

# Evaluation Of Accuracy And Reliability Of Structural Analysis And Steel Design Software

by

Dharmesh Divecha

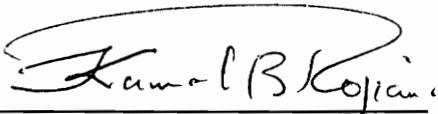
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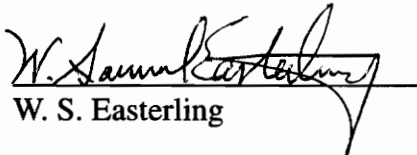
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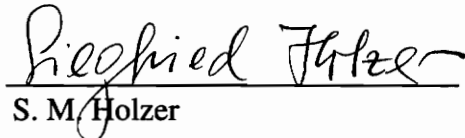
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# **Evaluation Of Accuracy And Reliability Of Structural Analysis And Steel Design Software**

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## **Abstract**

The accuracy and reliability of three structural analysis and design programs was evaluated. The three programs considered were MicasPlus, STAAD III, and GTSTRUDL. Nine different test cases of three basic steel space frames were analyzed and designed using the programs. The nine cases were formed by modifying different modeling, analysis, and design parameters. Comparison of results obtained from the programs for each case were presented. It was found that the percentage differences in the analysis results obtained from the programs were typically less than five percent. For steel design, both MicasPlus and GTSTRUDL gave member sizes that were very close. It was also found that changing modeling parameters can have a significant effect on analysis results. This confirms the importance of accurate structural modeling.

The functionality and usability of the three programs were also evaluated. After an extensive study of MicasPlus a list of suggested modifications and additions to the program was presented.

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## TABLE OF CONTENTS

	Page
<b>Chapter 1</b> Introduction .....	1
1.1 Computers in Structural Engineering .....	1
1.2 Objective and Scope .....	3
1.3 Organization .....	5
<b>Chapter 2</b> Software Verification and Validation .....	6
2.1 Software Verification and Validation .....	7
<b>Chapter 3</b> Structural Models, Analysis And Design Cases .....	12
3.1 Structural Models .....	13
3.1.1 Moment Resisting Frame .....	14
3.1.2 Frame with X-Bracing .....	14
3.1.3 Frame with Chevron Bracing .....	20
3.2 Analysis and Design Cases .....	28
3.2.1 Case 1 - Analytical Model .....	28
3.2.2 Case 2 - Physical Model .....	29
3.2.3 Case 3 - Inactive Secondary Members .....	30
3.2.4 Case 4 - Rigid End Offsets .....	30
3.2.5 Case 5 - Rigid End Offsets for Bracing Members .....	45
3.2.5 Case 6 - Rigid End Offsets for Bracing Members with Ends Fixed .....	45
3.2.7 Case 7 - Rigid End Offsets for Beams .....	46
3.2.8 Case 8 - Design for Wind and Gravity Loads .....	46
3.2.9 Case 9 - Design of Entire Frame Including Secondary Members .....	49
3.3 Loads .....	50
<b>Chapter 4</b> Discussion of Results .....	51
4.1 Analysis Results .....	51
4.1.1 Tabulation of Analysis Results .....	52
4.1.2 Discussion of Analysis Results .....	77
4.2 Design Results .....	79
4.2.1 Tabulation of Design Results .....	79
4.2.2 Discussion of Design Results .....	79
4.3 Parametric Study Results .....	85
4.3.1 Comparison of Results of Cases 1 and 4 .....	85
4.3.2 Comparison between Results of Case 1 and 5 .....	92
4.3.3 Comparison between Case 1 and 6 .....	93
4.3.4 Comparison of Cases 1 and 7 .....	101
<b>Chapter 5</b> Functionality and Usability .....	105
5.1 Functionality .....	106
5.2 Usability .....	109

<b>Chapter 6</b>	<b>Summary and Conclusions</b>	115
6.1	Summary	115
6.1.1	Analysis Results	115
6.1.2	Design Results	115
6.1.3	Parametric Study Results	116
6.1.4	Integration Between Various Modules of MicasPlus	117
6.1.5	Functionality and Usability	117
6.2	Conclusions	118
References		119
Vita		120

## List of Figures

<b>Figure 1</b>	Dimensions and preliminary member sizes of moment resisting frame.....	15
<b>Figure 2</b>	Analytical model of moment resisting frame for Cases 1 and 4 through 8, showing element and node numbers.....	16
<b>Figure 3</b>	Orientation of primary members of moment resisting frame.....	17
<b>Figure 4</b>	Orientation of secondary members of all three frames.....	18
<b>Figure 5</b>	Dimensions and preliminary member sizes of frame with X- bracing.....	19
<b>Figure 6</b>	Analytical model of frame with X-bracing for Cases 1 and 4 through 8, showing node numbers.....	21
<b>Figure 7</b>	Analytical model of frame with X-bracing for Cases 1 and 4 through 8, showing element numbers.....	22
<b>Figure 8</b>	Orientation of primary members of the frame with X- bracing.....	23
<b>Figure 9</b>	Dimensions and preliminary member sizes of frame with Chevron bracing.....	24
<b>Figure 10</b>	Analytical model of frame with Chevron bracing for Cases 1 and 4 through 8, showing node numbers.....	25
<b>Figure 11</b>	Orientation of primary members of the frame with Chevron bracing.....	26
<b>Figure 12</b>	Moment resisting frame for Case 2, showing node numbers and physical member numbers.....	27
<b>Figure 13</b>	Analytical model of moment resisting frame for Case 2, showing element numbers.....	31
<b>Figure 14</b>	Frame with X-bracing for Case 2, showing node numbers.....	32
<b>Figure 15</b>	Frame with X-bracing for Case 2, showing physical member numbers.....	33
<b>Figure 16</b>	Analytical model of the frame with X-bracing for case 2, showing element numbers.....	34
<b>Figure 17</b>	Frame with Chevron bracing for Case 2, showing physical member numbers.....	35
<b>Figure 18</b>	Analytical model of frame with Chevron bracing for Case 2, showing element numbers.....	36
<b>Figure 19</b>	Node numbers of secondary members for Cases 3 and 9.....	37

**Figure 20** Moment resisting frame for Cases 3 and 6, showing element numbers of secondary members.....38

**Figure 21** Frame with X-bracing for Cases 3 and 9, showing node numbers of secondary members.....39

**Figure 22** Analytical model of frame with X-bracing for Cases 3 and 9, showing element numbers of secondary members. ....40

**Figure 23** Frame with Chevron bracing for Cases 3 and 9, showing node numbers for secondary members.....41

**Figure 24** Analytical model of frame with Chevron bracing for Cases 3 and 9, showing element numbers of secondary members.....42

**Figure 25** Frame with Chevron bracing for Cases 3 and 9, showing node numbers for secondary members.....43

**Figure 26** Analytical model of frame with Chevron bracing for Cases 3 and 9, showing element numbers of secondary members.....44

**Figure 27** Node names as referred to in Tables 1 and 2.....55

**Figure 28** Line element names as referred to in Tables 7 and 9.....58

**Figure 29** Line element names as referred to in Tables 5 and 6.....61

**Figure 30** Percentage difference versus absolute value of line element end forces for moment resisting frame (from Table 5). ....63

**Figure 31** Percentage difference versus absolute value of line element end moments for moment resisting frame (from Table 6). ....64

**Figure 32** Line element names as referred to in Tables 7 and 9.....67

**Figure 33** Line element names as referred to in Tables 8 and 10.....68

**Figure 34** Percentage difference versus absolute value of line element end forces for frame with X-bracing (from Table 7).....69

**Figure 35** Percentage difference versus absolute value of line element end moments for frame with X-bracing (from Table 8). ....70

**Figure 36** Percentage difference versus absolute value of line element end forces for



frame with Chevron bracing (from Table 9).....	73
<b>Figure 37</b> Percentage difference versus absolute value of line element end moments for frame with Chevron bracing (from Table 10).....	74
<b>Figure 38</b> Line element names as referred to in Tables 19, 21, 23, 24, 26, 27, 29, and 30....	91

## List of Tables

<b>Table 1</b>	Comparison of support reactions obtained from MicasPlus and STAAD III for Cases 1, and 4 to 7 for all three frames. ....	53
<b>Table 2</b>	Comparison of support reactions obtained from MicasPlus and STAAD III. for Cases 2 and 3 for all three frames. ....	54
<b>Table 3</b>	Comparison of displacements obtained from MicasPlus and STAAD III. for Cases 1, and 4 through 7 for all three frames. ....	56
<b>Table 4</b>	Comparison of displacements obtained from MicasPlus for Cases 2 and 3 with those obtained for Case 1. ....	57
<b>Table 5</b>	Comparison of element end forces obtained from MicasPlus and STAAD III for Cases 1 and 4 for the moment resisting frame. ....	59
<b>Table 6</b>	Comparison of element end moments obtained from MicasPlus and STAAD III for Cases 1 and 4 for the moment resisting frame. ....	60
<b>Table 7</b>	Comparison of element end forces obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with X-bracing. ....	65
<b>Table 8</b>	Comparison of element end moments obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with X-bracing. ....	66
<b>Table 9</b>	Comparison of element end forces obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with Chevron bracing. ....	71
<b>Table 10</b>	Comparison of element end moments obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with Chevron bracing. ....	72
<b>Table 11</b>	Comparison of element end forces obtained from MicasPlus for Cases 2 and 3 with those obtained from MicasPlus for Case 1 for all three frames. ....	75
<b>Table 12</b>	Comparison of element end moments obtained from MicasPlus for Cases 2 and 3 with those obtained from MicasPlus for Case 1 for all three frames. ....	76
<b>Table 13</b>	Comparison of design results obtained from MicasPlus and GTSTRUDL for Case 8 for the frame with X-bracing. ....	80
<b>Table 14</b>	Comparison of design results obtained from MicasPlus and GTSTRUDL for Case 9 for the moment resisting frame. ....	81
<b>Table 15</b>	Comparison of design results obtained from MicasPlus and GTSTRUDL for Case 9 for the frame with X-bracing. ....	82

<b>Table 16</b>	Comparison of design results obtained from MicasPlus and GTSTRUDL for Case 9 for the frame with Chevron bracing. ....	83
<b>Table 17</b>	Comparison of displacements obtained from MicasPlus for Cases 1 and 4 for all three frames. ....	86
<b>Table 18</b>	Comparison of element end forces obtained from MicasPlus for the moment resisting frame for Cases 1 and 4. ....	87
<b>Table 19</b>	Comparison of element end forces obtained from MicasPlus analysis for Cases 1 and 4 for the frames with X-bracing and Chevron bracing. ....	88
<b>Table 20</b>	Comparison of element end moments obtained from MicasPlus for the frame with moment resisting connections for Cases 1 and 4. ....	89
<b>Table 21</b>	Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and Chevron bracing for Cases 1 and 4. ....	90
<b>Table 22</b>	Comparison of displacements obtained from MicasPlus for all three frames for Cases 1 and 5. ....	94
<b>Table 23</b>	Comparison of element end forces obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 5. ....	95
<b>Table 24</b>	Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and the frame Chevron bracing for Cases 1 and 5. ....	96
<b>Table 25</b>	Comparison of displacements obtained from MicasPlus for all three frames for Cases 1 and 6. ....	97
<b>Table 26</b>	Comparison of element end forces obtained from MicasPlus for the frame with X-bracing and the frame Chevron bracing for Cases 1 and 6. ....	99
<b>Table 27</b>	Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 6. ....	100
<b>Table 28</b>	Comparison of displacements obtained from MicasPlus for all three frames for Cases 1 and 7. ....	102
<b>Table 29</b>	Comparison of element end forces obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 7. ....	103
<b>Table 30</b>	Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 7. ....	104

# Chapter 1

## Introduction

### 1.1 Computers in Structural Engineering

Computers are being used not only for the usual and repetitive number crunching types of tasks but also for obtaining reliable results for complex structural engineering problems. Computers reduce the time required for analysis, design and re-analysis of structures and provide more accurate results at lower cost. They allow engineers to concentrate on other aspects of analysis and design besides number crunching, such as understanding the intricate behavior of the structure and its components. Computers have also aided in developing better coordination between engineers working in different areas of the same project by sharing a common database.

Many computer programs are now available for structural analysis and design. However, only a small percentage of these programs have been verified and validated. In using computer programs for structural engineering, it is the engineer who is ultimately responsible for the accuracy and reliability of the software.

The process of analysis and design of a structure with the aid of computers consists of three major phases:

1. Construction of a computer model of the real structure
2. Analysis and design of this computer model by the program.

3. Interpretation and verification of results, which may also include verification of the program itself.

In the first phase, the structural engineer is concerned with the issue of the computer model representing the actual three dimensional structure. Considerable skill and experience is required in arriving at an accurate structural model [9]. The engineer has to be knowledgeable about the modeling techniques used in the program in order to arrive at an accurate and complete representation of the real structure. It is necessary to have a good understanding of various assumptions and simplifications made in the analysis and design process and their effect on the analysis and design results. Familiarity with all aspects of the particular program in use and full understanding of the behavior of the structure to be analyzed is essential.

In the second phase, the engineer is concerned with the method of analysis and design employed by the program and the computer hardware. The analysis and design limitations should be fully understood. A background in programming makes it easier to understand these limitations. The engineer should also be somewhat knowledgeable about the type of computer being used, including relevant details of the hardware and the software. The choice of the computing environment can affect the cost and efficiency of analysis and design.

In the third phase of the analysis and design process, the engineer is faced with the issue of the accuracy and reliability of the program itself. The structural engineer is ultimately responsible for the accuracy of the results of analysis and design [9]. Validating structural analysis software is a labor intensive and time consuming process since there are many factors that can affect the results. The accuracy of the results obtained from a structural analysis and design program has to be verified for a wide range of structural

configurations and for a number of different values of analysis and design parameters. Programs for performing structural analysis and design tend to be fairly complex and thus require considerable time and resources for verification.

In this study the term "accuracy" means that results obtained from a program match those obtained by hand calculation or from another program which has previously been verified. The results can be considered to be reliable when their accuracy does not change for a wide variety of models. Verification is the process by which it is determined whether results obtained from a program are accurate and reliable. In this study, the results obtained from GTSTRUDL were used as a benchmark since this program has been verified and accepted by most organizations. It should also be noted that as of now no standards are available for the verification and validation of structural engineering software.

Another aspect of computer usage for structural analysis and design is the efficiency of the engineer in using the software. This depends on the functionality and user-friendliness of the software. Structural analysis and design programs typically require a large amount of input data and a major part of the effort involved in performing structural analysis and design involves the creation of the computer model and entering the necessary information for defining this model. Many of the current generation of structural analysis programs have a character based user interface. Input to these programs is primarily through a text file containing a series of commands and/or data. Such an interface is quite inefficient for entering input data and it also requires considerable amount of effort on the part of the structural engineer in checking the accuracy of the structural model. Recent advances in hardware and computer languages have led to the development of programs that employ a graphical user interface. The visual feedback provided by such programs makes it easier to build the structural model, and to edit and verify the model. This is a

more efficient way of entering data and is easier to use.

## 1.2 Objective and Scope

The objective of the present study is to verify the accuracy of several structural analysis and design programs. The three programs considered in the study are Intergraph's MicasPlus [6], Research Engineers Structural Analysis And Design (STAAD III) program[10 ], and Georgia Tech's GTSTRUDL[4]. Specific objectives include the following:

1. Verify the accuracy of structural analysis performed by structural engineering software by comparing analysis results obtained from the MicasPlus analysis module, STAAD III, and GTSTRUDL.
2. Verify the accuracy of steel design performed by comparing steel design results for the AISC Allowable Stress Design (ASD) specification [7] obtained from the MicasPlus steel design module and the GTSTRUDL steel design module.
3. Test the interface between the various modules of the MicasPlus software such as ModelDraft, MicasPlus Analysis, and MicasPlus Steel Design.
4. Study the effect of changing various structural modeling parameters, such as rigid end offsets, on analysis results.
5. Verify the accuracy of the automatic computation of effective length factors.
6. Evaluate the functionality of the programs.

The verification was based on the analysis of a series of two story steel space frames using each of the above programs and comparing the results. The three basic frames considered are:

1. Frame with X-bracing.

2. Frame with Chevron bracing.
3. Frame with moment resisting connections.

Various configurations of the three frames were considered to study the effect of changing various modeling, loading, and design parameters in the parametric study. Support reactions, element end forces, displacements, and member sizes were compared. To evaluate the steel design module, several frames were designed using MicasPlus and GTSTRUDL. Design member sizes, effective length factors for columns and steel take off obtained from the two programs were compared. The interface between the analysis and design module was tested to ensure that there is no loss of accuracy in the structural models transferred from one module to the other.

The factors considered in the evaluation of functionality of the program included ease of modeling, ease of entering structural parameters and loads, potential for user errors, and quality and format of the final output.

### **1.3 Organization**

Chapter 2 presents an overview of published literature on the verification and validation of structural engineering software. A brief description of the capabilities and features of the three programs considered in this study is also presented in Chapter 2. Details of the structural models used in the parametric study are given in Chapter 3. Results of the analysis and design are presented in Chapter 4. Issues related to the functionality of structural analysis and design software are discussed in Chapter 5. Chapter 6 presents a summary and major conclusions of the study.



## Chapter 2

### Software Verification and Validation

In recent years, computers have assumed a more important role in structural engineering due to the availability of affordable and easily accessible computer hardware and software. There are now numerous programs which can help structural engineers perform many of the routine analysis and design tasks that were previously done manually. The hardware is increasingly becoming speedier and more powerful and can handle large complicated tasks in a matter of seconds. The increased use of computer applications in structural engineering has created outstanding opportunities for the engineer but it has also resulted in an increased dependency on the computer. The accuracy and validity of analysis and design results now depends not only on the engineer but also on the quality of the software and the hardware used to obtain these results.

Engineers should be aware of the dangers in the use of the computer programs in professional practice. Many engineers believe that computer programs are free of errors. However, this is not the case[2]. Some of the common pitfalls, as mentioned in Ref. [3], are:

1. limited software and/or hardware functionality,
2. inadequate software quality and reliability,
3. insufficient software and hardware maintenance,

4. non-existent education and training in techniques of effectively integrating computers into engineering practice,
5. poor and incomplete software documentation,
6. training in software and hardware use provided by persons with poor qualifications as instructors and/or with inadequate engineering experience, and
7. poor and discourteous technical support services from the software vendors.

A disturbing trend in engineering software today is the rapidly growing use of a large number of low quality and unverified engineering programs. Software testing has become just as important as the design of software [3] because of the significant role of computers in engineering design. The professional engineer needs to apply the full range expertise, experience, knowledge, and concern for excellence to the evaluation, selection and use of computer software for engineering analysis and design [2]. Many engineers fail to realize that software developers may not consider themselves responsible for errors in their software. It is the engineer who is ultimately responsible for the accuracy, correctness and relevance of results.

In the following sections a review of the literature on software verification and validation is presented.

## **2.1 Software Verification and Validation**

There are many published papers in different technical disciplines such as aerospace, mechanical, electrical, and civil engineering, and computer science, that discuss verification and validation of computer software. Since techniques for verification and validation

of computer software are similar across disciplines the techniques used in one discipline can be effectively applied to other disciplines. Unfortunately there only a few papers which actually present verification and validation results. From the literature reviewed, it is seen that verification and validation of software can be classified into two categories:

1. Verification and validation by the software developer during or after the software development process, and
2. Verification and validation by the user before and during the use of the software.

Hambling [5] presents structured testing techniques which can be applied during the structured development life-cycle of a program. He characterizes verification as a "backward looking" activity which seeks to determine whether a given product meets its specification and validation as a "forward looking", which seeks to determine whether a given product meets its requirements. In this classification "product" means the intermediate, development product not the final product. He presents verification techniques such as formal notations with correctness proofs, and design reviews, and validation techniques such as design reviews early in the life cycle, and testing. Hambling advocates a process in which the development of a program and its verification and validation goes hand in hand in developing a quality software. He proposes a test team, which is independent of the development process, for achieving high levels of quality assurance for the product. The test team would play a proactive role with the authority to initiate a planning dialogue at every stage of program development. The development team would ultimately have the authority to control the development process but with the responsibility of defending any argument against delivering functional modules in the order identified by the test team.

Ackerman, *et. al.*, [1] discuss the issue of software verification by inspection. They attempt to clarify the role of software inspection and explain how this can be used to improve the development process of the product. They also discuss the effectiveness of software inspections in enhancing software quality. According to Ackerman, *et. al.*, the elements which constitute the software inspection process are the following:

1. Six well-defined inspection steps (planning, overview, preparation, meeting, rework, and follow-up),
2. Four well-defined inspection roles (moderator, recorder, reader, and producer),
3. The formal collection of process and product data,
4. The product being inspected, and
5. A supporting infrastructure.

The paper also presents some essential characteristics of software inspection - as opposed to other types of reviews - such as, a set of technical examinations of a completed product performed by knowledgeable peers at which the program developer is present and participates, used routinely and according to some plan. Finally, they list examples of experiences with software inspection and discuss the benefits of software inspection over testing.

Terry [11] presents a discussion on verification of engineering software from the viewpoint of the user. He states that software verification by users generally focuses on determining whether or not a program performs as described in the user's manual. There are three problems with this approach:

1. The approach incorrectly implies that testing can be performed at a single point

in time, since the program is verified against a static standard - the user's manual.

2. Another weakness of this approach is that the user manual-based verification does not attempt to address the possibility of user input errors.
3. The final weakness of the approach is the fact that the user's manual is not a reliable standard.

A few of the verification guidelines presented by Terry include:

1. Pondering the validity of the program methodology and assumptions.
2. Reviewing the documentation and "known bug" list.
3. Checking input and checking input again.
4. Trying simple examples and checking results by hand.
5. Using separate programs and comparing results.
6. Having all assumptions, input and output checked by two or more professionals.
7. Knowing the limits of the program such as checking minimum and maximum values. Trying negative values where they shouldn't normally be used.
8. Checking the sensitivity of the method for minor variations in the input.

The level of verification would depend on the importance of the output and the safety and quality of the project. The author proposes that the users check the computer programs in the same way as any tool against an accepted standard to prevent errors, such as a measuring tape which can lose accuracy over a period of time. The most professional and conservative approach suggested, is to have an attitude that results are incorrect until proven otherwise.

Melosh and Utku in [8] have proposed a sequence of independent analysis for verify-

ing the accuracy of the numerical analysis of a structure. The tests separately assay the approximations of round-off, logic, discretization and idealization on a quality assurance basis. The tests are suitable for use with public domain software and they detect sensitivity of results to changes in the problem definition and hence for changes of computer precision, computer logic, grid size and idealization parameters. Some of these tests simply involve scaling responses. In these tests they have tried to address only verification of analysis i.e, assessing whether the computer configuration and the analyst's modelling decisions have produced results of adequate accuracy for the structure for the structure represented by the analyst. The round-off test involves re-analysis with a scaled stiffness matrix and loading vector. One logic test addresses, assessing satisfaction of nodal compatibility requirements and a second demonstrates the adequacy of the model in meeting nodal equilibrium needs. The grid-size test estimates discretization errors by extrapolating results of two hereditary grids. One of the idealization test deals with manufacturing and material processing intolerance; and another for switching the mathematical model from plane stress to plane strain.

## Chapter 3

### Structural Models, Analysis And Design Cases

One of the primary objectives of the study was to verify the accuracy of the structural analysis and design results from several computer programs. The three structural analysis and design programs considered in this study, as stated earlier, are MicasPlus, STAAD III and GTSTRUDL. However, the MicasPlus software was studied more extensively than the other two as it is a relatively new program and has not yet been extensively verified by independent sources.

In a structural analysis and design program there are many analysis and design variables that can affect the accuracy of the results. Thus, to verify the accuracy of the analysis and design results, it is necessary to consider a wide variety of structural models having different configurations and a wide range of modelling and design parameters. Also, many of the newer structural analysis and design programs like MicasPlus contain several separate modules such as analysis, design, and drawing modules which share a common structural database. To verify the accuracy of such programs it is necessary to test each module independently. The interface between the modules has to be tested for effective transfer of information between the various modules and the structural database. Based on the above requirements, various analysis and design test cases are formed with different structural models. The analysis and design cases and the structural models are described in this

chapter.

To evaluate the three programs, a parametric study on a two story steel space frame was performed. The frame consists of one bay in one direction and two bays in the perpendicular direction. Three variations of the frame are considered by modifying the bracing conditions. They were: 1) a moment resisting frame, 2) a frame with X-bracing and 3) a frame with Chevron bracing.

A number of different analysis and design cases were studied for each of the three basic frames. These were obtained by modifying the basic frame in various ways such as changing rigid end offsets, activating and inactivating secondary framing members, changing program options for manual and automatic computation of effective length factors, changing support and bracing conditions and varying a number of other structural modeling and design parameters. Details of these various cases are presented in sections that follow.

### **3.1 Structural Models**

The three structural models were a variation of a two story steel space frame, having two bays in one direction (global x-direction) and one bay in the perpendicular direction (global y-direction.) The first frame was an unbraced frame in which all joints were modeled as moment resisting connections. The other two frames were braced frames, one with X-bracing and the other with Chevron bracing. All of the members consisted of standard steel sections. The initial member sizes were selected by inspection. The columns, braces, and all beams framing into the columns were classified as primary members. All remaining beams were classified as secondary members.



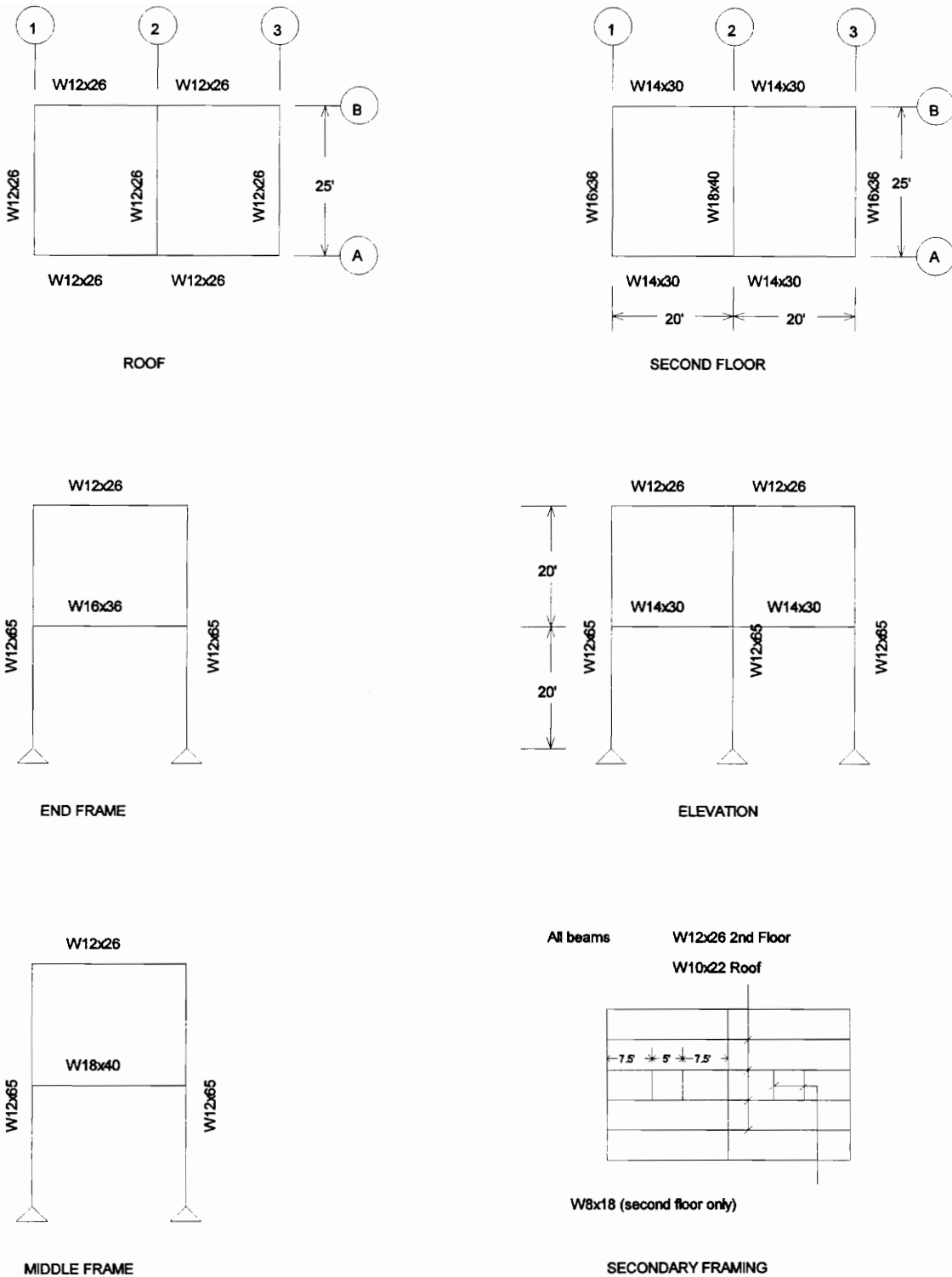
### **3.1.1 Moment Resisting Frame**

The moment resisting frame is formed by restraining the rotational degrees of freedom at the ends of all members of the frame. However, the column bases are pinned at the supports. The dimensions and preliminary member sizes for the frame are shown in Figure 1. The columns consists of W12x65 sections for both floors. In the y-direction, the primary beams at first floor level of the exterior frames are made up of W16x36 sections. The beam of the interior frame in the y-direction is made up of a W18x40 section. In the x-direction, the primary beams of both frames at the first floor level consist of W14x30 sections. All primary beams at the roof level consist of W12x26 sections. The analytical model of the basic moment resisting frame is shown in Figure 2 along with the joint and element numbers. The orientation of the members of the moment resisting frame is shown in Figure 3.

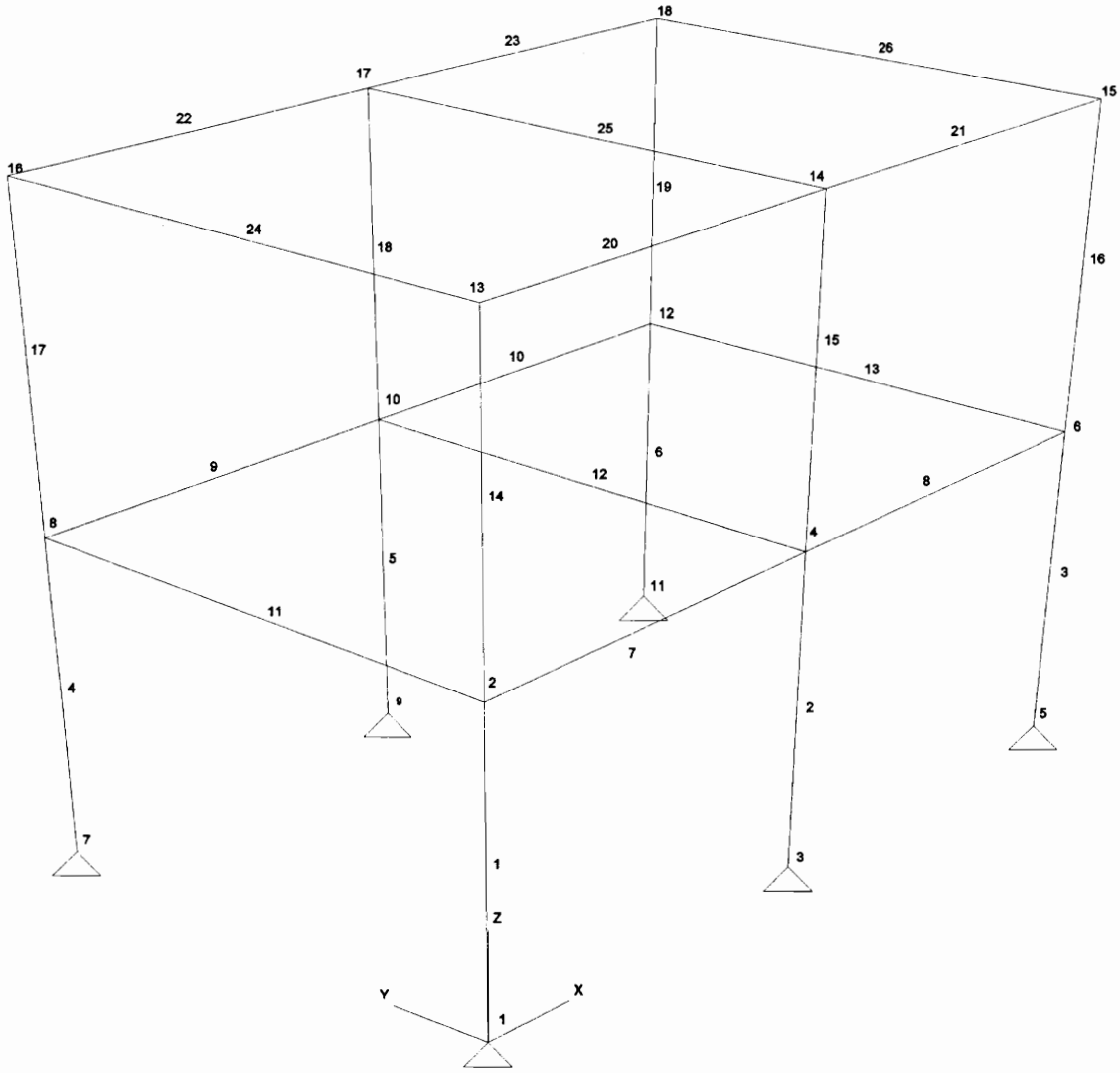
The moment resisting frame also has secondary framing members. The secondary framing members consist of a series of beams running parallel to the global x-axis. The beams consist of W12x26 sections at the first floor level and W10x22 sections at the roof level. Four smaller secondary beams made up of W8x18 sections span across these interior beams as shown in Figure 1. The orientation of the secondary framing members is shown in Figure 4.

### **3.1.2 3.1.2 Frame With X-Bracing**

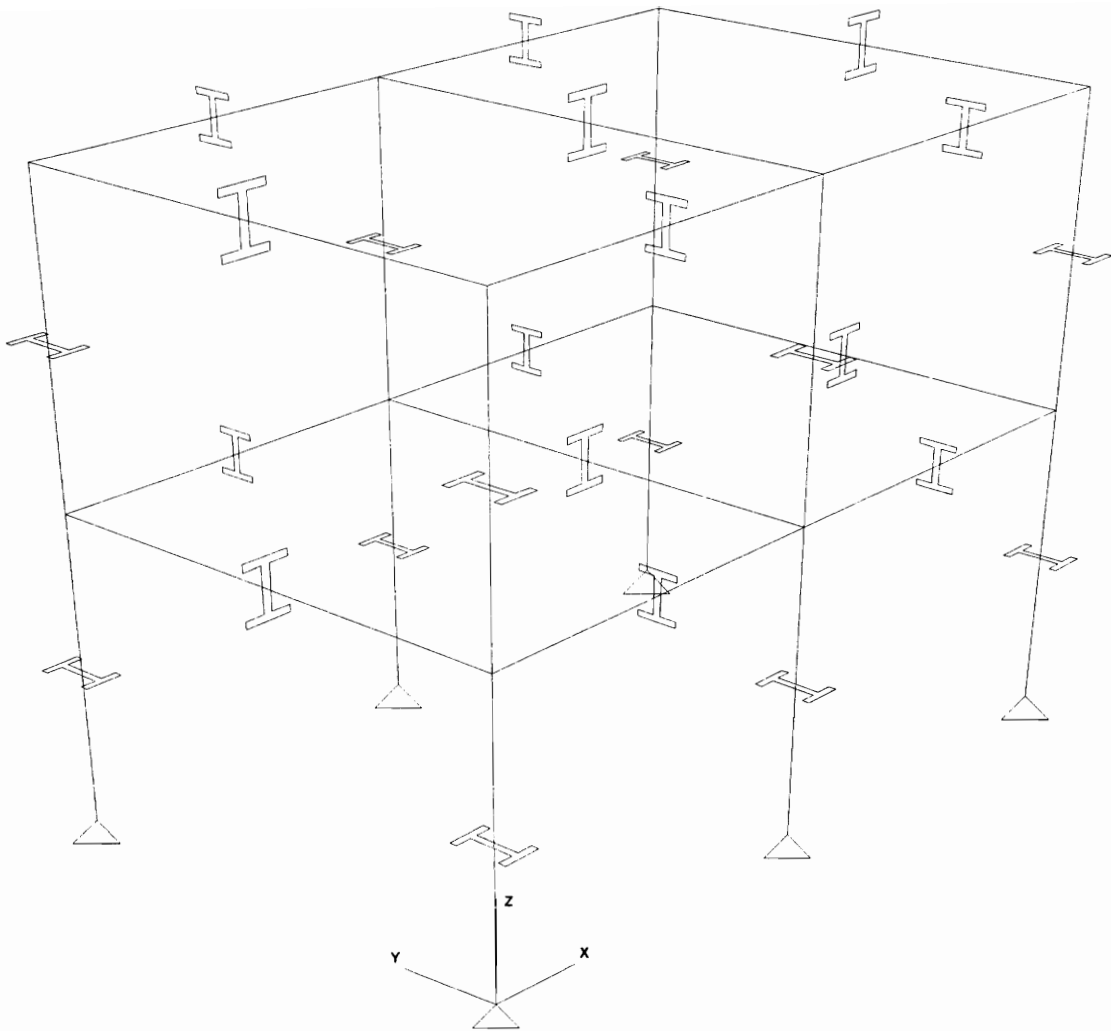
The dimensions and preliminary member sizes of the frame with X-bracing are shown in Figure 5. The initial column and beam sizes are the same as those of the moment resisting frame. The X-bracing is made up of WT5x11 sections. It is provided on both floors, in



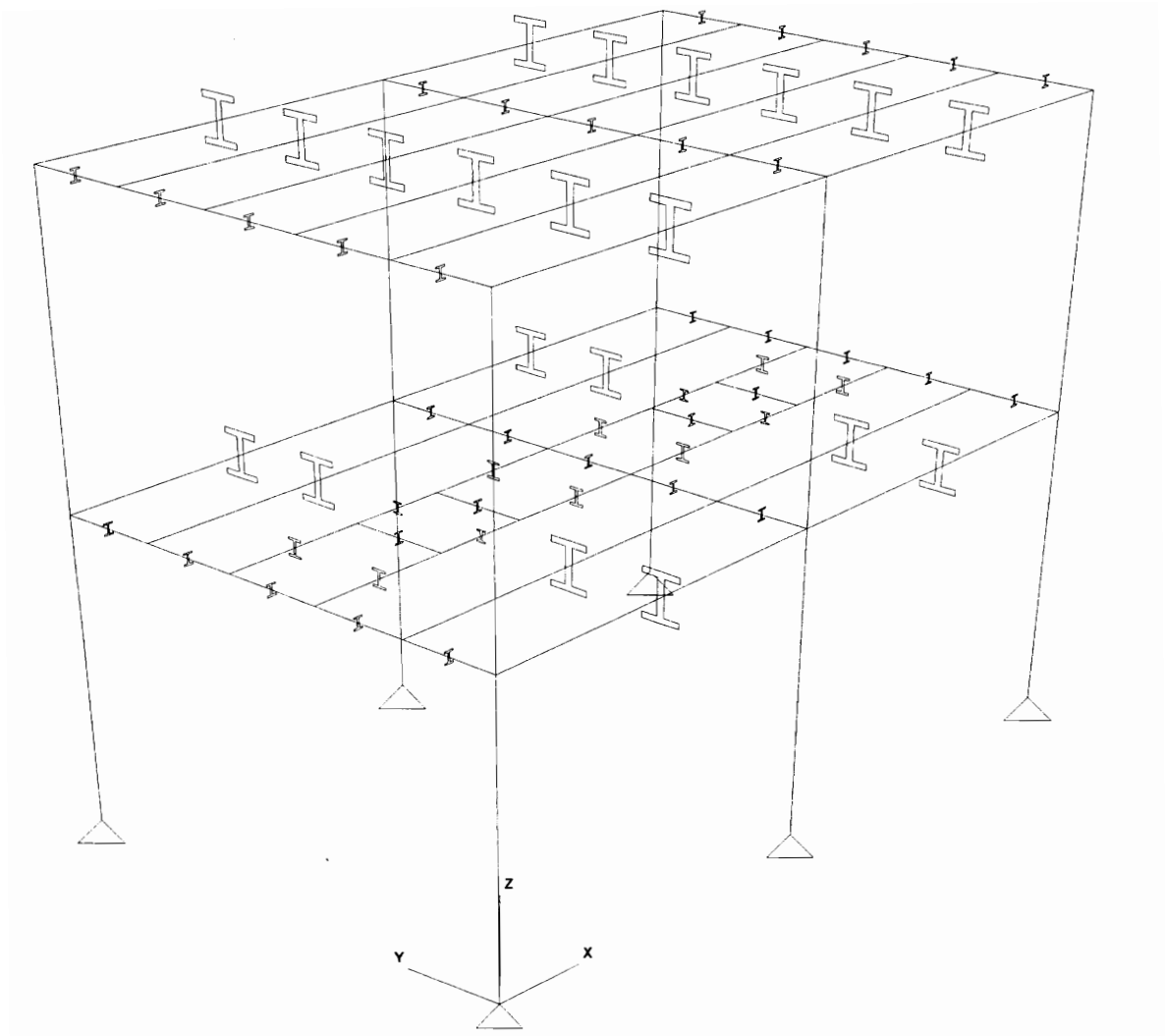
**Figure 1.** Dimensions and preliminary member sizes of moment resisting frame.



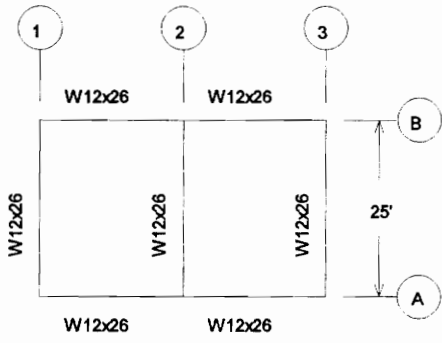
**Figure 2.** Analytical model of moment resisting frame for Cases 1 and 4 through 8, showing element and node numbers.



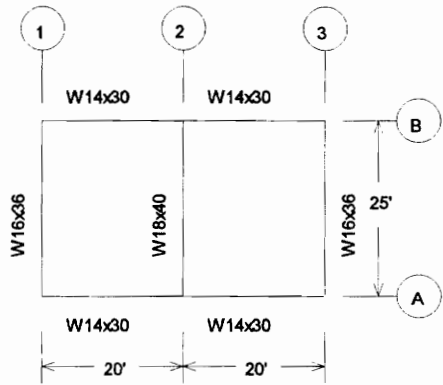
**Figure 3.** Orientation of primary members of moment resisting frame.



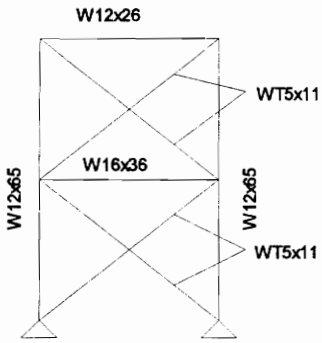
**Figure 4.** Orientation of secondary members of all three frames.



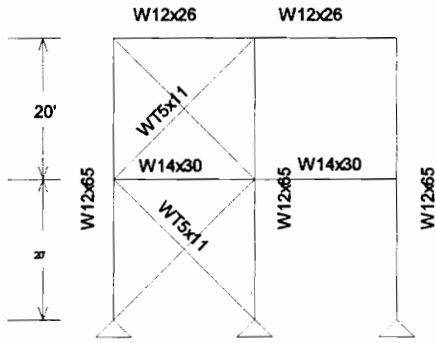
ROOF



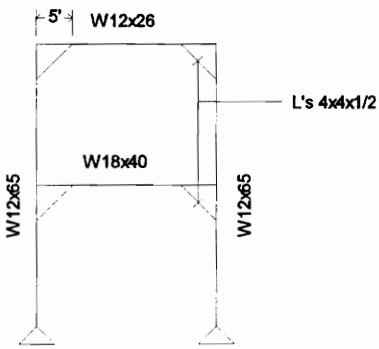
SECOND FLOOR



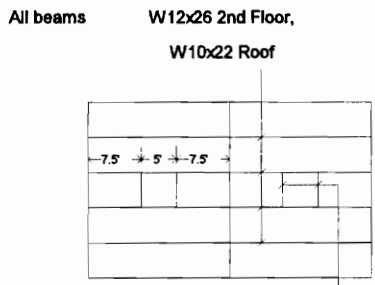
END FRAME



ELEVATION



MIDDLE FRAME



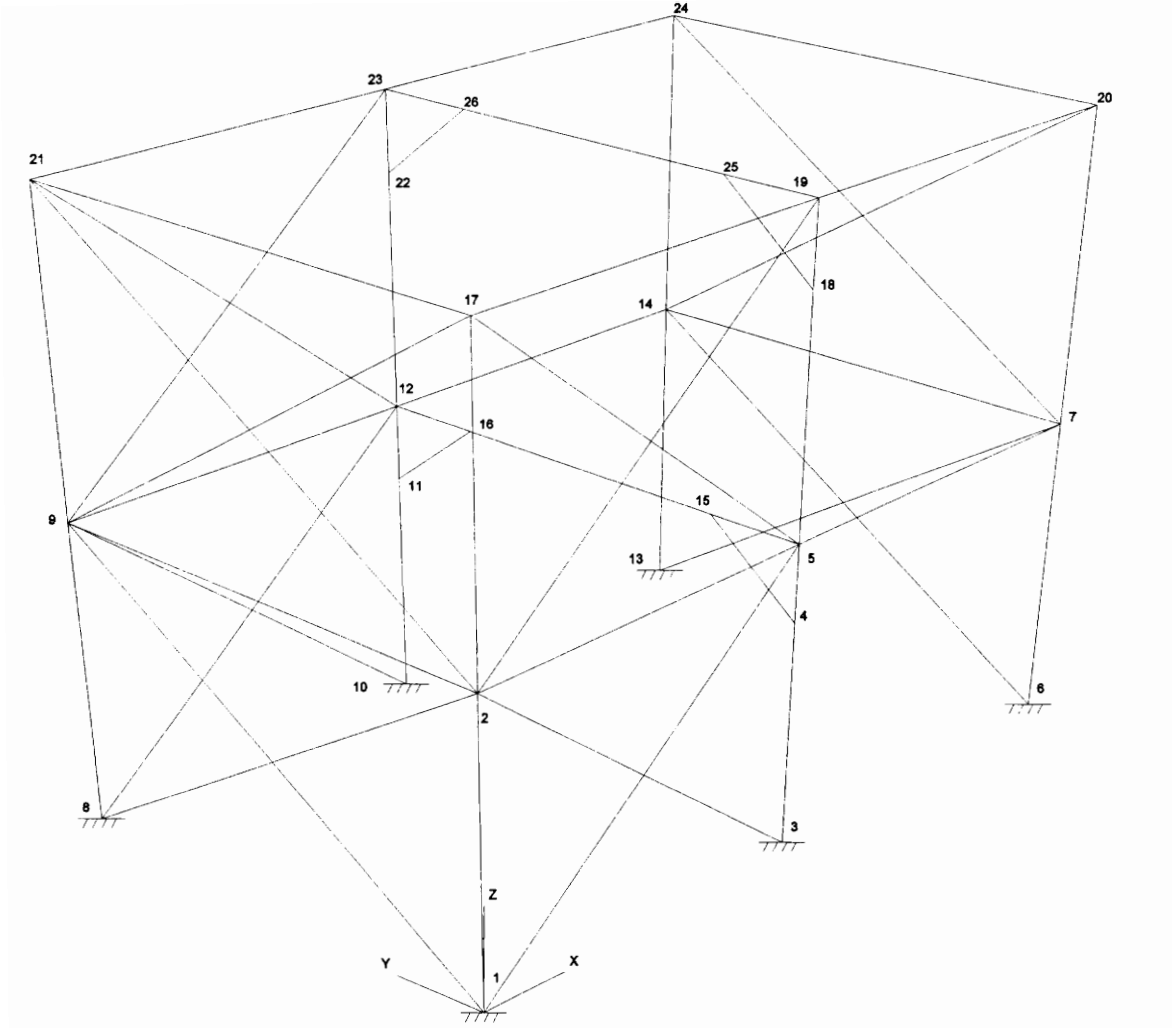
SECONDARY FRAMING

Figure 5. Dimensions and preliminary member sizes of frame with X-bracing.

the first bay of the frames in the global x-direction and in the exterior frames in global y-direction (see Figure 5.) Knee bracing is provided in the interior frame and consists of L4x4x1/2 in. angles. All beams framing into the columns and all bracing members are pinned, that is, the joint rotations  $R_y$  and  $R_z$  are released at both ends of the members. The columns are pinned at their bases. The rotation of the columns about their own axis is restrained by the supports. The X-bracing members are not connected at the point where they cross, however their axial unbraced length for buckling in the plane of the X-bracing was taken as half the member length, since in an actual structure they would be connected at the point of crossing. Figure 6 shows the joint numbers of the analytical model and Figure 7 shows the element numbers. The orientation of the members is shown in Figure 8.

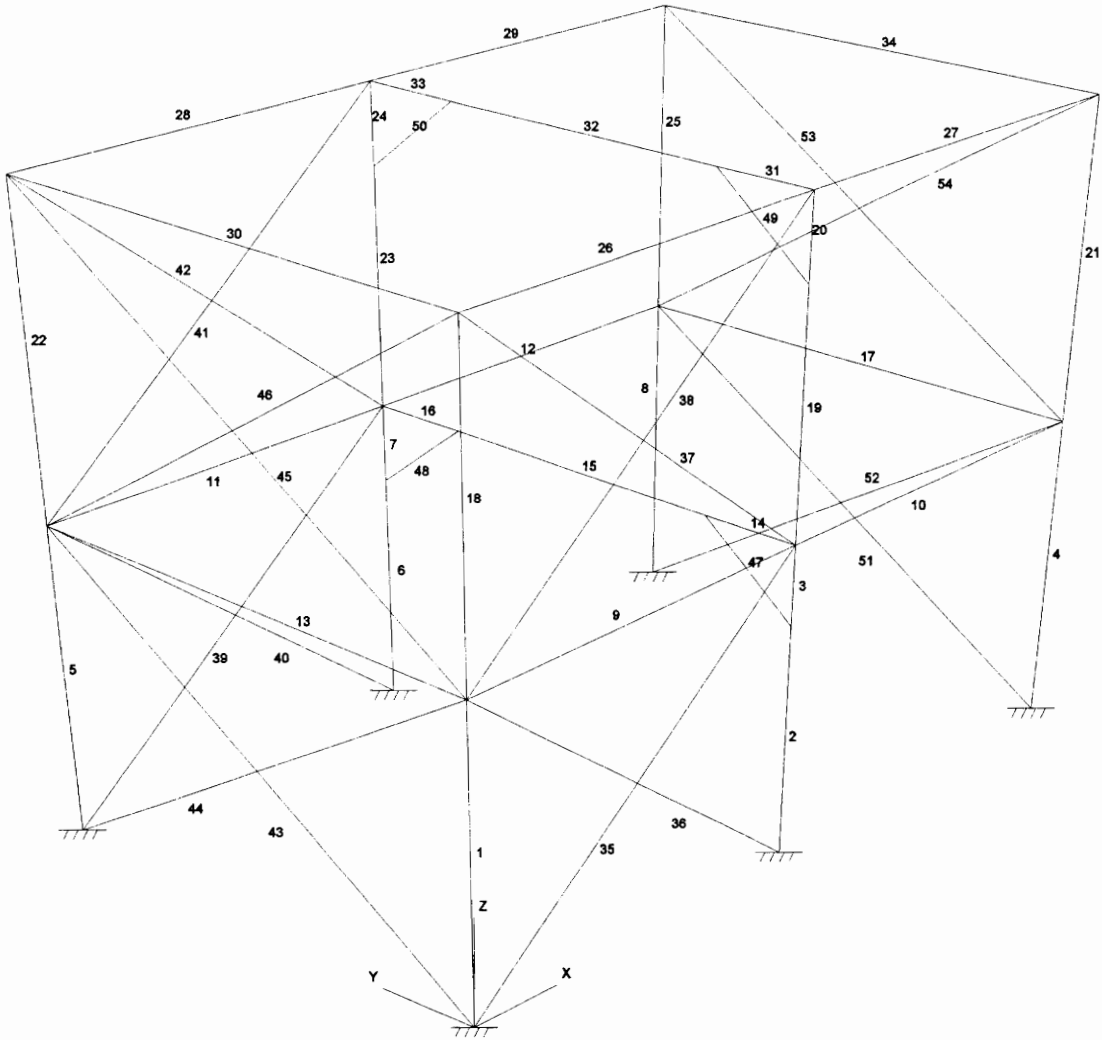
### **3.1.3 Frame With Chevron Bracing**

The configuration of the frame with Chevron bracing structure is the same as that of the frame with X-bracing except that the X-bracing is replaced by Chevron bracing (sometimes referred to as K-bracing). The dimensions and preliminary member sizes of the frame are shown in Figure 9. The initial column and beam sizes are the same as those of the moment resisting frame. The Chevron bracing is made up of WT6x13 sections. The ends of beams framing into the column and the ends of the bracing members are pinned. The columns are pinned at the supports. The analytical model of the frame along with node numbers and element numbers is shown in Figures 10 and 11 respectively. The orientation of the members of the frame is shown in Figure 12.

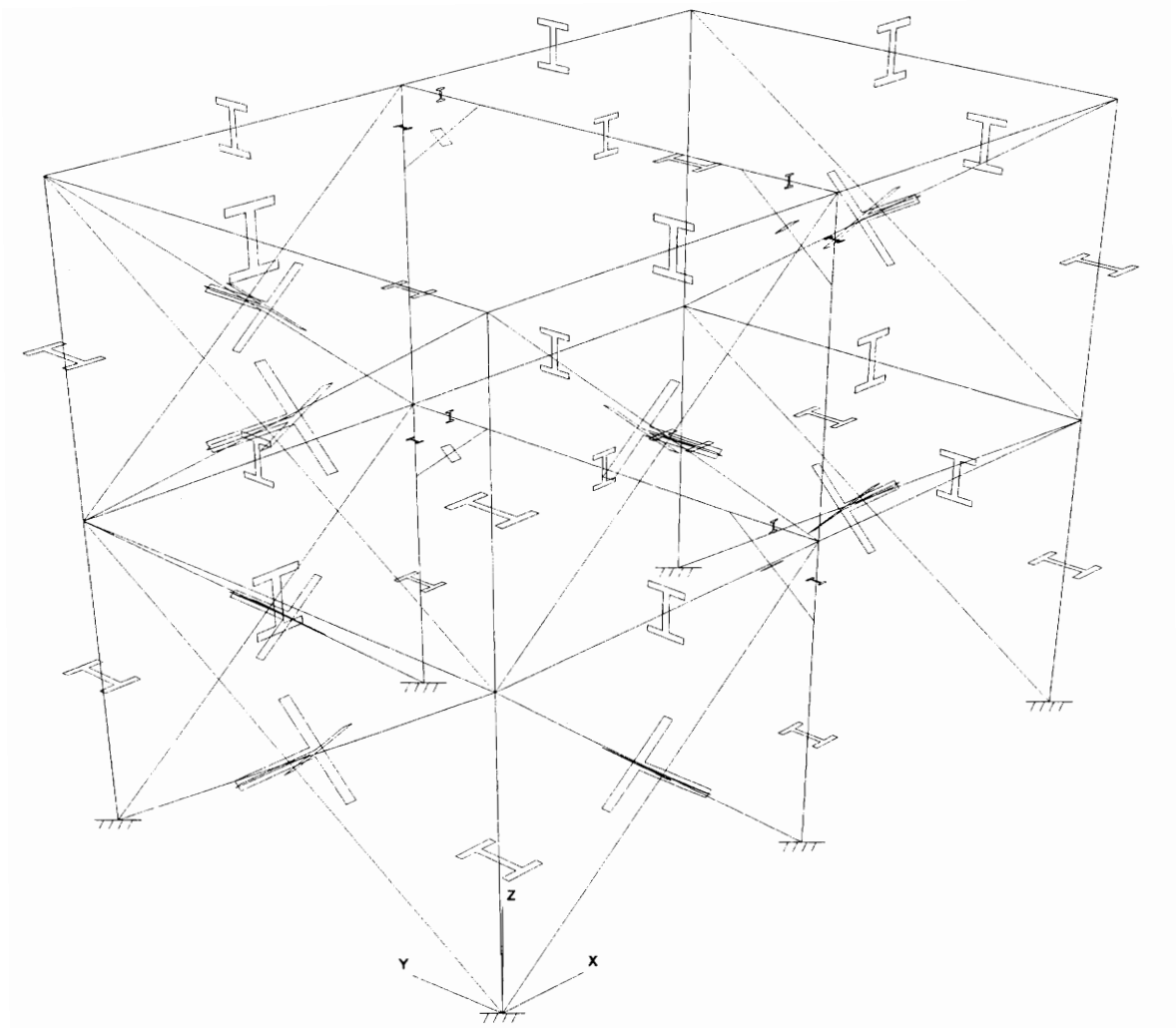


**Figure 6.** Analytical model of frame with X-bracing for Cases 1 and 4 through 8, showing node numbers.

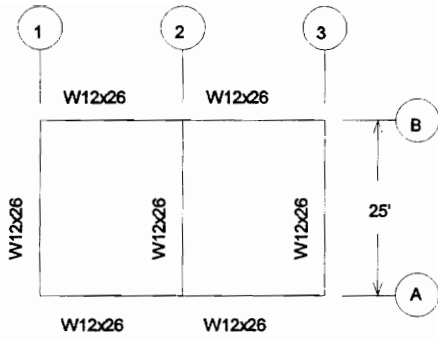




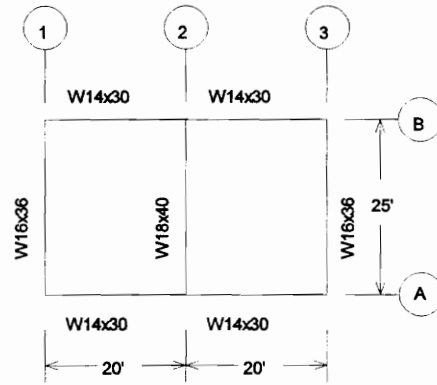
**Figure 7.** Analytical model of frame with X-bracing for Cases 1 and 4 through 8, showing element numbers.



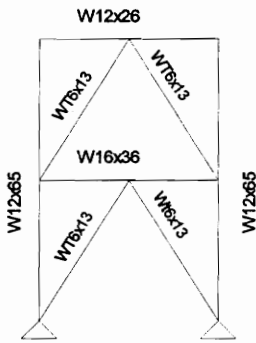
**Figure 8.** Orientation of primary members of the frame with X-bracing.



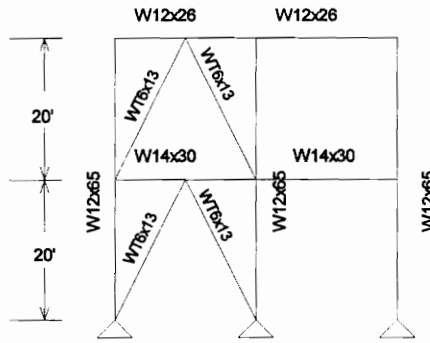
ROOF



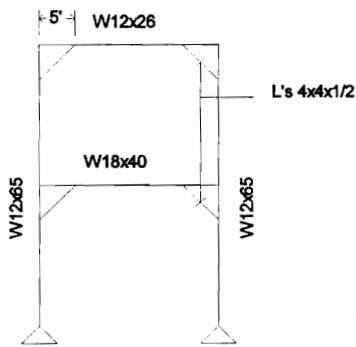
SECOND FLOOR



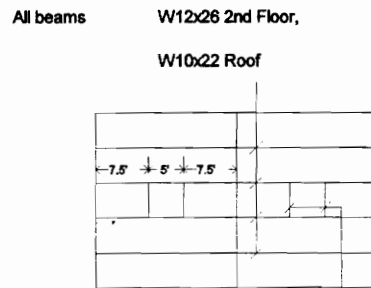
END FRAME



ELEVATION



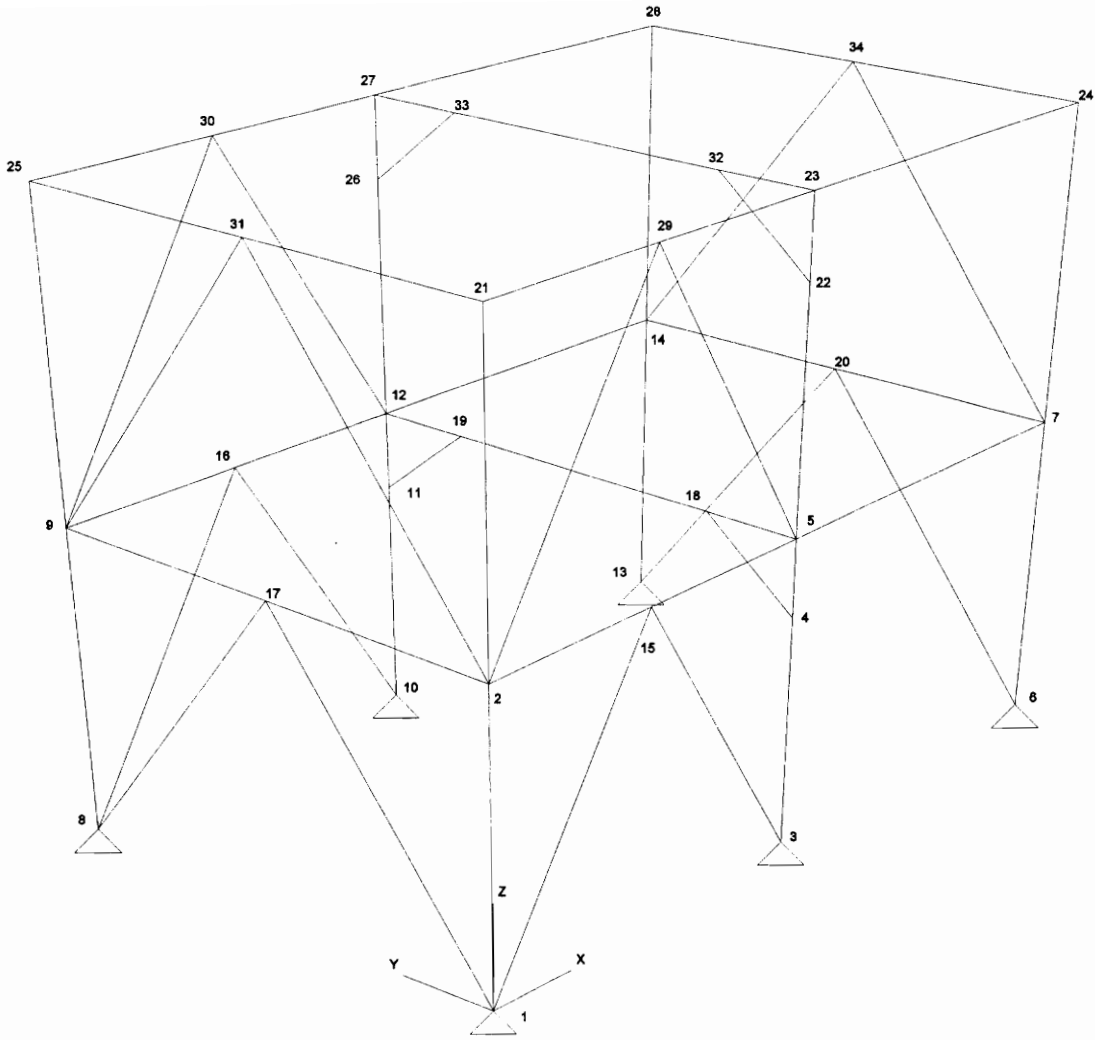
MIDDLE FRAME



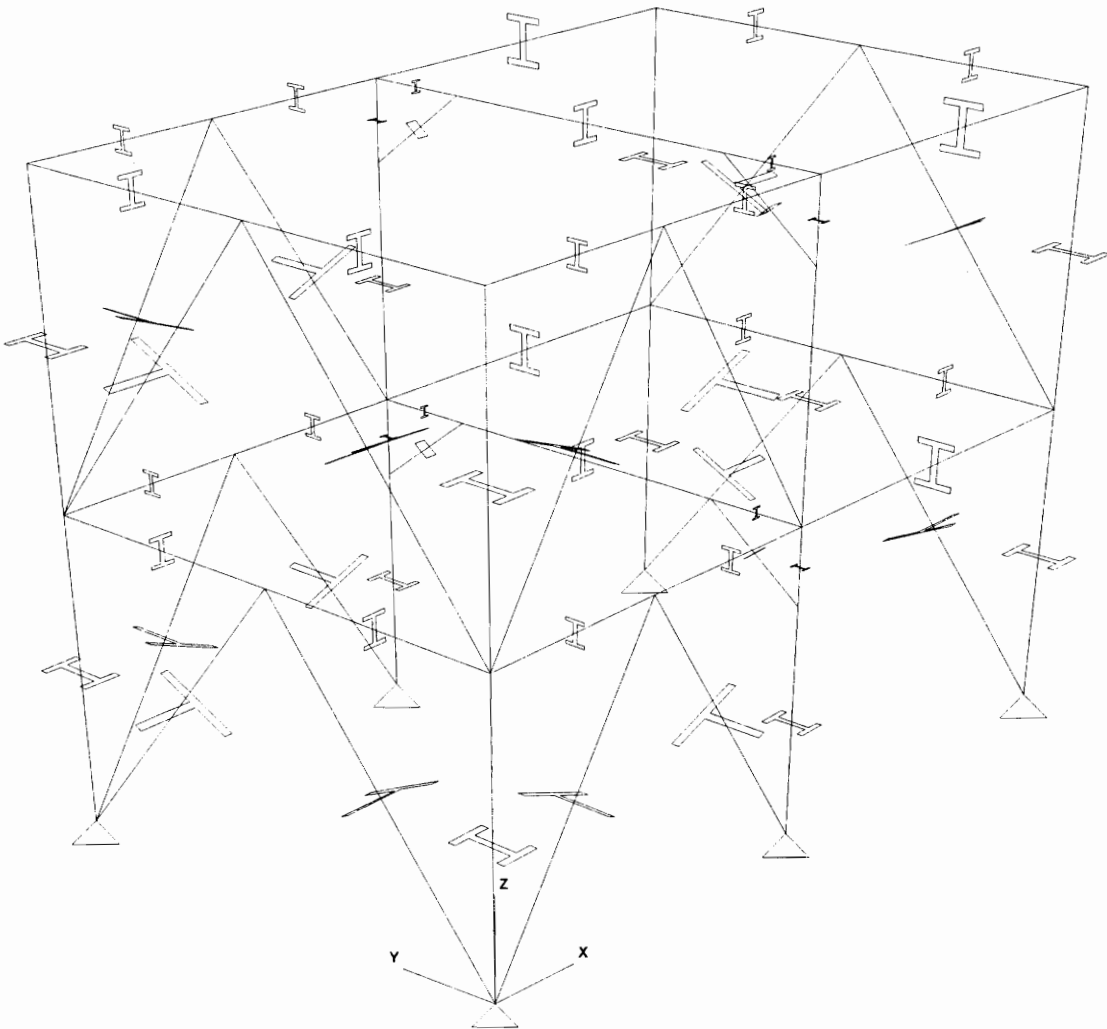
W8x18 2nd Floor only

SECONDARY FRAMING

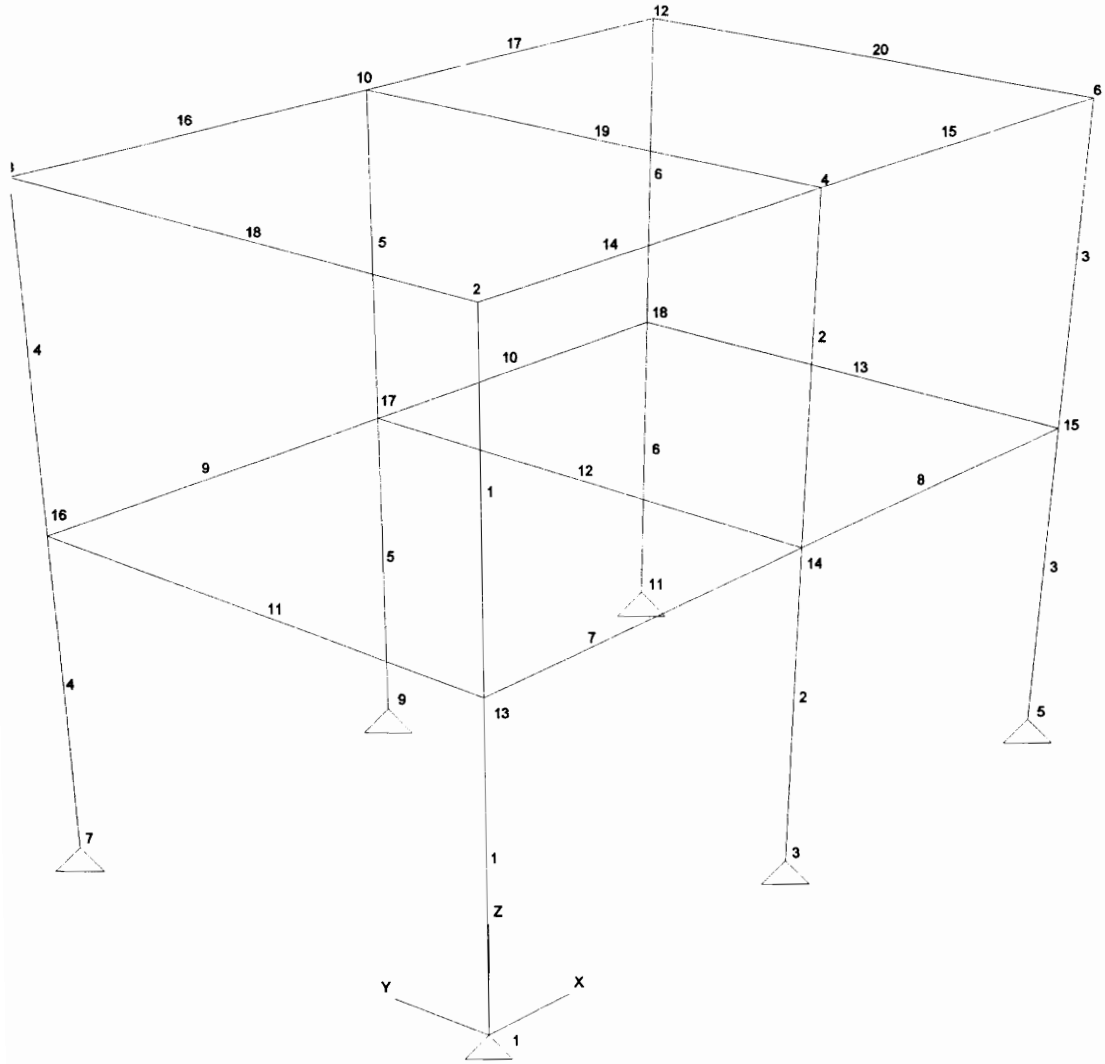
**Figure 9.** Dimensions and preliminary member sizes of frame with Chevron bracing.



**Figure 10.** Analytical model of frame with Chevron bracing for Cases 1 and 4 through 8, showing node numbers.



**Figure 11.** Orientation of members of the frame with Chevron bracing.



**Figure 12.** Moment resisting frame for Case 2, showing node numbers and physical member numbers.

## 3.2 Analysis And Design Cases

In this section, details of the various analysis and design cases considered in the study are presented. The frame with X-bracing and the frame with Chevron bracing were both analyzed and designed for a total of nine different cases. Six different cases were studied for the moment resisting frame. The different cases were set up with the aim of verifying the different modules, such as the analysis and design module of MicasPlus and the interface between these modules. The effect of changing various modelling and design parameters on the results was also studied. For Cases 1 through 7, the structural models were analyzed using MicasPlus Analysis and STAAD III and the results obtained from the two programs were compared to verify the accuracy of the analysis results. For Cases 8 and 9 the analysis and design was performed using MicasPlus and GTSTRUDL and the results from these programs were compared to verify the accuracy of the design modules.

Cases 1, 3, 4, 5, 6 and 7 were set up to study the effect of changing various structural modeling parameters such as rigid end offsets, on the analysis results. Case 2 was set up to verify the interface between ModelDraft and the Analysis module of MicasPlus. Cases 8 and 9 were set up to verify the interface between the analysis and design modules of MicasPlus. Case 9 was also used to verify the accuracy of automatic calculation of the effective length factor ( $K$ ). Static analysis and design was performed in all cases. The design was based on the AISC Allowable Stress Design specification.

### 3.2.1 Case 1 - Analytical Model

In Case 1 the analytical model of the frame was created in MicasPlus Analysis (MPA). Analytical models are made up of analytical or finite elements that are used

directly in the analysis by MPA, unlike physical members which are split up into one or more analytical or finite elements. Only the primary framing members were included in the model. Wind loads were applied as joint loads on the structure, acting in the global x and y directions. The three models were analyzed for support reactions, displacements and element forces. A similar analysis was performed using STAAD III. The results obtained from the two programs were compared to verify the accuracy of the analysis. The analytical model of the moment resisting frame for Case 1 is shown in Figures 2 and 3. The analytical model for the frame with the X-bracing is shown in Figures 7 and 8. Figures 10, 11, and 12 show the analytical model of the frame with Chevron bracing. It should be noted that the analytical model for Cases 4 through 8 is similar in that the same element and node numbers are used.

### **3.2.2 Case 2 - Physical Model**

The structural models of Case 2 were built in ModelDraft (MDR) and are made up of physical members, unlike in Case 1 where the structural models are made up of analytical members. Secondary framing members were included in the structural model and were classified as secondary members. The MDR physical models were then transferred to the MicasPlus Analysis module (MPA) by writing the model to the Project Structural Database (PSD) and reading it in MPA. However, the secondary members are not read into MPA. Thus the model in MPA consists of primary members only. While reading the structural model, MPA converts the physical model built in MDR into an analytical model by splitting the physical members into elements. The frames were then analyzed in MPA. The results of the analysis of Case 2 were compared with those obtained for Case 1 to verify that there are no differences between analytical model generated in the two cases and



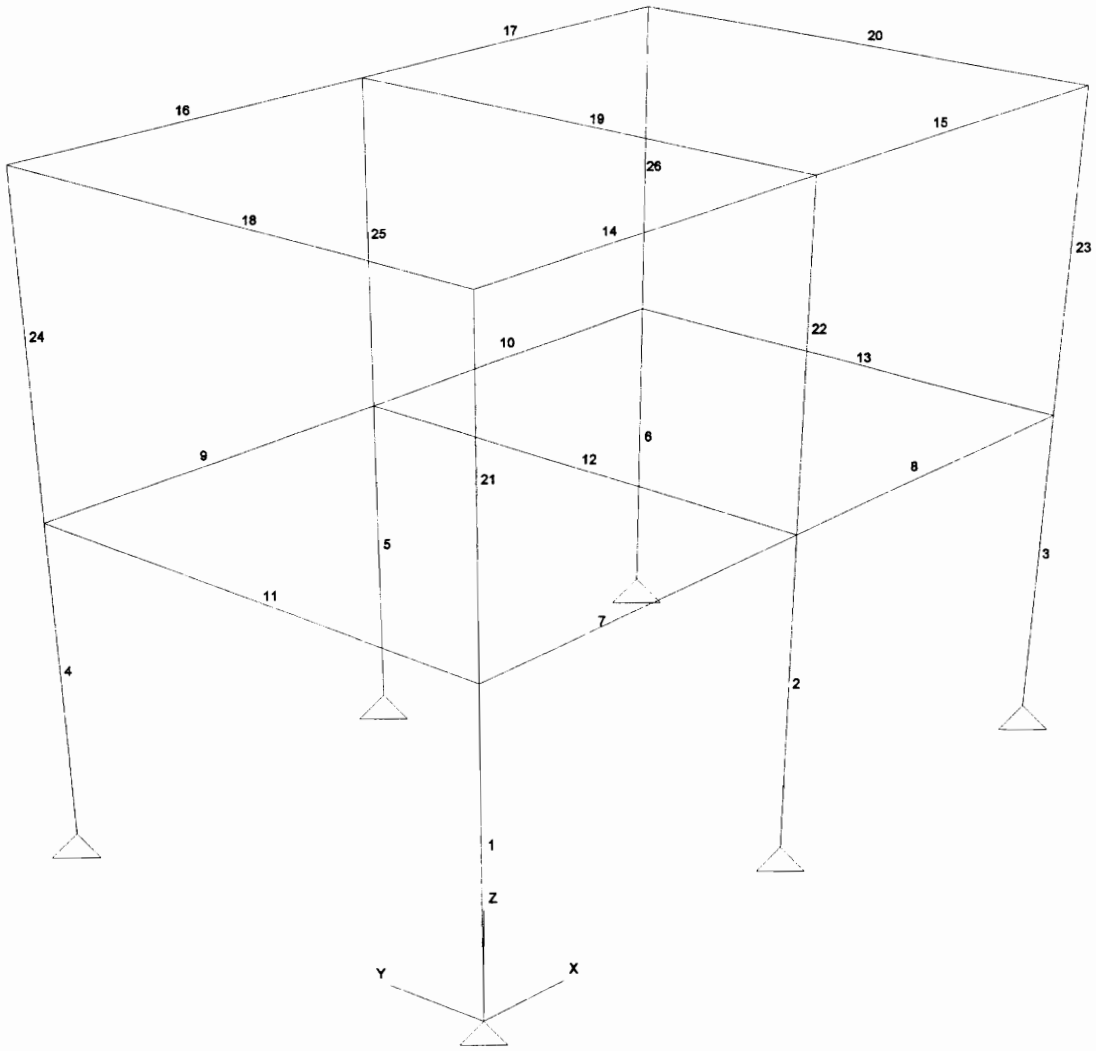
also to verify that the secondary framing members do not get transferred from MDR to MPA through the PSD. The physical members, element and node numbers for the models of Case 2 are shown in Figures 13 through 20.

### **3.2.3 Case 3 - Inactive Secondary Members**

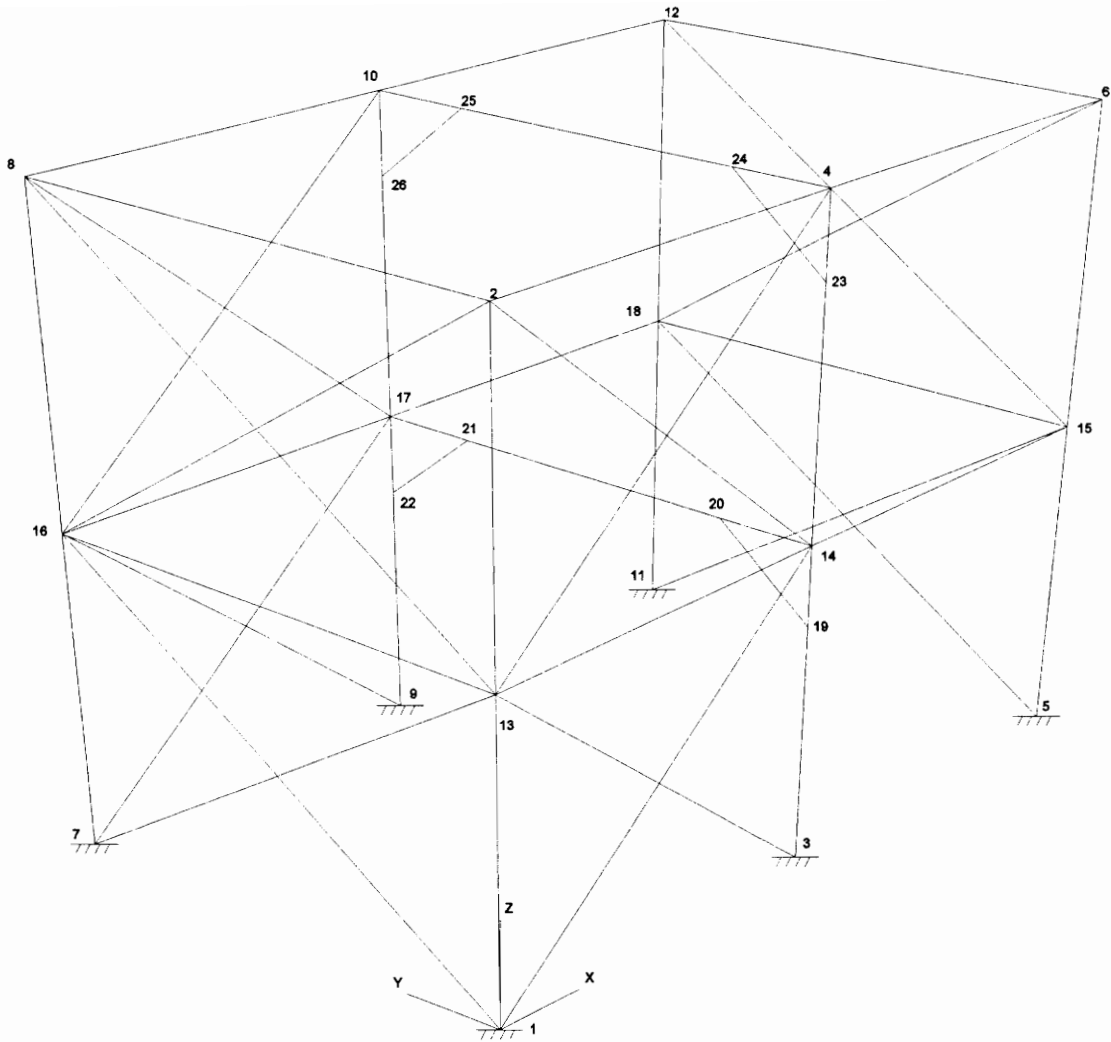
Secondary framing members were added to the MPA analytical models created in Case 1. The secondary members were made inactive for analysis and no load was applied on these members. The results of the analysis of Case 3 were compared with that of Case 1 to determine if the presence of inactive secondary framing members as part of the structural model, has any effect on the analysis results and to ascertain that the secondary members are indeed ignored in the analysis. The node numbers and element numbers for the various models for Case 3 are shown in Figures 21 through 26.

### **3.2.4 Case 4 - Rigid End Offsets**

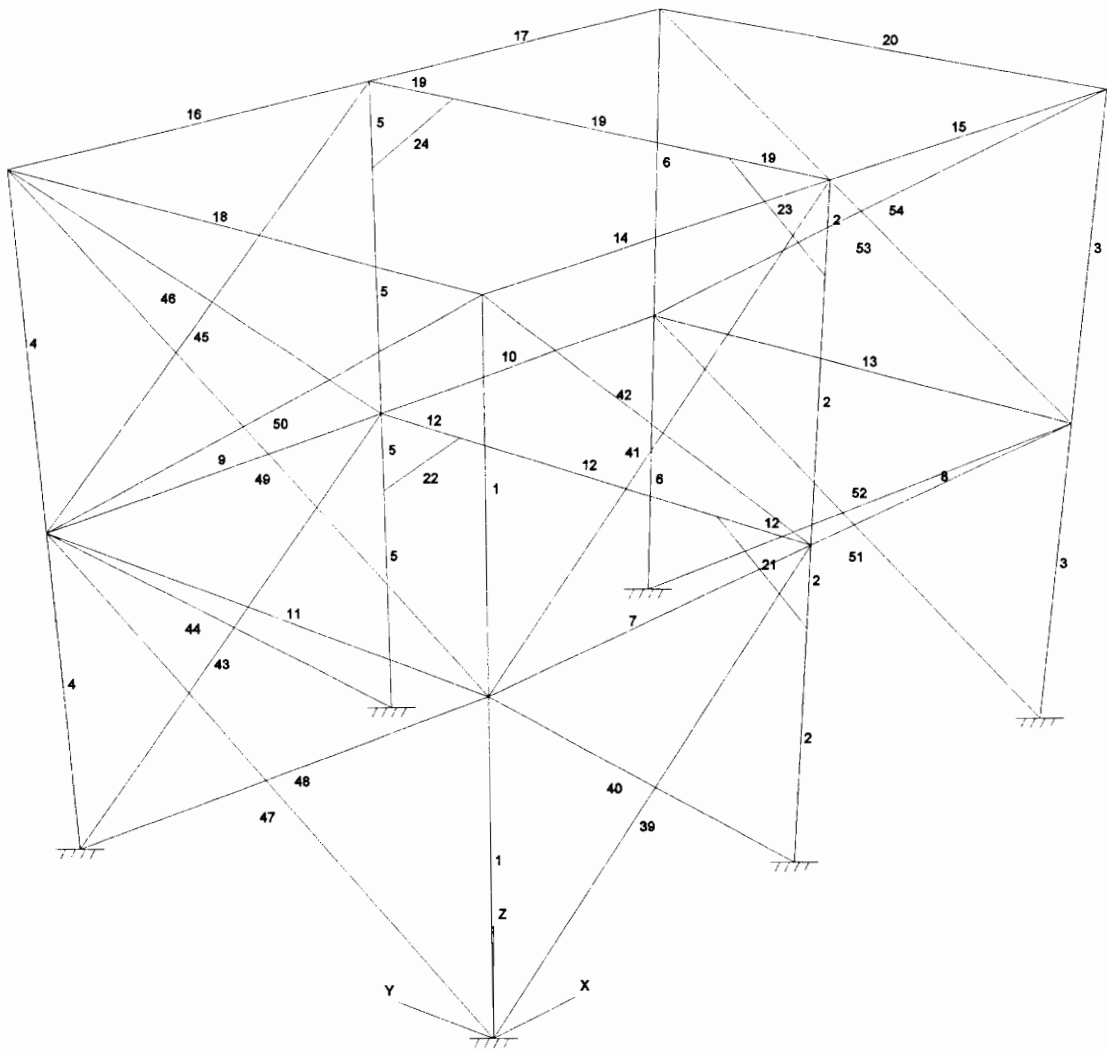
In Case 4, rigid end offsets were specified for all members of frames of Case 1. The "Global Rigid End Offset From Cardinal Point" option in MicasPlus was used to specify rigid end offsets for all members globally. A cardinal point is a point on the cross section of a member through which the stick model line of the member passes. The rigid end offset from cardinal point is the distance between the cardinal point and the shear center on the cross section of a member. Turning this option on, moves the line of action of forces through the member from its theoretical point of action towards the cardinal point, by the offset distance. This induces an eccentricity in the forces acting through the member. The frames were analyzed using MicasPlus Analysis and STAAD III. The results from the analysis of Case 4 were compared with those of Case 1 to determine the effect of specify-



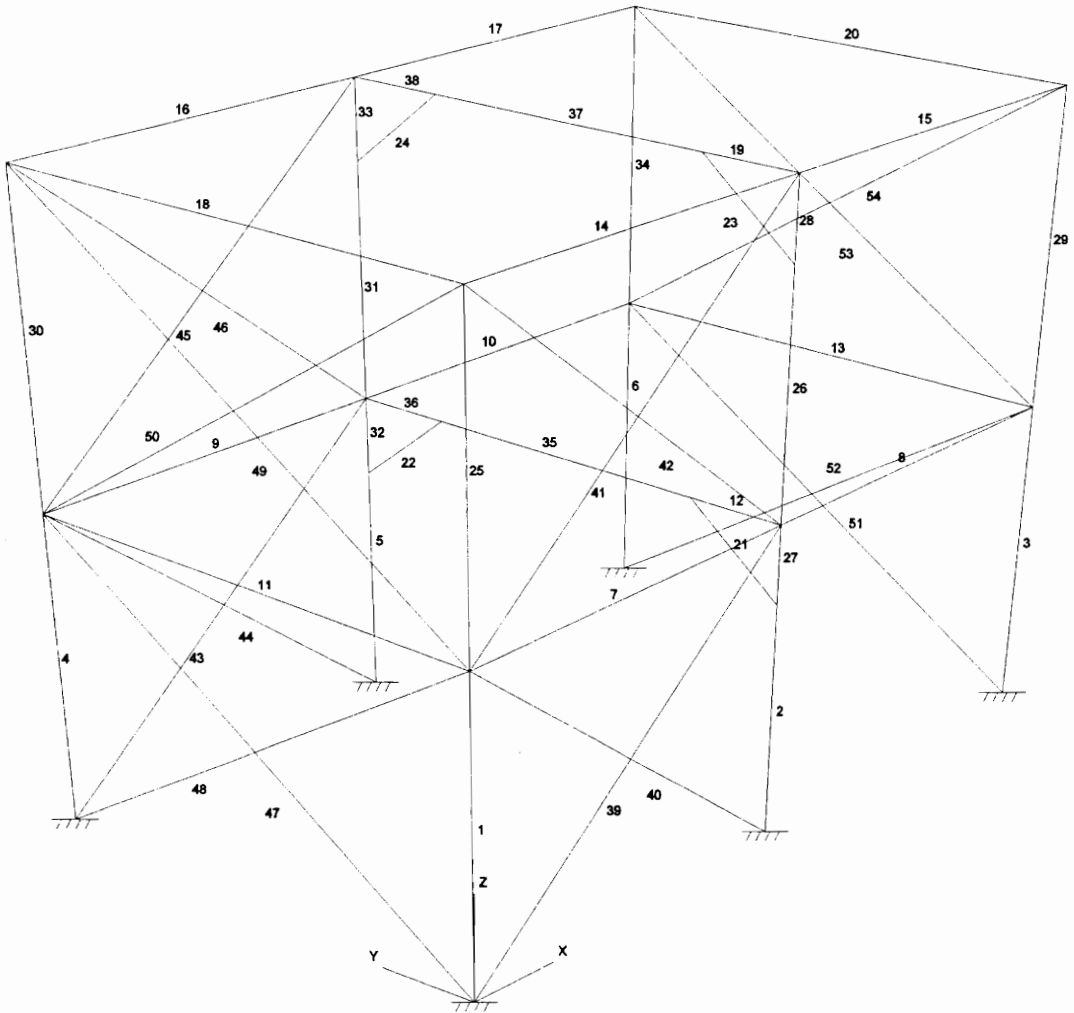
**Figure 13.** Analytical model of moment resisting frame for Case 2, showing element numbers.



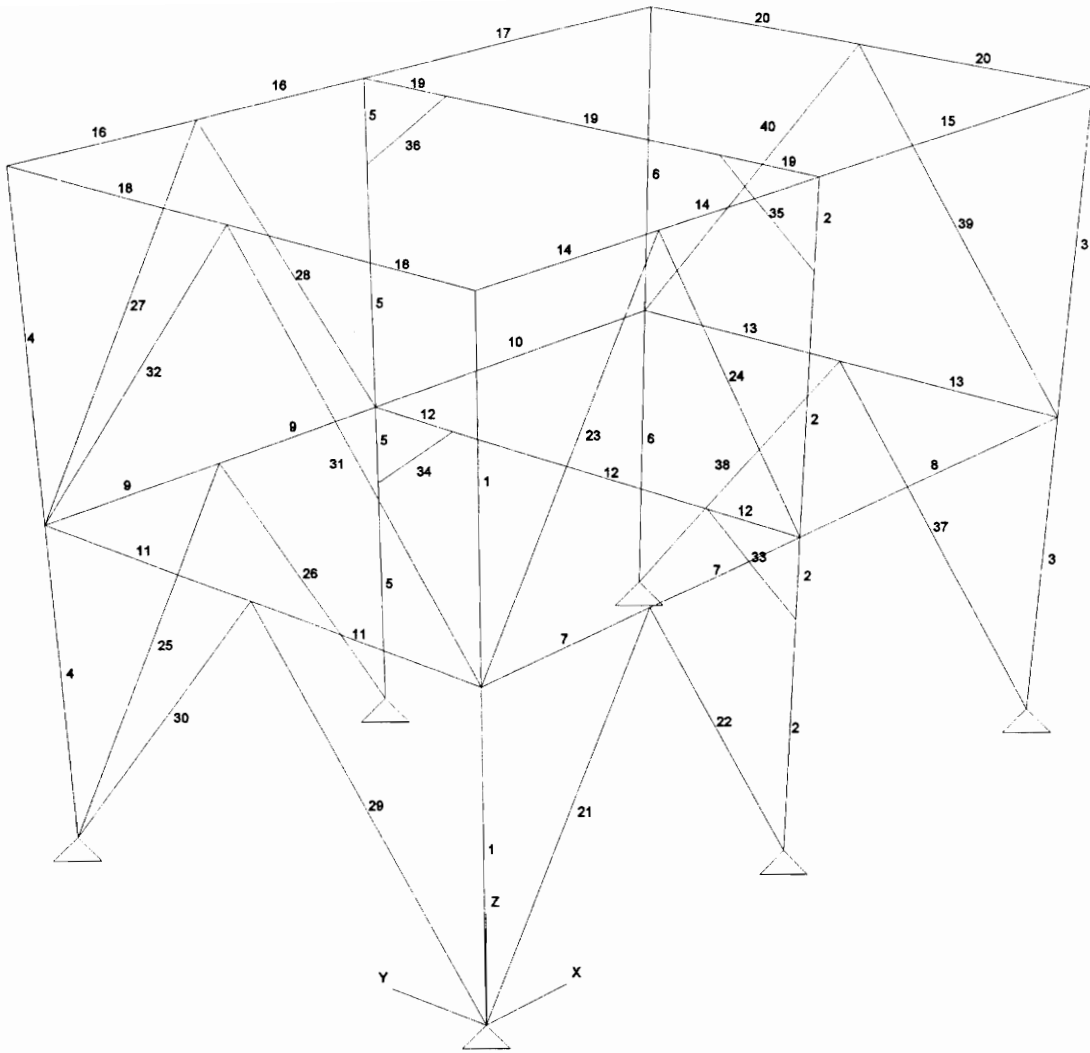
**Figure 14.** Frame with X-bracing for Case 2, showing node numbers.



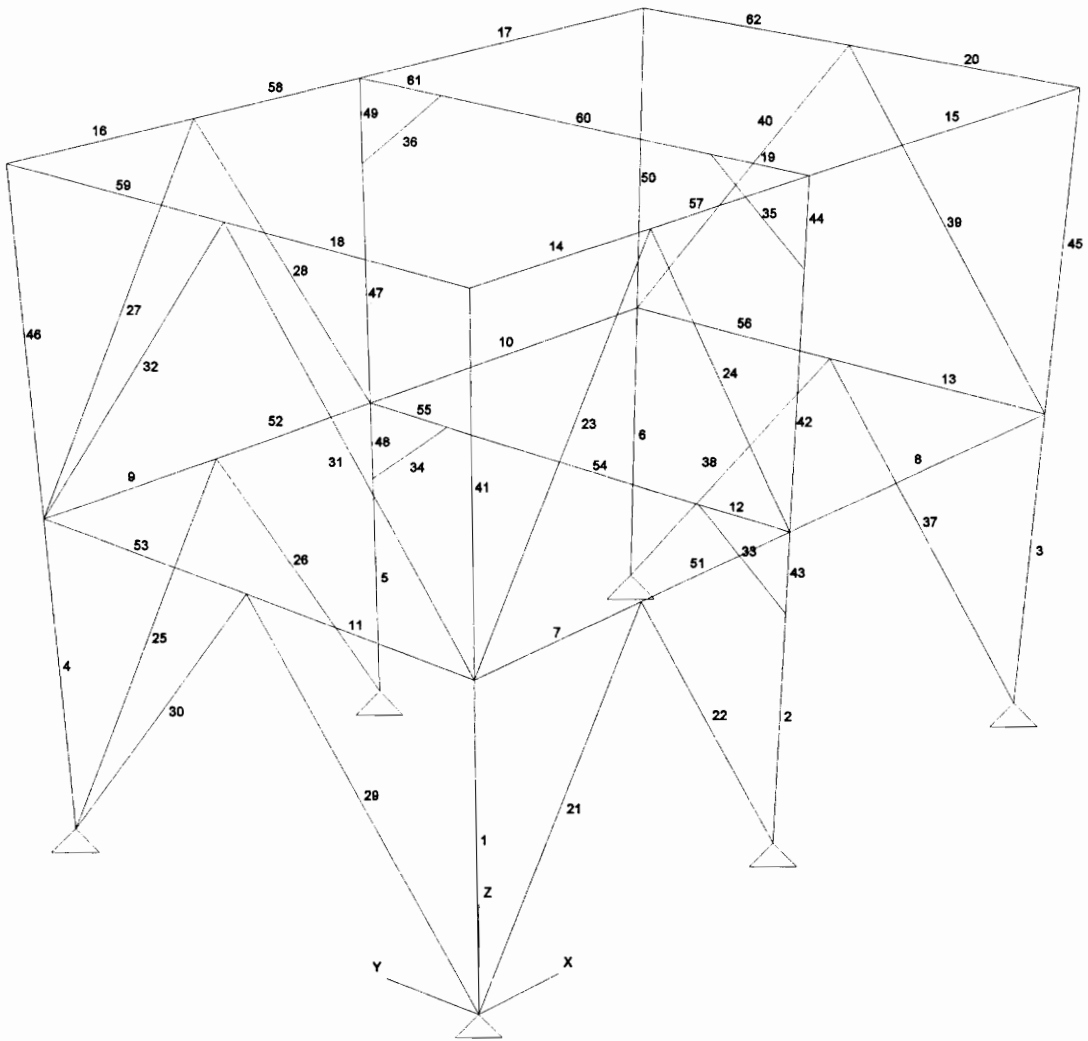
**Figure 15.** Frame with X-bracing for Case 2, showing physical member numbers.



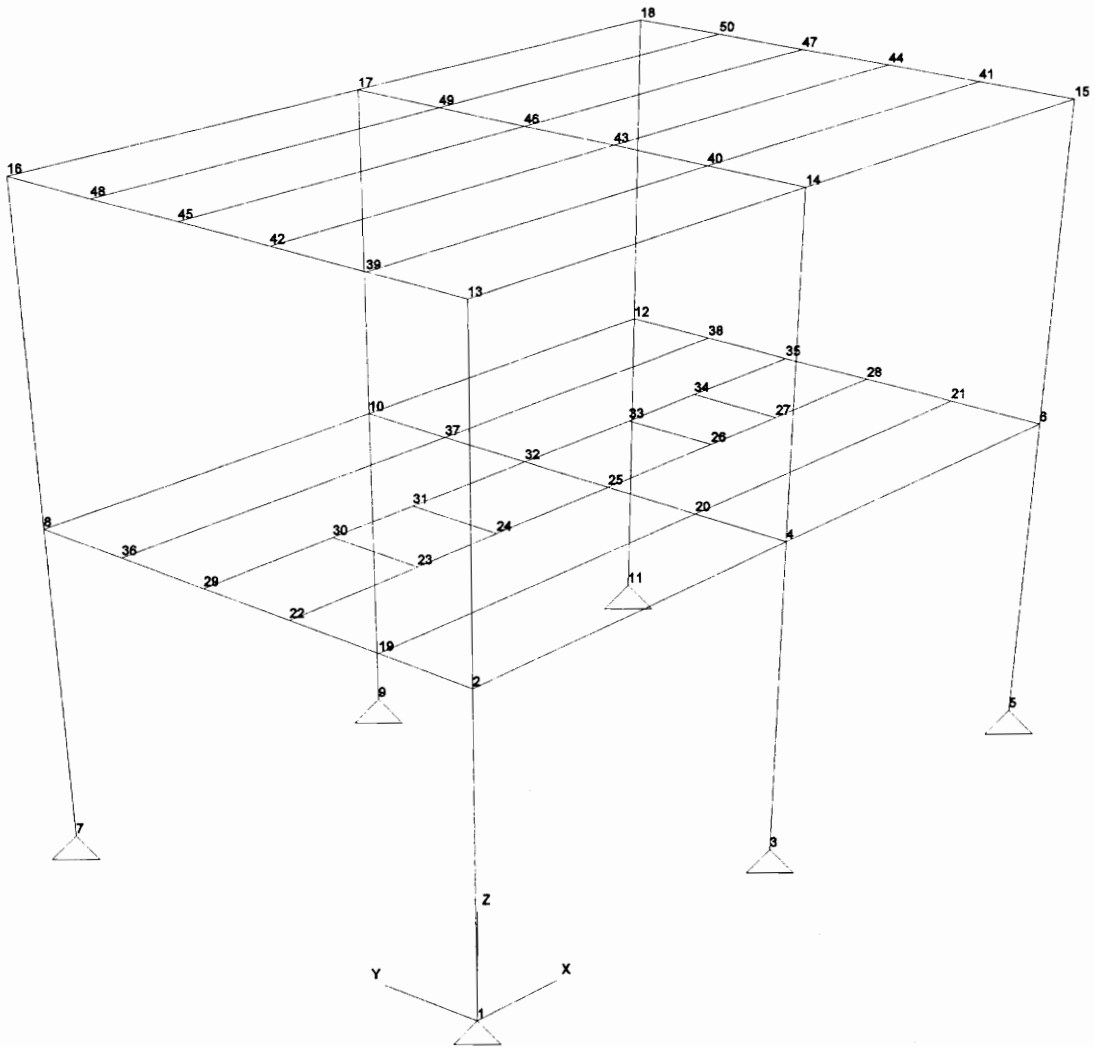
**Figure 16.** Analytical model of the frame with X-bracing for Case 2, showing element numbers.



**Figure 17.** Frame with Chevron bracing for Case 2, showing physical member numbers.

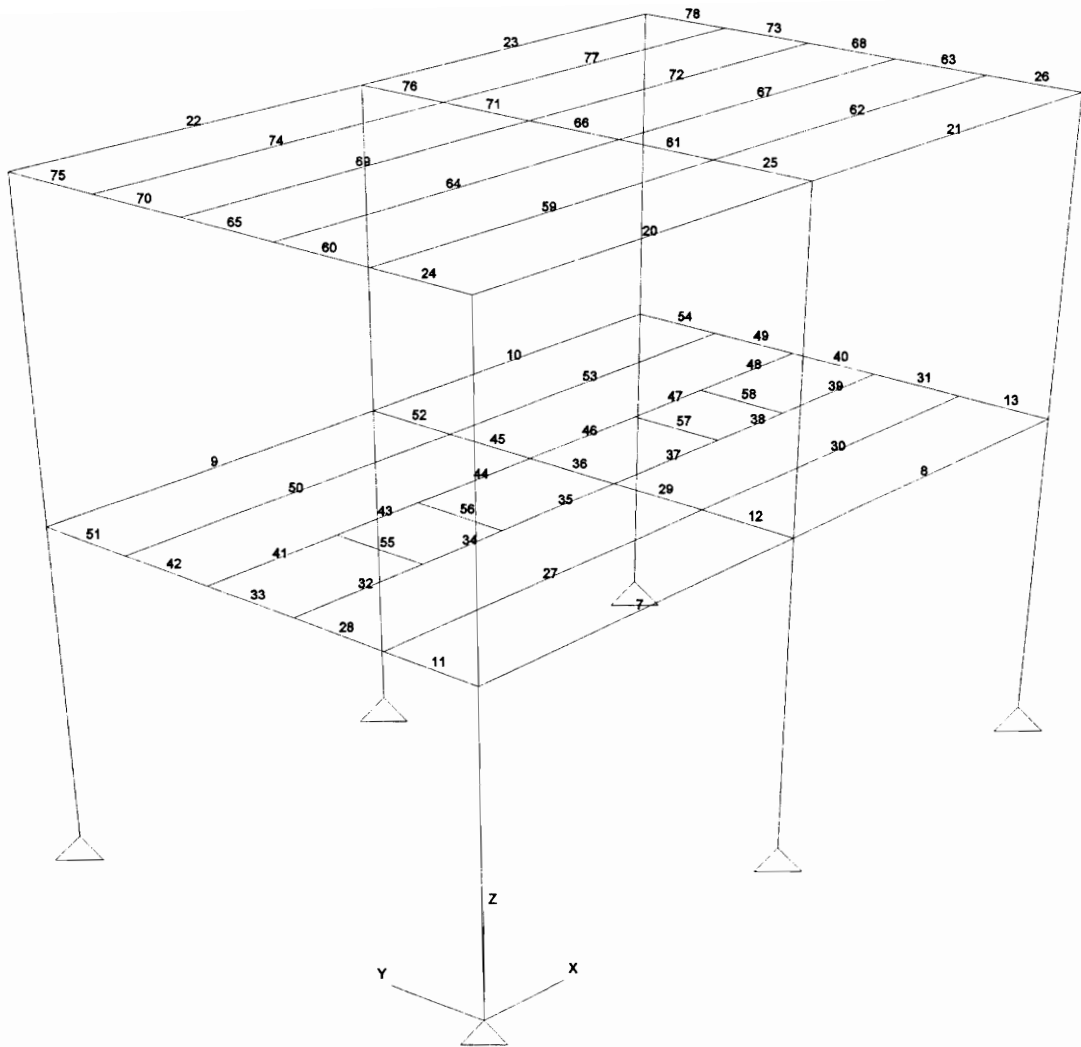


**Figure 18.** Analytical model of frame with Chevron bracing for Case 2, showing element numbers.

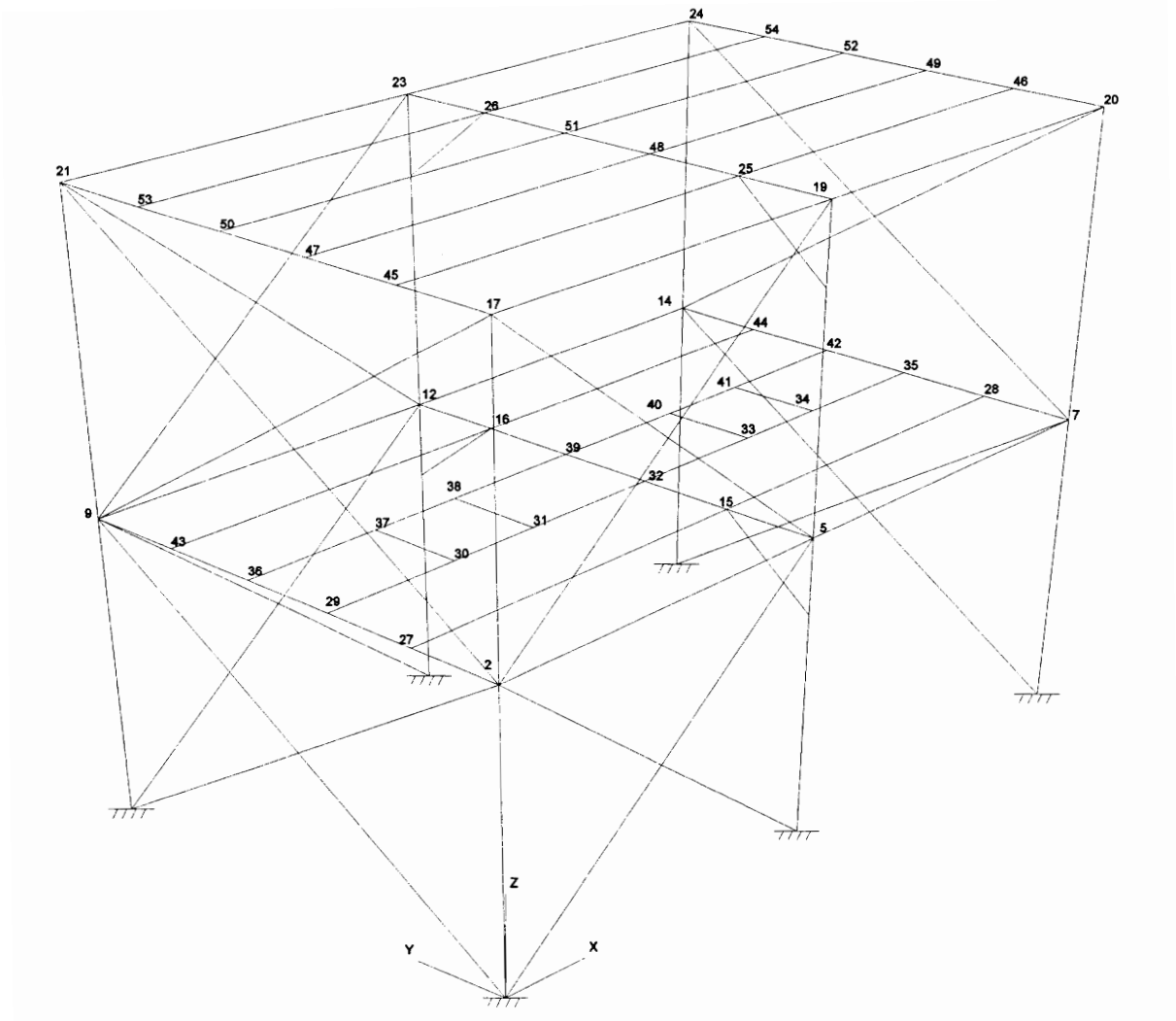


**Figure 19.** Node numbers of secondary members for Cases 3 and 9.

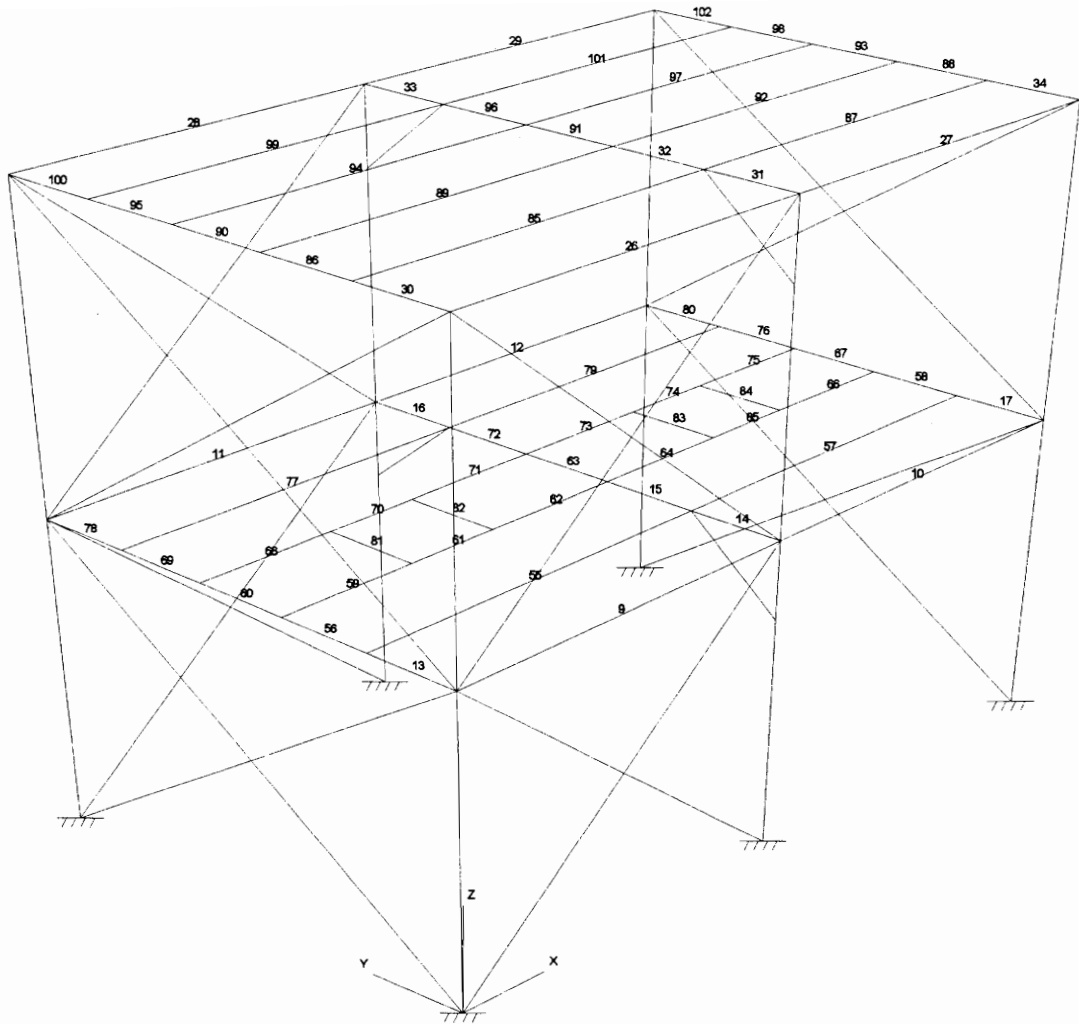




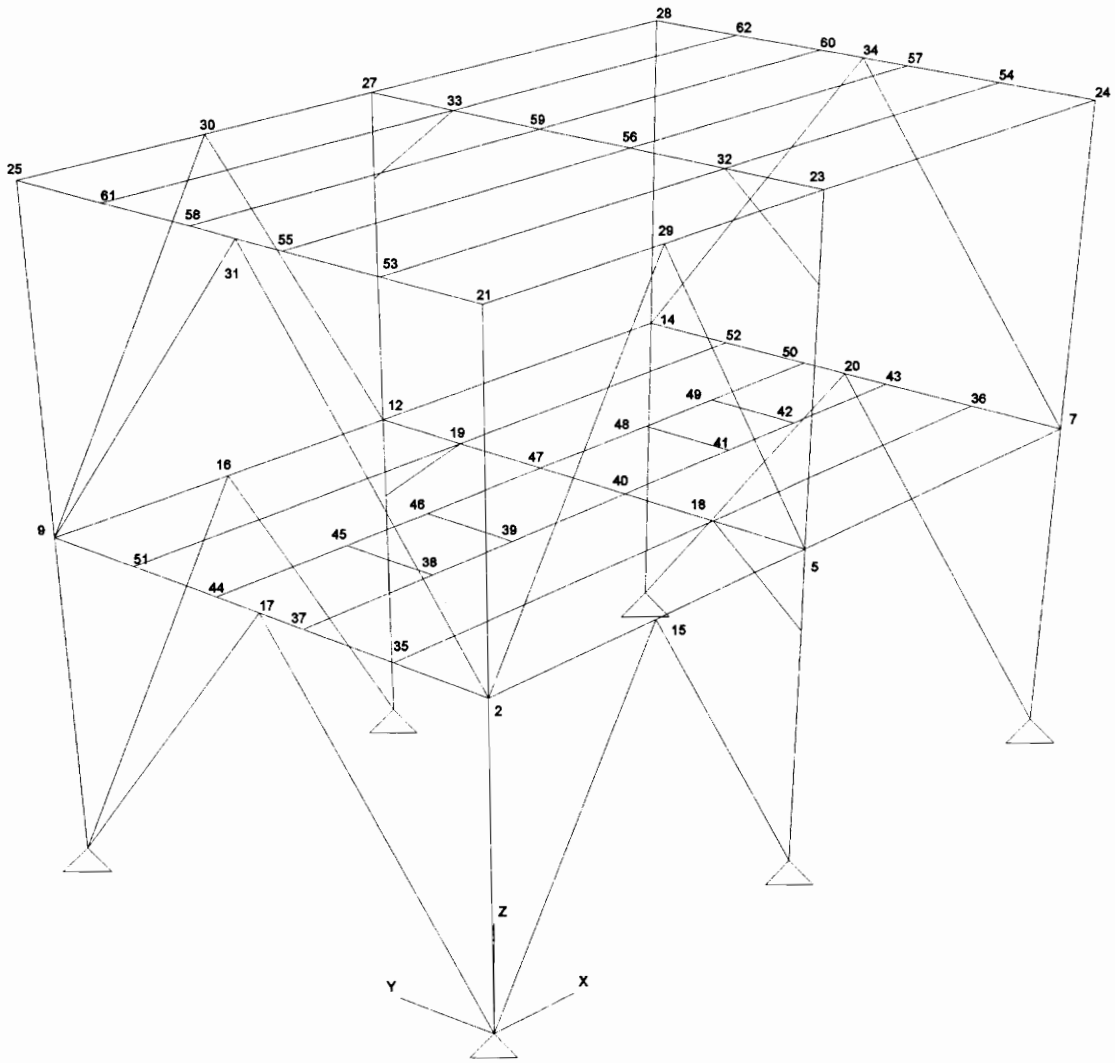
**Figure 20.** Moment resisting frame for Cases 3 and 6, showing element numbers of secondary members.



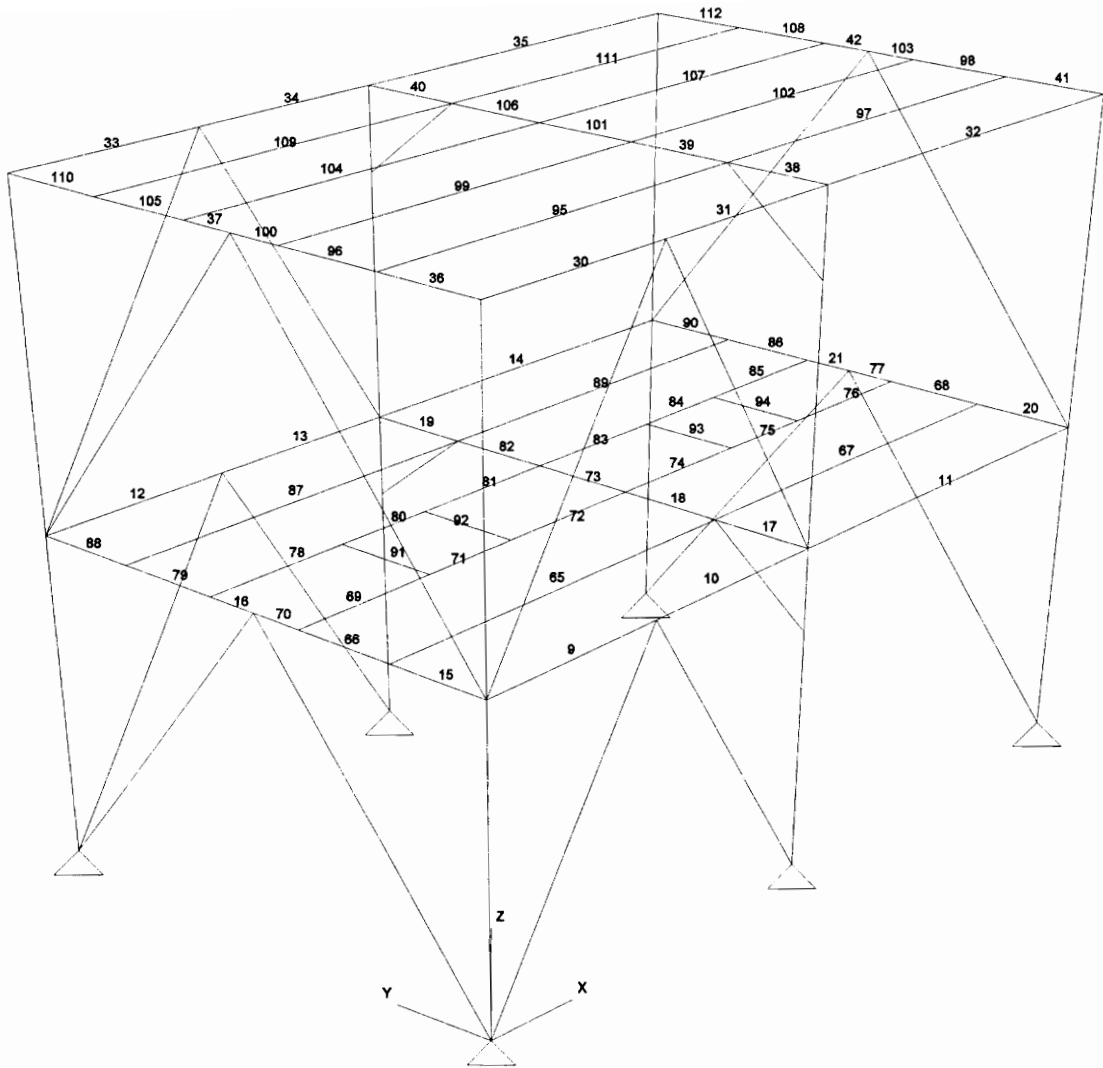
**Figure 21.** Frame with X-bracing for Cases 3 and 9, showing node numbers of secondary members.



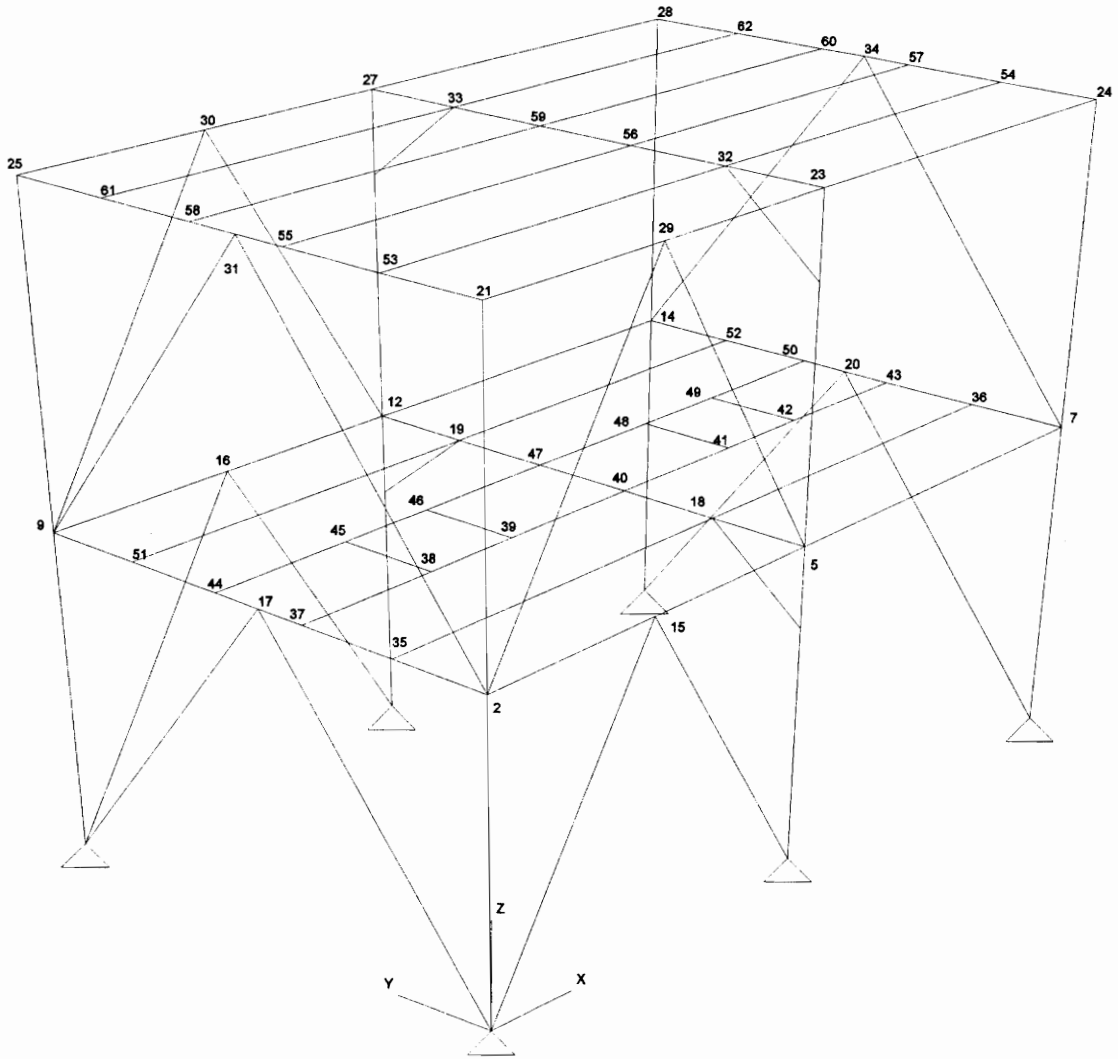
**Figure 22.** Analytical model of frame with X-bracing for Cases 3 and 9, showing element numbers of secondary members.



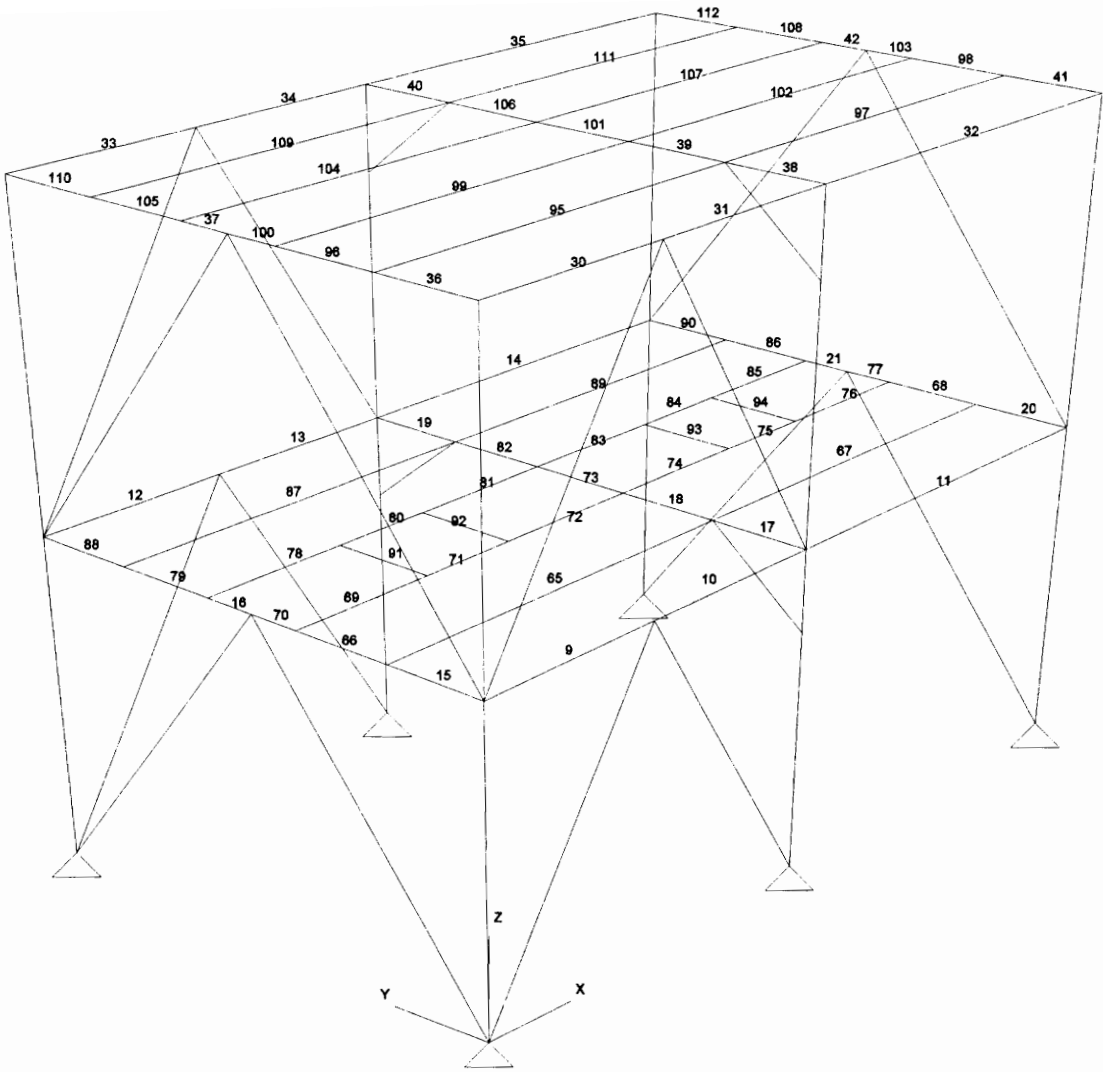
**Figure 23.** Frame with Chevron bracing for Cases 3 and 9, showing node numbers for secondary members.



**Figure 24.** Analytical model of frame with Chevron bracing for Cases 3 and 9, showing element numbers of secondary members.



**Figure 25.** Frame with Chevron bracing for Cases 3 and 9, showing node numbers for secondary members.



**Figure 26.** Analytical model of frame with Chevron bracing for Cases 3 and 9, showing element numbers of secondary members.

ing the rigid end offsets. The results for Case 4 obtained from the two programs were compared to verify the calculation of the rigid end offset. The node numbers and the element numbers of frames for Case 4 are same as those for Case 1.

### **3.2.5 Case 5 - Rigid End Offsets for Bracing Members**

The MPA analytical model of Case 1 was modified by specifying rigid end offsets from the cardinal point to the centroid for all of the bracing members. The ends of the bracing members were pinned as in Case 1. Specifying rigid end offset for bracing members would result in the line of force passing through the centroid to move to the cardinal point. This would induce a moment in the members which could be the controlling factor in their design. The frames were analyzed using MicasPlus Analysis and STAAD III. The analysis results obtained from MicasPlus Analysis were compared with those from Case 1 to determine the significance of the moment. Further more, the results obtained for Case 5 from both programs were compared to determine the accuracy of the results from MicasPlus Analysis. The node numbers and element numbers of Case 5 are the same as those for Case 1.

### **3.2.6 Case 6 - Rigid End Offsets For Bracing Members With Ends Fixed**

The MPA analytical model of Case 5 was modified by fixing the ends of the bracing members. This was to determine the difference in forces in the bracing members when their ends are pinned as compared to when they are fixed, while the rigid end offsets from cardinal point to the centroid is specified in both cases. Fixing the ends of the braces will induce a moment in the bracing members which could be the controlling factor in their design. The resulting structure was analyzed using MicasPlus Analysis and STAAD III.



The results obtained from both programs were compared. The results for this case were also compared with those obtained for Case 5 to determine the effects of rigid end offsets on forces in the bracing members.

### **3.2.7 Case 7 - Rigid End Offsets for Beams**

The MPA analytical model of Case 1 was modified by specifying rigid end offsets from the cardinal point to the centroid for all primary beams. This case was used to determine the magnitude of the moment induced in the beams of the frames with X-bracing and Chevron bracing, when a rigid end offset from the cardinal point to the centroid is specified. The structure was analyzed using MicasPlus Analysis and STAAD III. The results obtained from both the programs were again compared. The results of this case were also compared with Case 1 to determine the difference of the forces in the beams.

### **3.2.8 Case 8 - Design for Wind and Gravity Loads**

The columns and bracing members for all three frames of Case 1 were designed using MicasPlus Design and GTSTRUDL. The frame was subjected to wind and gravity loading. However, these loads were applied as joint loads. The corner columns formed one mark group, and the interior columns formed a second mark group.

For the braced frames, the effective length factor,  $K$ , for the columns was entered manually. This was to eliminate the possibility of an error induced in the design results, due to the different assumptions used by the programs to compute  $K$ . The corner columns were pinned at the support. Also, all members framing these columns were pinned. Side-sway in the global  $y$ -direction was inhibited for all columns with the exception of the columns of the interior frame, because the columns had knee bracing. Hence, the behavior of

corner columns at each floor level was similar to columns pinned at both ends and their effective length factor was specified as one. For the interior columns, the effective length factor was calculated considering sidesway of the interior frame in the global y-direction. The effective length factors were specified at the beginning of the design phase and the same factors were used for all designs, in order to simplify the amount of effort required to enter the data.

The columns of the interior frame were broken into two elements of five and fifteen feet length, due to the presence of the knee bracing. The actual length of these columns were twenty feet without the knee bracing. The knee bracing does not provide adequate stiffness to the compression flange of these columns, neither does it effectively restrain them from axial buckling. Hence, the effective axial unbraced length and the unbraced compression flange length for the interior columns was set equal to twenty feet.

The effective net area factor in tension for bracing members was set to 0.7 to compensate for bolt holes. The code tolerance was set to zero for all members. The code used for design was the 1978 AISC Allowable Stress Design specification.

For the moment resisting frame, the effective length factors were calculated by GTSTRUDL in each design cycle and these values were then used as input to the Micas-Plus Steel Design module. This was because the value of K calculated by MicasPlus is incorrect since it uses the theoretical value of the G factor instead of the practical value of the G factor to calculate K. Sidesway was permitted for all of the columns of the moment resisting frame.

In the design phase, design options were set so that W12 sections were selected for all the columns, WT sections for the X-bracing and Chevron bracing, and equal leg angles for the knee bracing.

Six load cases were considered. The wind loads acting in all four directions (namely, 'WLeft', 'WRight', 'WFront' and 'WBack') form four of the load cases. The self weight of members forms another load case. The sixth and last load case consisted of the dead and live loads. Five load combinations were formed. The load combinations called 'MaxGr' was made up of 1.0 times the sum of dead load, live load and self weight. Load combinations 'LWind', 'RWind', 'FWind', and 'BWind' were each made up of 0.75 times the sum of dead and live load, self weight and wind load in the direction represented by the first letter of the name of the combination. For example, 'L' for wind from left of the structure which represents the positive global x axis, 'F' for wind from the front of the structure which represents the positive global y axis and so on.

The structure was first analyzed using MPA, and then designed using MPD. The analysis and design were performed iteratively for five cycles. At the end of each analysis and design cycle, member sizes were updated to reflect the new sizes obtained from the design stage. Also, at the end of each cycle, individual member sizes obtained from the two programs were compared. The purpose of this case was to verify the accuracy of results from the design module, and the interface between the analysis and design module of MicasPlus. Also, the rate of convergence of the design algorithm and the total weight of steel in the structure given by the two programs were compared.

### 3.2.9 Case 9 - Design of Entire Frame Including Secondary Members

In this case, all members of the structure of Case 3, including secondary members were designed using MicasPlus Design and GTSTRUDL. The frame was subjected to wind loading which was applied as joint loads. The vessel load was increased from 20 kips in Case 8 to 40 kips for Case 9. The live load was increased from 150 psf to 250 psf on the second floor and 50 psf to 150 psf on the roof. Moreover, these loads were applied as member loads unlike in Case 8 where they were applied as joint loads. The load cases and load combinations were the same as in Case 8.

As in Case 8, the corner columns and the interior columns formed separate mark groups. The bracing members, at a given floor level, in parallel frames were placed in separate mark groups. The beam elements forming a physical member were placed in separate mark groups. The effective length factor ( $K$ ) for columns were specified as in Case 8, except for the moment resisting frame where  $K$  was calculated by both the programs. For this purpose the base of the columns of the moment resisting frame were fixed as MicasPlus does not follow the code to calculate  $K$  for columns pinned at the base.

The compression flange of the interior and secondary beams was fully braced with the exception of the beams carrying the vessel load, because the space between these beams is kept open for the vessel. In the design phase, design options were set so that W10 sections were selected for all the exterior columns, W14 for the interior columns and sections of depth more than or equal to 10 inches were selected for all beams. All other parameters were set the same as in Case 8. The purpose of this case was the same as that of Case 8. In addition this case was also used to verify the accuracy of the effective length factors

computed by the MicasPlus steel design module.

### 3.3 Loads

The loads applied on the frames were as follows:

1. Cases 1 through 7: Wind Load @ 40 psf from two directions namely front and left of the structure which are positive directions of global y and x axis respectively.
2. Case 8: All loads applied as joint loads except self weight which is applied as uniformly distributed member load.
  - a Wind load : @ 20 psf from all four horizontal directions.
  - b Self weight of all members
  - c Dead load : Second floor - 75 psf, Roof - 50 psf
  - d Live load : Second floor - 150 psf, Roof - 50 psf
  - e Vessel load : Two 20 kip vessels on second floor, one in each bay.
3. Case 9 : Dead, live and member loads applied as uniformly distributed loads.

Vessel and wind loads applied as joint load.

- a Dead load : Second floor and roof - 75 psf
- b Live load : Second floor - 250 psf, Roof - 150 psf
- c Vessel load : Two 40 kip vessels on second floor, one in each bay.
- d Wind and self weight applied as in Case 8.

## **Chapter 4**

### **Discussion of Results**

In this chapter the results of the analysis, design and parametric study are presented followed by a discussion of the results. In Section 4.1 a comparison of the results of the static analysis obtained from MicasPlus Analysis and STAAD III for the various cases are presented. A discussion of the interface between the MicasPlus ModelDraft and Analysis modules is also presented. Section 4.2 presents a comparison of the steel design results obtained from MicasPlus Design and GTSTRUDL. The result of the evaluation of the interface between the Analysis and Design module of MicasPlus are also given in this section. In Section 4.3, the results of the parametric study are presented.

#### **4.1 Analysis Results**

As described in Chapter 3, nine different cases of the braced frames and six cases of the moment resisting frame were studied. Analysis results obtained for Cases 1,4,5,6 and 7 from MicasPlus Analysis were compared with those from STAAD III to verify the accuracy of the analysis. Results from MicasPlus Analysis for Cases 2 and 3 are also compared to those obtained from MicasPlus Analysis for Case 1 in order to verify the interface between Modeldraft and MicasPlus Analysis and to determine the effect of keeping secondary framing members inactive during analysis.

#### 4.1.1 Tabulation of Analysis Results

The comparison of support reactions obtained from MicasPlus Analysis and STAAD III for Cases 1, 4, 5, 6 and 7 is presented in Table 1. The results for Cases 2 and 3 are presented in Table 2. Only those values of support reactions that gave the maximum percentage differences are tabulated. Node names 'A' through 'F' are assigned to the support nodes for easy reference. These node names are shown in Figure 27 which follows the tables. The actual node numbers are also given in the tables. The tabulated percentage differences were rounded off to the second decimal place and were not computed for support reactions of 0.5 kips or less.

The comparison of nodal translations for Cases 1, 4, 5, 6 and 7 is presented in Table 3. The results for Cases 2 and 3 are given in Table 4. Again, only those values of translations that yielded the maximum percentage differences are tabulated. The nodes selected for tabulation are assigned node names and are shown in Figure 28. Percentage differences are not computed for translations of 0.5 inches or less since this is value is less than an allowable deflection of  $L/300$ . For the frames considered in this study this would correspond to a deflection of  $15 \times 12 / 300 = 0.6$  inches.

Line element end forces and line element end moments for the moment resisting frame are presented in Tables 5 and 6 respectively for Cases 1 and 4. Percentage differences for line element actions of 0.5 kips or kip-ft. and less were not computed. Only selected line elements are tabulated. These are named C1, C2, etc. for columns, and B1, B2, etc. for beams, as shown in Figure 29.

Figures 30 and 31 show graphically the variation of percentage difference between

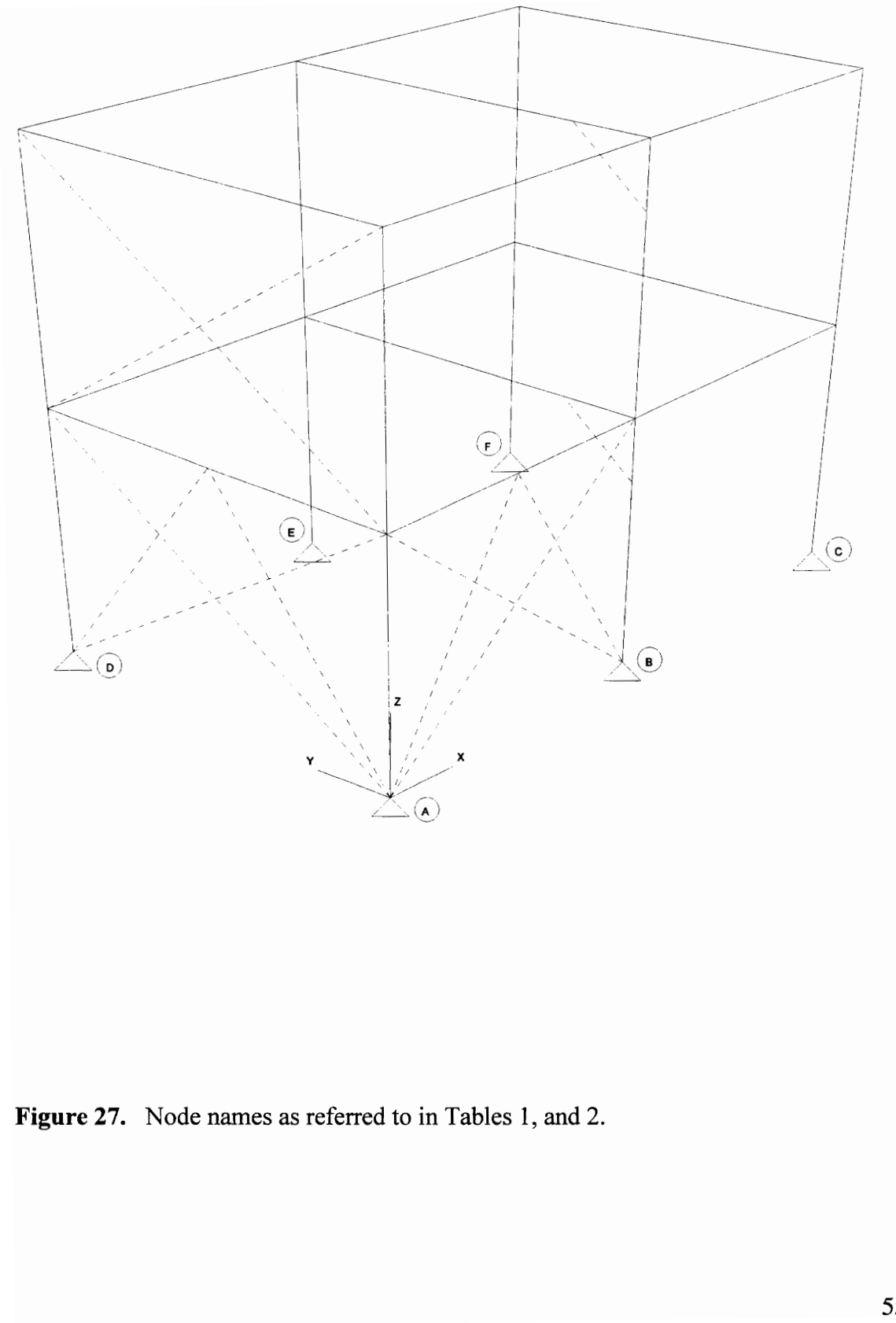
**Table 1.** Comparison of support reactions obtained from MicasPlus and STAAD III for Cases 1, and 4 to 7 for all three frames.

Type of frame	Case	Node name (no.)	Load ca/co	MicasPlus			STAAD III			% difference		
				Fx	Fy	Fz	Fx	Fy	Fz	Fx	Fy	Fz
				kips			kips			%		
M	1	A	XD	-4.667	-1E-14	-9.9978	-4.66715	0	-9.99781	0.00%	--	0.00%
			YD	-0.0021	-6.8582	-14.874	-0.00213	-6.8586	-14.8742	--	-0.01%	0.00%
	1	B	XD	-5.6753	9.7E-17	-0.0043	-5.67504	0	-0.00437	0.00%	--	--
			YD	1.4E-14	-10.302	-21.453	0	-10.3006	-21.4516	--	0.01%	0.01%
	4	C	XD	-4.6906	-7E-14	9.8714	-4.69079	0	9.87284	0.00%	--	-0.01%
			YD	0.002344	-6.8186	-14.8428	0.00234	-6.81874	-14.8434	--	0.00%	0.00%
	4	D	XD	-4.6428	6.98E-14	-10.1286	-4.64299	0	-10.1272	0.00%	--	0.01%
			YD	0.002344	-6.892	14.8428	0.00234	-6.89278	14.84335	--	-0.01%	0.00%
	4	E	XD	-5.6667	4.07E-16	0.2571	-5.66623	0	0.25431	0.01%	--	--
			YD	9.04E-15	-10.3705	21.5143	0	-10.3701	21.5133	--	0.00%	0.00%
	1	F	XD	-4.6577	1.3E-14	10.0022	-4.6578	0	10.00218	0.00%	--	0.00%
			YD	-0.0021	-6.8487	14.8737	-0.00213	-6.84912	14.87421	--	-0.01%	0.00%
X	5	A	XD	-8.6672	-0.293	-19.9984	-8.68058	-0.29385	-19.9983	-0.15%	--	0.00%
			YD	21.9279	3.8888	-12.5056	21.82027	3.75197	-12.505	0.49%	3.65%	0.00%
	4	B	XD	-7.8895	0.0159	19.9992	-7.8948	0.02611	20	-0.07%	--	0.00%
			YD	-1.3495	-11.9148	-25.7686	-0.32292	-11.914	-25.754	317.91%	0.01%	0.06%
	4	C	XD	-0.0129	0.0000122	3.29E-08	-0.01568	0.00156	0	--	--	--
			YD	0.009785	-5.6852	-12.8013	0.00006	-5.709	-12.801	--	-0.42%	0.00%
	1	D	XD	-7.2175	0.5892	-20	-7.21716	0.58997	-20	0.00%	-0.13%	0.00%
YD			0.5403	-6.2318	12.8012	0.54244	-6.2321	12.80127	-0.39%	0.00%	0.00%	
6	E	XD	-7.8789	0.024	20.0042	-7.88118	0.02374	20.00418	-0.03%	--	0.00%	
		YD	2.7639	-11.7057	24.7633	2.84516	-11.7045	24.75078	-2.86%	0.01%	0.05%	
7	F	XD	-0.015	-3.6E-07	0	-0.01502	0	0	--	--	--	
		YD	0.000137	-6.3233	12.8011	0.00015	-6.32477	12.80117	--	-0.02%	0.00%	
K	4	A	XD	-7.4109	-0.1323	-20	-7.4135	-0.12327	-20	-0.04%	--	0.00%
			YD	0.1573	-5.9312	-12.6804	0.12068	-5.93326	-12.6926	--	-0.03%	-0.10%
	4	B	XD	-7.5587	-0.047	20	-7.55611	-0.03535	20	0.03%	--	0.00%
			YD	-0.1325	-11.9373	-25.7179	-0.09974	-11.934	-25.7058	--	0.03%	0.05%
	1	C	XD	-0.0292	7.416E-08	0	-0.02927	0	0	--	--	--
			YD	-0.002125	-6.0042	-12.8007	-0.00214	-6.00419	-12.8008	--	0.00%	0.00%
	6	D	XD	-7.5054	0.1616	-20	-7.50537	0.1614	-20	0.00%	--	0.00%
			YD	0.0829	-6.0189	13.0944	0.0845	-6.02152	13.11042	--	-0.04%	-0.12%
	6	E	XD	-7.462	-0.1032	20	-7.46195	-0.10317	20	0.00%	--	0.00%
			YD	0.0113	-11.9731	25.3047	0.01379	-11.9705	25.28862	--	0.02%	0.06%
	7	F	XD	-0.0295	-7E-08	-2.3E-20	-0.0296	0	0	--	--	--
			YD	0.001826	-6.0455	12.8011	0.00185	-6.04596	12.80135	--	-0.01%	0.00%



**Table 2.** Comparison of support reactions obtained from MicasPlus and STAAD III. for Cases 2 and 3 for all three frames.

Type of frame	Case	Load ca/co	Node name (no.)	MicasPlus (Case 2 - 3)			Node name (no.)	MicasPlus (Case 1)			% difference		
				Fx	Fy	Fz		Fx	Fy	Fz	Fx	Fy	Fz
				kips				kips			%		
M	2	XD	A	-4.67	0.00	-10.00	A	-4.67	0.00	-10.00	0.00%	--	0.00%
		YD	[1]	0.00	-6.86	-14.87	[1]	0.00	-6.86	-14.87	--	0.00%	0.00%
	2	XD	B	-5.68	0.00	0.00	B	-5.68	0.00	0.00	0.00%	--	--
		YD	[3]	0.00	-10.30	-21.45	[3]	0.00	-10.30	-21.45	--	0.00%	0.00%
	2	XD	C	-4.66	0.00	10.00	C	-4.66	0.00	10.00	0.00%	--	0.00%
		YD	[5]	0.00	-6.86	-14.87	[5]	0.00	-6.86	-14.87	--	0.00%	0.00%
3	XD	D	-4.67	0.00	-10.00	D	-4.67	0.00	-10.00	0.00%	--	0.00%	
	YD	[7]	0.00	-6.85	14.87	[7]	0.00	-6.85	14.87	--	0.00%	0.00%	
3	XD	E	-5.68	0.00	0.00	E	-5.68	0.00	0.00	0.00%	--	--	
	YD	[9]	0.00	-10.28	21.45	[9]	0.00	-10.29	21.45	--	0.00%	0.00%	
3	XD	F	-4.66	0.00	10.00	F	-4.66	0.00	10.00	0.00%	--	0.00%	
	YD	[11]	0.00	-6.85	14.87	[11]	0.00	-6.85	14.87	--	0.00%	0.00%	
X	2	XD	A	-7.22	-0.59	-20.00	A	-7.22	-0.59	-20.00	0.00%	0.00%	0.00%
		YD	[1]	-0.55	-5.77	-12.80	[1]	-0.55	-5.77	-12.80	0.00%	0.00%	0.00%
	2	XD	B	-7.77	0.01	20.00	B	-7.77	0.01	20.00	0.00%	--	0.00%
		YD	[3]	0.55	-12.00	-25.60	[3]	0.55	-12.00	-25.60	0.00%	0.00%	0.00%
	2	XD	C	-0.01	0.00	0.00	C	-0.01	0.00	0.00	--	--	--
		YD	[5]	0.00	-5.77	-12.80	[6]	0.00	-5.77	-12.80	--	0.00%	0.00%
3	XD	D	-7.22	0.59	-20.00	D	-7.22	0.59	-20.00	0.00%	0.00%	0.00%	
	YD	[8]	0.54	-6.23	12.80	[8]	0.54	-6.23	12.80	0.00%	0.00%	0.00%	
3	XD	E	-7.77	-0.01	20.00	E	-7.77	-0.01	20.00	0.00%	--	0.00%	
	YD	[10]	-0.54	-12.00	25.60	[10]	-0.54	-12.00	25.60	0.00%	0.00%	0.00%	
3	XD	F	-0.01	0.00	0.00	F	-0.01	0.00	0.00	--	--	--	
	YD	[13]	0.00	-6.23	12.80	[13]	0.00	-6.23	12.80	--	0.00%	0.00%	
K	2	XD	A	-7.49	-0.01	-20.00	A	-7.49	-0.01	-20.00	0.00%	--	0.00%
		YD	[1]	-0.02	-6.00	-12.80	[1]	-0.02	-6.00	-12.80	--	0.00%	0.00%
	2	XD	B	-7.48	0.00	20.00	B	-7.48	0.00	20.00	0.00%	--	0.00%
		YD	[3]	0.02	-12.00	-25.60	[3]	0.02	-12.00	-25.60	--	0.00%	0.00%
	2	XD	C	-0.03	0.00	0.00	C	-0.03	0.00	0.00	--	--	--
		YD	[5]	0.00	-6.00	-12.80	[6]	0.00	-6.00	-12.80	--	0.00%	0.00%
3	XD	D	-7.22	0.59	-20.00	D	-7.22	0.59	-20.00	0.00%	0.00%	0.00%	
	YD	[8]	0.54	-6.23	12.80	[8]	0.54	-6.23	12.80	0.00%	0.00%	0.00%	
3	XD	E	-7.77	-0.01	20.00	E	-7.77	-0.01	20.00	0.00%	--	0.00%	
	YD	[10]	-0.54	-12.00	25.60	[10]	-0.54	-12.00	25.60	0.00%	0.00%	0.00%	
3	XD	F	-0.01	0.00	0.00	F	-0.01	0.00	0.00	--	--	--	
	YD	[13]	0.00	-6.23	12.80	[13]	0.00	-6.23	12.80	--	0.00%	0.00%	



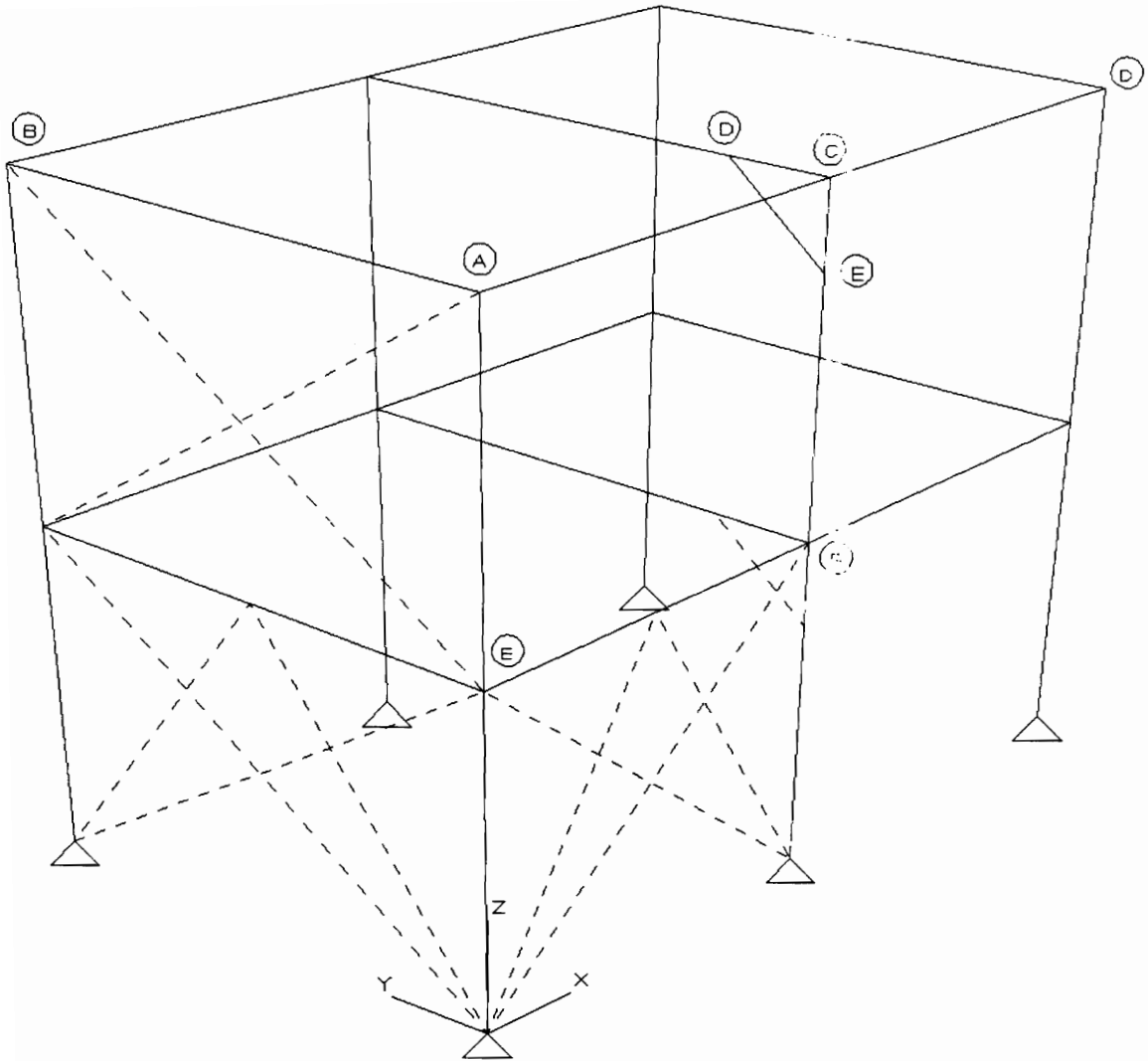
**Figure 27.** Node names as referred to in Tables 1, and 2.

**Table 3.** Comparison of displacements obtained from MicasPlus and STAAD III. for Cases 1, and 4 through 7 for all three frames.

Type of frame	Case	Node name (no)	Load ca/co	MicasPlus			STAAD III			% difference		
				Tx	Ty	Tz	Tx	Ty	Tz	Tx	Ty	Tz
				inches			inches			%		
M	1	A	XD	7.1556	1.1E-14	0.0051	7.14718504	0	0.00509843	0.12%	--	--
			YD	0.0003	5.2563	0.00782	0.00029528	5.29151969	0.0078189	--	-0.67%	--
	1	B	XD	7.1556	1.1E-14	0.0051	7.14718504	0	0.00509843	0.12%	--	--
			YD	-0.0003	5.2536	-0.0078	-0.0002953	5.28880709	-0.0078189	--	-0.67%	--
	1	C	XD	7.1512	-1E-16	0.000005	7.14278346	0	3.937E-06	0.12%	--	--
			YD	-2E-14	6.7497	0.0109	0	6.78372047	0.01091339	--	-0.50%	--
	4	D	XD	7.1564	5.85E-14	-0.00503	7.14784646	0	-0.0050315	0.12%	--	--
			YD	-0.00024	5.2514	0.007803	-0.0002441	5.28664567	0.00780315	--	-0.67%	--
	4	E	XD	5.9325	-4E-14	0.004389	5.92393701	0	0.00438976	0.14%	--	--
			YD	0.000224	3.7343	0.006431	0.00022441	3.75754331	0.00643307	--	-0.62%	--
	1	F	XD	5.9142	-6E-17	0.0000019	5.90572835	0	0	0.14%	--	--
			YD	-1E-14	4.9756	0.0093	0	5.00038189	0.00929528	--	-0.50%	--
X	5	A	XD	0.3971	-0.3425	0.005919	0.39181496	-0.337685	0.00590551	--	--	--
			YD	0.4984	0.3081	0.0184	0.49191339	0.30562992	0.01825591	--	--	--
	5	B	XD	0.3903	-0.3425	0.005637	0.385	-0.337748	0.00563386	--	--	--
			YD	-0.7662	0.3065	-0.00787	-0.7559646	0.30394882	-0.0078898	1.35%	--	--
	4	C	XD	0.0981	0.0000013	-0.00609	0.09054331	2.7559E-05	-0.0061417	--	--	--
			YD	0.0271	5.4329	0.006095	0.01560236	5.62271654	0.0064685	--	-3.38%	--
	4	D	XD	0.1176	-0.00048	-0.00044	0.10482677	-0.0002756	-0.0027165	--	--	--
			YD	0.3924	5.4047	-0.1604	0.35205118	5.59338583	-0.1715748	--	-3.37%	--
	7	E	XD	0.0818	0.0000785	-0.00587	0.08170472	7.4803E-05	-0.005874	--	--	--
			YD	-0.00196	4.7457	0.006118	-0.0020118	4.95787402	0.00618504	--	-4.28%	--
	7	F	XD	0.0563	0.0000259	-0.00524	0.05624016	2.3622E-05	-0.0052441	--	--	--
			YD	-0.00096	3.6331	0.00441	-0.0009764	3.75949213	0.00444488	--	-3.36%	--
K	5	A	XD	0.8981	-0.0000092	0.000935	0.86355118	-7.874E-06	0.00098425	4.00%	--	--
			YD	-3.0441	2.2119	0.003735	-2.7800551	2.02649213	0.00356693	9.50%	9.15%	--
	4	B	XD	0.1749	0.00000268	0.001998	0.17192913	3.937E-06	0.00200394	--	--	--
			YD	0.113	0.1247	-0.00154	0.09156299	0.12093307	-0.0014882	--	--	--
	4	C	XD	0.171	-0.00008	-0.0021	0.16809055	-7.087E-05	-0.0020945	--	--	--
			YD	-0.1131	6.6121	0.005623	-0.0916024	6.48973228	0.00551969	--	1.89%	--
	1	D	XD	0.129	6.43E-07	-0.00216	0.12887008	0	-0.0021614	--	--	--
			YD	-0.00242	4.3288	-0.1322	-0.002437	4.49515354	-0.1390906	--	-3.70%	--
	1	E	XD	0.1228	0.0000438	-0.0022	0.12261417	4.3307E-05	-0.0022008	--	--	--
			YD	-0.00277	4.1715	0.006927	-0.0027874	4.33051181	0.00698031	--	-3.67%	--
	5	F	XD	0.5032	0.000959	-0.00239	0.48575984	0.00090551	-0.0023858	3.59%	--	--
			YD	-1.538	14.2196	0.006832	-1.4047874	13.5972874	0.00675591	9.48%	4.58%	--

**Table 4.** Comparison of displacements obtained from MicasPlus for Cases 2 and 3 with those obtained for Case 1.

Type of frame	Case	Load ca/co	Node no.	MicasPlus (Case 2 - 3)			Node no.	MicasPlus (Case 1)			% difference		
				Tx	Ty	Tz		Tx	Ty	Tz	Tx	Ty	Tz
				inches				inches			%		
M	2	XD	2	7.16	0.00	0.01	13	7.16	0.00	0.01	0.00%	--	--
		YD		0.00	5.26	0.01		0.00	5.26	0.01	--	0.00%	--
	2	XD	4	7.15	0.00	0.00	14	7.15	0.00	0.00	0.00%	--	--
		YD		0.00	6.75	0.01		0.00	6.75	0.01	--	0.00%	--
	2	XD	6	7.15	0.00	-0.01	15	7.15	0.00	-0.01	0.00%	--	--
		YD		0.00	5.26	0.01		0.00	5.26	0.01	--	0.00%	--
	3	XD	13	7.16	0.00	0.01	13	7.16	0.00	0.01	0.00%	--	--
		YD		0.00	5.26	0.01		0.00	5.26	0.01	--	0.00%	--
	3	XD	14	7.15	0.00	0.00	14	7.15	0.00	0.00	0.00%	--	--
		YD		0.00	6.75	0.01		0.00	6.75	0.01	--	0.00%	--
	3	XD	15	7.15	0.00	-0.01	15	7.15	0.00	-0.01	0.00%	--	--
		YD		0.00	5.26	0.01		0.00	5.26	0.01	--	0.00%	--
X	2	XD	2	0.09	0.00	0.01	17	0.09	0.00	0.01	0.00%	--	--
		YD		0.00	0.06	0.00		0.00	0.06	0.00	--	0.00%	--
	2	XD	4	0.09	0.00	-0.01	19	0.09	0.00	-0.01	0.00%	--	--
		YD		0.00	4.33	0.01		0.00	4.33	0.01	--	0.00%	--
	2	XD	6	0.09	0.00	0.00	20	0.09	0.00	0.00	0.00%	--	--
		YD		0.00	0.06	0.00		0.00	0.06	0.00	--	0.00%	--
	3	XD	17	0.09	0.00	0.01	17	0.09	0.00	0.01	0.00%	--	--
		YD		0.00	0.06	0.00		0.00	0.06	0.00	--	0.00%	--
	3	XD	19	0.09	0.00	-0.01	19	0.09	0.00	-0.01	0.00%	--	--
		YD		0.00	4.33	0.01		0.00	4.33	0.01	--	0.00%	--
	3	XD	20	0.09	0.00	0.00	20	0.09	0.00	0.00	0.00%	--	--
		YD		0.00	0.06	0.00		0.00	0.06	0.00	--	0.00%	--
K	2	XD	2	0.13	0.00	0.00	21	0.13	0.00	0.00	0.00%	--	--
		YD		0.00	0.08	0.00		0.00	0.08	0.00	--	0.00%	--
	2	XD	4	0.13	0.00	0.00	23	0.13	0.00	0.00	0.00%	--	--
		YD		0.00	4.33	0.01		0.00	4.33	0.01	--	0.00%	--
	2	XD	6	0.13	0.00	0.00	24	0.13	0.00	0.00	0.00%	--	--
		YD		0.00	0.08	0.00		0.00	0.08	0.00	--	0.00%	--
	3	XD	21	0.13	0.00	0.00	21	0.13	0.00	0.00	0.00%	--	--
		YD		0.00	0.08	0.00		0.00	0.08	0.00	--	0.00%	--
	3	XD	23	0.13	0.00	0.00	23	0.13	0.00	0.00	0.00%	--	--
		YD		0.00	4.33	0.01		0.00	4.33	0.01	--	0.00%	--
	3	XD	24	0.13	0.00	0.00	24	0.13	0.00	0.00	0.00%	--	--
		YD		0.00	0.08	0.00		0.00	0.08	0.00	--	0.00%	--



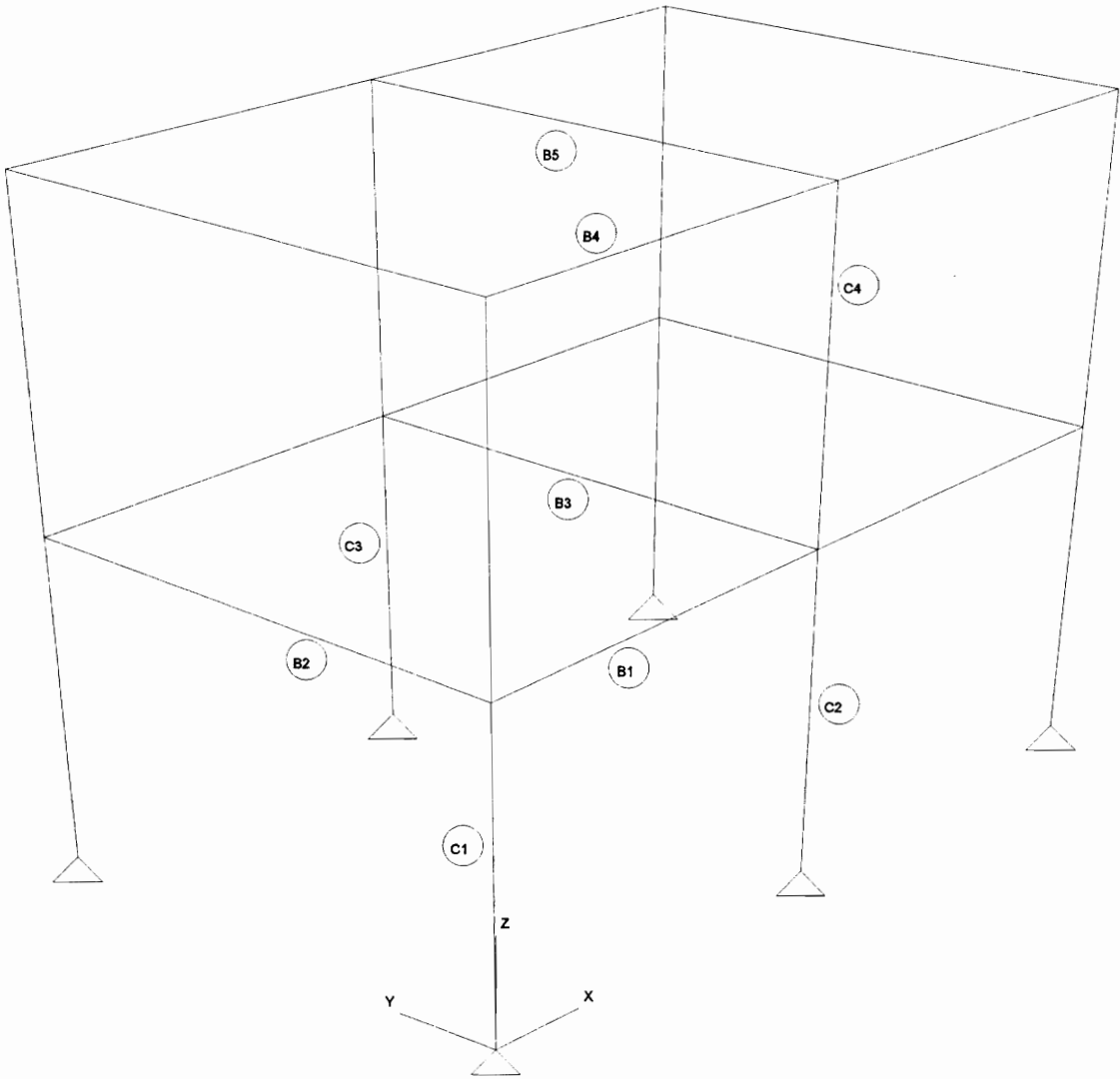
**Figure 28.** Line element names as referred to in Tables 7 and 9.

**Table 5.** Comparison of element end forces obtained from MicasPlus and STAAD III for Cases 1 and 4 for the moment resisting frame.

Case no.	Elem name [no.]	Load ca/co	Node no.	MicasPlus			STAAD III			Percentage difference		
				Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
				Kips			Kips			%		
1	C1 [1]	XD	1	-10.00	0.00	4.67	-10.00	0.00	4.67	0.00%	--	0.00%
			2	10.00	0.00	-4.67	10.00	0.00	-4.67	0.00%	--	0.00%
		YD	1	-14.87	-6.86	0.00	-14.87	-6.86	0.00	0.00%	-0.01%	--
			2	14.87	6.86	0.00	14.87	6.86	0.00	0.00%	-0.01%	--
1	C2 [2]	XD	3	0.00	0.00	5.68	0.00	0.00	5.68	--	--	0.00%
			4	0.00	0.00	-5.68	0.00	0.00	-5.68	--	--	0.00%
		YD	3	-21.45	-10.30	0.00	-21.45	-10.30	0.00	0.01%	0.01%	--
			4	21.45	10.30	0.00	21.45	10.30	0.00	0.00%	0.01%	--
4	C3 [5]	XD	9	0.26	0.00	5.67	0.25	0.00	5.67	--	--	0.01%
			10	-0.26	0.00	-5.67	-0.25	0.00	-5.67	--	--	0.01%
		YD	9	21.51	-10.37	0.00	21.51	-10.37	0.00	0.00%	0.00%	--
			10	-21.51	10.37	0.00	-21.51	10.37	0.00	0.00%	0.00%	--
4	C4 [15]	XD	4	0.07	0.00	3.24	0.06	0.00	3.25	--	--	-0.25%
			14	-0.07	0.00	-3.24	-0.06	0.00	-3.25	--	--	-0.25%
		YD	4	-3.77	-2.89	0.00	-3.76	-2.89	0.00	0.38%	-0.07%	--
			14	3.77	2.89	0.00	3.76	2.89	0.00	0.38%	-0.07%	--
1	B1 [7]	XD	2	6.27	-8.23	0.00	6.27	-8.23	0.00	0.06%	0.01%	--
			4	-6.27	8.23	0.00	-6.27	8.23	0.00	0.06%	0.01%	--
		YD	2	0.30	-0.01	0.43	0.30	-0.01	0.43	--	--	--
			4	-0.30	0.01	-0.43	-0.30	0.01	-0.43	--	--	--
1	B2 [11]	XD	2	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			8	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	2	3.99	-11.68	-0.29	3.99	-11.69	-0.29	0.00%	-0.04%	--
			8	-3.99	11.68	0.29	-3.99	11.69	0.29	0.00%	-0.04%	--
4	B3 [12]	XD	4	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			10	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	4	7.83	-17.77	0.00	7.83	-17.78	0.00	-0.04%	-0.07%	--
			10	-7.83	17.77	0.00	-7.83	17.78	0.00	-0.04%	-0.07%	--
4	B4 [20]	XD	13	4.22	-1.80	0.00	4.22	-1.80	0.00	-0.11%	-0.02%	--
			14	-4.22	1.80	0.00	-4.22	1.80	0.00	-0.11%	-0.02%	--
		YD	13	0.27	-0.01	0.43	0.27	-0.01	0.43	--	--	--
			14	-0.27	0.01	-0.43	-0.27	0.01	-0.43	--	--	--
1	B5 [25]	XD	14	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			17	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	14	4.01	-3.77	0.00	4.01	-3.76	0.00	0.01%	0.38%	--
			17	-4.01	3.77	0.00	-4.01	3.76	0.00	0.01%	0.38%	--

**Table 6.** Comparison of element end moments obtained from Micas-Plus and STAAD III for Cases 1 and 4 for the moment resisting frame.

Case no.	Elem name [no.]	Load ca/co	Node no.	MicasPlus			STAAD III			Percentage difference		
				Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
				kip-ft			kip-ft			%		
1	C1 [1]	XD	1	0	-3E-14	0	0	1.0577E-05	-3.281E-08	--	--	--
			2	0	-93.34	-3E-13	0	-91.863517	-2.477E-06	--	1.61%	--
		YD	1	0	3.5E-18	1.4E-14	-3.281E-09	9.8425E-09	-5.413E-07	--	--	--
			2	0	-0.0428	-137.17	3.2808E-09	-0.0425751	-137.79528	--	--	-0.45%
1	C2 [2]	XD	3	0	2.7E-14	0	-3.281E-09	1.1877E-06	3.2808E-09	--	--	--
			4	0	-113.51	2E-15	3.2808E-09	-114.8294	-1.119E-06	--	-1.15%	--
		YD	3	0	0	7.1E-14	1.3123E-08	-2.297E-08	-7.23E-05	--	--	--
			4	0	2.7E-13	-206.03	-1.312E-08	2.8215E-07	-206.69291	--	--	-0.32%
4	C3 [5]	XD	9	0	-2.8E-14	0	3.2808E-09	-4.154E-06	5.9055E-08	--	--	--
			10	0	-113.334	8.14E-15	-3.281E-09	-114.8294	-9.678E-07	--	-1.30%	--
		YD	9	0	0	-4.3E-14	-9.843E-09	1.9029E-07	-3.403E-05	--	--	--
			10	0	1.81E-13	-207.409	9.8425E-09	-8.333E-07	-206.69291	--	--	0.35%
4	C4 [15]	XD	4	-1.7E-15	-29.549	4.42E-15	-9.843E-09	-29.620312	-6.037E-07	--	-0.24%	--
			14	1.68E-15	-35.2336	5.04E-15	9.8425E-09	-36.089239	-5.577E-07	--	-2.37%	--
		YD	4	-1.3E-16	-5.7E-14	-12.7831	0	2.2966E-08	-12.990922	--	--	-1.60%
			14	1.29E-16	-6.6E-14	-44.9336	0	-1.148E-07	-45.931759	--	--	-2.17%
1	B1 [7]	XD	2	-2E-17	-6E-14	-93.684	0	-8.99E-07	-95.144357	--	--	-1.53%
			4	2.1E-17	-4E-14	-70.933	0	2.1654E-07	-72.178478	--	--	-1.73%
		YD	2	0.00128	-3.653	-0.1214	0.00122885	-3.6570801	-0.121312	--	-0.11%	--
			4	-0.0013	-4.8786	-0.1625	-0.0012289	-4.8842946	-0.1620656	--	-0.12%	--
1	B2 [11]	XD	2	-1E-16	5.8E-14	-3E-13	0	9.3504E-07	-2.293E-06	--	--	--
			8	1.3E-16	5.8E-14	-3E-13	0	3.2316E-06	-2.077E-06	--	--	--
		YD	2	-0.00002	3.6625	-146.03	-2.337E-05	3.66660433	-147.6378	--	-0.11%	-1.09%
			8	0.000024	3.6574	-146	2.3366E-05	3.66150919	-147.6378	--	-0.11%	-1.11%
4	B3 [12]	XD	4	7.25E-16	-4.7E-13	1.26E-14	3.2808E-09	-6.89E-07	-1.644E-06	--	--	--
			10	-7.2E-16	-4.7E-13	1.25E-14	-3.281E-09	-7.743E-07	-1.699E-06	--	--	--
		YD	4	2.36E-17	6.66E-14	-223.276	0	-5.479E-07	-223.09711	--	--	0.08%
			10	-2.4E-17	6.51E-14	-220.909	0	5.9055E-08	-219.81627	--	--	0.50%
4	B4 [20]	XD	13	6.17E-17	4.54E-13	-19.056	0	1.9718E-06	-19.024065	--	--	0.17%
			14	-6.2E-17	3.54E-13	-17.0063	0	1.3058E-06	-17.045348	--	--	-0.23%
		YD	13	0.001003	-3.5569	-0.0854	0.00099615	-3.5565584	-0.0852215	--	0.01%	--
			14	-0.001	-5.0404	-0.1223	-0.0009962	-5.0392684	-0.1214495	--	0.02%	--
4	B5 [25]	XD	14	1.48E-16	-7.2E-13	4.74E-15	0	-2.582E-06	-5.151E-07	--	--	--
			17	-1.5E-16	-7.1E-13	4.66E-15	0	-2.523E-06	-4.331E-07	--	--	--
		YD	14	4.02E-18	5.96E-14	-47.5355	0	-9.58E-07	-45.931759	--	--	3.49%
			17	-4E-18	5.77E-14	-47.3377	0	-1.06E-06	-45.931759	--	--	3.06%



**Figure 29.** Line element names as referred to in Tables 5 and 6.



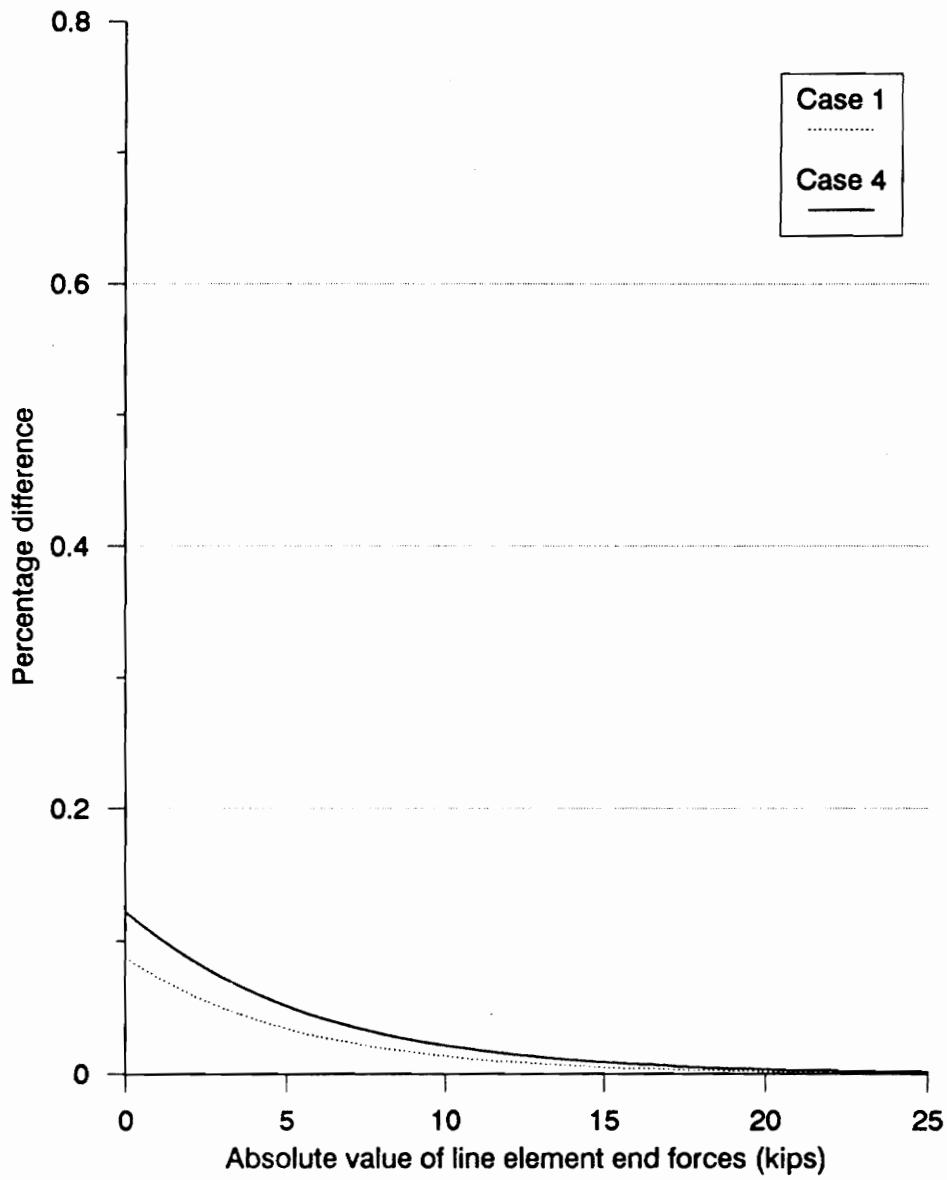
MicasPlus Analysis and STAAD III results from Tables 5 and 6. The graphs are exponential regression curves and are plotted using the results for the selected line elements only. The graphs also give an idea of which analysis case has more percentage difference than the other.

Line element end actions for the frame with X-bracing frame are presented in Tables 7 and 8 for Cases 1, 4, 5, 6 and 7. Figure 32 shows the line elements for which the percentage differences in element end forces are tabulated in Table 7. Figure 33 shows the elements for which the element end moments are tabulated in Table 8.

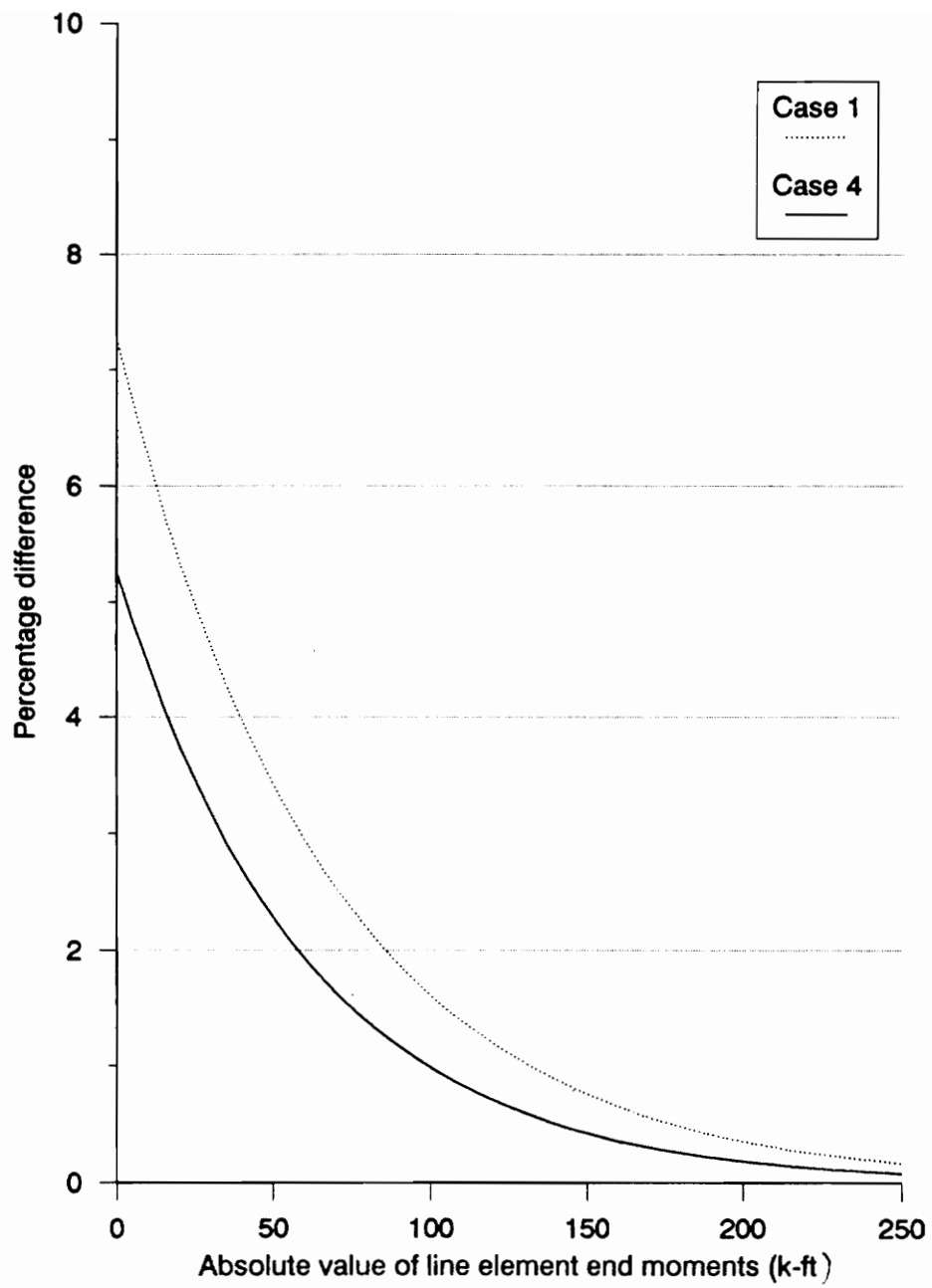
Figures 34 and 35 show graphically the percentage differences from Tables 7 and 8 respectively. In Figure 34, the curve for Case 4 indicates a higher percentage difference because of the unusually higher difference in results in the y-direction of the frame. It can be seen from Figures 34 and 35 that the percentage difference in the calculated values is greater for line element end moments than for line element end forces.

Line element end actions for the frame with Chevron bracing frame for Cases 1, 4, 5, 6 and 7 are shown in Tables 9 and 10. Figures 36 and 37 show graphically the percentage differences from Tables 9 and 10 respectively.

Line element end actions for all the three type of frames are tabulated together in Tables 11 and 12. The line element end actions for all three frames are tabulated together instead of separately because the percentage differences in these cases are very small. The tabulated values are representative of the results for other elements of the frame.



**Figure 30.** Percentage difference versus absolute value of line element end forces for moment resisting frame (from Table 5).



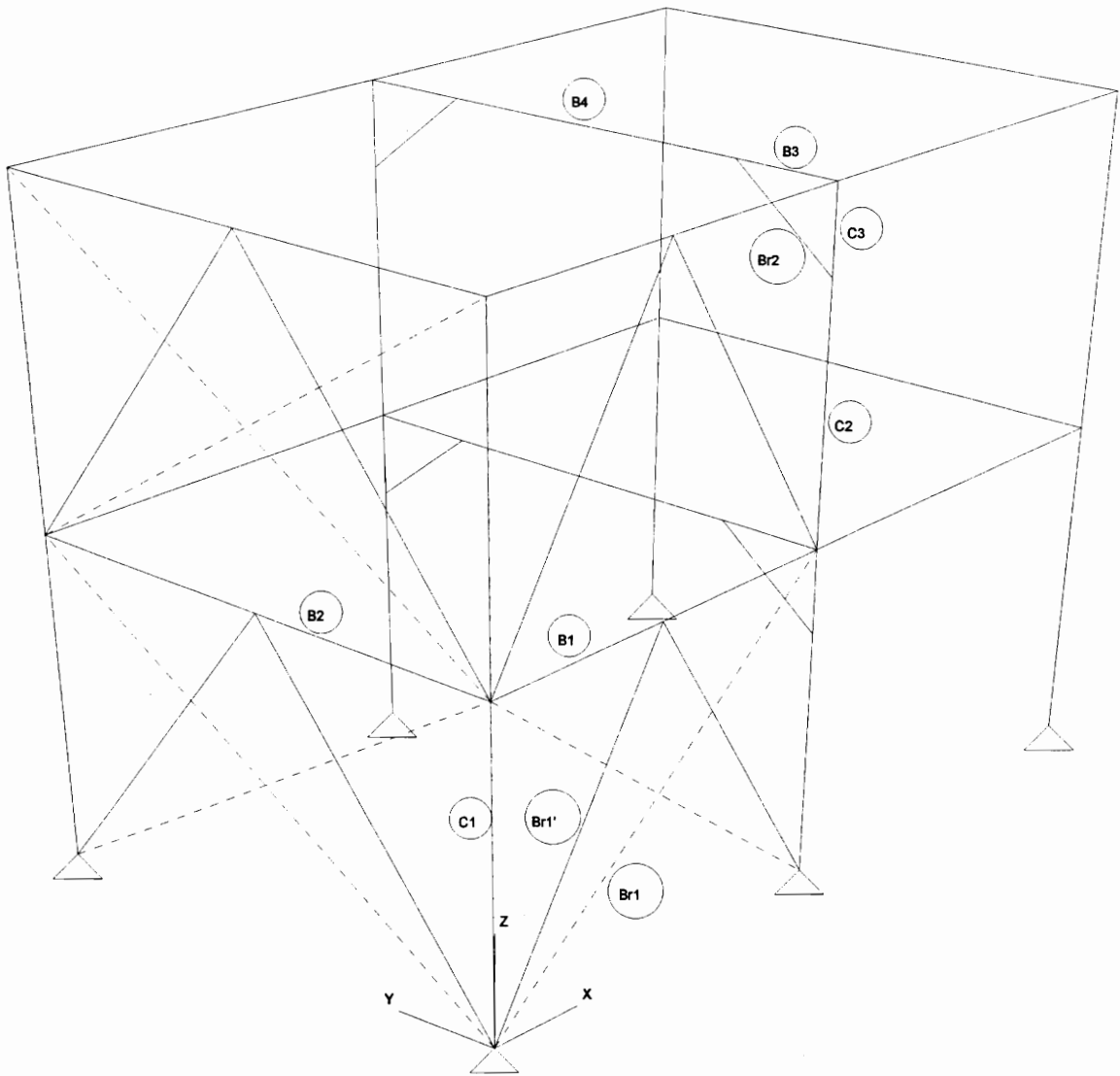
**Figure 31.** Percentage difference versus absolute value of line element end moments for moment resisting frame (from Table 5).

**Table 7.** Comparison of element end forces obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with X-bracing.

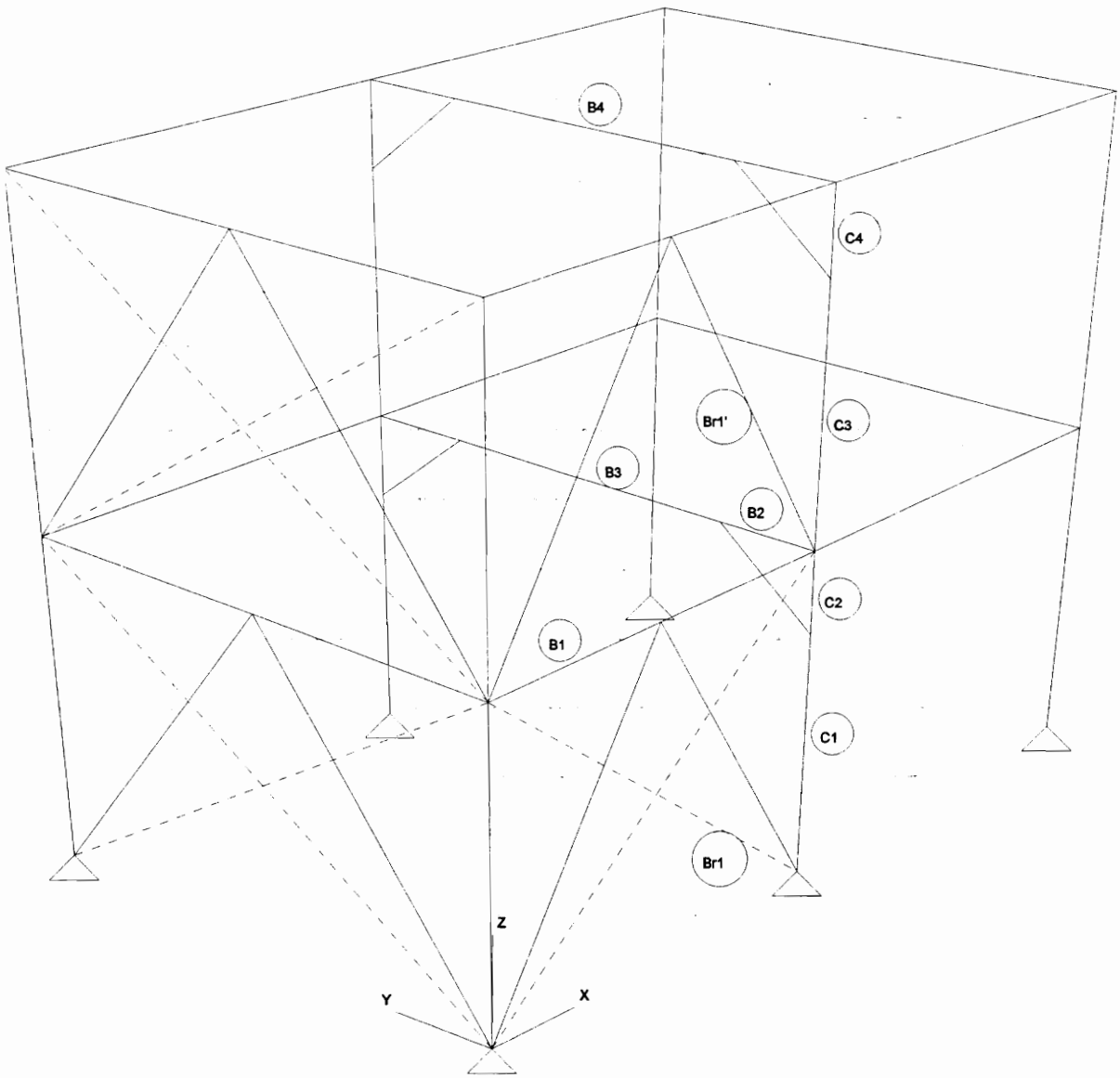
Case no.	Elem name [no.]	Load ca/co	Node no.	MicasPlus			STAAD III			Percentage difference		
				Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
				Kips			Kips			%		
4	C1 [1]	XD	1	-12.43	0.00	-0.03	-12.64	-0.01	-0.03	-1.63%	--	--
			2	12.43	0.00	0.03	12.64	0.01	0.03	-1.63%	--	--
		YD	1	-9.49	0.01	0.02	-8.54	0.00	0.03	11.14%	--	--
			2	9.49	-0.01	-0.02	8.54	0.00	-0.03	11.14%	--	--
5	C2 [19]	XD	5	2.61	0.57	0.05	2.62	0.56	0.04	-0.39%	2.11%	--
			18	-2.61	-0.57	-0.05	-2.62	-0.56	-0.04	-0.39%	2.11%	--
		YD	5	-8.27	-4.10	0.09	-8.32	-4.10	0.09	-0.68%	0.08%	--
			18	8.27	4.10	-0.09	8.32	4.10	-0.09	-0.68%	0.08%	--
6	C3 [20]	XD	18	2.20	0.01	-0.03	2.20	0.01	-0.03	-0.10%	--	--
			19	-2.20	-0.01	0.03	-2.20	-0.01	0.03	-0.10%	--	--
		YD	18	6.90	8.18	-0.10	6.97	8.36	-0.10	-0.98%	-2.18%	--
			19	-6.90	-8.18	0.10	-6.97	-8.36	0.10	-0.98%	-2.18%	--
5	B1 [9]	XD	2	6.27	0.00	0.00	6.30	0.00	0.00	-0.38%	--	--
			5	-6.27	0.00	0.00	-6.30	0.00	0.00	-0.38%	--	--
		YD	2	-24.70	0.00	0.00	-24.60	0.00	0.00	0.44%	--	--
			5	24.70	0.00	0.00	24.60	0.00	0.00	0.44%	--	--
7	B2 [13]	XD	2	0.66	0.00	0.00	0.66	0.00	0.00	-0.06%	--	--
			9	-0.66	0.00	0.00	-0.66	0.00	0.00	-0.06%	--	--
		YD	2	3.19	0.00	0.00	3.19	0.00	0.00	0.09%	--	--
			9	-3.19	0.00	0.00	-3.19	0.00	0.00	0.09%	--	--
4	B3 [31]	XD	19	-0.05	-0.09	0.00	-0.03	-0.05	0.00	--	--	--
			25	0.05	0.09	0.00	0.03	0.05	0.00	--	--	--
		YD	19	18.87	9.29	0.02	19.43	9.71	0.02	-2.86%	-4.36%	--
			25	-18.87	-9.29	-0.02	-19.43	-9.71	-0.02	-2.86%	-4.35%	--
7	B4 [32]	XD	25	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			26	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	25	4.29	-5.31	0.00	4.29	-5.41	0.00	0.01%	-1.98%	--
			26	-4.29	5.31	0.00	-4.29	5.41	0.00	0.01%	-1.98%	--
1	Br1 [35]	XD	1	-10.18	0.00	0.00	-10.18	0.00	0.00	0.00%	--	--
			5	10.18	0.00	0.00	10.18	0.00	0.00	0.00%	--	--
		YD	1	-0.78	0.00	0.00	-0.78	0.00	0.00	-0.39%	--	--
			5	0.78	0.00	0.00	0.78	0.00	0.00	-0.39%	--	--
4	Br2 [49]	XD	18	0.13	0.00	0.00	0.08	0.00	0.00	--	--	--
			25	-0.13	0.00	0.00	-0.08	0.00	0.00	--	--	--
		YD	18	-20.62	0.00	0.00	-21.41	0.00	0.00	-3.69%	--	--
			25	20.62	0.00	0.00	21.41	0.00	0.00	-3.69%	--	--

**Table 8.** Comparison of element end moments obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with X-bracing.

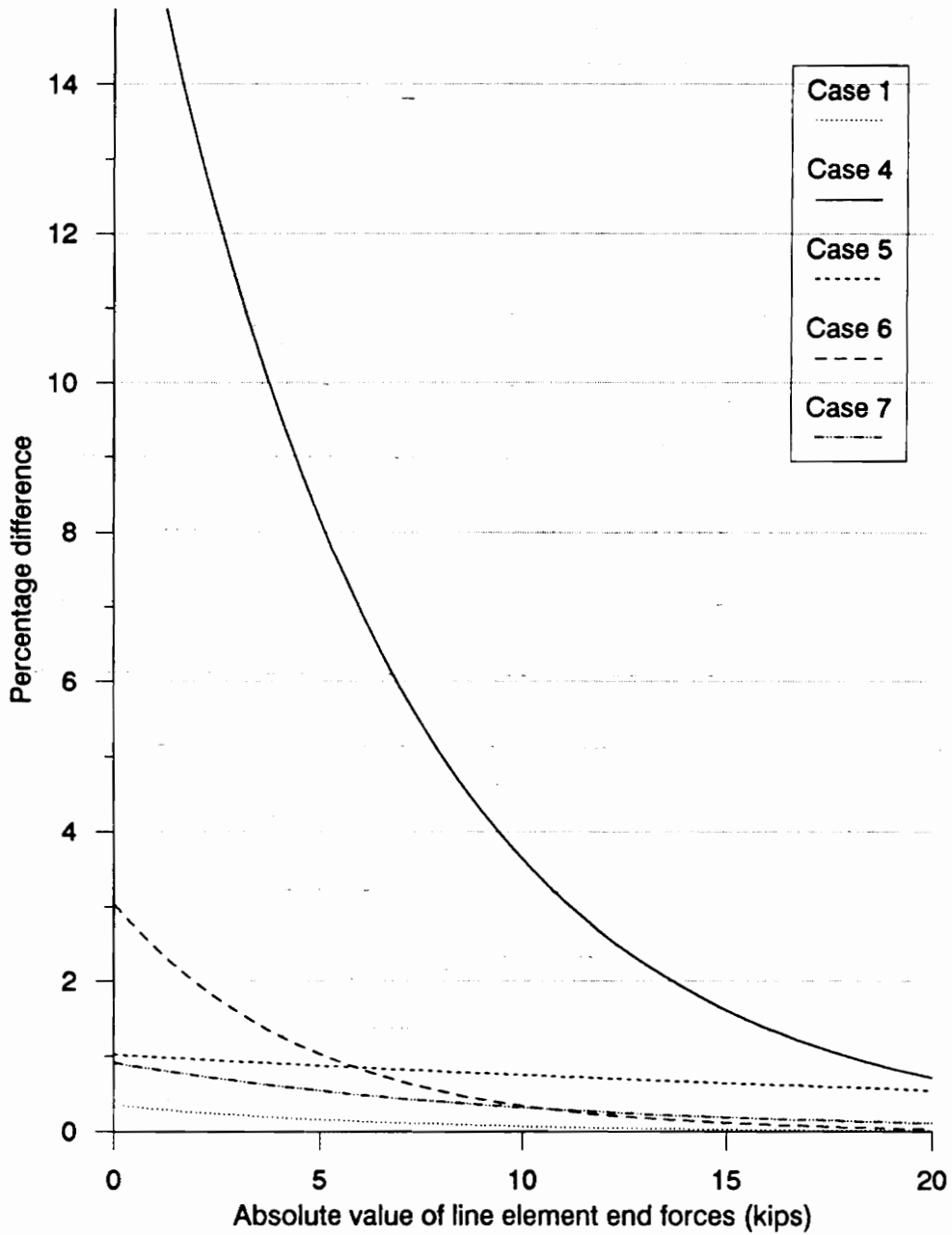
Case no.	Elem name [no.]	Load ca/co	Node no.	MicasPlus			STAAD III			Percentage difference		
				Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
				kip-ft			kip-ft			%		
4	C1 [2]	XD	3	-0.1266	2.22E-16	-0.1206	-0.069718	9.8425E-09	0.1246063	--	--	--
			4	0.1266	-0.8439	0.3589	0.06971719	-0.888458	0.26705118	--	-5.02%	--
		YD	3	-1.4399	-6.9E-18	-0.0206	-1.228875	-3.28E-09	0.00104247	17.17%	--	--
			4	1.4399	-0.1669	-178.701	1.22887467	-0.280338	-164.042	17.17%	--	8.94%
4	C2 [3]	XD	4	-0.1472	0.832	-0.3527	-0.082277	0.8808727	-0.269537	--	-5.55%	--
			5	0.1472	-1.1133	-0.4932	0.0822769	-1.177021	-0.196719	--	-5.41%	--
		YD	4	-0.131	-1.3205	176.7238	-0.066033	-1.044488	180.446194	--	26.43%	-2.06%
			5	0.131	1.2649	60.3787	0.06603445	0.95104331	59.0551181	--	33.00%	2.24%
1	C3 [19]	XD	5	0.0000013	0.2883	0.0729	9.9081E-07	0.28860991	0.07109252	--	--	--
			18	-0.000001	-0.0721	-0.0018	-9.91E-07	-0.072152	-0.0017	--	--	--
		YD	5	-0.0003	0.0038	-21.265	-0.000345	0.00399062	-19.68504	--	--	8.03%
			18	0.00029	-0.001	-38.498	0.00034531	-0.001025	-32.8084	--	--	17.34%
5	C4 [20]	XD	18	-0.2051	-0.2315	-3.5666	-0.203839	-0.235167	-3.28084	--	--	8.71%
			19	0.2051	0.000649	0.2597	0.20383727	0.01037234	0.26286253	--	--	--
		YD	18	0.3533	-1.3503	41.7648	0.35730971	-1.366726	42.6509186	--	-1.20%	-2.08%
			19	-0.3533	0.8798	-0.2821	-0.35731	0.89830381	-0.276545	--	-2.06%	--
4	B1 [9]	XD	2	0.0000283	0	0	1.8389E-05	0	0	--	--	--
			5	-0.000028	0	0	-1.84E-05	0	0	--	--	--
		YD	2	0.0111	0	-6E-08	0.01180915	0	0	--	--	--
			5	-0.0111	0	5.96E-08	-0.011809	0	0	--	--	--
1	B2 [14]	XD	5	-0.00005	0	0	-4.89E-05	0	0	--	--	--
			15	0.000045	-2E-11	-0.2094	4.8917E-05	2.6247E-07	-0.206155	--	--	--
		YD	5	-0.00006	0	0	-6.66E-05	0	0	--	--	--
			15	0.000059	0.000019	156.731	6.6558E-05	2.2671E-05	164.041995	--	--	-4.46%
1	B3 [15]	XD	15	2.2E-19	0.000045	0.2094	0	4.896E-05	0.20615486	--	--	--
			16	-2E-19	-0.00005	-0.2094	0	-4.89E-05	-0.206155	--	--	--
		YD	15	-0.00001	0.000027	-156.73	-8.06E-06	3.582E-05	-164.042	--	--	-4.46%
			16	0.000013	0.000028	-157.02	8.0643E-06	3.2205E-05	-164.042	--	--	-4.28%
5	B4 [32]	XD	25	0.000106	0.2425	6.1484	9.9377E-05	0.24816207	6.04506234	--	--	1.71%
			26	-0.00011	-0.243	-6.1674	-9.94E-05	-0.248658	-6.56168	--	--	-6.01%
		YD	25	0.5937	-0.5978	-37.6617	0.60720144	-0.595686	-32.8084	-2.22%	0.35%	14.79%
			26	-0.5937	-0.5041	-35.3423	-0.607201	-0.500827	-32.8084	-2.22%	0.65%	7.72%
1	Br1 [36]	XD	3	3.1E-08	0	0	1.2139E-07	0	0	--	--	--
			2	-3E-08	0	0	-1.21E-07	0	0	--	--	--
		YD	3	0.00431	0	0	0.00482579	0	0	--	--	--
			2	-0.0043	0	0	-0.004826	0	0	--	--	--



**Figure 32.** Line Element names as referred to in Tables 7 and 9.

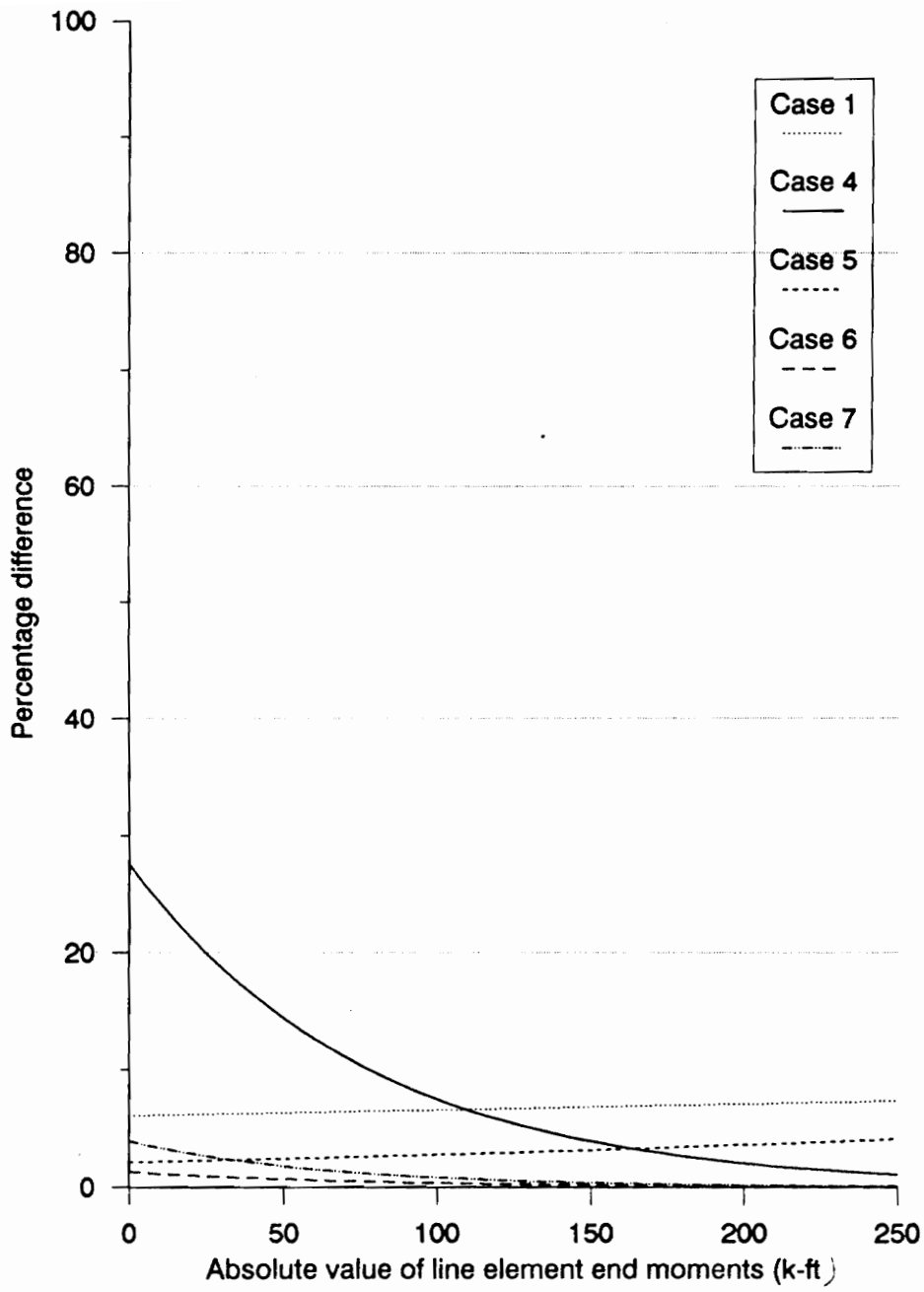


**Figure 33.** Line element names as referred to in Tables 8 and 10.



**Figure 34.** Percentage difference versus absolute value of line element end forces for frame with X-bracing (from Table 7).





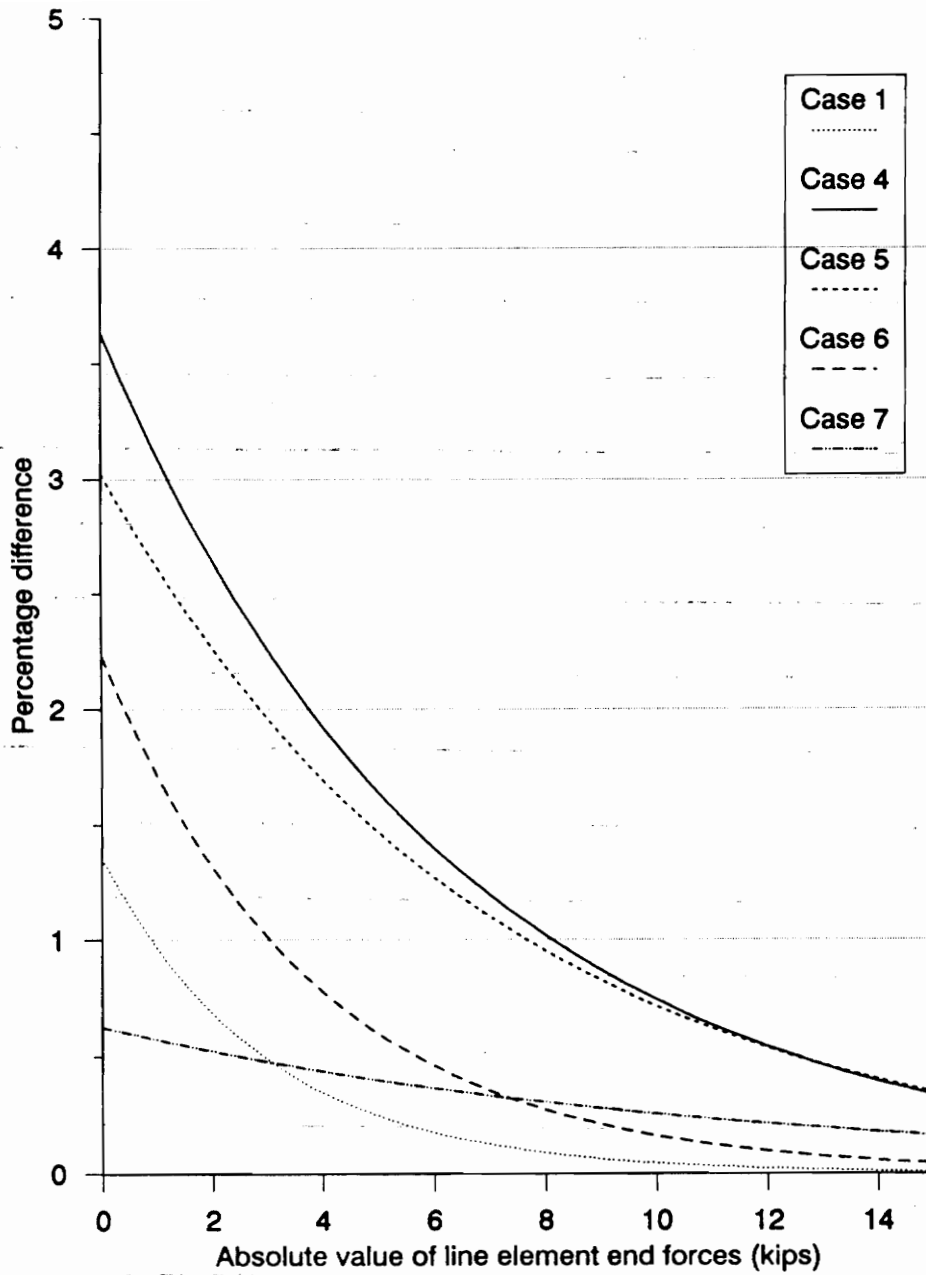
**Figure 35.** Percentage difference versus absolute value of line element end moments for frame with X-bracing (from Table 8).

**Table 9.** Comparison of element end forces obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with Chevron bracing.

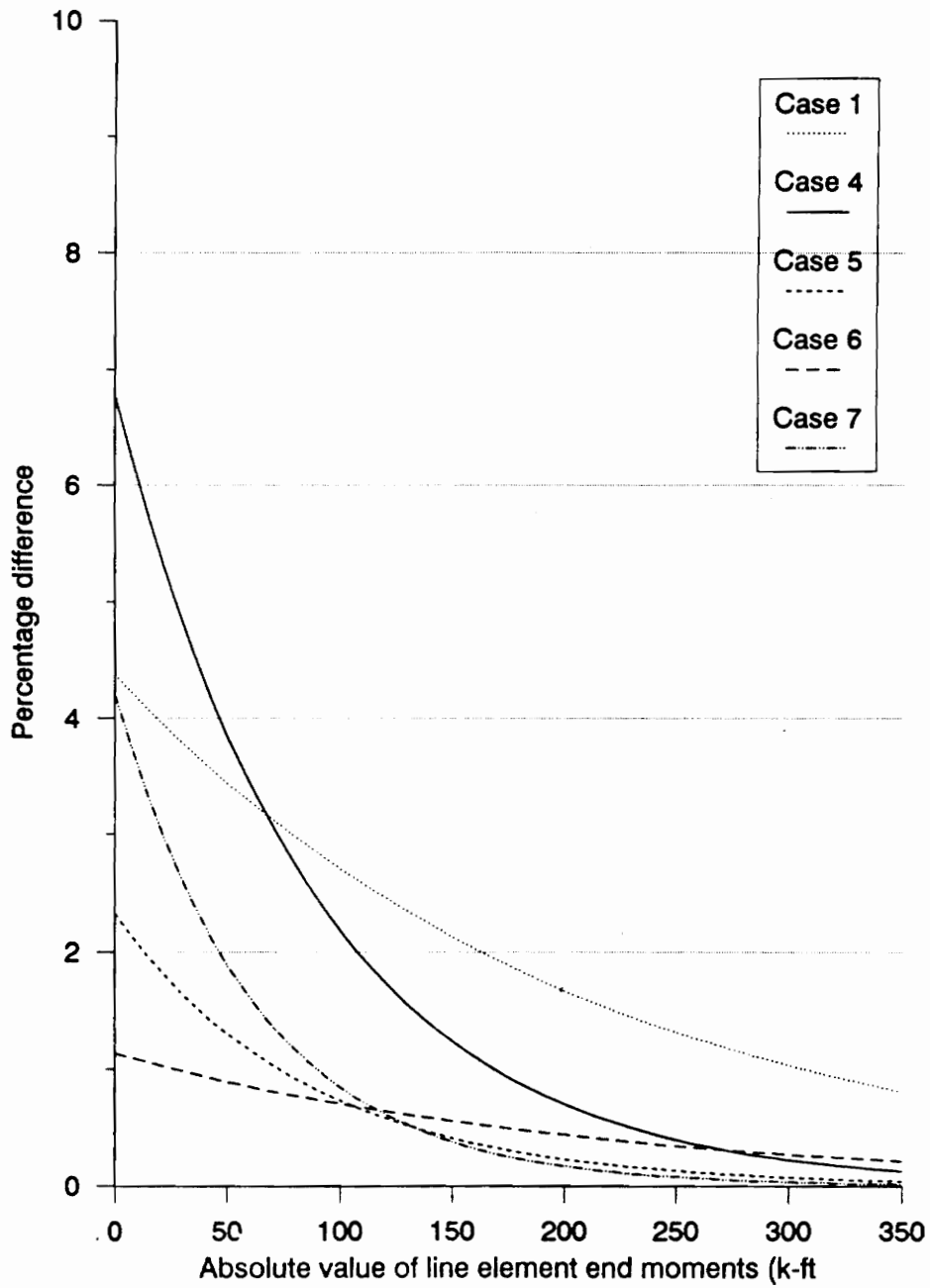
Case no.	Elem name [no.]	Load ca/co	Node no.	MicasPlus			STAAD III			Percentage difference		
				Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
				Kips			Kips			%		
1	C1 [1]	XD	1	-5.07	0.00	0.03	-5.07	0.00	0.03	0.00%	--	--
			2	5.07	0.00	-0.03	5.07	0.00	-0.03	0.00%	--	--
		YD	1	-3.25	-0.06	0.00	-3.25	-0.06	0.00	0.02%	--	--
			2	3.25	0.06	0.00	3.25	0.06	0.00	0.02%	--	--
6	C2 [23]	XD	5	-0.01	0.00	-0.03	-0.01	0.00	-0.03	--	--	--
			22	0.01	0.00	0.03	0.01	0.00	0.03	--	--	--
		YD	5	-4.95	-3.93	-0.01	-5.03	-3.93	-0.01	-1.53%	0.01%	--
			22	4.95	3.93	0.01	5.03	3.93	0.01	-1.53%	0.01%	--
7	C3 [24]	XD	22	-0.16	0.00	-0.07	-0.16	0.00	-0.07	--	--	--
			23	0.16	0.00	0.07	0.16	0.00	0.07	--	--	--
		YD	22	9.43	11.03	0.00	9.62	11.32	0.00	-1.99%	-2.64%	--
			23	-9.43	-11.03	0.00	-9.62	-11.32	0.00	-1.99%	-2.64%	--
4	B1 [9]	XD	2	12.44	0.39	-0.01	12.44	0.39	-0.01	-0.01%	--	--
			15	-12.44	-0.39	0.01	-12.44	-0.39	0.01	-0.01%	--	--
		YD	2	-0.13	-0.25	-0.01	-0.10	-0.19	-0.01	--	--	--
			15	0.13	0.25	0.01	0.10	0.19	0.01	--	--	--
5	B2 [15]	XD	2	0.77	3.02	0.00	0.73	2.90	0.00	5.53%	4.20%	--
			17	-0.77	-3.02	0.00	-0.73	-2.90	0.00	5.53%	4.20%	--
		YD	2	9.84	0.00	0.03	9.84	0.00	0.03	0.02%	--	--
			17	-9.84	0.00	-0.03	-9.84	0.00	-0.03	0.02%	--	--
4	B3 [38]	XD	23	0.12	0.21	0.00	0.10	0.18	0.00	--	--	--
			32	-0.12	-0.21	0.00	-0.10	-0.18	0.00	--	--	--
		YD	23	19.13	9.45	-0.02	19.61	9.83	-0.02	-2.47%	-3.85%	--
			32	-19.13	-9.45	0.02	-19.61	-9.83	0.02	-2.47%	-3.85%	--
5	B4 [39]	XD	32	-0.87	0.00	0.00	-0.82	0.00	0.00	5.46%	--	--
			33	0.87	0.00	0.00	0.82	0.00	0.00	5.46%	--	--
		YD	32	4.01	-5.03	-0.07	4.01	-5.10	-0.07	-0.03%	-1.29%	--
			33	-4.01	5.03	0.07	-4.01	5.10	0.07	-0.03%	-1.29%	--
5	Br1 [43]	XD	1	-15.67	0.00	0.00	-15.72	0.00	0.00	-0.29%	--	--
			15	15.67	0.00	0.00	15.72	0.00	0.00	-0.29%	--	--
		YD	1	3.61	0.00	0.00	3.37	0.00	0.00	7.18%	--	--
			15	-3.61	0.00	0.00	-3.37	0.00	0.00	7.18%	--	--
4	Br2 [57]	XD	22	-0.30	0.00	0.00	-0.25	0.00	0.00	--	--	--
			32	0.30	0.00	0.00	0.25	0.00	0.00	--	--	--
		YD	22	-20.98	0.00	0.00	-21.67	0.00	0.00	-3.18%	--	--
			32	20.98	0.00	0.00	21.67	0.00	0.00	-3.18%	--	--

**Table 10.** Comparison of element end moments obtained from MicasPlus and STAAD III for Cases 1, and 4 through 7 for frame with Chevron bracing.

Case no.	Elem name [no.]	Load ca/co	Node no.	MicasPlus			STAAD III			Percentage difference		
				Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
				kip-ft			kip-ft			%		
1	C1 [2]	XD	3	0.000014	0	0.0000069	1.5144E-05	3.937E-08	7.5689E-06	--	--	--
			4	-0.00001	-0.4395	0.0433	-1.514E-05	-0.4401936	0.04287664	--	--	--
		YD	3	0.00081	1.7E-18	0.00041	0.00096999	3.2808E-09	0.0004879	--	--	--
			4	-0.0008	-0.0332	-180.04	-0.00097	-0.0336188	-196.85039	--	--	-8.54%
1	C2 [3]	XD	4	-0.00004	0.4394	-0.0433	-4.237E-05	0.4401378	-0.0428773	--	--	--
			5	0.000039	-0.5859	-0.0287	4.2365E-05	-0.5868635	-0.0280174	--	-0.16%	--
		YD	4	-0.0025	0.0298	180.043	-0.0028073	0.02983625	180.446194	--	--	-0.22%
			5	0.00251	-0.0409	21.2545	0.00280725	-0.0410564	20.1587008	--	--	5.44%
1	C3 [23]	XD	5	-0.00003	0.586	0.0287	-2.807E-05	0.58691929	0.02802103	--	-0.16%	--
			22	0.000026	-0.1465	-0.0049	2.8071E-05	-0.1467323	-0.0048379	--	--	--
		YD	5	0.00277	0.0429	-21.265	0.0030864	0.04336385	-19.685039	--	--	8.03%
			22	-0.0028	-0.0115	-38.492	-0.0030864	-0.0117428	-32.808399	--	--	17.32%
4	C4 [24]	XD	22	0	0.3609	0.5284	-3.937E-08	0.36202395	0.44788025	--	--	17.98%
			23	0	-0.00509	0.0662	3.937E-08	-0.0066032	0.0569581	--	--	--
		YD	22	0	-0.6052	45.8357	-4.232E-07	-0.5444849	48.0310367	--	11.15%	-4.57%
			23	0	0.5803	9.7572	4.2323E-07	0.5223855	10.00125	--	11.09%	-2.44%
4	B1 [9]	XD	2	0.005231	0	4.77E-07	0.00515615	0	0	--	--	--
			15	-0.00523	0.0867	3.8888	-0.0051561	0.08522575	3.93662402	--	--	-1.21%
		YD	2	0.0522	0	7.45E-09	0.04714843	0	0	--	--	--
			15	-0.0522	0.1189	-2.547	-0.0471483	0.10642113	-1.8976608	--	--	34.22%
5	B2 [17]	XD	5	-0.2007	0	0	-0.1672113	0	0	--	--	--
			18	0.2007	2.69E-07	22.121	0.16721115	5.3478E-07	21.121729	--	--	4.73%
		YD	5	-4.5784	0	0	*****	0	0	#VALUE!	--	--
			18	4.5784	-1.0469	155.5386	4.58871719	-1.0252986	155.047014	-0.22%	2.11%	0.32%
1	B3 [18]	XD	18	1.3E-18	0.000053	0.0865	7.874E-08	5.7608E-05	0.08519226	--	--	--
			19	-1E-18	-0.00005	-0.0865	-7.874E-08	-5.797E-05	-0.0852034	--	--	--
		YD	18	0.00129	0.00199	-156.73	0.00146936	0.00226684	-164.04199	--	--	-4.46%
			19	-0.0013	0.00199	-157.02	-0.0014694	0.00226425	-164.04199	--	--	-4.28%
6	B4 [39]	XD	32	6.91E-18	-0.0262	-0.01	0	-0.0262387	-0.0096999	--	--	--
			33	-6.9E-18	0.0262	0.01	0	0.02623867	0.00969989	--	--	--
		YD	32	0.0234	0.0879	-36.7019	0.02382385	0.09003458	-36.089239	--	--	1.70%
			33	-0.0234	0.0874	-36.9043	-0.0238239	0.08951027	-36.089239	--	--	2.26%
5	Br1 [46]	XD	29	-0.0535	0	-2.8E-08	-0.0551808	0	0	--	--	--
			5	0.0535	0	2.79E-08	0.05518074	0	0	--	--	--
		YD	29	0.789	0	-3E-08	0.77939272	0	0	1.23%	--	--
			5	-0.789	0	2.98E-08	-0.779393	0	0	1.23%	--	--



**Figure 36.** Percentage difference versus absolute value of line element end forces for frame with Chevron bracing (from Table 9).



**Figure 37.** Percentage difference versus absolute value of line element end moments for frame with Chevron bracing (from Table 10).

**Table 11.** Comparison of element end forces obtained from MicasPlus for Cases 2 and 3 with those obtained from MicasPlus for Case 1 for all three frames.

Frame (Case)	MicasPlus (Case 2 - 3)						MicasPlus (Case 1)						Percentage difference		
	Elem no.	Load ca/co	Node no.	FX	Fy	Fz	Elem no.	Node no.	FX	Fy	Fz	FX	Fy	FZ	
				Kips					Kips						%
M [2]	1	XD	1	-10.00	0.00	4.67	1	1	-10.00	0.00	4.67	0.00%	--	0.00%	
			13	10.00	0.00	-4.67		2	10.00	0.00	-4.67	0.00%	--	0.00%	
		YD	1	-14.87	-6.86	0.00		1	-14.87	-6.86	0.00	0.00%	0.00%	--	
			13	14.87	6.86	0.00		2	14.87	6.86	0.00	0.00%	0.00%	--	
M [2]	2	XD	3	0.00	0.00	5.68	2	3	0.00	0.00	5.68	--	--	0.00%	
			14	0.00	0.00	-5.68		4	0.00	0.00	-5.68	--	--	0.00%	
		YD	3	-21.45	-10.30	0.00		3	-21.45	-10.30	0.00	0.00%	0.00%	--	
			14	21.45	10.30	0.00		4	21.45	10.30	0.00	0.00%	0.00%	--	
M [3]	1	XD	1	-10.00	0.00	4.67	1	1	-10.00	0.00	4.67	0.00%	--	0.00%	
			2	10.00	0.00	-4.67		2	10.00	0.00	-4.67	0.00%	--	0.00%	
		YD	1	-14.87	-6.86	0.00		1	-14.87	-6.86	0.00	0.00%	0.00%	--	
			2	14.87	6.86	0.00		2	14.87	6.86	0.00	0.00%	0.00%	--	
M [3]	3	XD	5	10.00	0.00	4.66	3	5	10.00	0.00	4.66	0.00%	--	0.00%	
			6	-10.00	0.00	-4.66		6	-10.00	0.00	-4.66	0.00%	--	0.00%	
		YD	5	-14.87	-6.86	0.00		5	-14.87	-6.86	0.00	0.00%	0.00%	--	
			6	14.87	6.86	0.00		6	14.87	6.86	0.00	0.00%	0.00%	--	
M [3]	20	XD	13	4.06	-1.77	0.00	20	13	4.06	-1.77	0.00	0.00%	0.00%	--	
			14	-4.06	1.77	0.00		14	-4.06	1.77	0.00	0.00%	0.00%	--	
		YD	13	0.27	-0.01	0.43		13	0.27	-0.01	0.43	--	--	--	
			14	-0.27	0.01	-0.43		14	-0.27	0.01	-0.43	--	--	--	
X [2]	12	XD	14	-0.04	-0.04	0.00	14	5	-0.04	-0.04	0.00	--	--	--	
			20	0.04	0.04	0.00		15	0.04	0.04	0.00	--	--	--	
		YD	14	60.24	31.35	0.00		5	60.24	31.35	0.00	0.00%	0.00%	--	
			20	-60.24	-31.35	0.00		15	-60.24	-31.35	0.00	0.00%	0.00%	--	
X [3]	14	XD	5	-0.04	-0.04	0.00	14	5	-0.04	-0.04	0.00	--	--	--	
			15	0.04	0.04	0.00		15	0.04	0.04	0.00	--	--	--	
		YD	5	60.24	31.35	0.00		5	60.24	31.35	0.00	0.00%	0.00%	--	
			15	-60.24	-31.35	0.00		15	-60.24	-31.35	0.00	0.00%	0.00%	--	
K [2]	12	XD	14	-0.02	-0.02	0.00	17	5	-0.02	-0.02	0.00	--	--	--	
			26	0.02	0.02	0.00		18	0.02	0.02	0.00	--	--	--	
		YD	14	60.24	31.35	0.00		5	60.24	31.35	0.00	0.00%	0.00%	--	
			26	-60.24	-31.35	0.00		18	-60.24	-31.35	0.00	0.00%	0.00%	--	
K [3]	17	XD	5	-0.02	-0.02	0.00	17	5	-0.02	-0.02	0.00	--	--	--	
			18	0.02	0.02	0.00		18	0.02	0.02	0.00	--	--	--	
		YD	5	60.24	31.35	0.00		5	60.24	31.35	0.00	0.00%	0.00%	--	
			18	-60.24	-31.35	0.00		18	-60.24	-31.35	0.00	0.00%	0.00%	--	

**Table 12.** Comparison of element end moments obtained from MicasPlus for Cases 2 and 3 with those obtained from MicasPlus for Case 1 for all three frames.

Frame (Case)	MicasPlus (Case 2 - 3)						MicasPlus (Case 1)						Percentage difference		
	Elem no.	Load ca/co	Node no.	Fx	Fy	Fz	Elem no.	Node no.	Fx	Fy	Fz	FX	Fy	FZ	
				kip-ft					kip-ft						%
M [2]	1	XD	1	0.00	0.00	0.00	1	1	0.00	0.00	0.00	--	--	--	
			13	0.00	-93.34	0.00		2	0.00	-93.34	0.00	--	0.00%	--	
		YD	1	0.00	0.00	0.00		1	0.00	0.00	0.00	--	--	--	
			13	0.00	-0.04	-137.17		2	0.00	-0.04	-137.17	--	--	0.00%	
M [2]	2	XD	3	0.00	0.00	0.00	2	3	0.00	0.00	0.00	--	--	--	
			14	0.00	-113.51	0.00		4	0.00	-113.51	0.00	--	0.00%	--	
		YD	3	0.00	0.00	0.00		3	0.00	0.00	0.00	--	--	--	
			14	0.00	0.00	-206.03		4	0.00	0.00	-206.03	--	--	0.00%	
M [3]	1	XD	1	0.00	0.00	0.00	1	1	0.00	0.00	0.00	--	--	--	
			2	0.00	-93.34	0.00		2	0.00	-93.34	0.00	--	0.00%	--	
		YD	1	0.00	0.00	0.00		1	0.00	0.00	0.00	--	--	--	
			2	0.00	-0.04	-137.17		2	0.00	-0.04	-137.17	--	--	0.00%	
M [3]	3	XD	5	0.00	0.00	0.00	3	5	0.00	0.00	0.00	--	--	--	
			6	0.00	-93.15	0.00		6	0.00	-93.15	0.00	--	0.00%	--	
		YD	5	0.00	0.00	0.00		5	0.00	0.00	0.00	--	--	--	
			6	0.00	0.04	-137.17		6	0.00	0.04	-137.17	--	--	0.00%	
M [3]	20	XD	13	0.00	0.00	-18.38	20	13	0.00	0.00	-18.38	--	--	0.00%	
			14	0.00	0.00	-16.96		14	0.00	0.00	-16.96	--	--	0.00%	
		YD	13	0.00	-3.54	-0.08		13	0.00	-3.54	-0.08	--	0.00%	--	
			14	0.00	-5.01	-0.12		14	0.00	-5.01	-0.12	--	0.00%	--	
X [2]	12	XD	14	0.00	0.00	0.00	14	5	0.00	0.00	0.00	--	--	--	
			20	0.00	0.00	-0.21		15	0.00	0.00	-0.21	--	--	--	
		YD	14	0.00	0.00	0.00		5	0.00	0.00	0.00	--	--	--	
			20	0.00	0.00	156.73		15	0.00	0.00	156.73	--	--	0.00%	
X [3]	14	XD	5	0.00	0.00	0.00	14	5	0.00	0.00	0.00	--	--	--	
			15	0.00	0.00	-0.21		15	0.00	0.00	-0.21	--	--	--	
		YD	5	0.00	0.00	0.00		5	0.00	0.00	0.00	--	--	--	
			15	0.00	0.00	156.73		15	0.00	0.00	156.73	--	--	0.00%	
K [2]	12	XD	14	0.00	0.00	0.00	17	5	0.00	0.00	0.00	--	--	--	
			26	0.00	0.00	-0.09		18	0.00	0.00	-0.09	--	--	--	
		YD	14	0.00	0.00	0.00		5	0.00	0.00	0.00	--	--	--	
			26	0.00	0.00	156.73		18	0.00	0.00	156.73	--	--	0.00%	
K [3]	17	XD	5	0.00	0.00	0.00	17	5	0.00	0.00	0.00	--	--	--	
			18	0.00	0.00	-0.09		18	0.00	0.00	-0.09	--	--	--	
		YD	5	0.00	0.00	0.00		5	0.00	0.00	0.00	--	--	--	
			18	0.00	0.00	156.73		18	0.00	0.00	156.73	--	--	0.00%	

#### 4.1.2 Discussion of Analysis Results

For Case 1, the maximum percentage difference in the support reactions given by MicasPlus Analysis and STAAD III was 0.01%, while for displacements it was 3.7%. For line element end forces, the maximum percentage difference was 2%. The maximum percentage difference for line element end moments was quite high when compared to support reactions, displacements and line element end forces. It ranged from around 5% to 17.5% for larger values of moments. The percentage difference for the smaller values was not computed because these differences are not necessarily due to inaccuracies in the program. Such differences can be attributed to difference in hardware, round off errors, and the number of decimal places in the printed output from each program. Percentage differences for support reactions and line element end forces of 0.5 kip or less, for displacements of 0.5 inch or less, and for line element end moments of 0.5 kip-ft or less are not presented.

The percentage difference between the results for Case 2 and Case 1, and between Case 3 and Case 1 was zero for higher values of support reactions, displacements, and line element end actions. Again, the percentage difference for very small insignificant values were not computed. Hence it can be stated that the analytical model generated from the ModelDraft physical model in Case 2 is identical to the analytical model created in MicasPlus Analysis in Case 1. Also, as desired, the secondary members did not get transferred from Modeldraft to MicasPlus Analysis, through the Project Structural Database(PSD). The zero difference in the results from Case 3 and Case 1 indicates that the inactive secondary members of Case 3 are indeed ignored in the analysis.

For Case 4, the maximum percentage difference in the support reactions computed by the two programs was 0.95%. For displacements, the maximum percentage difference was 3.5% for the higher values. The maximum percentage difference for line element end



forces was 4.0%.

For Case 5, the maximum percentage difference for support reactions given by Micas-Plus Analysis and STAAD III was 0.87%. For displacements it was 5% for the higher values. The maximum percentage difference between results for line element end forces was 2.56%.

For Cases 6 and 7 the percentage differences between the two programs were typically less than 5% for all of the analysis results. As seen from Cases 1, 4, 5, 6 and 7 the analysis results obtained from MicasPlus Analysis are acceptable since they compare quite favorably with analysis results obtained from STAAD III. The difference in results was less than 5% with most being less than 3%. Of Cases 1, 4, 5, 6 and 7, the highest percentage difference were in Case 4 and Case 1 had the lowest percentage difference.

In addition to the fact that the percentage difference in results between MicasPlus Analysis and STAAD III increased as the magnitude of the results decreased, the results also revealed the following trends:

1. The percentage differences in the results for the moment resisting frame were lower than those for the braced frames.
2. The percentage differences for Cases 4 and 5 were larger than those for Cases 6 and 7. Case 1 had the least percentage differences.
3. The percentage differences were less for support reactions than those for displacements. Also, the differences in the values of the line element end forces were less than those for line element end moments.
4. The percentage differences for support reactions and displacements were larger

in the direction perpendicular to the wind load.

5. For most of the cases, the percentage difference were larger for values in the global y- direction than for those in the global x-direction.
6. The percentage differences for displacements and line element end actions were larger at the upper level of the frames.
7. The percentage differences were larger for rotations and line element end moments than those for translations and line element end forces respectively.
8. The percentage differences were larger for results for the bent in the middle frame than for the results for the bent at the ends of the frame.
9. The percentage difference in results were larger for the knee bracing and its adjoining members than other elements in the frame.

## **4.2 Design Results**

### **4.2.1 Tabulation of Design Results**

A representative sample of the design results from MicasPlus and GTSTRUDL for Cases 8 and 9 are shown in Tables 13 to 16. All columns at the first floor level of the three type of frames and the bracing members were designed in Case 8. All members of the three type of frames, including secondary framing members were designed in Case 9. The frames were subjected through five analysis and design cycles in both programs separately. Member sizes at the end of each analysis and design cycle were compared

### **4.2.2 Discussion of Design Results**

Design results from Case 8 for all three type of frames from MicasPlus and GTSTRUDL were similar for all five design cycles. Steel sections selected for most (but

**Table 13.** Comparison of design results obtained from MicasPlus and GTSTRUDL for Case 8 for the frame with X-bracing.

Design Cycle No.	Section size selected for Elem. No. 1 (Column)	
	MicasPlus	GTSTRUDL
1	W12x30	W12x30
2	W12x30	W12x30
3	W12x26	W12x26
4	W12x26	W12x26
5	W12x26	W12x26
	Section size selected for Elem. No. 35 (Brace)	
1	WT7x11	WT7x11
2	WT7x11	WT6x13
3	WT7x11	WT6x13
4	WT7x11	WT6x13
5	WT7x11	WT6x13

**Table 14.** Comparison of design results obtained from MicasPlus and GTSTRU DL for Case 9 for the moment resisting frame.

Design Cycle No.	Section size selected for Elem. No. 5 (Column)	
	MicasPlus	GTSTRU DL
1	W14x109	W14x120
2	W14x109	W14x120
3	W14x99	W14x109
4	W14x99	W14x109
5	W14x99	W14x109
	Section size selected for Elem. No. 24 (Beam)	
1	W16x36	W16x31
2	W14x34	W14x30
3	W14x34	W14x30
4	W14x34	W14x30
5	W14x34	W14x30

**Table 15.** Comparison of design results obtained from MicasPlus and GTSTRUDL for Case 9 for the frame with X-bracing.

Design Cycle No.	Section size selected for Elem. No. 6 (Column)	
	MicasPlus	GTSTRUDL
1	W14x99	W14x109
2	W14x99	W14x109
3	W14x99	W14x99
4	W14x99	W14x99
5	W14x99	W14x99
	Section size selected for Elem. No. 65 (Beam)	
1	W18x50	W21x50
2	W18x50	W21x50
3	W21x50	W21x50
4	W21x50	W21x50
5	W21x50	W21x50

**Table 16.** Comparison of design results obtained from MicasPlus and GTSTRU DL for Case 9 for the frame with Chevron bracing.

Design Cycle No.	Section size selected for Elem. No. 4 (Column)	
	MicasPlus	GTSTRU DL
1	W10x33	W10x33
2	W10x33	W10x33
3	W10x33	W10x33
4	W10x33	W10x33
5	W10x33	W10x33
	Section size selected for Elem. No. 51 (Brace)	
1	WT7x21.5	WT7x26
2	WT7x24	WT7x26
3	WT7x26	WT7x26
4	WT7x26	WT7x26
5	WT7x26	WT7x26

not all) of the members by the two programs matched for every design cycle. For some members, the steel sections selected by the two programs were such that the section selected by one program in a particular design cycle would be the section selected by the other program in the next design cycle. Design results were also verified by hand-calculations for selected members.

The results for Case 9 from MicasPlus and GTSTRUDL were in agreement for each design cycle for most of the members in the three frames. Some of the sections, as shown in Tables 14, 15 and 16, did not match exactly, for example, MicasPlus selected a W14x109 for element 5 while a W14x120 section was selected by GTSTRUDL. This difference in design results may be due to small differences in analysis results between the two programs. A small difference in analysis results could result in the selection of a W14x120 instead of a W14x109 section. The W14x120 section is the next available W14 section therefore if the W14x109 section is overstressed by even a small amount, the program will select a W14x120, though in practice a W14x109 would still be acceptable. Hence, these differences in the design results are insignificant as far as the design capability of the programs is concerned.

In general the design results from both programs are similar and acceptable. The sections selected by both programs may not exactly match for all line elements because the analysis results do not match exactly. Moreover, after the first design cycle, even if one section selected by the two programs did not match the stiffness of the frame in the next analysis cycle would be different in the two programs and hence the analysis results would also be different.

In summary, the design results from both the structural programs were similar for all five analysis and design cycles for both cases of the three frames. Both programs gave

essentially the same sections and converged within three cycles.

### **4.3 Parametric Study Results**

Cases 4, 5, 6 and 7 were formed by varying analysis and modeling parameters. Results obtained for each of these cases were compared with those from Case 1 to study the effect of the change in the parameter value on analysis results. This section shows the importance of correct computer modeling of the actual structure as it can be seen that change in one of the modeling parameters can significantly effect the results of the structural analysis.

#### **4.3.1 Comparison of Results of Cases 1 And 4**

As described in Chapter 3, Case 1 was modified by turning the "global rigid end offset from cardinal point" option on to form Case 4. The comparison of displacements for Case 1 and Case 4 at selected nodes for all three frames is presented in Table 17. The node names are same as in Figure 28. The comparison of line element end forces for selected line elements is presented in Tables 18 and 19. Tables 20 and 21 present the corresponded results for line element end moments. The selected line elements for the X-bracing and Chevron bracing frames are shown in Figure 38.

As seen from Tables 17, 18, and 20, the results obtained for the moment resisting frame for Case 1 and Case 4 differed by less than 1.0%. The percentage difference between Case 1 and Case 4 for the line element end actions was around 3.5%, implying that turning the "global rigid end offset from cardinal point" option on does not significantly effect the analysis results for the moment resisting frame.

Table 17 shows that the percentage differences for translations in the X-braced frame have increased from between 8% to 25% and the rotations in global x-direction have increased from anywhere between 10% to 25%. The rotations in global z-direction have



**Table 17.** Comparison of displacements obtained from MicasPlus for Cases 1 and 4 for all three frames.

Type of frame	Node name (no)	Load ca/co	MicasPlus (Case 4)			MicasPlus (Case 1)			Percentage difference		
			Tx	Ty	Tz	Tx	Ty	Tz	Tx	Ty	Tz
			inches			inches			%		
M	A	XD	7.1627	-5.9E-14	0.00517	7.1556	1.1E-14	0.0051	0.10%	--	--
	[13]	YD	0.000242	5.2514	0.007803	0.0003	5.2563	0.00782	--	-0.09%	--
	B	XD	7.1627	-5.9E-14	0.00517	7.1556	1.1E-14	0.0051	0.10%	--	--
	[16]	YD	-0.00024	5.2484	-0.0078	-0.0003	5.2536	-0.0078	--	-0.10%	--
	C	XD	7.1551	-3E-16	-0.00014	7.1512	-1E-16	0.000005	0.05%	--	--
	[14]	YD	1.13E-14	6.7582	0.011	-2E-14	6.7497	0.0109	--	0.13%	--
	D	XD	7.1564	5.85E-14	-0.00503	7.1502	-1E-14	-0.0051	0.09%	--	--
	[15]	YD	-0.00024	5.2514	0.007803	-0.0003	5.2563	0.00782	--	-0.09%	--
	E	XD	5.9325	-4E-14	0.004389	5.92	7.2E-15	0.00433	0.21%	--	--
	[2]	YD	0.000224	3.7343	0.006431	0.00028	3.7359	0.00645	--	-0.04%	--
	F	XD	5.8986	-2E-16	-0.00011	5.9142	-6E-17	0.0000019	-0.26%	--	--
	[4]	YD	9.07E-15	4.9794	0.009322	-1E-14	4.9756	0.0093	--	0.08%	--
X	A	XD	0.101	-0.0114	0.006694	0.0904	0.0000613	0.006583	--	--	--
	[17]	YD	0.0273	0.0739	0.005005	-0.00273	0.0631	0.004139	--	--	--
	B	XD	0.1005	-0.0115	0.006694	0.0904	-0.000061	0.006583	--	--	--
	[21]	YD	-0.0356	0.0715	-0.00443	0.003104	0.0609	-0.00372	--	--	--
	C	XD	0.0981	0.0000013	-0.00609	0.0882	0.00000202	-0.00622	--	--	--
	[19]	YD	0.0271	5.4329	0.006095	-0.0028	4.3328	0.005927	--	25.39%	--
	D	XD	0.1176	-0.00048	-0.00044	0.0882	0.00000192	-0.00592	--	--	--
	[25]	YD	0.3924	5.4047	-0.1604	-0.00161	4.3286	-0.1324	--	24.86%	--
	E	XD	0.09	-0.00031	-0.00589	0.082	0.0000798	-0.00599	--	--	--
	[18]	YD	0.0247	5.1572	0.007085	-0.00238	4.1713	0.006692	--	23.64%	--
	F	XD	0.0595	0.0000362	-0.00525	0.0573	-0.0000064	-0.0053	--	--	--
	[5]	YD	0.008994	3.863	0.005318	-0.00122	3.3298	0.005192	--	16.01%	--
K	A	XD	0.1749	-0.0000027	0.001998	0.1317	1.17E-09	0.002201	--	--	--
	[21]	YD	-0.1132	0.1278	0.001544	-0.00399	0.0807	0.001411	--	--	--
	B	XD	0.1749	0.00000268	0.001998	0.1317	-1.2E-09	0.002201	--	--	--
	[25]	YD	0.113	0.1247	-0.00154	0.003984	0.078	-0.00141	--	--	--
	C	XD	0.171	-0.00008	-0.0021	0.129	9.09E-07	-0.0022	--	--	--
	[23]	YD	-0.1131	6.6121	0.005623	-0.00399	4.3331	0.006168	--	52.60%	--
	D	XD	0.1236	0.001039	-0.0156	0.129	6.43E-07	-0.00216	--	--	--
	[32]	YD	0.6921	6.5696	-0.1636	-0.00242	4.3288	-0.1322	>100%	51.76%	--
	E	XD	0.164	0.000525	-0.0021	0.1228	0.0000438	-0.0022	--	--	--
	[22]	YD	-0.0971	6.1968	0.006622	-0.00277	4.1715	0.006927	--	48.55%	--
	F	XD	0.1138	-0.00012	-0.00216	0.0914	-0.0000025	-0.0022	--	--	--
	[5]	YD	-0.0543	4.4679	0.004799	-0.000038	3.3299	0.005407	--	34.18%	--

**Table 18.** Comparison of element end forces obtained from MicasPlus for the moment resisting frame for Cases 1 and 4.

Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 4)			MicasPlus (Case 1)			Percentage difference		
			Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
			Kips			Kips			%		
C1 [1]	XD	1	-10.13	0.00	4.64	-10.00	0.00	4.67	1.31%	--	-0.52%
		2	10.13	0.00	-4.64	10.00	0.00	-4.67	1.31%	--	-0.52%
	YD	1	-14.84	-6.82	0.00	-14.87	-6.86	0.00	-0.21%	-0.58%	--
		2	14.84	6.82	0.00	14.87	6.86	0.00	-0.21%	-0.58%	--
C2 [2]	XD	3	0.26	0.00	5.67	0.00	0.00	5.68	--	--	-0.15%
		4	-0.26	0.00	-5.67	0.00	0.00	-5.68	--	--	-0.15%
	YD	3	-21.51	-10.21	0.00	-21.45	-10.30	0.00	0.29%	-0.91%	--
		4	21.51	10.21	0.00	21.45	10.30	0.00	0.29%	-0.90%	--
C3 [5]	XD	9	0.26	0.00	5.67	0.00	0.00	5.68	--	--	-0.15%
		10	-0.26	0.00	-5.67	0.00	0.00	-5.68	--	--	-0.15%
	YD	9	21.51	-10.37	0.00	21.45	-10.29	0.00	0.29%	0.83%	--
		10	-21.51	10.37	0.00	-21.45	10.28	0.00	0.29%	0.83%	--
C4 [15]	XD	4	0.07	0.00	3.24	-0.01	0.00	3.12	--	--	3.96%
		14	-0.07	0.00	-3.24	0.01	0.00	-3.12	--	--	3.96%
	YD	4	-3.77	-2.89	0.00	-3.75	-3.14	0.00	0.65%	-8.04%	--
		14	3.77	2.89	0.00	3.75	3.14	0.00	0.65%	-8.04%	--
B1 [7]	XD	2	6.14	-8.33	0.00	6.27	-8.23	0.00	-2.05%	1.15%	--
		4	-6.14	8.33	0.00	-6.27	8.23	0.00	-2.05%	1.15%	--
	YD	2	0.30	-0.01	0.43	0.30	-0.01	0.43	--	--	--
		4	-0.30	0.01	-0.43	-0.30	0.01	-0.43	--	--	--
B2 [11]	XD	2	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		8	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
	YD	2	3.91	-11.66	-0.29	3.99	-11.68	-0.29	-1.95%	-0.15%	--
		8	-3.91	11.66	0.29	-3.99	11.68	0.29	-1.95%	-0.15%	--
B3 [12]	XD	4	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		10	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
	YD	4	7.83	-17.77	0.00	7.98	-17.73	0.00	-1.98%	0.21%	--
		10	-7.83	17.77	0.00	-7.98	17.73	0.00	-1.98%	0.21%	--
B4 [20]	XD	13	4.22	-1.80	0.00	4.06	-1.77	0.00	3.76%	2.04%	--
		14	-4.22	1.80	0.00	-4.06	1.77	0.00	3.76%	2.04%	--
	YD	13	0.27	-0.01	0.43	0.27	-0.01	0.43	--	--	--
		14	-0.27	0.01	-0.43	-0.27	0.01	-0.43	--	--	--
B5 [25]	XD	14	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		17	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
	YD	14	4.25	-3.79	0.00	4.01	-3.77	0.00	6.18%	0.65%	--
		17	-4.25	3.79	0.00	-4.01	3.77	0.00	6.18%	0.65%	--

**Table 19.** Comparison of element end forces obtained from MicasPlus analysis for Cases 1 and 4 for the frames with X-bracing and Chevron bracing.

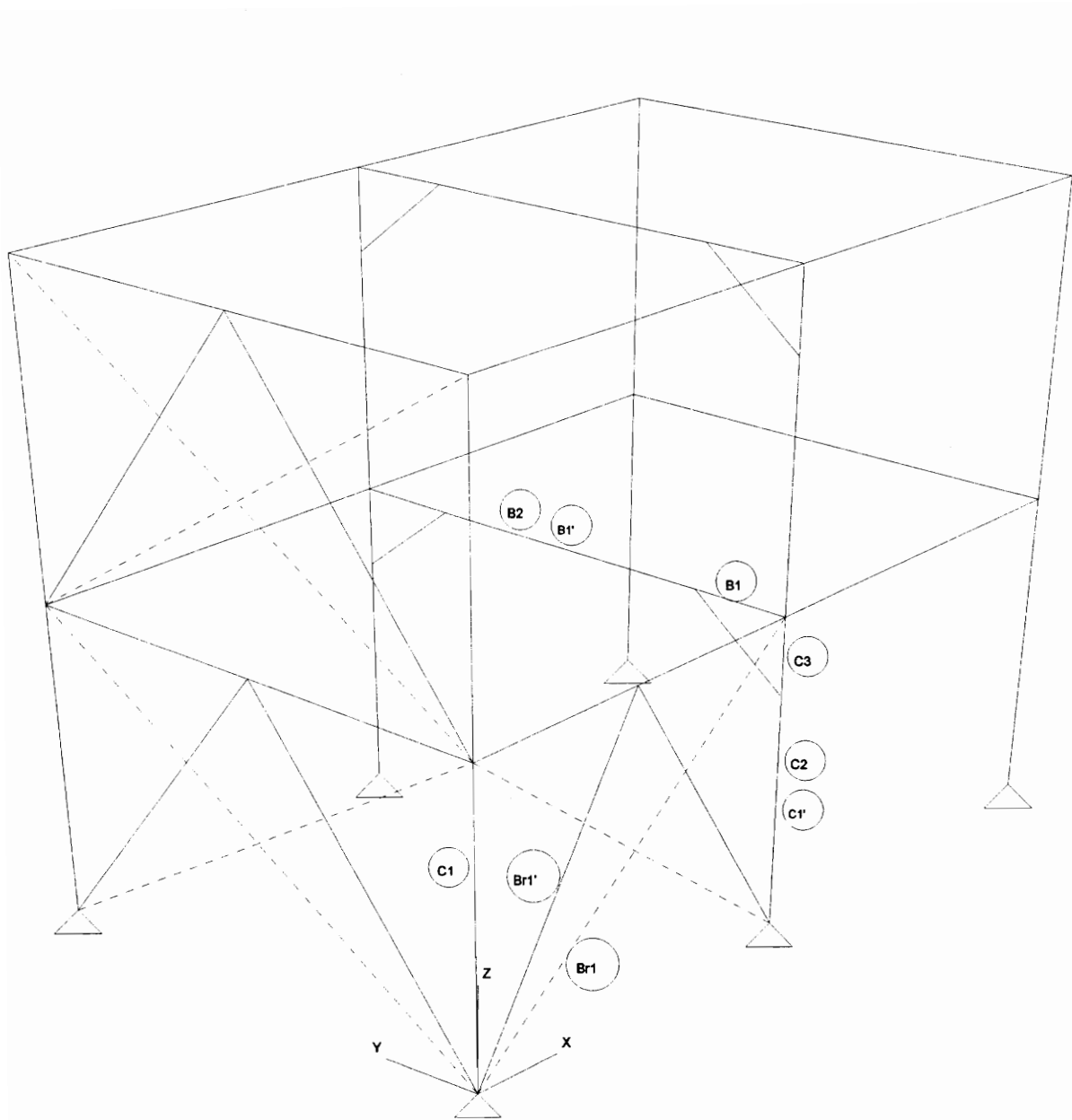
Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 4)			MicasPlus (Case 1)			Percentage difference		
				Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
				Kips			Klps			%		
X	C1 [1]	XD	1	-12.43	0.00	-0.03	-12.33	0.00	0.02	0.85%	--	--
			2	12.43	0.00	0.03	12.33	0.00	-0.02	0.85%	--	--
		YD	1	-9.49	0.01	0.02	-7.67	-0.04	0.00	23.75%	--	--
			2	9.49	-0.01	-0.02	7.67	0.04	0.00	23.75%	--	--
X	C2 [2]	XD	3	12.17	0.02	0.06	12.25	0.01	0.01	-0.66%	--	--
			4	-12.17	-0.02	-0.06	-12.25	-0.01	-0.01	-0.65%	--	--
		YD	3	-27.11	-11.91	0.01	-25.05	-12.00	0.00	8.22%	-0.73%	--
			4	27.11	11.91	-0.01	25.05	12.00	0.00	8.22%	-0.74%	--
X	C3 [3]	XD	4	11.98	-0.17	0.06	12.20	-0.04	0.01	-1.83%	--	--
			5	-11.98	0.17	-0.06	-12.21	0.04	-0.01	-1.84%	--	--
		YD	4	32.23	47.42	0.01	27.22	40.26	0.00	18.42%	17.79%	--
			5	-32.23	-47.42	-0.01	-27.22	-40.26	0.00	18.42%	17.79%	--
X	B1 [14]	XD	5	-0.21	-0.19	0.00	-0.04	-0.04	0.00	--	--	--
			15	0.21	0.19	0.00	0.04	0.04	0.00	--	--	--
		YD	5	67.13	39.03	0.10	60.24	31.35	0.00	11.42%	24.51%	--
			15	-67.13	-39.03	-0.10	-60.24	-31.35	0.00	11.42%	24.51%	--
X	B2 [15]	XD	15	-0.03	0.00	0.00	0.00	0.00	0.00	--	--	--
			16	0.03	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	15	7.79	-20.31	0.10	7.98	-20.92	0.00	-2.37%	-2.93%	--
			16	-7.79	20.31	-0.10	-7.98	20.92	0.00	-2.37%	-2.92%	--
X	Br1 [35]	XD	1	-10.08	0.00	0.00	-10.18	0.00	0.00	-1.03%	--	--
			5	10.08	0.00	0.00	10.18	0.00	0.00	-1.03%	--	--
		YD	1	2.09	0.00	0.00	-0.78	0.00	0.00	>100%	--	--
			5	-2.09	0.00	0.00	0.78	0.00	0.00	>100%	--	--
K	C1 [2]	XD	3	4.87	-0.05	-0.01	5.09	0.00	0.03	-4.44%	--	--
			4	-4.87	0.05	0.01	-5.09	0.00	-0.03	-4.44%	--	--
		YD	3	-25.87	-11.94	0.05	-25.54	-12.00	0.00	1.29%	-0.55%	--
			4	25.87	11.94	-0.05	25.54	12.00	0.00	1.29%	-0.55%	--
K	B1 [18]	XD	18	0.06	0.00	0.00	0.00	0.00	0.00	--	--	--
			19	-0.06	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	18	7.79	-20.26	0.05	7.98	-20.92	0.00	-2.37%	-3.15%	--
			19	-7.79	20.26	-0.05	-7.98	20.92	0.00	-2.37%	-3.15%	--
k	Br1 [43]	XD	1	-16.82	0.00	0.00	-16.67	0.00	0.00	0.90%	--	--
			15	16.82	0.00	0.00	16.67	0.00	0.00	0.90%	--	--
		YD	1	0.39	0.00	0.00	-0.05	0.00	0.00	--	--	--
			15	-0.39	0.00	0.00	0.05	0.00	0.00	--	--	--

**Table 20.** Comparison of element end moments obtained from MicasPlus for the frame with moment resisting connections for Cases 1 and 4.

Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 4)			MicasPlus (Case 1)			Percentage difference		
			Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
			kip-ft			kip-ft			%		
C1 [1]	XD	1	0	-3E-14	0	0	-1.903E-06	1.0171E-07	--	--	--
		2	0	-93.34	-3E-13	0	-91.863517	4.4948E-07	--	1.61%	--
	YD	1	0	3.5E-18	1.4E-14	0	-9.843E-09	-9.186E-08	--	--	--
		2	0	-0.0428	-137.17	0	-0.0467119	-137.79528	--	--	-0.45%
C2 [2]	XD	3	0	2.7E-14	0	0	-9.35E-07	0	--	--	--
		4	0	-113.51	2E-15	0	-114.8294	-1.079E-06	--	-1.15%	--
	YD	3	0	0	7.1E-14	0	4.2651E-08	-4.639E-05	--	--	--
		4	0	2.7E-13	-206.03	0	-5.807E-07	-203.41207	--	--	1.29%
C3 [5]	XD	9	0	-3E-14	0	0	-4.154E-06	5.9055E-08	--	--	--
		10	0	-113.51	1.9E-15	0	-114.8294	-9.678E-07	--	-1.15%	--
	YD	9	0	0	1.4E-14	0	1.9029E-07	-3.403E-05	--	--	--
		10	0	-3E-13	-205.69	0	-8.333E-07	-206.69291	--	--	-0.49%
C4 [15]	XD	4	-1.7E-15	-28.341	2.4E-15	3.1E-16	-29.620312	-6.037E-07	--	-4.32%	--
		14	1.68E-15	-33.973	2E-15	-3E-16	-36.089239	-5.577E-07	--	-5.86%	--
	YD	4	-1.3E-16	1.3E-13	-15.65	1.3E-15	2.2966E-08	-12.990922	--	--	20.47%
		14	1.29E-16	1.4E-13	-47.112	-1E-15	-1.148E-07	-45.931759	--	--	2.57%
B1 [7]	XD	2	1.15E-16	-6E-14	-93.684	-2E-17	-6.398E-07	-95.144357	--	--	-1.53%
		4	-1.2E-16	-4E-14	-70.933	2.1E-17	-5.413E-07	-72.178478	--	--	-1.73%
	YD	2	0.001407	-3.653	-0.1214	0.00128	-3.6535728	-0.112563	--	-0.02%	--
		4	-0.00141	-4.8786	-0.1625	-0.0013	-4.8798852	-0.1592818	--	-0.03%	--
B2 [11]	XD	2	7.28E-16	5.8E-14	-3E-13	-1E-16	-1.033E-06	1.857E-06	--	--	--
		8	-7.3E-16	5.8E-14	-3E-13	1.3E-16	-1.089E-06	2.1818E-06	--	--	--
	YD	2	-0.000027	3.6625	-146.03	-0.00002	3.66331693	-147.6378	--	-0.02%	-1.09%
		8	0.000027	3.6574	-146	0.000024	3.65770013	-144.35696	--	-0.01%	1.14%
B3 [12]	XD	4	7.25E-16	8.7E-14	4.3E-15	-9E-17	-6.89E-07	-1.644E-06	--	--	--
		10	-7.2E-16	8.8E-14	4.4E-15	8.9E-17	-7.743E-07	-1.699E-06	--	--	--
	YD	4	2.36E-17	-5E-14	-221.68	-4E-17	-5.479E-07	-223.09711	--	--	-0.64%
		10	-2.4E-17	-5E-14	-221.6	3.9E-17	5.9055E-08	-219.81627	--	--	0.81%
B4 [20]	XD	13	6.17E-17	-9E-14	-18.376	-1E-17	1.9718E-06	-19.024065	--	--	-3.41%
		14	-6.2E-17	-7E-14	-16.963	1.2E-17	1.3058E-06	-17.045348	--	--	-0.48%
	YD	13	0.001003	-3.5375	-0.0847	0.00093	-3.5565584	-0.0852215	--	-0.54%	--
		14	-0.001	-5.0129	-0.1205	-0.0009	-5.0392684	-0.1214495	--	-0.52%	--
B5 [25]	XD	14	1.48E-16	1.3E-13	2.1E-15	-2E-17	-2.582E-06	-5.151E-07	--	--	--
		17	-1.5E-16	1.3E-13	2.3E-15	2.2E-17	-2.523E-06	-4.331E-07	--	--	--
	YD	14	4.02E-18	-1E-13	-47.11	-8E-18	-9.58E-07	-45.931759	--	--	2.57%
		17	-4E-18	-1E-13	-47.15	7.7E-18	-1.06E-06	-45.931759	--	--	2.65%

**Table 21.** Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and Chevron bracing for Cases 1 and 4.

Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 4)			MicasPlus (Case 1)			Percentage difference		
				Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
				Kip-ft			Kip-ft			%		
X	C1 [1]	XD	1	0.18	0.00	-0.11	0.00	0.00	0.00	--	--	--
			2	-0.18	0.57	0.03	0.00	-0.35	-0.02	--	>100%	--
		YD	1	-0.16	-0.07	0.00	0.00	0.00	0.00	--	--	--
			2	0.16	-0.25	0.15	0.00	-0.02	-0.84	--	--	>100%
X	C2 [2]	XD	3	-0.13	0.00	-0.12	0.00	0.00	0.00	--	--	--
			4	0.13	-0.84	0.36	0.00	-0.22	0.10	--	>100%	--
		YD	3	-1.44	0.00	-0.02	0.00	0.00	0.00	>100%	--	--
			4	1.44	-0.17	-178.70	0.00	0.00	-180.05	>100%	--	-0.75%
X	C3 [3]	XD	4	-0.15	0.83	-0.35	0.00	0.22	-0.10	--	>100%	--
			5	0.15	-1.11	-0.49	0.00	-0.29	-0.07	--	>100%	--
		YD	4	-0.13	-1.32	176.72	0.00	0.00	180.05	--	>100%	-1.85%
			5	0.13	1.26	60.38	0.00	0.00	21.25	--	>100%	>100%
X	B1 [14]	XD	5	-0.01	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.01	0.00	-0.93	0.00	0.00	-0.21	--	--	>100%
		YD	5	-0.89	0.00	0.00	0.00	0.00	0.00	>100%	--	--
			15	0.89	-0.52	195.15	0.00	0.00	156.73	>100%	>100%	24.51%
X	B2 [15]	XD	15	0.00	0.02	0.79	0.00	0.00	0.21	--	--	>100%
			16	0.00	-0.02	-0.79	0.00	0.00	-0.21	--	--	>100%
		YD	15	0.59	-0.79	-152.87	0.00	0.00	-156.73	>100%	>100%	-2.46%
			16	-0.59	-0.78	-151.70	0.00	0.00	-157.02	>100%	>100%	-3.39%
X	Br1 [35]	XD	1	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			5	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	1	-0.03	0.00	0.00	0.00	0.00	0.00	--	--	--
			5	0.03	0.00	0.00	0.00	0.00	0.00	--	--	--
K	C1 [2]	XD	3	-0.10	0.00	0.25	0.00	0.00	0.00	--	--	--
			4	0.10	0.13	-0.95	0.00	-0.44	0.04	--	--	>100%
		YD	3	-0.20	0.00	-0.10	0.00	0.00	0.00	--	--	--
			4	0.20	-0.81	-178.96	0.00	-0.03	-180.04	--	>100%	-0.60%
K	B1 [18]	XD	18	0.00	-0.07	-2.21	0.00	0.00	0.09	--	--	>100%
			19	0.00	0.07	2.21	0.00	0.00	-0.09	--	--	>100%
		YD	18	0.84	-0.41	-152.50	0.00	0.00	-156.73	>100%	--	-2.70%
			19	-0.84	-0.40	-151.38	0.00	0.00	-157.02	>100%	--	-3.59%
k	Br1 [43]	XD	1	-0.05	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.05	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	1	0.04	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	-0.04	0.00	0.00	0.00	0.00	0.00	--	--	--



**Figure 38.** Line element names as referred to in Tables 19, 21, 23, 24, 26, 27, 29 and 30.

increased to about eight degrees from nearly zero degrees. This implies that the overall rigidity of the structure has reduced from Case 1 to Case 4.

Tables 19 and 21 show that the larger element end forces in the X-bracing frame have increased from between 15% to 25% in the beams and columns, and from between 1% to 14% in the bracing members. The larger element end moments in the columns have changed from between 1% and 50%, and in beams by 3% to 33%. Line element end actions in the knee bracing and its adjoining members, in the middle bent of the braced frames, varied significantly when compared to other elements of the frame.

The general trend of changes in the results for the frame with Chevron bracing is the same as that of for the frame with X-bracing except that the changes in the frame with Chevron bracing are more pronounced due to the fact that the columns are free to rotate about their own axis. In the frame with Chevron bracing, the columns are free to rotate about all three axes at the support nodes and all members framing into the columns are pinned, thus the columns can undergo rigid body rotation about their own axis. This is an unstable condition and no warning was given by either MicasPlus Analysis or STAAD II. Only GTSTRUDL gave a warning of instability. Hence only the frame with X-bracing should be used to evaluate the effect of Case 4 on the analysis results.

#### **4.3.2 Comparison Between Results of Case 1 And 5**

Case 5 was formed by specifying the rigid end offset from the cardinal point to the center of gravity of bracing members in the braced frames of Case 1. The bracing members were pinned at connections as in Case 1. Comparison of displacements between Case 1 and Case 5 at selected nodes of frames with X-bracing and Chevron bracing is presented in

Table 22. Again, the node names are same as in Figure 28. Comparison of line element end forces and moments for selected line elements is presented in Tables 23 and 24, respectively. The selected line elements are shown in Figure 38.

Table 22 shows that for the X-bracing frame, the translations have increased from between 68% to 125%. The rotations have increased to more than 10 degrees from nearly zero degrees, implying the reduction in the rigidity of the X-bracing frame. Large rotations in the columns about their own axis implies that the rigid link formed by the specifying of rigid end offset in the bracing members induces rotation in the columns. This rotation induces torsional moment ( $M_x$ ) in the columns. For example, the torsional moment in element 6 of the frame with X-bracing has increased from about 0.0003 k-ft in Case 1 to 4 k-ft in Case 5. The strong axis bending in the columns did not undergo any significant change, but overall there was a considerable change in the line element end actions, from between 10% to more than 100%, for certain values.

The trend of changes in the frame with Chevron bracing is same as for the frame with X-bracing, except that the changes are more pronounced, which may be due to the possibility of rigid body rotation of the columns about their own axis.

#### **4.3.3 Comparison between Case 1 and 6**

In Case 6, the bracing members of Case 5 were moment connected or fixed at the ends. This was done to evaluate the effect of moments induced in the bracing members while the rigid end offset from the cardinal point to the center of gravity of the bracing members is specified. The comparison of displacements between Case 1 and Case 6 at selected nodes in the frames with X-bracing and Chevron bracing is presented in Table 25.



**Table 22.** Comparison of displacements obtained from MicasPlus for all three frames for Cases 1 and 5.

Type of frame	Node name (no)	Load ca/co	MicasPlus (Case 5)			MicasPlus (Case 1)			Percentage difference		
			Tx	Ty	Tz	Tx	Ty	Tz	Tx	Ty	Tz
			inches			inches			%		
X	A	XD	0.3971	-0.3425	0.005919	0.0904	0.0000613	0.006583	>100%	>100%	--
	[17]	YD	0.4984	0.3081	0.0184	-0.00273	0.0631	0.004139	>100%	>100%	--
	B	XD	0.3903	-0.3425	0.005637	0.0904	-0.000061	0.006583	>100%	>100%	--
	[21]	YD	-0.7662	0.3065	-0.00787	0.003104	0.0609	-0.00372	>100%	>100%	--
	C	XD	0.3942	0.00152	-0.00668	0.0882	0.00000202	-0.00622	>100%	--	--
	[19]	YD	0.5018	9.7793	0.0172	-0.0028	4.3328	0.005927	>100%	>100%	--
	D	XD	0.3615	0.001699	0.0773	0.0882	0.00000192	-0.00592	>100%	--	>100%
	[25]	YD	0.2617	9.7749	-0.1477	-0.00161	4.3286	-0.1324	>100%	>100%	11.56%
	E	XD	0.3297	-0.00401	-0.00653	0.082	0.0000798	-0.00599	>100%	--	--
	[18]	YD	0.4104	8.9543	0.0177	-0.00238	4.1713	0.006692	>100%	>100%	--
	F	XD	0.156	0.00058	-0.00568	0.0573	-0.0000064	-0.0053	>100%	--	--
	[5]	YD	0.1652	6.0785	0.015	-0.00122	3.3298	0.005192	>100%	82.55%	--
K	A	XD	0.8981	-0.0000092	0.000935	0.1317	1.17E-09	0.002201	>100%	--	--
	[21]	YD	-3.0441	2.2119	0.003735	-0.00399	0.0807	0.001411	>100%	>100%	--
	B	XD	0.8981	0.00000923	0.000935	0.1317	-1.2E-09	0.002201	>100%	--	--
	[25]	YD	3.0458	2.2091	-0.00373	0.003984	0.078	-0.00141	>100%	>100%	--
	C	XD	0.8954	-0.00013	-0.00227	0.129	9.09E-07	-0.0022	>100%	--	--
	[23]	YD	-3.0441	25.9866	0.008707	-0.00399	4.3331	0.006168	>100%	>100%	--
	D	XD	0.9378	-0.00035	-0.1172	0.129	6.43E-07	-0.00216	>100%	--	>100%
	[32]	YD	-1.8341	25.9821	-0.1418	-0.00242	4.3288	-0.1322	>100%	>100%	7.26%
	E	XD	0.8042	0.002328	-0.00216	0.1228	0.0000438	-0.0022	>100%	--	--
	[22]	YD	-2.666	23.1504	0.009259	-0.00277	4.1715	0.006927	>100%	>100%	--
	F	XD	0.5032	0.000959	-0.00239	0.0914	-0.0000025	-0.0022	>100%	--	--
	[5]	YD	-1.538	14.2196	0.006832	-0.000038	3.3299	0.005407	>100%	>100%	--

**Table 23.** Comparison of element end forces obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 5.

Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 5)			MicasPlus (Case 1)			Percentage difference		
				Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
				Kips			Kips			%		
X	C1 [1]	XD	1	-11.26	-0.25	-0.04	-12.33	0.00	0.02	-8.72%	--	--
			2	11.26	0.25	0.04	12.33	0.00	-0.02	-8.71%	--	--
		YD	1	-37.16	0.29	-0.16	-7.67	-0.04	0.00	>100%	--	--
			2	37.16	-0.29	0.16	7.67	0.04	0.00	>100%	--	--
X	C2 [2]	XD	3	13.57	0.22	-0.05	12.25	0.01	0.01	10.85%	--	--
			4	-13.57	-0.22	0.05	-12.25	-0.01	-0.01	10.85%	--	--
		YD	3	-47.43	-12.08	0.04	-25.05	-12.00	0.00	89.36%	0.64%	--
			4	47.43	12.08	-0.04	25.05	12.00	0.00	89.36%	0.64%	--
X	C3 [3]	XD	4	11.71	-1.64	-0.05	12.20	-0.04	0.01	-4.01%	>100%	--
			5	-11.71	1.64	0.05	-12.21	0.04	-0.01	-4.02%	>100%	--
		YD	4	4.01	39.36	0.04	27.22	40.26	0.00	-85.28%	-2.24%	--
			5	-4.01	-39.36	-0.04	-27.22	-40.26	0.00	-85.28%	-2.24%	--
X	B1 [14]	XD	5	-2.21	-1.86	0.00	-0.04	-0.04	0.00	>100%	>100%	--
			15	2.21	1.86	0.00	0.04	0.04	0.00	>100%	>100%	--
		YD	5	59.46	31.01	0.39	60.24	31.35	0.00	-1.30%	-1.06%	--
			15	-59.46	-31.01	-0.39	-60.24	-31.35	0.00	-1.30%	-1.06%	--
X	B2 [15]	XD	15	-0.35	0.00	0.00	0.00	0.00	0.00	--	--	--
			16	0.35	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	15	8.02	-20.42	0.39	7.98	-20.92	0.00	0.53%	-2.35%	--
			16	-8.02	20.42	-0.39	-7.98	20.92	0.00	0.53%	-2.35%	--
X	Br1 [35]	XD	1	-12.31	0.00	0.00	-10.18	0.00	0.00	20.94%	--	--
			5	12.31	0.00	0.00	10.18	0.00	0.00	20.93%	--	--
		YD	1	30.79	0.00	0.00	-0.78	0.00	0.00	>100%	--	--
			5	-30.79	0.00	0.00	0.78	0.00	0.00	>100%	--	--
K	C1 [2]	XD	3	4.42	-0.53	0.06	5.09	0.00	0.03	-13.27%	>100%	--
			4	-4.42	0.53	-0.06	-5.09	0.00	-0.03	-13.27%	>100%	--
		YD	3	-28.73	-12.10	0.17	-25.54	-12.00	0.00	12.47%	0.84%	--
			4	28.73	12.10	-0.17	25.54	12.00	0.00	12.47%	0.85%	--
K	B1 [18]	XD	18	0.42	0.00	0.00	0.00	0.00	0.00	--	--	--
			19	-0.42	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	18	7.98	-20.74	0.21	7.98	-20.92	0.00	0.03%	-0.83%	--
			19	-7.98	20.74	-0.21	-7.98	20.92	0.00	0.03%	-0.83%	--
k	Br1 [43]	XD	1	-15.67	0.00	0.00	-16.67	0.00	0.00	-5.96%	--	--
			15	15.67	0.00	0.00	16.67	0.00	0.00	-5.96%	--	--
		YD	1	3.61	0.00	0.00	-0.05	0.00	0.00	>100%	--	--
			15	-3.61	0.00	0.00	0.05	0.00	0.00	>100%	--	--

**Table 24.** Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and the frame Chevron bracing for Cases 1 and 5.

Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 5)			MicasPlus (Case 1)			Percentage difference		
				Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
				Kip-ft			Kip-ft			%		
X	C1 [1]	XD	1	0.88	0.01	-0.79	0.00	0.00	0.00	>100%	--	>100%
			2	-0.88	0.79	-4.16	0.00	-0.35	-0.02	>100%	>100%	>100%
		YD	1	0.03	0.24	1.90	0.00	0.00	0.00	--	--	>100%
			2	-0.03	2.86	3.86	0.00	-0.02	-0.84	--	>100%	>100%
X	C2 [2]	XD	3	-0.62	0.00	-0.59	0.00	0.00	0.00	>100%	--	>100%
			4	0.62	0.69	3.84	0.00	-0.22	0.10	>100%	>100%	>100%
		YD	3	-3.77	0.00	-1.93	0.00	0.00	0.00	>100%	--	>100%
			4	3.77	-0.59	-179.27	0.00	0.00	-180.05	>100%	>100%	-0.43%
X	C3 [3]	XD	4	-0.90	-0.61	-3.84	0.00	0.22	-0.10	>100%	>100%	>100%
			5	0.90	0.84	-4.38	0.00	-0.29	-0.07	>100%	>100%	>100%
		YD	4	1.15	-4.60	179.27	0.00	0.00	180.05	>100%	>100%	-0.43%
			5	-1.15	4.40	17.51	0.00	0.00	21.25	>100%	>100%	-17.58%
X	B1 [14]	XD	5	0.09	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	-0.09	0.00	-9.29	0.00	0.00	-0.21	--	--	>100%
		YD	5	-3.12	0.00	0.00	0.00	0.00	0.00	>100%	--	--
			15	3.12	-1.95	155.06	0.00	0.00	156.73	>100%	>100%	-1.06%
X	B2 [15]	XD	15	0.00	0.28	9.29	0.00	0.00	0.21	--	--	>100%
			16	0.00	-0.28	-9.27	0.00	0.00	-0.21	--	--	>100%
		YD	15	2.08	-2.98	-155.06	0.00	0.00	-156.73	>100%	>100%	-1.06%
			16	-2.08	-2.86	-151.31	0.00	0.00	-157.02	>100%	>100%	-3.64%
X	Br1 [35]	XD	1	-0.02	0.00	0.00	0.00	0.00	0.00	--	--	--
			5	0.02	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	1	-0.06	0.00	0.00	0.00	0.00	0.00	--	--	--
			5	0.06	0.00	0.00	0.00	0.00	0.00	--	--	--
K	C1 [2]	XD	3	-0.74	0.00	1.66	0.00	0.00	0.00	>100%	--	>100%
			4	0.74	-0.96	-9.64	0.00	-0.44	0.04	>100%	>100%	>100%
		YD	3	-0.86	0.00	-0.08	0.00	0.00	0.00	>100%	--	--
			4	0.86	-2.59	-181.48	0.00	-0.03	-180.04	>100%	>100%	0.80%
K	B1 [18]	XD	18	0.00	-0.67	-22.12	0.00	0.00	0.09	--	>100%	>100%
			19	0.00	0.67	22.12	0.00	0.00	-0.09	--	>100%	>100%
		YD	18	3.00	-1.57	-155.54	0.00	0.00	-156.73	>100%	>100%	-0.76%
			19	-3.00	-1.57	-155.61	0.00	0.00	-157.02	>100%	>100%	-0.90%
k	Br1 [43]	XD	1	-0.20	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.20	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	1	0.33	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	-0.33	0.00	0.00	0.00	0.00	0.00	--	--	--

**Table 25.** Comparison of displacements obtained from MicasPlus for all three frames for Cases 1 and 6.

Type of frame	Node name (no)	Load ca/co	MicasPlus (Case 6)			MicasPlus (Case 1)			Percentage difference		
			Tx	Ty	Tz	Tx	Ty	Tz	Tx	Ty	Tz
			inches			inches			%		
X	A	XD	0.1015	-0.00941	0.006584	0.0904	0.0000613	0.006583	12.28%	--	--
		YD	0.007183	0.0758	0.005709	-0.00273	0.0631	0.004139	--	20.13%	--
	B	XD	0.1013	-0.00957	0.006575	0.0904	-0.000061	0.006583	12.06%	--	--
		YD	-0.0152	0.0736	-0.00574	0.003104	0.0609	-0.00372	--	20.85%	--
	C	XD	0.0991	-0.00046	-0.00622	0.0882	0.00000202	-0.00622	12.36%	--	--
		YD	0.007399	4.6194	0.007486	-0.0028	4.3328	0.005927	--	6.61%	--
	D	XD	0.0817	-0.00046	-0.00489	0.0882	0.00000192	-0.00592	-7.37%	--	--
		YD	-0.00663	4.615	-0.1351	-0.00161	4.3286	-0.1324	--	6.62%	2.04%
	E	XD	0.0912	-0.00012	-0.00598	0.082	0.0000798	-0.00599	11.22%	--	--
		YD	0.006277	4.4327	0.008233	-0.00238	4.1713	0.006692	--	6.27%	--
	F	XD	0.0613	-0.00037	-0.00526	0.0573	-0.0000064	-0.0053	6.98%	--	--
		YD	-0.00089	3.4779	0.006598	-0.00122	3.3298	0.005192	--	4.45%	--
K	A	XD	0.1442	-0.000019	0.002175	0.1317	1.17E-09	0.002201	9.49%	--	--
		YD	0.034	0.1012	0.001461	-0.00399	0.0807	0.001411	--	25.40%	--
	B	XD	0.1442	0.0000188	0.002175	0.1317	-1.2E-09	0.002201	9.49%	--	--
		YD	-0.034	0.0985	-0.00146	0.003984	0.078	-0.00141	--	26.28%	--
	C	XD	0.1416	0.0000242	-0.00223	0.129	9.09E-07	-0.0022	9.77%	--	--
		YD	0.0341	4.7017	0.006279	-0.00399	4.3331	0.006168	--	8.51%	--
	D	XD	0.1457	0.0000141	-0.00237	0.129	6.43E-07	-0.00216	12.95%	--	--
		YD	0.0154	4.6973	-0.1374	-0.00242	4.3288	-0.1322	--	8.51%	3.93%
	E	XD	0.1348	0.0000661	-0.00223	0.1228	0.0000438	-0.0022	9.77%	--	--
		YD	0.0336	4.5154	0.00705	-0.00277	4.1715	0.006927	--	8.24%	--
	F	XD	0.1008	0.0000476	-0.00223	0.0914	-0.0000025	-0.0022	10.28%	--	--
		YD	0.0257	3.5487	0.005441	-0.000038	3.3299	0.005407	--	6.57%	--

he node names are same as in Figure 28. Comparison of line element end forces and moments for selected line elements is presented in Tables 26 and 27, respectively. The selected line elements are shown in Figure 38.

Comparing Tables 22 and 25, it can be seen that for the X-bracing frame the translations of Case 6, compared to those from Case 1, have increased from between 6% to 12%. This is less than the percentage increases of Case 5, implying that the frame of Case 6 is more rigid compared to the frame of Case 5, but less rigid when compared to the frame of Case 1. The rotation of the nodes in the vertical direction  $R_z$  has increased in Case 6 but not as much as in Case 5. For example, at node 5 the rotation  $R_z$  is only 1.04 degrees for load combination YD in Case 6 as compared to 17.1 degrees in Case 5, implying that fixing the bracing members in Case 6 resulted in a reduction of the rotation of the joints. However, this induces bending in the bracing members of Case 6 of about 2 k-ft in the WT bracing members and about 6 k-ft in the angle bracing members. The moments in the bracing members reduces moments in the adjoining columns, though this reduction is not significant, for example, the moment in a column was 179 k-ft for Case 5 and 174 k-ft for the same column in Case 6.

Tables 26 and 27 show that compared to Case 1 the element end forces in columns and beams of Case 6 have increased from between 5% to 20%. The axial forces in the bracing members have increased by around 2%. A maximum shear force of about 0.2 kips is induced in the bracing members. The element end moments have increased from between 3% to 20%. A weak axis bending moment of about 0.1 k-ft maximum is induced in the WT bracing members. The trend of changes in the Chevron bracing frame is same

**Table 26.** Comparison of element end forces obtained from MicasPlus for the frame with X-bracing and the frame Chevron bracing for Cases 1 and 6.

Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 6)			MicasPlus (Case 1)			Percentage difference		
				Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
				Kips			Kips			%		
X	C1 [1]	XD	1	-12.44	-0.05	0.01	-12.33	0.00	0.02	0.92%	--	--
			2	12.44	0.05	-0.01	12.33	0.00	-0.02	0.92%	--	--
		YD	1	-10.99	0.06	0.00	-7.67	-0.04	0.00	43.31%	--	--
			2	10.99	-0.06	0.00	7.67	0.04	0.00	43.31%	--	--
X	C2 [2]	XD	3	12.14	-0.04	0.01	12.25	0.01	0.01	-0.85%	--	--
			4	-12.14	0.04	-0.01	-12.25	-0.01	-0.01	-0.85%	--	--
		YD	3	-27.76	-11.83	0.01	-25.05	-12.00	0.00	10.81%	-1.44%	--
			4	27.76	11.83	-0.01	25.05	12.00	0.00	10.81%	-1.45%	--
X	C3 [3]	XD	4	12.10	-0.08	-0.01	12.20	-0.04	0.01	-0.82%	--	--
			5	-12.10	0.08	0.01	-12.21	0.04	-0.01	-0.83%	--	--
		YD	4	22.36	38.20	0.01	27.22	40.26	0.00	-17.85%	-5.12%	--
			5	-22.36	-38.20	-0.01	-27.22	-40.26	0.00	-17.85%	-5.12%	--
X	B1 [14]	XD	5	-0.06	-0.04	0.02	-0.04	-0.04	0.00	--	--	--
			15	0.06	0.04	-0.02	0.04	0.04	0.00	--	--	--
		YD	5	58.02	29.97	0.04	60.24	31.35	0.00	-3.68%	-4.38%	--
			15	-58.02	-29.97	-0.04	-60.24	-31.35	0.00	-3.68%	-4.38%	--
X	B2 [15]	XD	15	-0.03	0.00	0.00	0.00	0.00	0.00	--	--	--
			16	0.03	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	15	7.99	-20.14	0.05	7.98	-20.92	0.00	0.17%	-3.71%	--
			16	-7.99	20.14	-0.05	-7.98	20.92	0.00	0.17%	-3.71%	--
X	Br1 [35]	XD	1	-10.03	-0.03	0.00	-10.18	0.00	0.00	-1.54%	--	--
			5	10.03	0.03	0.00	10.18	0.00	0.00	-1.54%	--	--
		YD	1	3.99	0.03	0.00	-0.78	0.00	0.00	>100%	--	--
			5	-3.99	-0.03	0.00	0.78	0.00	0.00	>100%	--	--
K	C1 [2]	XD	3	5.15	0.01	0.04	5.09	0.00	0.03	1.17%	--	--
			4	-5.15	-0.01	-0.04	-5.09	0.00	-0.03	1.17%	--	--
		YD	3	-25.28	-11.89	0.02	-25.54	-12.00	0.00	-1.04%	-0.97%	--
			4	25.28	11.89	-0.02	25.54	12.00	0.00	-1.04%	-0.97%	--
K	B1 [18]	XD	18	0.10	0.00	0.00	0.00	0.00	0.00	--	--	--
			19	-0.10	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	18	7.98	-20.45	0.03	7.98	-20.92	0.00	-0.01%	-2.23%	--
			19	-7.98	20.45	-0.03	-7.98	20.92	0.00	-0.01%	-2.23%	--
k	Br1 [43]	XD	1	-16.66	0.06	0.00	-16.67	0.00	0.00	-0.02%	--	--
			15	16.66	-0.06	0.00	16.67	0.00	0.00	-0.02%	--	--
		YD	1	-0.05	-0.08	0.00	-0.05	0.00	0.00	--	--	--
			15	0.05	0.08	0.00	0.05	0.00	0.00	--	--	--

**Table 27.** Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 6.

Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 6)			MicasPlus (Case 1)			Percentage difference		
				Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
				Kip-ft			Kip-ft			%		
X	C1 [1]	XD	1	0.03	0.04	-0.84	0.00	0.00	0.00	--	--	>100%
			2	-0.03	-0.32	-0.19	0.00	-0.35	-0.02	--	--	--
		YD	1	-0.06	-0.34	1.11	0.00	0.00	0.00	--	--	>100%
			2	0.06	0.41	0.07	0.00	-0.02	-0.84	--	--	>100%
X	C2 [2]	XD	3	-0.01	-0.03	-0.84	0.00	0.00	0.00	--	--	>100%
			4	0.01	-0.19	0.21	0.00	-0.22	0.10	--	--	--
		YD	3	-0.31	-0.01	-1.97	0.00	0.00	0.00	--	--	>100%
			4	0.31	-0.14	-175.48	0.00	0.00	-180.05	--	--	-2.54%
X	C3 [3]	XD	4	-0.13	0.30	-0.20	0.00	0.22	-0.10	--	--	--
			5	0.13	-0.26	-0.18	0.00	-0.29	-0.07	--	--	--
		YD	4	0.27	-0.45	174.01	0.00	0.00	180.05	--	--	-3.36%
			5	-0.27	0.38	17.00	0.00	0.00	21.25	--	--	-20.02%
X	B1 [14]	XD	5	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.00	-0.12	-0.18	0.00	0.00	-0.21	--	--	--
		YD	5	-0.34	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.34	-0.21	149.87	0.00	0.00	156.73	--	--	-4.38%
X	B2 [15]	XD	15	0.00	0.12	0.17	0.00	0.00	0.21	--	--	--
			16	0.00	-0.12	-0.13	0.00	0.00	-0.21	--	--	--
		YD	15	0.23	-0.35	-150.92	0.00	0.00	-156.73	--	--	-3.70%
			16	-0.23	-0.33	-151.18	0.00	0.00	-157.02	--	--	-3.72%
X	Br1 [35]	XD	1	0.00	-0.04	-0.30	0.00	0.00	0.00	--	--	--
			5	0.00	-0.03	-0.61	0.00	0.00	0.00	--	--	-100.00%
		YD	1	0.00	0.01	1.26	0.00	0.00	0.00	--	--	-100.00%
			5	0.00	-0.01	-0.42	0.00	0.00	0.00	--	--	--
K	C1 [2]	XD	3	-0.09	-0.02	0.19	0.00	0.00	0.00	--	--	--
			4	0.09	-0.52	0.01	0.00	-0.44	0.04	--	18.04%	--
		YD	3	-0.07	0.03	0.13	0.00	0.00	0.00	--	--	--
			4	0.07	-0.34	-178.42	0.00	-0.03	-180.04	--	--	-0.90%
K	B1 [18]	XD	18	0.00	-0.15	-0.07	0.00	0.00	0.09	--	--	--
			19	0.00	0.15	0.07	0.00	0.00	-0.09	--	--	--
		YD	18	0.24	-0.20	-153.23	0.00	0.00	-156.73	--	--	-2.23%
			19	-0.24	-0.20	-153.52	0.00	0.00	-157.02	--	--	-2.23%
k	Br1 [43]	XD	1	0.00	0.01	0.89	0.00	0.00	0.00	--	--	-100.00%
			15	0.00	0.07	0.48	0.00	0.00	0.00	--	--	--
		YD	1	0.00	0.00	0.12	0.00	0.00	0.00	--	--	--
			15	0.00	0.02	-1.94	0.00	0.00	0.00	-25.76%	--	-100.00%

as in the X-bracing frame except that the changes are more pronounced.

#### **4.3.4 Comparison Of Cases 1 and 7**

Case 7 was formed by specifying the rigid end offset from the cardinal point to the center of gravity of beams in the braced frames of Case 1. The comparison of displacements between Cases 1 and 7 at selected nodes of the frames with X-bracing and Chevron bracing is presented in Table 28. Figure 28 shows the selected nodes and their node names. A comparison of line element end forces and moments for selected line elements is presented in Tables 29 and 30 respectively. The selected line elements are shown in Figure 38.

Table 28 shows that compared to Case 1 the translations of Case 7 have increased from between 7% to 14%, implying a decrease in the rigidity of the frame of Case 7. No significant changes in the rotation of the nodes is observed. A noticeable change in the element end forces in columns is observed. Most of the axial forces in the beams have reduced by around 3%. There has been a change in the line element end moments, but this change does not follow any particular trend.

The comparisons of Cases 4, 5, 6, and 7 with Case 1 show the effect on the analysis results due to changes in the analysis parameters. In some cases the effect on the results is significant which stresses the importance of correct computer modeling of the structure.



**Table 28.** Comparison of displacements obtained from MicasPlus for all three frames for Cases 1 and 7.

Type of frame	Node name (no)	Load ca/co	MicasPlus (Case 7)			MicasPlus (Case 1)			Percentage difference		
			Tx	Ty	Tz	Tx	Ty	Tz	Tx	Ty	Tz
			inches			inches			%		
X	A [17]	XD	0.0907	0.0000322	0.006718	0.0904	0.0000613	0.006583	0.33%	--	--
		YD	-0.00152	0.0632	0.004214	-0.00273	0.0631	0.004139	--	0.16%	--
	B [21]	XD	0.0907	-0.000032	0.006718	0.0904	-0.000061	0.006583	0.33%	--	--
		YD	0.002028	0.0609	-0.00371	0.003104	0.0609	-0.00372	--	0.00%	--
	C [19]	XD	0.0878	-0.0000067	-0.00608	0.0882	0.00000202	-0.00622	-0.45%	--	--
		YD	-0.00144	4.9593	0.005091	-0.0028	4.3328	0.005927	--	14.46%	--
	D [25]	XD	0.088	-0.000022	-0.00578	0.0882	0.00000192	-0.00592	-0.23%	--	--
		YD	-0.00066	4.9373	-0.1625	-0.00161	4.3286	-0.1324	--	14.06%	22.73%
	E [18]	XD	0.0818	0.0000785	-0.00587	0.082	0.0000798	-0.00599	-0.24%	--	--
		YD	-0.00196	4.7457	0.006118	-0.00238	4.1713	0.006692	--	13.77%	--
	F [5]	XD	0.0563	0.0000259	-0.00524	0.0573	-0.0000064	-0.0053	-1.75%	--	--
		YD	-0.00096	3.6331	0.00441	-0.00122	3.3298	0.005192	--	9.11%	--
K	A [21]	XD	0.1433	1.2E-08	0.002066	0.1317	1.17E-09	0.002201	8.81%	--	--
		YD	-0.00319	0.088	0.001317	-0.00399	0.0807	0.001411	--	9.05%	--
	B [25]	XD	0.1433	-1.2E-08	0.002066	0.1317	-1.2E-09	0.002201	8.81%	--	--
		YD	0.003218	0.085	-0.00131	0.003984	0.078	-0.00141	--	8.97%	--
	C [23]	XD	0.1395	-0.000004	-0.00206	0.129	9.09E-07	-0.0022	8.14%	--	--
		YD	-0.00319	4.9595	0.005299	-0.00399	4.3331	0.006168	--	14.46%	--
	D [32]	XD	0.1395	-0.0000015	-0.00203	0.129	6.43E-07	-0.00216	8.14%	--	--
		YD	0.000527	4.9374	-0.1624	-0.00242	4.3288	-0.1322	--	--	--
	E [22]	XD	0.1361	0.0000436	-0.00207	0.1228	0.0000438	-0.0022	--	--	--
		YD	-0.00221	4.7458	0.00632	-0.00277	4.1715	0.006927	--	--	--
	F [5]	XD	0.0973	0.0000116	-0.00213	0.0914	-0.0000025	-0.0022	--	--	--
		YD	0.0000162	3.6331	0.004597	-0.000038	3.3299	0.005407	--	--	--

**Table 29.** Comparison of element end forces obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 7.

Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 7)			MicasPlus (Case 1)			Percentage difference		
				Fx	Fy	Fz	Fx	Fy	Fz	FX	Fy	FZ
				Kips			Kips			%		
X	C1 [1]	XD	1	-12.47	0.01	-0.03	-12.33	0.00	0.02	1.10%	--	--
			2	12.47	-0.01	0.03	12.33	0.00	-0.02	1.11%	--	--
		YD	1	-7.78	0.00	-0.01	-7.67	-0.04	0.00	1.46%	--	--
			2	7.78	0.00	0.01	7.67	0.04	0.00	1.46%	--	--
X	C2 [2]	XD	3	12.12	0.01	0.06	12.25	0.01	0.01	-1.07%	--	--
			4	-12.12	-0.01	-0.06	-12.25	-0.01	-0.01	-1.06%	--	--
		YD	3	-25.12	-11.92	0.01	-25.05	-12.00	0.00	0.28%	-0.73%	--
			4	25.12	11.92	-0.01	25.05	12.00	0.00	0.28%	-0.73%	--
X	C3 [3]	XD	4	12.06	-0.04	0.06	12.20	-0.04	0.01	-1.15%	--	--
			5	-12.06	0.04	-0.06	-12.21	0.04	-0.01	-1.16%	--	--
		YD	4	34.65	47.85	0.01	27.22	40.26	0.00	27.30%	18.85%	--
			5	-34.65	-47.85	-0.01	-27.22	-40.26	0.00	27.30%	18.85%	--
X	B1 [14]	XD	5	-0.05	-0.05	0.00	-0.04	-0.04	0.00	--	--	--
			15	0.05	0.05	0.00	0.04	0.04	0.00	--	--	--
		YD	5	67.56	39.47	0.00	60.24	31.35	0.00	12.14%	25.93%	--
			15	-67.56	-39.47	0.00	-60.24	-31.35	0.00	12.14%	25.93%	--
X	B2 [15]	XD	15	0.00	0.00	0.00	0.00	0.00	0.00	--	--	
			16	0.00	0.00	0.00	0.00	0.00	0.00	--	--	
		YD	15	7.79	-20.29	0.00	7.98	-20.92	0.00	-2.37%	-2.99%	
			16	-7.79	20.29	0.00	-7.98	20.92	0.00	-2.37%	-2.9%	
X	Br1 [35]	XD	1	-10.00	0.00	0.00	-10.18	0.00	0.00	-1.81%	--	
			5	10.00	0.00	0.00	10.18	0.00	0.00	-1.82%	--	
		YD	1	-0.68	0.00	0.00	-0.78	0.00	0.00	-12.94%	--	
			5	0.68	0.00	0.00	0.78	0.00	0.00	-12.94%	--	
K	C1 [2]	XD	3	4.91	0.00	-0.01	5.09	0.00	0.03	-3.54%	--	
			4	-4.91	0.00	0.01	-5.09	0.00	-0.03	-3.54%	--	
		YD	3	-25.55	-11.91	0.00	-25.54	-12.00	0.00	0.02%	--	
			4	25.55	11.91	0.00	25.54	12.00	0.00	0.02%	--	
K	B1 [18]	XD	18	0.00	0.00	0.00	0.00	0.00	0.00	--	--	
			19	0.00	0.00	0.00	0.00	0.00	0.00	--	--	
		YD	18	7.79	-20.29	0.00	7.98	-20.92	0.00	-2.37%	-2.99%	
			19	-7.79	20.29	0.00	-7.98	20.92	0.00	-2.37%	-2.9%	
k	Br1 [43]	XD	1	-16.87	0.00	0.00	-16.67	0.00	0.00	1.2%	--	
			15	16.87	0.00	0.00	16.67	0.00	0.00	1.2%	--	
		YD	1	-0.04	0.00	0.00	-0.05	0.00	0.00	--	--	
			15	0.04	0.00	0.00	0.05	0.00	0.00	--	--	

**Table 30.** Comparison of element end moments obtained from MicasPlus for the frame with X-bracing and the frame with Chevron bracing for Cases 1 and 7.

Frame	Elem name [no.]	Load ca/co	Node no.	MicasPlus (Case 7)			MicasPlus (Case 1)			Percentage difference		
				Mx	My	Mz	Mx	My	Mz	Mx	My	Mz
				Kip-ft			Kip-ft			%		
X	C1 [1]	XD	1	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			2	0.00	0.51	0.18	0.00	-0.35	-0.02	--	>100%	--
		YD	1	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			2	0.00	0.13	-0.01	0.00	-0.02	-0.84	--	--	-98.42%
X	C2 [2]	XD	3	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			4	0.00	-0.86	0.11	0.00	-0.22	0.10	--	>100%	--
		YD	3	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			4	0.00	-0.10	-178.73	0.00	0.00	-180.05	--	--	-0.73%
X	C3 [3]	XD	4	0.00	0.86	-0.11	0.00	0.22	-0.10	--	>100%	--
			5	0.00	-1.14	-0.11	0.00	-0.29	-0.07	--	>100%	--
		YD	4	0.00	0.10	178.73	0.00	0.00	180.05	--	--	-0.73%
			5	0.00	-0.14	60.51	0.00	0.00	21.25	--	--	>100%
X	B1 [14]	XD	5	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.00	0.00	-0.26	0.00	0.00	-0.21	--	--	--
		YD	5	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.00	0.00	197.37	0.00	0.00	156.73	--	--	25.93%
X	B2 [15]	XD	15	0.00	0.00	0.22	0.00	0.00	0.21	--	--	--
			16	0.00	0.00	-0.22	0.00	0.00	-0.21	--	--	--
		YD	15	0.00	0.00	-152.79	0.00	0.00	-156.73	--	--	-2.51%
			16	0.00	0.00	-151.57	0.00	0.00	-157.02	--	--	-3.47%
X	Br1 [35]	XD	1	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			5	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	1	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			5	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
K	C1 [2]	XD	3	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			4	0.00	0.13	0.05	0.00	-0.44	0.04	--	--	--
		YD	3	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			4	0.00	-0.03	-178.72	0.00	-0.03	-180.04	--	--	-0.73%
K	B1 [18]	XD	18	0.00	0.00	0.09	0.00	0.00	0.09	--	--	--
			19	0.00	0.00	-0.09	0.00	0.00	-0.09	--	--	--
		YD	18	0.00	0.00	-152.79	0.00	0.00	-156.73	--	--	-2.51%
			19	0.00	0.00	-151.57	0.00	0.00	-157.02	--	--	-3.47%
k	Br1 [43]	XD	1	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
		YD	1	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--
			15	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--

## **Chapter 5**

### **Functionality and Usability**

In Chapter 5, an evaluation of the functionality and usability of the software is presented. A program with good functionality is one which has sufficient functions, commands and utilities to allow the user to efficiently perform all required tasks. A program with good usability is one which has functions, commands, and utilities that are easy to understand and use. The software should provide the ease and flexibility of performing any task, at any stage of its execution. Usability depends on various factors such as the user interface and the pre- and post-processors.

The MicasPlus software provides better functionality and usability compared to STAAD III and GTSTRUDL. It has the best user interface and is very user-friendly. The graphical user interface(GUI) provides a visual representation of most of the entities needed for modeling a structure such as physical members, analytical members, nodes, loads, and boundary conditions. Most of the interactions between the user and the software can be done graphically, among them placing members, applying loads, setting boundary conditions, etc. This provides the user with instant visual verification (feedback). This method of structural modeling is more efficient than the textual input methods used by GTSTRUDL and STAAD III. MicasPlus also has very good pre- and post-processors which provides many features and sufficient flexibility. The structural modeling, analysis, design, and drawing creation features are very well integrated and easy to use.

## 5.1 Functionality

Of the three programs studied, MicasPlus seems to have some of the best features and functionality. It has the best graphical user interface with good pre-and post-processors. The integration between modeling, analysis, design and drawing is much better than the other two programs.

A few of the useful functions available in MicasPlus are listed below:

1. Graphical display of node coordinates of a structure.
2. Graphical display of the magnitude of selected loads, their direction, and the load case to which they belong.
3. Access to steel and concrete modules of MicasPlus from within the analysis modules and vice versa.
4. The ability to re-sequence and compress user ID numbers for members in a structure.
5. Graphical display of shear and bending moment diagrams.
6. Inquire and Criteria commands in the design module for assigning design parameters to the members.
7. The 'Trouble Reports' documentation and the features in the readme file, though not be complete, are amongst the best when compared to other similar programs.
8. The ability to place area loads.
9. The seed files, the 'Parametric Modeling Language' and other parameter files which provide the ability to customize the software for any given industry

Some of the functions or functionality which could be improved or added to Micas-Plus are listed below.

1. An 'undo' feature is needed in MicasPlus Analysis module similar to the 'undo' command in Modeldraft.
2. There is no capability for changing the physical user ID number in MicasPlus Analysis, similar to the existing capability for changing the analytic user ID number of a member.
3. A warning message should appear when the 'Exit' button is selected. This would prevent the user from accidentally exit the program without saving the current results.
4. The commands for manipulating and modifying a structure in Modeldraft need to be modified since they are complex and difficult to use. The corresponding commands in the Analysis module are relatively simple and easy to use.
5. ModelDraft has a set of five active parameter tutorials which need to be setup before modeling any structure. It is necessary to save the active parameters after setting them and before exiting ModelDraft otherwise the settings are lost. MicasPlus should warn the user to save the active parameters prior to exiting the program.
6. The program should provide a warning when a change is made to the structural model that would cause instability in the structure during analysis such as when the 'Rx' and 'Ry' degrees of freedom are released instead of 'Ry' and 'Rz' at both ends of a beam. Releasing the 'Rx' degree of freedom will release the torsional restraint in the beam and make it unstable.
7. Instability in the structure during analysis can be caused due to many reasons. Although MicasPlus gives an error message it would be helpful if the message

were more specific about the location and the reason of instability in the structure.

8. MicasPlus Design allows the user to either input the effective length factors for members or let the software calculate them. For some reason, the software calculates erroneous values of effective length factors for columns. Hence the user needs to be careful and should not let the software calculate the effective length factors.
9. The format of the MicasPlus Analysis and Design output is different when compared with other software. Since MicasPlus uses many more parameters to model, analyze, and design a structure, its output lists all those parameters which makes it lengthy and some of this information is not very useful. The program should allow the user to select the information to be printed and its format.
10. A 'Rebuild Database' feature should be available in the graphical user interface as is available in the alphanumeric interface of MicasPlus.
11. It is difficult to determine the name of the seed files used for a particular project. Therefore the user should carefully record the seed files used in case so that they can be used again for a similar project.
12. There is no capability for renaming the structural models or projects once they have been created. The only way to rename projects and models in the present version is by copying the models or projects to the new names and deleting the old ones.
13. There is no warning message when the body load (self weight) is placed on the same member twice.

## 5.2 Usability

The graphical user interface together with good pre-and post-processors make MicasPlus a flexible and an easy to use program. Compared to GTSTRU DL and STAAD III, it does not have a fixed and rigid sequential input format thus providing considerable flexibility and freedom. The "pull-down" and "pop-up" menus provide immediate access to the numerous commands. Also, a minimum amount of typing is required by the user which saves time and reduces the number of typing related errors.

MicasPlus has many commands and features thus it takes more time to learn to use the program, but the effort seem to pay off in the long run. For an experienced user, a program with many functions and features makes his/her task easier, whereas for a beginner, the software would seem complicated and cumbersome. Moreover if a beginner is not familiar with the graphical user interface and the 3-dimension concept he/she would need extra time to get familiar with the software.

A few points that may help in using MicasPlus more effectively are listed below.

1. Setup seed files before starting on any project. Seed files save the time required to change default parameters at different stages of every project. Parameters such as steel tables, cardinal points, color and levels for members, loads, and labels, load cases and combinations, mark groups, can save a lot of time since they can be the same for most projects. Seed files also help achieve uniformity between various projects.
2. Change the 'Number of VMD (Shear and Moment Diagram) Segments' default parameter, in the Analysis module, to preferably between 8 and 16 for beams and columns.



During analysis, every span of a member is divided by the number of VMD segments. The stresses in a member are stored at these points which are used later on, among other things, for designing the member. Therefore, in case of a member where the maximum stresses could occur at any point along its length, it would be preferable to have maximum number of sections to get as close as possible to that maximum stress point and use the maximum stresses for the design.

3. In the analysis module, individual colors and levels can be assigned to different load cases and to the various type of labels. This helps in group manipulation of loads and printing of labels.
4. Use the 'saved views' command to save different views of a model. In case of large models, saved views are very helpful in viewing certain portions of the model very often when the need arises.
5. It is very useful to make backups at different stages of a project in order to retrieve the project saved at any particular stage. For example, backups should be made after modeling in ModelDraft, after reading the model into the Analysis module and just before performing the analysis, and definitely before using an unfamiliar model manipulation command. It is also very helpful to try the major manipulations on a copy before performing them on the original project.
6. MicasPlus provides a 'Readme' file and a 'Trouble' report which lists the problems and deficiencies of a given version and also the improvements made in the current version.
7. Each time an analysis is performed on a model, MicasPlus generates two types of output files, \*.pd\* and \*.ptr. These output files keep on accumulating each time

a new analysis is performed. Therefore, if the previous analysis output is no longer required, it is desirable to eventually delete the unwanted output files since they occupy a lot of valuable disk space.

8. In many structures the use of MPA locks may be inevitable when two members cross each other without forming an analytical node at their crossing. An example is the case of horizontal floor bracing where the bracing member passes below the floor beams without forming a connection with them. The formation of a node at the crossing of the members can be avoided by manipulating the MPA locks.
9. The associative and the non-associative move, and other manipulation commands in MPA should be used with care while using them with the 'Fence' command and with different MPA lock settings. The commands will produce different results when used with the fence overlap lock 'ON' and 'OFF' and for different MPA lock settings. It is desirable to check the fence and the MPA lock settings, every time, before using the manipulation commands. Also, since MPA does not provide an undo feature, it is desirable to keep the 'Tentative move' option 'ON' while using the move commands.
10. The 'Rebuild Database' command in the Alphanumeric interface of the Analysis module is useful in verifying the completeness and correctness of a model. It is possible that member data for some members may be incomplete or wrong or, may be a member is modeled incorrectly. This will cause the analysis module to stop analyzing the model and list error messages. These messages are sometimes not very explicit about the cause of the errors. In such a case, the 'Rebuild Data-

base' command can be used which may delete the members causing the problem. The 'Rebuild Database' command will also create an error log file with the name <Model name>.msg, in the analysis file's directory, to list the reasons causing the problems.

11. The three most common reasons which cause instability in a structure during analysis are:

- a Too many releases in a member. The most common, for example, is the cantilever beam with the its 'Ry' (rotation in its weak axis) degree of freedom released at its support end.
- b One end of a member disconnected from the structure. This usually happens when the user snaps to a graphical element other than the node while placing a member.
- c An analytical element not split into two at a location where another member was placed on it. This situation arises when the 'Automatic member split' MPA lock is set to 'Off' setting while placing the second member. In this case the second member is theoretically not connected to the first member causing instability during analysis. To avoid this situation it is a good practice to check the MPA lock settings from time to time.

If a structure does become unstable during analysis, the following three ways can be used to detect the problem.

- a Check the member end releases,
- b Use the 'Rebuild Database' command to eliminate defective members and

to create the error log file.

- c Specify 'fixed support node' boundary condition for all nodes in the structure. Now delete the boundary condition for few nodes and analyze the structure. Repeat this process until the structure becomes unstable during analysis. Thus the nodes released just before the last analysis may be the cause of the instability.
12. The analysis and design parameters in MicasPlus are assigned, depending on its type, to a physical member, or an analytical member, or a span of a member. For example, the end releases are assigned to a physical member where as the number of VMD segments are assigned to a span of a member. An understanding of the above feature for different parameters is necessary for the correct modeling of the structure
13. To perform an independent member and a mark group design together on a structure, the user needs to assign certain design parameters, such as the alternate section criteria, to both the independent members and the mark groups separately to obtain the desired results.
14. It is very important to execute a selected primary command completely before selecting the next primary command in order to avoid confusion in the execution of the two the commands. In some cases, selection of another primary command while still executing the previous one can cause error and can even hang up the workstation.
15. In the Alphanumeric interface of MicasPlus, the 'Return' key on the key board is

often substituted by the `Enter' key. Therefore, while in the Alphanumeric interface, the user should try to use the Enter key whenever the Return key does not respond.

16. In the Analysis module, while using the PSD read-write tutorial the program asks for the model type to read and write from. While reading the PSD the model type should be `Analysis model' type and while writing the PSD the model type should be `ModelDraft model'.

## Chapter 6

### Summary and Conclusions

#### 6.1 Summary

A study was performed to verify the accuracy and evaluate the functionality of three structural analysis and design programs. The programs that were studied were MicasPlus, GTSTRUDL and STAAD III. The verification was based on a comparison of results obtained for several steel space frames. Nine different variations of three basic frames a) a frame with moment resisting connections, b) a frame with X-bracing and, c) a frame with Chevron bracing were considered. The different cases were formed by changing modeling, analysis and design parameters. The factors considered in the comparison included support reactions, member forces, displacements and member sizes.

##### 6.1.1 Analysis Results

A summary of the differences in the analysis results obtained from MicasPlus and STAAD III is given in the table that appears on the next page. Cases 1, 4, 5, 6, and 7 were used to determine the percentage differences in analysis results between MicasPlus and STAAD III.

##### 6.1.2 Design Results

Cases 8 and 9 were used to compare the design results between MicasPlus and GTSTRUDL. The design results did not match exactly for all the members, but were very

close. For example, section sizes selected for some members by one program were the next best available section size selected by the other program. For both programs, the designs converged in three cycles.

<b>Case</b>	<b>Response</b>	<b>Maximum Percentage Difference</b>
Case 1. Analysis models built in Micas-Plus Analysis and STAAD III	Support reactions	0.01%
	Displacements	3.7%
	Element end actions	2% to 17%
Case 4. Global rigid end offset from cardinal point option specified in MicasPlus for models of Case 1	Support reactions	0.95%
	Displacements	3.5%
	Element end actions	4.0%
Case 5. Rigid end offset to centroid for bracing members only specified in MicasPlus for models of Case 1	Support reactions	0.87%
	Displacements	5.0%
	Element end actions	2.6%
Case 6. Ends of bracing members of Case 5 were fixed.	Support reactions	less than 5%
	Displacements	less than 5%
	Element end actions	less than 5%
Case 7. Rigid end offset to centroid for beams only specified on Micas-Plus for models of Case 1.	Support reactions	less than 5%
	Displacements	less than 5%
	Element end actions	less than 5%

### 6.1.3 Parametric Study Results

Cases 4, 5, 6, and 7 were used to study the effect of changing parameters on the analysis results. Results from MicasPlus for the above cases were compared with those for Case 1 also from MicasPlus. Results of the moment resisting frame for Cases 4 and 7 differed with Case 1 by less than four percent. The differences in the results are summarized below.

<b>Case</b>	<b>Response</b>	<b>Change</b>
Case 4 versus Case 1. In Case 4 global rigid end offset was specified from cardinal point.	Translations	8% to 25%
	Rotations	from 0 degrees to 8 degrees
	Element end actions	1% to 50%
Case 5 versus Case 1. In Case 5 global rigid end offset specified for bracing members only.	Translations	68% to 125%
	Rotations	from 0 degrees to 10 degrees
	Element end actions	10% to 100%
Case 6 versus Case 1. In Case 6 ends of bracing members of Case 5 were fixed.	Translations	6% to 12%
	Rotations	from 0 degrees to 1 degree
	Element end actions	5% to 20%
Case 7 versus Case 1. In Case 7 rigid end offsets were specified for beams only. .	Translations	7% to 14%
	Element end actions - beams	Reduced by about 3%
	Element end actions- columns	No noticeable change

#### **6.1.4 Integration Between Various Modules of MicasPlus**

Case 2 was used to verify the integration between MicasPlus ModelDraft, the Project Structural Database (PSD) and MicasPlus Analysis. In Case 2, the Models of Case 1 were built in ModelDraft and transferred to the analysis module and analyzed. There was no difference between the results of Case 1 and Case 2. In Cases 8 and 9 the models were analyzed and designed alternately for five cycles successfully in MicasPlus verifying the integration between its analysis and design modules.

#### **6.1.5 Functionality and Usability**

Overall, MicasPlus has good functionality and usability compared to STAAD III and



GTSTRUDL. MicasPlus uses a graphical user interface, has good pre- and post-processors, and is user friendly.

## **6.2 Conclusions**

From the comparison of analysis and design results, it can be seen that analysis results vary by as much as five percent for larger values and that sections selected are very close but not same. It is proposed that members be designed for at least five percent less than their maximum allowable stress to account for the above inaccuracy in results obtained from computer software. The above results can then be considered acceptable. From the parametric study it is seen that the results are very sensitive to changes in parameters. This highlights the importance of correct modeling of the structure. The results for Cases 2, 8 and 9 demonstrate the complete integration between the Modeldraft, Analysis and Design modules of MicasPlus. MicasPlus has better functionality and usability compared to STAAD III and GTSTRUDL.

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## Vita

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A handwritten signature in black ink, appearing to read "D. R. Divecha", written in a cursive style with a horizontal line underneath.