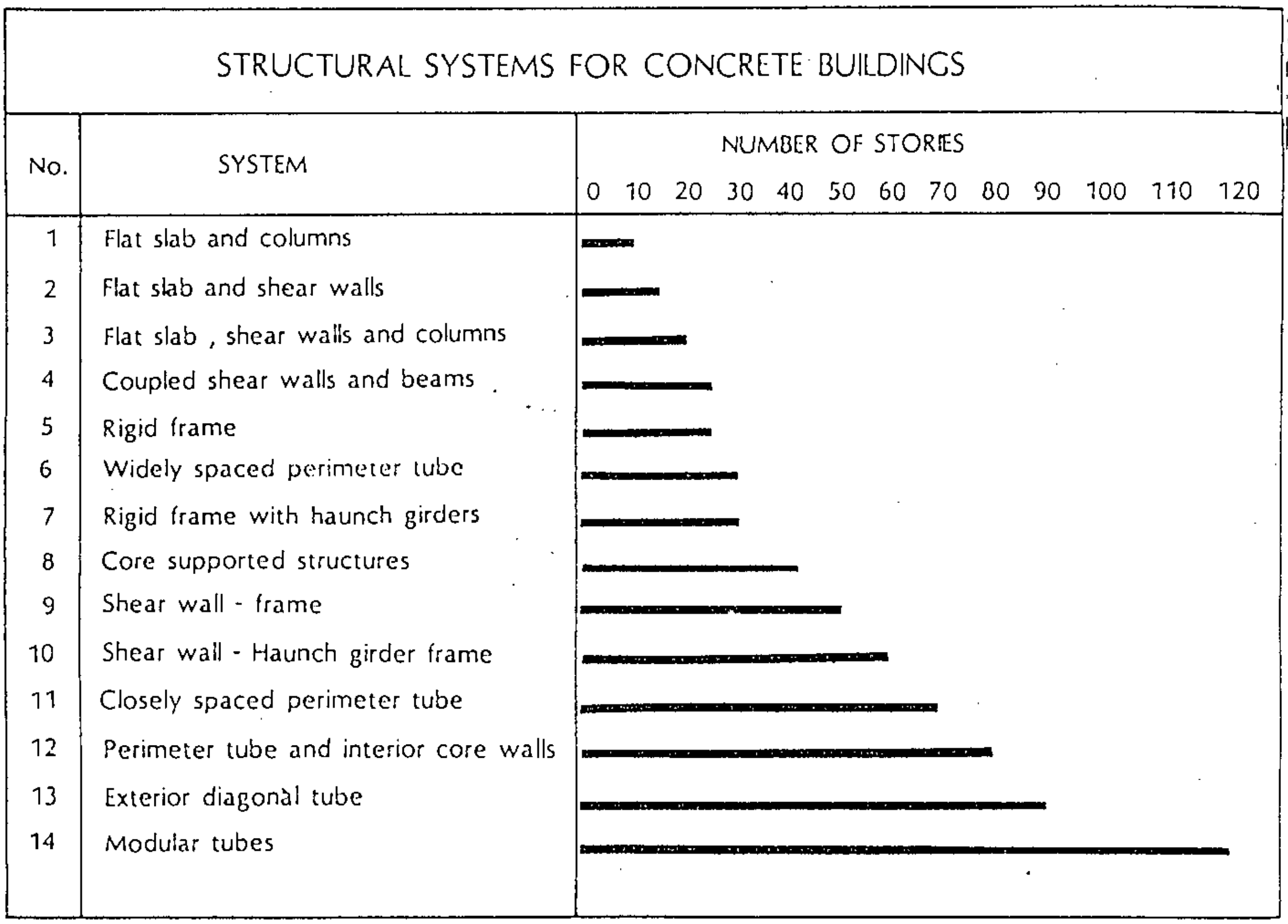


Figure 1.2 Structural systems for concrete buildings. (26)

1.5.3 Lateral systems for composite construction

In order to get a broad picture of composite schemes that are popular for high-rise office buildings, it is instructive to consider the different elements of the buildings that lend themselves to composite construction. These are (1) slab systems; (2) beams, girders, and spandrels; (3) columns; and (4) shear walls.

Even with the cacophony of composite systems in use today, for purposes of presentation it is convenient to classify the major systems into the following categories.

1. Shear wall systems
2. Shear wall-frame interacting systems
3. Tube systems
4. Vertically mixed systems.

1.6 TUBULAR SYSTEMS

1.6.1 Introduction

In its simplest terms the tube design can be defined as a structural system that prompts the building to behave as an equivalent hollow tube. At present four of the five world's tallest buildings are tubular systems. They are the 110-story Sears Tower, the 100-story John Hancock Building, and the 83-story Standard Oil Building, all in Chicago, and the 110-story World Trade Center towers in New York. The earliest application of the tubular concept is credited to the late Dr. Fazlur Khan of the architectural engineering firm of Skidmore, Owings & Merrill, who first introduced the system in a 43-story apartment building in Chicago. Tubular systems are so efficient that in most cases the amount of structural material used is comparable to that used in conventionally framed buildings half the size. Their development is the result of the continuing quest by the structural engineer for the most economical and yet safe and serviceable system for the design of high-rise buildings. Until the evolution of the tube, which has become the workhorse of the lateral system in tall buildings, most high rises were designed as frames consisting of vertical columns usually arranged on an uncompromising grid pattern in two perpendicular directions, with beams and girders spanning between the columns. Lateral loads were resisted by various girder-to-column connections, supplemented if required by vertical shear walls or trusses located within the service core of the building or by various types of knee braces. Further improvement in the structural economy was achieved by engaging the exterior frames with core trusses by tying the two systems through belt and outrigger trusses. The belt trusses, as the name implies, encircled the building perimeter, and the outriggers, strategically located at various levels, forced the participation of exterior columns in resisting the lateral loads. The resulting partial tubular behavior extended the range of application of the frame and core truss systems, but the radical departure in structural action occurred only when the structure on the perimeter was modified to behave as a three-dimensional cantilever. This concept led to the exploitation of the maximum plan dimensions, greatly enhancing the efficiency of the structural systems.

The introduction of the tubular system for resisting lateral loads has brought about a revolution in the design of high-rise buildings. All recent high-rise buildings in excess of 50 to 60 stories employ the tubular concept in one form or another. In essence the system strives to create a rigid wall-like structure around the building exterior. In a framed tube this is achieved by a closely spaced column and deep spandrel arrangement placed around the entire perimeter of the building. Because the entire lateral load is resisted by the perimeter frame, the interior floor plan is kept relatively free of core bracing and large columns, thus increasing the net leasable area for the building. As a trade-off, views from the interior of the building are somewhat limited by the presence of large exterior columns.

Maximum efficiency for lateral strength and stiffness using the exterior wall alone as the wind-resisting element is achieved by making the entire building act as a hollow tube cantilevering out of the ground. The structure can then be thought of as a cantilever tube with holes punched for windows.

The tube system can be constructed of reinforced concrete, structural steel, or a combination of the two, termed composite construction, in various degrees. The tube has become the workhorse of the high-rise construction system because it minimizes the structural premium for lateral strength and stiffness, simultaneously accommodating recent trends in architectural forms.

The center-to-center spacing of the exterior columns in the framed tube structural system is generally from 4 ft. to a maximum of about 10 ft. Depending on the overall proportion and height of the building, the maximum center-to-center spacing of the peripheral columns can probably be increased to 15 ft. The spandrel beams interconnecting the closely spaced columns generally vary from 2 ft. in depth to about 4 ft. in depth with widths from 10 in up to 3 ft. In designing the framed tube structural system it is necessary to keep the proper balance of stiffness between the spandrels and the columns so that both of these elements are efficiently utilized to provide stiffness of the structure against lateral sway, and to assure the overall strength of the tube system to resist lateral forces. In most recent structures stiffness for limiting lateral sway controlled the proportions more often than strength requirements. In the DeWitt-Chestnut apartment building the columns were spaced on 5 ft. 6 in. centers and the spandrels were 2 ft. deep. The spacing of the columns in this case was also related to the module for interior planning of the apartment floors.

The framed tube structural system has expanded in its application and in its variation over the last few years. One of these variations is its application with an interior shear wall, commonly referred to as 'tube-in-tube' system as used in the 52-story One Shell Plaza Building in Houston, reaching a height of 714 ft. Another variation of the framed tube system has been used as the exterior envelope in conjunction with the traditional steel framing for the interior of the building. This system, known as the SOM Composite System, has been used in three major tall buildings in the United States, namely: the 24-story CDC Building in Houston, the 35-story Union Station Building in Chicago, and the 50-story One Shell Square Building in New Orleans.

1.6.2 Behavior of the Framed tube system

The framed tube system combines the behavior of a true cantilever, such as a shear wall, with that of a beam-column-frame. The overturning under lateral load is resisted by the tube form causing compression and tension in the columns, while the shear from the lateral load is resisted by bending in columns and beams primarily in the two sides of the building parallel to the direction of the lateral load. Therefore, for all practical purposes the bending moments in these columns can be determined by judicious choice of the point of contraflexure in each story. While it is true that in the lower few stories, as well as in the upper few stories, the point of contraflexure does not remain in the middle of story height, the intermediate stories which constitute the major portion of the building generally have the point of contraflexure at mid-height of each story. It is, therefore, possible to compute the bending moments in these columns with reasonable accuracy for any known lateral shear at each story. One can, of course, make a simple iterative, Maney-Goldberg type, slope-deflection solution, or a modified moment distribution solution to determine more accurate moments in these columns. In fact, such an iterative solution will also give a good approximation of that portion of the total deflection which is caused by the frame action only. To this the additional overturning deflection caused by tension or compression in the column must be added to compute the total lateral deflection.

1.6.3 Different forms of tubular system

The concept of tubular behavior introduced by F.R. Khan is one of the recent philosophies in the design of tall buildings. Four out of the five tallest buildings in the world now (1988) have been built using this concept. These buildings are the John Hancock Building, the Sears Tower and the Standard Oil Building in Chicago and the World Trade Center in New York. The system is so efficient that in most cases the amount of structural material used per square foot of floor space is comparable to that used in conventional framed buildings half the height.

Tubular design is based on the assumption that the facade structure responds to lateral loads as a closed hollow box beam cantilevering out of the ground. Since the exterior walls resist all or most of the lateral load, costly interior diagonal bracing or shear walls are eliminated.

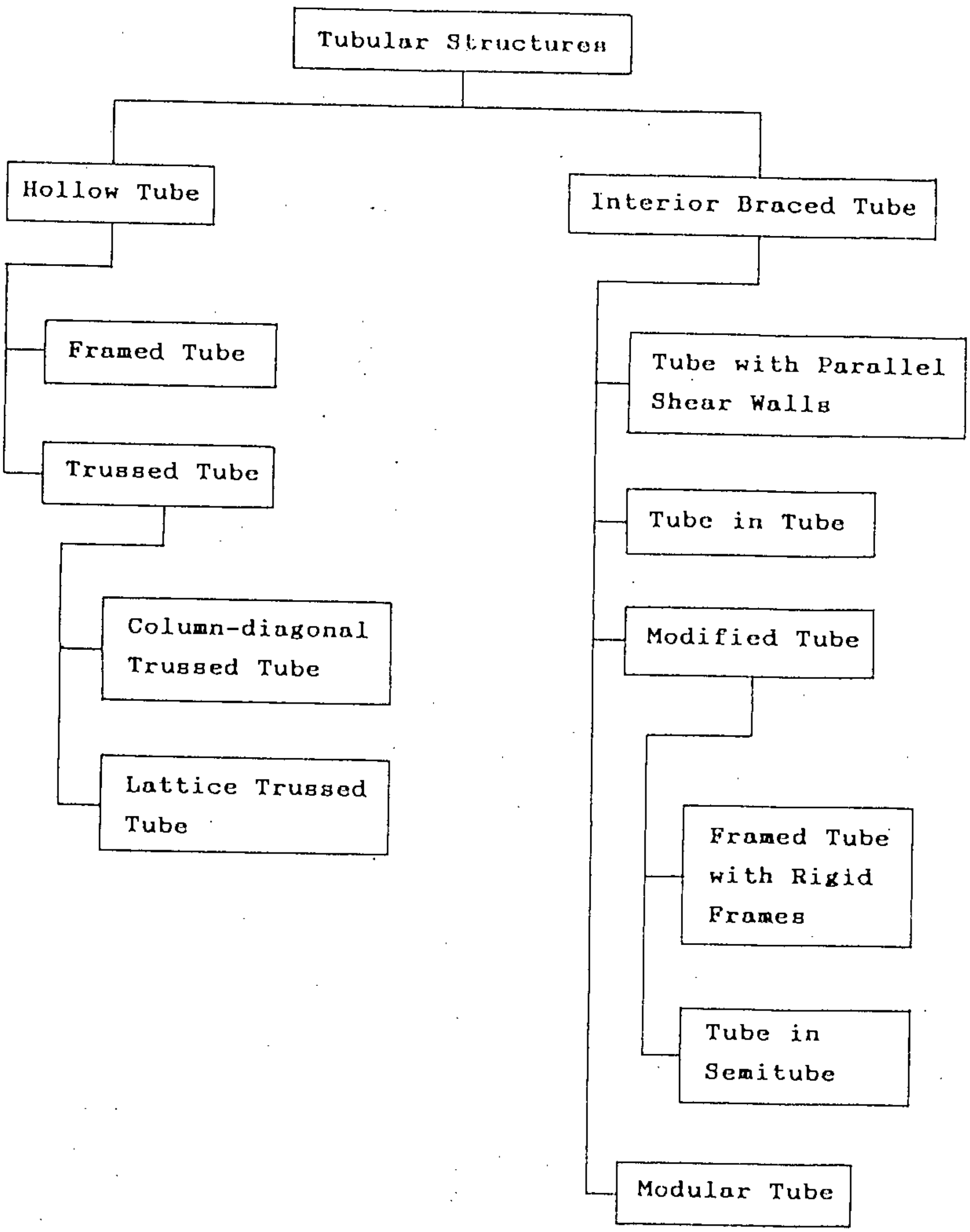
There are several forms of tubular structures, which may be classified as shown Table1.1. A few examples are shown in Fig.1.3.

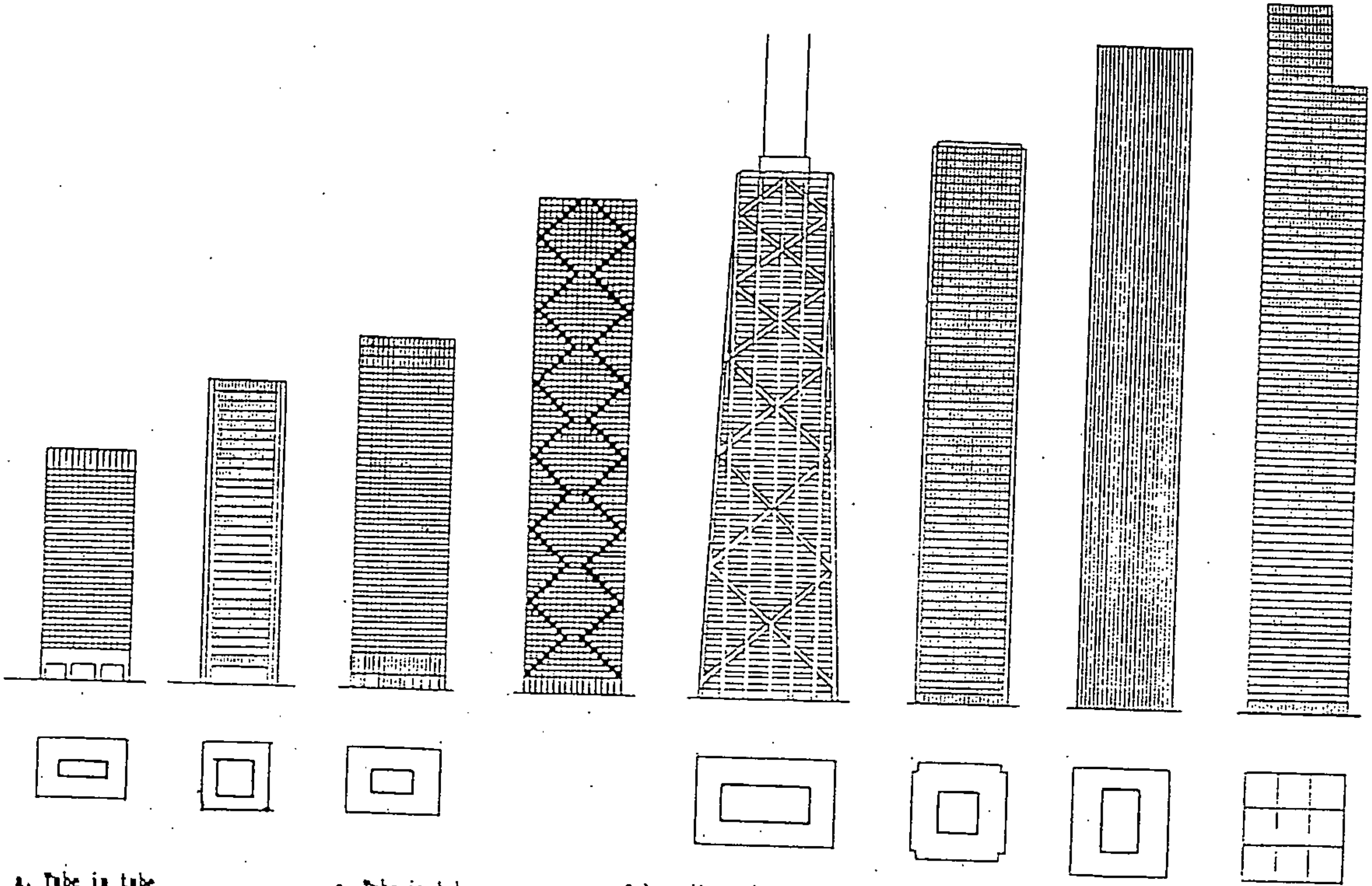
1.6.3.1 Different types of Hollow Tube

(a) Framed Tube

The framed tube, the earliest among the various tubular systems, was first used in 1961 in the 43 story Dewitt Chestnut Apartment Building in Chicago. In this Vierendeel tube system the exterior walls of the building, consisting of a closely spaced rectangular grid of beams and columns rigidly connected together, resist lateral loads through cantilever tube action without using interior bracing. The interior columns are assumed to carry gravity loads and do not contribute to the exterior tube's stiffness (Fig.1.4). The stiff floors act as diaphragms with

Table 1.1: Classification of tubular structures (22)





a. Tube in tube

b. Vierendeel framed single tube

c. Tube in tube

d. Diagonal bracing in concrete

e. Column diagonal trussed single tube

f. Vierendeel framed single tube

g. Vierendeel framed single tube

h. Modular tube

Fig 1.3 : Various types of tubular building structures (22)

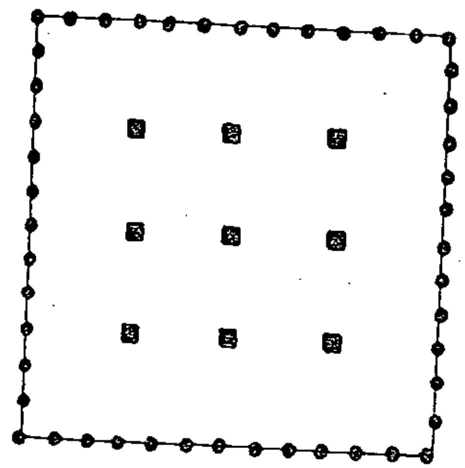


Fig 1.4 : Framed hollow tube

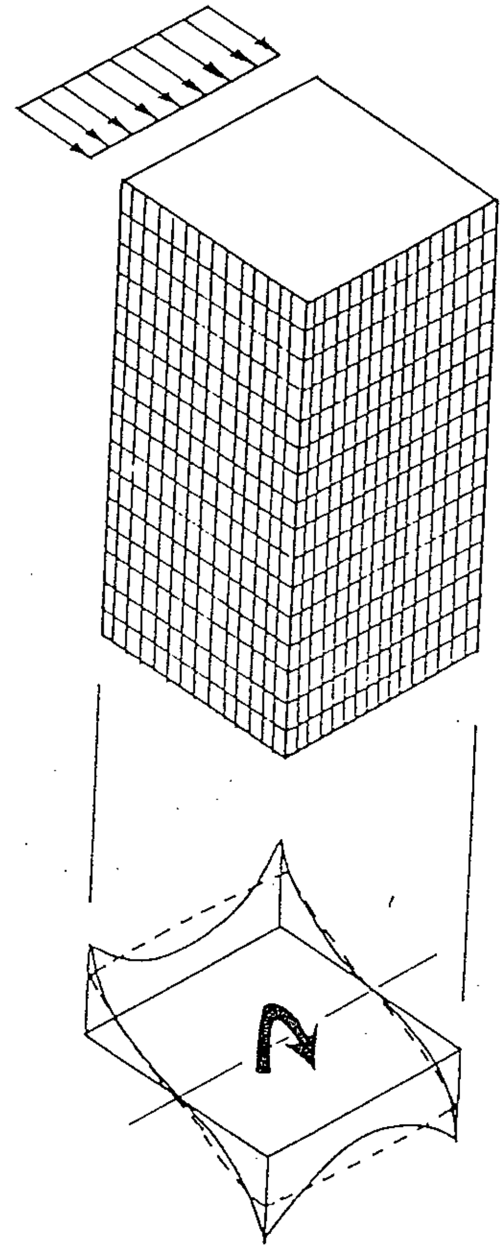


Fig 1.5 : Stress distribution in a framed tube

respect to distributing the lateral forces to the perimeter walls.

Other example of hollow framed tube buildings are the 83-story Standard Oil Building in Chicago and the 110-story World Trade Center in New York. Although these buildings have interior cores, they act as hollow tubes because the cores are not designed to resist lateral loads.

It would be ideal in the design of framed tube system of the exterior walls were to act as a unit, responding to lateral loads in pure cantilever bending. If this were the case, all columns that make up the tube, analogous to the fibers of a beam, would be either in axial tension or in compression. The linear stress distribution that would result is indicated by broken lines in Fig.1.5.

The true behavior of the tube lies somewhere between that of a pure cantilever and a pure frame. The sides of the tube parallel to the wind tend to act as independent multibay rigid frames, given the flexibility of the spandrel beams. This flexibility results in wracking of the frame due to shear, called shear lag. The effect of shear lag on the tube action results in nonlinear pressure distribution along the column envelope; the columns at the corners of the building are forced to take a higher shear of the load than the columns in between. Furthermore, the deflected shape of the building no longer resembles that of a cantilever beam, as shear mode deformation becomes more significant.

The shear lag problem severely affects the efficiency of tubular systems, and all lateral developments of tubular design attempt to overcome it. The framed tube principle seems to be economical for steel buildings up to 80 stories and concrete buildings up to 60 stories.

(b) Trussed Tube

The inherent weakness of the framed tube lies in the flexibility of its spandrel beams. Its rigidity is greatly improved by adding diagonal members. The shear is now primarily absorbed by the diagonals and not by the spandrels. The diagonals carry the lateral forces directly in predominantly axial action. This reduction of shear lag provides for nearly pure cantilever behavior.

Column Diagonal Trussed Tube

This system uses diagonals within the rectangular grid of beams and columns. The diagonals with the spandrel beams create a wall-like rigidity against lateral loads (Fig.1.6).

Not only do the diagonals carry the major portion of lateral loads, they act as inclined columns supporting gravity loads, as well.

Normally the compression induced by gravity loads is not overcome by the tension caused by lateral loads. This dual function of the diagonal members makes this system rather efficient for very tall buildings (upto about 100 stories in steel). It allows much larger spacing of columns than the framed tube.

An essential characteristic of the system is its capability to distribute a concentrated load evenly through the entire structure.

An interesting approach to achieving diagonals in an exterior concrete wall is to fill the window openings in a diagonal pattern.

Lattice Trussed Tube

In this system the tube is made up of closely spaced diagonals

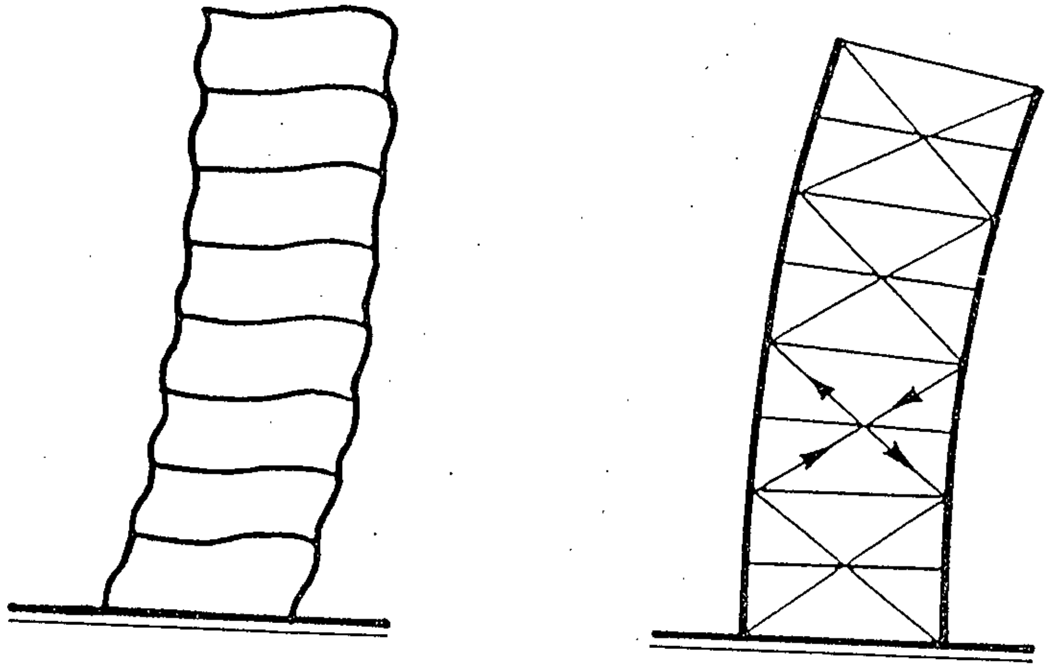


Fig 1.6 : Column diagonal trussed tube

with no vertical columns. The diagonals act as inclined columns, carry all gravity loads and stiffen then structure against lateral loads. The diagonals may be tied together by horizontal beams.

The diagonals are extremely efficient in responding to lateral loads, but they are less efficient than vertical columns in transmitting gravity loads to the ground. Furthermore, the large number of joints required between diagonals and the problems related to window details make the lattice truss system generally impractical.

1.6.3.2 Different types of interior braced tube

The framed exterior tube may be stiffened in plane by adding diagonals, or it may be stiffened from within the building by adding shear walls or interior cores. Several approaches to interior bracing are discussed in the following paragraphs.

(a) Tube with Parallel Shear Walls

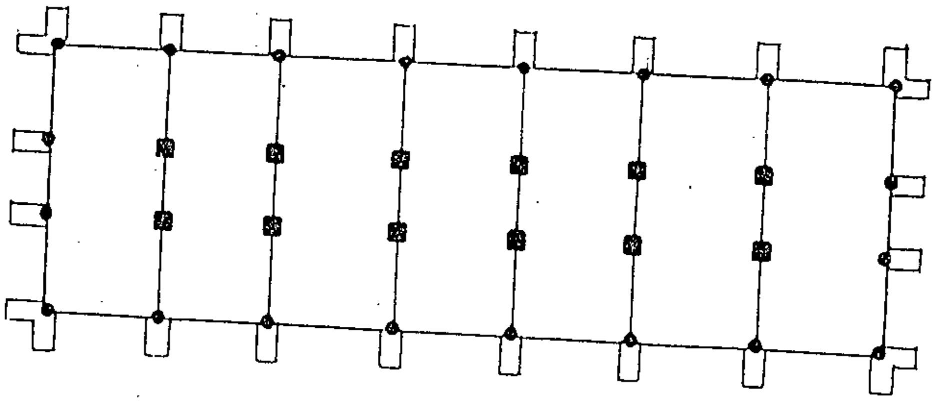
The exterior tubular wall can be stiffened by incorporating interior shear walls into the plan. One can visualize the exterior tube walls as the flanges of a huge built-up system in which the shear walls represent the webs. The stresses in the exterior tube walls are primarily axial, since shear lag is minimized.

The examples in Figs.1.7 (a) and (b) respectively, illustrate two approaches: wide spacing of facade columns, requiring a shear wall for every column, and close spacing of facade columns, requiring only two shear walls.

(b) Tube-in-Tube

The stiffness of a hollow tube system is very much improved by using the core not only for gravity loads but to resist lateral

(a)



(b)

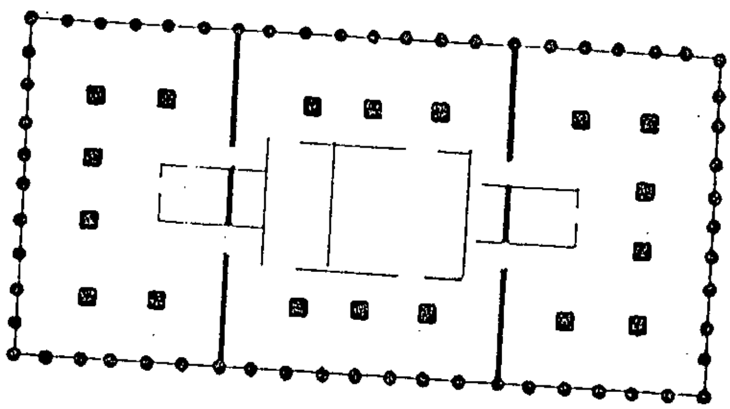


Fig 1.7 : Tube with parallel shear walls

loads, as well. The floor structure ties the exterior and interior tubes together, and they respond as a unit to lateral forces.

The reaction of a tube-in-tube system to lateral loads is similar to that of a frame and shear wall structure.

However the framed exterior tube is much stiffer than a rigid frame.

Fig.1.8 indicates that the exterior tube resists most of the lateral load in the upper portion of the building, whereas the core carries most of the loads in the lower portion.

The tube-in-tube approach has been used in the 38-story Brunswick Building in Chicago, and the 52-story One Shell Plaza Building in Houston.

Taking the tube-in-tube concept one step further, the designers of a 60-story office building in Tokyo used a triple tube (Fig. 1.9). In this system the exterior tube alone resists wind loads, but all three tubes, connected by the floor systems interact in resisting earthquake loads, a significant factor in Japan.

(c) Modified Tube

Tubular action is most efficient in round and nearly square buildings. Buildings deviating from these forms present special structural considerations when tubular action is desired. The following two examples describe such conditions.

Framed Tube with Rigid Frames

The hexagonal shape of a 40-story office building in Charlotte, North Carolina (Fig.1.10), forced the designers to modify the tubular principle. The pointed ends of this hexagonal building exhibited excessive shear lag, making it impossible to get

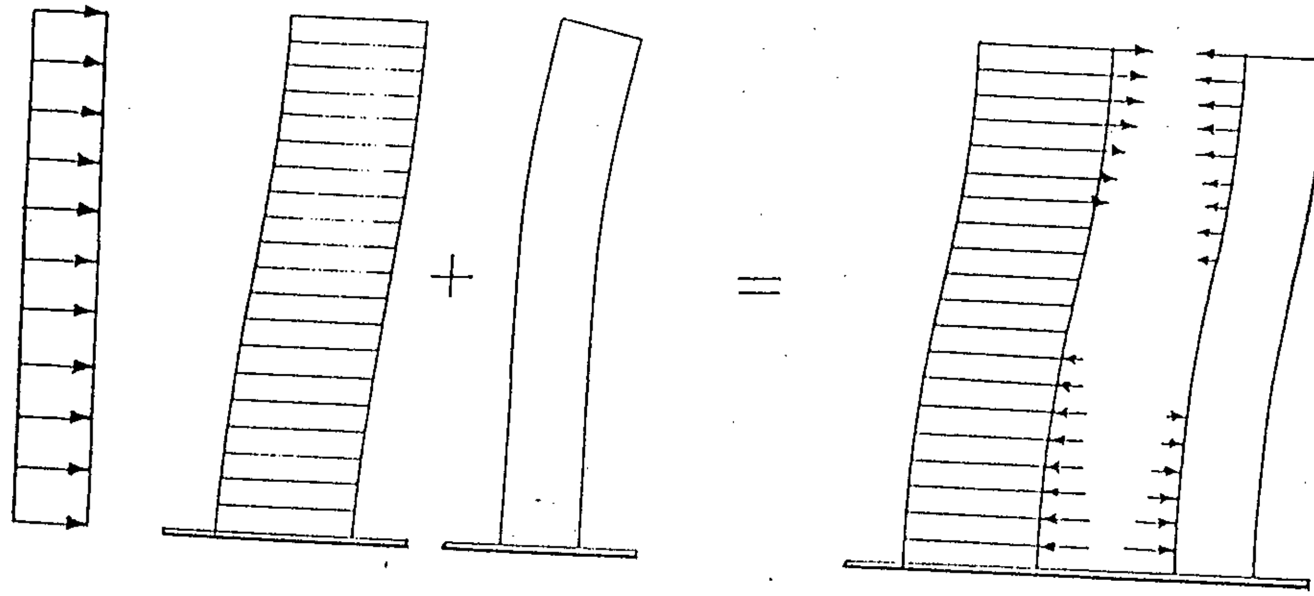


Fig 1.8 : Load distribution in a wall-frame structure

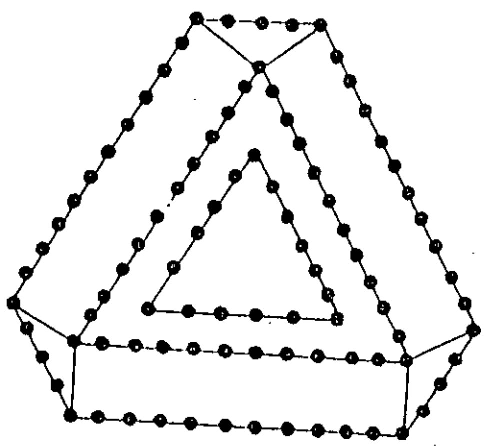


Fig1,9 : Triple tube (tube in tube)

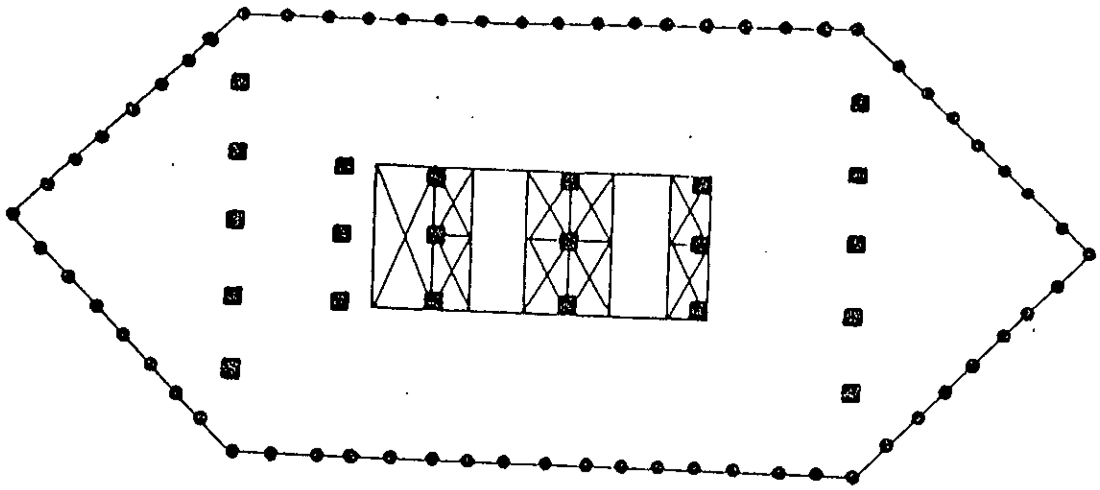


Fig 1.10: Framed tube with rigid frames

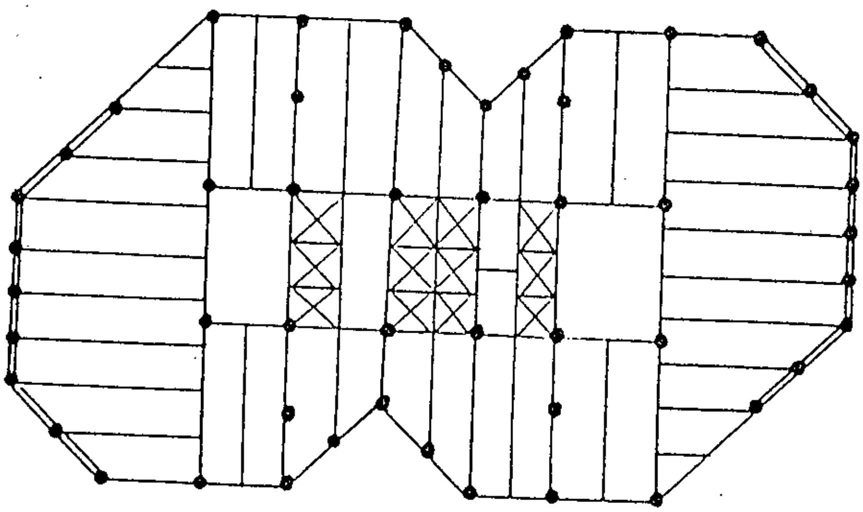


Fig 1.11: Tube in semitube

effective tubular response. Adding rigid frames in the transverse direction served to tie the exterior walls together. Thus the end walls in triangular arrangement were reinforced by rigid frames. By tying together the perimeter walls, effective tubular action was achieved.

Tube in Semitube

The irregular plan of the 32-story Western Pennsylvania National Bank in Pittsburgh (Fig. 1.11) gave rise to still another special solution of tubular design. In most tubular buildings, the tubular effect is generated by the exterior walls. In this building, however, the two intersecting octagons form a structural tube in the central part of the building.

The two end portions of the building are stiffened by channel like wall frame systems. The lateral load is resisted by the combination of interior tube and the huge exterior end-wall channels.

(d) Modular Tubes

One of the latest developments in tubular design is the modular or bundled tube principle. This system has been used for the Sears Tower in Chicago, currently the tallest building in the world.

The exterior framed tube is stiffened by interior cross diaphragms in both directions; an assemblage of cell tubes is formed. These individual tubes are independently strong, therefore may be bundled in any configuration and discontinued at any level. A further advantage of this bundled tube system lies in the extremely large floor areas that may be enclosed.

The interior diaphragms act as webs of a huge cantilever beam in resisting shear forces, thus minimizing shear lag. In addition, they contribute strength against bending.

The behavior of this system is shown in the stress distribution diagram in Fig.1.12. The diaphragms parallel to the wind (i.e. webs) absorb shear, thereby generating points of peak stress at points of intersection with perpendicular walls (i.e. flanges) indicating the individual action of each tube. The difference in axial stress distribution if there are no internal stiffeners that is, a single tube may be noted. The vertical diaphragms tend to distribute the axial stresses equally, although shear lag still occurs to some extent. However the deviation from ideal tubular behavior, indicated by broken lines, does not seem to be very significant.

1.7 OBJECTIVES OF THE PRESENT WORK

The present study is aimed at

a) developing an approximate method for linear elastic analysis of multicellular high rise tubular structures of arbitrary plan shape under static lateral loads;

b) developing a computer program on the basis of the method developed;

c) checking the accuracy of the approximate method by comparing the results of the approximate method with those obtained by using a software "STAAD-III/ISDS", based on exact method of space frame analysis;

d) studying the shear lag effect in multicellular tubular structures of different aspect ratios;

e) comparing the results of the column axial forces with those found from the application of "The Cantilever Method"(27); and

f) comparing the results of the deflections with those found

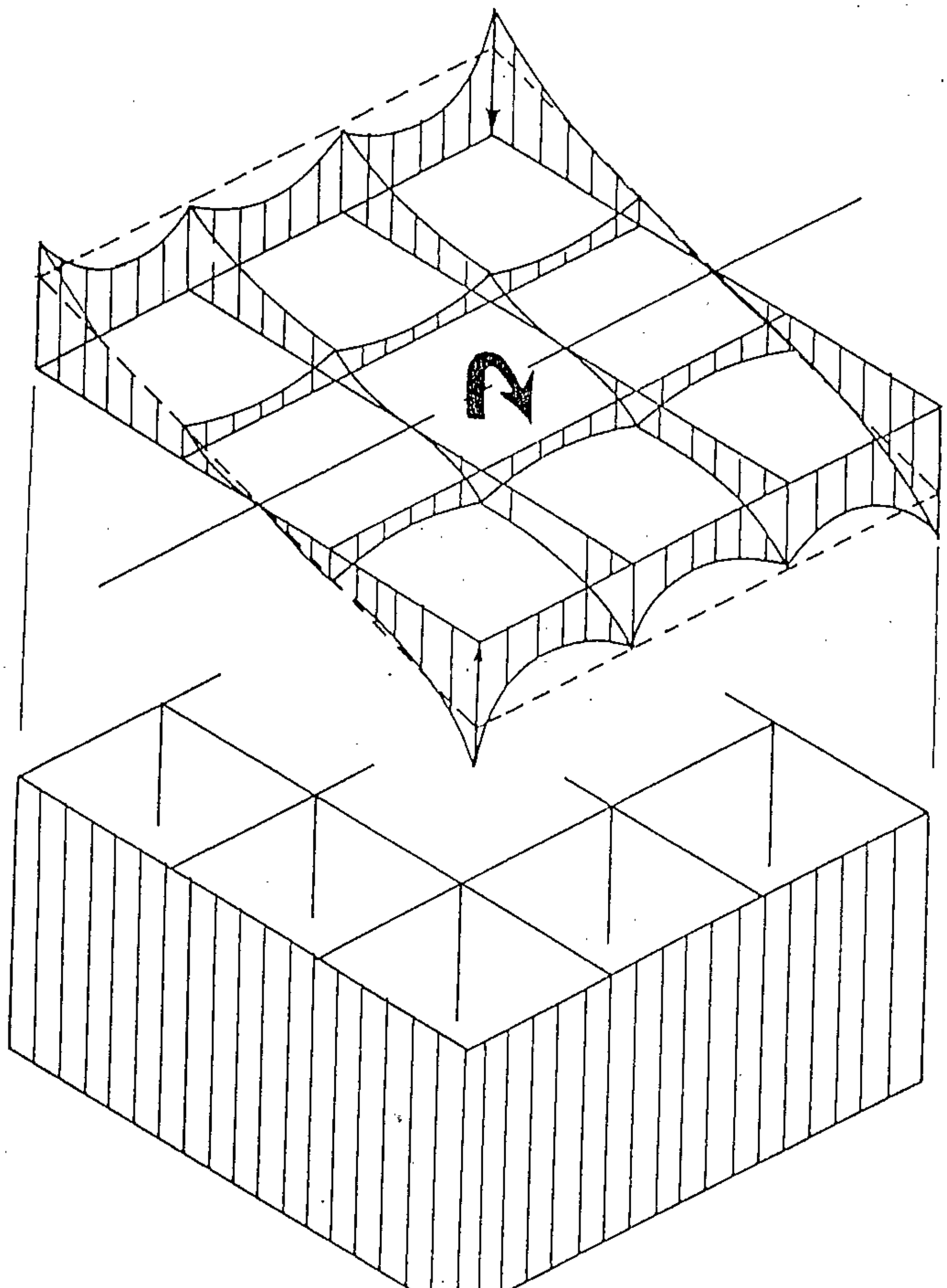


Fig 1.12 : Behaviour of a modular tube

from the application of "The Engineer's Theory of Bending" (based on the assumption that plane sections before bending remain plane after bending).

CHAPTER 2
AVAILABLE METHODS FOR APPROXIMATE ANALYSIS OF TUBULAR STRUCTURES

2.1 INTRODUCTION

Structural engineers are always concerned with optimization to provide the most economic solution to any problem. But the process of optimization is an iterative one and for tall buildings which, in general, involve a large number of redundants requires considerable amount of time and money unless the number of iterative loops is kept to a minimum. The economy and in some cases, the true success of this iterative process depends to a considerable extent upon the correctness of the preliminary selection of member dimensions. The use of a dependable and informative approximate method of analysis is of great help in making the preliminary selection of members and this, in turn, enhances the possibility of rapid convergence.

Approximate methods have several uses in addition to providing a basis for preliminary selection of members. In the very early stage of design when the type of structure and basic dimensions are yet to be determined, approximate methods may prove useful in choosing the basic design that is best, or more likely to be best, from the standpoint of economy or other defined factors. Required sizes of members often may be calculated by approximate methods with sufficient accuracy to provide relative figures of merit for the several designs which may be under consideration.

Finally, approximate methods provide values of forces, moments and deflections to serve as a check on the validity of more "exact" computer analyses which are in general so complex that error at any step is not unlikely.

2.2 APPROXIMATE METHODS FOR ANALYZING TUBULAR STRUCTURES

A number of methods have been developed for approximate analysis of single celled tubular structures. Outlines of some of these methods are given in the following few paragraphs.

Recognizing the fact that under lateral loads the major interactions between the web frames and the flange frames of a rectangular tubular structure are the vertical shear forces at the corners, Coull and Subedi (9) have suggested that an approximate solution for forces in the various members of the tube may be obtained by analyzing an equivalent plane frame. The equivalent plane frame is obtained by putting the orthogonal frames side by side and connecting them in series by fictitious linking member of such stiffnesses so as to allow only vertical forces to be transmitted between the frames. Since this method requires a two dimensional analysis the amount of computational effort is reduced considerably. Another advantage of this method is that a plane frame program with little modifications may be used to analyze tubular structures.

Rutenberg (21) has proposed a method quite similar to that of Coull and Subedi. In this method instead of using fictitious links, fictitious beams of very short length with moment and thrust releases are used to transmit shear forces between orthogonal frames. This allows the use of standard plane frame programs without any modification to account for the shear transfer mechanisms.

Ast and Schwaighofer (1) have developed another plane frame approach which is quite efficient for large symmetric tube structures. It involves determining the interaction forces at a limited number of points on the junctions of the peripheral frames, and superimposing their effect on that of the horizontal external loading acting on the frames parallel to the external loading.

According to Khan (14) for a very preliminary analysis of the overall resistance, as well as the deflection of a tubular structure, the effective configuration of the tube may be reduced to two equivalent channels resisting the total overturning moments. Comparison of results of such an analysis with those obtained from exact analyses performed by a generalized computer program such as STRESS, STRUDL etc. has indicated that such an analysis generally gives conservative values of shear and moments.

Khan and Amin (18) have developed a semi-graphical semi-analytical solution method for analyzing framed tubes of any dimension and of any height. On the basis of the results of computer analyses of a large number of framed tubes with various bending and shearing stiffness ratios of columns to beams they have developed a series of influence curves. From these curves the axial forces in the columns and shear forces in the spandrel beams of a tube of any height can be determined using a reduction modeling technique. The influence curves have been constructed taking the shear lag effect into consideration and are quite useful for design engineers.

Ali Khan (17) has suggested a simplified method of analysis of tubular structures. The mathematical model for this method takes into account the effects of shear lag as well as of rigid joints. In this method the perforated tube is converted into an equivalent unperforated tube of undeformable cross sections with appropriate stiffness properties. The solid walled tube is analyzed by the generalized energy principles and variational methods and then stresses and displacements of this equivalent tube are converted to the design stresses of the rigid tube structure using stress factors. This method is limited to structures having height to width ratio greater than two and with relatively deep members. Also the properties of the structure must be constant across its width and along its height. The accuracy of the method is lost appreciably when the ratios of beam depth to story height and column depth to bay width are less than 0.25 (20).

Heiderbrecht and Stafford Smith (16), on the basis of the fact that the deformation of a tall wall-frame building structure is a combination of flexure and shear deformations, developed a few curves using non-dimensional parameters for evaluating stress resultants, interacting forces and deflections. The mathematical model for these curves has been developed from the differential equations relating loads with deflections. For framed-tube structures these non-dimensional curves may be used assuming that the pair of outer walls parallel to the direction of lateral loading act as a frame whilst the outer walls normal to the loading act as flexural cantilevers.

A simple method for the analysis of large multistory multibay frame work has been presented by Kinh et al (20). It is based on replacing the actual structure by an elastically equivalent orthotropic membrane which is then analyzed by the finite element technique. The inflection points for the bottom story column are assumed at 2/3 of the story height from the base. The refined expressions for the equivalent elastic properties in combination with the versatility of the finite element technique make this method well adaptable to a wide range of tubular structures.

On the basis of the fact that in a rectangular tubular structure the lateral load is resisted primarily by (i) the rigidly jointed frame actions of the shear resisting panels parallel to the load, (ii) the axial deformations of the frame panels normal to the direction of the load and (iii) the axial forces in the discrete corner columns, Coull and Bose (7) have developed a simplified method for the analysis of tubular structures. This method consists of replacing the discrete structure by an equivalent orthotropic tube and obtaining stresses in the tube on the basis of a few simplifying assumptions. They have also developed a few curves which may be used in design offices for rapid assessment of stress and deflection.

Chang and Foutch (3) have presented an approximate method for the analysis of tube frames using an equivalent continuum. The idealized structure is first obtained by defining the material and geometric properties of the tube in terms of the properties of various substructures within the frame. Once the building is represented as a tube, it is analyzed as a thin-walled tube. The tube model allows for shear lag in the flange as well as flexural and shear deformations. The governing differential equations are found through the Minimum Potential Energy principle and from that approximate deflection for the model may be calculated. Although this method cannot be directly used for the calculation of forces and stresses for the final design of structural members, it does provided valuable information on the global behavior of the structure.

2.3 WORKS ON BUNDLED TUBE STRUCTURES

The concept of bundled tube being a recent innovation, research on analysis of such structures is still at the initial stage. The problem with bundled tube structures is that a three dimensional analysis is a must, in no way it may be idealized as two dimensional structure.

A simplified method of obtaining closed form solutions for bundled tube structures has been developed by Coull et al (8). In this method the rigidly-jointed perimeter and interior web frame panels are replaced by equivalent orthotropic plates, whose properties are chosen to represent both the axial and shearing deformation characteristics of the frames. The force and stress distributions in the substitute panels are assumed to be represented with sufficient accuracy by polynomial series in the horizontal coordinates, the coefficients of the series being functions of the height only. The unknown functions are determined from the principle of least work. The influence of stiffer corner columns is included in the analysis. By incorporating simplifying assumptions regarding the form of stress distribution in the frame panels, the structural behavior can be reduced to the solution of a single order differential equation.

2.4 WORKS ON SHEAR LAG IN BOX GIRDERS

Shear lag phenomenon, resulting in a nonuniform distribution of bending stresses across wide flanges of a beam cross-section has long been recognized. The analysis and design of box-beams with this special problem have also been investigated by aeronautical engineers. The pre and post World War II periods are especially marked for researches on box-like components of aircraft structure and so most of the significant papers on box beams were published during this time.

Ali Khan (17) has extensively studied the past research on shear-lag analysis of box beams. Many early works on shear-lag problem are referred to in his thesis. He used energy theorems and calculus of variation to present a general solution for bending and twisting of this walled closed tubular structure. He assumed the spanwise displacements of a beam in the form of finite series incorporating the chordwise (transverse) displacements as some chosen and simple functions. A number of simultaneous differential equations are obtained which can be solved for stresses and displacements.

Foutch and Chang (15) have reported an interesting phenomenon associated with shear-lag in the flanges of box girders that is quite contrary to the well established ideas concerning this subject. If a cantilever tube is loaded laterally under non-uniform shear, a reversal of the shear-lag distribution may occur at some point in the beam and the center-line stress may exceed the edge stress.

CHAPTER 3
SIMPLIFIED ANALYSIS OF TUBULAR STRUCTURES BY THE CONTINUOUS MEDIUM METHOD

3.1 INTRODUCTION

In this method of analysis, the discrete system of connections formed by lintel beams, is replaced by an equivalent continuous medium, as shown in Fig. 3.1.

This chapter presents a simplified method for analysis of tubular structures. Choudhury (4) first developed the method for analyzing plane shear walls with openings. Bari (2) extended the method to analyze single celled tubular structures having a rectangular plan shape, followed by Zubair (24) to analysis single celled tubular structures of arbitrary plan shape. Asif Ahmed (25) further modified this method to analyze multicellular tubular structures having regular plan shape.

This method consists in replacing the deep spandrel beams of Tubular Structures by a continuous medium as shown in Fig. 3.1, obtaining a set of simultaneous ordinary differential equations for the shear forces in the continuous medium by minimizing the strain energy and solving the equations by using a weighted residual method.

The primary advantage of this method is that the solution time is independent of the number of stories and depends only on the number of opening lines. This makes it possible to obtain approximate solutions very rapidly using a microcomputer.

3.2 ASSUMPTIONS

Following are the assumptions made in developing the theory of the continuous medium method.

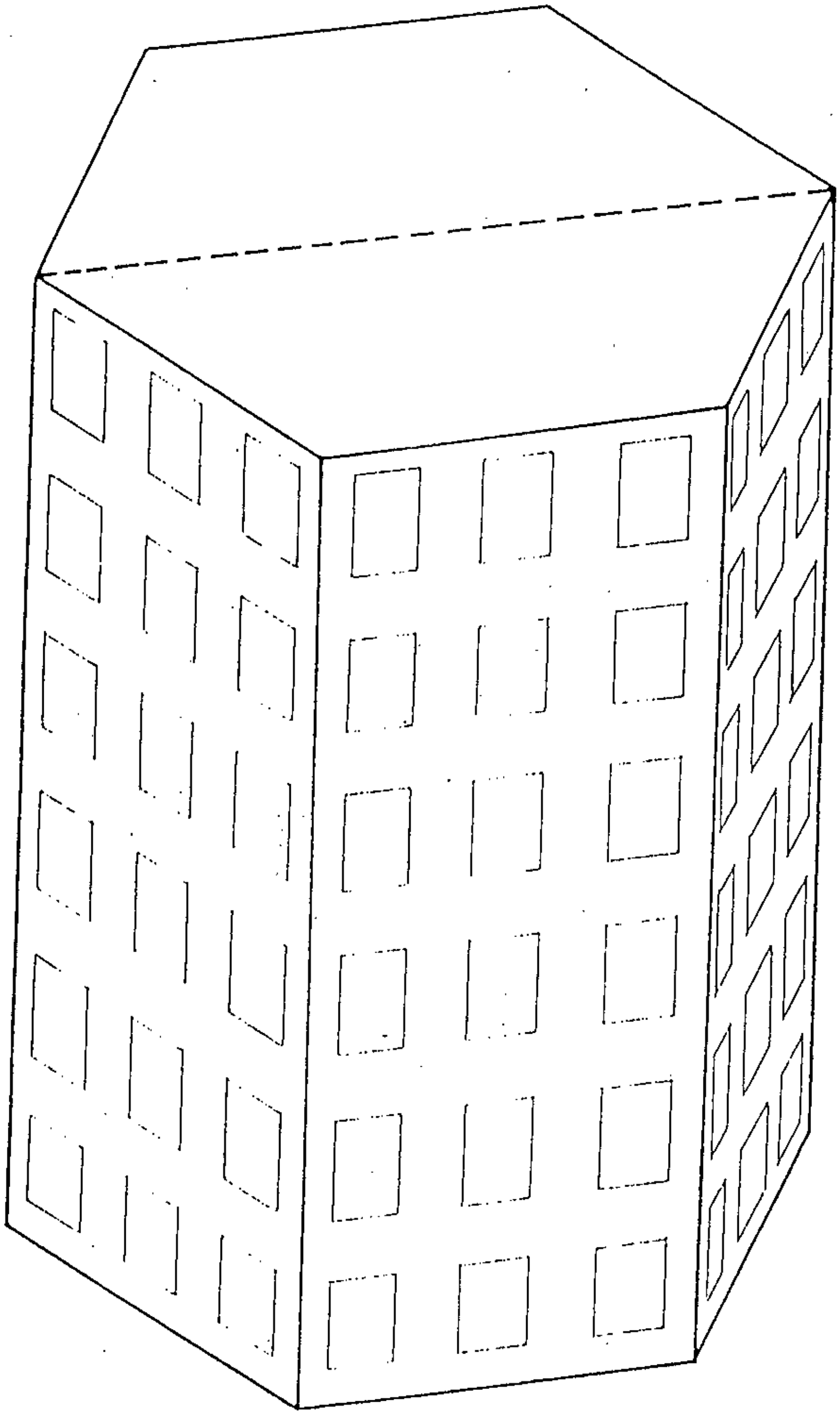


Fig 3.1a: Idealization of a tubular structure - Actual structure.

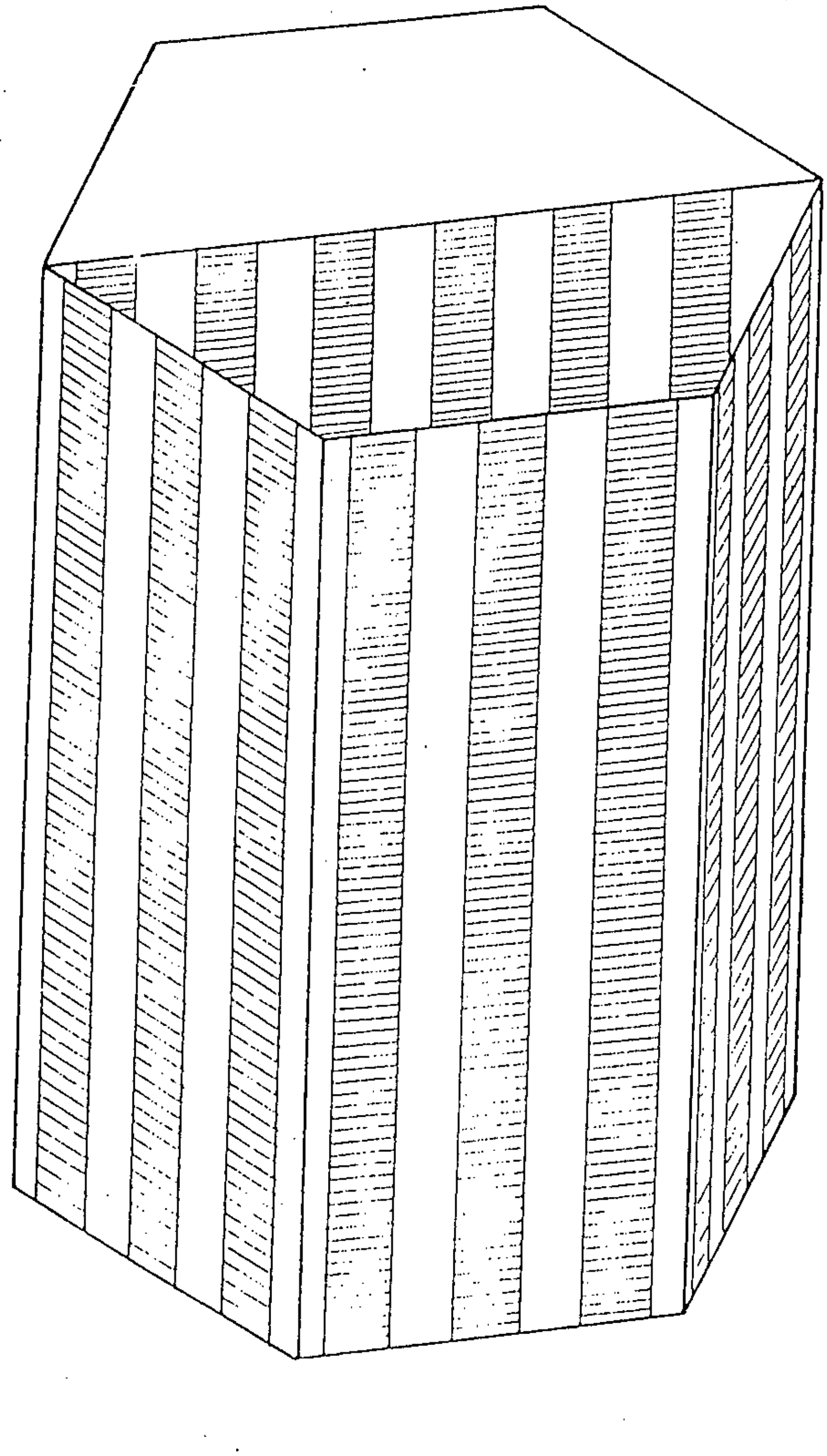


Fig 3.1b: Idealization of a tubular structure -
Beams replaced by continuous medium.

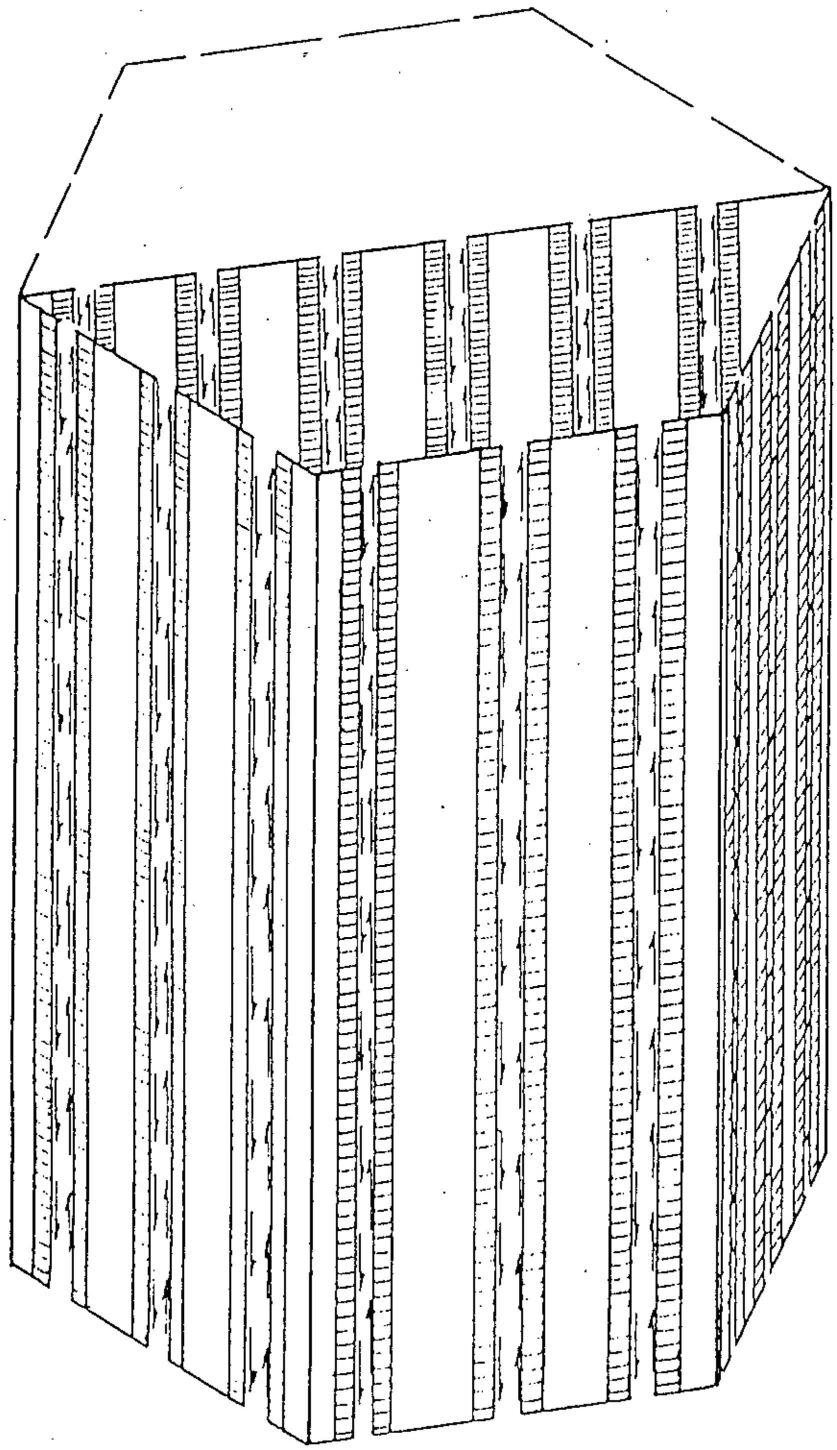


Fig 3.1c: Idealization of a tubular structure - Released structure.

1) The connecting beams do not deform axially and hence the lateral deflection of all the individual walls/columns is the same at any level.

2) The moment of inertia and cross-sectional areas of the spandrel beams are constant throughout the height of the building, except those at the top most story which have half the moment of inertia and half the cross-sectional areas of the other beams in the same band of opening.

3) The moment of inertia and cross-sectional area of the columns/walls are constant throughout the height of the building.

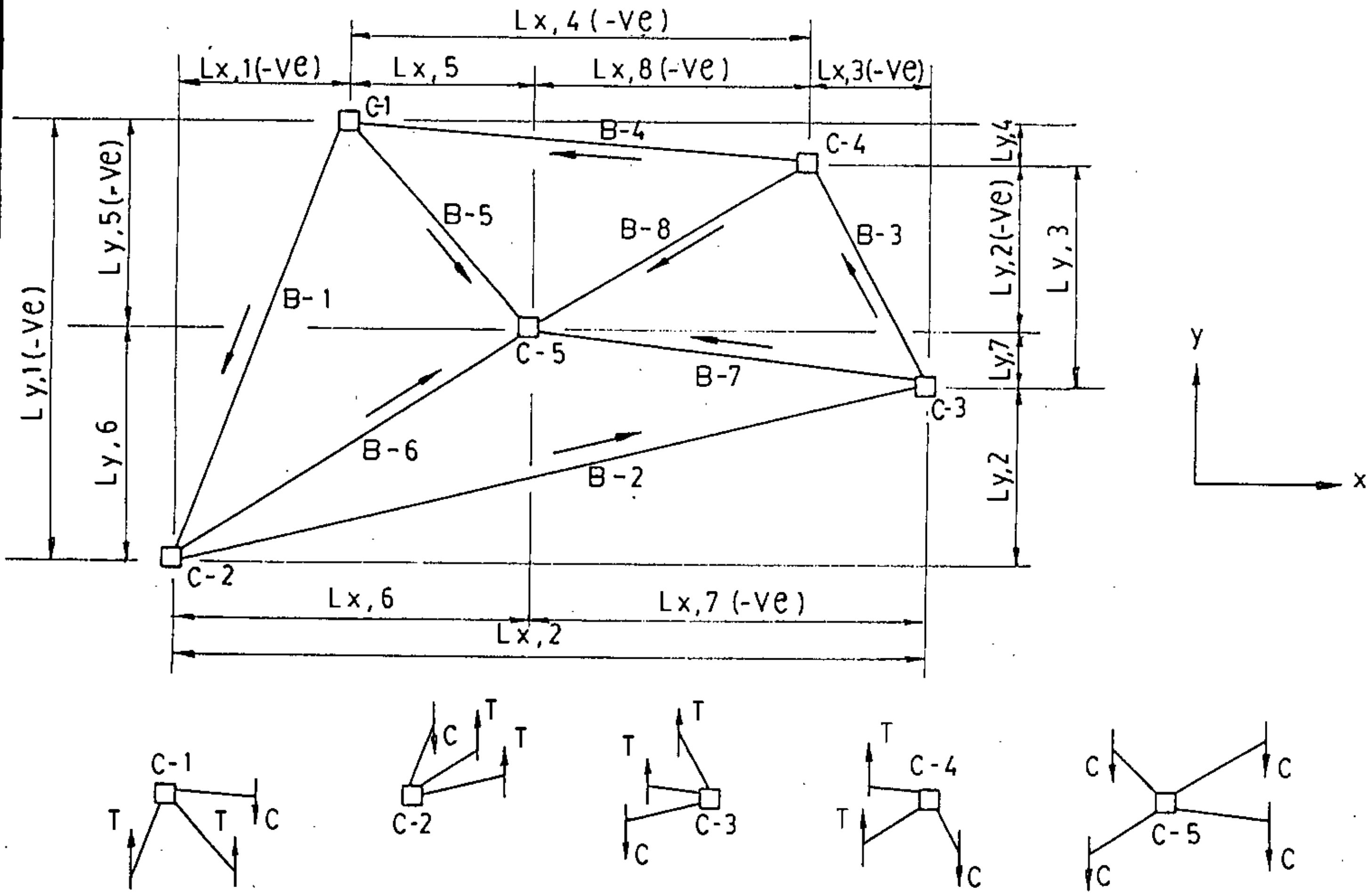
4) The points of contraflexure in the connecting beams are at mid spans.

5) Engineers theory of bending is valid i.e. plane sections before bending remain plane after bending.

6) At any level the total moment to be carried by the columns/walls is shared by the individual columns/walls in proportion to their moment of inertia.

3.3 GENERAL FORMULATION

The general formulation technique follows that of Choudhury J.R. (4). Figure 3.2 shows a typical floor plan of a tubular structure, consisting of closely spaced walls/columns at arbitrary locations and interconnected by deep spandrel beams at floor levels. The discrete connecting beams of stiffness EI_p are replaced by a continuous medium connecting the wall/beams for the full height and having the same bending stiffness as beams they replace, e.g. in an opening with story height `h´ beams of stiffness EI_p are replaced by continuous medium of stiffness EI_p/h. The structure is then released by introducing a cut along the line of contraflexure and the integral of disttributed shear forces in the connecting medium,



Beam connectivity matrix:

BEAM	END-1	END-2
1	1	2
2	2	3
3	3	4
4	4	1
5	1	5
6	2	5
7	3	5
8	4	5

WCM-1

COLM.NO.	BEAM NO.
1	1, 5
2	2, 6
3	3, 7
4	4, 8
5	—

WCM-2

COLM.NO.	BEAM. NO.
1	4
2	1
3	2
4	3
5	5,6,7,8

Fig. 3.2 : Floor plan of a typical tubular structure of arbitrary plan shape and its different connectivity matrices

$$T = \int_0^z q\,dz \qquad (3.1)$$

where `T´, the integral of shear force, is taken as the redundant function. The governing equation for the function T can now be derived from energy considerations (as originally suggested by Rosman).

Neglecting the effect of axial forces and assuming that the wall/column cross sections are rectangular and doubly symmetric, the strain energy due to bending and shear of the continuous medium in the ith opening and having a height of dz is

$$u_{1,i} = \int_0^H \delta u_{1,i}$$

$$\delta u_{1,i} = 2\left[\int_0^{b_i/2} \left(\frac{M_i^2}{2EI_i}\,dz\right)dx + \int_0^{b_i/2}\left(\frac{\tau_i^2}{2AG_{iav}}\,dz\right)dx\right]$$

$$= 2\int_0^{b_i/2}\left[\frac{(q_i x)^2}{2EI_{p,i}/h_i} + \frac{1.2(q_i)^2}{2A_{p,i}/h_i G}\right] dz\,dx$$

$$= \frac{q_i^2\, b_i^3 h_i}{24EI_{p,i}}\left[1 + 2.4(1+\nu)\left(\frac{d_i}{b_i}\right)^2\right]dz$$

$$u_{1,i} = \int_0^H \delta u_{1,i}$$

$$= \int_0^H \frac{q_i^2\, b_i^3 h_i}{24EI_{p,i}}\left[1 + 2.4(1+\nu)\left(\frac{d_i}{b_i}\right)^2\right]dz \qquad (3.2)$$

$$= \int_0^H (T'_i)^2\, \frac{b_i^3 h_i}{24EI_{c,i}}\,dz \qquad (3.3)$$

where, $$I_{c,i} = \frac{I_{p,i}}{1+2.4(d_i/b_i)^2\,(1+\nu)} \qquad (3.4)$$

The total strain energy due to flexure and shear in the continuous medium in all bands of openings is

$$u_1 = \sum_{i=1}^{n} u_{1,i} = \sum_{i=1}^{n} \int_0^H (T'_i)^2\, \frac{b_i^3 h_i}{24\,EI_{c,i}}\,dz \qquad (3.5)$$

Introduction of Sign Convention

1) At any band of opening of the released structure positive shear in the continuous medium adjacent to "End 1" wall of the beams (as defined in the beam connectivity matrix) is directed along decreasing z and that in the continuous medium adjacent to "End 2" wall is directed along increasing z and also that

2) Positive value of the center to center length of any band of openings is obtained by subtracting the coordinates of "End 1" wall from those of "End 2" wall.

We can write for the axial force in the ith wall.

$$F_i = \Sigma T_r - \Sigma T_s \qquad (3.6)$$

where, ΣT_r = sum of shear forces in the spandrel beams having wall/column i as their end-1. These beams are found in the ith row of WCM-1 (wall connectivity matrix one)

ΣT_s = sum of shear forces in the spandrel beams having wall/column i as their end-2. These beams are found in the ith row of WCM-2 (wall connectivity matrix two)

For the section shown in Fig. 3.2.

$$F_1 = (T_1+T_5) - T_4 = (\Sigma T_r - \Sigma T_s)_1$$

$$F_2 = (T_2+T_6) - T_1 = (\Sigma T_r - \Sigma T_s)_2$$

$$F_3 = (T_3+T_7) - T_2 = (\Sigma T_r - \Sigma T_s)_3$$

$$F_4 = (T_4+T_8) - T_3 = (\Sigma T_r - \Sigma T_s)_4$$

$$F_5 = 0 - (T_5+T_6+T_7+T_8) = (\Sigma T_r - \Sigma T_s)_5$$

Strain energy, due to axial deformation of the ith wall is,

$$u_{2,i} = \int_0^H \frac{(\Sigma T_r - \Sigma T_s)_i^2}{2EA_i}\, dz \qquad (3.8)$$

Therefore the total strain energy due to axial deformation of all the walls is

$$u_2 = \sum_{i=1}^{m} \int_0^H \frac{(\Sigma T_r - \Sigma T_s)_i^2}{2EA_i} dz \qquad (3.8)$$

Strain energy, due to flexural deformation of the ith wall is

$$u_{3,i} = \int_0^H \left[\frac{(M_{x,i})^2}{2EI_{x,i}} + \frac{(M_{y,i})^2}{2EI_{y,i}} \right] dz \qquad (3.9)$$

Now, on the basis of the sixth assumption mentioned in Section 3.2, at any distance z from the top of the tube the bending moments $M_{x,i}$ and $M_{y,i}$ are given by

$$M_{x,i} = \frac{-\dfrac{w_y z^2}{2} + \sum_{j=1}^{n} (T_j L_{y,j})}{\sum_{j=1}^{m} I_{x,j}} I_{x,i} \qquad (3.10)$$

$$M_{y,i} = \frac{\dfrac{w_x z^2}{2} - \sum_{j=1}^{n} (T_j L_{x,j})}{\sum_{j=1}^{m} I_{y,j}} I_{y,i} \qquad (3.11)$$

<u>Sign Convention for moments(fig 3.3)</u>

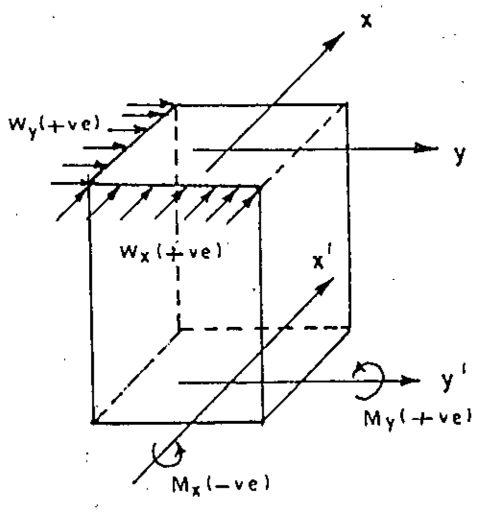


Fig. 3.3 Sign Convention for Moments

Substituting these values of $M_{x,i}$ and $M_{y,i}$ in Eqn.(3.9) we get,

$$u_{3,i} = \int_0^H \left[\frac{(M_{x,i})^2}{2E\, I_{x,i}} + \frac{(M_{y,i})^2}{2EI_{y,i}} \right] dz$$

$$= \left[\frac{(I_{x,i})^2}{2EI_{x,i}\left(\sum_{j=1}^{m} I_{x,j}\right)^2} * \left(\frac{-w_y z^2}{2} + \sum_{j=1}^{n} T_j L_{y,i}\right)^2 \right.$$

$$\left. + \frac{(I_{y,i})^2}{2EI_{y,i}\left(\sum_{j=1}^{m} I_{y,j}\right)^2} \left(\frac{w_x z^2}{2} - \sum_{j=1}^{n} T_j L_{x,j}\right)^2 \right] dz \tag{3.12}$$

$$u3 = \int_0^H \left[\frac{\left(\frac{-w_y z^2}{2} + \sum_{j=1}^{n} T_j L_{y,j}\right)^2}{2E\left(\sum_{j=1}^{m} I_{x,j}\right)^2} \sum_{i=1}^{m} I_{x,i} \right.$$

$$\left. + \frac{\left(\frac{w_x z^2}{2} - \sum_{j=1}^{n} T_j L_{x,j}\right)^2}{2E\left(\sum_{j=1}^{m} I_{y,j}\right)^2} \sum_{i=1}^{m} I_{y,i} \right] dz \tag{3.13}$$

Total strain energy of the whole system, considering all kinds of deformation is

$$U = U_1 + U_2 + U_3 = F(Z,T,T')dz \tag{3.14}$$

Then Euler equation for the calculus of variations states that if

$$\varnothing = F(z,y,y')dz$$

then for $\varnothing$ to be a minimum

$$\frac{\delta F}{\delta y} - \frac{d}{dz}\left(\frac{\delta F}{\delta y'}\right) = 0$$

Applying this to minimize the strain energy of the system we will have

$$\frac{\delta u}{\delta T_i} - \frac{d}{dz}\left(\frac{\delta u}{\delta T_i'}\right) = 0 \tag{3.15}$$

or,
$$\left[\frac{\delta u_1}{\delta T_i} + \frac{\delta u_2}{\delta T_i} + \frac{\delta u_3}{\delta T_i}\right] - \left[\frac{d}{dz}\left(\frac{\delta u1}{\delta T'_i}\right) + \frac{d}{dz}\left(\frac{\delta u_2}{\delta T'_i}\right) + \frac{d}{dz}\left(\frac{\delta u_3}{\delta T_i'}\right)\right] = 0 \tag{3.16}$$

Here,
$$\frac{\delta u_1}{\delta T_i} = 0 \tag{3.17}$$

$$\frac{\delta u_1}{\delta T_i'} = \frac{T_i' \; b_i^3 h_i}{12EI_{c,i}} \tag{3.18}$$

$$\frac{d}{dz}\left(\frac{\delta u_1}{\delta T_i'}\right) = \frac{T_i'' \; b_i^3 h_i}{12EI_{c,i}} \tag{3.19}$$

Similarly,

$$\frac{\delta u_2}{\delta T_i} = \frac{(\Sigma\, T_r - \Sigma\, T_s)_u}{A_u E}(1) + \frac{(\Sigma\, T_r - \Sigma\, T_s)_v}{A_v E}(-1) \tag{3.20}$$

For the section shown in Fig. 3.2,

$$u_2 = \sum_{i=1}^{n} \int_0^H \frac{(\Sigma T_r - \Sigma T_s)_i^2}{2EA_i}\, dz$$

$$= \int_0^H \left[\frac{(T_1+T_5-T_4)^2}{2EA_1} + \frac{(T_2+T_6-T_1)}{2EA_2} + \frac{(T_3+T_7-T_2)^2}{2EA_3} + \frac{(T_4+T_8+T_3)^2}{2EA_4} + \frac{(-T_5-T_6-T_7-T_8)^2}{2EA_5}\right]dz \tag{3.21}$$

$$\frac{\delta u_2}{\delta T_1} = \frac{T_1+T_5-T_4}{EA_1}(1) + \frac{T_2+T_6-T_1}{EA_2}(-1)$$

$$\frac{\delta u_2}{\delta T_2} = \frac{T_2+T_6-T_1}{EA_2}(1) + \frac{T_3+T_7-T_2}{EA_3}(-1)$$

$$\frac{\delta u_2}{\delta T_3} = \frac{T_3+T_7-T_2}{EA_3}(1) + \frac{T_4+T_8-T_3}{EA_4}(-1)$$

$$\frac{\delta u_2}{\delta T_4} = \frac{T_4+T_8-T_3}{EA_4}(1) + \frac{T_1+T_5-T_4}{EA_1}(-1) \quad \text{etc.}$$

In general, $$\frac{\delta u_2}{\delta T_i} = \frac{(\Sigma T_r - \Sigma T_s)_u}{A_u E}(1) + \frac{(\Sigma T_r - \Sigma T_s)_v}{A_v E}(-1)$$

Similarly, $$\frac{\delta u_2}{\delta T'_i} = 0$$

$$\frac{\delta u_3}{\delta T_i} = \frac{2(-w_y Z^2/2 + \sum_{j=1}^{n} T_j L_{y,j})}{2E(\sum_{k=1}^{m} I_{x,k})^2} L_{y,i} \sum_{k=1}^{m} I_{x,k}$$

$$+ \frac{2(w_x Z^2/2 - \sum_{j=1}^{n} T_j L_{x,j})}{2E(\sum_{k=1}^{m} I_{y,k})^2}(-L_{x,j}) \sum_{k=1}^{m} I_{y,k} \quad (3.23)$$

From Euler's equation,

$$\frac{\delta u}{\delta T_i} - \frac{d}{dz}\left(\frac{\delta u}{\delta T'_i}\right) = 0$$

$$\text{or, } \frac{\delta u_1}{\delta T_i} + \frac{\delta u_2}{\delta T_i} + \frac{\delta u_3}{\delta T_i} - \frac{d}{dz}\left(\frac{\delta u_1}{\delta T'_i}\right) - \frac{d}{dz}\left(\frac{\delta u_2}{\delta T'_i}\right) - \frac{d}{dz}\left(\frac{\delta u_3}{\delta T'_i}\right) = 0$$

$$\text{or, } \frac{\delta u_2}{\delta T_i} + \frac{\delta u_3}{\delta T_i} - \frac{d}{dz}\left(\frac{\delta u_1}{\delta T'_i}\right) = 0$$

Putting the value of the differentials and solving , we get

$$T''_i - \frac{12\, I_{c,i}}{b_i^3 h_i}\Big[\sum_{j=1}^{n} T_j \Big(\frac{L_{y,j}L_{y,i}}{(\sum_{k=1}^{m} I_{x,k})^2}\sum_{k=1}^{m} I_{x,k} + \frac{L_{x,j}L_{x,i}}{(\sum_{k=1}^{m} I_{y,k})^2}\sum_{k=1}^{m} I_{y,k}\Big)$$

$$+ \frac{(\Sigma T_r - \Sigma T_s)_u}{A_u} - \frac{(\Sigma T_r - \Sigma T_s)_v}{A_v}\Big] + \frac{12 I_{c,i}}{b_i^3 h_i}\Big[\frac{w_x L_{x,i}}{2(\sum_{k=1}^{m} I_{y,k})^2}\sum_{k=1}^{m} I_{y,k}$$

$$+ \frac{w_y L_{y,i}}{2(\sum_{k=1}^{m} I_{x,k})^2}\sum_{k=1}^{m} I_{x,k}\Big] z^2 = 0 \qquad (3.24)$$

where, $i = 1,2,3 \ldots\ldots\ldots n$

The above system of simultaneous second under differential equations may be written as

$$T''_1 - \alpha_{11}^2 T_1 - \alpha_{12}^2 T_2 \ldots\ldots - \alpha_{1n}^2 T_n + \beta_1 z^2 = 0$$

$$T''_2 - \alpha_{21}^2 T_1 - \alpha_{22}^2 T_2 \ldots\ldots - \alpha_{2n}^2 T_n + \beta_2 z^2 = 0$$

$$\ldots\ldots\ldots$$

$$T''_n - \alpha_{n1}^2 T_1 - \alpha_{n2}^2 T_2 \ldots\ldots - \alpha_{nn}^2 T_n + \beta_n z^2 = 0 \qquad (3.25)$$

where,

$$(\alpha_{i,j})^2 = \frac{12\, I_{c,i}}{b_i^3 h_i}\Big\{\frac{L_{y,j}L_{y,i}}{(\sum_{k=1}^{m} I_{x,k})^2}\sum_{k=1}^{m} I_{x,k} + \frac{L_{x,j}L_{x,i}}{(\sum_{k=1}^{m} I_{y,k})^2}\sum_{k=1}^{m} I_{y,k}\Big\}$$

where no entry in row numbers "End 1" and "End 2" (of the ith band of openings) of "WCM1" or "WCM2" is equal to j

$$(\alpha_{i,j})^2 = \frac{12\, I_{c,i}}{b_i^3 h_i}\Big\{\frac{L_{y,j}L_{y,i}}{(\sum_{k=1}^{m} I_{x,k})^2}\sum_{k=1}^{m} I_{x,k}$$

$$+ \left\{ \frac{L_{x,j}L_{x,i}}{\left(\sum_{k=1}^{m} I_{y,k}\right)^2} \sum_{k=1}^{m} I_{y,k} + \frac{1}{A_u} \right\}$$

where j is equal to one entry in row no "End 1" (of the ith band of openings), say row as u, of "WCM1"

$$(\alpha_{i,j})^2 = \frac{12\ I_{c,i}}{b_i^3 h_i} \left\{ \frac{L_{y,j}L_{y,i}}{\left(\sum_{k=1}^{m} I_{x,k}\right)^2} \sum_{k=1}^{m} I_{x,k} \right.$$

$$\left. + \left\{ \frac{L_{x,j}L_{x,i}}{\left(\sum_{k=1}^{m} I_{y,k}\right)^2} \sum_{k=1}^{m} I_{y,k} - \frac{1}{A_u} \right\}\right.$$

where j is equal to one entry in row no "End 1" (of the ith band of openings), say row no u, of "WCM2"

$$(\alpha_{i,j})^2 = \frac{12\ I_{c,i}}{b_i^3 h_i} \left\{ \frac{L_{y,j}L_{y,i}}{\left(\sum_{k=1}^{m} I_{x,k}\right)^2} \sum_{k=1}^{m} I_{x,k} \right.$$

$$\left. + \left\{ \frac{L_{x,j}L_{x,i}}{\left(\sum_{k=1}^{m} I_{y,k}\right)^2} \sum_{k=1}^{m} I_{y,k} - \frac{1}{A_v} \right\}\right.$$

where j is equal to one entry in row no "End 2" (of the ith band of openings), say row no v, of "WCM1"

$$(\alpha_{i,j})^2 = \frac{12\ I_{c,i}}{b_i^3 h_i} \left\{ \frac{L_{y,j}L_{y,i}}{\left(\sum_{k=1}^{m} I_{x,k}\right)^2} \sum_{k=1}^{m} I_{x,k} \right.$$

$$\left. + \left\{ \frac{L_{x,j}L_{x,i}}{\left(\sum_{k=1}^{m} I_{y,k}\right)^2} \sum_{k=1}^{m} I_{y,k} + \frac{1}{A_v} \right\}\right.$$

where j is equal to one entry in row no "End 2" (of the ith band of openings), say row no v, of "WCM2"

$$\beta_i = \frac{12\, I_{c,i}}{b_i^3 h_i} \frac{1}{2} \left\{ \frac{w_y L_{y,i}}{\left(\sum_{k=1}^{m} I_{x,k}\right)^2} \sum_{k=1}^{m} I_{x,k} + \left\{ \frac{w_x L_{x,i}}{\left(\sum_{k=1}^{m} I_{y,k}\right)^2} \sum_{k=1}^{m} I_{y,k} \right\}\right.$$

It should be noted that in each of the expressions above u and v may have multiple values.

when written in matrix notation, Eqn. (3.25) becomes

$$\frac{d^2}{dz^2} \begin{bmatrix} T_1 \\ T_2 \\ \cdots \\ T_n \end{bmatrix} = \begin{bmatrix} \alpha_{11}^2 & \alpha_{12}^2 & \cdots\cdots & \alpha_{1n}^2 \\ \alpha_{21}^2 & \alpha_{22}^2 & \cdots\cdots & \alpha_{2n}^2 \\ & & & \\ \alpha_{n1}^2 & \alpha_{n2}^2 & \cdots\cdots & \alpha_{nn}^2 \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ \\ T_n \end{bmatrix} - z^2 \begin{bmatrix} \beta_1 \\ \beta_2 \\ \\ \beta_n \end{bmatrix} \quad (3.26)$$

or,
$$\frac{d^2}{dz^2} \underline{T} = \underline{A}\, \underline{T} + z^2\, \underline{B} \quad (3.27)$$

Assuming a family of solutions

$$T_j = \sum_{i=1,3,5}^{\alpha} a_{ij} \operatorname{Sin}\left(\frac{i\pi z}{2H}\right) \quad (3.28)$$

at $z=0$, $T_i=0$ and at $z=H$,$T'_i=0$

Applying Galerkin's method to minimize residuals, the following system of simultaneous equations in terms of aij's is obtained:

$$\begin{bmatrix} \left(\frac{i\pi}{2H}\right)+\alpha_{11}^2 & \alpha_{12}^2 \ldots & \alpha_{1n}^2 \\ \alpha_{21}^2 & \left(\frac{i\pi}{2H}\right)^2+\alpha_{22}^2 \ldots & \alpha_{2n}^2 \\ \alpha_{n1}^2 & \alpha_{n2}^2 & \left(\frac{i\pi}{2H}\right)+\alpha_{nn}^2 \end{bmatrix} \begin{bmatrix} a_{i1} \\ a_{i2} \\ a_{in} \end{bmatrix} = \frac{16H^2}{\pi^3 i^3} \{i\pi \, \mathrm{Sin}\left(\frac{\pi i}{2}\right) -2\} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \cdot \\ \cdot \\ \beta_3 \end{bmatrix} \tag{3.24}$$

where i = 1,3,5 ......

In matrix form

$$\underline{C}\, \underline{D}_i = \underline{k} \tag{3.30}$$

the solution of which gives Aij´s

$$\underline{D}_i = \underline{C}^{-1}\, \underline{K} \tag{3.31}$$

Once the A_{ij}´s are determined, the values of the T_i´s at different heights may be evaluated by summing the series. (Eqn. 3.28)

For wall i, at height z,

$$M_{x,i} = \frac{-\dfrac{w_y z^2}{2} + \sum_{k=1}^{n} (T_k L_{y,k})}{\sum_{k=1}^{m} I_{x,k}} I_{x,i} \tag{3.32a}$$

$$M_{y,i} = \frac{\dfrac{w_x z^2}{2} - \sum_{k=1}^{n} (T_k L_{x,k})}{\sum_{k=1}^{m} I_{y,k}} I_{y,i} \tag{3.32b}$$

where the T_k´s are calculated at height z.

Axial force in wall i at height z is

$$F_i = (\Sigma\, T_r - \Sigma\, T_s)_i \tag{3.33}$$

Deflections

The tube deflections can be determined by using the load-deflection equation as shown below:

$$EI\frac{d^2y_x}{dz^2} = -\frac{w_x z^2}{2} + \sum_{j=1}^{n} T_j L_{x,j} \qquad (3.34a)$$

$$EI\frac{d^2y_y}{dz^2} = \frac{w_y z^2}{2} - \sum_{j=1}^{n} T_j L_{y,j} \qquad (3.34b)$$

Substituting the values of T_j's from Eqn.3.28

$$EI\frac{d^2y_x}{dz^2} = -\frac{w_x z^2}{2} + \sum_{j=1}^{n}\{\sum_{i=1,3,5}^{\alpha} a_{ij}\sin(\frac{i\pi z}{2H})\}L_{x,j} \qquad (3.35a)$$

$$EI\frac{d^2y_y}{dz^2} = \frac{w_y z^2}{2} - \sum_{j=1}^{n}\{\sum_{i=1,3,5}^{\alpha} a_{ij}\sin(\frac{i\pi z}{2H})\}L_{y,j} \qquad (3.35b)$$

Integrating twice and substituting the appropriate boundary conditions i.e.

$$\text{at } z=H , \quad y_x = y_y = \frac{dy_x}{dz} = \frac{dy_y}{dz} = 0 \qquad (3.36)$$

We get

$$EI\, y_x = -\frac{w_x}{2}\left(\frac{z^4}{12} - \frac{H^3 z}{3} + \frac{H^4}{4}\right) + \frac{4H^2}{\pi^2}\sum_{j=1}^{n}$$

$$\left[\sum_{i=1,3,5}^{\alpha} \frac{a_{ij}}{i^2}\{\operatorname{Sin}\frac{i\pi}{2} - \operatorname{Sin}\frac{i\pi z}{2H}\}\right] L_{x,j} \qquad (3.37a)$$

$$EI\, y_y = \frac{w_y}{2}\left(\frac{z^4}{12} - \frac{H^3 z}{3} + \frac{H^4}{4}\right) - \frac{4H^2}{\pi^2}\sum_{j=1}^{n}$$

$$\left[\sum_{i=1,3,5}^{\alpha} \frac{a_{ij}}{i^2}\{\operatorname{Sin}\frac{i\pi}{2} - \operatorname{Sin}\frac{i\pi z}{2H}\}\right] L_{y,j} \qquad (3.37b)$$

<u>For point load at top</u>

The derivation follows exactly the same pattern as for the uniformly distributed load, the only difference is in the values of loading terms in Eqn (3.27) expressed by $z^2\underline{B}$, wchich is now replaced by $z\underline{B}$

$$\text{where } \underline{B} = \begin{bmatrix} \beta 1 \\ \beta 2 \\ . \\ . \\ . \\ \beta n \end{bmatrix}$$

$$\text{and } \beta_i = \frac{12 I_{c,i}}{b_i{}^3 h_i} \left\{ \frac{P_y L_{y,i}}{\left(\sum_{k=1}^{m} I_{x,k}\right)^2} \sum_{k=1}^{m} I_{x,k} + \frac{P_x L_{x,i}}{\left(\sum_{k=1}^{m} I_{y,k}\right)^2} \sum_{k=1}^{m} I_{y,k} \right\} \qquad (3.38)$$

where P_x and P_y are the concentrated loads applied horizontally at top.

In Eqn. (3.31) the $\underline{k}$ matrix becomes

$$\underline{k} = \frac{8H}{i^2\pi^2} \text{ Sin } \left(\frac{i\pi}{2}\right) \begin{bmatrix} \beta 1 \\ \beta 2 \\ . \\ . \\ \beta n \end{bmatrix} \qquad (3.39)$$

The equations for moments (Eqn. 3.32) are modified to

$$M_{x,i} = \frac{-P_y z + \sum_{j=1}^{n} T_j L_{y,j}}{\sum_{k=1}^{m} (I_{x,k})} I_{x,i} \qquad (3.40a)$$

$$M_{y,i} = \frac{P_x z - \sum_{j=1}^{n} T_j L_{x,j}}{\sum_{k=1}^{m} (I_{y,k})} I_{y,i} \qquad (3.40b)$$

and the equations for deflections (Eqn. 3.39) become

$$EIy_x = -P_x\left(\frac{z^3}{6} - \frac{H^2 z}{2} + \frac{H^3}{3}\right) \tag{3.41a}$$

$$+\frac{4H^2}{\pi^2}\sum_{j=1}^{n}\sum_{i=1,3,5}^{\alpha}\frac{a_{ij}}{i^2}\left\{\mathrm{Sin}\left(\frac{i\pi}{2}\right) - \mathrm{Sin}\left(\frac{i\pi z}{2H}\right)\right\}L_{x,j}$$

$$EIy_y = P_y\left(\frac{z^3}{6} - \frac{H^2 z}{2} + \frac{H^3}{3}\right)$$

$$-\frac{4H^2}{\pi^2}\sum_{j=1}^{n}\sum_{i=1,3,5}^{\alpha}\frac{a_{ij}}{i^2}\left\{\mathrm{Sin}\left(\frac{i\pi}{2}\right) - \mathrm{Sin}\left(\frac{i\pi z}{2H}\right)\right\}L_{y,j} \quad \ldots.(3.41b)$$

3.4 MODIFICATION FOR NON-RECTANGULAR PLAN SHAPE

In buildings with rectangular plan shape the walls are always parallel to either of the global axes. Hence the moments of inertia of the walls about the global axes are the same as those about their local principal axes. But in buildings with non-rectangular plan shape the wall principal axes are, in general, not parallel to the global axes. Since evaluation of the, $\alpha_{i,j}^2$ and β_i requires wall moments of inertia about the global axes, the moments of inertia of the walls about their local axes must be transferred to the global axes.

In Fig. 3.4 x-y are the global axes and u-v are the local axes of a wall making an angle θ with the global x axis. The moments of inertia of the wall about the x and y axes i.e. I_x and I_y are given by

$$I_x = I_u \,\mathrm{Cos}^2\theta + I_v \,\mathrm{Sin}^2\theta$$

$$I_y = I_u \,\mathrm{Sin}^2\theta + I_v \,\mathrm{Cos}^2\theta$$

where I_u and I_v are the moment of inertia of the wall about its local axes.

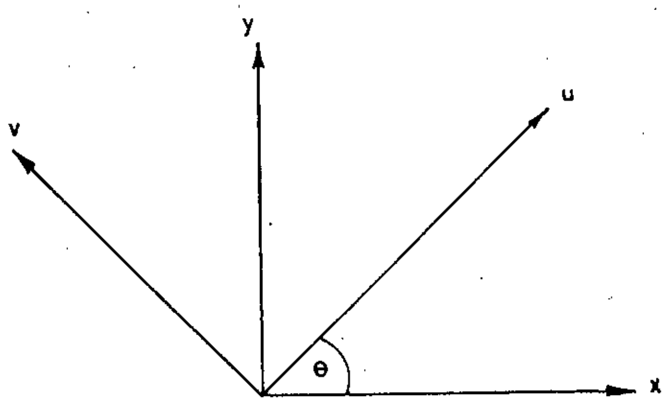


Fig. 3.4 Axis Transformation

3.5 COMPUTER PROGRAM

A computer program, based on the theory presented in Section 3.3 has been written in FORTRAN. The program is completely general in nature and can be used for analyzing tubular structures having any plan shape and any number of interconnected cells. It can also be used for analyzing plane frames and shear walls.

The program can be run in any microcomputer having a FORTRAN compiler. Since the matrices used in the program are small they do not present any storage problem.

A block flow diagram of the program is given in Fig. 3.5. A listing of the computer program with detailed instructions inside the program and sample input data files are given in Appendix-A.

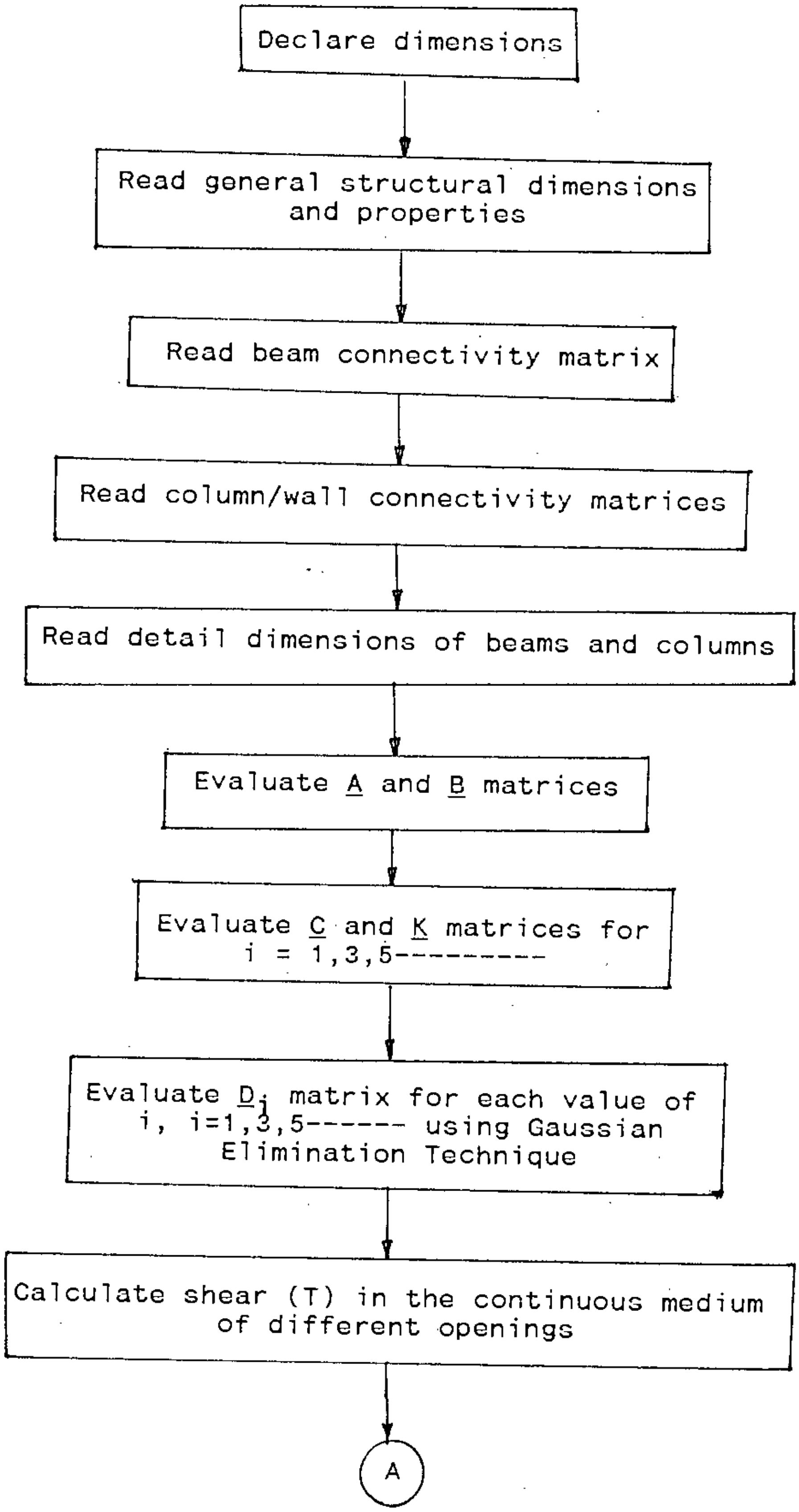


Fig. 3.5: Block flow diagram for the computer program described in section 3.5

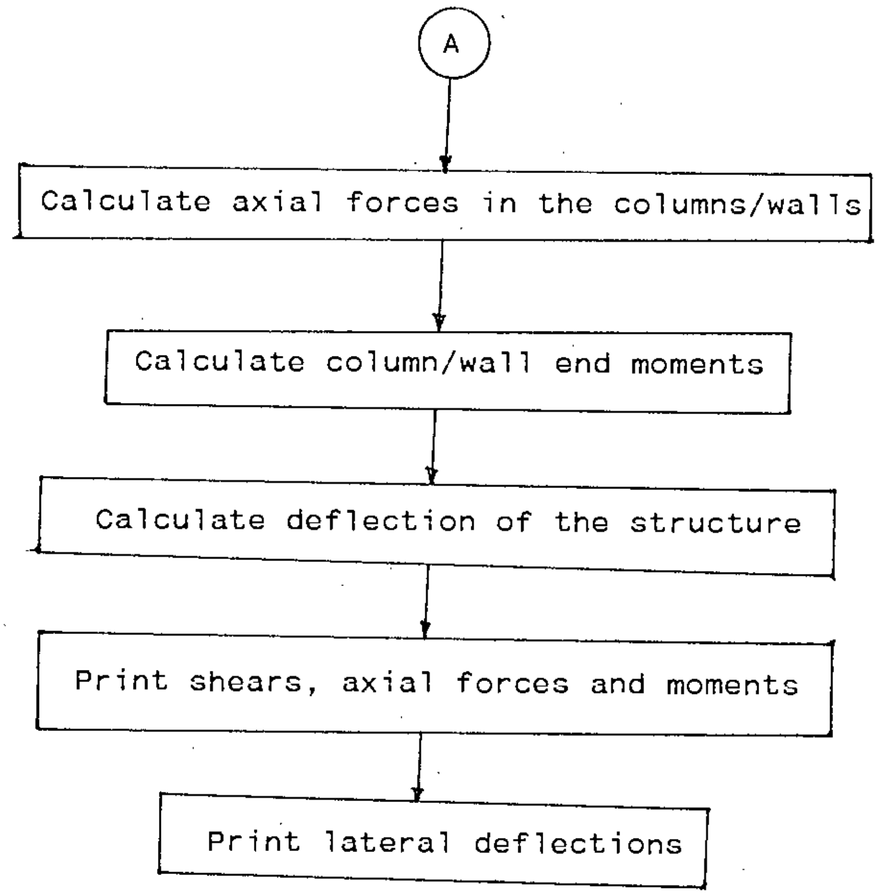


Fig. 3.5: (continued)

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In order to demonstrate the applicability of the continuous medium method to multicellular tubular structures of arbitrary plan shape, two example problems of 20-storied building are analyzed. The computer program described in Chapter 3 has been used to calculate column axial forces, column shear forces, column end moments and lateral deflections of the example problems and the results of column axial forces and lateral deflections have been compared with those obtained from the more 'exact' space frame analysis technique.

Fig. 4.1 and 4.6 show the details of the two 20-story concrete modular tube which were analyzed. The tube considered in example problem 1, consists of 33 columns and 36 beams per story. It is 200 ft. high, each story being 10 ft. high. The column are spaced at 8.33 ft. c/c and each side of the tube has a length of 50 ft. The other tube considered is example problem 2, consists of 30 columns and 32 beams per story. It is also 200 ft. high, each story being 10 ft. high. the columns have variable spacings as shown in Fig. 4.6. In both the example problem the column spacing has been kept small in order to keep the base width to height ratio within a realistic range for high rise tubular structures. If a longer beam is used the height of the building should also be increased but that would make the space frame analysis much more time consuming because the number of unknowns increase as the number of stories increases.

The material properties used are:

Poisson's ratio = 0.18

Modulus of elasticity = 432000 ksf

Following Khan's (14) approach of reduction modeling two 10 story equivalent stiffness factor (S'_{f10}) has been considered for two example problem. The 10 story equivalent stiffness factor S'_{f10} is given by

$$S'_{f10} = S_f \times (N/10)^2$$

where S_f is the actual stiffness factor for the tube and is given by

$$S_f = S_b/S_c$$

in which S_b = shear stiffness of spandrel beam
$= 12\ EI_b/L^3$

and S_c = Axial stiffness of the column
$= A_cE/H$

where,
I_b = moment of inertia of the spandrel beams
A_c = Cross-sectional area of the column
H = height of column
L = effective span of the spandrel beam
E = modulus of elasticity
N = number of stories

The properties of the different components of example problem 1 and 2 are kept same and given in Table 4.1. the tubes have been analyzed for two load conditions

a) 100 kips point load applied at the top and
b) 1 kip/ft. uniformly distributed load.

Table 4.1 : Properties of the Tubes shown in Fig.4.1 and Fig.4.6

Beam width (ft.)	1.5
Beam depth (ft.)	3.6550
Beam moment of inertia (ft^4.)	6.1034
Column size (ft.*ft.)	2.25*2.25
Column area ($ft.^2$)	5.0625
Column moment of inertia($ft.^4$)	2.13574
Story height (ft.)	10.00
Number of stories	20

Considering above properties and beam lengths

S'_{f10} = 1.00 ; for example problem 1.It is a constant value for all beams, since all beams are of equal length.

S'_{f10} = 1.56 ; for example problem 2. It is a average value of all the S'_{f10}s considering all beams, since the beams are of variable lengths.

4.2 RESULTS OBTAINED BY CONTINUOUS MEDIUM METHOD

As already stated the program developed on the basis of the theory presented in Chapter 3 of this thesis has been used to analyze the structures shown in Fig. 4.1 and 4.6 under two loading conditions and a 10-story equivalent stiffness factor 1.0 for fig.4.1 and 1.56(average) considering all beams of different lengths for fig.4.6. In example problem 2 loads were applied in both long and short directions of the building and both results were presented. The column axial forces at various levels are shown in figures 4.2, 4.4,4.7,4.9,4.11 and 4.13. The deflected shapes of the tubes under different load conditions are shown in figures 4.3, 4.5,4.8,4.10,4.12 and 4.14.

4.3 RESULTS OBTAINED FROM SPACE FRAME ANALYSIS

The space frame analysis program package STAAD-III/ISDS(Appendix-B) was used to analyze all the tubes analyzed by the continuous medium method. Rigid zone depths were considered for both beam and column elements. The results of this analysis are shown in the same diagrams on which the results of the continuous Medium Method are plotted.

4.4 RESULTS OBTAINED BY APPLYING THE CANTILEVER METHOD

The cantilever method(27) was applied to find the column axial forces of the tubes at mid depth and bottom. The results along with those found from continuous Medium Method and Space frame Analysis were presented in Tabular forms in Table 4.2 to 4.7.

4.5 COMPARISON BETWEEN THE RESULTS OF THE THREE METHODS UNDER CONSIDERATION

The column axial forces obtained from the continuous Medium analysis are compared with those obtained from space frame analysis in Fig. Nos. 4.2,4.4,4.7,4.9,4.11 and 4.13. In these diagrams the variation of column axial forces as given by the continuous medium method is shown by solid lines while that given by the space frame method is shown by broken lines. Deflected shapes of both methods mentioned above are presented in Figs. 4.3,4.5,4.8,4.10,4.12 and 4.14.

<u>Structure of Example Problem 1:</u>

(a) <u>Stresses</u>

When the structure is subjected to point load (100k) at top, shear lag effect in the continuous medium method is not very prominent at low z/H ratio of the building but quite comparable to that of space frame method at high z/H ratio. At low z/H ratio the axial force distribution in the flange frame is almost uniform in the continuous medium method but in the space frame method axial force is maximum in the middle of the flange frame and gradually decreases at the corners, at Z/H = 0.25 the middle axial force is approximately twice that that of at the corner.

When the structure is subjected to uniformly distributed load (1k/ft.) , both the method show same axial force distribution pattern. But at the lower and upper levels (Z/H = 1.0 and Z/H = 0.25) the difference in axial forces in the two methods at the middle and corner of the flange frame is great. At very high z/H ratio shear lag effect is prominent in both methods but at other ratios this effect is not seen. At Z/H = 0.25 the axial force at the middle of the flange frame in the continuous medium method is about 3 times to that of space frame method and at Z/H = 1.0 this difference is about 0.83 times. At corner columns above difference is 1.55 at Z/H = 0.25 and 1.05 at Z/H = 1.0. So except at very high z/H ratios continuous medium method always overestimates the axial force in case of uniformly distributed load.

It is interesting to see that the cantilever method gives result for column axial forces that is almost comparable to that found from continuous Medium Method. Specially at low z/H ratios both methods give approximately the same result for uniformly distributed load. Results of the cantilever method are given in Table 4.2 and 4.3 along with the results of other two methods.

(b) Deflections

The lateral deflections of the structure are shown in Figs. 4.3 and 4.5. These figures show that both the methods give the same kind of deflected shape. the magnitudes of deflections are also comparable. At top the deflection value of continuous medium method is about 88% of the space frame method value for uniformly distributed load as well as point load at top. Using engineer's theory of bending, the deflections of the structure for uniformly distributed and point load at top are found to be 0.008434 ft. and 0.01125 ft. respectively. They are about 72% and 69% of the exact values.

(c) Computer Time and Storage Requirements

For the example problem 1, the continuous medium method requires approximately 270 kilobytes of disk space, while STAAD-III/ISDS, the space frame program requires 16 megabytes of disk space. With regard to time, with a FORTRAN compiler (WATFOR77), the continuous medium method requires approximately 1 minute 7 seconds on an IBM compatible machine with 80486 processor operating at 33 MHz, whereas STAAD-III/ISDS requires 23 minutes 15 seconds in the same computer.

Structure of Example Problem 2:

In order to demonstrate the applicability of the continuous medium method to multicellular structures of arbitrary plan shape, example problem 2 whose plan shape is shown in Fig. 4.6, has been analyzed by the continuous medium method and the results have been checked against those obtained from space frame analysis method.

(a) Stresses

The column axial forces at various levels as obtained from the two analyses are compared in Figs. 4.7,4.9,4.11 and 4.13. Figs. 4.7 and 4.9 show the results when a uniformly distributed load (1k/ft.) or a point load (100k) at top acts along the long direction of the building and Fig. 4.11 and 4.13 show the results when they act in the short direction. At high z/H ratios both methods gives very close results, but at low z/H ratios differences in results are prominent.

For both point load at top and uniformly distributed load and for their application at any direction, the shear lag effect is very weak at low z/H ratios and is quite pronounced at high z/H ratios, especially at Z/H = 1.00.

The cantilever method can not give satisfactory results of column axial forces in case of structures of arbitrary plan shape, is clearly seen in Tables 4.4,4.5,4.6 and 4.7.

(b) Deflections

The deflection predicted by continuous medium method is very close to that of space frame method when the load acts in the long direction as well as in the short direction of the building. The ratio of the two deflection is 1.194 for uniformly distributed load (1k/ft.) but 1.191 for point load (100k) at top. When the load acts in the short direction this ratio is 1.24 for uniformly distributed load (1k/ft) and 1.164 for point load(100k) at top.

Considering engineer's theory of bending, when the load acts in the long direction of the building, the deflections of the top for uniformly distributed load and point load at top are are 0.00501 ft. and 0.00668 ft. respectively and they are approximately 49% and 54% of the exact values. And when the load acts in the short direction, above values are 0.0229 ft. and 0.0305 ft. respectively , which are approximately 87% and 84% of exact values.

(c) Computer Time and Storage Requirements

For the example problem 2, the continuous medium method requires approximately 270 kilobytes of disk space, while STAAD-III/ISDS, the space frame program requires 13.39 megabytes of disk space. With regard to time, with the same compiler as example problem 1, the continuous medium method requires approximately 57 seconds on an IBM compatible machine same as used in example problem 1, whereas STAAD-III/ISDS requires 14 minutes 53 seconds in the same computer.

EXAMPLE PROBLEM 1

Wx = 1 K/FT

$S'_{f10} = 1.0$

TABLE - 4.2

(column axial forces in kips)

COLUMN NO	Z/H=1.0			Z/H=0.5		
	CMM	SFA	CM	CMM	SFA	CM
1	52.68	49.98	46.11	10.94	9.81	11.53
2	28.81	22.66	30.74	7.67	7.96	7.69
3	13.35	10.41	15.37	3.96	4.30	3.84
4	0.0	0.0	0.0	0.0	0.0	0.0
5	-13.35	-10.44	-15.37	-3.96	-4.28	-3.84
6	-28.81	-22.68	-30.74	-7.67	-7.95	-7.69
7	-52.68	-49.97	-46.11	-10.94	-9.82	-11.53
8	-41.57	-38.86	-46.11	-11.76	-11.00	-11.53
9	-40.73	-42.05	-46.11	-11.91	-10.32	-11.53
10	-49.51	-59.69	-46.11	-11.41	-8.43	-11.53
11	-40.73	-42.08	-46.11	-11.91	-10.32	-11.53
12	-41.57	-38.86	-46.11	-11.76	-11.00	-11.53
13	-52.68	-49.99	-46.11	-10.94	-9.82	-11.53
14	-28.81	-22.69	-30.74	-7.67	-7.95	-7.69
15	-17.35	-10.44	-15.37	-3.96	-4.29	-3.84
16	0.0	0.0	0.0	0.0	0.0	0.0
17	13.35	10.42	15.37	3.96	4.30	3.84
18	28.81	22.67	30.74	7.67	7.96	7.69
19	52.68	50.0	46.11	10.94	9.82	11.53
20	41.57	38.86	46.11	11.76	11.00	11.53
21	40.73	42.08	46.11	11.91	10.32	11.53
22	49.51	59.73	46.11	11.41	8.42	11.53
23	40.73	42.05	46.11	11.91	10.31	11.53
24	41.57	38.86	46.11	11.76	10.99	11.53
25	0.0	0.0	0.0	0.0	0.0	0.0
26	-12.76	-10.52	-15.37	-4.09	-4.12	-3.84
27	-27.39	-21.87	-30.74	-7.95	-7.55	-7.69
28	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0
30	12.76	10.44	15.37	4.09	4.14	3.84
31	27.39	21.80	30.74	7.95	7.57	7.69
32	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0

NOTE:

CMM = Continuous Medium Method

SFA = Space Frame Analysis

CM = Cantilever Method

EXAMPLE PROBLEM 1
Px = 100 K
$S'_{f10} = 1.0$

TABLE - 4.3
(column axial forces in kips)

COLUMN NO	Z/H=1.0			Z/H=0.5		
	CMM	SFA	CM	CMM	SFA	CM
1	49.44	50.56	46.11	23.07	19.81	23.06
2	29.79	26.22	30.74	15.39	13.46	15.37
3	14.31	12.33	15.37	7.70	6.77	7.69
4	0.0	0.0	0.0	0.0	0.0	0.0
5	-14.31	-12.34	-15.37	-7.69	-6.76	-7.69
6	-29.79	-26.23	-30.74	-15.39	-13.45	-15.37
7	-49.44	-50.55	-46.11	-23.07	-19.81	-23.06
8	-43.72	-42.64	-46.11	-23.06	-21.49	-23.06
9	-43.21	-43.17	-46.11	-23.05	-23.37	-23.06
10	-47.60	-50.51	-46.11	-23.04	-24.73	-23.06
11	-43.21	-43.19	-46.11	-23.05	-23.38	-23.06
12	-43.72	-42.64	-46.11	-23.06	-21.50	-23.06
13	-49.44	-50.57	-46.11	-23.07	-19.82	-23.06
14	-29.79	-26.24	-30.74	-15.39	-13.45	-15.37
15	-14.31	-12.35	-15.37	-7.70	-6.76	-7.69
16	0.0	0.0	0.0	0.0	0.0	0.0
17	14.31	12.34	15.37	7.69	6.77	7.69
18	29.79	26.23	30.74	15.39	13.46	15.37
19	49.44	50.58	46.11	23.07	19.81	23.06
20	43.72	42.63	46.11	23.06	21.49	23.06
21	43.21	43.19	46.11	23.05	23.38	23.06
22	47.60	50.52	46.11	23.04	24.72	23.06
23	43.21	43.17	46.11	23.05	23.37	23.06
24	43.72	42.63	46.11	23.06	21.48	23.06
25	0.0	0.0	0.0	0.0	0.0	0.0
26	-13.93	-12.54	-15.37	-7.67	-7.85	-7.69
27	-28.89	-25.90	-30.74	-15.35	-15.91	-15.37
28	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0
30	13.93	12.52	15.37	7.67	7.86	7.69
31	28.90	25.88	30.74	15.35	15.91	15.37
32	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0

NOTE:
CMM = Continuous Medium Method
SFA = Space Frame Analysis
CM = Cantilever Method

EXAMPLE PROBLEM 2

Wx = 1 K/FT

S'_{f10} = 1.56

TABLE - 4.4

(column axial forces in kips)

COLUMN NO	Z/H=1.0			Z/H=0.5		
	CMM	SFA	CM	CMM	SFA	CM
1	48.76	45.65	40.1	6.37	6.08	10.02
2	22.51	23.76	35.53	5.03	3.91	8.88
3	4.27	5.43	26.4	3.54	3.73	6.6
4	-15.27	-11.60	17.28	2.15	1.26	4.32
5	-27.77	-23.44	12.71	3.04	2.18	3.18
6	6.70	7.27	12.71	3.30	2.57	3.18
7	-2.27	-4.81	12.71	7.50	6.93	3.18
8	17.89	21.87	17.28	9.84	8.37	4.32
9	31.56	30.36	26.4	12.17	11.29	6.6
10	51.15	47.90	35.53	23.27	12.82	8.88
11	66.08	64.64	40.09	12.25	11.00	10.02
12	45.37	42.05	40.09	10.19	9.82	10.02
13	43.80	42.63	12.71	6.50	5.14	3.18
14	19.06	14.51	3.59	4.94	4.78	0.90
15	3.57	4.50	-5.53	2.72	2.42	-1.38
16	1.24	4.43	-14.66	-3.49	-3.50	-3.67
17	-3.12	0.19	-14.66	-5.38	-5.14	-3.67
18	-2.68	-3.60	-14.66	-7.27	-6.36	-3.67
19	-27.0	-31.47	-14.66	-7.46	-5.62	-3.67
20	-20.80	-23.63	-5.53	-6.19	-5.04	-1.38
21	4.89	3.83	3.59	-4.95	-4.75	0.89
22	-3.54	-3.81	-20.74	-3.46	-3.10	-5.18
23	-6.64	-4.52	-26.83	-3.51	-3.45	-6.71
24	-9.20	-5.86	-32.90	-3.46	-3.74	-8.23
25	-40.60	-41.96	-42.04	-4.25	-2.83	-10.51
26	-34.81	-35.15	-42.04	-8.51	-7.62	-10.51
27	-43.67	-43.04	-42.04	-11.31	-10.43	-10.51
28	-70.01	-67.73	-42.04	-12.36	-11.07	-10.51
29	-38.31	-34.36	-32.90	-11.70	-11.11	-8.23
30	-21.15	-24.05	-23.79	-9.79	-8.55	-5.95

NOTE:

CMM = Continuous Medium Method

SFA = Space Frame Analysis

CM = Cantilever Method

EXAMPLE PROBLEM 2

Px = 100 K

S'_{f10} = 1.56

TABLE - 4.5

(column axial forces in kips)

COLUMN NO	Z/H=1.0			Z/H=0.5		
	CMM	SFA	CM	CMM	SFA	CM
1	42.14	42.32	40.1	16.98	14.75	20.05
2	22.73	23.49	35.53	11.19	8.71	17.77
3	6.40	6.76	26.4	4.79	5.32	13.2
4	-10.40	-9.29	17.28	-1.43	-0.81	8.64
5	-17.16	-16.16	12.71	-1.67	-0.42	6.36
6	6.90	6.74	12.71	4.19	5.12	6.36
7	7.47	5.60	12.71	9.64	10.16	6.36
8	23.03	24.71	17.28	15.17	15.73	8.64
9	36.21	35.35	26.4	21.19	20.97	13.2
10	52.99	50.91	35.53	27.37	25.87	17.77
11	61.33	61.43	40.09	27.76	25.68	20.05
12	45.64	44.15	40.09	22.48	20.20	20.05
13	37.77	36.28	12.71	15.49	16.05	6.36
14	19.70	17.13	3.59	10.12	10.07	1.80
15	6.37	7.62	-5.53	4.71	4.34	-2.77
16	-2.40	-0.38	-14.66	-3.74	-3.90	-7.33
17	-7.47	-5.24	-14.66	-6.83	-6.91	-7.33
18	-10.48	-10.18	-14.66	-10.00	-10.00	-7.33
19	-26.17	-27.74	-14.66	-13.21	-13.21	-7.33
20	-20.91	-21.82	-5.53	-10.91	-10.64	-2.77
21	-2.10	-3.34	3.59	-5.48	-4.91	1.80
22	-5.76	-5.63	-20.74	-4.54	-4.68	-10.37
23	-8.44	-7.11	-26.83	-5.48	-5.72	-13.41
24	-11.03	-8.79	-32.90	-6.50	-7.03	-16.45
25	-33.82	-35.07	-42.04	-12.73	-12.90	-21.02
26	-35.82	-36.33	-42.04	-18.18	-17.43	-21.02
27	-45.46	-45.27	-42.04	-23.46	-21.87	-21.02
28	-64.26	-64.12	-42.04	-28.57	-26.38	-21.02
29	-41.18	-39.00	-32.90	-22.30	-20.80	-16.45
30	-25.79	-27.03	-23.79	-16.05	-15.38	-11.90

NOTE:

CMM = Continuous Medium Method

SFA = Space Frame Analysis

CM = Cantilever Method

EXAMPLE PROBLEM 2

Wy = 1 K/FT

S'_{f10} = 1.56

TABLE - 4.6

(column axial forces in kips)

COLUMN NO	Z/H=1.0			Z/H=0.5		
	CMM	SFA	CM	CMM	SFA	CM
1	-35.45	-34.69	-68.49	-10.03	-9.50	-17.12
2	-76.86	-71.13	-89.34	-17.15	-16.45	-22.34
3	-72.52	-66.33	-89.34	-21.00	-19.36	-22.34
4	-93.26	-96.86	-89.34	-23.08	-19.97	-22.34
5	-62.38	-56.46	-68.49	-18.68	-17.30	-17.12
6	-10.41	-4.11	-26.79	-5.87	-5.71	-6.70
7	17.03	11.38	14.92	8.93	8.85	3.73
8	65.81	68.48	35.80	15.71	13.71	8.95
9	65.51	58.77	35.80	19.03	18.18	8.95
10	88.21	80.25	35.80	20.72	19.45	8.95
11	58.18	51.83	14.92	16.20	15.56	3.73
12	10.10	7.61	-26.79	3.21	3.10	-6.70
13	87.20	95.90	56.68	20.57	16.67	14.17
14	63.62	65.59	56.68	18.98	16.36	14.17
15	59.50	71.73	56.68	15.81	12.47	14.17
16	26.61	29.01	31.64	4.74	3.25	7.91
17	-7.77	-5.29	6.61	-2.79	-3.15	1.65
18	-40.55	-38.77	-18.42	-10.22	-9.02	-4.61
19	-85.43	-92.75	-43.46	-16.93	-13.09	-10.86
20	-88.96	-95.61	-68.49	-23.42	-19.54	-17.12
21	-75.01	-75.27	-68.49	-21.30	-18.98	-17.12
22	38.86	36.19	56.68	11.60	10.86	14.17
23	60.15	51.32	81.71	17.72	17.48	20.43
24	94.60	84.94	106.74	22.65	21.64	26.69
25	88.75	80.20	106.74	19.49	18.28	26.69
26	28.03	24.20	65.04	7.53	7.24	16.26
27	-21.97	-17.73	23.33	-5.13	-5.44	5.83
28	-82.70	-72.54	-18.42	-17.25	-16.32	-4.61
29	-55.19	-48.92	-18.42	-16.25	-16.00	-4.61
30	-43.68	-40.93	-18.42	-13.82	-13.25	-4.61

NOTE:

CMM = Continuous Medium Method

SFA = Space Frame Analysis

CM = Cantilever Method

EXAMPLE PROBLEM 1

Py=100 K

S'_{f10}=1.56

TABLE - 4.7

(column axial forces in kips)

COLUMN NO	Z/H=1.0			Z/H=0.5		
	CMM	SFA	CM	CMM	SFA	CM
1	-37.59	-38.43	-68.49	-19.89	-17.44	-34.25
2	-74.05	-74.25	-89.34	-35.54	-31.48	-44.67
3	-76.74	-73.49	-89.34	-40.78	-37.86	-44.67
4	-92.52	-93.07	-89.34	-46.11	-45.09	-44.67
5	-66.59	-62.10	-68.49	-35.78	-34.74	-34.25
6	-14.71	-11.35	-26.79	-9.89	-8.74	-13.40
7	24.18	21.69	14.92	15.93	16.72	7.46
8	64.36	65.22	35.80	31.62	31.63	17.9
9	69.36	65.71	35.80	36.90	33.80	17.9
10	86.35	84.23	35.80	42.26	35.80	17.9
11	60.91	58.39	14.92	31.93	26.41	7.46
12	10.96	8.93	-26.79	6.01	4.38	-13.40
13	85.46	90.05	56.68	41.88	44.70	28.34
14	67.93	69.96	56.68	36.49	39.90	28.34
15	60.73	65.87	56.68	31.16	34.66	28.34
16	23.68	24.78	31.64	10.30	11.25	15.82
17	-9.10	-7.72	6.61	-5.29	-4.36	3.31
18	-41.22	-40.34	-18.42	-20.85	-20.13	-9.21
19	-79.51	-83.34	-43.46	-36.45	-36.29	-21.73
20	-90.90	-94.02	-68.49	-46.57	-47.70	-34.25
21	-78.28	-77.63	-68.49	-41.20	-42.23	-34.25
22	41.52	39.46	56.68	22.32	21.16	28.34
23	64.16	58.37	81.71	34.36	30.81	40.86
24	93.84	89.22	106.74	46.43	40.61	53.37
25	85.81	82.24	106.74	41.11	35.50	53.37
26	29.12	26.53	65.04	15.11	12.90	32.52
27	-22.02	-19.65	23.33	-10.88	-9.95	11.67
28	-78.61	-74.65	-18.42	-36.88	-32.0	-9.21
29	-58.86	-55.10	-18.42	-31.52	-28.0	-9.21
30	-47.66	-45.53	-18.42	-26.18	-24.21	-9.21

NOTE:

CMM = Continuous Medium Method

SFA = Space Frame Analysis

CM = Cantilever Method

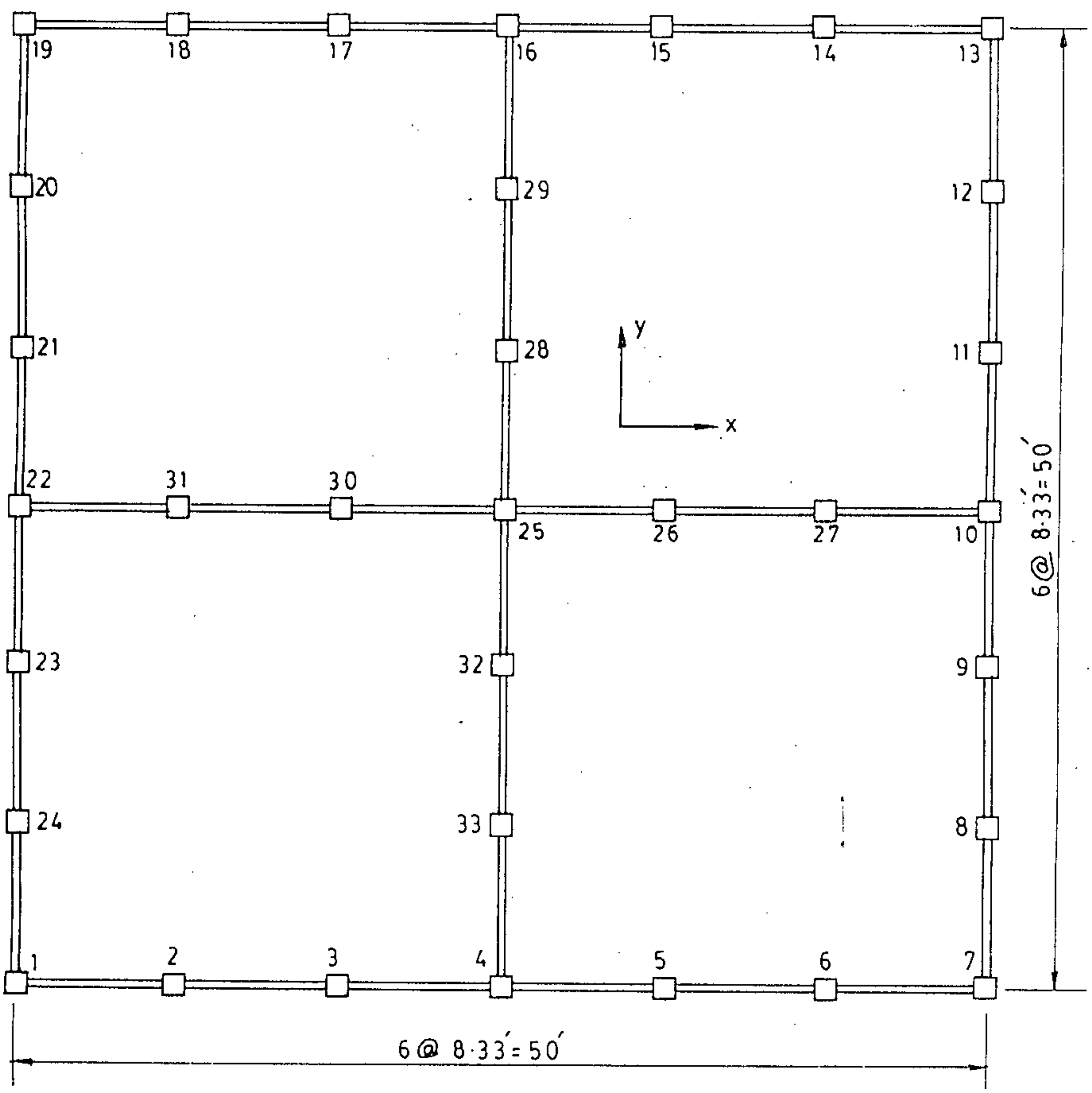


Fig. 4.1 Floor plan of the example problem 1

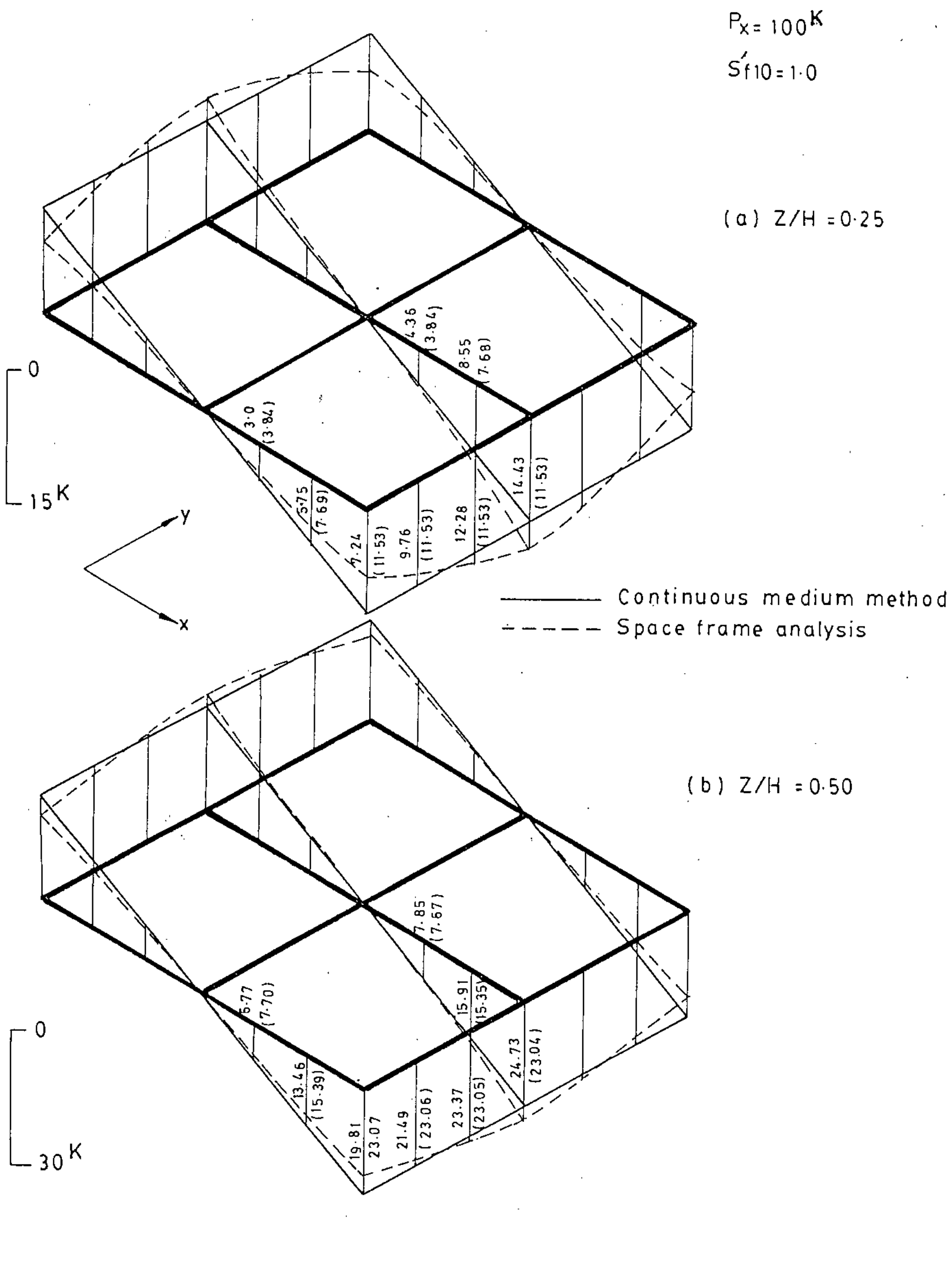


Fig. 4·2 a & b : Axial forces in the columns of the example problem 1.

(Values within parentheses are from continuous medium method)

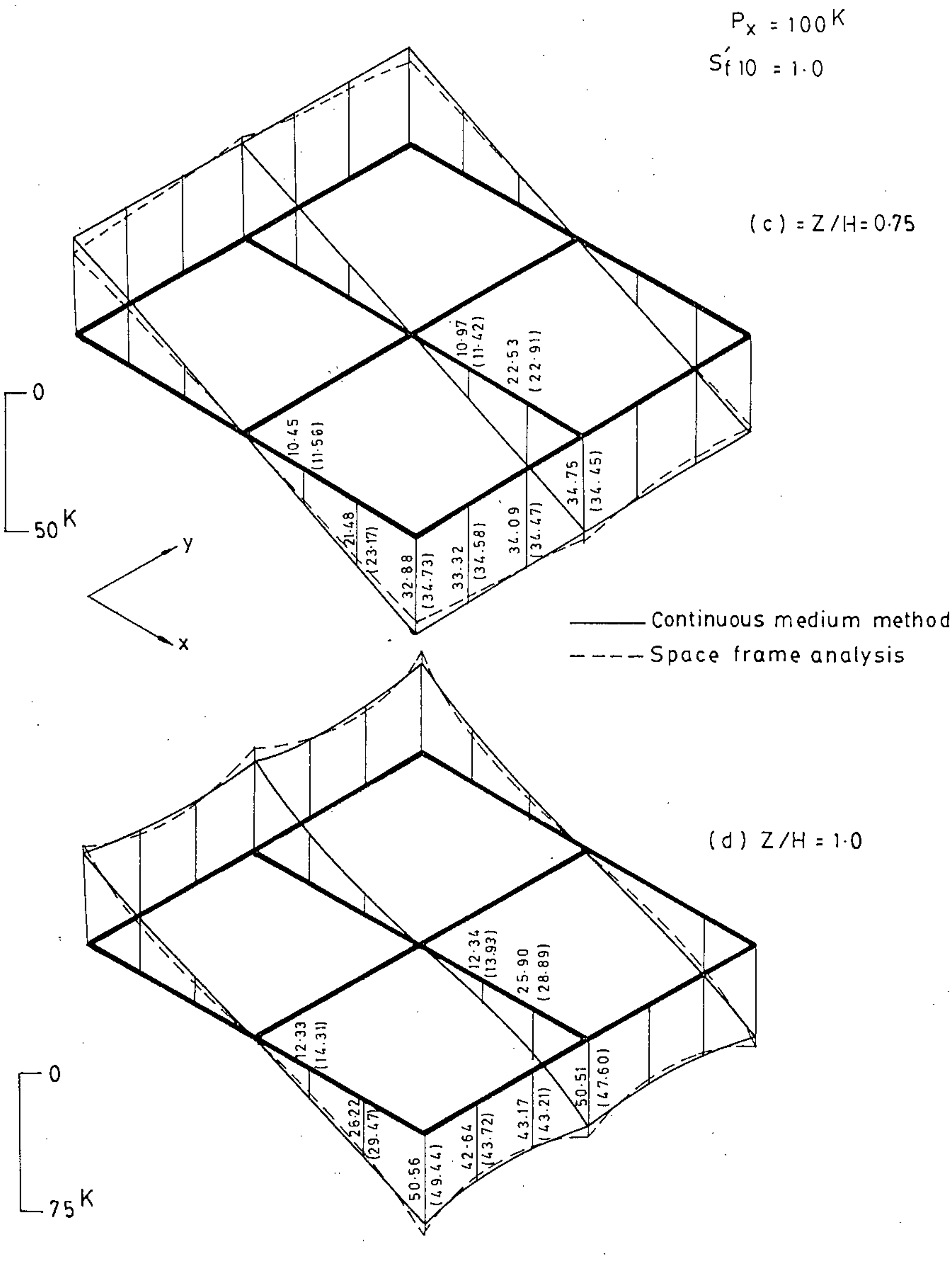


Fig. 4.2 c& d : Axial forces in the columns of the example problem 1.

(Values within parentheses are from continuous medium method)

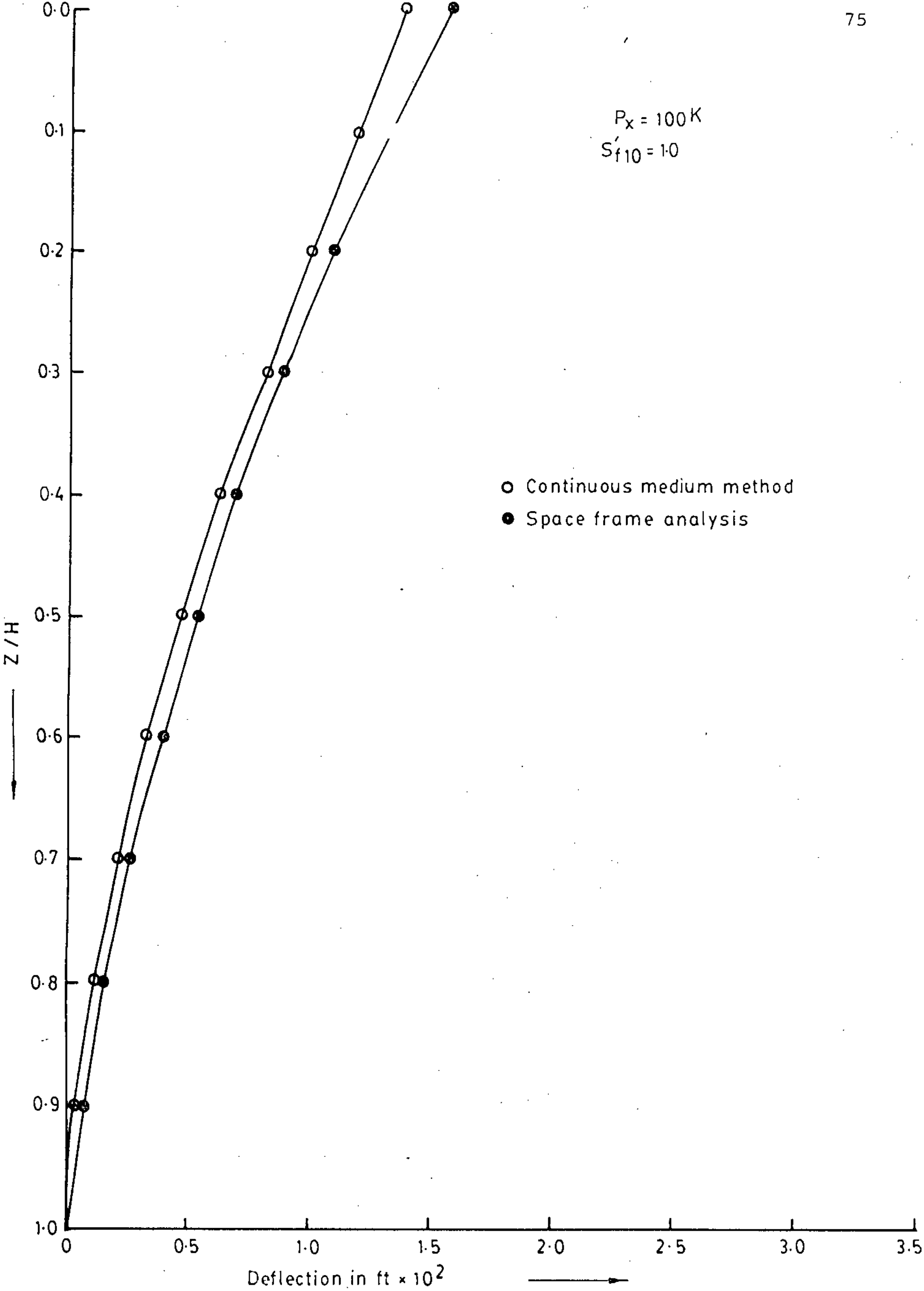
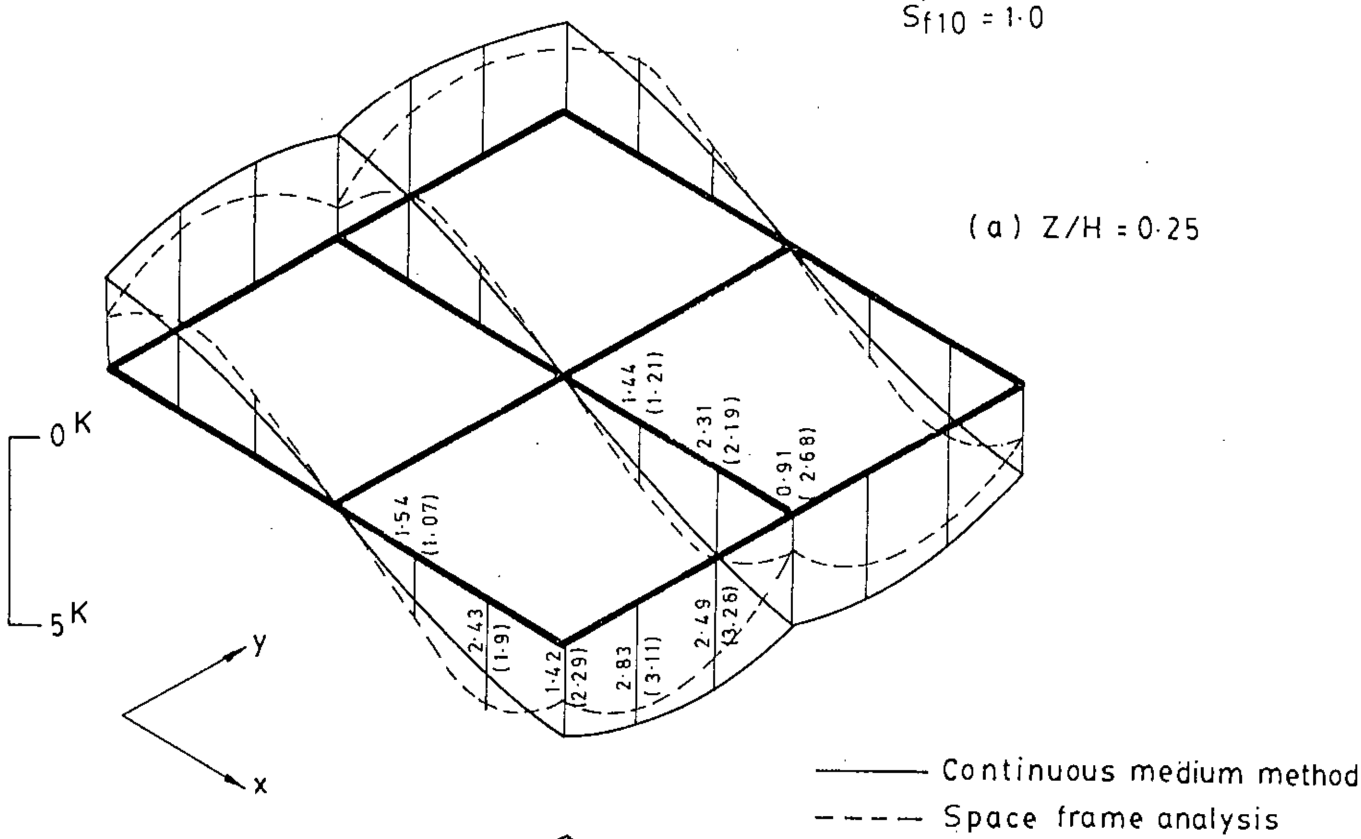


Fig. 4·3 : Lateral deflection of the example problem 1.

$W_x = 1^K/ft$

$S'_{f10} = 1.0$



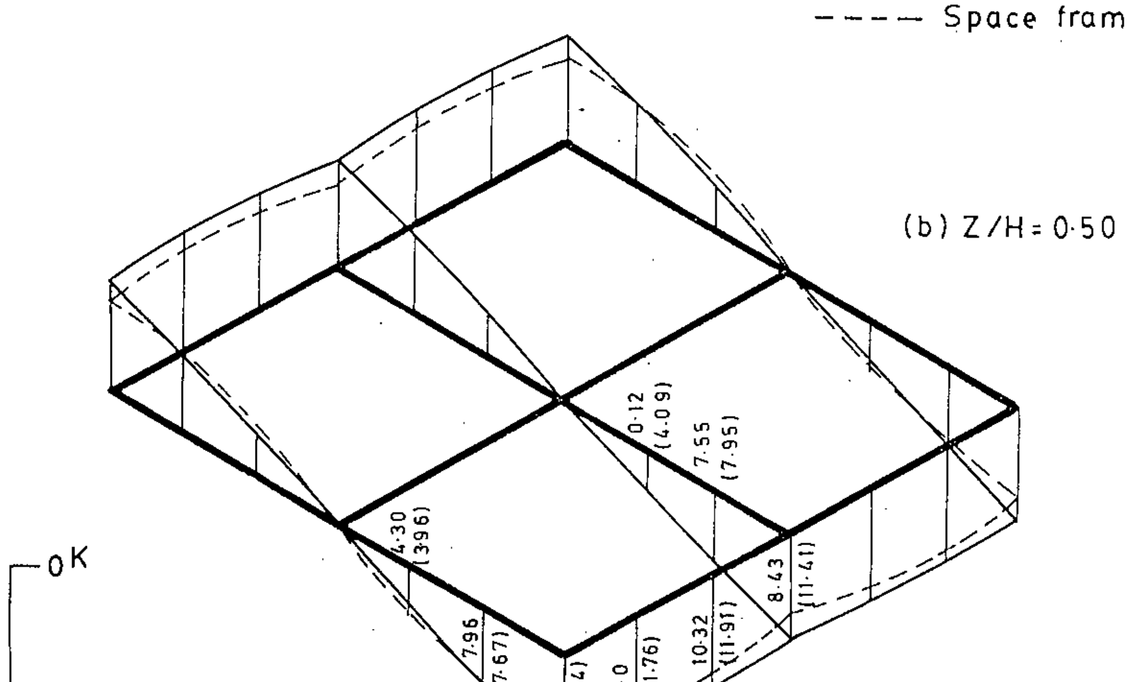


Fig. 4.4 a &b : Axial forces in the columns of the example problem 1.
(Values within parentheses are from continuous medium method)

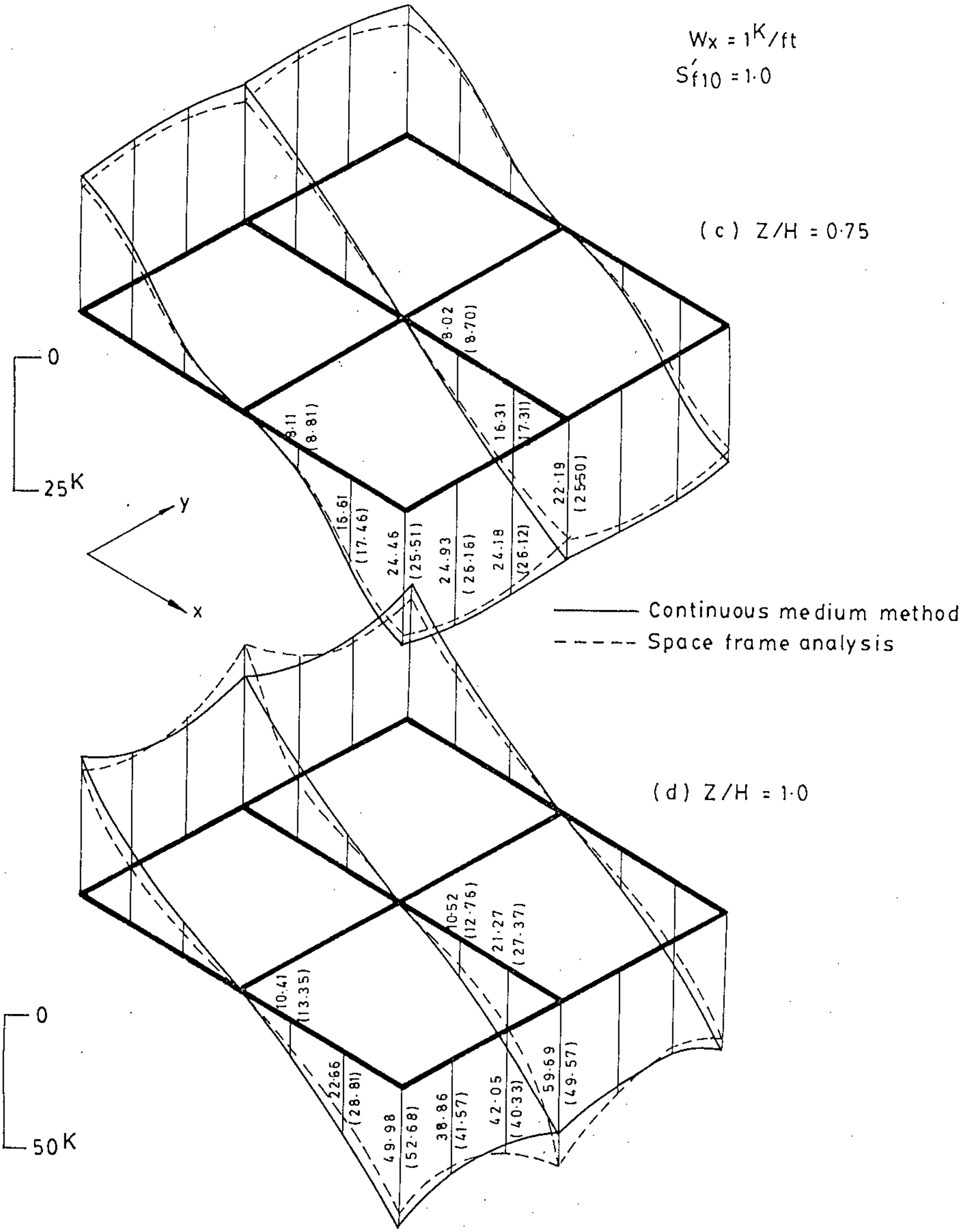


Fig. 4.4 c & d : Axial forces in the columns of the example problem 1. (Values within parentheses are from continuous medium method)

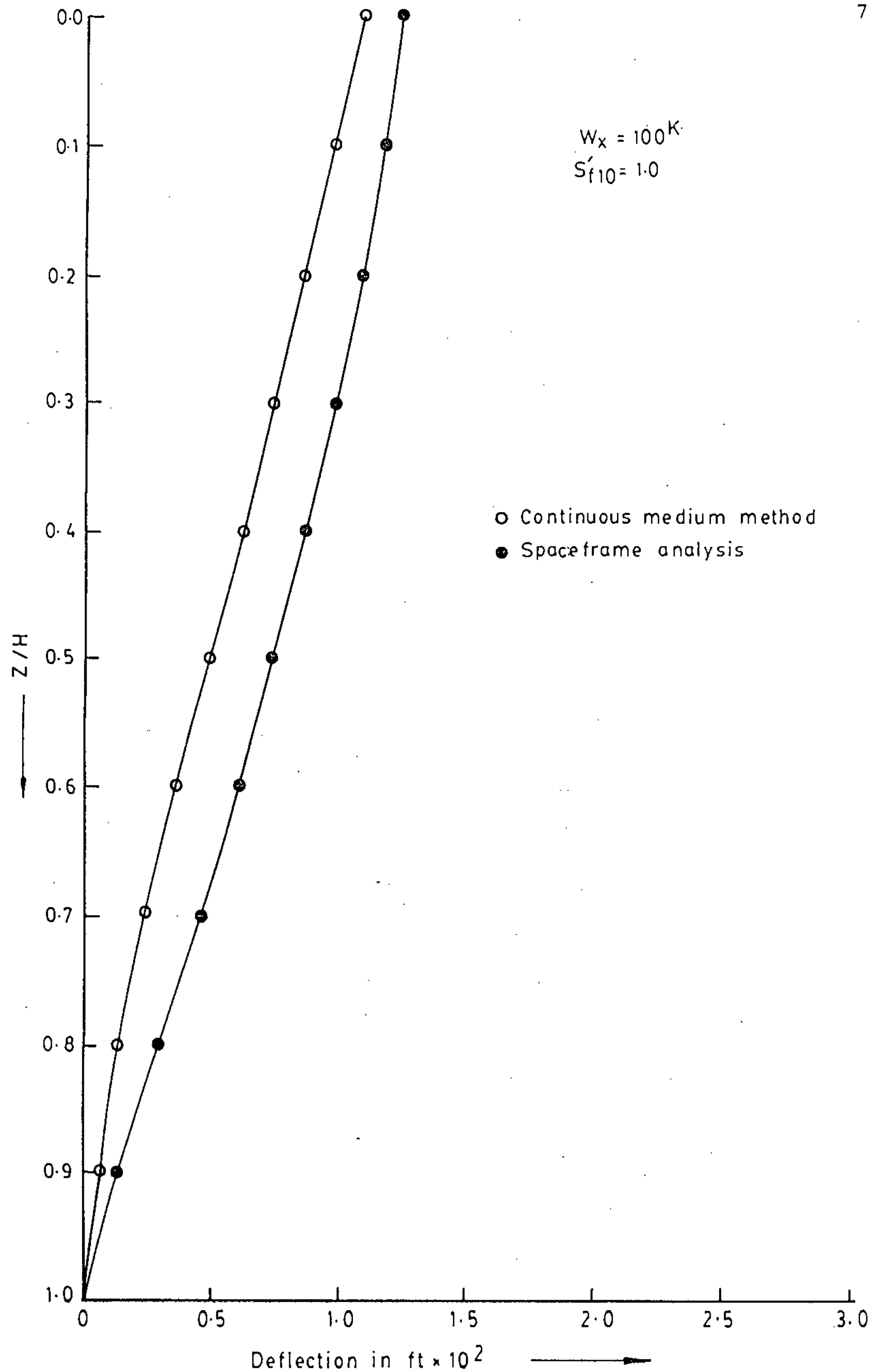


Fig. 4·5 : Lateral deflection for the example problem 1

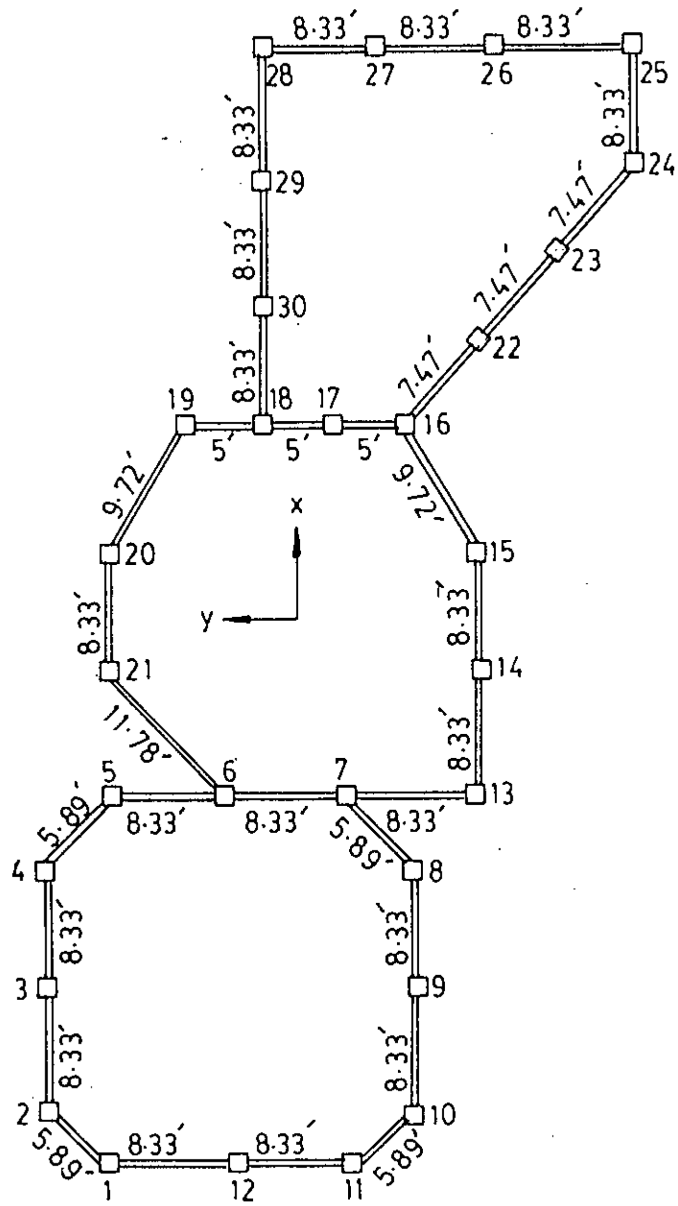


Fig. 4·6 : Floor plan of the example problem 2

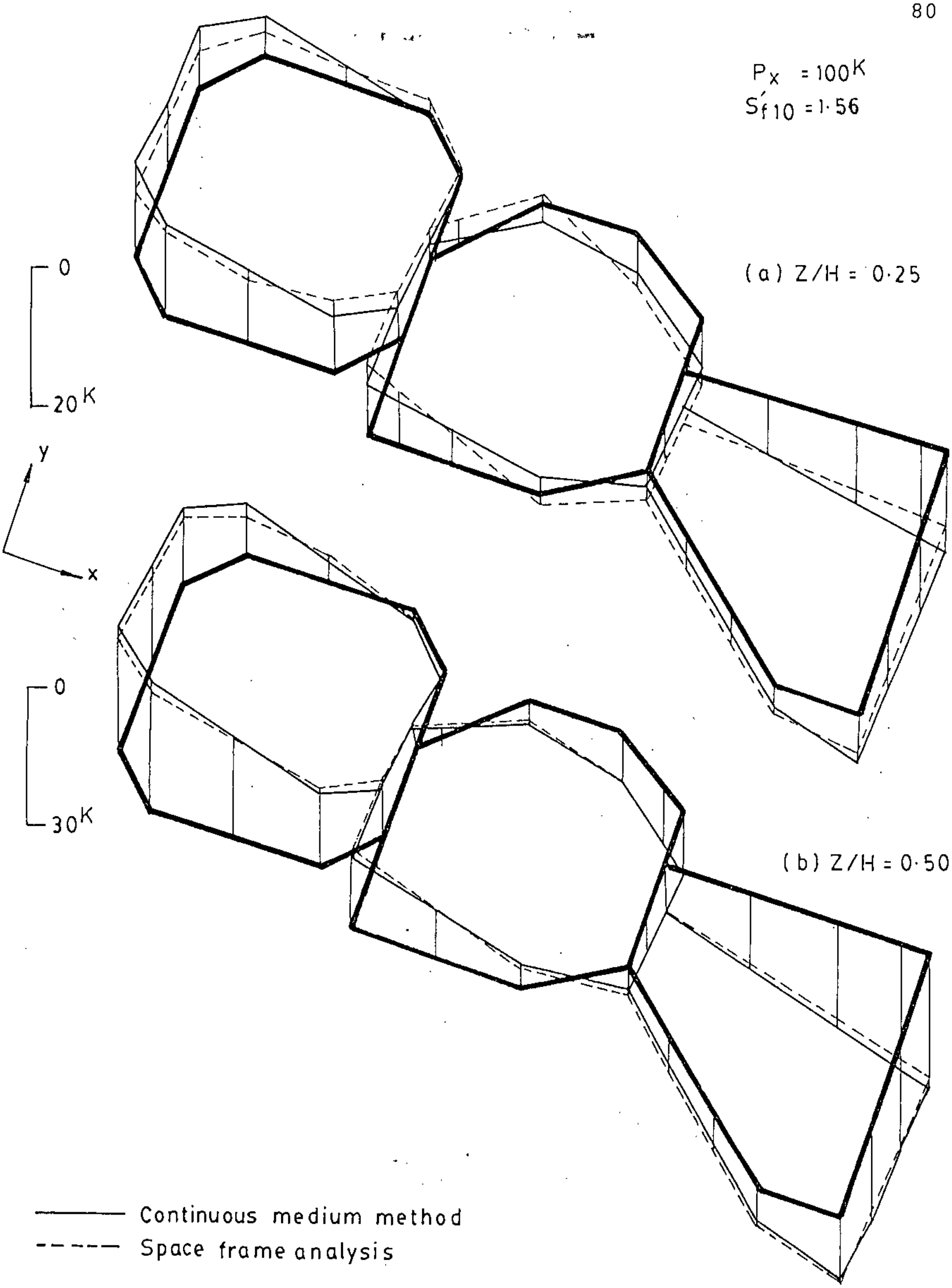


Fig. 4.7a & b : Axial forces in the columns of the example problem 2

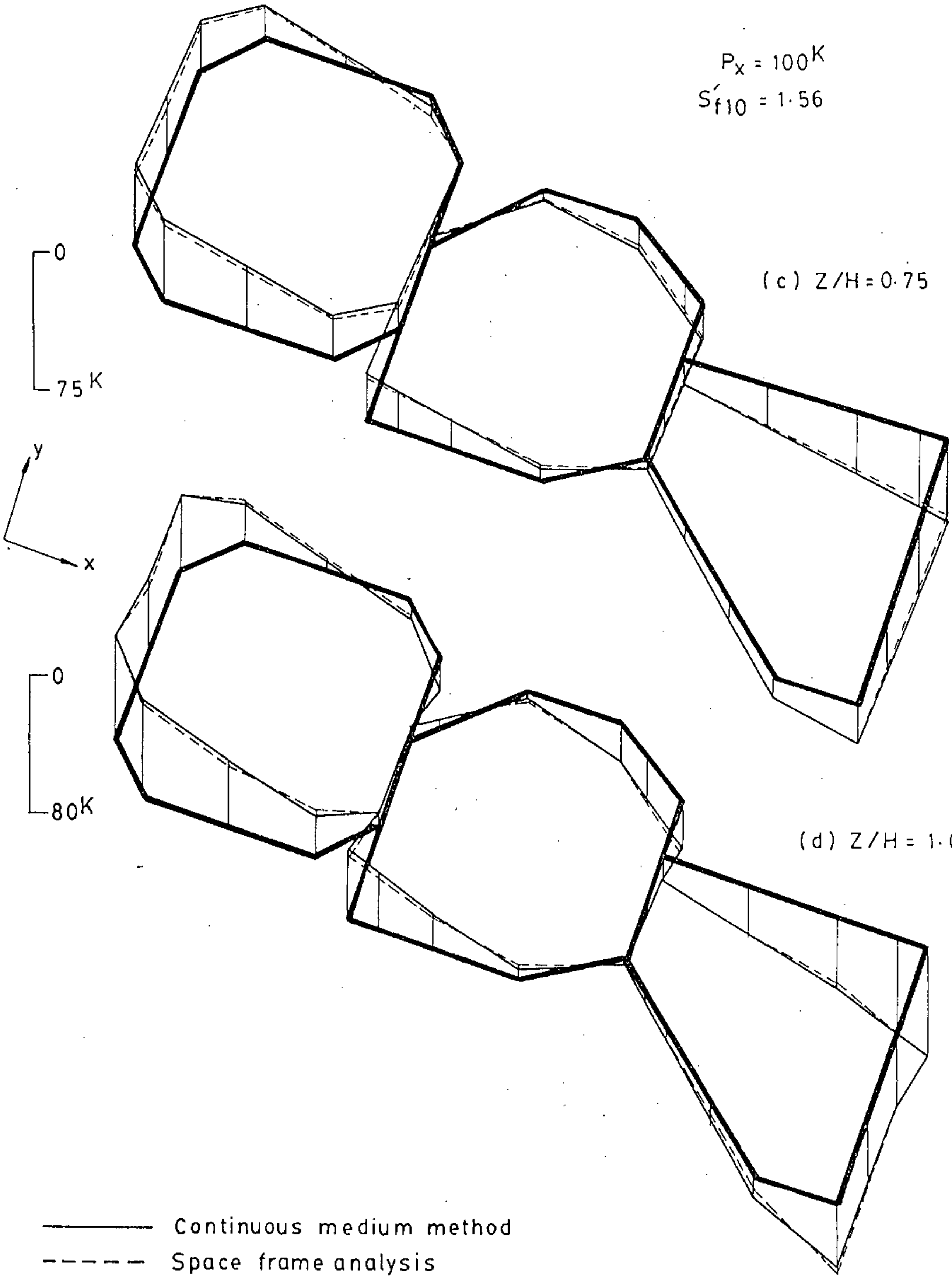


Fig. 4.7 c & d : Axial forces in the columns of the exmple problem 2

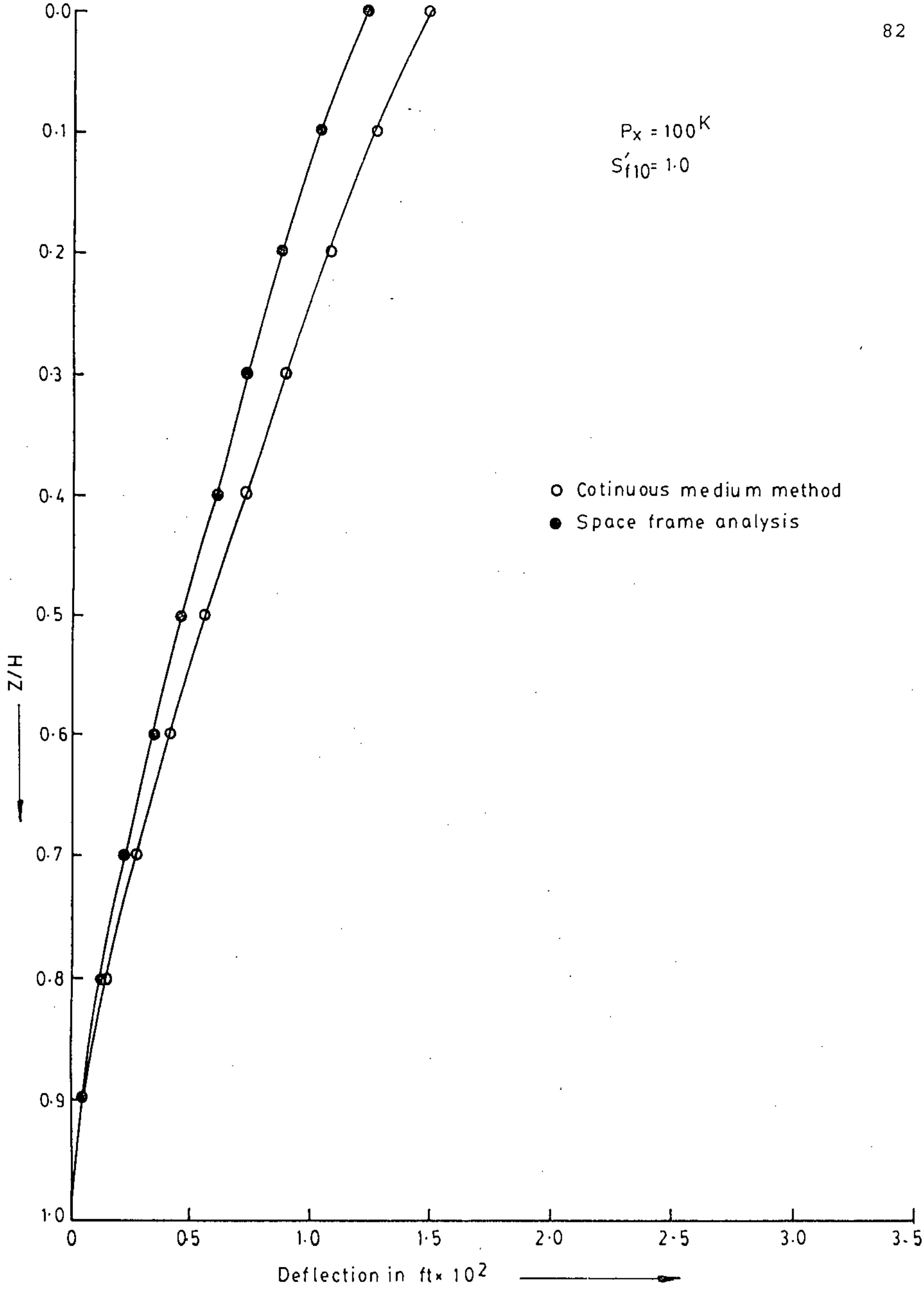


Fig. 4.8 Lateral deflection for the example problem 2

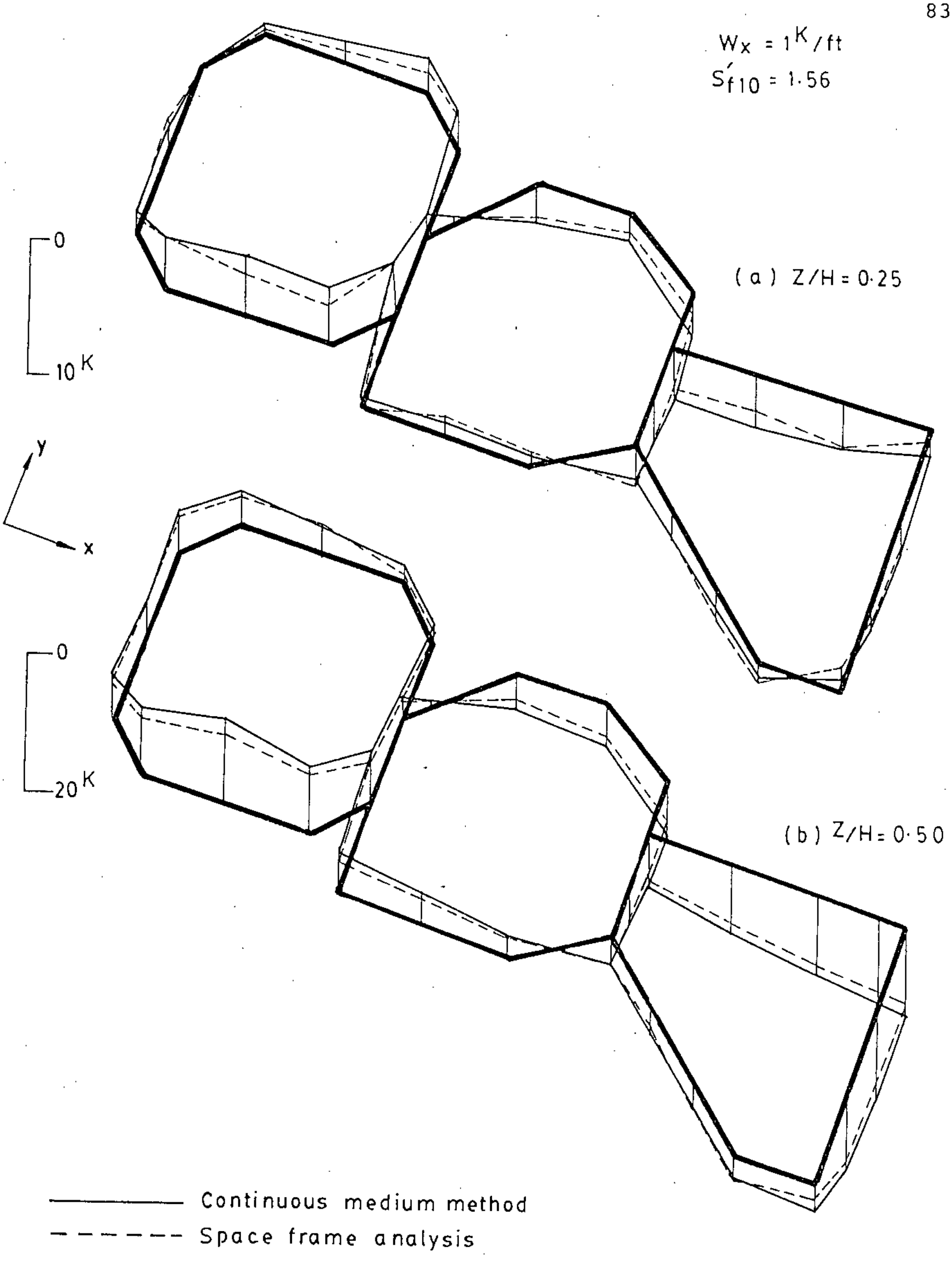


Fig. 4.9 a & b : Axial forces in the columns of the example problem 2

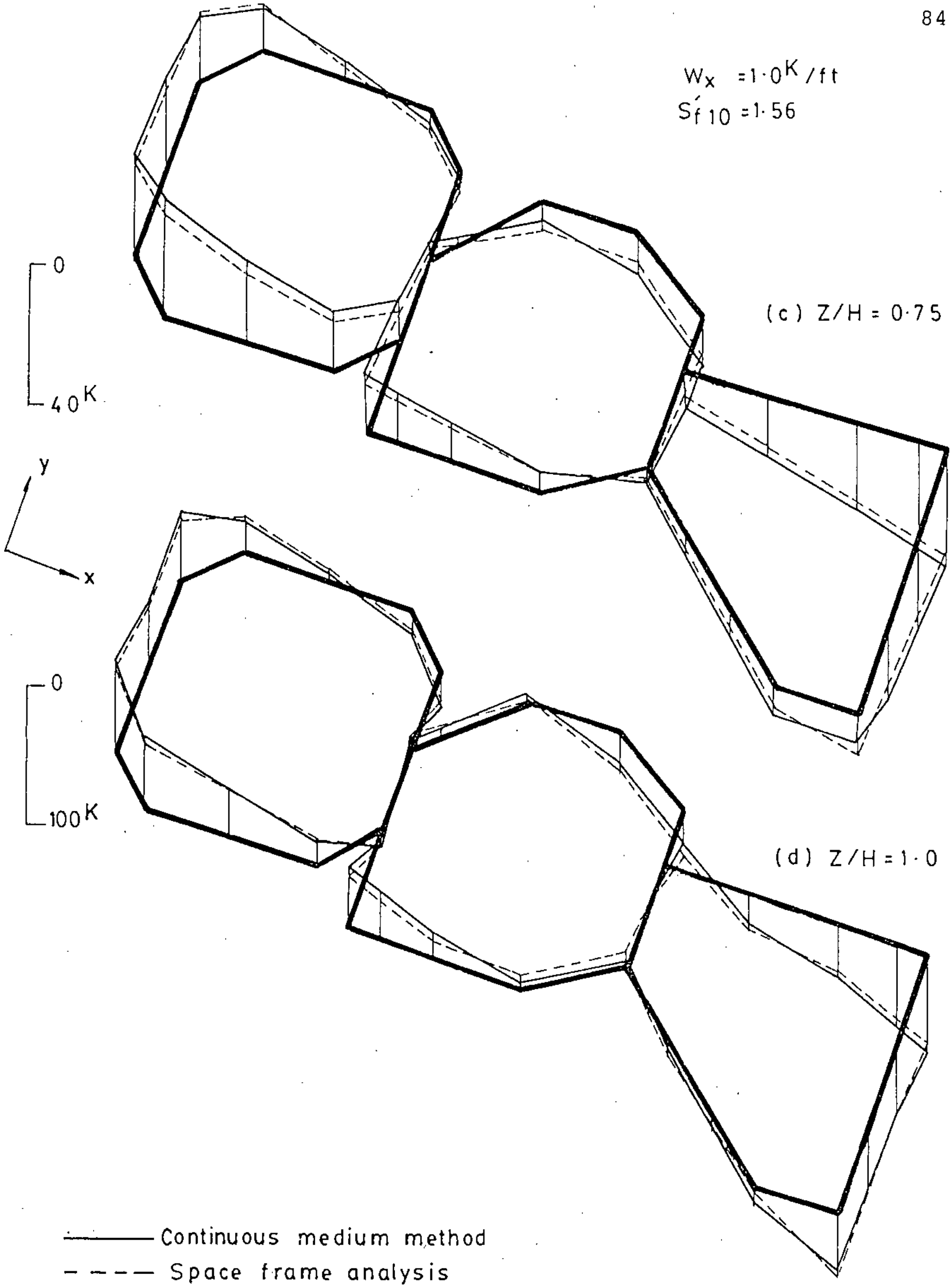


Fig. 4·9 c & d : Axial forces in the columns of the example problem 2

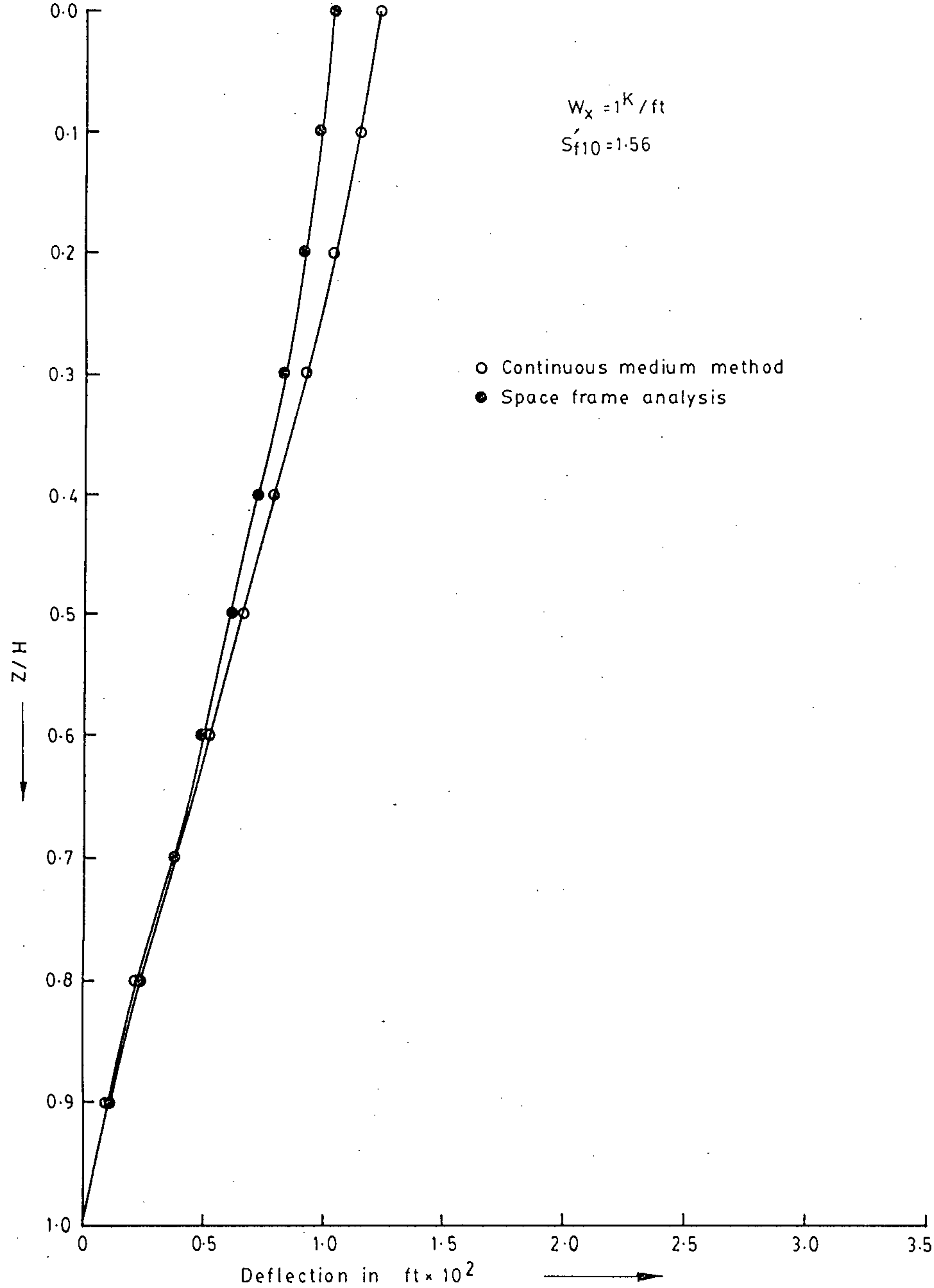
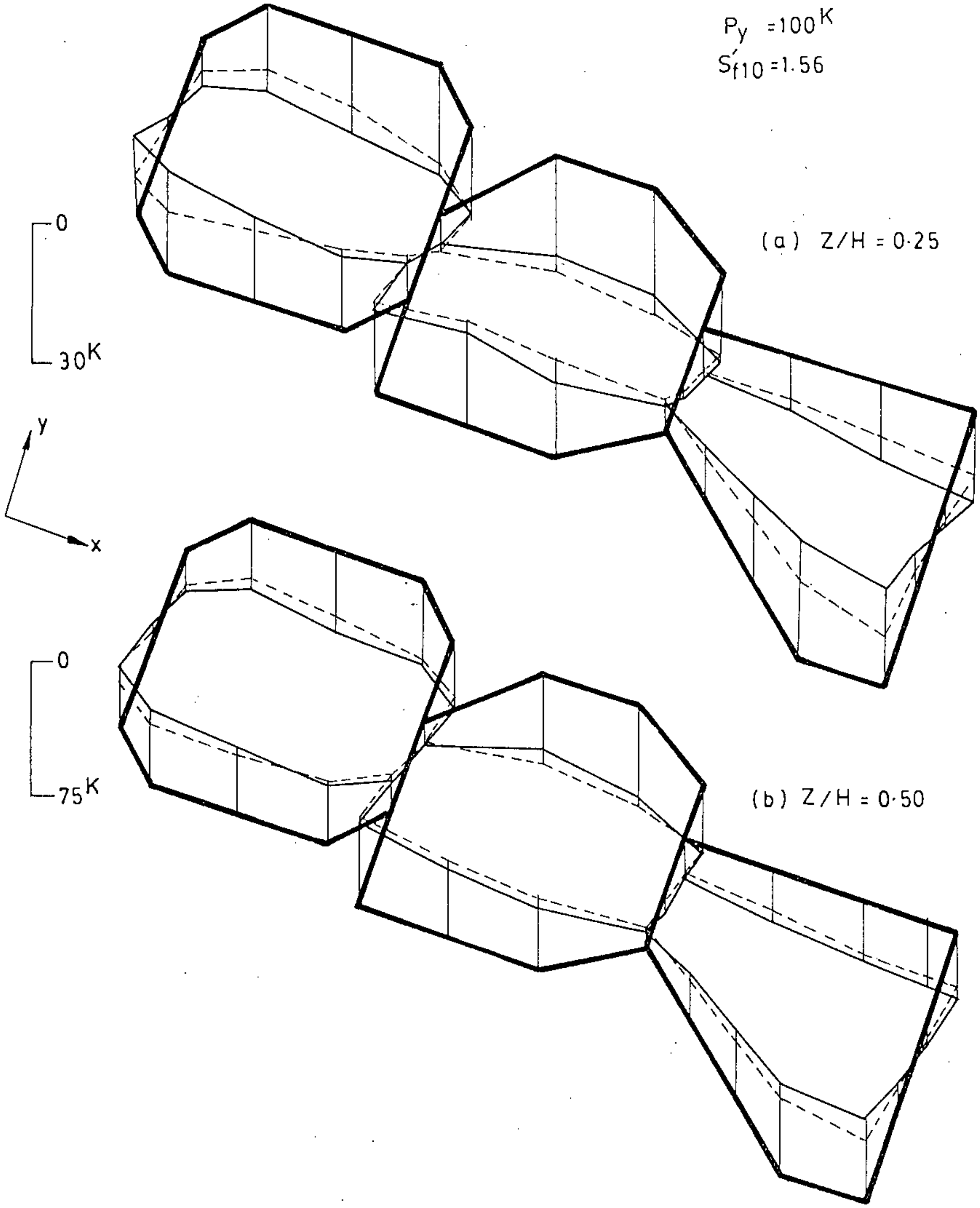


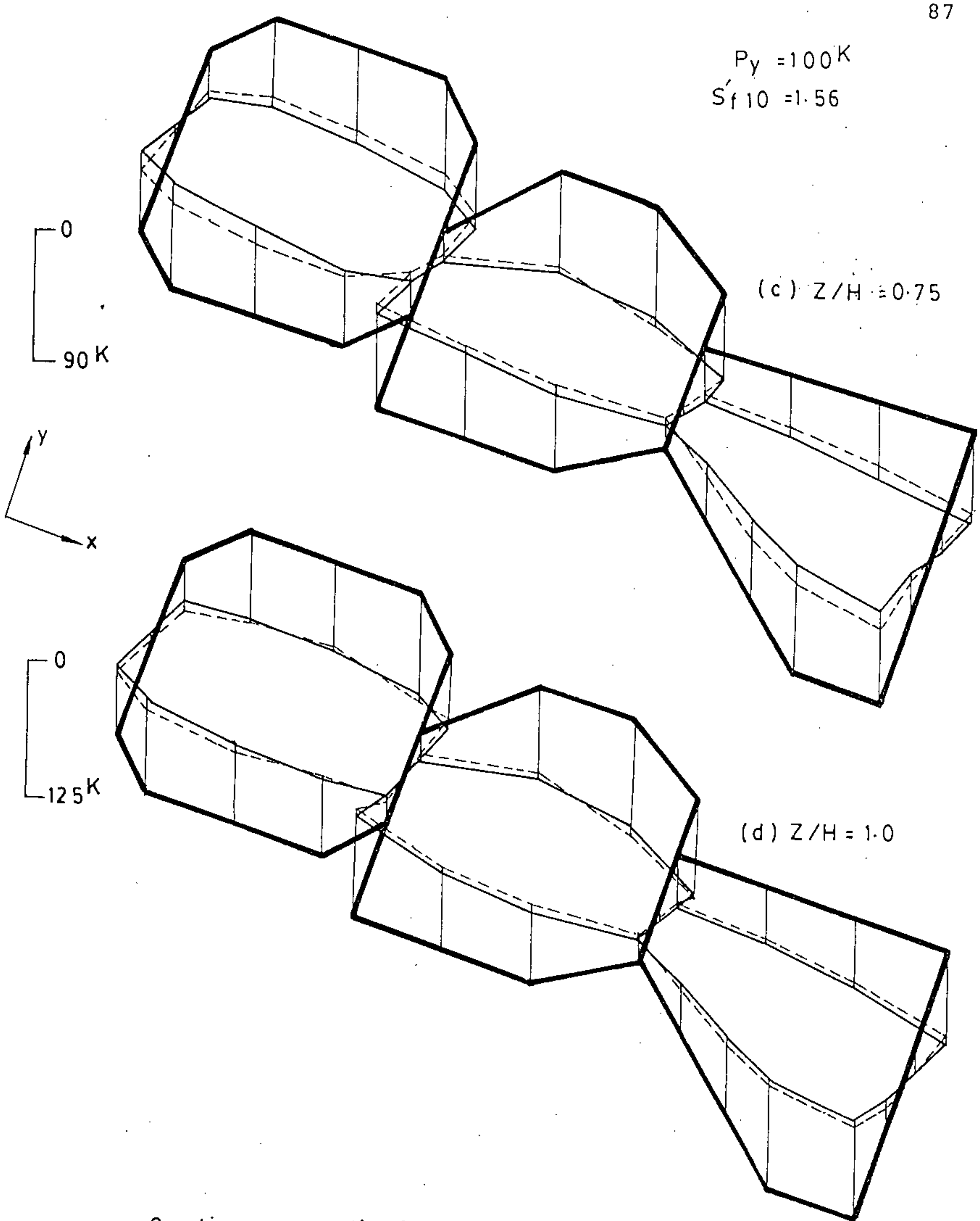
Fig. 4·10 : Lateral deflection for the example problem 2.



——— Continuous medium method

– – – – Space frame analysis

Fig. 4·11 a&b : Axial forces in the columns of the example problem 2 .



——— Continuous medium method
– – – – Space frame analysis

Fig. 4·11 c & d : Axial forces in the columns of the example problem 2.

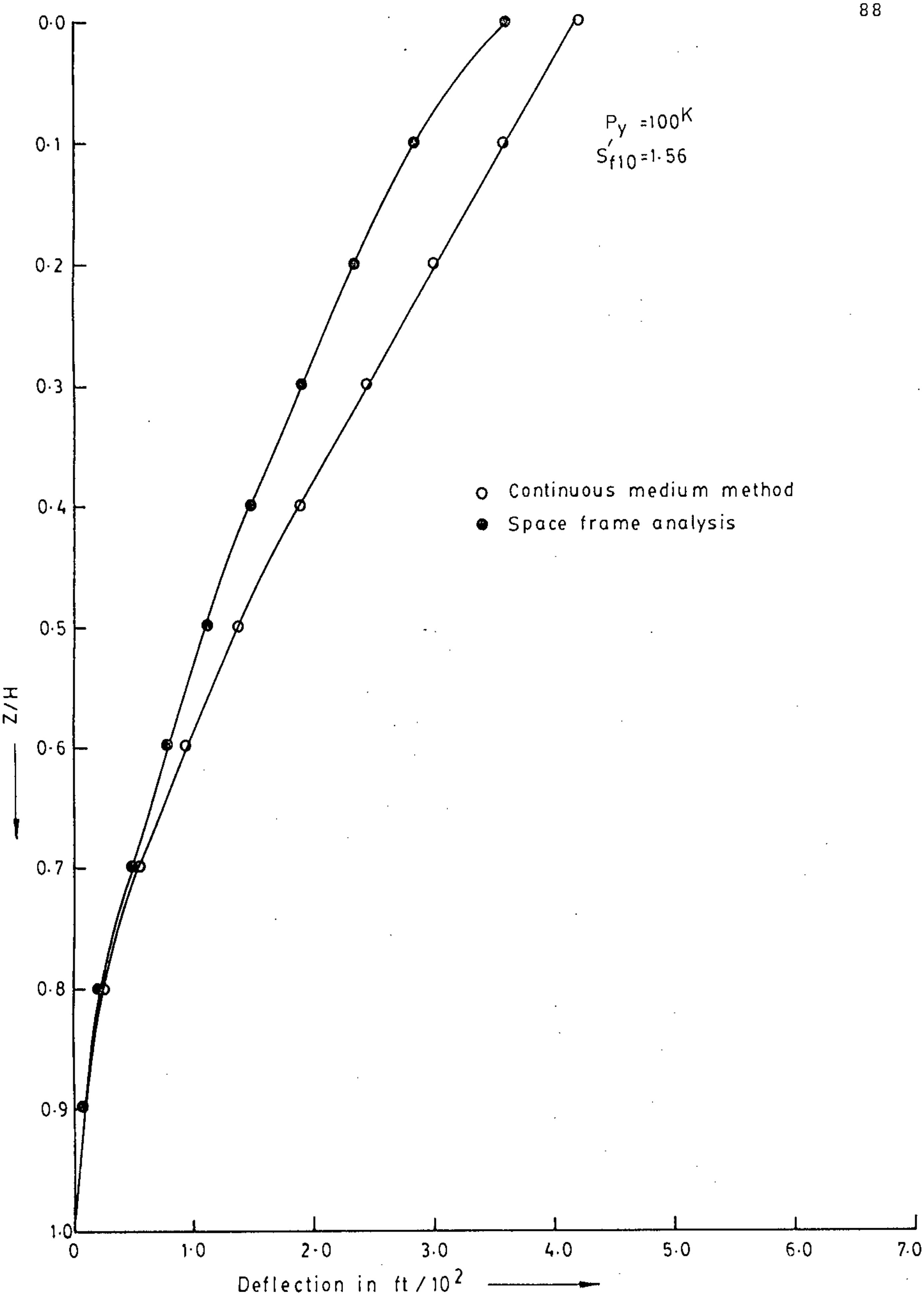
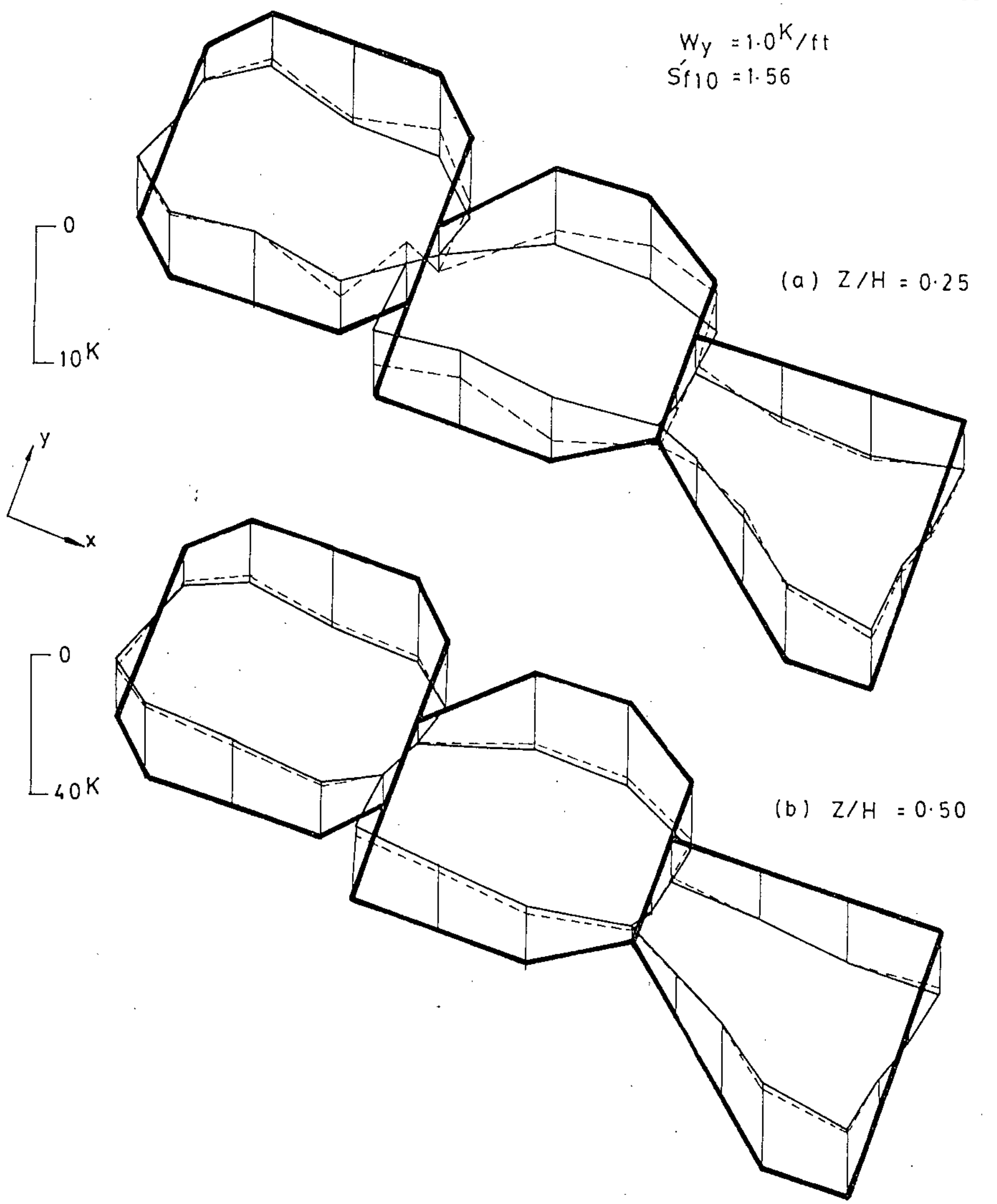


Fig. 4·12 : Lateral deflection for the example problem 2.



——— Continuous medium method
- - - - Space frame analysis

Fig. 4·13 a & b : Axial forces in the columns of the example problem 2.

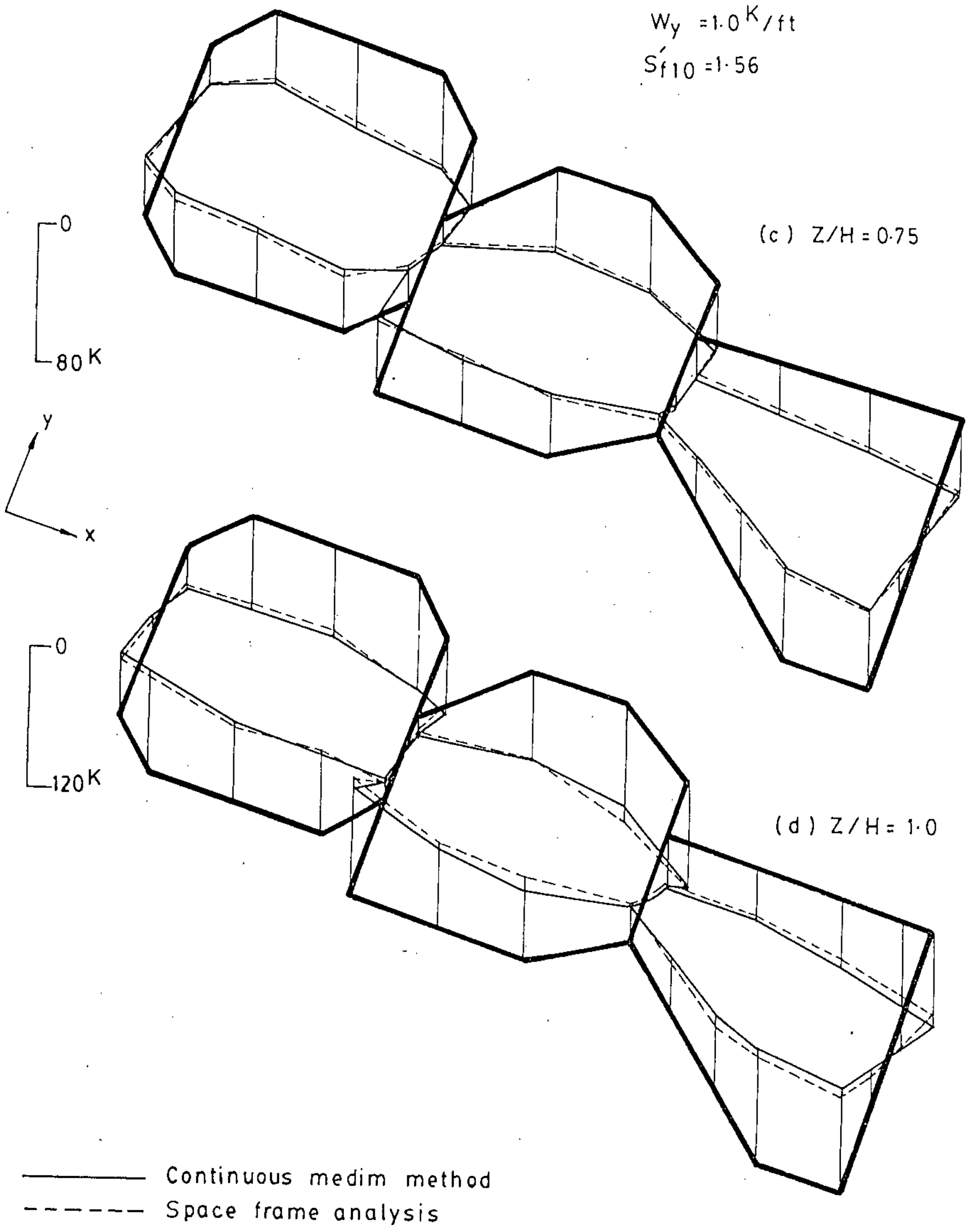


Fig. 4.13 c&d : Axial forces in the columns of the example problem 2.

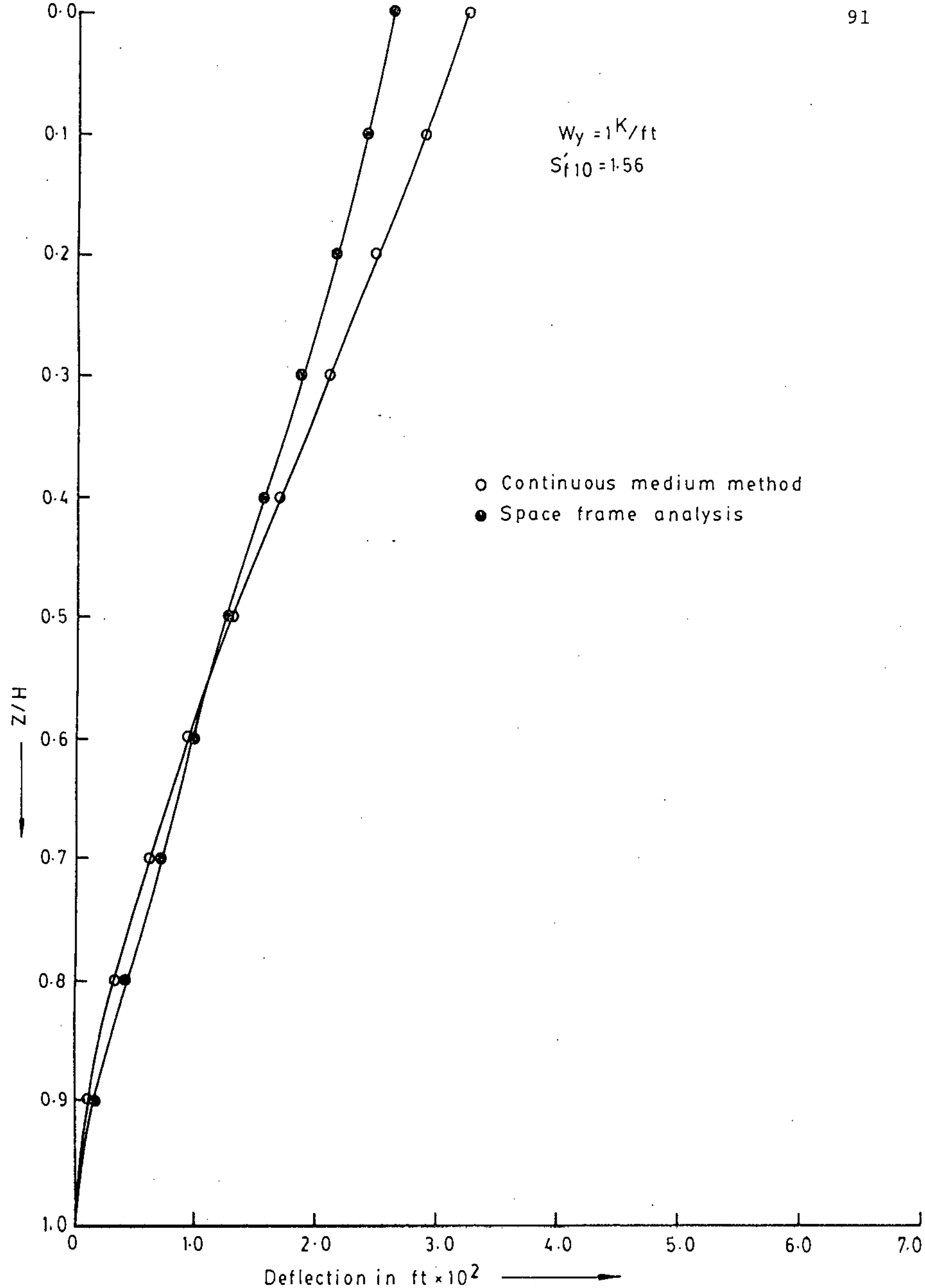


Fig. 4.14 : Lateral deflection for the example problem 2

CHAPTER 5
CONCLUSIONS

5.1 CONCLUSIONS

Based on analyses of the two tubular structures under different loading conditions the following conclusions may be drawn:

An analysis of the example problem 1 shows that the proposed approximate method gives column axial forces that are very close to those given by more exact space frame method (except at very low z/H ratios of the building), for tubular structures of regular plan shape with stiffness factor $S'_{f10}=1.0$. At low z/H ratios the differences in results are prominent at corner columns and middle column of the flange frame. With a point load at the top a maximum difference of 59% between the two methods is observed at the corner columns at z/H = 0.25 . For uniformly distributed load a maximum difference of 55% between the two methods is observed at corner columns for the same depth and stiffness factor. For uniformly distributed loads, except at very high z/H ratios, continuous medium method slightly overestimates the results of column axial forces.

The cantilever method gives results for column axial forces that are almost comparable to that found from continuous medium method. Specially at low z/H ratios of the building, both methods give approximately the same results for uniformly distributed load.

The proposed continuous method also works well for deflections for structures of regular plan shape. It predicts the same deflected shape as well as very close magnitude, but continuous medium method almost always slightly underestimates the magnitude of deflections. Engineer's theory of bending gives deflection values which are approximately 70%(at top of the structure) of the exact values.

An analysis of example problem 2 shows that the continuous medium method gives results similar to that of space frame method for tubular structures of arbitrary plan shape with stiffness factor $s'_{f10}=1.56$. At high z/H ratios of the building both approximate and exact method give very close results for column axial forces, but at low z/H ratios the differences in results are prominent. The deflections predicted by both the methods are very close to each other, when the load acts in the long direction as well as in the short direction of the building, but continuous medium method almost always slightly overestimates the magnitude of deflection.

The cantilever method cannot give satisfactory results of column axial forces in case of structures of arbitrary plan shape. Engineer's theory of bending gives deflection values that are about 85% of the exact values when the load acts in the short direction , but when the load acts in the long direction it gives results which is about 50% of the exact values.

For the example problem 1, the continuous medium method requires approximately 270 kilobytes of disk space, while STAAD-III/ISDS, the space frame program requires 16 megabytes of disk space and for the example problem 2, the continuous medium method requires approximately 270 kilobytes of disk space, while the space frame program requires 13.39 megabytes of disk space. Also the computer time requirement in the continuous medium method is much less than the space frame method in both the example.

Sine the continuous medium method predicts forces as well as deflections that are close to their exact values and it requires much less computer time and storage it may be used for preliminary analysis of tubular structures of any shape and any number of interconnected cells.

5.2 RECOMMENDATIONS FOR FURTHER STUDY

The present study has yielded an approximate method that can fairly accurately predict the forces as well as deflections in a tubular structure of any plan shape and having any number of interconnected cells.

In developing the theory, the shift of point of contraflexure is not considered, but assumed to lie in the midspans of the spandrel beams. This assumption is valid for tubular structures with flexible beams. In structures when the beams are stiff compared to the walls the point of contraflexure in a beam line may drift away from the midspans, if the supporting columns are of unequal stiffnesses. So, a more refined theory may be developed considering this concept under consideration.

In developing the theory, the torsional stiffness of the flange beams has been neglected. A more general method may be developed taking care of torsional stiffness of the flange beams.

The torsional effect of lateral load on the buildings of arbitrary plan shape was not considered in developing the theory. For more refined results this should also be taken under consideration.

REFERENCES

1. Ast, R.F. and Schwaighofer, J., "Economical Analysis of Large Framed-Tube Structures", Building Science, Vol. 9, Pergamon Press, London, 1974.

2. Bari, S., "An Approximate Method of Analysis of High Rise Tubular Structures", M.Sc.Engg. Thesis, B.U.E.T., Dhaka, 1984.

3. Chang, P.C. and Foutch, D.A., "Static and Dynamic Modeling and Analysis of Tube Frames", Journal of Structural Division, Proceedings ASCE, Vol. 110, No. ST12, Dec. 1984, pp. 2955-2975.

4. Choudhury, J.R., "Analysis of Plane and Spatial Systems of Interconnected Shear Walls", Ph.D. Thesis, University of Southampton, Southampton, 1968.

5. Chowdhury, M.R., "Three Dimensional Analysis of Tall Buildings with Shear Walls and Columns of Non-Uniform Cross-section", M.Sc. Thesis, B.U.E.T., Dhaka, 1983.

6. Coull, A. and Ahmed, A., "Deflections of Framed Tube Structures", Journal of Structural Division, Proc. ASCE, Vol. 104, No. ST5, New York, 1978.

7. Coull, A. and Bose, B.,"Simplified Analysis of Frame- Tube Structures", Journal of Structural Division, Proc. ASCE, Vol. 101, No. ST11, New york, 1975.

8. Coull, A., Bose, B. and Ahmed, A.K., "Simplified Analysis of Bundled-Tube Structures", Journal of Structural Division, Proc. ASCE, Vol. 108, No. ST5, May 1982.

9. Coull, A. and Subedi, N.K., "Framed Tube Structures for High Rise Buildings", Journal of Structural Division, Proc. ASCE, Vol.97, No ST8, New York, 1971.

10. Coull, A. and Subedi, N.K., "Hull-Core Structures Subject to Bending and Torsion", Proc. of 9th Congress of International Association for Bridge and Structural Engineering, Amsterdam, 1972.

11. Council on Tall Buildings, Group CB, "Structural Design of Tall Concrete and Masonry Buildings", Volume CB of Monograph on Planning and Design of Tall Buildings, ASCE, New York, 1978.

12. Chan Paul, C.K., "Analysis of Framed-Tube Structures", Ph.D. thesis, Mc-Master University, Hamilton, Canada, 1973.

13. Chan Paul, C.K., Tso and Heidebrecht, A.C., "Effects of Normal Frames on Shear Walls", Building Science, Vol. 9, Pergamon Press, London, 1974.

14. Fintel, M., "Handbook of Concrete Engineering", Van Nostrand Reinhold Company, New York, 1974. (Chapter 11: Tubular Structures for Tall Buildings by F.R. Khan).

15. Foutch, D.A. and Chang, P.C., "A Shear Lag Anomaly", Journal of Structural Division, Proc. ASCE, Vol. 108, No. ST7, New York, 1982.

16. Heidebrecht, A.C. and Smith, B.S., "Approximate Analysis of Tall Wall Frame Building Structures", Journal of Structural Division, Proceedings ASCE, Vol. 99, No. ST2, Feb. 1982.

17. Khan, A.H., "Analysis of Tall Shear wall Frame and Tube Structures", Ph.D. thesis, University of Southampton, U.K, 1974.

18. Khan, F.R. and Amin, N.R., "Analysis and Design of Framed Tube Structures for Tall Concrete Buildings", The Structural Engineering, Vol. 51, 1973.

19. Khan, A.H. and Smith, B.S., "A Simple Method of Analysis for Deflections and Stresses in Wall-Frame Structures", Building Environment, Vol. 11, 1976.

20. Kinh, H.H., Fazio, P. and Moselhi, O., "Orthotropic Membrane for Tall Building Analysis", Journal of Structural Division, Proc. ASCE, Vol. 104, No. ST9, New York, 1978.

21. Rutenberg, A. and Heidebrecht, A.C., "Approximate Analysis of Asymmetric Wall-Frame Structures", Building Science, Vol.10, Pergamon Press, London, 1975.

22. Schueller, W., "High Rise Building Structures", John Wiley and Sons, Inc., New York, 1977.

23. Sokolnikoff, I.S. and Redheffer, R.M., "Mathematics of Physics and Modern Engineering", McGraw-Hill Book Company, New York, 1966.

24. Zubair, A.K.M., "Analysis of Non-Rectangular High Rise Tubular Structures", M.Sc.Engg. Thesis, B.U.E.T., Dhaka, 1985.

25. Ahmed, A.,"An Approximate Method for the Analysis of Multicellular High Rise Tubular Structures of Arbitrary Plan Shape", M.Sc.Engg. Thesis, B.U.E.T., Dhaka, 1988.

26. Taranath, B.S., "Structural Analysis and Design of Tall Buildings", McGraw-Hill Book Company, Singapore, 1988.

27. Norris, C.H., Wilbur,J.B. and Utku, S., "Elementary Structural Analysis", 3rd Edition, McGraw-Hill, Inc.(Page-205)

APPENDIX A

LISTING OF THE COMPUTER PROGRAM

```
C###################################################################
C## A COMPUTER PROGRAM  FOR THE APPROXIMATE  ANALYSIS OF A TUBULER ##
C## STRUCTURE OF ANY PLAN SHAPE USING THE CONTINUOUS MEDIUM METHOD ##
C##                           !!!                                  ##
C##                            !                                   ##
C##                   PROGRAM DEVELOPED BY                         ##
C##                   MD. NASSER BIN HOSSAIN                       ##
C##                       ROLL-891230P                             ##
C##                      SESSION-1987-88                           ##
C##                                                                ##
C###################################################################
C-----COMPUTER PROGRAM FOR CONTINUOUS MEDIUM METHOD---
C
C   TWO SUBSCRIPTS USED ARE J,K --- I USED FOR MOMENT OF INERTIA
C
      IMPLICIT REAL (I,J,K,L,M,N)
      INTEGER I,J,K,M,N,N1,N2,II,JJ,KK,LL,MM,NN,E1B(50),E2B(50),
     -E1C(50,50),E2C(50,50),WCM1(50,50),WCM2(50,50),I1,I2,J1,J2,
     -K2,INT,TYPE
      DIMENSION B(50),H(50),THETA(50)
     -,WB(50),WD(50),IB(50),IC(50),A(50),IW(50),
     -N1(50),N2(50),MX(100),MY(100),MXX(50,100),MYY(50,100),
     -SQALPH(50,50),L(50),BETA(50),AA(49,50),X(50),BB(50,500),
     -T(50,100),D(50),IP(50),F(50,100),DEFX(100),DEFY(100)
      REAL IX(50),IY(50),LX(50),LY(50)
      OPEN(1,FILE='CONSTAAD.DATA',STATUS='OLD')
      OPEN(3,FILE='CONSTAAD2.OUT',STATUS='UNKNOWN')
      WRITE(*,*)'TYPE OF LATERAL LOADING=?'
      WRITE(*,*)'ENTER  1  FOR POINT LATERAL LOAD AT TOP'
      WRITE(*,*)'ENTER  2  FOR UNIFORMLY DISTRIBUTED LOAD'
      WRITE(*,*)'TYPE=?'
      READ(*,*)TYPE
      WRITE(3,*)'TYPE=',TYPE
c      WRITE(*,*)'NO OF WALLS,M= ?'
c      READ(*,*)M
c      WRITE(*,*)'TOTAL HEIGHT OF THE BLDG.,TH=?'
C      READ(*,*)TH
C
C
C              DATA FOR THE ANALYSIS
C-------------------------------------------------------------------
C----------READING GENERAL DIMENSION & PROPERTIES-----------------
C     M=NO. OF COLUMN/WALLS AT EACH FLOOR
C     TH=TOTAL HEIGHT OF THE BUILDING
C     NEU=POISSON'S RATIO
C     E=MODULUS OF ELASTICITY
C     NB= NO OF BEAMS AT EACH FLOOR OF THE STRUCTURE
C     NC,NW=M=NO OF COLUMNS/WALLS AT EACH FLOOR
C     WX=UNIFORMLY DISTRIBUTED LOAD ON THE TOTAL HEIGHT OF THE STRUCTURE
```

```
C          IN THE X-DIRECTION
C       WY=UNIFORMLY DISTRIBUTED LOAD ON THE TOTAL HEIGHT OF THE STRUCTURE
C          IN THE Y-DIRECTION
C       PX=POINT LOAD IN THE X-DIRECTION AT THE TOP OF THE STRUCTURE
C       PY=POINT LOAD IN THE Y-DIRECTION AT THE TOP OF THE STRUCTURE
C
C
        READ(1,*)M,TH,NEU,E,NB,NC,WX,WY,PX,PY
        NW=NC
C
C----------READING OF BEAM CONNECTIVITY MATRIX-----------------------------
C       I1=I=BEAM NO.
C       E1B(I)=COLUMN/WALLS AT END-1 OF BEAM-I
C       E2B(I)=COLUMN/WALLS AT END-2 OF BEAM-I
C
        DO 11 I=1,NB
        READ(1,*)I1,E1B(I),E2B(I)
 11     CONTINUE
C
C----------READING OF WALL CONNECTIVITY MATRIX-------------------
C-------------------------------------------------------------------------
C       I1=I=COLUMN NO.
C       E1C(I,II)= A NC*NB MATRIX CONTAINING ALL ZERO ELEMENTS EXCEPT
C       AT LOCATIONS CORRESPONDING TO THE BEAM NOS. CONNECTING WALL-I
C       AS THEIR END-1. AT THESE LOCATIONS THE ELEMENTS CONTAIN THE SAME
C       NOS. AS THE CORRESPONDING BEAM NOS.

        DO 12 I=1,NC
        READ(1,*)I1,(E1C(I,II),II=1,NB)
 12     CONTINUE
C-------------------------------------------------------------------------------
C       I1=I=COLUMN NO.
C       E1C(I,II)= A NC*NB MATRIX CONTAINING ALL ZERO ELEMENTS EXCEPT
C       AT LOCATIONS CORRESPONDING TO THE BEAM NOS. CONNECTING WALL-I
C       AS THEIR END-2. AT THESE LOCATIONS THE ELEMENTS CONTAIN THE SAME
C       NOS. AS THE CORRESPONDING BEAM NOS.
        DO 13 I=1,NC
        READ(1,*)I1,(E2C(I,II),II=1,NB)
 13     CONTINUE
C---------------------------------------------------------------------
C
C---------------------------------------------------------------------
C                   L(I)=C/C DISTANCE OF WALLS IN Ith OPENING
C                   A(I)=X-SECTION OF Ith WALL
C                   B(I)=CLEAR BEAM LENGTH IN Ith OPENING
C                   H(I)=VERTICAL C/C DISTANCE OF BEAMS IN Ith BAND OF OPEN.
C         WB(I) <   T(I)=HORIZ. WIDTH OF BEAM IN Ith BAND OF OPENING
C         WD(I) <    D(I)=DEPTH OF BEAM IN Ith BAND OF OPENING
C
C
C                   IB(I)=BEAM MOM.OF INERTIA FOR Ith BAND , (m-1) BAND OF
C                          OPENING
C                   IC(I)=REDUCED BEAM MOM.OF INERTIA FOR Ith BAND
C                   IW(I)=WALL MOM.OF INERTIA FOR Ith WALL , (m) NO OF WALLS
C                   TI=SUM OF ALL WALL MOM. OF INERTIA
```

```
C
C---- TO FIND TI= SUM OFMOMENT OF INERTIA---------------------
C
C                 IB(I)=BEAM MOM.OF INERTIA , (m-1) BAND OF OPENING
C                 IC(I)=REDUCED BEAM MOM.OF INERTIA
C                 IW(I)=WALL MOM.OF INERTIA , (M) NO OF WALLS
C                 TI=SUM OF ALL WALL MOM OF INERTIA
C                 IX(I),IY(I)=COLUMN SECTION MOMENT OF INERTIA WITH RESPECT
C                             TO ITS LOCAL X & Y AXIS.
C
C---------READING DETAIL DIMENSIONS OF BEAMS---------------------
      DO 14 I=1,NB
      READ(1,*)I1,B(I),H(I),LX(I),LY(I)
 14   CONTINUE
C
C---------READING DETAILS OF BEAM X-SECTIONS----------------------
      DO 15 I=1,NB
      READ(1,*)I1,WB(I),WD(I)
      IB(I)=WB(I)*WD(I)**3/12.
      IC(I)=IB(I)/(1.+2.4*(1.+NEU)*(WD(I)/B(I))**2)
      WRITE(3,*)'IC(1)=',IC(1),'IB(1)=',IB(1)
C15   CONTINUE
C---------READING DETAILS OF COLUMN X-SECTIONS-------------------
      PIE=3.141592654
C   THETA(I)=ANGLE THAT COLUMN-I'S LOCAL AXIS MAKES WITH THE GLOBAL AXIS
C   OF THE STRUCTURE, CONSIDERING COUNTER CLOCKWISE DIRECTION AS POSITIVE.
C
      DO 16 I=1,NC
      READ(1,*)I1,A(I),IX(I),IY(I),THETA(I)
      IF(THETA(I).NE.0.)IX(I)=IX(I)*(COS(THETA(I)/180.*PIE))**2+
     -IY(I)*(SIN(THETA(I)/180.*PIE))**2
      IF(THETA(I).NE.0.)IY(I)=IX(I)*(SIN(THETA(I)/180.*PIE))**2+
     -IY(I)*(COS(THETA(I)/180.*PIE))**2
 16   CONTINUE

C
      DO 1110 J=1,NB
C
CC
      WRITE(3,*)'J=',J,'LX(J)=',LX(J),'LY(J)=',LY(J),
     -'TI=',TI,'IC(J)=',IC(J),'B(J)=',B(J),'H(J)=',
     -H(J),'A(J)=',A(J),'PIE=',PIE,'TH=',TH
CC
 1110 CONTINUE
C---------------------------------------------------------------
C----FORMATION OF ALPHA(I,J) MATRIX-----------------------------
C----FORMATION OF NEW WCM-1-------------------------------------
      DO 20 I=1,NB
      DO 21 J=1,NC
      DO 21 K=1,NB
      IF(E1C(J,K).EQ.I)N1(I)=J
      IF(E1C(J,K).EQ.I)GO TO 211
 21   CONTINUE
 211  DO 22 I1=1,NB
      IF(E1C(N1(I),I1).NE.0) WCM1(I,I1)=E1C(N1(I),I1)/
```

```
     -E1C(N1(I),I1)
      IF(E1C(N1(I),I1).EQ.0)WCM1(I,I1)=0.
      IF(E2C(N1(I),I1).NE.0)WCM1(I,I1)=-E2C(N1(I),I1)/
     -E2C(N1(I),I1)
 22   CONTINUE
 20   CONTINUE
C----FORMATION OF NEW WCM-2-----------------------------------
      DO 30 I=1,NB
      DO 31 J=1,NC
      DO 31 K=1,NB
      IF(E2C(J,K).EQ.I)N2(I)=J
      IF(E2C(J,K).EQ.I)GO TO 311
 31   CONTINUE
 311  DO 32 I2=1,NB
      IF(E2C(N2(I),I2).NE.0)WCM2(I,I2)=E2C(N2(I),I2)/
     -E2C(N2(I),I2)
      IF(E2C(N2(I),I2).EQ.0)WCM2(I,I2)=0.
      IF(E1C(N2(I),I2).NE.0)WCM2(I,I2)=-E1C(N2(I),I2)/
     -E1C(N2(I),I2)
 32   CONTINUE
 30   CONTINUE
C
C
      DO 444 I=1,NB
      WRITE(3,*)'I=',I
      WRITE(3,*)'E1C=',(E1C(I,J),J=1,NB)
      WRITE(3,*)'E2C=',(E2C(I,J),J=1,NB)
      WRITE(3,*)'WCM1=',(WCM1(I,J),J=1,NB)
      WRITE(3,*)'WCM2=',(WCM2(I,J),J=1,NB)
 444  CONTINUE
      DO 445 I=1,NB
      WRITE(3,*)'I=',I
      WRITE(3,*)'N1=',N1(I),'N2=',N2(I),'A=',A(I)
      WRITE(3,*)'A(N1(I))=',A(N1(I)),'A(N2(I))=',A(N2(I))
 445  CONTINUE
      WRITE(3,*)'(N1(I),I=1,NB)=',(N1(I),I=1,NB)
      WRITE(3,*)'(N2(I),I=1,NB)=',(N2(I),I=1,NB)
      WRITE(3,*)'(A(N1(I)),I=1,NB)=',(A(N1(I)),I=1,NB)
      WRITE(3,*)'(A(N2(I)),I=1,NB)=',(A(N2(I)),I=1,NB)
      DO 40 I=1,NB
      DO 40 J=1,NB
      WRITE(3,*)'I=',I,'J=',J,'WCM1(I,J)=',WCM1(I,J),
     -'WCM2(I,J)=',WCM2(I,J),'IC(I)=',IC(I),'B(I)=',B(I),'H(I)=',
     -H(I)
      SQALPH(I,J)=(WCM1(I,J)/A(N1(I))+WCM2(I,J)/A(N2(I)))*12.*
     -IC(I)/(B(I)**3*H(I))
      WRITE(3,*)'SQALPH(I,J)=',SQALPH(I,J)
 40   CONTINUE
C
C
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      DO 41 I=1,NC
```

```
C        SUM1=SUM1+(1./SX(I)**2)
C        SUM2=SUM2+(1./(IX(I)*SX(I)**2))
C        SUM3=SUM3+(1./SY(I)**2)
C        SUM4=SUM4+(1./(IY(I)*SY(I)**2))
       SUM1=SUM1+IX(I)
       SUM2=SUM2+(IX(I)**2/IX(I))
       SUM3=SUM3+IY(I)
       SUM4=SUM4+(IY(I)**2/IY(I))
C        WRITE(3,*)'SUM1=',SUM1,'SUM2=',SUM2,'SUM3=',SUM3,'SUM4=',SUM4,
C      -'WX=',WX,'LX(1)=',LX(1),'B(1)=',B(1),'H(1)=',H(1),'IC(1)=',IC(1)
 41    CONTINUE
C
C
       DO 42 I=1,NB
       IF(TYPE.EQ.1)BETA(I)=12.*IC(I)/(B(I)**3*H(I))*(PY*
      -(LY(I))/SUM1**2*SUM2+PX*(LX(I))/SUM3**2*SUM4)
       IF(TYPE.EQ.2)BETA(I)=12.*IC(I)/(B(I)**3*H(I))*0.5*(WY*
      -(LY(I))/SUM1**2*SUM2+WX*(LX(I))/SUM3**2*SUM4)
       DO 42 J=1,NB
       SQALPH(I,J)=12.*IC(I)/(B(I)**3*H(I))*(LY(I)*LY(J)/
      -SUM1**2*SUM2+LX(I)*LX(J)/SUM3**2*SUM4)+SQALPH(I,J)
 42    CONTINUE
       DO 422 I=1,NB
       WRITE(3,*)'I=',I,'SQALPH(I,J)=',(SQALPH(I,J),J=1,NB)
       WRITE(3,*)'BETA(I)=',BETA(I)
       WRITE(3,*)' '
 422   CONTINUE
C-------------------------------------------------------------
C              II=INFINITE SERIES NOTATION ,'I'USED IN DERIVATION
C              TH=TOTAL HEIGHT OF THE BUILDING
C
C              WHAT SHOULD BE THE VALUE OF THE ULTIMATE SERIES=?
C
       III=0
       DO 45 II=1,1000,2
       III=III+1
C
C
       WRITE(*,*)'NO OF ITERATIONS=',III
C      WRITE(3,*)'NO OF ITERATIONS=',III
C
C
       DO 50 J=1,NB
       DO 50 K=1,NB
       AA(J,K)=SQALPH(J,K)
       IF(J.EQ.K) AA(J,K)=AA(J,K)+II**2*PIE**2/(4.*(TH)**2)
       IF(TYPE.EQ.2)GO TO 501
       IF(K.EQ.NB) AA(J,K+1)=8.*TH*SIN(PIE*II/2.)/
      -(PIE**2*II**2)*BETA(J)
       GO TO 50
 501   IF(K.EQ.NB) AA(J,K+1)=16.*TH**2*(PIE*II*SIN(PIE*II/2.)-2.)/
      -(PIE**3*II**3)*BETA(J)
 50    CONTINUE
C
C              SUBROUTINE FOR GAUSSIAN ELIMIATION
```

```
C
      CALL GAUSS(NB,AA,X)
      DO 80 J=1,NB
      BB(J,II)=X(J)
 80   CONTINUE
C
      DO 100 J=1,NB
 100  IF(ABS(BB(J,II)).GT..1)GO TO 45
      KK=II
      WRITE(3,*)'LAST ITERATION NO=',KK
      WRITE(*,*)'LAST ITERATION NO=',KK
      WRITE(3,*)'FINAL BB(I,J) I=1,NB/J=1,KK  MATRIX FOR',KK,
     -'ITERATIONS'
      WRITE(3,*)'FINAL A-MATRIX'
      DO 101 K=1,NB
 101  WRITE(3,*)(BB(K,J),J=1,KK,2)
C
      GO TO 110
C
 45   CONTINUE
C
C
C                 TO FIND T1  , T2 ..... Tm-1 DISTRIBUTIONS
C
 110  WRITE(*,*)'INTERVAL=?'
      READ(*,*)INTER
C
      NN=TH/INTER
      DO 120 K=1,NB
      DO 90 K2=1,NN+1
      XX=(K2-1)*INTER
      T(K,K2)=0.
      DO 90 J=1,KK,2
      T(K,K2)=T(K,K2)+BB(K,J)*SIN(J*PIE*XX/(2.*TH))
90    CONTINUE
      WRITE(3,*)'SHEAR FROM TOP TO BOTTOM HORIZONTALLY SHOWN AT
     -INTERVALS OF=',INTER,' FT'
      WRITE(3,*)'OPENING,K=',K
      WRITE(3,*)(T(K,K2),K2=1,NN+1)
 120  CONTINUE
C------------------------------------------------------------------
C-----AXIAL FORCE CALCULATION--------------------------------------
C------------------------------------------------------------------
      DO 130 INT=1,NN+1
      DO 131 I=1,NC
      SUM1=0.
      SUM2=0.
      DO 132 J=1,NB
      IF(E1C(I,J).NE.0.)SUM1=SUM1+T(E1C(I,J),INT)
      IF(E2C(I,J).NE.0.)SUM2=SUM2+T(E2C(I,J),INT)
 132  CONTINUE
      F(I,INT)=SUM1-SUM2
 131  CONTINUE
 130  CONTINUE
      WRITE(3,*)'AXIAL FORCE FROM TOP TO BOTTOM HORIZONTALLY SHOWN AT
```

```
     -INTERVALS OF=',INTER,' FT'
      DO 133 I=1,NC
      WRITE(3,*)'COLUMN NO=',I
      WRITE(3,*)(F(I,J),J=1,NN+1)
 133  CONTINUE
C-------------------------------------------------------------------
C--------- MOMENT CALCULATION ---------------------------------------
C-------------------------------------------------------------------
      DO 140 I=1,NN+1
      Z=INTER*(I-1)
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      DO 141 J=1,NB
      SUM1=SUM1+T(J,I)*LY(J)
      SUM2=SUM2+T(J,I)*LX(J)
 141  CONTINUE
      DO 142 J=1,NC
      SUM3=SUM3+IX(J)
      SUM4=SUM4+IY(J)
 142  CONTINUE
      IF(TYPE.EQ.1)MX(I)=(-PY*Z+SUM1)/SUM3
      IF(TYPE.EQ.1)MY(I)=(PX*Z-SUM2)/SUM4
      IF(TYPE.EQ.2)MX(I)=(-WY*Z**2/2.+SUM1)/SUM3
      IF(TYPE.EQ.2)MY(I)=(WX*Z**2/2.-SUM2)/SUM4
      DO 143 J=1,NC
      MXX(J,I)=MX(I)*IX(J)
      MYY(J,I)=MY(I)*IY(J)
 143  CONTINUE
 140  CONTINUE
      WRITE(3,*)'MOMENTS ABOUT X-AXIS IN K-FT FROM TOP TO BOTTOM
     -HORIZONTALLY SHOWN AT INTERVALS OF=',INTER,' FT'
      DO 144 I=1,NC
      WRITE(3,*)'COLUMN NO=',I
      WRITE(3,*)(MXX(I,J),J=1,NN+1)
 144  CONTINUE
      WRITE(3,*)'MOMENTS ABOUT Y-AXIS IN K-FT FROM TOP TO BOTTOM
     -HORIZONTALLY SHOWN AT INTERVALS OF=',INTER,' FT'
      DO 145 I=1,NC
      WRITE(3,*)'COLUMN NO=',I
      WRITE(3,*)(MYY(I,J),J=1,NN+1)
 145  CONTINUE
C-------------------------------------------------------------------
C----------DEFLECTION CALCULATION ----------------------------------
C-------------------------------------------------------------------
      IXSUM=0.
      IYSUM=0.
      DO 146 I=1,NC
      IXSUM=IXSUM+IX(I)
      IYSUM=IYSUM+IY(I)
 146  CONTINUE
      WRITE(3,*)'IXSUM=',IXSUM,'IYSUM=',IYSUM
C
C
```

```
      DO 150 K=1,NN+1
      Z=INTER*(K-1)
      SUM2=0.
      SUM3=0.
      DO 151 J=1,NB
C      WRITE(3,*)'J=',J,'LX=',LX(J),'LY=',LY(J)
      SUM1=0.
      DO 152 I=1,KK,2
      SUM1=SUM1+BB(J,I)/(I*I)*(SIN(I*PIE/2.)-SIN(I*PIE*Z/(2.*TH)))
 152  CONTINUE
      SUM2=SUM2+SUM1*(LX(J))
      SUM3=SUM3+SUM1*(LY(J))
 151  CONTINUE
C      WRITE(3,*)'HEIGHT=',Z,'SUM2=',SUM2,'SUM3=',SUM3,'WX=',WX
C     -,'WY=',WY
      IF(TYPE.EQ.1)DEFX(K)=1./(E*IYSUM)*(-PX*(Z**3/6.-TH**2*Z/2.
     -+TH**3/3.)+4.*TH*TH/(PIE*PIE)*SUM2)
      IF(TYPE.EQ.1)DEFY(K)=1./(E*IXSUM)*(PY*(Z**3/6.-TH**2*Z/2.+
     -TH**3/3.)-4.*TH*TH/(PIE*PIE)*SUM3)
      IF(TYPE.EQ.2)DEFX(K)=1./(E*IYSUM)*(-WX/2.*(Z**4/12.-
     -TH**3*Z/3.+TH**4/4.)+4.*TH*TH/(PIE*PIE)*SUM2)
      IF(TYPE.EQ.2)DEFY(K)=1./(E*IXSUM)*(WY/2.*(Z**4/12.-
     -TH**3*Z/3.+TH**4/4.)-4.*TH*TH/(PIE*PIE)*SUM3)
 150  CONTINUE
      WRITE(3,*)'WX=',WX,'WY=',WY
      WRITE(3,*)'DEFLECTION IN X-DIRECTION  IN FT FROM TOP TO BOTTOM
     -HORIZONTALLY SHOWN AT INTERVALS OF=',INTER,' FT'
      WRITE(3,*)(DEFX(I),I=1,NN+1)
      WRITE(3,*)'DEFLECTION IN Y-DIRECTION  IN FT FROM TOP TO BOTTOM
     -HORIZONTALLY SHOWN AT INTERVALS OF=',INTER,' FT'
      WRITE(3,*)(DEFY(I),I=1,NN+1)
      STOP
      END


CCC
C ####################################################################
C ###SUBROUTINE FOR ANALYSIS LATERAL LOAD PARALLEL TO LONG. AXIS######
C ####################################################################
      SUBROUTINE GAUSS(NB,A,X)
      IMPLICIT REAL(I,J,K,L,M,N)
      INTEGER I,J,K,L,M,N,II,JJ,KK,LL,MM,NN
      DIMENSION X(50),A(49,50),BB(49,50)
      N=NB
      DO 371 II=1,N
 371  CONTINUE
CC
      DO 701 I=1,N
      DO 701 J=1,N+1
 701  BB(I,J)=A(I,J)
CCC
CCC
      DO 10 K=1,N-1
C     ROW INTERCHANGE
      IF(K.EQ.N)GO TO 50
```

```
      J=K
      BIG=ABS(A(K,K))
      DO 100 KK=J+1,N
      IF(BIG.GE.ABS(A(KK,K+1)))GO TO 100
      BIG=ABS(A(KK,K+1))
      J=KK
 100  CONTINUE
      IF(J.EQ.1)GO TO 50
C     INTERCHANGE
      DO 200 L=K,N+1
      TE=A(K,L)
      A(K,L)=A(J,L)
      A(J,L)=TE
 200  CONTINUE
      WRITE(3,*)' '
      WRITE(3,*)' '
 50   DO 10 I=K,N-1
      S=A(I+1,K)/A(K,K)
      DO 10 J=K+1,N+1
      A(I+1,J)=A(I+1,J)-A(K,J)*S
 10   CONTINUE
      X(N)=A(N,N+1)/A(N,N)
      DO 20 I=1,N-1
      J=N-I
      DO 30 K=1,I
 30   A(J,N+1)=A(J,N+1)-A(J,N+1-K)*X(N-K+1)
 20   X(J)=A(J,N+1)/A(J,J)
      DO 501 I=1,N
      SUM=0.0
      DO 502 J=1,N
 502  SUM=SUM+BB(I,J)*X(J)
 501  CONTINUE
      RETURN
      END
```

A.1 Sample Input Data File for Example Problem-1 of Continuous Medium Method

The following is an image of the input data file used for the analysis of example problem 1 (when a uniformly distributed load of 1k/ft. acts on the stucture) using the continuous medium method.

```
33,200.,0.18,432000.,36,33,1.,0.,100.,0.,
1,1,2,
2,2,3,
3,3,4,
4,4,5,
5,5,6,
6,6,7,
7,7,8,
8,8,9,
9,9,10,
10,10,11,
11,11,12,
12,12,13,
13,13,14,
14,14,15,
15,15,16,
16,16,17,
17,17,18,
18,18,19,
19,19,20,
20,20,21,
21,21,22,
22,22,23,
23,23,24,
24,24,1,
25,25,26,
26,26,27,
27,27,10,
28,28,25,
29,29,28,
30,16,29,
31,30,25,
32,31,30,
33,22,31,
34,25,32,
35,32,33,
36,33,4,
01,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
02,0,2,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
03,0,0,3,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
04,0,0,0,4,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
05,0,0,0,0,5,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
06,0,0,0,0,0,6,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
07,0,0,0,0,0,0,7,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
```

```
08,0,0,0,0,0,0,0,8,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
09,0,0,0,0,0,0,0,0,9,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
10,0,0,0,0,0,0,0,0,0,10,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
11,0,0,0,0,0,0,0,0,0,0,11,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
12,0,0,0,0,0,0,0,0,0,0,0,12,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
13,0,0,0,0,0,0,0,0,0,0,0,0,13,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
14,0,0,0,0,0,0,0,0,0,0,0,0,0,14,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
16,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,16,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
17,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,16,0,0,0,0,0,0,0,0,0,0,0,0,30,0,0,0,0,0,0,
18,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,17,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
19,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,18,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
20,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,19,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
21,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,20,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
22,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,21,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
23,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,22,0,0,0,0,0,0,0,0,0,33,0,0,0,
24,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,23,0,0,0,0,0,0,0,0,0,0,0,0,
25,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,24,0,0,0,0,0,0,0,0,0,0,0,
26,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,25,0,0,0,0,0,0,0,34,0,0,
27,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,26,0,0,0,0,0,0,0,0,0,
28,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,27,0,0,0,0,0,0,0,0,
29,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,28,0,0,0,0,0,0,0,
30,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,29,0,0,0,0,0,0,
31,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,31,0,0,0,0,0,
32,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,32,0,0,0,0,
33,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,35,0,
01,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,36,
02,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,24,0,0,0,0,0,0,0,0,0,0,0,0,
03,0,2,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
04,0,0,3,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
05,0,0,0,4,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,36,
06,0,0,0,0,5,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
07,0,0,0,0,0,6,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
08,0,0,0,0,0,0,7,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
09,0,0,0,0,0,0,0,8,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
10,0,0,0,0,0,0,0,0,9,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
11,0,0,0,0,0,0,0,0,0,10,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,27,0,0,0,0,0,0,0,0,0,
12,0,0,0,0,0,0,0,0,0,0,11,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
13,0,0,0,0,0,0,0,0,0,0,0,12,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
14,0,0,0,0,0,0,0,0,0,0,0,0,13,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
15,0,0,0,0,0,0,0,0,0,0,0,0,0,14,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
16,0,0,0,0,0,0,0,0,0,0,0,0,0,0,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
17,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
18,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,16,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
19,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,17,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
20,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,18,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
21,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,19,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
22,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,20,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
23,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,21,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
24,0,0,0,0,0,0,0;0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,22,0,0,0,0,0,0,0,0,0,0,0,0,0,
25,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,23,0,0,0,0,0,0,0,0,0,0,0,0,
26,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,28,0,0,31,0,0,0,0,0,
27,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,25,0,0,0,0,0,0,0,0,0,0,
28,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,26,0,0,0,0,0,0,0,0,0,
29,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,29,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,30,0,0,0,0,0,0,
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A.2 Sample Input Data File for Example Problem-2 of Continuous Medium Method

The following is an image of the input data file used for the analysis of example problem 2 (when a uniformly distributed load acts in the long direction of the building) using the continuous medium method.

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30,200.,0.18,432000.,32,30,1.,0.,100.,0.,
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APPENDIX B
STAAD-III/ISDS (SPACE FRAME ANALYSIS PROGRAM)

INTRODUCTION

STAAD-III/ISDS is the most powerful structural analysis and design software available today. The ISDS environment (PC software version only) can be thought of as a shell encompassing facilities for analysis/design, graphics, and drafting. These modules are called, respectively, STAAD-III, STAADPL, STAAD-DRAFT and STAAD-UTIL. It is the ISDS environment that integrates these different, yet related activities into a single continuous process. STAAD-UTIL module handles file management, drawing, plotting, text editing, device configuration, communication with peripherals, and interaction with the operating system.

STAAD-III

STAAD-III performs analysis and design of the structure. If run in batch mode, the contents of an input file are read and results are written to an output file.

STAADPL INTERACTIVE GRAPHICS

STAADPL, a complementary graphics module to STAAD-III, has both pre-processing and post-processing facilities. A complete interactive input generator with graphics interface leads the user through a sequence of menus and questions to create the input file. For post-processing, STAADPL can display the structure geometry from existing input files. In addition, if other STAADPL output files have been created from a prior STAAD-III run STAADPL can display deflected shapes, bending moment/shear force diagrams, section displacements, mode shapes, stress contours and failure diagrams.

STAADPL INTERACTIVE DESIGN

ISDS provides features to interactively design single steel/concrete members directly by providing their forces.

STAAD-DRAFT

STAAD-DRAFT is a general purpose drafting package. Basic drawing primitives such as lines, arcs, polygons and text are available. Editing capabilities include deleting, copying, moving, etc. In addition, drawings can be dimensioned and combined to form a single drawing.

After a STAAD-III run, STAAD-DRAFT can generate general arrangement section drawings for plans and elevations. These are extracted from a central database and contain all member designations and dimensions. These sections can be merged to form single drawings and edited as required.

STAAD-UTIL

The utility module of ISDS contains options for system configuration and other file utilities. Also included are a text editor for input files and a text view module for output files. Drawings can also be plotted or converted for use with other CAD packages. Access to the operating system (DOS) is also available.

HARDWARE

STAAD-III/ISDS runs on a wide range of computers, but only the Personal Computer (PC) version will be discussed here.

PC Requirements:

1) CGA,EGA,VGA or HGC Graphics card and compatible monitor.

2) Hard Disk with minimum 5MB of available space.

3) Minimum of 550,000 (537 KB) bytes of free Memory (commonly known as RAM).

4) Math Co-Processor (example 8087,80287,80387). Note: The evaluation/demo version does not require a Math Co-Processor.

The following articles will familiarize the user with the basic principles involved in the implementation of the various analysis/design facilities. As a general rule, the sequence in which the facilities are discussed follows the recommended sequence of their usage in the input file.

INPUT GENERATION

The user communicates with STAAD-III through an input file. the input file is a text file consisting of a series of commands which are executed sequentially. The commands contain either instructions or data pertaining to analysis and/or design.

The STAAD-III input file can be created through a text editor or STAADPL's input generation facility. The PC version of the software is equipped with a text editor-STAAD-ED which is available under STAAD-UTIL. In general, any text editor may be utilized to create the input file. The input generation facility creates the input file through an interactive menu-driven graphics oriented procedure. This facility is available under STAADPL.

Although a user can prepare input through Graphic input Generator, it is extremely useful to understand the language of the input for the following three reasons:

1) STAAD-III/ISDS is a very large and comprehensive structural engineering software. The capability of the program is enormous, and with a little imagination user, capability can be extended to

the limit of all structural engineering needs.

Graphic input generator can only do most of the basic structural engineering needs. After the file is generated by this with the knowledge of the style of input the user can alter the input file to extend the capability.

2) Graphic input generator is normally slow, and so an experienced user may find it a handicap when time is very important. With an understanding of the language of the input, the user can quickly create an input file through some knowledge of any editor (an editor called STAADED is also included with the program).

3) The input file represents the user's thought about what he wants to analyze or design. With the knowledge of STAAD-III/ISDS command language, the user himself or any other user can verify the accuracy of the work.

TYPES OF STRUCTURES

A STRUCTURE can be defined as an assemblage of elements. STAAD-III is capable of analyzing and designing structures consisting of both frame and plate/shell elements. Almost any type of structure can be analyzed by STAAD-III. Most general is the SPACE structure, which is a three dimensional framed structure with loads applied in any plane. A PLANE structure is bound by a global X-Y coordinate system with loads in the same plane. A TRUSS structure consists of truss members which can only have axial member forces and no bending in the members. A FLOOR structure is a two or three dimensional structure having no horizontal (global X of Z) applied loads or any load which may cause any horizontal movement of the structure. The floor framing (in global X-Z plane) of a building is an ideal example of a FLOOR structure. Columns can also be modeled with the floor in a FLOOR structure as long as the structure has no horizontal loading. If there is any horizontal load, it must be analyzed as a SPACE structure. Specification of the correct structure type reduces the number of equations to be solved during the solution. This results in a faster and more economic solution for the user.

UNIT SYSTEMS

The user is allowed to input data and request output in almost all commonly used engineering unit systems including FPS, MKS and SI. In the input file, the user may change units as many times as required. Mix and match between length and force units from different unit systems is also allowed. The input-unit for angles (or rotations) is degrees. However, in JOINT DISPLACEMENT output, the rotations are provided in radians. For all output, the units are clearly specified by the program.

STRUCTURE GEOMETRY AND COORDINATE SYSTEMS

A structure is an assembly of individual components such as beams, columns, slabs, plates etc. In STAAD-III, frame elements and plate elements may be used to model the structural components. Typically, modeling of the structure geometry consists of two steps:

A. Identification and description of joints or nodes.

B. Modeling of members or elements through specification of connectivity (incidences) between joints.

In general, the term MEMBER is used to refer to frame elements and the term ELEMENT is used to refer to plate/shell elements. Connectivity for MEMBERs may be provided through the MEMBER INCIDENCE command while connectivity for ELEMENTs may be provided through the ELEMENT INCIDENCE command.

STAAD-III uses two types of coordinate systems to define the structure geometry and loading patterns. The GLOBAL coordinate system is an arbitrary coordinate system in space which is utilized to specify the overall geometry and loading pattern of the structure. A LOCAL coordinate system is associated with each member (or element) and is utilized in MEMBER END FORCE output or local load specification.

B.1 STAAD-III/ISDS Input Data File for Example Problem 1

The following is a sample of the input data file for space frame analysis of the example problem no 1 (for a uniformly distributed load of 1k/ft.) using the microcomputer package STAAD-III/ISDS.

```
STAAD SPACE
UNIT KIP FT
JOINT COORDINATE
R A 0 0 0
1 0. 0. 0. ; 2 0. 0. 8.33 ; 3 0. 0. 16.66 ; 4 0. 0. 25. ; 5 0. 0. 33.32
6 0. 0. 41.65 ; 7 0. 0. 50. ;8 8.33 0. 50. ; 9 16.66 0. 50.
10 25. 0. 50.;11 33.32 0. 50. ; 12 41.65 0. 50. ; 13 50. 0. 50.
14 50. 0. 41.65 ; 15 50. 0. 33.32;16 50. 0. 25. ; 17 50. 0. 16.66
18 50. 0. 8.33 ; 19 50. 0. 0. ; 20 41.65 0. 0.;21 33.32 0. 0.
22 25. 0. 0. ; 23 16.66 0. 0. ; 24 8.33 0. 0. ; 25 25. 0. 25.
26 25. 0. 33.32 ; 27 25. 0. 41.65 ; 28 33.32 0. 25. ; 29 41.65 0. 25.
30 25. 0. 16.66;31 25. 0. 8.33 ; 32 16.66 0. 25. ; 33 8.33 0. 25.
R A 20 0 10 0
MEMBER INCIDENCES
* COLUMN MEMBERS
R A 0 0 0
1 1 34 ; 2 2 35 ; 3 3 36 ; 4 4 37 ; 5 5 38 ; 6 6 39 ; 7 7 40 ; 8 8 41
9 9 42 ; 10 10 43 ; 11 11 44 ; 12 12 45 ; 13 13 46 ; 14 14 47
15 15 48 ;16 16 49 ; 17 17 50 ; 18 18 51 ; 19 19 52 ; 20 20 53
21 21 54 ; 22 22 55;23 23 56 ; 24 24 57 ; 25 25 58 ; 26 26 59
27 27 60 ; 28 28 61 ; 29 29 62;30 30 63 ; 31 31 64 ; 32 32 65
33 33 66
R A 19 33 33
* BEAM MEMBERS
R A 0 0 0
1001 34 35 ; 1002 35 36 ; 1003 36 37 ; 1004 37 38 ; 1005 38 39
1006 39 40;1007 40 41 ;1008 41 42 ; 1009 42 43 ; 1010 43 44
1011 44 45 ; 1012 45 46 ;1013 46 47;1014 47 48 ; 1015 48 49
1016 49 50 ; 1017 50 51;1018 51 52 ; 1019 52 53;1020 53 54
1021 54 55 ;1022 55 56 ;1023 56 57 ; 1024 57 34 ; 1025 58 59
1026 59 60 ; 1027 60 43;1028 61 58 ; 1029 62 61 ; 1030 49 62
1031 63 58 ;1032 64 63;1033 55 64 ; 1034 58 65 ; 1035 65 66
1036 66 37
R A 19 36 33
MEMBER PROPERTY
* COLUMN MEMBERS
```

```
1 TO 660 PRI YD 2.25 ZD 2.25
* BEAM MEMBERS
1001 TO 1720 PRI YD 3.655 ZD 1.5
*
MEMBER OFFSET
* COLUMN MEMBERS
1 TO 33 START 0. 1.8275 0.
1 TO 33 END 0. -1.8275 0.
34 TO 66 START 0. 1.8275 0.
34 TO 66 END 0. -1.8275 0.
67 TO 99 START 0. 1.8275 0.
67 TO 99 END 0. -1.8275 0.
100 TO 132 START 0. 1.8275 0.
100 TO 132 END 0. -1.8275 0.
133 TO 165 START 0. 1.8275 0.
133 TO 165 END 0. -1.8275 0.
166 TO 198 START 0. 1.8275 0.
166 TO 198 END 0. -1.8275 0.
199 TO 231 START 0. 1.8275 0.
199 TO 231 END 0. -1.8275 0.
232 TO 264 START 0. 1.8275 0.
232 TO 264 END 0. -1.8275 0.
265 TO 297 START 0. 1.8275 0.
265 TO 297 END 0. -1.8275 0.
298 TO 330 START 0. 1.8275 0.
298 TO 330 END 0. -1.8275 0.
331 TO 363 START 0. 1.8275 0.
331 TO 363 END 0. -1.8275 0.
364 TO 396 START 0. 1.8275 0.
364 TO 396 END 0. -1.8275 0.
397 TO 429 START 0. 1.8275 0.
397 TO 429 END 0. -1.8275 0.
430 TO 462 START 0. 1.8275 0.
430 TO 462 END 0. -1.8275 0.
463 TO 495 START 0. 1.8275 0.
463 TO 495 END 0. -1.8275 0.
496 TO 528 START 0. 1.8275 0.
496 TO 528 END 0. -1.8275 0.
529 TO 561 START 0. 1.8275 0.
529 TO 561 END 0. -1.8275 0.
562 TO 594 START 0. 1.8275 0.
562 TO 594 END 0. -1.8275 0.
595 TO 627 START 0. 1.8275 0.
595 TO 627 END 0. -1.8275 0.
628 TO 660 START 0. 1.8275 0.
628 TO 660 END 0. -1.8275 0.
* BEAM MEMBERS
1001 TO 1006 1025 TO 1027 1031 TO 1033 START 0. 0. 1.125
1001 TO 1006 1025 TO 1027 1031 TO 1033 END 0. 0. -1.125
1037 TO 1042 1061 TO 1063 1067 TO 1069 START 0. 0. 1.125
1037 TO 1042 1061 TO 1063 1067 TO 1069 END 0. 0. -1.125
1073 TO 1078 1097 TO 1099 1103 TO 1105 START 0. 0. 1.125
1073 TO 1078 1097 TO 1099 1103 TO 1105 END 0. 0. -1.125
1109 TO 1114 1133 TO 1135 1139 TO 1141 START 0. 0. 1.125
1109 TO 1114 1133 TO 1135 1139 TO 1141 END 0. 0. -1.125
```

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1145 TO 1150 1169 TO 1171 1175 TO 1177 START 0. 0. 1.125
1145 TO 1150 1169 TO 1171 1175 TO 1177 END 0. 0. -1.125
1181 TO 1186 1205 TO 1207 1211 TO 1213 START 0. 0. 1.125
1181 TO 1186 1205 TO 1207 1211 TO 1213 END 0. 0. -1.125
1217 TO 1222 1241 TO 1243 1247 TO 1249 START 0. 0. 1.125
1217 TO 1222 1241 TO 1243 1247 TO 1249 END 0. 0. -1.125
1253 TO 1258 1277 TO 1279 1283 TO 1285 START 0. 0. 1.125
1253 TO 1258 1277 TO 1279 1283 TO 1285 END 0. 0. -1.125
1289 TO 1294 1313 TO 1315 1319 TO 1321 START 0. 0. 1.125
1289 TO 1294 1313 TO 1315 1319 TO 1321 END 0. 0. -1.125
1325 TO 1330 1349 TO 1351 1355 TO 1357 START 0. 0. 1.125
1325 TO 1330 1349 TO 1351 1355 TO 1357 END 0. 0. -1.125
1361 TO 1366 1385 TO 1387 1391 TO 1393 START 0. 0. 1.125
1361 TO 1366 1385 TO 1387 1391 TO 1393 END 0. 0. -1.125
1397 TO 1402 1421 TO 1423 1427 TO 1429 START 0. 0. 1.125
1397 TO 1402 1421 TO 1423 1427 TO 1429 END 0. 0. -1.125
1433 TO 1438 1457 TO 1459 1463 TO 1465 START 0. 0. 1.125
1433 TO 1438 1457 TO 1459 1463 TO 1465 END 0. 0. -1.125
1469 TO 1474 1493 TO 1495 1499 TO 1501 START 0. 0. 1.125
1469 TO 1474 1493 TO 1495 1499 TO 1501 END 0. 0. -1.125
1505 TO 1510 1529 TO 1531 1535 TO 1537 START 0. 0. 1.125
1505 TO 1510 1529 TO 1531 1535 TO 1537 END 0. 0. -1.125
1541 TO 1546 1565 TO 1567 1571 TO 1573 START 0. 0. 1.125
1541 TO 1546 1565 TO 1567 1571 TO 1573 END 0. 0. -1.125
1577 TO 1582 1601 TO 1603 1607 TO 1609 START 0. 0. 1.125
1577 TO 1582 1601 TO 1603 1607 TO 1609 END 0. 0. -1.125
1613 TO 1618 1637 TO 1639 1643 TO 1645 START 0. 0. 1.125
1613 TO 1618 1637 TO 1639 1643 TO 1645 END 0. 0. -1.125
1649 TO 1654 1673 TO 1675 1679 TO 1681 START 0. 0. 1.125
1649 TO 1654 1673 TO 1675 1679 TO 1681 END 0. 0. -1.125
1685 TO 1690 1709 TO 1711 1715 TO 1717 START 0. 0. 1.125
1685 TO 1690 1709 TO 1711 1715 TO 1717 END 0. 0. -1.125
*
1013 TO 1018 START 0. 0. -1.125
1013 TO 1018 END 0. 0. 1.125
1049 TO 1054 START 0. 0. -1.125
1049 TO 1054 END 0. 0. 1.125
1085 TO 1090 START 0. 0. -1.125
1085 TO 1090 END 0. 0. 1.125
1121 TO 1126 START 0. 0. -1.125
1121 TO 1126 END 0. 0. 1.125
1157 TO 1162 START 0. 0. -1.125
1157 TO 1162 END 0. 0. 1.125
1193 TO 1198 START 0. 0. -1.125
1193 TO 1198 END 0. 0. 1.125
1229 TO 1234 START 0. 0. -1.125
1229 TO 1234 END 0. 0. 1.125
1265 TO 1270 START 0. 0. -1.125
1265 TO 1270 END 0. 0. 1.125
1301 TO 1306 START 0. 0. -1.125
1301 TO 1306 END 0. 0. 1.125
1337 TO 1342 START 0. 0. -1.125
1337 TO 1342 END 0. 0. 1.125
1373 TO 1378 START 0. 0. -1.125
1373 TO 1378 END 0. 0. 1.125
```

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1409 TO 1414 START 0. 0. -1.125
1409 TO 1414 END 0. 0. 1.125
1445 TO 1450 START 0. 0. -1.125
1445 TO 1450 END 0. 0. 1.125
1481 TO 1486 START 0. 0. -1.125
1481 TO 1486 END 0. 0. 1.125
1517 TO 1522 START 0. 0. -1.125
1517 TO 1522 END 0. 0. 1.125
1553 TO 1558 START 0. 0. -1.125
1553 TO 1558 END 0. 0. 1.125
1589 TO 1594 START 0. 0. -1.125
1589 TO 1594 END 0. 0. 1.125
1625 TO 1630 START 0. 0. -1.125
1625 TO 1630 END 0. 0. 1.125
1661 TO 1666 START 0. 0. -1.125
1661 TO 1666 END 0. 0. 1.125
1697 TO 1702 START 0. 0. -1.125
1697 TO 1702 END 0. 0. 1.125
*
1007 TO 1012 START 1.125 0. 0.
1007 TO 1012 END -1.125 0. 0.
1043 TO 1048 START 1.125 0. 0.
1043 TO 1048 END -1.125 0. 0.
1079 TO 1084 START 1.125 0. 0.
1079 TO 1084 END -1.125 0. 0.
1115 TO 1120 START 1.125 0. 0.
1115 TO 1120 END -1.125 0. 0.
1151 TO 1156 START 1.125 0. 0.
1151 TO 1156 END -1.125 0. 0.
1187 TO 1192 START 1.125 0. 0.
1187 TO 1192 END -1.125 0. 0.
1223 TO 1228 START 1.125 0. 0.
1223 TO 1228 END -1.125 0. 0.
1259 TO 1264 START 1.125 0. 0.
1259 TO 1264 END -1.125 0. 0.
1295 TO 1300 START 1.125 0. 0.
1295 TO 1300 END -1.125 0. 0.
1331 TO 1336 START 1.125 0. 0.
1331 TO 1336 END -1.125 0. 0.
1367 TO 1372 START 1.125 0. 0.
1367 TO 1372 END -1.125 0. 0.
1403 TO 1408 START 1.125 0. 0.
1403 TO 1408 END -1.125 0. 0.
1439 TO 1444 START 1.125 0. 0.
1439 TO 1444 END -1.125 0. 0.
1475 TO 1480 START 1.125 0. 0.
1475 TO 1480 END -1.125 0. 0.
1511 TO 1516 START 1.125 0. 0.
1511 TO 1516 END -1.125 0. 0.
1547 TO 1552 START 1.125 0. 0.
1547 TO 1552 END -1.125 0. 0.
1583 TO 1588 START 1.125 0. 0.
1583 TO 1588 END -1.125 0. 0.
1619 TO 1624 START 1.125 0. 0.
1619 TO 1624 END -1.125 0. 0.
```

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1655 TO 1660 START 1.125 0. 0.
1655 TO 1660 END -1.125 0. 0.
1691 TO 1696 START 1.125 0. 0.
1691 TO 1696 END -1.125 0. 0.
*
1019 TO 1024 1028 TO 1030 1034 TO 1036 START -1.125 0. 0.
1019 TO 1024 1028 TO 1030 1034 TO 1036 END 1.125 0. 0.
1055 TO 1060 1064 TO 1066 1070 TO 1072 START -1.125 0. 0.
1055 TO 1060 1064 TO 1066 1070 TO 1072 END 1.125 0. 0.
1091 TO 1096 1100 TO 1102 1106 TO 1108 START -1.125 0. 0.
1091 TO 1096 1100 TO 1102 1106 TO 1108 END 1.125 0. 0.
1127 TO 1132 1136 TO 1138 1142 TO 1144 START -1.125 0. 0.
1127 TO 1132 1136 TO 1138 1142 TO 1144 END 1.125 0. 0.
1163 TO 1168 1172 TO 1174 1178 TO 1180 START -1.125 0. 0.
1163 TO 1168 1172 TO 1174 1178 TO 1180 END 1.125 0. 0.
1199 TO 1204 1208 TO 1210 1214 TO 1216 START -1.125 0. 0.
1199 TO 1204 1208 TO 1210 1214 TO 1216 END 1.125 0. 0.
1235 TO 1240 1244 TO 1246 1250 TO 1252 START -1.125 0. 0.
1235 TO 1240 1244 TO 1246 1250 TO 1252 END 1.125 0. 0.
1271 TO 1276 1280 TO 1282 1286 TO 1288 START -1.125 0. 0.
1271 TO 1276 1280 TO 1282 1286 TO 1288 END 1.125 0. 0.
1307 TO 1312 1316 TO 1318 1322 TO 1324 START -1.125 0. 0.
1307 TO 1312 1316 TO 1318 1322 TO 1324 END 1.125 0. 0.
1343 TO 1348 1352 TO 1354 1358 TO 1360 START -1.125 0. 0.
1343 TO 1348 1352 TO 1354 1358 TO 1360 END 1.125 0. 0.
1379 TO 1384 1388 TO 1390 1394 TO 1396 START -1.125 0. 0.
1379 TO 1384 1388 TO 1390 1394 TO 1396 END 1.125 0. 0.
1415 TO 1420 1424 TO 1426 1430 TO 1432 START -1.125 0. 0.
1415 TO 1420 1424 TO 1426 1430 TO 1432 END 1.125 0. 0.
1451 TO 1456 1460 TO 1462 1466 TO 1468 START -1.125 0. 0.
1451 TO 1456 1460 TO 1462 1466 TO 1468 END 1.125 0. 0.
1487 TO 1492 1496 TO 1498 1502 TO 1504 START -1.125 0. 0.
1487 TO 1492 1496 TO 1498 1502 TO 1504 END 1.125 0. 0.
1523 TO 1528 1532 TO 1534 1538 TO 1540 START -1.125 0. 0.
1523 TO 1528 1532 TO 1534 1538 TO 1540 END 1.125 0. 0.
1559 TO 1564 1568 TO 1570 1574 TO 1576 START -1.125 0. 0.
1559 TO 1564 1568 TO 1570 1574 TO 1576 END 1.125 0. 0.
1595 TO 1600 1604 TO 1606 1610 TO 1612 START -1.125 0. 0.
1595 TO 1600 1604 TO 1606 1610 TO 1612 END 1.125 0. 0.
1631 TO 1636 1640 TO 1642 1646 TO 1648 START -1.125 0. 0.
1631 TO 1636 1640 TO 1642 1646 TO 1648 END 1.125 0. 0.
1667 TO 1672 1676 TO 1678 1682 TO 1684 START -1.125 0. 0.
1667 TO 1672 1676 TO 1678 1682 TO 1684 END 1.125 0. 0.
1703 TO 1708 1712 TO 1714 1718 TO 1720 START -1.125 0. 0.
1703 TO 1708 1712 TO 1714 1718 TO 1720 END 1.125 0. 0.
*
CONSTANTS
E 432000 ALL
POI 0.18 ALL
SUPPORT
1 TO 33 FIXED
*
LOAD 2  LATERAL LOAD
JOI LOAD
58 FZ 10
```

```
91 FZ 10
124 FZ 10
157 FZ 10
190 FZ 10
223 FZ 10
256 FZ 10
289 FZ 10
322 FZ 10
355 FZ 10
388 FZ 10
421 FZ 10
454 FZ 10
487 FZ 10
520 FZ 10
553 FZ 10
586 FZ 10
619 FZ 10
652 FZ 10
685 FZ 5
PERFORM ANALYSIS
PRI JOI COORD
PRI MEM FORCES
PRINT ANALYSIS RESULTS
*PRINT CG
*PRINT JOI DISPLACEMENTS
PRI SUPPORT REACTIONS
*PRI MAT PROP
*PRI MEM INF
FIN
```

APPENDIX B.2 STAAD-III/ISDS Input Data File for Example Problem 2

The following is a sample of the input data file for space frame analysis of the example problem no 2 (for uniformly distributed load of 1k/ft acting in the long direction) using the microcomputer package STAAD-III/ISDS.

```
STAAD SPACE
UNIT KIP FT
JOINT COORDINATE
R A 0 0 0
1 0. 0. 0.; 2 4.165 0. 4.165; 3 4.165 0. 12.5 ; 4 4.165 0. 20.83
5 0. 0. 25. ; 6 -8.33 0. 25. ; 7 -16.66 0. 25. ; 8 -20.83 0. 20.83
9 -20.83 0. 12.5; 10 -20.83 0. 4.165; 11 -16.66 0. 0. ; 12 -8.33 0. 0.
13 -25. 0. 25. ; 14 -25. 0. 33.33 ; 15 -25. 0. 41.66 ; 16 -20. 0. 50.
17 -15. 0. 50. ; 18 -10. 0. 50. ; 19 -5. 0. 50. ; 20 0. 0. 41.66
21 0. 0. 33.33 ; 22 -25. 0. 55.55 ; 23 -30. 0. 61.11
24 -35. 0. 66.66; 25 -35. 0. 75.; 26 -26.67 0. 75. ; 27 -18.34 0. 75.
28 -10. 0. 75.;29 -10. 0. 66.66 ; 30 -10. 0. 58.34
R A 20 0 10 0
MEMBER INCIDENCES
* COLUMN MEMBERS
R A 0 0 0
1 1 31 ; 2 2 32 ; 3 3 33 ; 4 4 34 ; 5 5 35 ; 6 6 36 ; 7 7 37 ; 8 8 38
9 9 39 ; 10 10 40 ; 11 11 41 ; 12 12 42 ; 13 13 43 ; 14 14 44
15 15 45;16 16 46 ; 17 17 47 ; 18 18 48 ; 19 19 49 ; 20 20 50
21 21 51 ; 22 22 52;23 23 53 ; 24 24 54 ; 25 25 55 ; 26 26 56
27 27 57 ; 28 28 58 ; 29 29 59;30 30 60
R A 19 30 30
* BEAM MEMBERS
R A 0 0 0
1001 31 32 ; 1002 32 33 ; 1003 33 34 ; 1004 34 35 ; 1005 35 36
1006 36 37
1007 37 38;1008 38 39 ; 1009 39 40 ; 1010 40 41 ; 1011 41 42
1012 42 31 ; 1013 37 43 ;1014 43 44 ; 1015 44 45 ; 1016 45 46
1017 46 47 ; 1018 47 48 ; 1019 48 49;1020 49 50 ; 1021 50 51
1022 51 36 ; 1023 46 52 ; 1024 52 53 ; 1025 53 54;1026 54 55
1027 55 56 ; 1028 56 57 ; 1029 57 58 ; 1030 58 59 ; 1031 59 60
1032 60 48
R A 19 32 30
*
MEM PRO
* COLUMN MEMBERS
1 TO 600 PRI YD 2.25 ZD 2.25
1001 TO 1640 PRI YD 3.655 ZD 1.5
*
MEMBER OFFSET
* COLUMN MEMBERS
1 TO 30 START 0. 1.8275 0.
1 TO 30 END 0. -1.8275 0.
31 TO 60 START 0. 1.8275 0.
```

```
31 TO 60 END 0. -1.8275 0.
61 TO 90 START 0. 1.8275 0.
61 TO 90 END 0. -1.8275 0.
91 TO 120 START 0. 1.8275 0.
91 TO 120 END 0. -1.8275 0.
121 TO 150 START 0. 1.8275 0.
121 TO 150 END 0. -1.8275 0.
151 TO 180 START 0. 1.8275 0.
151 TO 180 END 0. -1.8275 0.
181 TO 210 START 0. 1.8275 0.
181 TO 210 END 0. -1.8275 0.
211 TO 240 START 0. 1.8275 0.
211 TO 240 END 0. -1.8275 0.
241 TO 270 START 0. 1.8275 0.
241 TO 270 END 0. -1.8275 0.
271 TO 300 START 0. 1.8275 0.
271 TO 300 END 0. -1.8275 0.
301 TO 330 START 0. 1.8275 0.
301 TO 330 END 0. -1.8275 0.
331 TO 360 START 0. 1.8275 0.
331 TO 360 END 0. -1.8275 0.
361 TO 390 START 0. 1.8275 0.
361 TO 390 END 0. -1.8275 0.
391 TO 420 START 0. 1.8275 0.
391 TO 420 END 0. -1.8275 0.
421 TO 450 START 0. 1.8275 0.
421 TO 450 END 0. -1.8275 0.
451 TO 480 START 0. 1.8275 0.
451 TO 480 END 0. -1.8275 0.
481 TO 510 START 0. 1.8275 0.
481 TO 510 END 0. -1.8275 0.
511 TO 540 START 0. 1.8275 0.
511 TO 540 END 0. -1.8275 0.
541 TO 570 START 0. 1.8275 0.
541 TO 570 END 0. -1.8275 0.
571 TO 600 START 0. 1.8275 0.
571 TO 600 END 0. -1.8275 0.
*BEAM MEMBERS
1002 1003 1014 1015 1026 START 0. 0. 1.125
1002 1003 1014 1015 1026 END 0. 0. -1.125
1034 1035 1046 1047 1058 START 0. 0. 1.125
1034 1035 1046 1047 1058 END 0. 0. -1.125
1066 1067 1078 1079 1090 START 0. 0. 1.125
1066 1067 1078 1079 1090 END 0. 0. -1.125
1098 1099 1110 1111 1122 START 0. 0. 1.125
1098 1099 1110 1111 1122 END 0. 0. -1.125
1130 1131 1142 1143 1154 START 0. 0. 1.125
1130 1131 1142 1143 1154 END 0. 0. -1.125
1162 1163 1174 1175 1186 START 0. 0. 1.125
1162 1163 1174 1175 1186 END 0. 0. -1.125
1194 1195 1206 1207 1218 START 0. 0. 1.125
1194 1195 1206 1207 1218 END 0. 0. -1.125
1226 1227 1238 1239 1250 START 0. 0. 1.125
1226 1227 1238 1239 1250 END 0. 0. -1.125
1258 1259 1270 1271 1282 START 0. 0. 1.125
```

```
1258 1259 1270 1271 1282 END 0. 0. -1.125
1290 1291 1302 1303 1314 START 0. 0. 1.125
1290 1291 1302 1303 1314 END 0. 0. -1.125
1322 1323 1334 1335 1346 START 0. 0. 1.125
1322 1323 1334 1335 1346 END 0. 0. -1.125
1354 1355 1366 1367 1378 START 0. 0. 1.125
1354 1355 1366 1367 1378 END 0. 0. -1.125
1386 1387 1398 1399 1410 START 0. 0. 1.125
1386 1387 1398 1399 1410 END 0. 0. -1.125
1418 1419 1430 1431 1442 START 0. 0. 1.125
1418 1419 1430 1431 1442 END 0. 0. -1.125
1450 1451 1462 1463 1474 START 0. 0. 1.125
1450 1451 1462 1463 1474 END 0. 0. -1.125
1482 1483 1494 1495 1506 START 0. 0. 1.125
1482 1483 1494 1495 1506 END 0. 0. -1.125
1514 1515 1526 1527 1538 START 0. 0. 1.125
1514 1515 1526 1527 1538 END 0. 0. -1.125
1546 1547 1558 1559 1570 START 0. 0. 1.125
1546 1547 1558 1559 1570 END 0. 0. -1.125
1578 1579 1590 1591 1602 START 0. 0. 1.125
1578 1579 1590 1591 1602 END 0. 0. -1.125
1610 1611 1622 1623 1634 START 0. 0. 1.125
1610 1611 1622 1623 1634 END 0. 0. -1.125
*
1008 1009 1021 1030 1031 1032 START 0. 0. -1.125
1008 1009 1021 1030 1031 1032 END 0. 0. 1.125
1040 1041 1053 1062 1063 1064 START 0. 0. -1.125
1040 1041 1053 1062 1063 1064 END 0. 0. 1.125
1072 1073 1085 1094 1095 1096 START 0. 0. -1.125
1072 1073 1085 1094 1095 1096 END 0. 0. 1.125
1104 1105 1117 1126 1127 1128 START 0. 0. -1.125
1104 1105 1117 1126 1127 1128 END 0. 0. 1.125
1136 1137 1149 1158 1159 1160 START 0. 0. -1.125
1136 1137 1149 1158 1159 1160 END 0. 0. 1.125
1168 1169 1181 1190 1191 1192 START 0. 0. -1.125
1168 1169 1181 1190 1191 1192 END 0. 0. 1.125
1200 1201 1213 1222 1223 1224 START 0. 0. -1.125
1200 1201 1213 1222 1223 1224 END 0. 0. 1.125
1232 1233 1245 1254 1255 1256 START 0. 0. -1.125
1232 1233 1245 1254 1255 1256 END 0. 0. 1.125
1264 1265 1277 1286 1287 1288 START 0. 0. -1.125
1264 1265 1277 1286 1287 1288 END 0. 0. 1.125
1296 1297 1309 1318 1319 1320 START 0. 0. -1.125
1296 1297 1309 1318 1319 1320 END 0. 0. 1.125
1328 1329 1341 1350 1351 1352 START 0. 0. -1.125
1328 1329 1341 1350 1351 1352 END 0. 0. 1.125
1360 1361 1373 1382 1383 1384 START 0. 0. -1.125
1360 1361 1373 1382 1383 1384 END 0. 0. 1.125
1392 1393 1405 1414 1415 1416 START 0. 0. -1.125
1392 1393 1405 1414 1415 1416 END 0. 0. 1.125
1424 1325 1437 1446 1447 1448 START 0. 0. -1.125
1424 1325 1437 1446 1447 1448 END 0. 0. 1.125
1456 1457 1469 1478 1479 1480 START 0. 0. -1.125
1456 1457 1469 1478 1479 1480 END 0. 0. 1.125
1488 1489 1501 1510 1511 1512 START 0. 0. -1.125
```

```
1488 1489 1501 1510 1511 1512 END 0. 0. 1.125
1520 1521 1533 1542 1543 1544 START 0. 0. -1.125
1520 1521 1533 1542 1543 1544 END 0. 0. 1.125
1552 1553 1565 1574 1575 1576 START 0. 0. -1.125
1552 1553 1565 1574 1575 1576 END 0. 0. 1.125
1584 1585 1597 1606 1607 1608 START 0. 0. -1.125
1584 1585 1597 1606 1607 1608 END 0. 0. 1.125
1616 1617 1629 1638 1639 1640 START 0. 0. -1.125
1616 1617 1629 1638 1639 1640 END 0. 0. 1.125
*
1005 1006 1013 START -1.125 0.0 0.
1005 1006 1013 END 1.125 0.0 0.
1037 1038 1045 START -1.125 0.0 0.
1037 1038 1045 END 1.125 0.0 0.
1069 1070 1077 START -1.125 0.0 0.
1069 1070 1077 END 1.125 0.0 0.
1101 1102 1109 START -1.125 0.0 0.
1101 1102 1109 END 1.125 0.0 0.
1133 1134 1141 START -1.125 0.0 0.
1133 1134 1141 END 1.125 0.0 0.
1165 1166 1173 START -1.125 0.0 0.
1165 1166 1173 END 1.125 0.0 0.
1197 1198 1205 START -1.125 0.0 0.
1197 1198 1205 END 1.125 0.0 0.
1229 1230 1237 START -1.125 0.0 0.
1229 1230 1237 END 1.125 0.0 0.
1261 1262 1269 START -1.125 0.0 0.
1261 1262 1269 END 1.125 0.0 0.
1293 1294 1301 START -1.125 0.0 0.
1293 1294 1301 END 1.125 0.0 0.
1325 1326 1333 START -1.125 0.0 0.
1325 1326 1333 END 1.125 0.0 0.
1357 1358 1365 START -1.125 0.0 0.
1357 1358 1365 END 1.125 0.0 0.
1389 1390 1397 START -1.125 0.0 0.
1389 1390 1397 END 1.125 0.0 0.
1421 1322 1429 START -1.125 0.0 0.
1421 1322 1429 END 1.125 0.0 0.
1453 1454 1461 START -1.125 0.0 0.
1453 1454 1461 END 1.125 0.0 0.
1485 1486 1493 START -1.125 0.0 0.
1485 1486 1493 END 1.125 0.0 0.
1517 1518 1525 START -1.125 0.0 0.
1517 1518 1525 END 1.125 0.0 0.
1549 1550 1557 START -1.125 0.0 0.
1549 1550 1557 END 1.125 0.0 0.
1581 1582 1589 START -1.125 0.0 0.
1581 1582 1589 END 1.125 0.0 0.
1613 1614 1621 START -1.125 0.0 0.
1613 1614 1621 END 1.125 0.0 0.
*
1011 1012 1017 1018 1019 1027 1028 1029 START 1.125 0. 0.
1011 1012 1017 1018 1019 1027 1028 1029 END -1.125 0. 0.
1043 1044 1049 1050 1051 1059 1060 1061 START 1.125 0. 0.
1043 1044 1049 1050 1051 1059 1060 1061 END -1.125 0. 0.
```

```
1075 1076 1081 1082 1083 1091 1092 1093 START 1.125 0. 0.
1075 1076 1081 1082 1083 1091 1092 1093 END -1.125 0. 0.
1107 1108 1113 1114 1115 1123 1124 1125 START 1.125 0. 0.
1107 1108 1113 1114 1115 1123 1124 1125 END -1.125 0. 0.
1139 1140 1145 1146 1147 1155 1156 1157 START 1.125 0. 0.
1139 1140 1145 1146 1147 1155 1156 1157 END -1.125 0. 0.
1171 1172 1177 1178 1179 1187 1188 1189 START 1.125 0. 0.
1171 1172 1177 1178 1179 1187 1188 1189 END -1.125 0. 0.
1203 1204 1209 1210 1211 1219 1220 1221 START 1.125 0. 0.
1203 1204 1209 1210 1211 1219 1220 1221 END -1.125 0. 0.
1235 1236 1241 1242 1243 1251 1252 1253 START 1.125 0. 0.
1235 1236 1241 1242 1243 1251 1252 1253 END -1.125 0. 0.
1267 1268 1273 1274 1275 1283 1284 1285 START 1.125 0. 0.
1267 1268 1273 1274 1275 1283 1284 1285 END -1.125 0. 0.
1299 1300 1305 1306 1307 1315 1316 1317 START 1.125 0. 0.
1299 1300 1305 1306 1307 1315 1316 1317 END -1.125 0. 0.
1331 1332 1337 1338 1339 1347 1348 1349 START 1.125 0. 0.
1331 1332 1337 1338 1339 1347 1348 1349 END -1.125 0. 0.
1363 1364 1369 1370 1371 1379 1380 1381 START 1.125 0. 0.
1363 1364 1369 1370 1371 1379 1380 1481 END -1.125 0. 0.
1395 1396 1401 1402 1403 1411 1412 1413 START 1.125 0. 0.
1395 1396 1401 1402 1403 1411 1412 1413 END -1.125 0. 0.
1427 1428 1433 1434 1435 1443 1444 1445 START 1.125 0. 0.
1427 1428 1433 1434 1435 1443 1444 1445 END -1.125 0. 0.
1459 1460 1465 1466 1467 1475 1476 1477 START 1.125 0. 0.
1459 1460 1465 1466 1467 1475 1476 1477 END -1.125 0. 0.
1491 1492 1497 1498 1499 1507 1508 1509 START 1.125 0. 0.
1491 1492 1497 1498 1499 1507 1508 1509 END -1.125 0. 0.
1523 1524 1529 1530 1531 1539 1540 1541 START 1.125 0. 0.
1523 1524 1529 1530 1531 1539 1540 1541 END -1.125 0. 0.
1555 1556 1561 1562 1563 1571 1572 1573 START 1.125 0. 0.
1555 1556 1561 1562 1563 1571 1572 1573 END -1.125 0. 0.
1587 1588 1593 1594 1595 1603 1604 1605 START 1.125 0. 0.
1587 1588 1593 1594 1595 1603 1604 1605 END -1.125 0. 0.
1619 1620 1625 1626 1627 1635 1636 1637 START 1.125 0. 0.
1619 1620 1625 1626 1627 1635 1636 1637 END -1.125 0. 0.
*
1001 START .7955 0. .7955
1001 END -.7955 0. -.7955
1033 START .7955 0. .7955
1033 END -.7955 0. -.7955
1065 START .7955 0. .7955
1065 END -.7955 0. -.7955
1097 START .7955 0. .7955
1097 END -.7955 0. -.7955
1129 START .7955 0. .7955
1129 END -.7955 0. -.7955
1161 START .7955 0. .7955
1161 END -.7955 0. -.7955
1193 START .7955 0. .7955
1193 END -.7955 0. -.7955
1225 START .7955 0. .7955
1225 END -.7955 0. -.7955
1257 START .7955 0. .7955
1257 END -.7955 0. -.7955
```

```
1289 START .7955 0. .7955
1289 END -.7955 0. -.7955
1321 START .7955 0. .7955
1321 END -.7955 0. -.7955
1353 START .7955 0. .7955
1353 END -.7955 0. -.7955
1385 START .7955 0. .7955
1385 END -.7955 0. -.7955
1417 START .7955 0. .7955
1417 END -.7955 0. -.7955
1449 START .7955 0. .7955
1449 END -.7955 0. -.7955
1481 START .7955 0. .7955
1481 END -.7955 0. -.7955
1513 START .7955 0. .7955
1513 END -.7955 0. -.7955
1545 START .7955 0. .7955
1545 END -.7955 0. -.7955
1577 START .7955 0. .7955
1577 END -.7955 0. -.7955
1609 START .7955 0. .7955
1609 END -.7955 0. -.7955
*
1004 START -.7955 0. .7955
1004 END .7955 0. -.7955
1036 START -.7955 0. .7955
1036 END .7955 0. -.7955
1068 START -.7955 0. .7955
1068 END .7955 0. -.7955
1100 START -.7955 0. .7955
1100 END .7955 0. -.7955
1132 START -.7955 0. .7955
1132 END .7955 0. -.7955
1164 START -.7955 0. .7955
1164 END .7955 0. -.7955
1196 START -.7955 0. .7955
1196 END .7955 0. -.7955
1228 START -.7955 0. .7955
1228 END .7955 0. -.7955
1260 START -.7955 0. .7955
1260 END .7955 0. -.7955
1292 START -.7955 0. .7955
1292 END .7955 0. -.7955
1324 START -.7955 0. .7955
1324 END .7955 0. -.7955
1356 START -.7955 0. .7955
1356 END .7955 0. -.7955
1388 START -.7955 0. .7955
1388 END .7955 0. -.7955
1420 START -.7955 0. .7955
1420 END .7955 0. -.7955
1452 START -.7955 0. .7955
1452 END .7955 0. -.7955
1484 START -.7955 0. .7955
1484 END .7955 0. -.7955
```

```
1516 START -.7955 0. .7955
1516 END .7955 0. -.7955
1548 START -.7955 0. .7955
1548 END .7955 0. -.7955
1580 START -.7955 0. .7955
1580 END .7955 0. -.7955
1612 START -.7955 0. .7955
1612 END .7955 0. -.7955
*
1007 1022 START -.7955 0. -.7955
1007 1022 END .7955 0. .7955
1039 1054 START -.7955 0. -.7955
1039 1054 END .7955 0. .7955
1071 1086 START -.7955 0. -.7955
1071 1086 END .7955 0. .7955
1103 1118 START -.7955 0. -.7955
1103 1118 END .7955 0. .7955
1135 1150 START -.7955 0. -.7955
1135 1150 END .7955 0. .7955
1167 1182 START -.7955 0. -.7955
1167 1182 END .7955 0. .7955
1199 1214 START -.7955 0. -.7955
1199 1214 END .7955 0. .7955
1231 1246 START -.7955 0. -.7955
1231 1246 END .7955 0. .7955
1263 1278 START -.7955 0. -.7955
1263 1278 END .7955 0. .7955
1295 1310 START -.7955 0. -.7955
1295 1310 END .7955 0. .7955
1327 1342 START -.7955 0. -.7955
1327 1342 END .7955 0. .7955
1359 1374 START -.7955 0. -.7955
1359 1374 END .7955 0. .7955
1391 1406 START -.7955 0. -.7955
1391 1406 END .7955 0. .7955
1423 1438 START -.7955 0. -.7955
1423 1438 END .7955 0. .7955
1455 1470 START -.7955 0. -.7955
1455 1470 END .7955 0. .7955
1487 1502 START -.7955 0. -.7955
1487 1502 END .7955 0. .7955
1519 1534 START -.7955 0. -.7955
1519 1534 END .7955 0. .7955
1551 1566 START -.7955 0. -.7955
1551 1566 END .7955 0. .7955
1583 1598 START -.7955 0. -.7955
1583 1598 END .7955 0. .7955
1615 1630 START -.7955 0. -.7955
1615 1630 END .7955 0. .7955
*
1010 START .7955 0. -.7955
1010 END -.7955 0. .7955
1042 START .7955 0. -.7955
1042 END -.7955 0. .7955
1074 START .7955 0. -.7955
```

```
1074 END -.7955 0. .7955
1106 START .7955 0. -.7955
1106 END -.7955 0. .7955
1138 START .7955 0. -.7955
1138 END -.7955 0. .7955
1170 START .7955 0. -.7955
1170 END -.7955 0. .7955
1202 START .7955 0. -.7955
1202 END -.7955 0. .7955
1234 START .7955 0. -.7955
1234 END -.7955 0. .7955
1266 START .7955 0. -.7955
1266 END -.7955 0. .7955
1298 START .7955 0. -.7955
1298 END -.7955 0. .7955
1330 START .7955 0. -.7955
1330 END -.7955 0. .7955
1362 START .7955 0. -.7955
1362 END -.7955 0. .7955
1394 START .7955 0. -.7955
1394 END -.7955 0. .7955
1426 START .7955 0. -.7955
1426 END -.7955 0. .7955
1458 START .7955 0. -.7955
1458 END -.7955 0. .7955
1490 START .7955 0. -.7955
1490 END -.7955 0. .7955
1522 START .7955 0. -.7955
1522 END -.7955 0. .7955
1554 START .7955 0. -.7955
1554 END -.7955 0. .7955
1586 START .7955 0. -.7955
1586 END -.7955 0. .7955
1618 START .7955 0. -.7955
1618 END -.7955 0. .7955
*
1016 START .579 0. .9646
1016 END -.579 0. -.9646
1048 START .579 0. .9646
1048 END -.579 0. -.9646
1080 START .579 0. .9646
1080 END -.579 0. -.9646
1112 START .579 0. .9646
1112 END -.579 0. -.9646
1144 START .579 0. .9646
1144 END -.579 0. -.9646
1176 START .579 0. .9646
1176 END -.579 0. -.9646
1208 START .579 0. .9646
1208 END -.579 0. -.9646
1240 START .579 0. .9646
1240 END -.579 0. -.9646
1272 START .579 0. .9646
1272 END -.579 0. -.9646
1304 START .579 0. .9646
```

```
1304 END -.579 0. -.9646
1336 START .579 0. .9646
1336 END -.579 0. -.9646
1368 START .579 0. .9646
1368 END -.579 0. -.9646
1400 START .579 0. .9646
1400 END -.579 0. -.9646
1432 START .579 0. .9646
1432 END -.579 0. -.9646
1464 START .579 0. .9646
1464 END -.579 0. -.9646
1496 START .579 0. .9646
1496 END -.579 0. -.9646
1528 START .579 0. .9646
1528 END -.579 0. -.9646
1560 START .579 0. .9646
1560 END -.579 0. -.9646
1592 START .579 0. .9646
1592 END -.579 0. -.9646
1624 START .579 0. .9646
1624 END -.579 0. -.9646
*
1020 START .579 0. -.9646
1020 END -.579 0. .9646
1052 START .579 0. -.9646
1052 END -.579 0. .9646
1084 START .579 0. -.9646
1084 END -.579 0. .9646
1116 START .579 0. -.9646
1116 END -.579 0. .9646
1148 START .579 0. -.9646
1148 END -.579 0. .9646
1180 START .579 0. -.9646
1180 END -.579 0. .9646
1212 START .579 0. -.9646
1212 END -.579 0. .9646
1244 START .579 0. -.9646
1244 END -.579 0. .9646
1276 START .579 0. -.9646
1276 END -.579 0. .9646
1308 START .579 0. -.9646
1308 END -.579 0. .9646
1340 START .579 0. -.9646
1340 END -.579 0. .9646
1372 START .579 0. -.9646
1372 END -.579 0. .9646
1404 START .579 0. -.9646
1404 END -.579 0. .9646
1436 START .579 0. -.9646
1436 END -.579 0. .9646
1468 START .579 0. -.9646
1468 END -.579 0. .9646
1500 START .579 0. -.9646
1500 END -.579 0. .9646
1532 START .579 0. -.9646
```

```
1532 END -.579 0. .9646
1564 START .579 0. -.9646
1564 END -.579 0. .9646
1596 START .579 0. -.9646
1596 END -.579 0. .9646
1628 START .579 0. -.9646
1628 END -.579 0. .9646
*
1023 1024 1025 START -.7528 0. .8361
1023 1024 1025 END .7528 0. -.8361
1055 1056 1057 START -.7528 0. .8361
1055 1056 1057 END .7528 0. -.8361
1087 1088 1089 START -.7528 0. .8361
1087 1088 1089 END .7528 0. -.8361
1119 1120 1121 START -.7528 0. .8361
1119 1120 1121 END .7528 0. -.8361
1151 1152 1153 START -.7528 0. .8361
1151 1152 1153 END .7528 0. -.8361
1183 1184 1185 START -.7528 0. .8361
1183 1184 1185 END .7528 0. -.8361
1215 1216 1217 START -.7528 0. .8361
1215 1216 1217 END .7528 0. -.8361
1247 1248 1249 START -.7528 0. .8361
1247 1248 1249 END .7528 0. -.8361
1279 1280 1281 START -.7528 0. .8361
1279 1280 1281 END .7528 0. -.8361
1311 1312 1313 START -.7528 0. .8361
1311 1312 1313 END .7528 0. -.8361
1343 1344 1345 START -.7528 0. .8361
1343 1344 1345 END .7528 0. -.8361
1375 1376 1377 START -.7528 0. .8361
1375 1376 1377 END .7528 0. -.8361
1407 1408 1409 START -.7528 0. .8361
1407 1408 1409 END .7528 0. -.8361
1439 1440 1441 START -.7528 0. .8361
1439 1440 1441 END .7528 0. -.8361
1471 1472 1473 START -.7528 0. .8361
1471 1472 1473 END .7528 0. -.8361
1503 1504 1505 START -.7528 0. .8361
1503 1504 1505 END .7528 0. -.8361
1535 1536 1537 START -.7528 0. .8361
1535 1536 1537 END .7528 0. -.8361
1567 1568 1569 START -.7528 0. .8361
1567 1568 1569 END .7528 0. -.8361
1599 1600 1601 START -.7528 0. .8361
1599 1600 1601 END .7528 0. -.8361
1631 1632 1633 START -.7528 0. .8361
1631 1632 1633 END .7528 0. -.8361
*
CONSTANTS
E 432000 ALL
POI 0.18 ALL
*
SUPPORT
1 TO 30 FIXED
```

```
*
LOAD 2  LATERAL LOAD
JOINT LOAD
*14 FZ 3.317; 15 FZ 2.155; 20 FZ 1.783; 21 FZ 2.745
44 FZ 3.317; 45 FZ 2.155; 50 FZ 1.783; 51 FZ 2.745
74 FZ 3.317; 75 FZ 2.155; 80 FZ 1.783; 81 FZ 2.745
104 FZ 3.317; 105 FZ 2.155; 110 FZ 1.783; 111 FZ 2.745
134 FZ 3.317; 135 FZ 2.155; 140 FZ 1.783; 141 FZ 2.745
164 FZ 3.317; 165 FZ 2.155; 170 FZ 1.783; 171 FZ 2.745
194 FZ 3.317; 195 FZ 2.155; 200 FZ 1.783; 201 FZ 2.745
224 FZ 3.317; 225 FZ 2.155; 230 FZ 1.783; 231 FZ 2.745
254 FZ 3.317; 255 FZ 2.155; 260 FZ 1.783; 261 FZ 2.745
284 FZ 3.317; 285 FZ 2.155; 290 FZ 1.783; 291 FZ 2.745
314 FZ 3.317; 315 FZ 2.155; 320 FZ 1.783; 321 FZ 2.745
344 FZ 3.317; 345 FZ 2.155; 350 FZ 1.783; 351 FZ 2.745
374 FZ 3.317; 375 FZ 2.155; 380 FZ 1.783; 381 FZ 2.745
404 FZ 3.317; 405 FZ 2.155; 410 FZ 1.783; 411 FZ 2.745
434 FZ 3.317; 435 FZ 2.155; 440 FZ 1.783; 441 FZ 2.745
464 FZ 3.317; 465 FZ 2.155; 470 FZ 1.783; 471 FZ 2.745
494 FZ 3.317; 495 FZ 2.155; 500 FZ 1.783; 501 FZ 2.745
524 FZ 3.317; 525 FZ 2.155; 530 FZ 1.783; 531 FZ 2.745
554 FZ 3.317; 555 FZ 2.155; 560 FZ 1.783; 561 FZ 2.745
584 FZ 3.317; 585 FZ 2.155; 590 FZ 1.783; 591 FZ 2.745
614 FZ 1.6585; 615 FZ 1.0775; 620 FZ .8915; 621 FZ 1.3725
*
PERFORM ANALYSIS
PRI JOI COORD
PRI MEM FORCES
PRINT ANALYSIS RESULTS
PRINT SUPPORT DISPLACEMENTS
*PRINT CG
*PRINT JOI DISPLACEMENTS
*PRI SUPPORT REACTIONS
*PRI MAT PROP
*PRI MEM INF
PLOT BEND FILE
PLOT DISP FILE
FIN
```