APPLICATION OF THE 13TH EDITION AISC DIRECT ANALYSIS METHOD TO HEAVY INDUSTRY INDUSTRIAL STRUCTURES

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APPLICATION OF THE 13TH EDITION AISC DIRECT ANALYSIS METHOD TO HEAVY INDUSTRY INDUSTRIAL STRUCTURES

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

The objective of this study was to understand and develop procedures for the use of the AISC 2005 Specification's Direct Analysis Method for the analysis and design of heavy-industry industrial structures, to layout a systematic approach for the engineer to analyze and design using this method, and to determine if there will be any consequences to the practicing engineer in using this method.

The relevant 13th Edition AISC stability analysis methods (Effective Length, First-Order, and Direct Analysis Methods) were researched in the 2005 Specification as well as in available technical literature, and then were critically evaluated by their applicability and limitations.

This study will help serve as a guide for the systematic approach for the practicing engineer to apply this method to analyze and design such complex steel frame structures using the computer-aided software called GTSTRUDL. To accomplish this purpose, two analytical models were studied using the Direct Analysis Method. The first model was a simple industrial structure and the second model was a more complex nuclear power plant boiler building.

CHAPTER I:

INTRODUCTION

1.1 Purpose and Objectives

The purpose of this study was to understand and develop procedures for the use of the AISC 2005 Specification's [1] Direct Analysis Method for the analysis and design of heavy-industry industrial structures, to layout a systematic approach for the engineer to analyze and design using this method, and to determine if there will be any consequences to the practicing engineer in using this method.

The relevant 13th Edition AISC stability analysis methods (Effective Length, First-Order, and Direct Analysis Methods) were researched in the 2005 Specification as well as in available technical literature, and then summarized. The limitations and inapplicability of the approximate Effective Length and First-Order Methods are given, which leads the engineer to use the rigorous Direct Analysis Method which is the only applicable method of nonlinear analysis and which is far more accurate when compared to the other approximate methods.

To accomplish this purpose, an analytical approach was coupled with a review of technical literature. GTSTRUDL, a computer-aided structural engineering program which excels in the analysis and design of structures, was used to create, analyze, and design the industrial structure models in this study. Two models were studied using the Direct Analysis Method. The first model was a simple industrial structure and the second model was a more complex nuclear power plant boiler building.

1.2 Motivation

In the engineering profession, complicated steel frame structures with significant loadings are being designed by practicing engineers for strength and stability of the system. The 13th Edition AISC and its 2005 Specification contains approximate methods (Effective Length and First-Order Methods) to analyze the stability of a structure. Traditionally, the Effective Length Method, which is based on a first order linear elastic analysis, has been used to conduct a stability analysis. However, both the Effective Length and First-Order methods operate under idealized assumptions and have many limitations and restrictions associate with them. For example, if a steel frame structure does not behave under its design load conditions in a manner that is the same as, or nearly the same as the behavior of the excessively simplified structure models upon which the formulation of the approximate methods is based, then the approximate methods are simply not applicable. Therefore, these methods are not suitable when designing more complex structures for stability, such as those found in heavy industry, which fall outside the limitations of the Effective Length and First-Order approximate analysis methods. The Direct Analysis Method (i.e., hereinafter referring to as a nonlinear geometric elastic analysis) must be used when the limitations of the approximate methods are not met. Therefore, the Direct Analysis Method was used to analyze the analytical models of this study. However, many experienced structural engineers have not been introduced to the Direct Analysis Method and how to implement it in the analysis and design of large and complex industrial structures. This study will help serve to give a systematic approach for the practicing engineer to apply this method to analyze and design such complex steel frame structures using computer software.

Benchmark studies that have been conducted on the Direct Analysis Method have been for smaller more idealized academic structures such as a cantilever compression column with a lateral load at the top of the column and a simply-supported beam-column under uniform transverse loading, both of which are found in the 13th Edition AISC Commentary [1], as well as excessively simplified plane and space frames with highly regular geometries, loading conditions, boundary conditions, etc., none of which represent the behavior of industrial steel frame structures. A conclusion that the Direct Analysis Method is valid for general frame structures cannot be made from studies on the behavior of such excessively simplified structure models.

Rather, this purpose of this study is to understand the use of the Direct Analysis Method for the analysis and design of more complex structures found in heavy industry. The two structural models used in this study were a small industrial structure and a more complex nuclear power plant boiler building.

1.3 Outline of Report

The specific components of this report are described below.

Chapter 2 presents a review of the technical literature of designing for stability using the 13th Edition AISC 2005 Specification.

Chapter 3 provides an introduction to the computer-aided structural engineering program GTSTRUDL which was used in this study. The general implementation procedure for analyzing and designing structures using the Direct Analysis Method and GTSTRUDL is mapped out for the reader.

Chapter 4 presents the first analytical model that was studied using the Direct Analysis Method approach for designing for the strength and stability of a structure. The first model was a small industrial structure that was studied with and without smoothing, as well as what impact the addition of a node at mid-column of each column would have on the stability of the structure.

Chapter 5 presents the second analytical model studied using the Direct Analysis Method approach. The second model studied was a nuclear power plant boiler building that was far more complex than the first model.

Chapter 6 summarizes the significant conclusions of this study and provides recommendations for future research.

CHAPTER II:

LITERATURE REVIEW

2.1 Design Using the 13th Edition AISC Specifications

The 13th Edition (2005) AISC Specification was used in this study to explore the stability of steel frame building structures, and particularly how the Direct Analysis Method is applied to industrial structures. This chapter assumes the reader is familiar with the 13th Edition AISC Specification and how to design for strength and stability; therefore, only a very brief overview of stability analysis and design provisions is given. The three methods of stability analysis given by the 2005 Specification: the Effective Length, First-Order, and Direct Analysis Methods, and their limitations are explained within this chapter.

2.1.1 Design for Stability

Stability has become a major concern when designing steel frame structures. A structural instability is defined as a structure or a structural component's inability to resist applied loadings in the deformed state of the structure or any of its component parts. A first-order analysis is simply not sufficient to design for stability for any but the simplest of structural configurations and applied loads and thus a second-order nonlinear geometric analysis is required [4].

2.1.1.1 General Requirements

To design for strength and stability in a structure, stability of the structure as a whole as well as strength and stability of each of its components must be provided [1]. When designing for the stability of a structure, the following considerations are mandatory:

1. The influence of second-order effects (P-Δ and P-δ effects),
2. Nonlinear geometric axial, biaxial shear, torsion, and biaxial bending deformations of members, and nonlinear geometric deformations of finite elements,
3. Geometric imperfections (initial out-of-plumbness) due to construction procedures,
4. Member stiffness reductions due to residual stress, and
5. All component deformations that contribute to the nonlinear geometric behavior of the structure.

To provide individual member strength and stability, the provisions of the AISC 13th Edition 2005 Specification must be satisfied [1].

The overall stability of the system is supplied by the type of structural system provided and which are listed below:

1. Braced-frame and shear-wall systems - the lateral stability of the structure is provided by diagonal bracing or shear walls.
2. Moment-frame systems - the lateral stability is provided by the flexural stiffness of connected beams and columns.
3. Gravity Framing Systems - the lateral stability is provided by moment frames, braced frames, shear walls, or equivalent lateral load resisting systems.
4. Combined Systems - combination of the above systems where requirements must be met for the respective systems.

2.1.1.2 Two Types of Analyses

A first-order elastic analysis is performed on the basis of the undeformed configuration of a structure. The material of the structure under a first-order elastic analysis is assumed to act in a linear-elastic manner. The loads and displacements are understood to have a linear relationship [12]. A first-order elastic analysis however, cannot be used for an accurate stability design of a structure; a second-order elastic analysis is necessary for such a solution.

A second-order elastic analysis is far more accurate than a first-order elastic analysis in the design of a frame for stability. In a second-order elastic analysis, both displacement compatibility and force equilibrium must be satisfied using the deformed configuration of the structure. In addition, the material of the structure is assumed to behave linear-elastically [12]. The second-order elastic analysis must account for the P-Δ and P-δ effects. The P-Δ effects are the effects of gravity loads, P, acting on the relative transverse displaced location of the joints, or the member ends, causing additional forces beyond those computed in a linear elastic analysis. The P-δ effects are the effects of compression axial forces acting on the flexural deflected shape of the member between its ends. These transverse displacements are relative to the member chord which runs between member ends, and causes an additional P-δ moment [10]. The P-Δ and P-δ effects are illustrated in Figure 1.

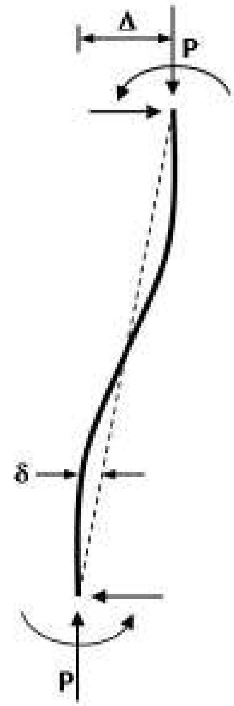

Figure 1: P-Δ and P-δ effect on a beam-column

2.2 Stability Design Methods in the 13th Edition AISC 2005 Specification

The AISC 13th Edition 2005 Specification has significant changes from previous AISC Specifications pertaining to the provisions for stability analysis and design [2]. In the 1989 AISC LRFD Specification, overall system stability is not directly checked using the interaction equations H1-1a and H1-1b in Chapter H of the Specification. The system is assumed to be stable if the most critical member within the system does not fail the beam-column strength checks [15]. The traditional approach found in previous AISC Specifications was modified and is now referred to as the Effective Length Method. One alternative to this approach is the First-Order Analysis Method which focuses on using a first-order elastic analysis to design frames [2]. The Effective Length Method and the First-Order Analysis Method are considered indirect methods of stability design, and are used when the second-order effects on a structure are not very large and may be ignored

[13]. A more rigorous and versatile alternative approach to the Effective Length Method was introduced in the 2005 AISC Specification and is referred to as the Direct Analysis Method [2].

2.2.1 Effective Length Method

The Effective Length Method is the traditional analysis procedure and is based on a first-order analysis of an elastic structure using nominal geometry and nominal elastic stiffness (EI, EA) [1]. The Effective Length Method is an approximate method that is derived from elastic buckling theory, and uses effective buckling lengths rather than the actual unbraced lengths of the column members [9]. The effective length factor, K, must be computed to determine the effective buckling lengths and then calculate the column strength. The residual stress and geometric imperfections which affect the stability of the structure are accounted for indirectly in the interaction equations through magnification factors. There are limitations using this approach, namely that the Effective Length Method can underestimate the internal forces within members. For example, important initial imperfections, like out-of-plumbness and residual stresses in the members, will increase the magnitude of load effects more than those predicted by this traditional method [2]. For instance, there will be additional internal moments due to initial imperfections and the amplification of these imperfections by second-order effects, will not be determined by this method [15]. To address this limitation, the 2005 AISC Specification restricts the use of this method to frames in which the ratio of the second-order drift to the first-order drift is less than or equal to 1.5 [2].

However, to determine if the frame meets this drift requirement and thus determining if the approximate analysis methods are applicable, a second-order analysis must be conducted. If a second-order analysis must be performed in order to determine if the Effective Length Method is applicable to a structure, the author fails to see how this method will save the engineer computational time or make the analysis simpler. Additionally, every time a change is made on the structure, such as a change in loading or geometry, a new second-order analysis must be performed. For any given structure, during the design process a multitude of changes are possible and probable, therefore multiple second-order analyses must automatically be conducted to determine if the use of an approximate method is valid.

To determine the K factors for the frame members, the alignment charts found in the AISC 13th Edition Commentary are used. The alignment charts and equations are only valid for structures whose behavior is similar to the behavior for which the alignment charts are based. They were formulated on the basis of highly idealized conditions that seldom exist in real-world heavy industry industrial structures. For a braced frame the determination of the K factor is based on a few assumptions. First, all members are prismatic and behave elastically. Second, the axial forces in the beams are considered negligible. Third, buckling occurs simultaneously for all columns within a given story. Fourth, at any given joint the restraining moment imposed by the beam is distributed to the columns proportional to the column stiffnesses (EI/L). Lastly, the girders are bent in single curvature, meaning the rotations at one end and the other end of the girders are equal and opposite in direction [4]. For an unbraced frame the assumptions for the determination of the K factor are the same with one exception; at buckling the girders are bent in double curvature rather than single curvature as was the case of the braced frame. When the girders are bent in double curvature, the rotations at both ends of the girders are equal in magnitude and direction [4]. Additionally, for both a braced and unbraced frame, the beam-column connections are assumed to be fully restrained (FR) connections. A beam's end condition may not be a FR connection, but rather behave more like a partially restrained (PR) connection, and thus adjustments must be taken into account.

The 13th Edition AISC Commentary comments on the assumptions of these highly idealized conditions as follows:

> "It is important to remember that the alignment charts are based on the assumptions of idealized conditions previously discussed and that these conditions seldom exist in real structures. Therefore, adjustments are required when the assumptions are violated and the alignment charts are still to be used."

As mentioned in the quotation excerpt above, adjustments must be made to the calculations for the relative stiffness factor, G, if the idealized conditions are not met. The code is suggesting that adjustments or approximations must be made to previous assumptions. This makes no sense since it implies that the Effective Length Method is applicable to general structures by replacing new assumptions with old assumptions. There is no reason to believe that any assumptions regarding the stability behavior of members in general industrial structures are sufficiently valid to justify the use of the K factor alignment charts. Thus the need for a more rigorous nonlinear geometric analysis that is far more accurate for the prediction of stability.

In addition to all of the assumptions made when developing the alignment charts, there are other major limitations to the Effective Length Method approach. One limitation is that the method does not give an accurate indication of how the members interact within the structural system directly; rather the effective length factor K is used to predict this interaction. The failure mode of the structure is assumed to be an elastic buckling mode which is the basis by which the K factor is determined; however the actual failure mode of a structure may not be elastic and therefore the strength and stability of the structure cannot be accurately described. Probably the most serious limitation of the Effective Length Method is the two-stage design process. In this two-stage process, a linear elastic analysis is used to calculate the forces acting on individual members within the structural system and an inelastic analysis is used to determine the strength of these members. There is no way to guarantee the compatibility between the isolated members and the structural system as a whole, and thus there is no way to verify whether the members can sustain the design loads [3]. Another less fundamental limitation to this method is the difficulty in calculating the K factor for each of the isolated column members; "engineering judgment" must be used when calculating these K factors [15]. The K factors must be determined for each of the column members, which in large industrial structures can be quite numerous, making it totally impractical for a computer-based design. The majority of present design procedures are computer-based, so a more computer efficient method that can be competitive in engineering practice must be implemented [3].

Considering all of the idealized assumptions and limitations of the Effective Length Method, this method cannot be considered as "generalized"' for steel frameworks. The Direct Analysis Method was introduced in the 2005 AISC Specification as a more versatile and accurate approach in engineering practice.

2.2.2 First-Order Method

One of the alternative approaches to the Effective Length Method is the simplified first-order method given in 13th Edition AISC Specification Chapter C, Section 2.2b [2]. This method uses the nominal member sizes and stiffnesses to complete a first-order linear elastic analysis. A value of K = 1 for the effective length factor is permitted when the First-Order Analysis Method is used, however there are important restrictions as to when the method may be used. One restriction is that the ratio of first-order drift to second-order drift must be less than or equal to a value of 1.5, just like the requirement for the Effective Length Method [1]. Again, a second-order analysis must be conducted each time a change is made to the structure to see if an approximate method is valid; therefore the engineer is not saving any time by doing the approximate First-Order Method because a second-order analysis is required to check the drift requirement. Additionally, the required compressive strength of all members that contribute to the lateral stability of the structure must be less than half of the yield strength of the members [1].

Like the Effective Length Method, the restrictions that the First-Order Method operates under are highly ideal conditions that rarely exist in industrial structures. When these restrictions cannot be met, the Direct Analysis Method should be used for both the stability and strength design of such structures.

2.2.3 Direct Analysis Method

The AISC 2005 Specification gives two options to perform the direct analysis method: an approximate first-order analysis method using the B_1 and B_2 force magnification factors or a rigorous second-order analysis method.

2.2.3.1 Approximate Direct Analysis Method Using B_1 & B_2 Force Magnification Factors

The 2005 Specification permits an approximate second-order analysis to be conducted by using the B_1 and B_2 force magnification factors to scale the forces from a conventional first-order analysis. The following is an excerpt from the 2005 Specification:

> "It is permitted to perform the analysis using… the first-order analysis method of Section C2, provided the B_1 and B_2 factors are based on the reduced stiffnesses defined in Equations A-7-2 and A-7-3." [1]

The flexural and axial stiffness reductions for the members are accounted for in the approximate force magnification factors. However the B_1 and B_2 force magnification factors are only accurate if the structure behaves in the same manner as the behavior of the highly simplified structure models upon which the formulation of the force magnification factors are based on. Additionally the AISC 2005 Commentary states:

> "Methods that modify first-order analysis results through second-order amplifiers (for example, B_1 and B_2 factors) are in some cases accurate enough to constitute a rigorous analysis." [1]

This author disagrees strongly with the above statement in the context of any but the most simple of structural configurations where second-order effects are completely negligible. Using approximate force magnification factors does not constitute a rigorous second-order analysis because the B_1 and B_2 factors are formulated using excessively simplified models that do not reflect the behavior of general steel frame structures, particularly industrial structures.

2.2.3.2 Rigorous Direct Analysis Method

The Direct Analysis Method was introduced in the 13th Edition AISC 2005 Specification in Appendix 7 as a more rigorous analysis method capable of more accurately predicting stability of steel frame structures. Unlike the Effective Length Method, the First-Order Analysis Method, and the B_1, B_2 Force Magnification Method all of which have substantial limitations, the Direct Analysis Method is applicable to all structures [14]. The Direct Analysis Method accounts for geometric imperfections and stiffness reductions directly in the analysis [2]. The Direct Analysis Method more accurately determines the load effects in the structure and eliminates the need for K factors. This method can be used to design all types of steel framed structures including braced, moment, and combined framing systems. Additionally, the Direct Analysis Method is far more versatile in that an elastic or an inelastic analysis can be performed [1].

Requirements are placed on the Direct Analysis Method to accurately calculate the second-order effects. The first requirement is that a rigorous second-order analysis that accounts for both the P-Δ and P-δ effects must be conducted. The second requirement is on the initial imperfections such as the out-of-plumbness of columns which can be accounted for by either directly modeling these imperfections or by applying notional loads based on the nominal geometry of the structure. Notional loads are used to represent the effects of initial out-of-plumb imperfections due to construction tolerances [14]. The third requirement is that the analysis is conducted using reduced stiffness, both flexural (EI*) and axial (EA*). Reducing the stiffness of the members accounts for the possibility of yielding in slender columns or inelastic softening in intermediate or stocky columns. The flexural stiffness reduction is used for all members whose flexural stiffness is considered to contribute to the lateral stability of the structure. Similarly the axial stiffness reduction is applied to all members whose axial stiffness contributes to the stability [1]. Applying these stiffness reductions to only some of the members can cause artificial distortions of the structure under the imposed loadings, possibly causing redistribution of forces; to avoid this, the stiffness reductions can conservatively be applied to all members in the structure [14].

Second-order effects are highly nonlinear and therefore superposition principles are not valid for a second-order analysis. Due to the nonlinear behavior, a second-order analysis is required to be carried out for each applicable load case [2]. In a large industrial structure, the load cases can be quite numerous and performing a nonlinear analysis for each load case can become quite cumbersome. This study focuses on a rigorous second-order analysis using the Direct Analysis Method in an efficient manner. Two models: a simplified industrial structure and a nuclear power plant boiler building are analyzed and designed by using a combination of traditional linear elastic stiffness analyses and rigorous nonlinear elastic analyses. This study aims to demonstrate the cycling process required of the engineer to analyze and design by the 13th Edition AISC 2005 Specification for strength and stability of a steel frame structure.

CHAPTER III:

IMPLEMENTATION PROCESS

The objective of this chapter is to present in detail the sequential process necessary to analyze and design a heavy industry industrial structure using the 13th Edition AISC 2005 Specification Direct Analysis Method as implemented in GTSTRUDL. A brief overview of the structural engineering software system GTSTRUDL is given first. Then each step in the sequential process is explained in detail.

3.1 Overview of GTSTRUDL

GTSTRUDL (Georgia Tech Structural Design Language) is a structural engineering software system that aids engineers in designing and analyzing a wide range of structures. The engineer can create a highly detailed model of the structure using GTSTRUDL, and perform static, dynamic, linear, and nonlinear analyses. GTSTRUDL contains two powerful interfaces between the user and the software. One such interface is the graphical user-friendly interface called GTMenu which allows the user to visually create the structure and apply its geometry, member properties, loading conditions, and other important modeling properties using pull-down menus and graphical tools. The other interface is a command driven text and menu oriented interface in which the user can directly specify commands using standard structural engineering vocabulary. GTSTRUDL has a unique ability to process multiple text files and user-data files which allow the engineer to better organize and access information. The output that is important to the engineer such as support joint reactions, joint displacements, and internal member section forces, are reported in a user-friendly and highly orderly fashion and can be either displayed on an interactive graphical interface or written to a text file for later review [6].

3.1.1 The Use of GTSTRUDL in this Study

The computer software GTSTRUDL was used to design the two models explained in Chapters 4 and 5 of this report for the stability and strength design of steel frame structures by using both linear elastic and nonlinear elastic analysis computations. The nonlinear analysis utilizes the Direct Analysis Method specified in the 13th Edition AISC 2005 Specification. The command driven interface was used in this study to create sequential files to create the model, form load combinations, perform linear elastic and nonlinear elastic analyses, and design and code check all members. The text input files are set-up so each step of the mapped out sequential process is a separate file to make the process extremely clear to the engineer and to ease the ability of manipulating all required information.

Quantities of steel (total weight) were output after each design was performed. These results were tabulated and compared to illustrate how the process of designing in accordance to the 2005 Specification proceeded.

3.2 Explanation of Flow Chart Sequence

Figure 2 shows a flow chart which maps out the sequential process to analyze and design an industrial structure pursuant to the 13th Edition AISC 2005 Specification, and based on the rigorous Direct Analysis Method. The process of designing these models for stability is highly iterative involving both linear analysis and code checks as well as nonlinear analysis and code checks. This process is cycled through until the lightest weight stable design is found for the structure in question. The flow chart is explained in detail as follows:

Step-by-Step Analysis and Design Process

The actual files names to implement the sequences for the two models can be found in Chapters 4 and 5 of this report. Chapter 4 gives the command file sequence for the simple industrial structure and Chapter 5 gives the command file sequence for the more complex nuclear power plant boiler building.

The square dashed box in the flow chart (Figure 2) describes the traditional iteration of the analysis and design method for strength and stability design using a linear elastic analysis. This process can be described as follows:

Linear Elastic Analysis:

1. Define Model: Defines all model attributes to be analyzed and designed including the geometry (joint coordinates), topology (member incidences), member and material properties, load conditions and independent design load conditions.

2. Linear Stiffness Analysis: Performs a traditional stiffness analysis based on linear elastic analysis. The linear elastic analysis results are used to perform a preliminary design for the structural model.

3. Select All Members: Design lightest weight shapes for strength and stability pursuant to the 13th Edition AISC 2005 Specification based on results from first linear elastic stiffness analysis (step 2).

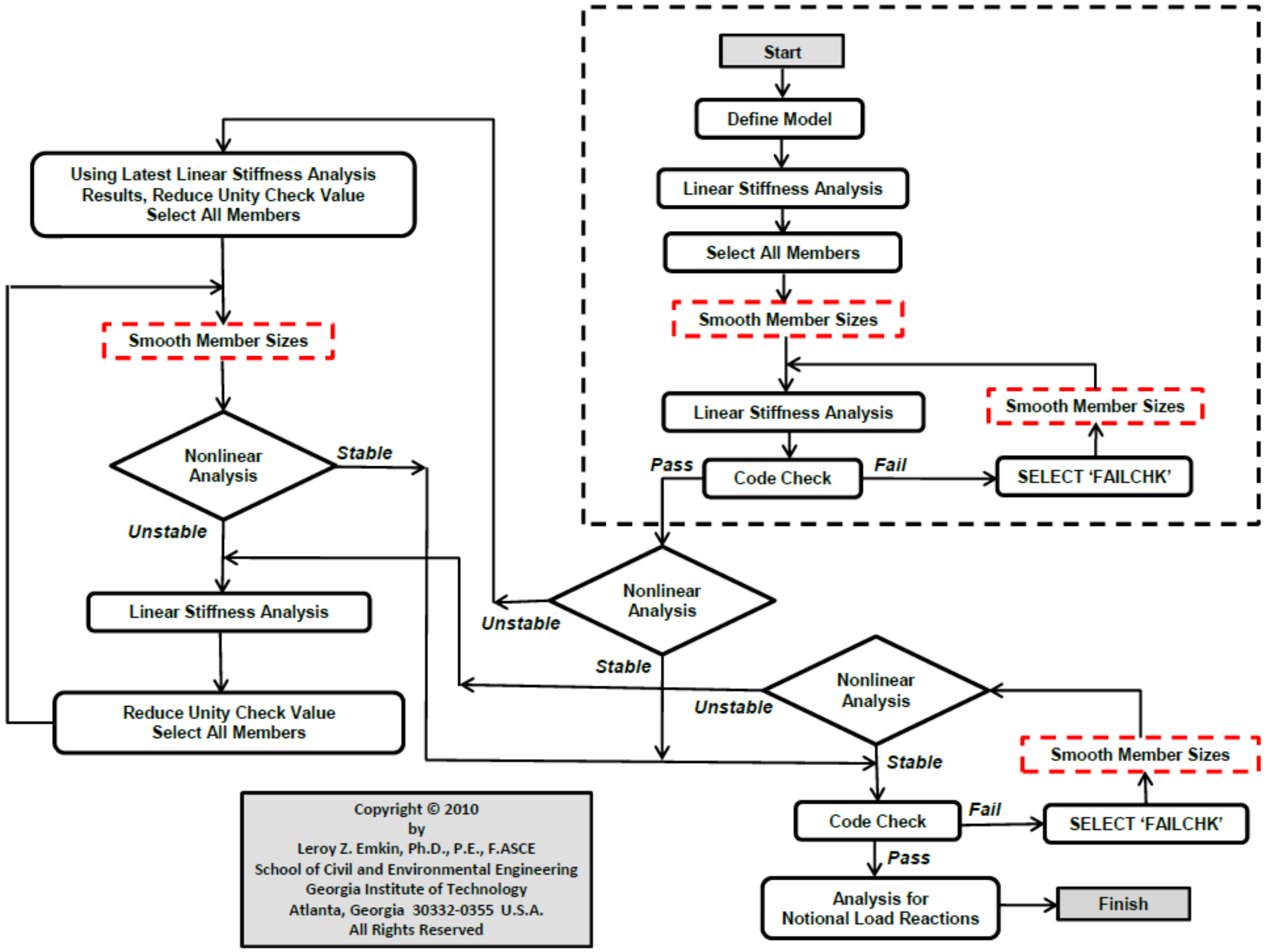

Figure 2: Flow Chart of Sequential Implementation Process [11]

4. Smooth Member Sizes: Specified member groups can be required to have the same member properties by taking either the largest cross-sectional area, "AX", or bending section modulus about the local Y or Z axes, "SZ" or "SZ", of the members within the group and then requiring all members within that group to have the same section properties as the controlling member [8].

For design and construction purposes, there are advantages to smoothing a structure. Without smoothing, the resulting design after a linear or nonlinear elastic analysis is the lightest weight design, which may be impractical or inefficient because a large variety of member shapes could be selected and each member may be a different size. For ease of construction in the field, smoothing all beams to be the same size on a given floor or all columns of a given story to be the same size, may be more cost effective and easier to assemble. If many different member shapes are specified, then fabrication will be more expensive and different connections must be designed and constructed which also adds to the cost.

5. Linear Stiffness Analysis: Perform a linear elastic stiffness analysis after member shapes are selected (Step 3) and member groups are smoothed (Step 4) to account for the redistribution of forces in the structure that results from the selection of members.

6. Code Check: Perform code checks to determine if each of the selected members have sufficient strength and stiffness using the LRFD method and the provisions in the 13th Edition AISC 2005 Specification. If any of these members fail these design checks, they are stored in a separate group, called "FAILCK" for redesigning purposes.

7. Select 'FAILCHK': Members in the group 'FAILCHK' that do not meet the provisions in the 2005 AISC Specification are redesigned using an interaction equation unity check which requires those members to be overdesigned by a corresponding percentage. For example an interaction equation unity check value of 0.90 corresponds to a 10% overdesign of the members being selected.

8. Smooth Member Sizes: Smooth specified member groups; smoothing must be specified after every redesign otherwise the lightest weight section will be chosen for each member that satisfies both the analyses and the provisions of the 2005 AISC Specification [8].

Steps 5 through 8 are performed in an iterative manner until a design is found that satisfies the provisions in the AISC 2005 Specification, meaning all members pass the code check. Once a design that satisfies the code is found, the structural model is analyzed and designed for strength and stability pursuant to the 13th Edition AISC 2005 Specification, and based on the rigorous Direct Analysis Method. This process is described as follows:

Nonlinear Elastic Analysis:

9. Nonlinear Analysis: The first nonlinear elastic analysis, pursuant to the AISC 13th Edition 2005 Specification Direct Analysis Method using the rigorous geometric nonlinear analysis procedure, is based on the design produced by the traditional linear elastic analysis approach described in Steps 1 through 8.

The nonlinear analysis procedure within GTSTRUDL is a small strain, small rotation, and large displacement static analysis, and is solved using a direct iteration technique [7]. The nonlinear analysis will continue to cycle until it converges or has reached the maximum number of equilibrium correction iterations given by the user.

Two possibilities result from the first nonlinear elastic analysis: one is that the design by the traditional linear elastic stiffness analysis procedure is stable and the other is that the design by the traditional linear elastic stiffness procedure is unstable. A structural instability is detected when either the maximum number of cycles is reached before equilibrium convergence or if a zero value lies on the diagonal of the stiffness matrix. If the traditional design is stable, then the design process proceeds to Step 15 (Code Check). However if the design is unstable then the structure must be redesigned in Step 10 (Using Latest Linear Elastic Stiffness Analysis Results, Reduce Unity Check Value Select All Members).

10. Using Latest Linear Stiffness Analysis Results, Reduce Unity Check Value Select All Members: When a structural instability is found in the first geometric nonlinear elastic analysis (Step 9) for one of the independent design load cases, results from which to formulate a design therefore, the members must be redesigned based on the previous linear elastic analysis and design (Step 5 through 8) by selecting larger sections for all of the members. Without any data to show which members or what components are causing the instability in the structure, larger members are selected for all of the members rather than only for the ones causing the instability.

11. Smooth Member Sizes: Member groups are smoothed after all members are redesigned in Step 10 (Using Latest Linear Elastic Stiffness Analysis Results, Reduce Unity Check Value Select All Members).

12. Nonlinear Analysis: Performs a new nonlinear elastic analysis based on the redesigned members in Steps 10 (Using Latest Linear Elastic Stiffness Analysis Results, Reduce Unity Check Value Select All Members) and 11 (Smooth Member Sizes).

Two possibilities result from the new nonlinear elastic analysis: one is that the design is stable and other is that the design is still unstable. If the design is stable, then the design process proceeds to Step 15 (Code Check). However if the design is unstable then the structure must be redesigned in Step 14 (Reduce Unity Check Value Select All Members) after performing a linear elastic stiffness analysis on the redesigned structure (Step 13).

13. Linear Stiffness Analysis: If the nonlinear elastic analysis (Step 12) yields a structural instability for one of the independent load combinations, then a linear elastic stiffness analysis is performed on the latest design of the structure to form a basis for the selection of the new member shapes for all of the members in the structure in Step 14 (Reduce Unity Check Value Select All Members).

14. Reduce Unity Check Value Select All Members: When a structural instability due to one or more of the independent load combinations is found after a geometric nonlinear elastic analysis is performed (Step 12), all members must be redesigned based on the last linear elastic analysis (Step 13). All members are overdesigned in the redesign of the structure because it is difficult to determine which members contributed to the instability of the structure; therefore larger sections are selected for all members.

Steps 11 through 14 are performed in an iterative manner until a design that satisfies a geometric nonlinear elastic analysis pursuant to the AISC 13th Edition 2005 Specification Direct Analysis Method is achieved. Once a design is found that is stable, the following process is completed:

15. Code Check: If the structure is found to be stable using the Direct Analysis Method, then another code check is performed to determine if all members meet the requirements in the 2005 Specification. Again, this is an iterative process in which any members that failed the code check, must be redesigned in Step 16 (Select ‘FAILCHK’) and then another nonlinear analysis (Step 18) must be performed to determine if the structure is stable.

16. Select ‘FAILCHK’: Members in the group ‘FAILCHK’ that do not meet the provisions in the 2005 AISC Specification are redesigned by requiring those selected members to be overdesigned by a certain percentage.

17. Smooth Member Sizes: Member groups are smoothed again after redesigning the members in the group ‘FAILCHK’ (Step 16).

18. Nonlinear Analysis: A new geometric nonlinear elastic analysis must be performed on the structure after the members that failed the code check (Step 15) are redesigned (Step 16) and member groups were smoothed (Step 17) because forces are redistributed with the new selection of steel member shapes.

Two possibilities result from the new nonlinear elastic analysis: one is that the new design is stable and other is that the design becomes unstable after being redesigned. If the design is stable, then the design process proceeds to Step 15 (Code Check). However if the design is unstable then the structure must be redesigned in Step 14 (Reduce Unity Check Value Select All Members) after performing a linear elastic stiffness analysis on the redesigned structure (Step 13).

This process is iterated through until a stable design using a geometric nonlinear analysis pursuant to the Direct Analysis Method rigorous nonlinear analysis that also satisfies all of the provisions in the AISC 2005 Specification (passes all code checks) is generated. Once a design is found that satisfies the requirements of the AISC 2005 Specification, then the notional load reactions are determined in Step 19.

19. Analysis for Notional Load Reactions: If all of the members meet the provisions in the 2005 AISC Specification and the design is stable using a geometric nonlinear elastic analysis, then the notional load reactions are found. The notional load reactions are found by performing a linear elastic analysis using the notional loads as the loading on the structure and subtracting that value from the reactions of the most recent nonlinear elastic analysis. The notional load reactions are equivalent to the summation of the notional loads and accounts for the possible fictitious base shears that can result from applying notional loads to a structure.

3.3 Limitations

There is one important limitation to this study. The issue of combining response spectra analysis results based on mode superposition procedures with nonlinear static analysis results is not addressed in the 2005 AISC Specification when designing for stability [1]. Superposition principles are not valid for results computed based on a nonlinear analysis; static analysis and dynamic analysis results can only be combined for a static linear elastic analysis [5]. Additionally, due to the irregular loadings and geometry of the building, the approximate technique of equivalent lateral loads would not be valid. Therefore, due to the inability of combining the dynamic and static results generated coupled with the invalidity of approximating the earthquake loading with equivalent lateral loads, it was decided to ignore the influence of earthquakes on the structures in this study.

CHAPTER IV:

MODEL 1 – SMALL INDUSTRIAL STRUCTURE

The small industrial structure was modeled as a moment frame and was comprised entirely of space-frame members (stick models illustrated in Figures 3 and 8). Four separate cases were studied for the structure: with and without the smoothing process, and with and without an extra joint at mid-column of all the columns in the structure. The total weight of the steel structure was tabulated and compared for each of these cases.

4.1 Case 1 – No Extra Joints Mid-Column and No Smoothing

The Case 1 model consisted of:

- 100 joints,
- 178 space frame members,
- 7 independent load conditions, and
- 30 design load conditions.

This Case 1 solution was performed in order to create a worst case scenario in regards to design based on the Direct Analysis Method. The first case studied for the simplified industrial structure did not contain extra joints at mid-column nor did it utilize the smoothing process.

4.1.1 Implementation Sequence

The sequence of GTSTRUDL command files that were used to analyze and design Case 1 of the small industrial building for stability are listed below. The command files follow the rigorous sequential process that is explained in detail and illustrated by the flow chart

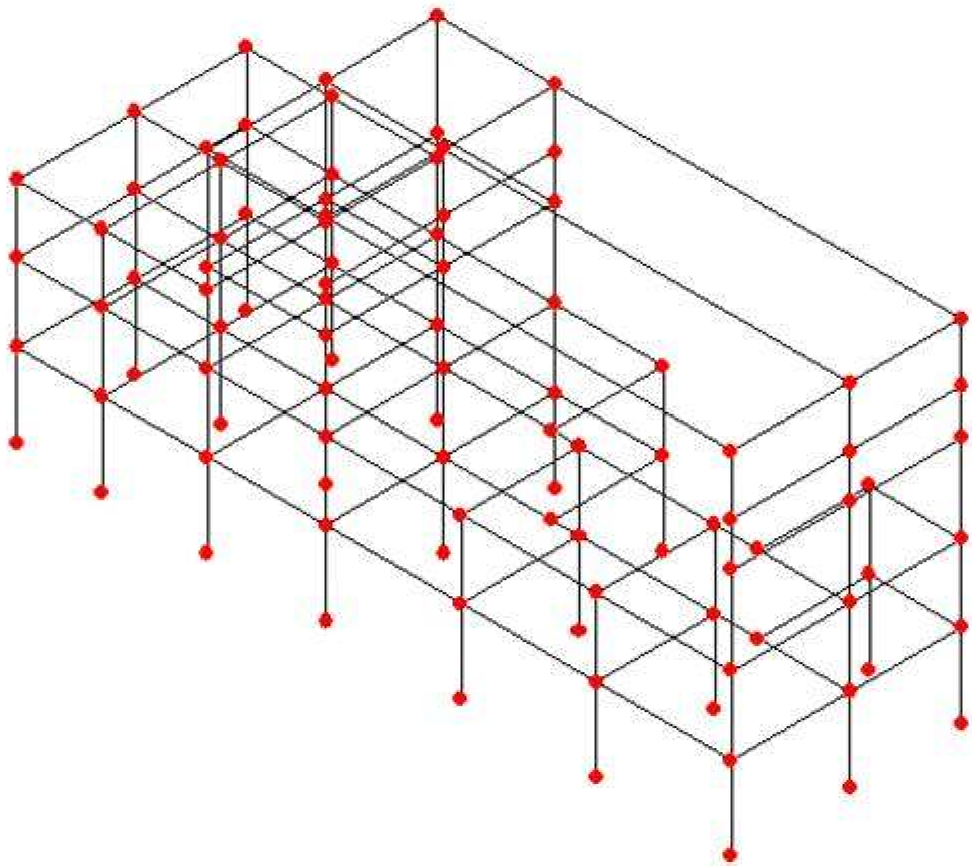

Figure 3: Stick Model of Case 1 and Case 2 of Small Industrial Structure

(Figure 2) in Chapter 3. Each of the command files that were required to design Case 1 of the small industrial structure are described in Section 4.1.2 of this paper.

```
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti
2. STATIC_LOADS_with_Notional_LOAD_Command.gti
3a. LINEAR_STATIC_ANALYSIS_Notional.gti
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti
4b. AISC13_LRFD_Design_Notional.gti
6c. NonlinearAnalysis_Original_Notional&AE_EI.gti
3b. LINEAR_STATIC_ANALYSIS_Notional.gti
4c. AISC13_LRFD_Design_Notional.gti
6c. NonlinearAnalysis_Original_Notional&AE_EI.gti
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti
99. NotionalLoadAnalysis_SupportJointReactions.gti
```

4.1.2 Description of Command Files Run in Sequence Case 1

The following is a description of the GTSTRUDL command files listed in Section 4.1.1 that are required to analyze and design Case 1 of the small industrial structure in this study:

File Name and Description

1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti

The model of the Case 1 small industrial structure contains a total of 100 joints and 178 space frame members, and is defined in the positive Y-up direction for the global coordinate system. The model attributes to be analyzed and designed including the geometry (joint coordinates), topology (member incidences), member and material properties, and boundary conditions, are defined. Figure 3 illustrates the geometry and topology of the Case 1 model. The material properties of steel include the modulus of elasticity, shear modulus, and density (defined as 29000 ksi, 11600 ksi, and 0.490 kip/ft^3 accordingly). All girders and beams are assigned an initial member shape of W21x101 and all columns are assigned an initial shape of W14x90 to use as a starting point for analysis and design of the structure. All support conditions are defined as either pinned or fixed conditions. The commands which define the geometry, topology, member and material properties, and boundary conditions within file "1. IndustrialStructure_No Bracing_13th_Ed_ AISC.gti" can be found in Appendix A.

The total weight of the initial sizes of the steel frame members in the Case 1 model was 429.96 kips.

2. STATIC_LOADS_with_Notional_LOAD_Command.gti

There are seven independent load conditions consisting of two gravity dead loads, a gravity live load, and four lateral (wind) load conditions as well as four notional load conditions acting on the model. The independent load conditions are formed into thirty independent design load conditions. The commands which define the seven independent load conditions, four notional load conditions and thirty independent design load conditions within file "2. STATIC_LOADS_with_ Notional_LOAD_Command.gti" can be found in Appendix B. A description of these loading conditions follows.

a. <u>Gravity Loads</u>

The gravity dead loads applied to the structure consist of two dead load conditions, SW and DL, that are described in the commands of this file.

The gravity live loads applied to the structure consist of the live load condition, LL, described in the commands of this file.

b. Lateral Loads

Wind loads are applied to the structure in the north, south, east, and west directions, WLN, WLS, WLE, and WLW, described in the commands of this file.

c. Notional Loads

Notional loads are intended to approximate the additional influence of initial out-of-plumb construction imperfections of the structure on its P-Δ behavior as described in the 2005 AISC Specification. Notional loads (N_i) are applied in the lateral directions of the model. The τ_b factor which is an additional flexural reduction factor as defined in Appendix 7 of the 2005 AISC Specification, is only applicable to structures whose behavior matches the behavior of the simple frame structures by which the formulations were developed. The 2005 Specification permits τ_b to be taken as a value of 1.0 as long as an additional notional load of $0.001Y_i$ is added to the $0.002Y_i$ notional load (N_i) requirement in Appendix 7 of the 2005 AISC Specification, where Y_i represents the gravity loads applied to the model. The resultant notional loads ($N_i = 0.003Y_i$) are formed in GTSTRUDL by using its "FORM NOTIONAL LOAD" command from the applied gravity dead loads and gravity live loads. Four notional loads were created as described below and applied laterally to the joints of the structure.

```
Name: 'NX_SW+DL' - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION
    Formed From: 'SW' 1.0 'DL' 1.0
Name: 'NZ_SW+DL' - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Z-DIRECTION
    Formed From: 'SW' 1.0 'DL' 1.0
Name: 'NX_LL'    - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION
    Formed From: 'LL' 1.0
Name: 'NZ_LL'    - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Z-DIRECTION
    Formed From: 'LL' 1.0
```

d. <u>Design Load Conditions</u>

The following thirty design load conditions pursuant to the 2005 AISC Specification were formed using GTSTRUDL's "FORM LOAD" command from the above independent and notional load loading conditions and are summarized below:

```
Name: 1.4(SW+ DL)
    Formed From: 'SW' 1.4 'DL' 1.4
Name: 1.4(SW+ DL) + NOTIONAL_X
    Formed From: 'SW' 1.4 'DL' 1.4 'NX_SW+DL' 1.4
Name: 1.4(SW+ DL) - NOTIONAL_X
    Formed From: 'SW' 1.4 'DL' 1.4 'NX_SW+DL' -1.4
Name: 1.4(SW+ DL) + NOTIONAL_Z
    Formed From 'SW' 1.4 'DL' 1.4 'NZ_SW+DL' 1.4
Name: 1.4(SW+ DL) - NOTIONAL_Z
    Formed From: 'SW' 1.4 'DL' 1.4 'NZ_SW+DL' -1.4
Name: 1.2(SW+ DL) + 1.6(LL)
    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 1.6
Name: 1.2(SW+ DL) + 1.6(LL) ++ NOTIONAL_X
    Formed From: ''SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' 1.2 'NX_LL' 1.6
Name: 1.2(SW+ DL) + 1.6(LL) -- NOTIONAL_X
    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL' -1.6
Name: 1.2(SW+ DL) + 1.6(LL) +- NOTIONAL_X
    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' 1.2 'NX_LL' -1.6
Name: 1.2(SW+ DL) + 1.6(LL) -+ NOTIONAL_X
    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL' 1.6
```

```
Name: 1.2(SW+ DL) + 1.6(LL) ++ NOTIONAL_Z

    Formed From: ''SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' 1.2 'NZ_LL' 1.6

Name: 1.2(SW+ DL) + 1.6(LL) -- NOTIONAL_Z

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -1.6

Name: 1.2(SW+ DL) + 1.6(LL) +- NOTIONAL_Z

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' 1.2 'NZ_LL' -1.6

Name: 1.2(SW+ DL) + 1.6(LL) -+ NOTIONAL_Z

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' 1.6

Name: 1.2(SW+DL) + 0.8(WLW) - NOTIONAL_X

    Formed From: 'SW' 1.2 'DL' 1.2 'WLW' 0.8 'NX_SW+DL' -1.2

Name: 1.2(SW+DL) + 0.8(WLE) + NOTIONAL_X

    Formed From: 'SW' 1.2 'DL' 1.2 'WLE' 0.8 'NX_SW+DL' 1.2

Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLW) -- NOTIONAL_X

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2

                 'NX_LL' -0.5

Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLE) ++ NOTIONAL_X

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL' 1.2

                 'NX_LL' 0.5

Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLW) -+ NOTIONAL_X

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2

                 'NX_LL' 0.5

Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLE) +- NOTIONAL_X

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL' 1.2

                 'NX_LL' -0.5

Name: 0.9(SW+DL) + 1.6(WLW) - NOTIONAL_X

    Formed From: 'SW' 0.9 'DL' 0.9 'WLW' 1.6 'NX_SW+DL' -0.9

Name: 0.9(SW+DL) + 1.6(WLE) + NOTIONAL_X

    Formed From: 'SW' 0.9 'DL' 0.9 'WLE' 1.6 'NX_SW+DL' 0.9

Name: 1.2(SW+DL) + 0.8(WLN) - NOTIONAL_Z

    Formed From: 'SW' 1.2 'DL' 1.2 'WLN' 0.8 'NZ_SW+DL' -1.2

Name: 1.2(SW+DL) + 0.8(WLS) + NOTIONAL_Z

    Formed From: 'SW' 1.2 'DL' 1.2 'WLS' 0.8 'NZ_SW+DL' 1.2

Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLN) -- NOTIONAL_Z

    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2

                 'NZ_LL' -0.5

Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLS) ++ NOTIONAL_Z
```

```
    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL' 1.2
                 'NZ_LL' 0.5
Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLN) -+ NOTIONAL_Z
    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2
                 'NZ_LL' 0.5
Name: 1.2(SW+DL) + 0.5(LL) + 1.6(WLS) +- NOTIONAL_Z
    Formed From: 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL' 1.2
                 'NZ_LL' -0.5
Name: 0.9(SW+DL) + 1.6(WLN) - NOTIONAL_Z
    Formed From: 'SW' 0.9 'DL' 0.9 'WLN' 1.6 'NZ_SW+DL' -0.9
Name: 0.9(SW+DL) + 1.6(WLS) + NOTIONAL_Z
    Formed From: 'SW' 0.9 'DL' 0.9 'WLS' 1.6 'NZ_SW+DL' 0.9
```

The total weight of the structure has not changed from file "1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti"; the weight is 429.96 kips.

3a. LINEAR_STATIC_ANALYSIS_Notional.gti

A traditional linear elastic analysis was used to create the first design of the model, when only geometry, topology, and loading conditions are known and the member shapes required for a stable design are unknown. Since initial member sizes are usually based on a guess or past experience, a nonlinear elastic analysis was not performed. Rather, a linear elastic analysis was performed as the basis of the first design of the model.

A traditional stiffness analysis based on linear elastic analysis was performed based on the design load conditions given in file "2. STATIC_LOADS_with_Notional_LOAD_Command.gti" and the initial member properties given in file "1. IndustrialStructure_NoBracing_13th_ Ed_AISC.gti". All internal member forces and joint displacements were computed and were used as a basis for a linear elastic design of the Case 1 model. The commands which describe the traditional linear elastic analysis within file "3a. LINEAR_STATIC_ANALYSIS_Notional.gti" can be found in Appendix C. After the stiffness analysis was performed on the structure, the total weight of the steel frame members in the structure was still 429.96 kips.

4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

Following the first linear elastic analysis, all of the space frame members were designed using W-shapes contained in GTSTRUDL's W-AISC13 table, which contains the wide-flange shapes as published in the 13th Edition AISC Manual. Steel grade A992 with a yield stress (F_y) of 50ksi is used for all of the steel members within the structure. The K factor is set to 1.0 for all of the members when designing based on a linear elastic analysis. All of the members were designed using an interaction equation unity check of 0.93. The unity check value of 0.93 corresponds to a 7% overdesign of all the members. After running several iterations, it was found by overdesigning the members by 7%, the design converged for a linear elastic analysis with fewer required iterations and therefore less computational time was necessary. The design was considered to converge after all members passed the code check. The process of smoothing was not used on the members to give the worst case design scenario for the engineer; therefore the lightest W-shapes were chosen for each member.

After all of the members were designed based on the initial linear elastic analysis results, they were reanalyzed with a second linear elastic analysis. The results of the linear elastic analysis for each member were checked against the 2005 AISC Specification to see if all code provisions are satisfied. Members that did not pass the code checks were stored into a group called "FAILCK", to be redesigned and reanalyzed in the subsequent files: "5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" and "5b. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti". After a linear elastic design was found that satisfied the code, a nonlinear analysis was performed on the structure. The commands which define the design based on the initial linear elastic analysis, reanalysis, and code checks within file "4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional .gti" can be found in Appendix D.

The total weight of 503.49 kips was found after all of the steel members were designed following the first linear elastic analysis, which was based on the initial member sizes.

5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

All of the steel frame members that failed the 2005 AISC Specification provisions (whose names were stored in the group "FAILCK") in file "4a. AISC13_LRFD_ Design_LinearAnalysis_CodeCheck_Notional.gti" were redesigned using an interaction equation unity check of 0.85. Members that failed the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.85 required that the members be overdesigned by a value of 15%. The value for the unity check of 0.85 was selected by a trial and error process after multiple iterations were performed, so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" can be found in Appendix E.

The total weight after the second design iteration based on a linear elastic analysis was 508.95 kips; however, a third design iteration was required to obtain design convergence based on a linear elastic analysis.

5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

The members that failed the code checks during the second design iteration within file "5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" were redesigned using an interaction equation unity check of 0.80. Members that fail the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.80 required that the members be overdesigned by a value of 20%. The value for the unity check of 0.80 was selected after multiple iterations were performed so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" can be found in Appendix F.

The total weight after the third design iteration based on a linear elastic analysis was 509.19 kips. Figure 4 illustrates the design after convergence for a linear elastic analysis.

6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

Following a design that was produced by the traditional iterative linear elastic analysis and design approach that satisfies all code checks, the first rigorous nonlinear geometric elastic analysis pursuant to the AISC 13th Edition 2005 Specification Direct Analysis Method was performed on the model. If the structure was found to be stable, then all members were checked against the 2005 Specification provisions based on the nonlinear elastic analysis results. If the structure contained an instability, then all members were redesigned based on the previous linear elastic analysis results because a nonlinear analysis does not yield results which are in equilibrium with the full value of the applied loads when an instability is detected within the model.

The first nonlinear elastic analysis in accordance with the AISC 2005 Specification Direct Analysis Method that accounts for geometric nonlinearities was performed for the design loads described in file "2. STATIC_LOADS_with_ Notional_LOAD_Command.gti". A separate nonlinear analysis must be run for each of the different design load cases. If the nonlinear analysis did not converge within a specified tolerance, the structure was determined to be unstable for that load case.

For each nonlinear analysis, the 2005 Specification specifies a 20% reduction of EI and EA only (i.e., flexural stiffness and axial stiffness reductions). While this may be permissible for models whose behavior is similar to the behavior of the simplistic models for which such EI and EA reductions may be valid, the stiffness influence on nonlinear geometric behavior of important industrial steel frameworks is not influenced simply by flexural and axial stiffness, but rather stiffness influences of all six stiffness components (ie. axial, biaxial shear, torsion, and biaxial bending) can have a significant influence on nonlinear geometric behavior of such frameworks. Therefore, a 20% reduction of the elastic modulus (E) and shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis pursuant to the 2005 AISC Specification rigorous Direct Analysis Method within file "6a. NonlinearAnalysis_Original_Notional&AE_EI.gti" can be found in Appendix G.

After the first nonlinear analysis was conducted, nine of the load cases caused a structural instability, while the rest of the load cases converged within three cycles. The total weight of the industrial structure after a nonlinear analysis was performed does not change from the weight determined from the linear elastic analysis design (the weight of the structure stayed at 509.19 kips) since a redesign based on the nonlinear analysis was not performed if instabilities were detected.

4b. AISC13_LRFD_Design_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to design and code checking. All members of the industrial structure were redesigned, because there was no way to determine which combination of members, or what part of the structure, caused the structural instability. The structure was redesigned based upon the last linear analysis performed in file "5b. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti". All of the steel members in the structure were redesigned (not just members that failed code checks) using an interaction equation unity check of 0.80. The value for the unity check of 0.80 was selected after multiple iterations were performed so a stable design could be found with fewer required iterations. The commands which describe the redesign of model within file “4b. AISC13_ LRFD_Design_Notional.gti” can be found in Appendix H.

The total weight of the structure after all of the members were redesigned was 540.43 kips.

6c. NonlinearAnalysis_Original_Notional&AE_EI.gti

A second nonlinear analysis was performed using the members redesigned in file “4b. AISC13_LRFD_Design_Notional.gti”. The analysis follows the Direct Analysis Method requirements and was formatted like file “6a. Nonlinear Analysis_Original_Notional&AE_EI.gti” and is described in greater detail in the description for file “6a. NonlinearAnalysis_Original_Notional&AE_EI.gti”. Again, a 20% reduction of the elastic modulus (E) and the shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis within file “6c. NonlinearAnalysis_ Original_Notional&AE_EI.gti” can be found in Appendix I.

After the second nonlinear analysis was performed, nine of the design load cases caused a structural instability. The total weight of the structure was 540.43 kips. This value does not change from file name “4b. AISC13_LRFD_Design_ Notional.gti” because the nonlinear analysis was based on the design of the steel frame members in file “4b. AISC13_LRFD_Design_Notional.gti”.

3b. LINEAR_STATIC_ANALYSIS_Notional.gti

A stiffness analysis was performed on the most recent design of the structure (File “4b. AISC13_LRFD_Design_Notional.gti”), so a redesign of the structure could be performed based on the redistribution of forces within the structure. The commands which described the linear elastic analysis after redesign within of file "3b. LINEAR_STATIC_ANALYSIS_Notional.gti" can be found in Appendix J. After the stiffness analysis was performed, the total weight of the steel frame members in the structure was still 540.43 kips.

4c. AISC13_LRFD_Design_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking and design. Again, all members of the structure must be redesigned because of the structural instability. The structure was redesigned based upon the last linear analysis found in file "3b LINEAR_STATIC_ANALYSIS_Notional.gti". All of the steel members in the structure are redesigned using an interaction equation unity check of 0.65. The value for the unity check of 0.65 was selected after multiple iterations were performed so a stable design could be found that required fewer nonlinear design iterations. The members needed to be overdesigned by 35% to find a stable design for the model without cycling through nonlinear analysis and redesign an unreasonable number of times. The commands which describe the redesign of model within file "4c. AISC13_LRFD_Design_Notional.gti" can be found in Appendix K. The total weight after all members were redesigned was 608.31 kips.

6c. NonlinearAnalysis_Original_Notional&AE_EI.gti

A third nonlinear analysis was conducted on the structure using the new members redesigned in file "4c. AISC13_LRFD_Design_Notional.gti". Again, a 20% reduction of the elastic modulus (E) and the shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis within file “6c. NonlinearAnalysis_ Original_Notional&AE_EI.gti” can be found in Appendix I. All of the load cases converged within three iterations and the entire structure was stable. The weight of the model does not change from file “4c. AISC13_LRFD_Design_ Notional.gti” because the nonlinear analysis was based on the design of the steel frame members in file “4c. AISC13_LRFD_ Design_Notional.gti”.

7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. The steel members that formed the stable design of the model were checked against the 2005 AISC Specification requirements and based on the nonlinear analysis results. The names of members that failed the code check were placed in the group called “FAILCHK”. The commands which describe the code checks after a nonlinear analysis within file “7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti” can be found in Appendix L.

The total weight of the structure did not change since only code checks are performed. The weight of the structure was 608.31 kips at this stage.

7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

The members that failed the code checks within file “7a. AISC13_LRFD_ CHECK_UsingNonlinear_Notional.gti” were redesigned and another nonlinear analysis was performed to determine if the model remained stable after the redesign process. The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. Additionally, all the members must satisfy the provisions within the 2005 AISC Specification. The commands which describe the redesign and reanalysis, using the nonlinear geometric analysis, and code checks within file "7b. Redesign, Nonlinear Analysis, & CodeCheck_Notional.gti" can be found in Appendix M.

The structure was found to be stable after the members that failed the previous code check were redesigned to satisfy the 2005 Specification. The total weight of Case 1 of the simple industrial structure after a suitable design that was both stable using a geometric nonlinear analysis and satisfied the code, was found to be 610.08 kips. Figure 5 gives the final design of the structure after converging for a nonlinear analysis.

99. NotionalLoadAnalysis_SupportJointReactions.gti

The application of notional loads may lead to fictitious base shears in a structure. A horizontal force that is equivalent to the sum of all of the notional loads can be applied at the base of the structure in the opposite direction as the notional loads to account for the fictitious loads [14].

Within this file, a linear elastic stiffness analysis was performed using the notional loads and the support reactions are listed which can be used to find the true base reactions by subtracting the value found by the analysis of the notional loads from the reactions of the most recent nonlinear analysis (file "7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti") conducted. The commands which describe a linear elastic analysis of the model using the notional loads within file “99. NotionalLoadAnalysis_SupportJointReactions.gti” can be found in Appendix N. The total weight of the structure remains as 610.08 kips.

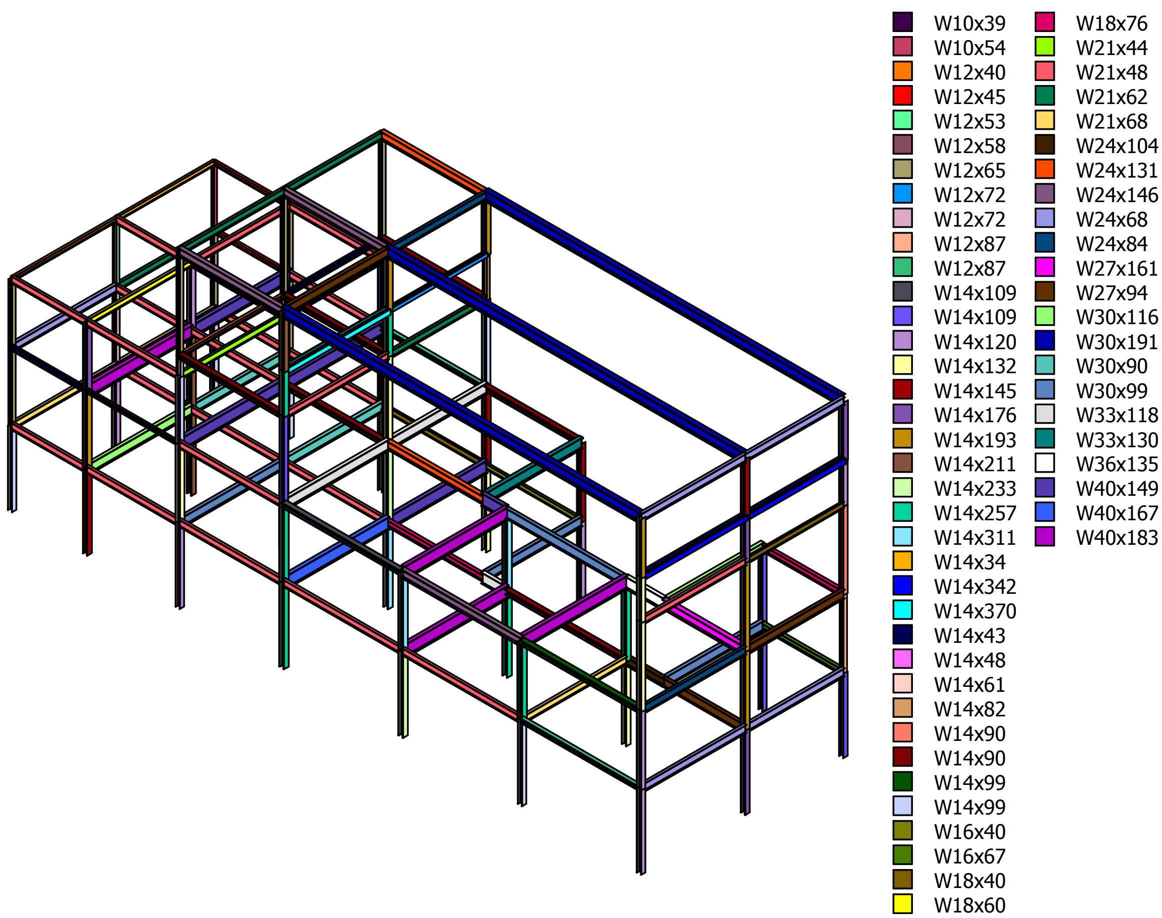

Figure 4: Case 1 Small Industrial Structure Design after Linear Elastic Design Convergence

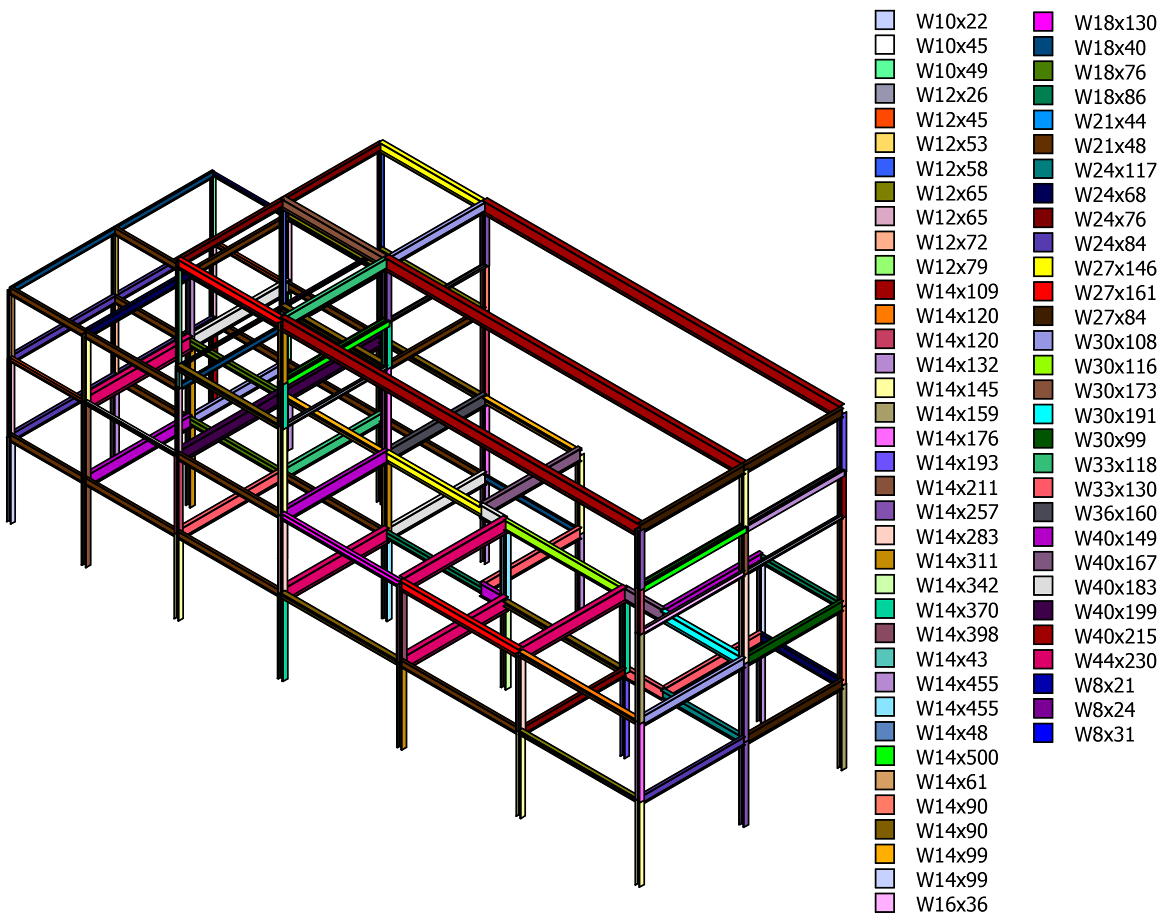

Figure 5: Case 1 Small Industrial Structure Design after Nonlinear Geometric Analysis Design Convergence

4.1.3 Discussion of Results Case 1

Two iterations were necessary to find a suitable linear elastic design that satisfied all of the provisions within the AISC 2005 Specification. The weight of the structure increased after each iteration, making the structure heavier and more costly.

Multiple iterations were also necessary to find a stable design by a nonlinear analysis that accounts for geometric nonlinearities following the Direct Analysis Method given in the 13th Edition AISC 2005 Specification. However for a nonlinear analysis, a separate nonlinear analysis must be conducted on each formed load case for each cycle. This model was highly simplified as compared to the nuclear power plant building studied in Model 2. In any given structure, there can be a large quantity of loading combinations acting on the structure, and for a much more complex structure as compared to this highly simplified industrial structure, the time required to perform multiple iterations of a nonlinear analysis for the required load combinations can be substantial. The weight of the steel members also increased because all of the members had to be redesigned when instability was detected since the members causing the instability could not be easily determined. The members had to be overdesigned by 35% to achieve a stable design through the iterative process, which added a substantial amount of weight to the structure.

The process of smoothing was not utilized in the Case 1 study, therefore the lightest weight structure was designed that satisfied both the provisions in the 2005 AISC Specification and provided a stable design by the Direct Analysis Method. The weight throughout the process is tabulated in Table 1.

Table 1: Total Weight of Steel – Case 1 Small Industrial Structure

File	Weight (Kips)
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti	429.96
2. STATIC_LOADS_with_Notional_LOAD_Command.gti	429.96
3a. LINEAR_STATIC_ANALYSIS_Notional.gti	429.96
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti (a)	503.49
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	508.95
5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	509.19
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti (c)	509.19
4b. AISC13_LRFD_Design_Notional.gti (d)	540.43
6c. NonlinearAnalysis_Original_Notional&AE_EI.gti (c)	540.43
3b. LINEAR_STATIC_ANALYSIS_Notional.gti	540.43
4c. AISC13_LRFD_Design_Notional.gti (e)	608.31
6c. NonlinearAnalysis_Original_Notional&AE_EI.gti (f)	608.31
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti	608.31
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti (g)	610.08
99. NotionalLoadAnalysis_SupportJointReactions.gti	610.08

Notes:

(a) Design all members based on first linear elastic analysis then reanalyze and code check.
(b) Redesign all members that fail code checks, reanalyze with linear elastic analysis and code check members.
(c) Structural Instability detected by nonlinear analysis.
(d) Redesign all members based on the last linear analysis results (in file 5b.)
(e) Redesign all members based on the last linear analysis results (in file 3b.)
(f) Stable structure.
(g) Redesign all members that fail code check, reanalyze with nonlinear geometric analysis and code check.

4.2 Case 2 – With Smoothing and No Extra Joints Mid-Column

The Case 2 model consisted of:

- 100 joints,
- 178 space frame members,
- 7 independent load conditions, and
- 30 design load conditions.

This Case 2 solution showed the impact of smoothing on the structural design process of the small industrial structure based on the Direct Analysis Method. The second case studied for the simplified industrial structure did not contain extra joints at mid-column but member groups were smoothed to create a design that was more realistic for construction.

4.2.1 Implementation Sequence

The sequence of GTSTRUDL command files that were used to analyze and design Case 2 of the small industrial building for stability are listed below. The command files follow the rigorous sequential process that is explained in detail and illustrated by the flow chart (Figure 2) in Chapter 3. Each of the command files that were required to design Case 2 of the small industrial structure are described in Section 4.2.2 of this paper.

```
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti
2. STATIC_LOADS_with_Notional_LOAD_Command.gti
3a. LINEAR_STATIC_ANALYSIS_Notional.gti
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti
99. NotionalLoadAnalysis_SupportJointReactions.gti
```

4.2.2 Description of Command Files Run in Sequence for Case 2

The following is a description of the GTSTRUDL command files listed in Section 4.2.1 that is required to analyze and design Case 2 of the small industrial structure in this study:

<u>**File Name and Description**</u>

1. **IndustrialStructure_NoBracing_13th_Ed_AISC.gti**

   The model of the Case 2 small industrial structure has the same geometry (joint coordinates), topology (member incidences), member and material properties, and boundary conditions, as the Case 1 model described in Section 4.1.2 (file "1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti") of this paper. Figure 3 illustrates the geometry and topology of the Case 2 model. Beams, girders, and columns are grouped to be smoothed throughout the design process by their location within the structure. For example, a column line could be designated as a group so all of the columns in that line could be assigned the same member properties. The commands which define the geometry, topology, member and material properties, and boundary conditions within file "1. IndustrialStructure_No Bracing_13th_Ed_ AISC.gti" can be found in Appendix O.

   The total weight of the initial size of the steel frame members in the Case 2 model was 429.96 kips.

2. **STATIC_LOADS_with_Notional_LOAD_Command.gti**

   There are seven independent load conditions, four notional load conditions and thirty independent design load conditions for the Case 2 model, which are the same as the Case 1 model loading conditions and are described in detail in Section 4.1.2 (File "2. STATIC_LOADS_with_Notional_LOAD_Command.gti"). The commands which define the seven independent load conditions, four notional load conditions and thirty independent design load conditions within file "2. STATIC_LOADS_with_Notional_LOAD_Command.gti" can be found in Appendix P. The total weight of the structure has not changed from file "1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti"; the weight is 429.96 kips.

3a. LINEAR_STATIC_ANALYSIS_Notional.gti

A traditional linear elastic analysis was used to create the first design of the model, when only geometry, topology, and loading conditions are known and the member shapes required for a stable design are unknown. Since initial members sizes are usually based on a guess or past experience, a nonlinear elastic analysis was not performed. Rather, a linear elastic analysis was performed as the basis of the first design of the model.

A traditional stiffness analysis based on linear elastic analysis was performed based on the design load conditions given in file "2. STATIC_LOADS_with_Notional_LOAD_Command.gti" and the initial member properties given in file "1. IndustrialStructure_NoBracing_13th_ Ed_AISC.gti". All internal member forces and joint displacements were computed and were used as a basis for a linear elastic design of the Case 2 model. The commands which describe the traditional linear elastic analysis within file "3a. LINEAR_STATIC_ ANALYSIS_Notional.gti" can be found in Appendix Q. After the stiffness analysis was performed on the structure, the total weight of the steel frame members in the structure was still 429.96 kips.

4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

Following the first linear elastic analysis, all of the space frame members were designed using W-shapes contained in GTSTRUDL's W-AISC13 table, which contains the wide-flange shapes as published in the 13^{th} Edition AISC Manual. Steel grade A992 with a yield stress (F_y) of 50ksi is used for all of the steel members within the structure. The K factor is set to 1.0 for all of the members when designing based on a linear elastic analysis. All members were designed using an interaction equation unity check of 0.93. The unity check value of 0.93 corresponds to a 7% overdesign of all the members. After running several iterations, it was found by overdesigning the members by 7%, the design converged for a linear elastic analysis with fewer required iterations and therefore less computational time was necessary. All of the members were smoothed in accordance to the groups established in file "1. IndustrialStructure_NoBracing_ 13th_Ed_AISC.gti", where columns are smoothed by Euler buckling and beams and girders are smoothing by bending. The commands which define the smoothing process ("TAKE" command) can be found in file "0.smooth.gti" located in Appendix AS.

After all of the members are designed based on the initial linear elastic analysis results, they were reanalyzed with a second linear elastic analysis. The results of the linear elastic analysis for each member are checked against the 2005 AISC Specification to see if all code provisions are satisfied. Members that do not pass the code checks are stored into a group called "FAILCK", to be redesigned and reanalyzed in the subsequent file: "5a. Redesign, LinearAnalysis, &

CodeCheck_Notional.gti" Once a linear elastic design is found that satisfies the code, a nonlinear analysis can be performed upon the structure. The commands which define the design based on the initial linear elastic analysis, smoothing, reanalysis, and code checks within file "4a. AISC13_LRFD_Design_Linear Analysis_CodeCheck_ Notional.gti" can be found in Appendix R.

The total weight of 663.92 kips was found after all of the steel members were designed following the first linear elastic analysis, which was based on the initial member sizes.

5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

All of the steel frame members that failed the 2005 AISC Specification provisions (whose names are stored in the group "FAILCK") in file "4a. AISC13_LRFD_ Design_LinearAnalysis_CodeCheck_Notional.gti" were redesigned using an interaction equation unity check of 0.85. These members were then smoothed by bending for beams and girders and Euler buckling for columns. Members that failed the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.85 required that the members be overdesigned by a value of 15%. The value for the unity check of 0.85 was selected by a trial and error process after multiple iterations were performed, so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" can be found in Appendix S.

The total weight after the second design iteration based on a linear elastic analysis was 663.92 kips. Figure 6 illustrates the design after convergence for a linear elastic analysis utilizing the smoothing process.

6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

Following a design that was produced by the traditional iterative linear elastic analysis and design approach that satisfies all code checks, the first nonlinear geometric analysis was performed on the model. If the structure was found to be stable, then all members were checked against the 2005 Specification provisions based on the nonlinear geometric analysis results. If the structure contained an instability, then all members were redesigned based on the previous linear elastic analysis results because a nonlinear analysis does not yield results which are in equilibrium with the full value of the applied loads when an instability is detected within the model.

The first nonlinear geometric analysis was performed for the design loads described in file “2. STATIC_LOADS_with_ Notional_LOAD_Command.gti”. A separate nonlinear analysis must be run for each of the different design load cases. If the nonlinear analysis did not converge within a specified tolerance, the structure was determined to be unstable for that load case.

For each nonlinear analysis, the 2005 Specification specifies a 20% reduction of EI and EA only (i.e., flexural stiffness and axial stiffness reductions). While this may be permissible for models whose behavior is similar to the behavior of the simplistic models for which such EI and EA reductions may be valid, the stiffness influence on nonlinear geometric behavior of important industrial steel frameworks is not influenced simply by flexural and axial stiffness, but rather stiffness influences of all six stiffness components (ie. axial, biaxial shear, torsion, and biaxial bending) can have a significant influence on nonlinear geometric behavior of such frameworks. Therefore, a 20% reduction of the elastic modulus (E) and shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis pursuant to the 2005 AISC Specification rigorous Direct Analysis Method within file "6a. NonlinearAnalysis_Original_Notional&AE_EI.gti" can be found in Appendix T.

After the first nonlinear analysis was performed, all load cases converged within three cycles and the structure was stable. The total weight of the model after a nonlinear analysis was performed does not change from the weight determined from the linear elastic analysis design (the weight of the structure stayed at 663.92 kips).

7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. The steel members that formed the stable design of the model were checked against the 2005 AISC Specification requirements and based on the nonlinear analysis results. The names of members that failed the code check were placed in the group called "FAILCHK". The commands which describe the code checks after a nonlinear analysis within file "7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti" can be found in Appendix U.

The total weight of the structure did not change since only code checks are performed. The weight of the structure was 663.92 kips at this stage.

7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

The members that failed the code checks within file "7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti" were redesigned and smoothed and another nonlinear analysis was performed to determine if the model remained stable after the redesign process. The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. Additionally, all the members must satisfy the provisions within the 2005 AISC Specification. The commands which describe the redesign and reanalysis, using the nonlinear geometric analysis, and code checks within file "7b. Redesign, Nonlinear Analysis, & CodeCheck_Notional.gti" can be found in Appendix V.

The structure was found to be stable after several of the members in the structure were redesigned and smoothed in their respective groups, to satisfy the 2005 Specification. The total weight of Case 2 of the simple industrial structure after a suitable design that was both stable using a geometric nonlinear analysis and satisfied the code, was found to be 708.94 kips. Figure 7 gives the final design of the structure after converging for a nonlinear analysis.

99. NotionalLoadAnalysis_SupportJointReactions.gti

The application of notional loads may lead to fictitious base shears in a structure, therefore a linear elastic stiffness analysis was performed using the notional loads and the support reactions are listed which can be used to find the true base reactions by subtracting the value found by the analysis of the notional loads from the reactions of the most recent nonlinear analysis (file “7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti”). The commands which describe a linear elastic analysis of the model using the notional loads within file “99. NotionalLoadAnalysis_SupportJointReactions.gti” can be found in Appendix W. The total weight of the structure remains as 708.94 kips.

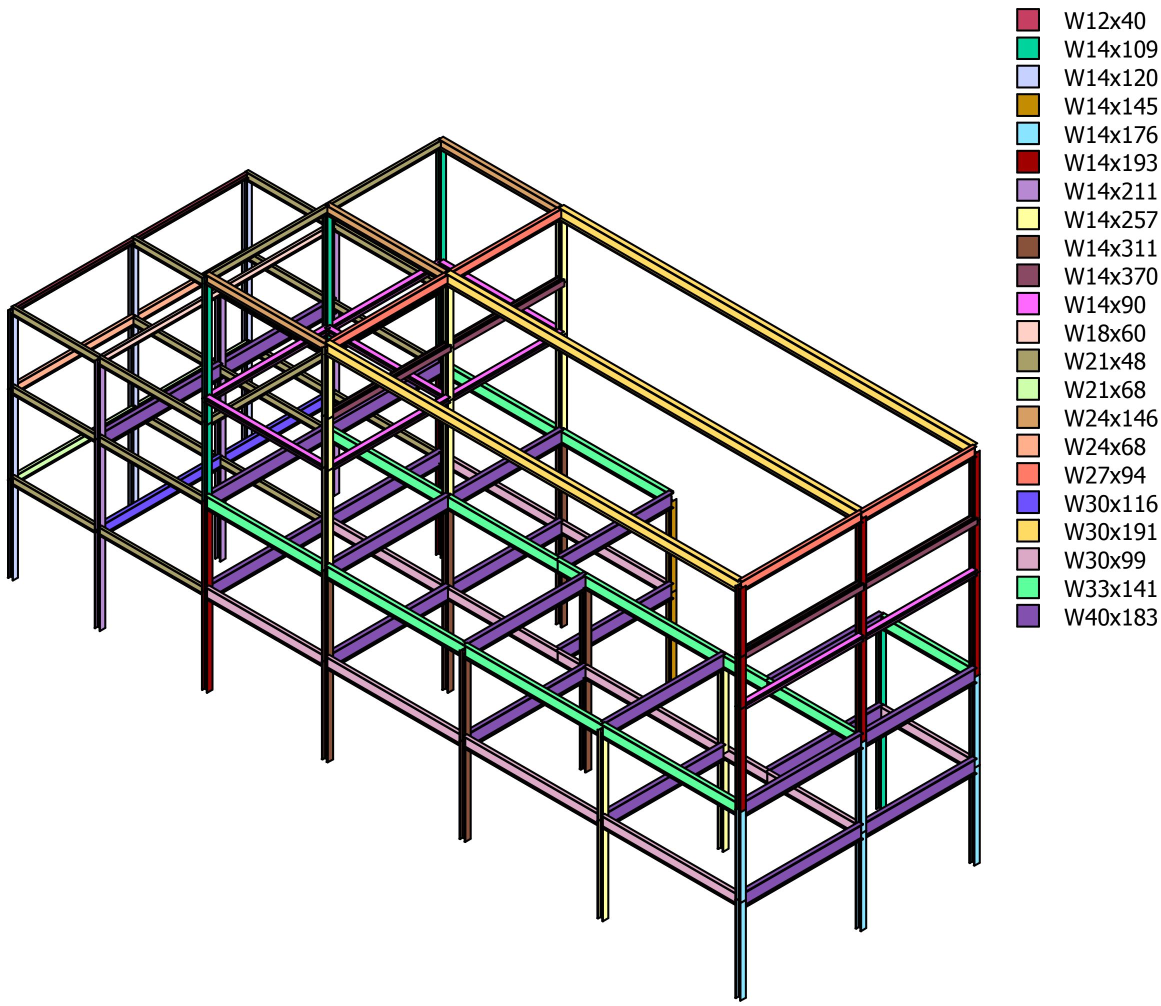

Figure 6: Case 2 Small Industrial Structure Design after Linear Elastic Design Convergence

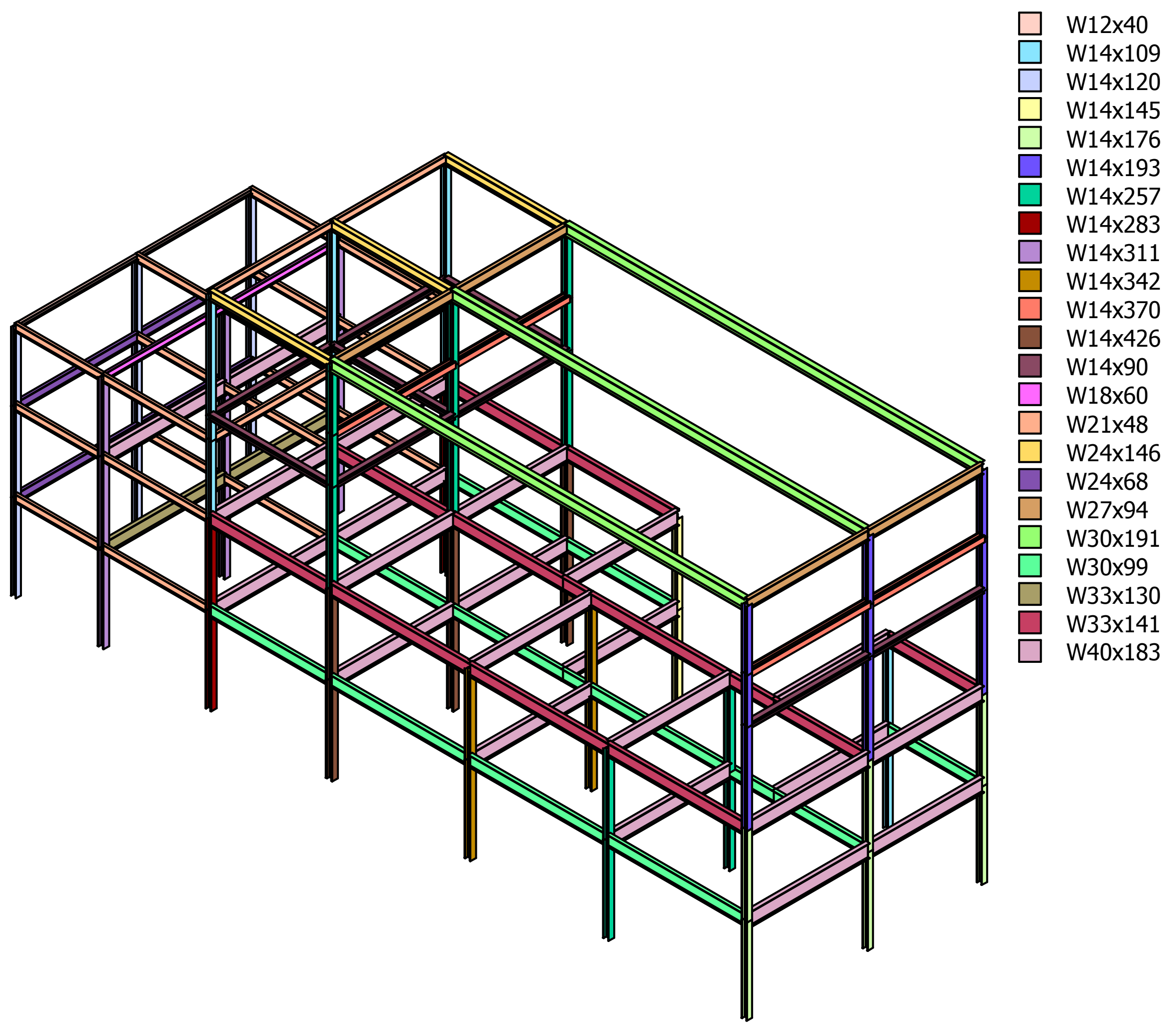

Figure 7: Case 2 Small Industrial Structure Design after Nonlinear Geometric Analysis Design Convergence

4.2.3 Discussion of Results Case 2

The Case 2 model of the small industrial structure utilizes the process of smoothing. The process of smoothing allowed the structure to converge quicker than Case 1 (no smoothing); only one iteration was necessary to find a suitable linear elastic design that satisfied all of the provisions within the AISC 2005 Specification. However the weight of the structure increases when the smoothing process is used; the weight of the structure is tabulated in Table 2. The largest member of each group was used for all of the members in the group, and therefore the structure was heavier. However, smoothing creates a more practical design in that construction is far more simplistic because fewer connections must be designed and constructed.

The Case 2 structure was stable using the 2005 AISC Direct Analysis Method approach in the first nonlinear analysis, because the structure was overdesigned as compared to Case 1 (without smoothing). Only having to perform one nonlinear analysis saves the engineer valuable time. For a nonlinear analysis, a separate nonlinear analysis must be conducted on each formed load case for each cycle; therefore the fewer the number of cycles, the more quickly the nonlinear analyses for all load cases completes.

Table 2: Total Weight of Steel – Case 2 Small Industrial Structure

File	Weight (Kips)
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti	429.96
2. STATIC_LOADS_with_Notional_LOAD_Command.gti	429.96
3a. LINEAR_STATIC_ANALYSIS_Notional.gti	429.96
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti (a)	663.92
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	663.92
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti (c)	663.92
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti	663.92
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti (d)	708.94
99. NotionalLoadAnalysis_SupportJointReactions.gti	708.94

Notes:

(a) Design all members based on first linear elastic analysis then reanalyze and code check.
(b) Redesign all members that fail code checks, reanalyze with linear elastic analysis and code check members.
(c) Stable structure.
(d) Redesign all members that fail code check, reanalyze with nonlinear geometric analysis and code check.

4.3 Case 3 – With Extra Joints at Mid-Column and No Smoothing

The Case 3 model consisted of:

- 175 joints,
- 253 space frame members,
- 7 independent load conditions, and
- 30 design load conditions.

This Case 3 solution was performed in order to create a worst case scenario in regards to design based on the Direct Analysis Method. The third case studied for the simplified industrial structure contained extra joints at mid-column to better predict the nonlinear geometric behavior of the column members in the model. The Case 3 model did not consider the smoothing process.

4.3.1 Implementation Sequence for Case 3

The sequence of GTSTRUDL command files that were used to analyze and design Case 3 of the small industrial building for stability are listed below. The command files follow the rigorous sequential process that is explained in detail and illustrated by the flow chart (Figure 2) in Chapter 3. Each of the command files that were required to design Case 3 of the small industrial structure are described in Section 4.3.2 of this paper.

```
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti
2. STATIC_LOADS_with_Notional_LOAD_Command.gti
3a. LINEAR_STATIC_ANALYSIS_Notional.gti
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti
4b. AISC13_LRFD_DESIGN_Notional.gti
6c. NonlinearAnalysis_Original_Notional&AE_EI.gti
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti
99. NotionalLoadAnalysis_SupportJointReactions.gti
```

4.3.2 Description of Command Files Run in Sequence for Case 3

The following is a description of the GTSTRUDL command files listed in Section 4.3.1 that is required to analyze and design Case 3 of the small industrial structure in this study:

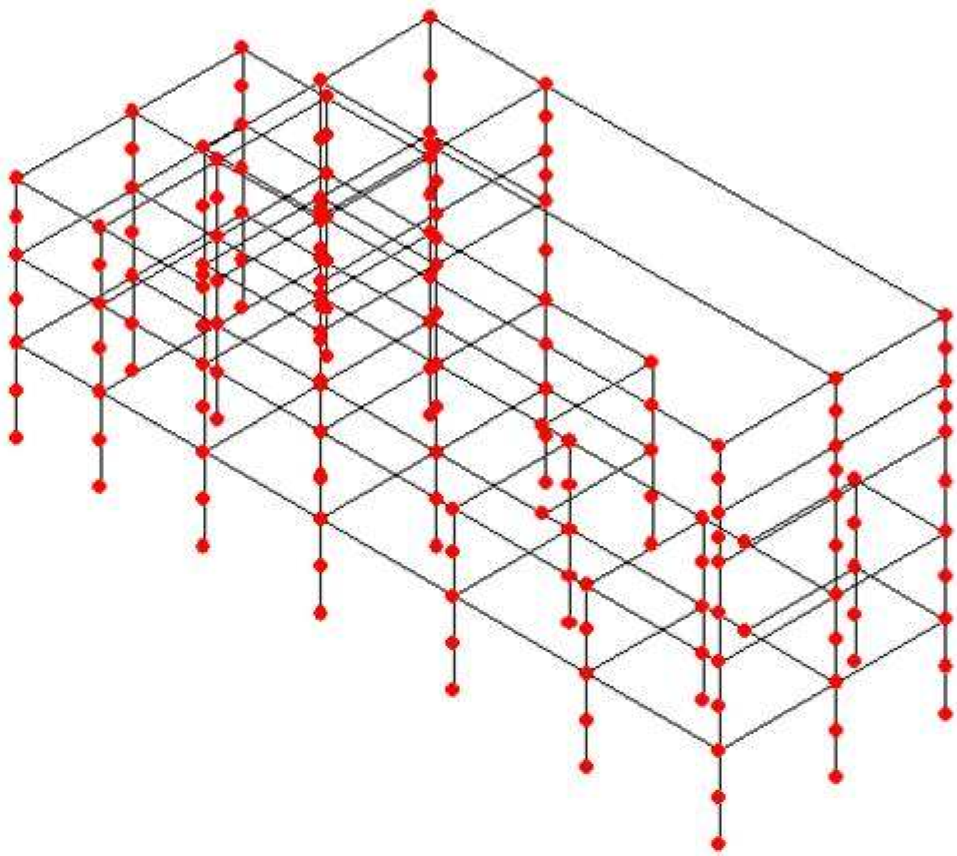

Figure 8: Stick Model Case 3 and 4 Small Industrial Structure

File Name and Description

1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti

The model of the Case 3 small industrial structure contains a total of 175 joints and 253 space frame members, and is defined in the positive Y-up direction for the global coordinate system. The model attributes to be analyzed and designed including the geometry (joint coordinates), topology (member incidences), member and material properties, and boundary conditions, are defined. Each of the columns contains an extra joint at mid-column to better predict the nonlinear geometric behavior of the members. Figure 8 illustrates the geometry and topology of the Case 3 model. The material properties of the steel included the modulus of elasticity, shear modulus, and density (defined as 29000 ksi, 11600 ksi, and 0.490 kip/ft^3 accordingly). All girders and beams are assigned an initial member shape of W21x101 and all columns are assigned an initial shape of W14x90 to use as a starting point for analysis and design of the structure. All support conditions are defined as either pinned or fixed. The commands which define the geometry, topology, member and material properties, and boundary conditions within file "1. IndustrialStructure_No Bracing_13th_Ed_ AISC.gti" can be found in Appendix X.

The total weight of the initial sizes of the steel frame members in the Case 3 model was 429.96 kips.

2. STATIC_LOADS_with_Notional_LOAD_Command.gti

There are seven independent load conditions, four notional load conditions and thirty independent design load conditions for the Case 3 model, which are the same as the loading conditions Case 1 and Case 2 and are described in detail in Section

4.1.2 (File "2. STATIC_LOADS_with_Notional_LOAD_Command.gti"). The commands which define the seven independent load conditions, four notional load conditions and thirty independent design load conditions within file "2. STATIC_LOADS_with_Notional_LOAD_Command.gti" can be found in Appendix Y. The total weight of the structure has not changed from file "1. IndustrialStructure_NoBracing_13th_ Ed_AISC.gti"; the weight is 429.96 kips.

3a. LINEAR_STATIC_ANALYSIS_Notional.gti

A traditional linear elastic analysis was used to create the first design of the model, when only geometry, topology, and loading conditions are known and the member shapes required for a stable design are unknown. Since initial members sizes are usually based on a guess or past experience, a nonlinear elastic analysis was not performed. Rather, a linear elastic analysis was performed as the basis of the first design of the model.

A traditional stiffness analysis based on linear elastic analysis was performed based on the design load conditions given in file "2. STATIC_LOADS_with_Notional_LOAD_Command.gti" and the initial member properties given in file "1. IndustrialStructure_NoBracing_13th_ Ed_AISC.gti". All internal member forces and joint displacements are computed and were used as a basis for a linear elastic design of the Case 3 model. The commands which describe the tradition linear elastic analysis within file "3a. LINEAR_STATIC_ ANALYSIS_Notional.gti" can be found in Appendix Z. After the stiffness analysis was performed on the structure, the total weight of the steel frame members in the structure was still 429.96 kips.

4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

Following the first linear elastic analysis, all of the space frame members were designed using W-shapes contained in GTSTRUDL's W-AISC13 table, which contains the wide-flange shapes as published in the 13th Edition AISC Manual. Steel grade A992 with a yield stress (F_y) of 50ksi is used for all of the steel members within the structure. The K factor is set to 1.0 for all of the members when designing based on a linear elastic analysis. All of the members were designed using an interaction equation unity check of 0.93. The unity check value of 0.93 corresponds to a 7% overdesign of all the members. After running several iterations, it was found by overdesigning the members by 7%, the design converged for a linear elastic analysis with less required iterations and therefore less computational time was necessary. The process of smoothing was not used on the members therefore, the lightest W-shapes were chosen for each member.

After all of the members are designed based on the initial linear elastic analysis results, they were reanalyzed with a second linear elastic analysis. The results of the linear elastic analysis for each member are checked against the 2005 AISC Specification to see if all code provisions are satisfied. Members that do not pass the code checks are stored into a group called "FAILCK", to be redesigned and reanalyzed in the subsequent files: "5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" and "5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti". Once a linear elastic design was found that satisfied the code, a nonlinear analysis was performed on the structure. The commands which define the design based on the initial linear elastic analysis, reanalysis, and code checks within file “4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_ Notional.gti” can be found in Appendix AA.

The total weight of 485.75 kips was found after all of the steel members were designed following the first linear elastic analysis, which was based on the initial member sizes.

5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

All of the steel frame members that fail the 2005 AISC Specification provisions (whose names are stored in the group “FAILCK”) in file “4a. AISC13_LRFD_ Design_LinearAnalysis_CodeCheck_Notional.gti” were redesigned using an interaction equation unity check of 0.85. Members that fail the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.85 required that the members be overdesigned by a value of 15%. The value for the unity check of 0.85 was selected by a trial and error process after multiple iterations were performed, so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file “5a. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti” can be found in Appendix AB.

The total weight after the second design iteration based on a linear elastic analysis was 490.38 kips; however, a third design iteration was required to obtain design convergence based on a linear elastic analysis.

5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

The members that fail the code checks during the second design iteration within file "5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" were redesigned using an interaction equation unity check of 0.80. Members that failed the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.80 required that the members be overdesigned by a value of 20%. The value for the unity check of 0.80 was selected after multiple iterations were performed so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5b. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti" can be found in Appendix AC.

The total weight after the third design iteration based on a linear elastic analysis was 490.59 kips. Figure 9 illustrates the design with an extra node at mid-column after convergence for a linear elastic analysis.

6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

Following a design that was produced by the traditional iterative linear elastic analysis and design approach that satisfies all code checks, the nonlinear geometric elastic analysis was performed on the model. If the structure was found to be stable, then all members were checked against the 2005 Specification provisions based on the nonlinear elastic analysis results. If the structure contained an instability, then all members were redesigned based on the previous linear elastic analysis results because a nonlinear analysis does not yield results which are in equilibrium with the full value of the applied loads when an instability is detected within the model.

The first nonlinear elastic analysis in accordance with the AISC 2005 Specification Direct Analysis Method that accounts for geometric nonlinearities was performed for the design loads described in file "2. STATIC_LOADS_with_ Notional_LOAD_Command.gti". A separate nonlinear analysis must be run for each of the different design load cases. If the nonlinear analysis did not converge within a specified tolerance, the structure was determined to be unstable for that load case.

For each nonlinear analysis, the 2005 Specification specifies a 20% reduction of EI and EA only (i.e., flexural stiffness and axial stiffness reductions). While this may be permissible for models whose behavior is similar to the behavior of the simplistic models for which such EI and EA reductions may be valid, the stiffness influence on nonlinear geometric behavior of important industrial steel frameworks is not influenced simply by flexural and axial stiffness, but rather stiffness influences of all six stiffness components (ie. axial, biaxial shear, torsion, and biaxial bending) can have a significant influence on nonlinear geometric behavior of such frameworks. Therefore, a 20% reduction of the elastic modulus (E) and shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis pursuant to the 2005 AISC Specification rigorous Direct Analysis Method within file "6a. NonlinearAnalysis_Original_Notional&AE_EI.gti" can be found in Appendix AD.

After the first nonlinear analysis was conducted, nine of the load cases caused a structural instability, while the rest of the load cases converged within three cycles. The total weight of the industrial structure after a nonlinear analysis was performed does not change from the weight determined from the linear elastic analysis design (the weight of the structure stayed at 490.59 kips) since a redesign based on the nonlinear analysis was not performed if instabilities were detected.

4b. AISC13_LRFD_Design_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking and design. All members of the industrial structure must be redesigned, because there was no way to determine which combination of members, or what part of the structure, caused the structural instability. The structure was redesigned based upon the last linear analysis performed in file "5b. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti". All of the steel members in the structure were redesigned (not just members that failed code checks) using an interaction equation unity check of 0.80. The value for the unity check of 0.80 was selected after multiple iterations were performed so a stable design could be found with fewer required iterations. The commands which describe the redesign of model within file "4b. AISC13_ LRFD_Design_Notional.gti" can be found in Appendix AE.

The total weight of the structure after all of the members were redesigned was 530.07 kips.

6c. NonlinearAnalysis_Original_Notional&AE_EI.gti

A second nonlinear analysis was performed using the members redesigned in file "4b. AISC13_LRFD_Design_Notional.gti". The analysis follows the Direct Analysis Method requirements and was formatted like file "6a. Nonlinear Analysis_Original_Notional&AE_EI.gti" and is described in greater detail in the description for file "6a. NonlinearAnalysis_Original_Notional& AE_EI.gti". Again, a 20% reduction of the elastic modulus (E) and the shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis within file "6c. NonlinearAnalysis_ Original_Notional&AE_EI.gti" can be found in Appendix AF.

After the second nonlinear analysis was performed, all of the load cases converged within three iterations and the entire structure was stable. The total weight of structure was 530.07 kips. This value does not change from file name "4b. AISC13_LRFD_Design_ Notional.gti" because the nonlinear analysis was based on the design of the steel frame members in file "4b. AISC13_LRFD_Design_Notional.gti".

7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. The steel members that formed the stable design of the model were checked against the 2005 AISC Specification requirements and based on the nonlinear analysis results. The names of members that failed the code check were placed in the group called "FAILCHK". The commands which describe the code checks after a nonlinear analysis within file “7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti” can be found in Appendix AG.

The total weight of the structure did not change since only code checks are performed. The weight of the structure was 530.07 kips at this stage.

7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

The members that failed the code checks within file “7a. AISC13_LRFD_ CHECK_UsingNonlinear_Notional.gti” were redesigned and another nonlinear analysis was performed to determine if the model was still stable after the redesign process. The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. Additionally, all the members must satisfy the provisions within the 2005 AISC Specification. The commands which describe the redesign and reanalysis, using a nonlinear geometric analysis, and code checks within file “7b. Redesign, Nonlinear Analysis, & CodeCheck_Notional.gti” can be found in Appendix AH.

The structure was found to be stable after several of the members in the structure were redesigned to satisfy the 2005 Specification. The total weight of Case 3 of the simple industrial structure after a suitable design that was both stable using a geometric nonlinear analysis and satisfied the code, was found to be 542.68 kips. Figure 10 gives the final design of the structure after converging for a nonlinear analysis.

99. NotionalLoadAnalysis_SupportJointReactions.gti

The application of notional loads may lead to fictitious base shears in a structure, therefore a linear elastic stiffness analysis was performed using the notional loads and the support reactions are listed which can be used to find the true base reactions by subtracting the value found by the analysis of the notional loads from the reactions of the most recent nonlinear analysis (file "7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti") conducted. The commands which describe a linear elastic analysis of the model using the notional loads within file "99. NotionalLoadAnalysis_SupportJointReactions.gti" can be found in Appendix AI. The total weight of the structure remains as 542.68 kips.

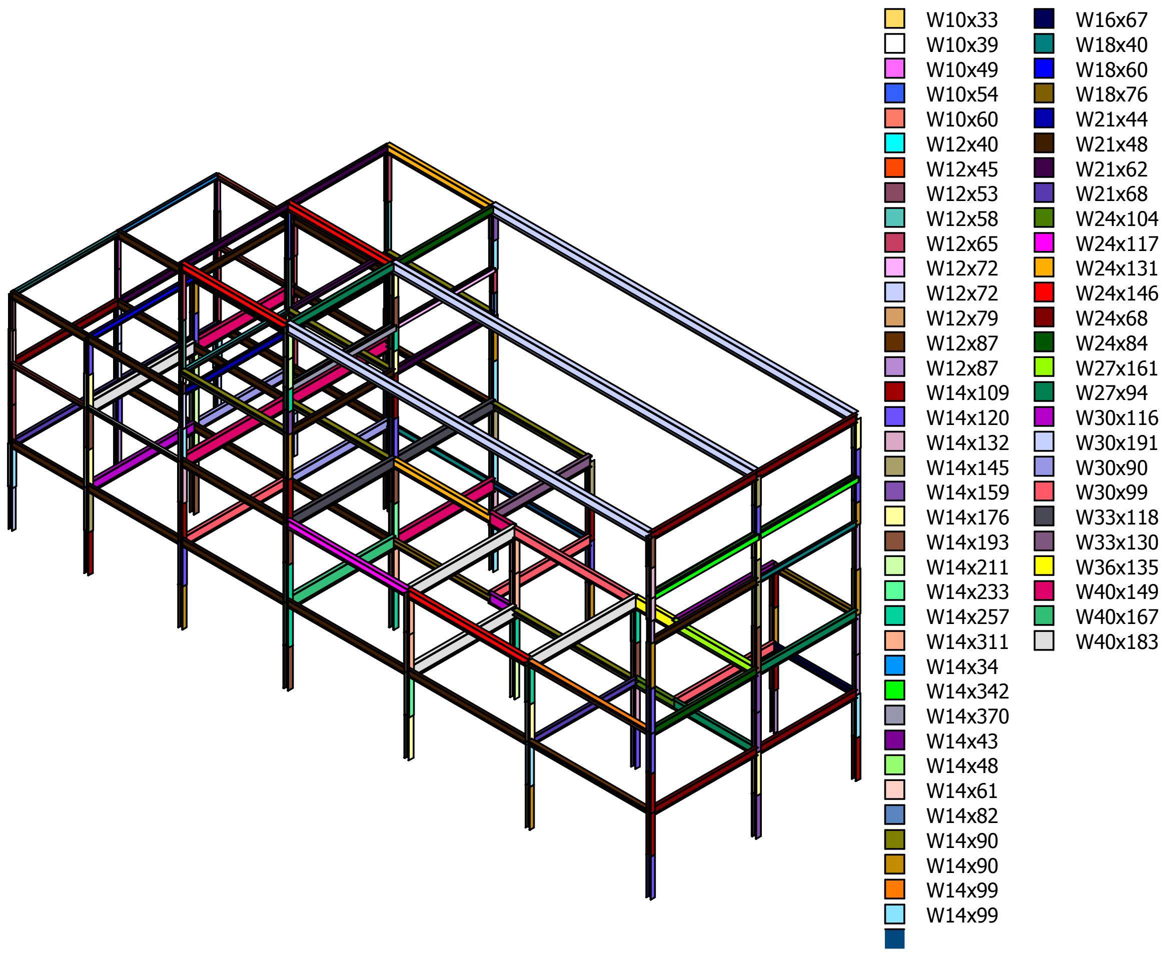

Figure 9: Case 3 Small Industrial Structure Design after Linear Elastic Design Convergence

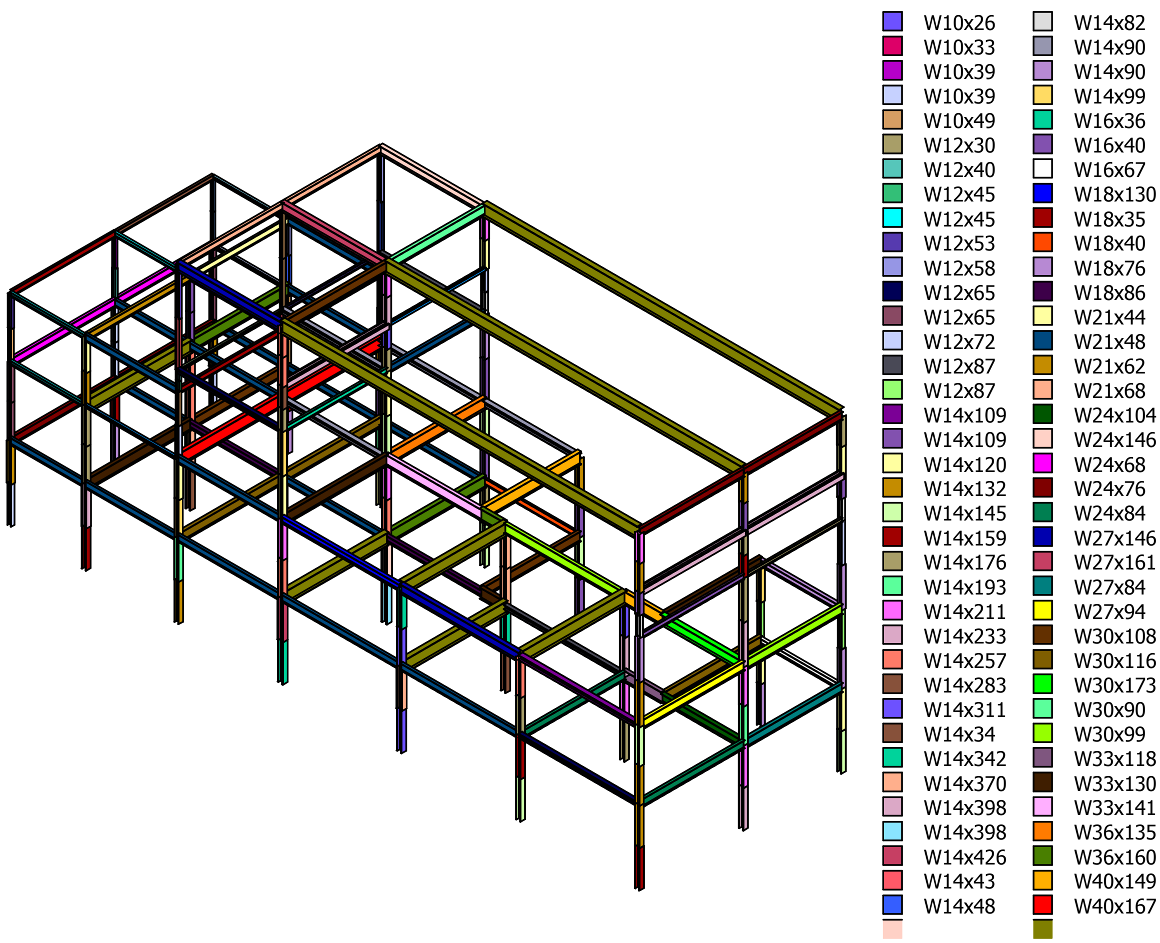

Figure 10: Case 3 Small Industrial Structure Design after Nonlinear Geometric Analysis Design Convergence

4.3.3 Discussion of Results Case 3

Case 3 of the small industrial model contains an extra joint at mid-column of each of the columns without smoothing any of the members, which converged more quickly than Case 1 (no extra joints and no smoothing); the extra joint at mid-column gave a better understanding of the nonlinear behavior of the member. Two iterations were necessary to find a suitable linear elastic design that satisfied all of the provisions within the AISC 2005 Specification. As compared to Case 1 which required four geometric nonlinear analyses and two complete redesigns of the structure, Case 3 required three geometric nonlinear analyses and one redesign of the entire structure. The weight of the structure increased after each iteration, making the structure heavier and more costly.

Multiple iterations were also necessary to find a stable design by a nonlinear analysis that accounts for geometric nonlinearities following the Direct Analysis Method given in the 13th Edition AISC 2005 Specification. However for a nonlinear analysis, a separate nonlinear analysis must be conducted on each formed load case for each cycle. The time required to perform multiple iterations of a nonlinear analysis for the required load combinations could be substantial for structures much larger and more complex than this highly simplified model. The weight of the steel members also increased with each nonlinear analysis performed on the structure, because all members had to be redesigned when instability was detected since the members causing the instability could not be determined. The members had to be overdesigned by 35% to achieve a stable design through the iterative process, which added a substantial amount of weight to the structure.

The process of smoothing was not utilized in the Case 3 study, therefore the lightest weight structure was designed that satisfied both the provisions in the 2005 AISC

Specification and provided a stable design by the Direct Analysis Method. The weight throughout the process is tabulated in Table 3.

Table 3: Total Weight of Steel – Case 3 Small Industrial Structure

File	Weight (Kips)
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti	429.96
2. STATIC_LOADS_with_Notional_LOAD_Command.gti	429.96
3a. LINEAR_STATIC_ANALYSIS_Notional.gti	429.96
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti (a)	485.75
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	490.38
5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	490.59
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti (c)	490.59
4b. AISC13_LRFD_DESIGN_Notional.gti (d)	530.07
6c. NonlinearAnalysis_Original_Notional&AE_EI.gti (e)	530.07
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti	530.07
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti (f)	542.68
99. NotionalLoadAnalysis_SupportJointReactions.gti	542.68

Notes:

(a) Design all members based on first linear elastic analysis then reanalyze and code check.
(b) Redesign all members that fail code checks, reanalyze with linear elastic analysis and code check members.
(c) Structural Instability detected by nonlinear analysis.
(d) Redesign all members based on the last linear analysis results (in file 5b.)
(e) Stable structure.
(f) Redesign all members that fail code check, reanalyze with nonlinear geometric analysis and code check.

4.4 Case 4 – With Smoothing and Extra Joints at Mid-Column

The Case 4 model consisted of:

- 175 joints,
- 253 space frame members,
- 7 independent load conditions, and
- 30 design load conditions.

This Case 4 showed the impact of smoothing on the structural design process of the small industrial structure based on the Direct Analysis Method. The fourth case studied for the simplified industrial structure contained extra joints at mid-column to better predict the behavior of the column members in the model. The Case 4 model member groups were smoothed to create an optimum design.

4.4.1 Implementation Sequence for Case 4

The sequence of GTSTRUDL command files that were used to analyze and design Case 4 of the small industrial building for stability are listed below. The command files follow the rigorous sequential process that is explained in detail and illustrated by the flow chart (Figure 2) in Chapter 3. Each of the command files that were required to design Case 4 of the small industrial structure are described in Section 4.4.2 of this paper.

```
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti
2. STATIC_LOADS_with_Notional_LOAD_Command.gti
3a. LINEAR_STATIC_ANALYSIS_Notional.gti
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti
99. NotionalLoadAnalysis_SupportJointReactions.gti
```

4.4.2 Description of Command Files Run in Sequence for Case 4

The following is a description of the GTSTRUDL command files listed in Section 4.4.1 that is required to analyze and design Case 4 of the small industrial structure in this study:

File Name and Description

1. **IndustrialStructure_NoBracing_13th_Ed_AISC.gti**

The model of the Case 4 small industrial structure has the same geometry (joint coordinates), topology (member incidences), member and material properties, and boundary conditions, as the Case 3 model described in Section 4.3.2 (file "1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti") of this paper. Figure 8 illustrates the geometry and topology of the Case 4 model. Beams, girders, and columns are grouped to be smoothed throughout the design process by their location within the structure. For example, a column line could be designated as a group so all of the columns in that line could be assigned the same member properties. The commands which define the geometry, topology, member and material properties, and boundary conditions within file "1. IndustrialStructure_No Bracing_13th_Ed_ AISC.gti" can be found in Appendix AJ.

The total weight of the initial size of the steel frame members in the Case 2 model was 429.96 kips.

2. **STATIC_LOADS_with_Notional_LOAD_Command.gti**

There are seven independent load conditions, four notional load conditions and thirty independent design load conditions for the Case 4 model, which are the same as the Case 1, Case 2, and Case 3 models' loading conditions and are described in detail in Section 4.1.2 (File "2. STATIC_LOADS_with_Notional_LOAD_

Command.gti"). The commands which define the seven independent load conditions, four notional load conditions and thirty independent design load conditions within file "2. STATIC_LOADS_with_Notional_LOAD_ Command.gti" can be found in Appendix AK. The total weight of the structure has not changed from file "1. IndustrialStructure_NoBracing_ 13th_Ed_AISC.gti"; the weight is 429.96 kips.

3a. LINEAR_STATIC_ANALYSIS_Notional.gti

A traditional linear elastic analysis was used to create the first design of the model, when only geometry, topology, and loading conditions are known and the member shapes required for a stable design are unknown. Since initial members sizes are usually based on a guess or past experience, a nonlinear elastic analysis was not performed. Rather, a linear elastic analysis was performed as the basis of the first design of the model.

A traditional stiffness analysis based on linear elastic analysis was performed based on the design load conditions given in file "2. STATIC_LOADS_with_Notional_LOAD_Command.gti" and the initial member properties given in file "1. IndustrialStructure_NoBracing_13th_ Ed_AISC.gti". All internal member forces and joint displacements are computed and were used as a basis for a linear elastic design of the Case 4 model. The commands which describe the tradition linear elastic analysis within file "3a. LINEAR_STATIC_ ANALYSIS_Notional.gti" can be found in Appendix AL. After the stiffness analysis was performed on the structure, the total weight of the steel frame members in the structure was still 429.96 kips.

4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

Following the first linear elastic analysis, all of the space frame members were designed using W-shapes contained in GTSTRUDL's W-AISC13 table, which contains the wide-flange shapes as published in the 13th Edition AISC Manual. Steel grade A992 with a yield stress (F_y) of 50ksi is used for all of the steel members within the structure. The K factor is set to 1.0 for all of the members when designing based on a linear elastic analysis. All members were designed using an interaction equation unity check of 0.93. The unity check value of 0.93 corresponds to a 7% overdesign of all the members. After running several iterations, it was found by overdesigning the members by 7%, the design converged for a linear elastic analysis with fewer required iterations and therefore less computational time was necessary. All of the members were smoothed in accordance to the groups established in file "1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti", where columns are smoothed by Euler buckling and beams and girders are smoothing by bending. The commands which define the smoothing process ("TAKE" command) can be found in file "0.smooth.gti" located in Appendix AS.

After all of the members are designed based on the initial linear elastic analysis results, they were reanalyzed with a second linear elastic analysis. The results of the linear elastic analysis for each member are checked against the 2005 AISC Specification to see if all code provisions are satisfied. Members that do not pass the code checks are stored into a group called "FAILCK", to be redesigned and reanalyzed in the subsequent file: "5a. Redesign, LinearAnalysis, &

CodeCheck_Notional.gti" Once a linear elastic design is found that satisfies the code, a nonlinear analysis can be performed upon the structure. The commands which define the design based on the initial linear elastic analysis, smoothing, reanalysis, and code checks within file "4a. AISC13_LRFD_Design_Linear Analysis_CodeCheck_ Notional.gti" can be found in Appendix AM.

The total weight of 663.92 kips was found after all of the steel members were designed following the first linear elastic analysis, which was based on the initial member sizes.

5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

All of the steel frame members that fail the 2005 AISC Specification provisions (whose names are stored in the group "FAILCK") in file "4a. AISC13_LRFD_ Design_LinearAnalysis_CodeCheck_Notional.gti" were redesigned using an interaction equation unity check of 0.85. These members were then smoothed by bending for beams and girders and Euler buckling for columns. Members that fail the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.85 required that the members be overdesigned by a value of 15%. The value for the unity check of 0.85 was selected by a trial and error process after multiple iterations were performed, so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5a. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti" can be found in Appendix AN.

The total weight after the second design iteration based on a linear elastic analysis was 663.92 kips. Figure 11 illustrates the design after convergence for a linear elastic analysis utilizing the smoothing process.

6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

Following a design that was produced by the traditional iterative linear elastic analysis and design approach that satisfies all code checks, the first rigorous nonlinear geometric elastic analysis pursuant to the AISC 13th Edition 2005 Specification Direct Analysis Method was performed on the model. If the structure was found to be stable, then all members were checked against the 2005 Specification provisions based on the nonlinear elastic analysis results. If the structure contained an instability, then all members were redesigned based on the previous linear elastic analysis results because a nonlinear analysis does not yield results which are in equilibrium with the full value of the applied loads when an instability is detected within the model.

The first nonlinear elastic analysis in accordance with the AISC 2005 Specification Direct Analysis Method that accounts for geometric nonlinearities was performed for the design loads described in file “2. STATIC_LOADS_with_ Notional_LOAD_Command.gti”. A separate nonlinear analysis must be run for each of the different design load cases. If the nonlinear analysis did not converge within a specified tolerance, the structure was determined to be unstable for that load case.

For each nonlinear analysis, the 2005 Specification specifies a 20% reduction of EI and EA only (i.e., flexural stiffness and axial stiffness reductions).

While this may be permissible for models whose behavior is similar to the behavior of the simplistic models for which such EI and EA reductions may be valid, the stiffness influence on nonlinear geometric behavior of important industrial steel frameworks is not influenced simply by flexural and axial stiffness, but rather stiffness influences of all six stiffness components (ie. axial, biaxial shear, torsion, and biaxial bending) can have a significant influence on nonlinear geometric behavior of such frameworks. Therefore, a 20% reduction of the elastic modulus (E) and shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis pursuant to the 2005 AISC Specification rigorous Direct Analysis Method within file "6a. NonlinearAnalysis_Original_Notional&AE_EI.gti" can be found in Appendix AO.

After the first nonlinear analysis was performed, all load cases converged within three cycles and the structure was stable. The total weight of the model after a nonlinear analysis was performed does not change from the weight determined from the linear elastic analysis design (the weight of the structure stayed at 663.92 kips).

7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. The steel members that formed the stable design of the model were checked against the 2005 AISC Specification requirements and based on the nonlinear analysis results. The names of members that failed the code check were placed in the group called

"FAILCHK". The commands which describe the code checks after a nonlinear analysis within file "7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti" can be found in Appendix AP.

The total weight of the structure did not change since only code checks are performed. The weight of the structure was 663.92 kips at this stage.

7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

The members that failed the code checks within file "7a. AISC13_LRFD_ CHECK_UsingNonlinear_Notional.gti" were redesigned and smoothed and another nonlinear analysis was performed to determine if the model remained stable after the redesign process. The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. Additionally, all the members must satisfy the provisions within the 2005 AISC Specification. The commands which describe the redesign and reanalysis, using the nonlinear geometric analysis, and code checks within file "7b. Redesign, Nonlinear Analysis, & CodeCheck_Notional.gti" can be found in Appendix AQ.

The structure was found to be stable after several of the members in the structure were redesigned and smoothed in their respective groups, to satisfy the 2005 Specification. The total weight of Case 4 of the simple industrial structure after a suitable design that was both stable using a geometric nonlinear analysis and satisfied the code, was found to be 708.94 kips. Figure 12 gives the final design of the structure after converging for a nonlinear analysis.

99. NotionalLoadAnalysis_SupportJointReactions.gti

The application of notional loads may lead to fictitious base shears in a structure, therefore a linear elastic stiffness analysis was performed using the notional loads and the support reactions are listed which can be used to find the true base reactions by subtracting the value found by the analysis of the notional loads from the reactions of the most recent nonlinear analysis (file “7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti”) conducted. The commands which describe a linear elastic analysis of the model using the notional loads within file “99. NotionalLoadAnalysis_SupportJointReactions.gti” can be found in Appendix AR. The total weight of the structure remains as 708.94 kips.

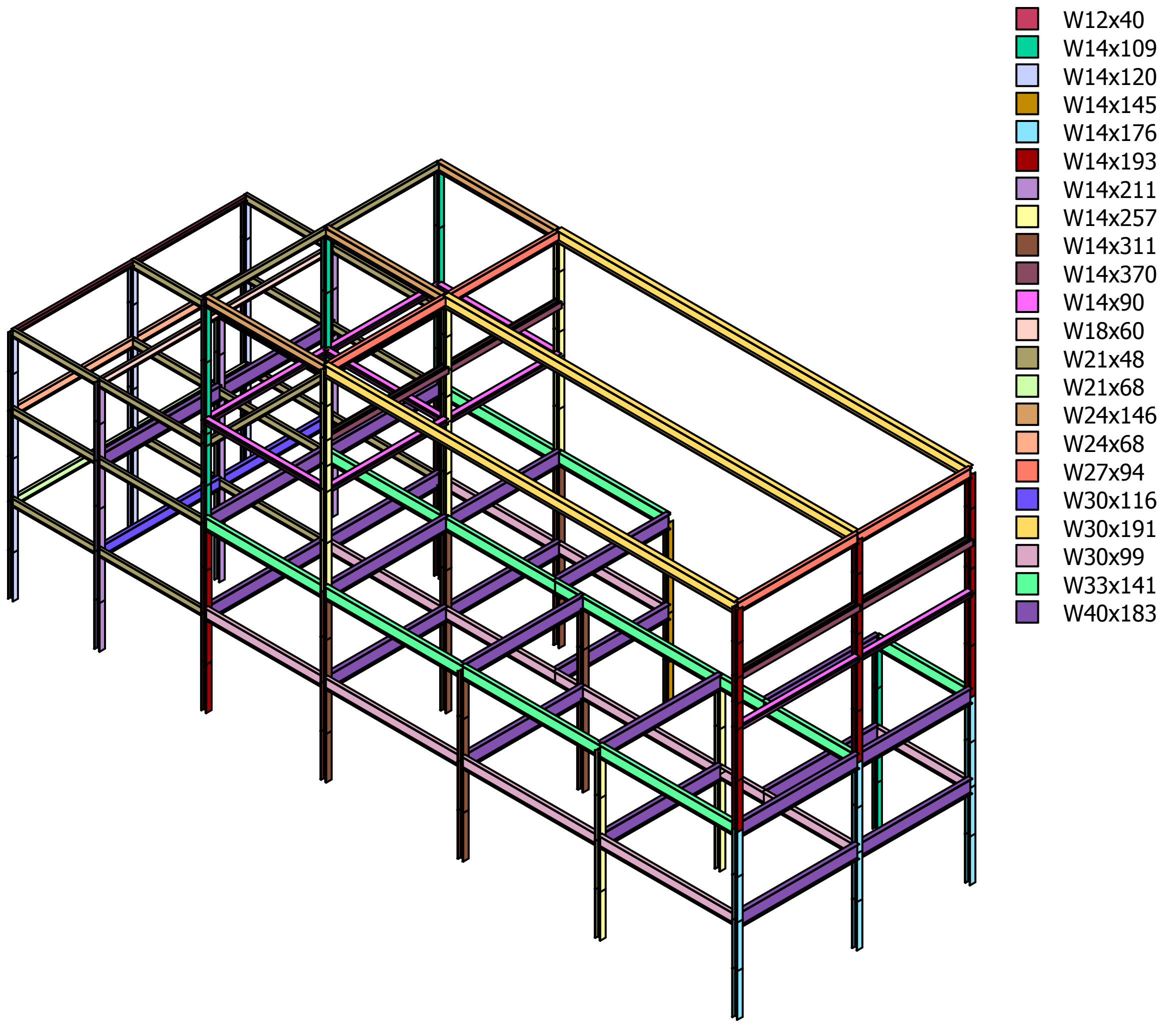

Figure 11: Case 4 Small Industrial Structure Design after Linear Elastic Design Convergence

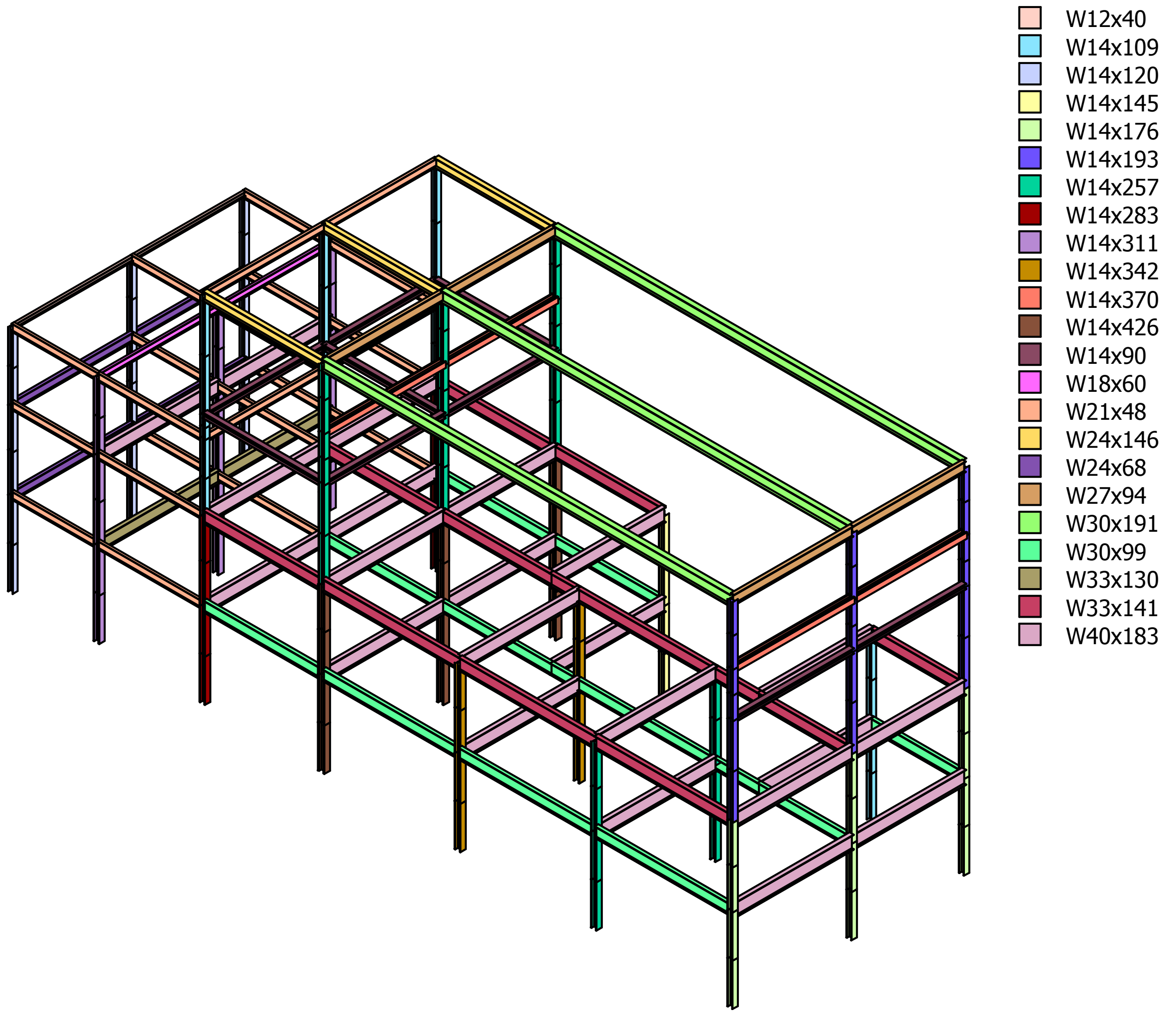

Figure 12: Case 4 Small Industrial Structure Design after Nonlinear Geometric Analysis Design Convergence

4.4.3 Discussion of Results Case 4

Case 4 of the small industrial model contains an extra joint at mid-column of each of the columns and smoothes members. One iteration is necessary to find a suitable linear elastic design that satisfied all of the provisions within the AISC 2005 Specification. Case 4 converges faster than Case 3 (with an extra joint at mid-column and no smoothing) and Case 1 (no extra joints and no smoothing). The extra joint at mid-column gave a better nonlinear geometric member model and thus converged faster than Case 1. The smoothing process caused Case 4 to converge faster than Cases 1 and 3 because the largest members are chosen from each group to smooth with and thus finds a suitable design for a linear elastic analysis quicker than Case 1 and 3. Due to the smoothing process, Case 4 and Case 2 converge at the same rate. The resulting structure was heavier; the weight of the steel members is tabulated through the design process in Table 4. The smoothing process creates a more practical design in that construction is far more simplistic because fewer different connections must be designed and constructed.

The Case 4 structure was stable using the 2005 AISC Direct Analysis Method approach in the first nonlinear analysis, because the structure was overdesigned as compared to Case 1 and 3 (without smoothing). Only having to perform one nonlinear analysis saves the engineer valuable time. For a nonlinear analysis, a separate nonlinear analysis must be conducted on each formed load case for each cycle; therefore the least number of cycles required is optimal.

Table 4: Total Weight of Steel – Case 4 Small Industrial Structure

File	Weight (Kips)
1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti	429.96
2. STATIC_LOADS_with_Notional_LOAD_Command.gti	429.96
3a. LINEAR_STATIC_ANALYSIS_Notional.gti	429.96
4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti (a)	663.92
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	663.92
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti (c)	663.92
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti	663.92
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti (d)	708.94
99. NotionalLoadAnalysis_SupportJointReactions.gti	708.94

Notes:

(a) Design all members based on first linear elastic analysis then reanalyze and code check.
(b) Redesign all members that fail code checks, reanalyze with linear elastic analysis and code check members.
(c) Stable structure.
(d) Redesign all members that fail code check, reanalyze with nonlinear geometric analysis and code check.

4.5 Comparison of Final Weight of all Four Cases Studied of Small Industrial Structure

The final weight of the small industrial structure for all four cases studied is tabulated below in Table 5 after analyzing and designing the structure by the Direct Analysis Method in the 2005 AISC Specification. Case 2 and 4 are the heaviest structures because steel member groups were smoothed throughout the design process. These designs are more optimal in terms of construction; fewer connection designs are required and fewer shapes have to be fabricated. Case 3 was much lighter than the other structures for two reasons. One, the smoothing process was not used and therefore the lightest weight structure that was stable and satisfied the provisions in the 2005 AISC Specification was designed. Secondly, an extra joint was located at mid-column of all of the columns within the structure (as compared to Case 1 which was considered to be the worst case scenario for the small industrial structure and does not have the extra joint in the columns); using an extra joint in the middle of the column members better predicts the nonlinear geometric behavior along the member and thus allowed for a lighter weight design. A better nonlinear geometric model (one which contained an extra joint at mid-column) allowed for member behavior within the highly simplified industrial model to be better predicted and thus the lightest weight members that could satisfy loading requirements and code checks were selected.

Table 5: Final Weight of Structure Comparison –Small Industrial Structure (Model 1)

Case Studied	Description	Weight (Kips)
1	No Smoothing and No Extra Joint Mid-Column	610.08
2	Includes Smoothing and No Extra Joint Mid-Column	708.94
3	No Smoothing and Contains an Extra Joint Mid-Column	542.68
4	Includes Smoothing and Contains an Extra Joint Mid-Column	708.94

CHAPTER V:

MODEL 2 – NUCLEAR POWER PLANT BOILER BUILDING

The second model studied (Figure 13) was a complex highly braced real industrial structure provided by an international engineering firm and is comprised entirely of space-frame members. The structure is a nuclear power plant boiler building whose lateral stability system can be classified by the 13th Edition AISC 2005 Specification as a combined system, or a combination of both the moment-frame and braced-frame systems. The model consisted of:

- 2517 joints,
- 5360 space frame members,
- 8 independent load conditions, and
- 16 design load conditions

The total weight of the steel structure was tabulated and compared throughout the analysis and design process (described in Chapter 3) to show the consequences of using the Direct Analysis Method to design and analyze for stability in a structure.

5.1 Implementation Sequence

The sequence of GTSTRUDL command files that were used to analyze and design the nuclear power plant boiler building for stability are listed below. The command files follow the rigorous sequential process that is explained in detail and illustrated by the flow chart (Figure 2) in Chapter 3. Each of the command files that were required to design the boiler building are described in Section 5.2 of this paper.

1. `Model&Indloads.gti`
2. `Notional_Loads.gti`

```
3a. LINEAR_STATIC_ANALYSIS_Notional.gti
4a. AISC13_LRFD_LinearAnal_Design&CodeChk_Notional.gti
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
5c. Redesign, LinearAnalysis, & CodeCheck_Notional.gti
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti
4b. AISC13_LRFD_Design_Notional.gti
6c. NonlinearAnalysis_Notional&AE_EI.gti
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti
99. NotionalLoadAnalysis_SupportJointReactions.gti
```

5.2 Description of Command Files Run in Sequence

The following is a description of the GTSTRUDL command files listed in Section 5.1 that is required to analyze and design the nuclear power plant boiler building in this study:

<u>File Name and Description</u>

1. Model&Indloads.gti

The model of the Case 1 simple industrial structure contains a total of 2517 joints and 5360 space frame members, and is defined in the positive Z-up direction for the global coordinate system. The model attributes to be analyzed and design including the geometry (joint coordinates), topology (member incidences), member and material properties, and boundary conditions, are defined. Figure 13 illustrates the geometry and topology of the boiler building model. The material properties of the steel included the modulus of elasticity, shear modulus, and density (defined as 30000 ksi, 12000 ksi, and 0.283 lb/in^3 accordingly). All members are assigned an initial member shape of HSS16x16x1/2 to form a basis for the design of the structure. Members are grouped for purposes of smoothing throughout the design

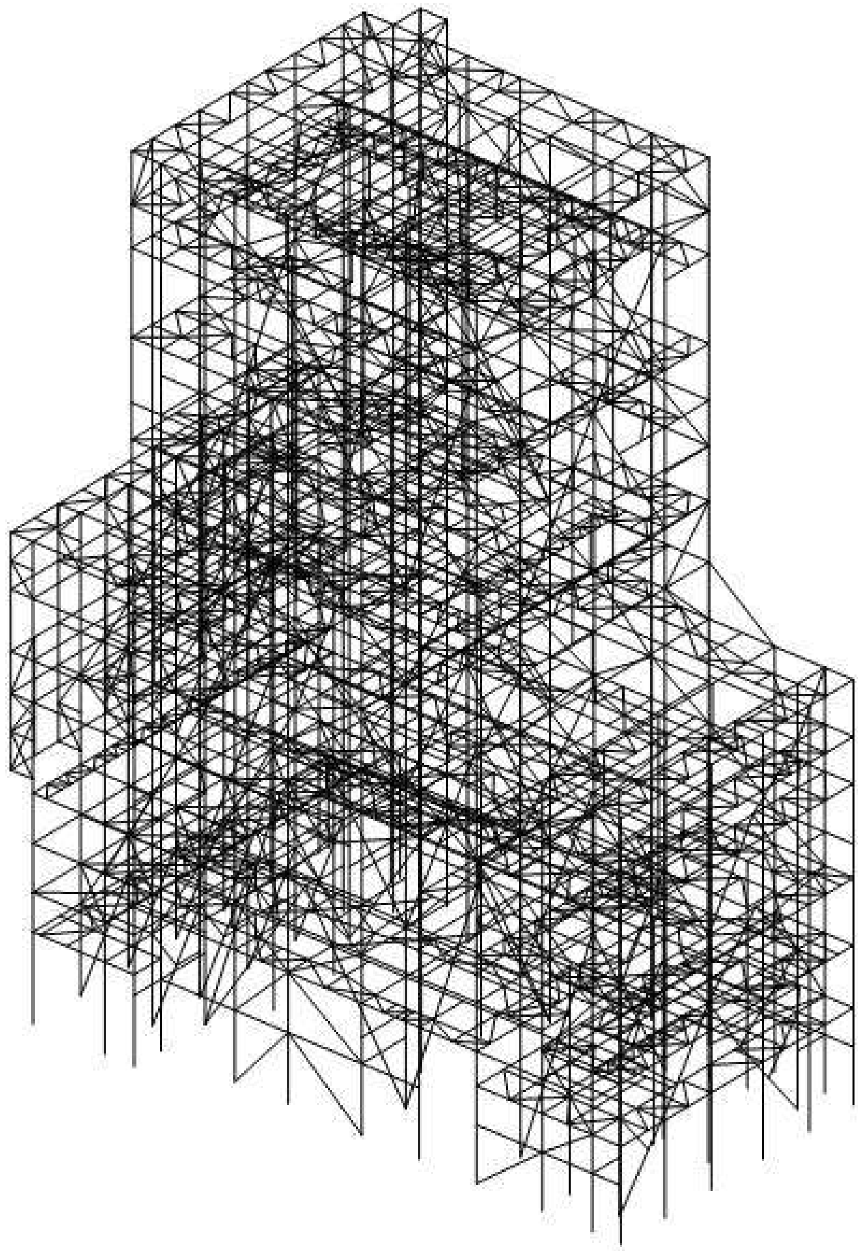

Figure 13: Stick Model of Boiler Building

process; columns were smoothed by Euler Buckling so the largest cross-sectional area was used for a given group and beams were smoothed by bending moment requirements. Smoothing is previously defined in Section 3.2 of this paper. All support conditions are defined as fixed condition.

Also contained within this file are defined loading conditions. Gravity dead load conditions included three dead load conditions: the self-weight of the steel members (SW), and load names 1 and 2. Gravity live load conditions included three live load conditions: load names 3, 4, and 5. The gravity loads included loads such as platform loads, ash and coal, piping, etc. Lateral wind load cases were applied in the North and East directions. The commands which define the geometry, topology, member and material properties, and boundary conditions within file "1. Model&Indloads.gti" can be found in Appendix AT.

The total weight of the initial sizes of the steel frame members in the nuclear power plant boiler building model was 3905.5 tons.

2. Notional_Loads.gti

There are eight independent load conditions consisting of three gravity dead loads, three gravity live loads, and two lateral (wind) load conditions as well as four notional load conditions acting on the model. The independent load conditions are formed into sixteen independent design load conditions. The commands which define the eight independent load conditions, four notional load conditions and sixteen independent design load conditions within file "2. Notional_Loads.gti" can be found in Appendix AU.

a. Gravity Loads

The gravity dead loads applied to the structure consists of three dead load conditions, 1, 2, and SW, that are described in the commands of file 1.Model&Indloads.gti.

The gravity live loads applied to the structure consists of three live load conditions, 3, 4, and 5, described in the commands of file 1.Model&Indloads.gti.

b. Lateral Loads

Wind loads are applied to the structure in the north and east directions, WLN and WLE, and are described in commands of file 1.Model&Indloads.gti.

c. Notional Loads

Notional loads are intended to approximate the additional influence of initial out-of-plumb construction imperfections of the structure on its P-Δ behavior as described in the 2005 AISC Specification. Notional loads (N_i) are applied in the lateral directions of the model. The τ_b factor which is an additional flexural reduction factor as defined in Appendix 7 of the 2005 AISC Specification, is only applicable to structures whose behavior matches the behavior of the simple frame structures by which the formulations were developed. The 2005 Specification permits τ_b to be taken as a value of 1.0 as long as an additional notional load of $0.001Y_i$ is added to the $0.002Y_i$ notional load (N_i) requirement in Appendix 7 of the 2005 AISC Specification, where Y_i represents the gravity loads applied to the model. The resultant notional loads ($N_i = 0.003Y_i$) are formed in GTSTRUDL by using its “FORM NOTIONAL LOAD” command from the applied gravity dead loads and gravity live loads. Four notional loads were created as described below and applied laterally to the joints of the structure.

```
Name: ‘NX_SW+1+2’ - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION
    Formed From: ‘SW’ 1.0 1 1.0 2 1.0
Name: ‘NY_SW+1+2’ - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Y-DIRECTION
    Formed From: ‘SW’ 1.0 1 1.0 2 1.0
Name: ‘NX_3+4+5’  - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION
    Formed From: 31.0 4 1.0 5 1.0
Name: ‘NY_3+4+5’  - NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Y-DIRECTION
    Formed From: 31.0 4 1.0 5 1.0
```

d. Design Load Conditions

The following sixteen design load conditions pursuant to the 2005 AISC Specification were formed using GTSTRUDL’s “FORM LOAD” command from the above loading independent and notional load loading conditions and are summarized below:

```
Name: 1.4(SW+1+2)
    Formed From: ‘SW’ 1.4 1 1.4 2 1.4
Name: 1.4(SW+1+2) + NOTIONAL_X
    Formed From: ‘SW’ 1.4 1 1.4 2 1.4 ‘NX_SW+1+2’ 1.4
Name: 1.4(SW+1+2) - NOTIONAL_X
    Formed From: ‘SW’ 1.4 1 1.4 2 1.4 ‘NX_SW+1+2’ -1.4
Name: 1.4(SW+1+2) + NOTIONAL_Y
    Formed From: ‘SW’ 1.4 1 1.4 2 1.4 ‘NY_SW+1+2’ 1.4
Name: 1.4(SW+1+2) - NOTIONAL_Y
    Formed From: ‘SW’ 1.4 1 1.4 2 1.4 ‘NY_SW+1+2’ -1.4
Name: 1.2(SW+1+2) + 1.6(3+4+5)
    Formed From: ‘SW’ 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6
```

```
Name: 1.2(SW+1+2) + 1.6(3+4+5) ++ NOTIONAL_X
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' 1.2
                 'NX_3+4+5' 1.6
Name: 1.2(SW+1+2) + 1.6(3+4+5) -- NOTIONAL_X
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' -1.2
                 'NX_3+4+5' -1.6
Name: 1.2(SW+1+2) + 1.6(3+4+5) +- NOTIONAL_X
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' 1.2
                 'NX_3+4+5' -1.6
Name: 1.2(SW+1+2) + 1.6(3+4+5) -+ NOTIONAL_X
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' -1.2
                'NX_3+4+5' 1.6
Name: 1.2(SW+1+2) + 1.6(3+4+5) ++ NOTIONAL_Y
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' 1.2
                 'NX_3+4+5' 1.6
Name: 1.2(SW+1+2) + 1.6(3+4+5) -- NOTIONAL_Y
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' -1.2
                 'NX_3+4+5' -1.6
Name: 1.2(SW+1+2) + 1.6(3+4+5) +- NOTIONAL_Y
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' 1.2
                 'NX_3+4+5' -1.6
Name: 1.2(SW+1+2) + 1.6(3+4+5) -+ NOTIONAL_Y
    Formed From: 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' -1.2
                 'NX_3+4+5' 1.6
Name: 1.2(SW+1+2) + 0.8(WLE) + NOTIONAL_X'
    Formed From: 'SW' 1.2 1 1.2 2 1.2 'WLE' 0.8 'NX_SW+1+2' 1.2
Name: 1.2(SW+1+2) + 0.8(WLN) - NOTIONAL_Y'
    Formed From: 'SW' 1.2 1 1.2 2 1.2 'WLN' 0.8 'NY_SW+1+2' -1.2
```

The total weight of the structure has not changed from file 1.Model&Indloads.gti; the weight is 3905.5 tons.

3a. LINEAR_STATIC_ANALYSIS_Notional.gti

A traditional linear elastic analysis was used to create the first design of the model, when only geometry, topology, and loading conditions are known and the member shapes required for a stable design are unknown. Since initial members sizes are usually based on a guess or past experience, a nonlinear elastic analysis was not performed. Rather, a linear elastic analysis was performed as the basis of the first design of the model.

A traditional stiffness analysis based on linear elastic analysis was performed based on the design load conditions given in file "2. Notional_ Loads.gti" and the initial member properties given in file "1. Model& Indloads.gti". All internal member forces and joint displacements were computed and were used as a basis for a linear elastic design of the model. The commands which describe the traditional linear elastic analysis within file "3a. LINEAR_STATIC_ ANALYSIS_Notional.gti" can be found in Appendix AV. After the stiffness analysis was performed on the structure, the total weight of the steel frame members in the structure was still 3905.5 tons.

4a. AISC13_LRFD_LinearAnal_Design&CodeChk_Notional.gti

Following the first linear elastic analysis, all of the space frame members were designed using the W-AISC13, 2L-EQ-13, and RecHSS13 tables defined within GTSTRUDL, which correspond to the wide-flange, equal leg double angle, and rectangle and square box shapes given within the AISC 2005 Specification. A yield stress (F_y) of 50ksi and an ultimate stress (F_u) of 70ksi are used for all of the steel members within the structure. The K factor is set to 1.0 for all of the members when designing based on a linear elastic analysis. Steel grade A992 with a yield stress (F_y) of 50ksi is used for all of the steel members within the structure. The K factor is set to 1.0 for all of the members when designing based on a linear elastic analysis. All members were smoothed in accordance to the groups established in file “1. Model&Indloads.gti”, where columns are smoothed by Euler buckling and beams and girders are smoothing by bending. The commands which define the smoothing process (“TAKE” command) can be found in file “0. SmoothMember Properties.gti” located in Appendix BG.

After all of the members are designed based on the initial linear elastic analysis results, they were reanalyzed with a second linear elastic analysis. The results of the linear elastic analysis for each member are checked against the 2005 AISC Specification to see if all code provisions are satisfied. Members that do not pass the code checks are stored into a group called “FAILCK”, to be redesigned and reanalyzed in the subsequent files: “5a. Redesign, LinearAnalysis, & Code Check_Notional.gti”, “5b.Redesign, LinearAnalysis, & CodeCheck_Notional.gti”, and “5c. Redesign, LinearAnalysis, & CodeCheck_Notional.gti”. Once a linear elastic design was found that satisfied the code, a nonlinear analysis could be performed upon the structure. The commands which define the design based on the initial linear elastic analysis, smoothing, reanalysis, and code checks within file “4a. AISC13_LRFD_Design_LinearAnal_CodeChk_ Notional.gti” can be found in Appendix AW.

The total weight of 2257.1 tons was found after all of the steel members were designed based on linear elastic analysis, which was based on the initial member sizes. The initial member tubular shape may have been a poor initial guess for the members because the weight of the structure after the first design based on a linear analysis decreased significantly.

5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

All of the steel frame members that fail the 2005 AISC Specification provisions (whose names are stored in the group "FAILCK") in file "4a.AISC13_LRFD_LinearAnal_Design &CodeChk_Notional.gti" were designed using an interaction equation unity check of 0.90. Members that fail the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.90 required that the members be overdesigned by a value of 10%. The value for the unity check of 0.90 was selected by a trial and error process after multiple iterations were performed, so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5a. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti" can be found in Appendix AX.

The total weight after the second design iteration based on a linear elastic analysis was 2293.6 tons; however, more design iterations were required to obtain design convergence based on a linear elastic analysis.

5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

The members that fail the code checks during the second design iteration within file "5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" were redesigned using an interaction equation unity check of 0.85. Members that fail the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.85 required that the members be overdesigned by a value of 15%. The value for the unity check of 0.85 was selected after multiple iterations were performed so convergence could be achieved with fewer required iterations. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5b. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti" can be found in Appendix AY.

The total weight after the third iteration based on a linear elastic analysis was 2311.0 tons. Another iteration was required in order to obtain design convergence for a linear elastic analysis.

5c. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

The members that fail the code checks during the third design iteration within file "5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti" were redesigned using an interaction equation unity check of 0.80. Members that fail the code check needed to have larger shapes selected to satisfy code provisions, therefore an interaction equation unity check value of 0.80 required that the members be overdesigned by a value of 20%. The value for the unity check of 0.80 was selected after multiple iterations were performed so convergence could be achieved with fewer required iterations. The provisions within the 2005 AISC Specification were met by the linear elastic design, and therefore a nonlinear analysis could be performed on the model. The commands which define the redesign of the members which failed the code check, reanalysis of the structure, and code checks within file "5c. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti" can be found in Appendix AZ.

The total weight after the fourth design iteration based on a linear elastic analysis was 2321.0 tons. Figure 14 illustrates the design after convergence for a linear elastic analysis.

6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

Following a design that was produced by the traditional iterative linear elastic analysis and design approach that satisfies all code checks, the first rigorous nonlinear geometric elastic analysis pursuant to the AISC 13th Edition 2005 Specification Direct Analysis Method was performed on the model. If the structure was found to be stable, then all members were checked against the 2005 Specification provisions based on the nonlinear geometric analysis results. If the structure contained an instability, then all members were redesigned based on the previous linear elastic analysis results because a nonlinear analysis does not yield results which are in equilibrium with the full value of the applied loads when an instability is detected within the model.

The first nonlinear geometric was performed for the design loads described in file “2. Notional_Loads.gti”. A separate nonlinear analysis must be run for each of the different design load cases. If the nonlinear analysis did not converge within a specified tolerance, the structure was determined to be unstable for that load case.

For each nonlinear analysis, the 2005 Specification specifies a 20% reduction of EI and EA only (i.e., flexural stiffness and axial stiffness reductions). While this may be permissible for models whose behavior is similar to the behavior of the simplistic models for which such EI and EA reductions may be valid, the stiffness influence on nonlinear geometric behavior of important industrial steel frameworks is not influenced simply by flexural and axial stiffness, but rather stiffness influences of all six stiffness components (ie. axial, biaxial shear, torsion, and biaxial bending) can have a significant influence on nonlinear geometric behavior of such frameworks. Therefore, a 20% reduction of the elastic modulus (E) and shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis pursuant to the 2005 AISC Specification rigorous Direct Analysis Method within file “6a. NonlinearAnalysis_Original_Notional&AE_EI.gti” can be found in Appendix BA.

After the first nonlinear analysis was conducted, one load case caused a structural instability, while the rest of the load cases converged within three cycles. The total weight of the boiler building after a nonlinear analysis was performed does not change from the weight determined from the linear elastic analysis design (the weight of the structure stayed at 2312.10 tons)

4b. AISC13_LRFD_Design_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking and design. All members of the industrial structure must be redesigned, because it is very difficult to determine which combination of members, or what part of the structure, caused the structural instability. The structure was redesigned based upon the last linear analysis performed in file “5c. Redesign, LinearAnalysis, & CodeCheck_ Notional.gti”. All of the steel members in the structure were redesigned (not just members that failed code checks) using an interaction equation unity check of 0.70.

The value for the unity check of 0.70 required that the members be redesigned b a value of 30%; this value was selected after multiple iterations were performed so a stable design could be found with fewer required iterations. All of the members were smoothed in accordance to the groups established in file “1. Model&Indloads.gti”, where columns are smoothed by Euler buckling and beams and girders are smoothing by bending. The commands which describe the redesign of model within file “4b. AISC13_ LRFD_Design_Notional.gti” can be found in Appendix BB.

The total weight of the structure after all of the members were redesigned was 2227.7 tons.

6c. NonlinearAnalysis_ Notional&AE_EI.gti

A second nonlinear analysis was conducted on the structure using the new members redesigned in file “4b. AISC13_LRFD_Design_Notional.gti”. Again, a 20% reduction of the elastic modulus (E) and the shear modulus (G) was specified to account for the reduction of all six stiffness influences. The commands which describe the nonlinear elastic analysis within file “6c. NonlinearAnalysis_ Notional&AE_EI.gti” can be found in Appendix BC. All of the load cases converged within three iterations and the entire structure was stable. The weight of the model does not change from file “4b. AISC13_LRFD_ Design_Notional.gti” because the nonlinear analysis was based on the design of the steel frame members in file “4b. AISC13_LRFD_ Design_Notional.gti”.

7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. The steel members that formed the stable design of the boiler building model were checked against the 2005 AISC Specification requirements and based on the nonlinear analysis results. The names of members that failed the code check were placed in the group called "FAILCHK". The commands which describe the code checks after a nonlinear analysis within file "7a. AISC13_LRFD_CHECK_Using Nonlinear_Notional.gti" can be found in Appendix BD.

The total weight of the structure did not change since only code checks are performed. The weight of the structure was 2227.7 tons at this stage.

7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

The members that failed the code checks within file 7a.ASIC13_LRFD_ CHECK_UsingNonlinear_Notional.gti were redesigned using an interaction unity check value of 0.80. The value for the unity check of 0.80 required that the members be redesigned b a value of 20%; this value was selected after multiple iterations were performed so the design could converge with fewer required iterations. Another nonlinear analysis was performed to determine if the model remained stable after the redesign process. The elastic modulus (E) and shear modulus (G) were then returned to their standard values after the nonlinear analysis but prior to code checking. Additionally, all the members must satisfy the provisions within the 2005 AISC Specification. The commands which describe the redesign and reanalysis, using the nonlinear geometric analysis, and code checks within file “7b. Redesign, Nonlinear Analysis, & CodeCheck_ Notional.gti” can be found in Appendix BE.

The structure was found to be stable after several of the members in the structure were redesigned to satisfy the 2005 Specification. The total weight of boiler building model after a suitable design that was both stable using a geometric nonlinear analysis and satisfied the code, was found to be 2229.1 tons. Figure 15 gives the final design of the structure after converging for a nonlinear analysis.

99. NotionalLoadAnalysis_SupportJointReactions.gti

The application of notional loads may lead to fictitious base shears in a structure. A horizontal force that is equivalent to the sum of all of the notional loads can be applied at the base of the structure in the opposite direction as the notional loads to account for the fictitious loads [14].

Within this file, a linear elastic stiffness analysis was performed using the notional loads and the support reactions are listed which can be used to find the true base reactions by subtracting the value found by the analysis of the notional loads from the reactions of the most recent nonlinear analysis (file “7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti”) conducted. The commands which describe a linear elastic analysis of the model using the notional loads within file “99. NotionalLoadAnalysis_SupportJointReactions.gti” can be found in Appendix BF. The total weight of the structure remains as 2229.1 tons.

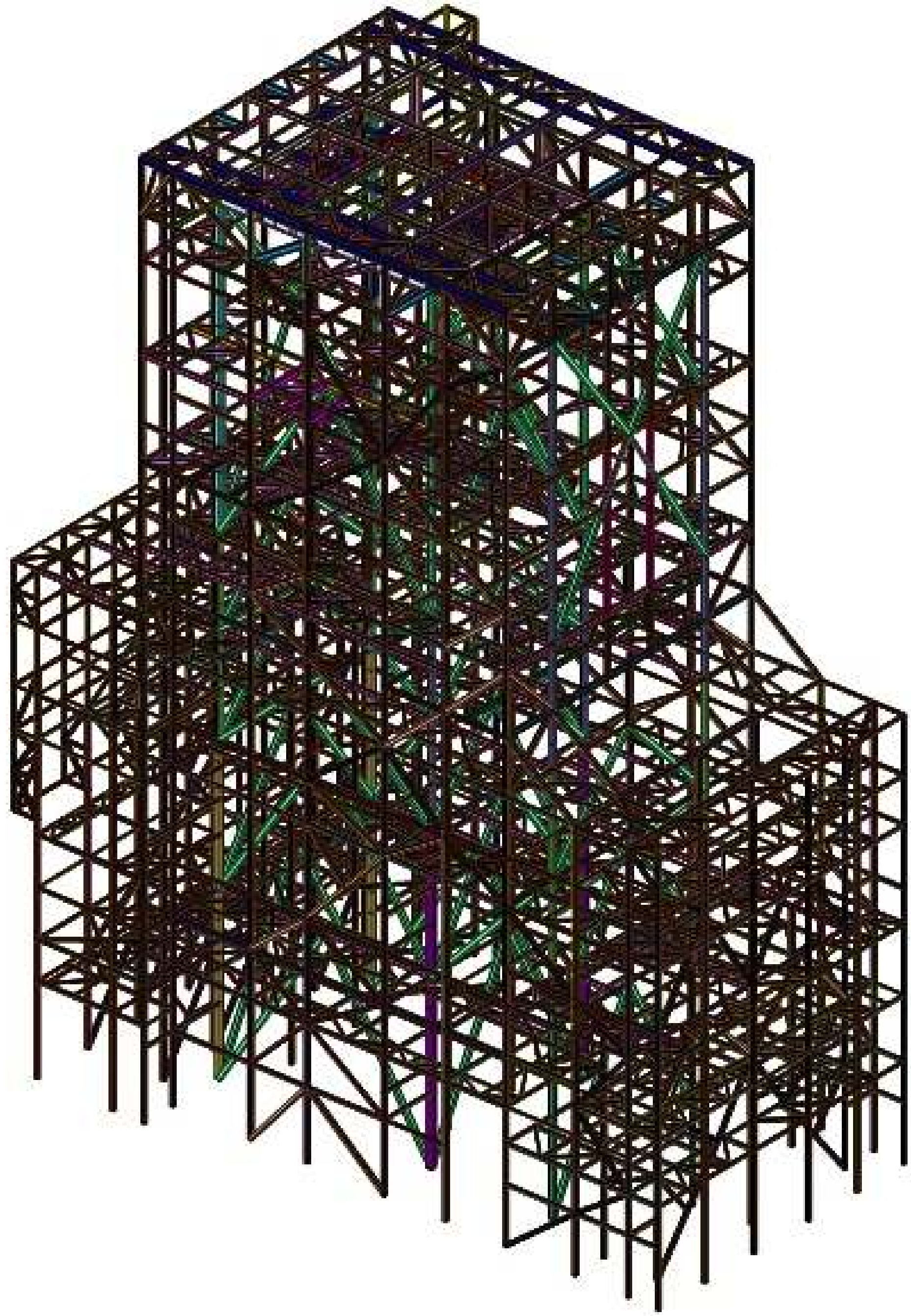

Figure 14: Boiler Building Design after Linear Elastic Design Convergence

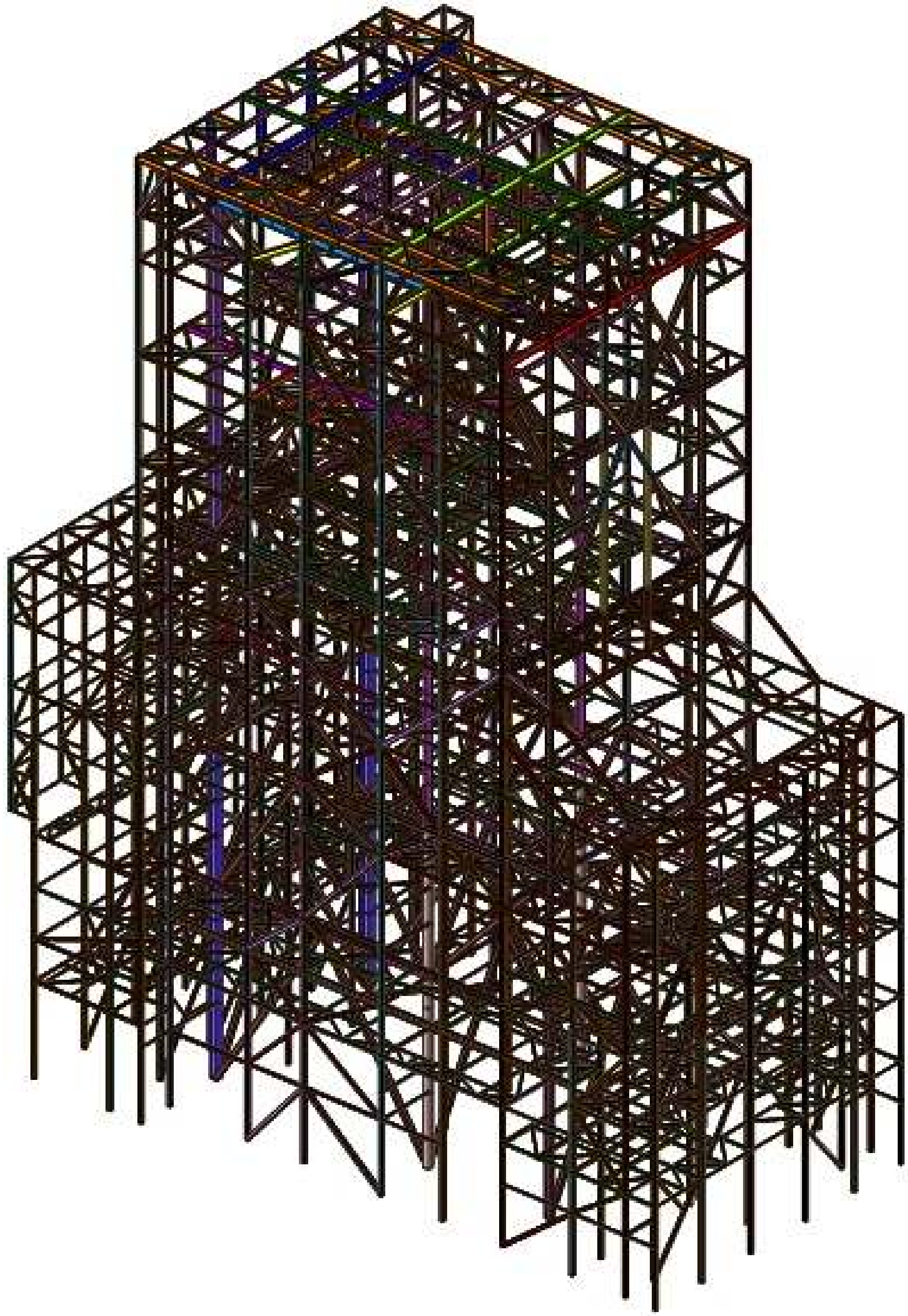

Figure 15: Boiler Building Design after Nonlinear Geometric Analysis Design Convergence

5.3 Discussion of Results

Multiple iterations were necessary to find a suitable linear elastic design that satisfies all of the provisions within the AISC 2005 Specification. The weight of the structure increased with each progressive iteration, making the structure more costly.

Multiple iterations were also necessary to find a stable design by a nonlinear analysis that accounts for geometric nonlinearities following the Direct Analysis Method given in the 13th Edition AISC 2005 Specification. However for a nonlinear analysis, a separate nonlinear analysis must be conducted on each formed load case for each cycle. This model, though complex, only contained 2517 joints and 5360 space frame members; much larger and more complex structures will need to be analyzed using a nonlinear analysis procedure. For a much larger structure, the time required to perform multiple iterations of a nonlinear analysis for the required load combinations could be substantial. The weight of the steel members also increased with each nonlinear analysis performed on the structure, because all members had to be redesigned when an instability was detected since the members causing the instability could not be determined.

Although the weight increased with each design cycle, the total weight of the structure decreased significantly from the original weight of the structure which contained the initial member sizes because the initial member shapes were guessed poorly. The weight of the steel frame members was tabulated throughout the process in Table 6.

Table 6: Total Weight of Steel - Boiler Building

File	Weight (Tons)
1. Model&Indloads.gti	3905.5
2. Notional_Loads.gti	3905.5
3a. LINEAR_STATIC_ANALYSIS_Notional.gti	3905.5
4a. AISC13_LRFD_LinearAnal_Design&CodeChk_Notional.gti (a)	2257.1
5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	2293.6
5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	2311.0
5c. Redesign, LinearAnalysis, & CodeCheck_Notional.gti (b)	2321.0
6a. NonlinearAnalysis_Original_Notional&AE_EI.gti (c)	2321.0
4b. AISC13_LRFD_Design_Notional.gti (d)	2227.7
6c. NonlinearAnalysis_Notional&AE_EI.gti (e)	2227.7
7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti	2227.7
7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti (f)	2229.1
99. NotionalLoadAnalysis_SupportJointReactions.gti	2229.1

Notes:

(a) Design all members based on first linear elastic analysis then reanalyze and code check.
(b) Redesign all members that fail code checks, reanalyze with linear elastic analysis and code check members.
(c) Structural Instability detected by nonlinear analysis.
(d) Redesign all members based on the last linear analysis results (in file 5c.)
(e) Stable structure.
(f) Redesign all members that fail code check, reanalyze with nonlinear geometric analysis and code check.

CHAPTER VI:

CONCLUSIONS AND RECOMMENDATIONS

6.1 Implications for the Engineer

The systematic approach for the practicing engineer to apply the Direct Analysis Method to analyze and design complex steel frame structures using computer software is highly iterative as is illustrated in the flow chart in Chapter 3 of this study as well as implemented in the sequence of files for Models 1 and 2 in this study. The consequence of this iterative process is computational time which will have an enormous impact on the practicing engineer. For a second-order analysis, the second-order effects on a structure are such that linear superposition principles are not valid; therefore a separate nonlinear analysis must be conducted for each of the independent design loading conditions on the structure. A given structure could have hundreds of independent design loading conditions and performing a nonlinear elastic analysis for each of the independent design load conditions could become quite time consuming and costly for the engineer.

Additionally, if structural instability is detected by a geometric nonlinear elastic analysis, all members within the structure may need to be redesigned by reducing the unity check, resulting in an overdesign of many members. All members must have new shapes selected because there is no way to determine in a reliable manner which combination of members and joints may have caused some structural instability from among a huge number of possible instabilities. In addition to the consequence of the time to the engineer, the structure could become much heavier (as seen in Model 1) when all members must be redesigned according to reduced unity checks.

6.2 Further Research

Further research is recommended to give a better understanding for the application of the AISC Direct Analysis Method on heavy industry industrial structures. The models of this study give a starting basis for research in heavy industry stability design.

The second model of this study, the nuclear power plant boiler building, should be studied further for the impact of adding a joint at mid-column of all the columns on the analyses and design process. Also the results of adding a joint in the midpoint of all of the beams could be studied on the boiler building (Model 2) as well as the simple industrial structure (Model 1).

Additionally, research is recommended to further study several other complex industrial structures. The original load conditions applied to the nuclear power plant boiler building (Model 2) in this study had to be significantly reduced to satisfy both linear and nonlinear elastic analysis and the provisions in the 2005 AISC Specification.

In addition to studying complex models, further research is recommended to determine what characteristics of the models in this study cause the linear analysis and subsequent design to have such a large difference in weight when the Direct Analysis Method is applied on the models and geometric nonlinear effects are considered. Smaller test problems are recommended to be developed to help answer this question. It is further recommended that an incremental nonlinear analysis be performed to aid in the determination of the source of the instabilities so members could be resized more selectively.

The geometric nonlinear analyses in this study are elastic. Further study on complex industrial models using nonlinear inelastic analysis procedures is desired to focus on the significance of using the Direct Analysis Method to analyze and design an industrial structure for strength and stability while considering the inelastic behavior of the structure.

APPENDIX A

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti

```
STRUDL 'bm2_01' 'Benchmark - GTSTRUDL'

LARGE PROBLEM SIZE 5

ACTIVE SOLVERS GTSES

$
UNIT FEET KIPS DEGREES
$
TYPE SPACE FRAME
$
JOINT COORDINATES
$
  101       821.67        -0.83     -1000.00
  102       821.67        -0.83     -1029.50
  103       821.67        -0.83     -1057.33
              .
              .
              .

STATUS SUPPORTS JOINTS 101 TO 121 BY 1
$
JOINT RELEASES
101 102 103 104 105 106 107 108 109 110   MOM X MOM Z
111 112 113 114 115 116 117 118   MOM X MOM Z
119 120 121
$

MEMBER INCIDENCES
$
  'Ca101'    101       201
  'Ca102'    102       202
  'Ca103'    103       203
              .
              .
              .

 'GZ201'     201       202
 'GZ202'     202       203
 'GZ203'     204       205
              .
              .
              .

 'GX201'     201       204
 'GX202'     204       207
 'GX203'     207       210
              .
              .
              .

UNITS INCH KIPS
CONSTANTS E 29000 ALL
          G 11600 ALL

UNITS FEET KIPS DEGREES
CONSTANTS
DENSITY 0.490 ALL

BETA 90.00 MEMBER -
'GZ601' 'GZ602' 'GZ603' 'GZ604'

$ PRINT STRUCTURE DATA

$ -----------------------------------------------------------------
```

```
$-----BEAM_and_COLUMN_MEMBERS-------------------------------------

$ ----------COLUMN GROUPS------------------------------------------

DEFINE GROUP 'C1-1' MEMBERS  -
   'Ca101'      'Ca102'      'Ca103'      'Ca201'      'Ca202'    -
   'Ca203'      'Ca301'      'Ca302'      'Ca303'

DEFINE GROUP 'C2-1' MEMBERS  -
   'Ca104'      'Ca105'      'Ca106'      'Ca204'      'Ca205'    -
   'Ca206'      'Ca304'      'Ca305'      'Ca306'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL COLUMNS------------------------
DEFINE GROUP 'COLUMNS' GROUPS -
   'C1-1'      'C2-1'      'C3-1'      'C3-2'      'C4-1'    -
   'C4-2'      'C5-1'      'C6-1'      'C7-1'      'C8-1'    -
   'C9-1'      'C9-2'
$ -----------------------------------------------------------------

$ ----------BEAMS and GIRDERS--------------------------------------

DEFINE GROUP '7Z-1' MEMBERS -
   'GZ701'      'GZ702'

DEFINE GROUP '7Z-2' MEMBERS -
   'GZ703'      'GZ704'      'GZ705'      'GZ706'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL BEAMS------------------------
DEFINE GROUP 'BEAMS' GROUPS -
   '7Z-1'      '7Z-2'      '7X-1'      '7X-2'      '6Z-1'    -
   '5X-1'      '5Z-1'      '4Z-1'      '4Z-2'      '4Z-3'    -
   '4X-1'      '4X-2'      '3Z-1'      '3Z-2'      '3Z-3'    -
   '3X-1'      '3X-2'      '2X-1'      '2X-2'      '2Z-1'    -
   '2Z-2'      '2Z-3'
$ -----------------------------------------------------------------


$ ---------------------------------------------------------------
DEFINE GRP 'ALLMEM' MEMBERS EXISTING MEMBERS ONLY
$ ---------------------------------------------------------------

MEMBER PROPERTIES TABLE 'W-AISC13'
   GRP 'COLUMNS' T 'W14X90'
   GRP 'BEAMS'   T  'W21X101'
$ ---------------------------------------------------------------

SAVE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

FINISH
```

APPENDIX B

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 2. STATIC_LOADS_with_Notional_LOAD_Command.gti

```
RESTORE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

LARGE PROBLEM SIZE 5

$ Define static loading conditions

UNITS KIPS FEET

SELF WEIGHT 'SW' 'SELF WEIGHT' DIRECTION -Y ALL MEMBERS

LOADING 'DL' 'ADDITIONAL DEAD LOADS'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.915
'GX704' FOR Y GLOB UNI W -0.889
'GX706' FOR Y GLOB UNI W -0.863
        .
        .
        .

$
LOADING 'LL' 'Live Loads'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.295
'GX704' FOR Y GLOB UNI W -0.287
'GX706' FOR Y GLOB UNI W -0.278
        .
        .
        .

JOINT LOADS
305 FORCE Y -100
308 FORCE Y -100


LOADING 'WLW' 'Wind Loads West'

JOINT LOADS

709     FOR     X       -9.48
708     FOR     X       -9.48
707     FOR     X       -9.48
        .
        .
        .


LOADING 'WLE' 'Wind Loads East'

JOINT LOADS

701     FOR     X       5.93
703     FOR     X       5.93
403     FOR     X       4.58
        .
        .
        .


LOADING 'WLN' 'Wind Loads North'

JOINT LOADS

704     FOR     Z       -6
701     FOR     Z       -6
317     FOR     Z       -6
        .
        .
        .
```

```
LOADING 'WLS' 'Wind Load South'

JOINT LOADS

709     FOR     Z       6
706     FOR     Z       6
703     FOR     Z       6
         .
         .
         .

$ ---------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NX_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'LL' 1.0         -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'LL' 1.0         -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------
$ 13th Edition LRFD Load Combinations

FORM LOADING '11-1' '1.4*(SW+DL)' -
       FROM 'SW' 1.4 'DL' 1.4
FORM LOADING '11-2' '1.4*(SW+DL) + NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL'  1.4
FORM LOADING '11-3' '1.4*(SW+DL) - NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL' -1.4
FORM LOADING '11-4' '1.4*(SW+DL) + NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL'  1.4
FORM LOADING '11-5' '1.4*(SW+DL) - NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL' -1.4

FORM LOADING '12-1' '1.2*(SW+DL)+1.6*(LL)' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6
FORM LOADING '12-2' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL'  1.6
FORM LOADING '12-3' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL' -1.6
FORM LOADING '12-4' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL' -1.6
FORM LOADING '12-5' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL'  1.6
```

```
FORM LOADING '12-6' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  1.6
FORM LOADING '12-7' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -1.6
FORM LOADING '12-8' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -1.6
FORM LOADING '12-9' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  1.6

FORM LOADING 13 '1.2*(SW+DL)+0.8*(WLW) - NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'WLW' 0.8 'NX_SW+DL' -1.2
FORM LOADING 14 '1.2*(SW+DL)+0.8*(WLE) + NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'WLE' 0.8 'NX_SW+DL'  1.2
FORM LOADING 15 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL' -0.5
FORM LOADING 16 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL'  0.5
FORM LOADING 17 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL'  0.5
FORM LOADING 18 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) +- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL' -0.5
FORM LOADING 19 '0.9*(SW+DL)+1.6*(WLW) - NOTIONAL_X' -
       FROM 'SW' 0.9 'DL' 0.9 'WLW' 1.6 'NX_SW+DL' -0.9
FORM LOADING 20 '0.9*(SW+DL)+1.6*(WLE) + NOTIONAL_X' -
       FROM 'SW' 0.9 'DL' 0.9 'WLE' 1.6 'NX_SW+DL'  0.9

FORM LOADING 21 '1.2*(SW+DL)+0.8*(WLN) - NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'WLN' 0.8 'NZ_SW+DL' -1.2
FORM LOADING 22 '1.2*(SW+DL)+0.8*(WLS) + NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'WLS' 0.8 'NZ_SW+DL'  1.2
FORM LOADING 23 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -0.5
FORM LOADING 24 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) ++ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  0.5
FORM LOADING 25 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -+ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  0.5
FORM LOADING 26 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) +- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -0.5
FORM LOADING 27 '0.9*(SW+DL)+1.6*(WLN) - NOTIONAL_Z' -
       FROM 'SW' 0.9 'DL' 0.9 'WLN' 1.6 'NZ_SW+DL' -0.9
FORM LOADING 28 '0.9*(SW+DL)+1.6*(WLS) + NOTIONAL_Z' -
       FROM 'SW' 0.9 'DL' 0.9 'WLS' 1.6 'NZ_SW+DL'  0.9

$ ---------------------------------------------------------------------------------------
QUERY

$ PRINT LOAD DATA

SAVE '2. STATIC_LOADS_Notional.gts'

FINISH
```

APPENDIX C

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 3a. LINEAR_STATIC_ANALYSIS_Notional.gti

```
RESTORE '2. Notional_Loads.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$  Perform linear static analysis for all currently
$  active factored limit state loading conditions.

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

UNITS INCH KIPS

OUTPUT DECIMAL 3
LIST DISPLACEMENTS JOINTS 'P2322' 'P2262' 'P1342' 'J1430'
$ LIST MAXIMUM JOINT DISPLACEMENT SUMMARY ONLY LOADS ACTIVE

OUTPUT BY JOINT $ ... and BY MEMBER
LIST SUM REACTIONS
LIST MAXIMUM REACTION ENVELOPE LOADS ACTIVE ONLY

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

FINISH
```

APPENDIX D

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

```
RESTORE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

LARGE PROBLEM SIZE 5

UNITS FT

$ ------------------------------------------
$ Steel design by the 13th Edition AISC code
$ ------------------------------------------
$ For all beams:
$     KY = KZ = 1.0
$
$ For all columns:
$     KY = KZ = 1.0
$
$ Use code units rather than:  UNITS ACTIVE ALL

$ ------------------------------------------------------------------


PARAMETERS
   CODE AISC13 ALL MEMEBERS
   METHOD LRFD ALL MEMBERS
   STEELGRD A992 ALL   $ 50 ksi STEEL
   CODETOL 0.0 ALL $ Unity check = 1.0

   TBLNAM   WBEAM-13 MEMBERS GRP 'BEAMS'   $ All beams
   TBLNAM   WCOL-13  MEMBERS GRP 'COLUMNS' $ All columns
   KZ       1.0      ALL MEMBERS
   KY       1.0      ALL MEMBERS
   SLENCOMP 300      MEMBERS GRP 'BEAMS'   $ All beams
   CB       1.0      ALL MEMBERS
   CM       1.0      ALL MEMBERS


$------------- UNLCF (Maximum unbraced length of compression flange) ----------------

UNLCF   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
UNLCF   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .


$-------------------------------------------------------------------------------------

$---------------------------------LY GIRDERS------------------------------------------

LY   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LY   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$---------------------------------LZ GIRDERS------------------------------------------

LZ  29.500  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LZ  27.833  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$---------------LZ (Unbraced length) of Columns--------------------------------------

$-------------------------------------------------------------------------------------

LZ  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121'
```

```
LZ  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221'
                .
                .
                .


$-------------------------------------------------------------------------------------


$---------------------------------LY of Columns--------------------------------------

LY  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121'

LY  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221'
                .
                .
                .

$-------------------------------------------------------------------------------------

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL -7.0 ALL $ 7% overdesign to improve design iteration convergence
$                     (i.e., Unity check = 0.93)

SELECT MEMBERS GRP 'BEAMS'    $ All beams
SELECT MEMBERS GRP 'COLUMNS'  $ All columns

UNITS KIP
STEEL TAKE OFF

$ ----------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix 7 states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.
```

```
$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION X JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION Z JOINTS EXISTING
$ ----------------------------------------------------------------------------------------

FORM LOAD REFORM $ Reform all FORM LOADS with the updated notional loads
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ -----------------------------------------------------------------
$ Perform a code check for all members for design loads
$ -----------------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '4a. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX E

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '4a. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------
$ Design all members that failed the previous code check
$ -------------------------------------------------------
PARAMETERS
   CODETOL -15.0 ALL $ Require a 15% overdesign to improve design iteration convergence
$                     (i.e., Unity check = 0.85)

SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

$ ------------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design.
$ ------------------------------------------------------------------
UNITS KIP
$ STEEL  TAKE  OFF  MEMBERS  EXISTING ITEMIZE BY PROFILE NAMES   $ All members
STEEL TAKE OFF $ All members

$ ------------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                               FROM 'SW' 1.0 'DL' 1.0 -
                               GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                               FROM 'SW' 1.0 'DL' 1.0 -
                               GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ------------------------------------------------------
$ Perform a code check for all members for design loads
$ ------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '5c. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX F

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '5c. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ ------------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design smoothing.
$ ------------------------------------------------------------------
UNITS KIP
STEEL TAKE OFF    $ All members

$ -----------------------------------------------------
$ Design all members that failed the previous code check
$ -----------------------------------------------------
PARAMETERS
   CODETOL -20.0 ALL $ Require a 5% overdesign to improve design iteration convergence $
-10.0 ALL $ Require a 5% overdesign to improve design iteration convergence
$                    (i.e., Unity check = 0.80)

SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

UNITS KIP
STEEL TAKE OFF  $ All members

$ ---------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ----------------------------------------------------
$ Perform a code check for all members for design loads
$ ----------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                      (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '5b. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX G

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

```
RESTORE '5b. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ -------------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

SAVE '6. NonlinearAnalysis_Original_Notional.gts'
FINISH
```

APPENDIX H

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 4b. AISC13_LRFD_DESIGN_Notional.gti

```
RESTORE '5b. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

UNITS KIP
STEEL  TAKE  OFF

$ Redesign all members
PARAMETERS
   CODETOL -20.0 ALL $ Unity check = 0.80

SELECT MEMBERS GRP 'BEAMS'    $ All beams
SELECT MEMBERS GRP 'COLUMNS'  $ All columns

UNITS KIP
STEEL TAKE OFF

$ ------------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------

FORM LOAD REFORM

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

SAVE '4b. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX I

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 6c. NonlinearAnalysis_Original_Notional&AE_EI.gti

```
RESTORE '4b. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ -------------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

SAVE '6. NonlinearAnalysis_Original_Notional.gts'
FINISH
```

APPENDIX J

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 3b. LINEAR_STATIC_ANALYSIS_Notional.gti

```
RESTORE '4b. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

$  Perform linear static analysis for all currently
$  active factored limit state loading conditions.

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

FORM LOAD REFORM

QUERY
STIFFNESS ANALYSIS

LIST SUM REACTIONS

SAVE '4b. LRFD3_DESIGN_Notional.gts'

FINISH
```

APPENDIX K

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 4c. AISC13_LRFD_DESIGN_Notional.gti

```
RESTORE '4b. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL -35.0 ALL $ Unity check = 0.65

SELECT MEMBERS GRP 'BEAMS'    $ All beams
SELECT MEMBERS GRP 'COLUMNS'  $ All columns

UNITS KIP
STEEL TAKE OFF

$ ---------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

SAVE '4b. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX L

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

```
RESTORE '6. NonlinearAnalysis_Original_Notional.gts'

LARGE PROBLEM SIZE 5

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

CHECK CODE ALL MEMBERS

UNITS KIP FEET
STEEL TAKE OFF

SAVE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX M

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SELECT MEMBERS GRP 'FAILCK'

STEEL TAKE OFF

$ ------------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ ----------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ ----------------------------------------------------------------------------------------

LIST SUM REACTIONS

UNITS INCH KIPS
CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

CHECK CODE ALL MEMBERS

UNITS KIP FEET
STEEL TAKE OFF

SAVE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX N

Model 1 - Case 1: No Extra Joints Mid-Column and No Smoothing
File: 99. NotionalLoadAnalysis_SupportJointReactions.gti

```
RESTORE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ -----------------------------------------------------
$ This is the last analysis run based on the following:
$ -----------------------------------------------------
$ ---------------------------------------------------------------------------------------
$ Paper by Dr. R. Shankar Nair, "Stability and Analysis Provisions of the 2005 AISC
$ Specification", Page 9 "2.2 Consideration of Initial Imperfections:  User Note: The
$ notional loads do not cause a net horizontal reaction on the foundation but may, in
$ some cases, cause horizontal reactions on the individual foundation components. A
$ horizontal force of Sum(Ni), opposite in direction to the notional loads, may be
$ applied in the analysis at the bases of all columns to yield the correct reactions at
$ the foundation."
$ ---------------------------------------------------------------------------------------
$ Therefore, perform a linear static analysis for the notional loads, output the support
$ reactions, and then use the notional load reaction components to subtract from the
$ reactions of the most recent nonlinear analyses.
$ ---------------------------------------------------------------------------------------

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST 'NX_SW+DL' 'NZ_SW+DL' 'NX_LL' 'NZ_LL'

QUERY
STIFFNESS ANALYSIS

OUTPUT DECIMAL 3
OUTPUT BY JOINT
LIST REACTIONS

LOAD LIST ALL

SAVE '99. NotionalLoadAnalysis_SupportJointReactions.gts'

FINISH
```

APPENDIX O

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti

```
STRUDL 'bm2_01' 'Benchmark - GTSTRUDL'

LARGE PROBLEM SIZE 5

ACTIVE SOLVERS GTSES

$
UNIT FEET KIPS DEGREES
$
TYPE SPACE FRAME
$
JOINT COORDINATES
$
  101       821.67        -0.83     -1000.00
  102       821.67        -0.83     -1029.50
  103       821.67        -0.83     -1057.33
              .
              .
              .

STATUS SUPPORTS JOINTS 101 TO 121 BY 1
$
JOINT RELEASES
101 102 103 104 105 106 107 108 109 110   MOM X MOM Z
111 112 113 114 115 116 117 118   MOM X MOM Z
119 120 121
$

MEMBER INCIDENCES
$
  'Ca101'    101       201
  'Ca102'    102       202
  'Ca103'    103       203
              .
              .
              .

 'GZ201'     201       202
 'GZ202'     202       203
 'GZ203'     204       205
              .
              .
              .

 'GX201'     201       204
 'GX202'     204       207
 'GX203'     207       210
              .
              .
              .

UNITS INCH KIPS
CONSTANTS E 29000 ALL
          G 11600 ALL

UNITS FEET KIPS DEGREES
CONSTANTS
DENSITY 0.490 ALL

BETA 90.00 MEMBER -
'GZ601' 'GZ602' 'GZ603' 'GZ604'

$ PRINT STRUCTURE DATA

$ ----------------------------------------------------------------
```

```
$-----BEAM_and_COLUMN_MEMBERS------------------------------------

$ ----------COLUMN GROUPS------------------------------------------

DEFINE GROUP 'C1-1' MEMBERS  -
   'Ca101'      'Ca102'      'Ca103'      'Ca201'      'Ca202'    -
   'Ca203'      'Ca301'      'Ca302'      'Ca303'

DEFINE GROUP 'C2-1' MEMBERS  -
   'Ca104'      'Ca105'      'Ca106'      'Ca204'      'Ca205'    -
   'Ca206'      'Ca304'      'Ca305'      'Ca306'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL COLUMNS------------------------
DEFINE GROUP 'COLUMNS' GROUPS -
   'C1-1'      'C2-1'      'C3-1'      'C3-2'      'C4-1'    -
   'C4-2'      'C5-1'      'C6-1'      'C7-1'      'C8-1'    -
   'C9-1'      'C9-2'
$ -----------------------------------------------------------------

$ ----------BEAMS and GIRDERS--------------------------------------

DEFINE GROUP '7Z-1' MEMBERS -
   'GZ701'      'GZ702'

DEFINE GROUP '7Z-2' MEMBERS -
   'GZ703'      'GZ704'      'GZ705'      'GZ706'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL BEAMS------------------------
DEFINE GROUP 'BEAMS' GROUPS -
   '7Z-1'      '7Z-2'      '7X-1'      '7X-2'      '6Z-1'    -
   '5X-1'      '5Z-1'      '4Z-1'      '4Z-2'      '4Z-3'    -
   '4X-1'      '4X-2'      '3Z-1'      '3Z-2'      '3Z-3'    -
   '3X-1'      '3X-2'      '2X-1'      '2X-2'      '2Z-1'    -
   '2Z-2'      '2Z-3'
$ -----------------------------------------------------------------


$ ---------------------------------------------------------------
DEFINE GRP 'ALLMEM' MEMBERS EXISTING MEMBERS ONLY
$ ---------------------------------------------------------------

MEMBER PROPERTIES TABLE 'W-AISC13'
   GRP 'COLUMNS' T 'W14X90'
   GRP 'BEAMS'   T  'W21X101'
$ ---------------------------------------------------------------

SAVE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

FINISH
```

APPENDIX P

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 2. STATIC_LOADS_with_Notional_LOAD_Command.gti

```
RESTORE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

LARGE PROBLEM SIZE 5

$ Define static loading conditions

UNITS KIPS FEET

SELF WEIGHT 'SW' 'SELF WEIGHT' DIRECTION -Y ALL MEMBERS

LOADING 'DL' 'ADDITIONAL DEAD LOADS'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.915
'GX704' FOR Y GLOB UNI W -0.889
'GX706' FOR Y GLOB UNI W -0.863
        .
        .
        .

$
LOADING 'LL' 'Live Loads'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.295
'GX704' FOR Y GLOB UNI W -0.287
'GX706' FOR Y GLOB UNI W -0.278
        .
        .
        .

JOINT LOADS
305 FORCE Y -100
308 FORCE Y -100


LOADING 'WLW' 'Wind Loads West'

JOINT LOADS

709     FOR     X       -9.48
708     FOR     X       -9.48
707     FOR     X       -9.48
        .
        .
        .


LOADING 'WLE' 'Wind Loads East'

JOINT LOADS

701     FOR     X       5.93
703     FOR     X       5.93
403     FOR     X       4.58
        .
        .
        .


LOADING 'WLN' 'Wind Loads North'

JOINT LOADS

704     FOR     Z       -6
701     FOR     Z       -6
317     FOR     Z       -6
        .
        .
        .
```

```
LOADING 'WLS' 'Wind Load South'

JOINT LOADS

709    FOR    Z      6
706    FOR    Z      6
703    FOR    Z      6
        .
        .
        .

$ ------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                              FROM 'SW' 1.0 'DL' 1.0 -
                              GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                              FROM 'SW' 1.0 'DL' 1.0 -
                              GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NX_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                              FROM 'LL' 1.0          -
                              GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                              FROM 'LL' 1.0          -
                              GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------
$ 13th Edition LRFD Load Combinations

FORM LOADING '11-1' '1.4*(SW+DL)' -
       FROM 'SW' 1.4 'DL' 1.4
FORM LOADING '11-2' '1.4*(SW+DL) + NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL'  1.4
FORM LOADING '11-3' '1.4*(SW+DL) - NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL' -1.4
FORM LOADING '11-4' '1.4*(SW+DL) + NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL'  1.4
FORM LOADING '11-5' '1.4*(SW+DL) - NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL' -1.4

FORM LOADING '12-1' '1.2*(SW+DL)+1.6*(LL)' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6
FORM LOADING '12-2' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL'  1.6
FORM LOADING '12-3' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL' -1.6
FORM LOADING '12-4' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL' -1.6
FORM LOADING '12-5' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL'  1.6
```

```
FORM LOADING '12-6' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  1.6
FORM LOADING '12-7' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -1.6
FORM LOADING '12-8' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -1.6
FORM LOADING '12-9' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  1.6

FORM LOADING 13 '1.2*(SW+DL)+0.8*(WLW) - NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'WLW' 0.8 'NX_SW+DL' -1.2
FORM LOADING 14 '1.2*(SW+DL)+0.8*(WLE) + NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'WLE' 0.8 'NX_SW+DL'  1.2
FORM LOADING 15 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL' -0.5
FORM LOADING 16 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL'  0.5
FORM LOADING 17 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL'  0.5
FORM LOADING 18 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) +- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL' -0.5
FORM LOADING 19 '0.9*(SW+DL)+1.6*(WLW) - NOTIONAL_X' -
       FROM 'SW' 0.9 'DL' 0.9 'WLW' 1.6 'NX_SW+DL' -0.9
FORM LOADING 20 '0.9*(SW+DL)+1.6*(WLE) + NOTIONAL_X' -
       FROM 'SW' 0.9 'DL' 0.9 'WLE' 1.6 'NX_SW+DL'  0.9

FORM LOADING 21 '1.2*(SW+DL)+0.8*(WLN) - NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'WLN' 0.8 'NZ_SW+DL' -1.2
FORM LOADING 22 '1.2*(SW+DL)+0.8*(WLS) + NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'WLS' 0.8 'NZ_SW+DL'  1.2
FORM LOADING 23 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -0.5
FORM LOADING 24 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) ++ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  0.5
FORM LOADING 25 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -+ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  0.5
FORM LOADING 26 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) +- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -0.5
FORM LOADING 27 '0.9*(SW+DL)+1.6*(WLN) - NOTIONAL_Z' -
       FROM 'SW' 0.9 'DL' 0.9 'WLN' 1.6 'NZ_SW+DL' -0.9
FORM LOADING 28 '0.9*(SW+DL)+1.6*(WLS) + NOTIONAL_Z' -
       FROM 'SW' 0.9 'DL' 0.9 'WLS' 1.6 'NZ_SW+DL'  0.9

$ -----------------------------------------------------------------------------------------
QUERY

$ PRINT LOAD DATA

SAVE '2. STATIC_LOADS_Notional.gts'

FINISH
```

APPENDIX Q

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 3a. LINEAR_STATIC_ANALYSIS_Notional.gti

```
RESTORE '2. Notional_Loads.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$  Perform linear static analysis for all currently
$  active factored limit state loading conditions.

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

UNITS INCH KIPS

OUTPUT DECIMAL 3
LIST DISPLACEMENTS JOINTS 'P2322' 'P2262' 'P1342' 'J1430'
$ LIST MAXIMUM JOINT DISPLACEMENT SUMMARY ONLY LOADS ACTIVE

OUTPUT BY JOINT $ ... and BY MEMBER
LIST SUM REACTIONS
LIST MAXIMUM REACTION ENVELOPE LOADS ACTIVE ONLY

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

FINISH
```

APPENDIX R

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

```
RESTORE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

LARGE PROBLEM SIZE 5

UNITS FT

$ ------------------------------------------
$ Steel design by the 13th Edition AISC code
$ ------------------------------------------
$ For all beams:
$     KY = KZ = 1.0
$
$ For all columns:
$     KY = KZ = 1.0
$
$ Use code units rather than:  UNITS ACTIVE ALL

$ -----------------------------------------------------------------


PARAMETERS
   CODE AISC13 ALL MEMEBERS
   METHOD LRFD ALL MEMBERS
   STEELGRD A992 ALL   $ 50 ksi STEEL
   CODETOL 0.0 ALL $ Unity check = 1.0

   TBLNAM   WBEAM-13 MEMBERS GRP 'BEAMS'   $ All beams
   TBLNAM   WCOL-13  MEMBERS GRP 'COLUMNS' $ All columns
   KZ       1.0      ALL MEMBERS
   KY       1.0      ALL MEMBERS
   SLENCOMP 300      MEMBERS GRP 'BEAMS'   $ All beams
   CB       1.0      ALL MEMBERS
   CM       1.0      ALL MEMBERS


$------------- UNLCF (Maximum unbraced length of compression flange) ----------------

UNLCF   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
UNLCF   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .


$-------------------------------------------------------------------------------------

$-------------------------------LY GIRDERS------------------------------------------

LY   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LY   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$-------------------------------LZ GIRDERS------------------------------------------

LZ  29.500  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LZ  27.833  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$---------------LZ (Unbraced length) of Columns-------------------------------------

$-------------------------------------------------------------------------------------

LZ  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121'
```

```
LZ  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221'
                .
                .
                .


$-------------------------------------------------------------------------------------


$---------------------------------LY of Columns--------------------------------------

LY  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121'

LY  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221'
                .
                .
                .

$-------------------------------------------------------------------------------------

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL -7.0 ALL $ 7% overdesign to improve design iteration convergence
$                    (i.e., Unity check = 0.93)

SELECT MEMBERS GRP 'BEAMS'    $ All beams
SELECT MEMBERS GRP 'COLUMNS'  $ All columns

UNITS KIP
STEEL TAKE OFF
$ ---------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0.smooth.gti'
$ ---------------------------------------------------------------
STEEL TAKE OFF

$ -------------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix 7 states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
```

```
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION X JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION Z JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM $ Reform all FORM LOADS with the updated notional loads
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ---------------------------------------------------------------
$ Perform a code check for all members for design loads
$ ---------------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '4a. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX S

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '4a. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------
$ Design all members that failed the previous code check
$ -------------------------------------------------------
PARAMETERS
   CODETOL -15.0 ALL $ Require a 15% overdesign to improve design iteration convergence
$                     (i.e., Unity check = 0.85)

SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

$ ------------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design.
$ ------------------------------------------------------------------
UNITS KIP

STEEL TAKE OFF $ All members
$ --------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0.smooth.gti'
$ --------------------------------------------------------------
STEEL TAKE OFF

$ ----------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ----------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ------------------------------------------------------
$ Perform a code check for all members for design loads
$ ------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '5c. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX T

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

```
RESTORE '5b. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -----------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ -----------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

SAVE '6. NonlinearAnalysis_Original_Notional.gts'
FINISH
```

APPENDIX U

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

```
RESTORE '6. NonlinearAnalysis_Original_Notional.gts'

LARGE PROBLEM SIZE 5

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

CHECK CODE ALL MEMBERS

UNITS KIP FEET
STEEL TAKE OFF

SAVE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX V

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SELECT MEMBERS GRP 'FAILCK'

UNITS KIP FEET
STEEL TAKE OFF

$ ---------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0.smooth.gti'
$ ---------------------------------------------------------------

STEEL TAKE OFF

$ ------------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ ----------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ ----------------------------------------------------------------------------------------

LIST SUM REACTIONS

UNITS INCH KIPS
CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

CHECK CODE ALL MEMBERS
```

```
UNITS KIP FEET
STEEL TAKE OFF

SAVE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX W

Model 1 - Case 2: With Smoothing and No Extra Joints Mid-Column
File: 99. NotionalLoadAnalysis_SupportJointReactions.gti

```
RESTORE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ -----------------------------------------------------
$ This is the last analysis run based on the following:
$ -----------------------------------------------------
$ ---------------------------------------------------------------------------------------
$  Paper by Dr. R. Shankar Nair, “Stability and Analysis Provisions of the 2005 AISC
$  Specification”, Page 9 “2.2 Consideration of Initial Imperfections:  User Note: The
$  notional loads do not cause a net horizontal reaction on the foundation but may, in
$  some cases, cause horizontal reactions on the individual foundation components. A
$  horizontal force of Sum(Ni), opposite in direction to the notional loads, may be
$ applied in the analysis at the bases of all columns to yield the correct reactions at
$ the foundation.”
$ ---------------------------------------------------------------------------------------
$ Therefore, perform a linear static analysis for the notional loads, output the support
$  reactions, and then use the notional load reaction components to subtract from the
$ reactions of the most recent nonlinear analyses.
$ ---------------------------------------------------------------------------------------

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST 'NX_SW+DL' 'NZ_SW+DL' 'NX_LL' 'NZ_LL'

QUERY
STIFFNESS ANALYSIS

OUTPUT DECIMAL 3
OUTPUT BY JOINT
LIST REACTIONS

LOAD LIST ALL

SAVE '99. NotionalLoadAnalysis_SupportJointReactions.gts'

FINISH
```

APPENDIX X

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti

```
STRUDL 'bm2_01' 'Benchmark - GTSTRUDL'

LARGE PROBLEM SIZE 5

ACTIVE SOLVERS GTSES

$
UNIT FEET KIPS DEGREES
$
TYPE SPACE FRAME
$
JOINT COORDINATES
$
  101       821.67        -0.83     -1000.00
  102       821.67        -0.83     -1029.50
  103       821.67        -0.83     -1057.33
              .
              .
              .

STATUS SUPPORTS JOINTS 101 TO 121 BY 1
$
JOINT RELEASES
101 102 103 104 105 106 107 108 109 110   MOM X MOM Z
111 112 113 114 115 116 117 118   MOM X MOM Z
119 120 121
$

MEMBER INCIDENCES
$
  'Ca101'    101       201
  'Ca102'    102       202
  'Ca103'    103       203
              .
              .
              .

  'Cb101'   1001       201
  'Cb102'   1002       202
  'Cb103'   1003       203
              .
              .
              .


 'GZ201'     201       202
 'GZ202'     202       203
 'GZ203'     204       205
              .
              .
              .

 'GX201'     201       204
 'GX202'     204       207
 'GX203'     207       210
              .
              .
              .

UNITS INCH KIPS
CONSTANTS E 29000 ALL
          G 11600 ALL

UNITS FEET KIPS DEGREES
CONSTANTS
DENSITY 0.490 ALL

BETA 90.00 MEMBER -
'GZ601' 'GZ602' 'GZ603' 'GZ604'
```

```
$ PRINT STRUCTURE DATA

$ ------------------------------------------------------------------

$-----BEAM_and_COLUMN_MEMBERS-------------------------------------

$ ----------COLUMN GROUPS------------------------------------------

DEFINE GROUP 'C1-1' MEMBERS  -
   'Ca101'      'Ca102'      'Ca103'      'Ca201'      'Ca202'    -
   'Ca203'      'Ca301'      'Ca302'      'Ca303'      'Cb101'    -
   'Cb102'      'Cb103'      'Cb201'      'Cb202'      'Cb203'    -
   'Cb301'      'Cb302'      'Cb303'

DEFINE GROUP 'C2-1' MEMBERS  -
   'Ca104'      'Ca105'      'Ca106'      'Ca204'      'Ca205'    -
   'Ca206'      'Ca304'      'Ca305'      'Ca306'      'Cb104'    -
   'Cb105'      'Cb106'      'Cb204'      'Cb205'      'Cb206'    -
   'Cb304'      'Cb305'      'Cb306'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL COLUMNS------------------------
DEFINE GROUP 'COLUMNS' GROUPS -
   'C1-1'      'C2-1'      'C3-1'      'C3-2'      'C4-1'    -
   'C4-2'      'C5-1'      'C6-1'      'C7-1'      'C8-1'    -
   'C9-1'      'C9-2'
$ -------------------------------------------------------------------

$ ----------BEAMS and GIRDERS--------------------------------------

DEFINE GROUP '7Z-1' MEMBERS -
   'GZ701'      'GZ702'

DEFINE GROUP '7Z-2' MEMBERS -
   'GZ703'      'GZ704'      'GZ705'      'GZ706'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL BEAMS------------------------
DEFINE GROUP 'BEAMS' GROUPS -
   '7Z-1'      '7Z-2'      '7X-1'      '7X-2'      '6Z-1'    -
   '5X-1'      '5Z-1'      '4Z-1'      '4Z-2'      '4Z-3'    -
   '4X-1'      '4X-2'      '3Z-1'      '3Z-2'      '3Z-3'    -
   '3X-1'      '3X-2'      '2X-1'      '2X-2'      '2Z-1'    -
   '2Z-2'      '2Z-3'
$ -------------------------------------------------------------------


$ ------------------------------------------------------------------
DEFINE GRP 'ALLMEM' MEMBERS EXISTING MEMBERS ONLY
$ ------------------------------------------------------------------

MEMBER PROPERTIES TABLE 'W-AISC13'
   GRP 'COLUMNS' T 'W14X90'
   GRP 'BEAMS'   T  'W21X101'
$ ------------------------------------------------------------------

SAVE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

FINISH
```

APPENDIX Y

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 2. STATIC_LOADS_with_Notional_LOAD_Command.gti

```
RESTORE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

LARGE PROBLEM SIZE 5

$ Define static loading conditions

UNITS KIPS FEET

SELF WEIGHT 'SW' 'SELF WEIGHT' DIRECTION -Y ALL MEMBERS

LOADING 'DL' 'ADDITIONAL DEAD LOADS'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.915
'GX704' FOR Y GLOB UNI W -0.889
'GX706' FOR Y GLOB UNI W -0.863
        .
        .
        .

$
LOADING 'LL' 'Live Loads'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.295
'GX704' FOR Y GLOB UNI W -0.287
'GX706' FOR Y GLOB UNI W -0.278
        .
        .
        .

JOINT LOADS
305 FORCE Y -100
308 FORCE Y -100


LOADING 'WLW' 'Wind Loads West'

JOINT LOADS

709     FOR     X       -9.48
708     FOR     X       -9.48
707     FOR     X       -9.48
        .
        .
        .


LOADING 'WLE' 'Wind Loads East'

JOINT LOADS

701     FOR     X       5.93
703     FOR     X       5.93
403     FOR     X       4.58
        .
        .
        .


LOADING 'WLN' 'Wind Loads North'

JOINT LOADS

704     FOR     Z       -6
701     FOR     Z       -6
317     FOR     Z       -6
        .
        .
        .
```

```
LOADING 'WLS' 'Wind Load South'

JOINT LOADS

709     FOR     Z       6
706     FOR     Z       6
703     FOR     Z       6
         .
         .
         .

$ ------------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                              FROM 'SW' 1.0 'DL' 1.0 -
                              GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                              FROM 'SW' 1.0 'DL' 1.0 -
                              GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NX_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                              FROM 'LL' 1.0          -
                              GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                              FROM 'LL' 1.0          -
                              GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------
$ 13th Edition LRFD Load Combinations

FORM LOADING '11-1' '1.4*(SW+DL)' -
       FROM 'SW' 1.4 'DL' 1.4
FORM LOADING '11-2' '1.4*(SW+DL) + NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL'  1.4
FORM LOADING '11-3' '1.4*(SW+DL) - NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL' -1.4
FORM LOADING '11-4' '1.4*(SW+DL) + NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL'  1.4
FORM LOADING '11-5' '1.4*(SW+DL) - NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL' -1.4

FORM LOADING '12-1' '1.2*(SW+DL)+1.6*(LL)' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6
FORM LOADING '12-2' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL'  1.6
FORM LOADING '12-3' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL' -1.6
FORM LOADING '12-4' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL' -1.6
FORM LOADING '12-5' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL'  1.6
```

```
FORM LOADING '12-6' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  1.6
FORM LOADING '12-7' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -1.6
FORM LOADING '12-8' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -1.6
FORM LOADING '12-9' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  1.6

FORM LOADING 13 '1.2*(SW+DL)+0.8*(WLW) - NOTIONAL_X' -
        FROM 'SW' 1.2 'DL' 1.2 'WLW' 0.8 'NX_SW+DL' -1.2
FORM LOADING 14 '1.2*(SW+DL)+0.8*(WLE) + NOTIONAL_X' -
        FROM 'SW' 1.2 'DL' 1.2 'WLE' 0.8 'NX_SW+DL'  1.2
FORM LOADING 15 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -- NOTIONAL_X' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL' -0.5
FORM LOADING 16 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) ++ NOTIONAL_X' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL'  0.5
FORM LOADING 17 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -+ NOTIONAL_X' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL'  0.5
FORM LOADING 18 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) +- NOTIONAL_X' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL' -0.5
FORM LOADING 19 '0.9*(SW+DL)+1.6*(WLW) - NOTIONAL_X' -
        FROM 'SW' 0.9 'DL' 0.9 'WLW' 1.6 'NX_SW+DL' -0.9
FORM LOADING 20 '0.9*(SW+DL)+1.6*(WLE) + NOTIONAL_X' -
        FROM 'SW' 0.9 'DL' 0.9 'WLE' 1.6 'NX_SW+DL'  0.9

FORM LOADING 21 '1.2*(SW+DL)+0.8*(WLN) - NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'WLN' 0.8 'NZ_SW+DL' -1.2
FORM LOADING 22 '1.2*(SW+DL)+0.8*(WLS) + NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'WLS' 0.8 'NZ_SW+DL'  1.2
FORM LOADING 23 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -- NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -0.5
FORM LOADING 24 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) ++ NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  0.5
FORM LOADING 25 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -+ NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  0.5
FORM LOADING 26 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) +- NOTIONAL_Z' -
        FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -0.5
FORM LOADING 27 '0.9*(SW+DL)+1.6*(WLN) - NOTIONAL_Z' -
        FROM 'SW' 0.9 'DL' 0.9 'WLN' 1.6 'NZ_SW+DL' -0.9
FORM LOADING 28 '0.9*(SW+DL)+1.6*(WLS) + NOTIONAL_Z' -
        FROM 'SW' 0.9 'DL' 0.9 'WLS' 1.6 'NZ_SW+DL'  0.9

$ ------------------------------------------------------------------------------------------
QUERY

$ PRINT LOAD DATA

SAVE '2. STATIC_LOADS_Notional.gts'

FINISH
```

APPENDIX Z

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 3a. LINEAR_STATIC_ANALYSIS_Notional.gti

```
RESTORE '2. Notional_Loads.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$  Perform linear static analysis for all currently
$  active factored limit state loading conditions.

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

UNITS INCH KIPS

OUTPUT DECIMAL 3
LIST DISPLACEMENTS JOINTS 'P2322' 'P2262' 'P1342' 'J1430'
$ LIST MAXIMUM JOINT DISPLACEMENT SUMMARY ONLY LOADS ACTIVE

OUTPUT BY JOINT $ ... and BY MEMBER
LIST SUM REACTIONS
LIST MAXIMUM REACTION ENVELOPE LOADS ACTIVE ONLY

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

FINISH
```

APPENDIX AA

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

```
RESTORE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

LARGE PROBLEM SIZE 5

UNITS FT

$ ------------------------------------------
$ Steel design by the 13th Edition AISC code
$ ------------------------------------------
$ For all beams:
$     KY = KZ = 1.0
$
$ For all columns:
$     KY = KZ = 1.0
$
$ Use code units rather than:  UNITS ACTIVE ALL

$ -----------------------------------------------------------------

PARAMETERS
   CODE AISC13 ALL MEMEBERS
   METHOD LRFD ALL MEMBERS
   STEELGRD A992 ALL   $ 50 ksi STEEL
   CODETOL 0.0 ALL $ Unity check = 1.0

   TBLNAM   WBEAM-13 MEMBERS GRP 'BEAMS'   $ All beams
   TBLNAM   WCOL-13  MEMBERS GRP 'COLUMNS' $ All columns
   KZ       1.0      ALL MEMBERS
   KY       1.0      ALL MEMBERS
   SLENCOMP 300      MEMBERS GRP 'BEAMS'   $ All beams
   CB       1.0      ALL MEMBERS
   CM       1.0      ALL MEMBERS


$------------- UNLCF (Maximum unbraced length of compression flange) ----------------

UNLCF   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
UNLCF   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$-------------------------------------------------------------------------------------

$--------------------------------LY GIRDERS------------------------------------------

LY   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LY   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$--------------------------------LZ GIRDERS------------------------------------------

LZ  29.500  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LZ  27.833  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$---------------LZ (Unbraced length) of Columns-------------------------------------

$-------------------------------------------------------------------------------------

LZ  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121' 'Cb101' 'Cb102' 'Cb103' -
                     'Cb104' 'Cb105' 'Cb106' 'Cb107' 'Cb108' 'Cb109' -
                     'Cb110' 'Cb111' 'Cb112' 'Cb113' 'Cb114' 'Cb115' -
                     'Cb116' 'Cb117' 'Cb118' 'Cb119' 'Cb120' 'Cb121'
```

```
LZ  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221' 'Cb201' 'Cb202' 'Cb203' -
                     'Cb204' 'Cb205' 'Cb206' 'Cb207' 'Cb208' 'Cb209' -
                     'Cb210' 'Cb211' 'Cb212' 'Cb213' 'Cb214' 'Cb215' -
                     'Cb216' 'Cb217' 'Cb218' 'Cb219' 'Cb220' 'Cb221'
                .
                .
                .

$------------------------------------------------------------------------------------

$----------------------------------LY of Columns-------------------------------------

LY  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121' 'Cb101' 'Cb102' 'Cb103' -
                     'Cb104' 'Cb105' 'Cb106' 'Cb107' 'Cb108' 'Cb109' -
                     'Cb110' 'Cb111' 'Cb112' 'Cb113' 'Cb114' 'Cb115' -
                     'Cb116' 'Cb117' 'Cb118' 'Cb119' 'Cb120' 'Cb121'

LY  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221' 'Cb201' 'Cb202' 'Cb203' -
                     'Cb204' 'Cb205' 'Cb206' 'Cb207' 'Cb208' 'Cb209' -
                     'Cb210' 'Cb211' 'Cb212' 'Cb213' 'Cb214' 'Cb215' -
                     'Cb216' 'Cb217' 'Cb218' 'Cb219' 'Cb220' 'Cb221'
                .
                .
                .

$------------------------------------------------------------------------------------

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL -7.0 ALL $ 7% overdesign to improve design iteration convergence
$                    (i.e., Unity check = 0.93)

SELECT MEMBERS GRP 'BEAMS'    $ All beams
SELECT MEMBERS GRP 'COLUMNS'  $ All columns

UNITS KIP
STEEL TAKE OFF

$ ----------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix 7 states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."
```

```
$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION X JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION Z JOINTS EXISTING
$ -------------------------------------------------------------------------------------------

FORM LOAD REFORM $ Reform all FORM LOADS with the updated notional loads
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ------------------------------------------------------------------
$ Perform a code check for all members for design loads
$ ------------------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '4a. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX AB

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '4a. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------
$ Design all members that failed the previous code check
$ -------------------------------------------------------
PARAMETERS
   CODETOL -15.0 ALL $ Require a 15% overdesign to improve design iteration convergence
$                     (i.e., Unity check = 0.85)

SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

$ ------------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design.
$ ------------------------------------------------------------------
UNITS KIP
$ STEEL  TAKE  OFF  MEMBERS  EXISTING ITEMIZE BY PROFILE NAMES   $ All members
STEEL TAKE OFF $ All members

$ ------------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ------------------------------------------------------
$ Perform a code check for all members for design loads
$ ------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '5c. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX AC

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '5c. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design smoothing.
$ -------------------------------------------------------------------
UNITS KIP
STEEL TAKE OFF    $ All members

$ ------------------------------------------------------
$ Design all members that failed the previous code check
$ ------------------------------------------------------
PARAMETERS
   CODETOL -20.0 ALL $ Require a 5% overdesign to improve design iteration convergence $
-10.0 ALL $ Require a 5% overdesign to improve design iteration convergence
$                     (i.e., Unity check = 0.80)

SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

UNITS KIP
STEEL TAKE OFF  $ All members

$ ------------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ----------------------------------------------------
$ Perform a code check for all members for design loads
$ ----------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '5b. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX AD

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

```
RESTORE '5b. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ -------------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

SAVE '6. NonlinearAnalysis_Original_Notional.gts'
FINISH
```

APPENDIX AE

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 4b. AISC13_LRFD_DESIGN_Notional.gti

```
RESTORE '5b. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

UNITS KIP
STEEL  TAKE  OFF

$ Redesign all members
PARAMETERS
   CODETOL -20.0 ALL $ Unity check = 0.80

SELECT MEMBERS GRP 'BEAMS'    $ All beams
SELECT MEMBERS GRP 'COLUMNS'  $ All columns

UNITS KIP
STEEL TAKE OFF

$ ---------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

SAVE '4b. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX AF

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 6c. NonlinearAnalysis_Original_Notional&AE_EI.gti

```
RESTORE '4b. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ -------------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

SAVE '6. NonlinearAnalysis_Original_Notional.gts'
FINISH
```

APPENDIX AG

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

```
RESTORE '6. NonlinearAnalysis_Original_Notional.gts'

LARGE PROBLEM SIZE 5

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

CHECK CODE ALL MEMBERS

UNITS KIP FEET
STEEL TAKE OFF

SAVE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX AH

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SELECT MEMBERS GRP 'FAILCK'

STEEL TAKE OFF

$ ------------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ------------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ ----------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ ----------------------------------------------------------------------------------------

LIST SUM REACTIONS

UNITS INCH KIPS
CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

CHECK CODE ALL MEMBERS

UNITS KIP FEET
STEEL TAKE OFF

SAVE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX AI

Model 1 - Case 3: With Extra Joints at Mid-Column and No Smoothing
File: 99. NotionalLoadAnalysis_SupportJointReactions.gti

```
RESTORE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ -----------------------------------------------------
$ This is the last analysis run based on the following:
$ -----------------------------------------------------
$ ----------------------------------------------------------------------------------------
$ Paper by Dr. R. Shankar Nair, "Stability and Analysis Provisions of the 2005 AISC
$ Specification", Page 9 "2.2 Consideration of Initial Imperfections:  User Note: The
$ notional loads do not cause a net horizontal reaction on the foundation but may, in
$ some cases, cause horizontal reactions on the individual foundation components. A
$ horizontal force of Sum(Ni), opposite in direction to the notional loads, may be
$ applied in the analysis at the bases of all columns to yield the correct reactions at
$ the foundation."
$ ----------------------------------------------------------------------------------------
$ Therefore, perform a linear static analysis for the notional loads, output the support
$ reactions, and then use the notional load reaction components to subtract from the
$ reactions of the most recent nonlinear analyses.
$ ----------------------------------------------------------------------------------------

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST 'NX_SW+DL' 'NZ_SW+DL' 'NX_LL' 'NZ_LL'

QUERY
STIFFNESS ANALYSIS

OUTPUT DECIMAL 3
OUTPUT BY JOINT
LIST REACTIONS

LOAD LIST ALL

SAVE '99. NotionalLoadAnalysis_SupportJointReactions.gts'

FINISH
```

APPENDIX AJ

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 1. IndustrialStructure_NoBracing_13th_Ed_AISC.gti

```
STRUDL 'bm2_01' 'Benchmark - GTSTRUDL'

LARGE PROBLEM SIZE 5

ACTIVE SOLVERS GTSES

$
UNIT FEET KIPS DEGREES
$
TYPE SPACE FRAME
$
JOINT COORDINATES
$
  101       821.67        -0.83     -1000.00
  102       821.67        -0.83     -1029.50
  103       821.67        -0.83     -1057.33
              .
              .
              .

STATUS SUPPORTS JOINTS 101 TO 121 BY 1
$
JOINT RELEASES
101 102 103 104 105 106 107 108 109 110   MOM X MOM Z
111 112 113 114 115 116 117 118   MOM X MOM Z
119 120 121
$

MEMBER INCIDENCES
$
  'Ca101'    101       201
  'Ca102'    102       202
  'Ca103'    103       203
              .
              .
              .

  'Cb101'   1001       201
  'Cb102'   1002       202
  'Cb103'   1003       203
              .
              .
              .


 'GZ201'     201       202
 'GZ202'     202       203
 'GZ203'     204       205
              .
              .
              .

 'GX201'     201       204
 'GX202'     204       207
 'GX203'     207       210
              .
              .
              .

UNITS INCH KIPS
CONSTANTS E 29000 ALL
          G 11600 ALL

UNITS FEET KIPS DEGREES
CONSTANTS
DENSITY 0.490 ALL

BETA 90.00 MEMBER -
'GZ601' 'GZ602' 'GZ603' 'GZ604'
```

```
$ PRINT STRUCTURE DATA

$ ------------------------------------------------------------------

$-----BEAM_and_COLUMN_MEMBERS-------------------------------------

$ ----------COLUMN GROUPS------------------------------------------

DEFINE GROUP 'C1-1' MEMBERS  -
   'Ca101'      'Ca102'      'Ca103'      'Ca201'      'Ca202'    -
   'Ca203'      'Ca301'      'Ca302'      'Ca303'      'Cb101'    -
   'Cb102'      'Cb103'      'Cb201'      'Cb202'      'Cb203'    -
   'Cb301'      'Cb302'      'Cb303'

DEFINE GROUP 'C2-1' MEMBERS  -
   'Ca104'      'Ca105'      'Ca106'      'Ca204'      'Ca205'    -
   'Ca206'      'Ca304'      'Ca305'      'Ca306'      'Cb104'    -
   'Cb105'      'Cb106'      'Cb204'      'Cb205'      'Cb206'    -
   'Cb304'      'Cb305'      'Cb306'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL COLUMNS------------------------
DEFINE GROUP 'COLUMNS' GROUPS -
   'C1-1'      'C2-1'      'C3-1'      'C3-2'      'C4-1'    -
   'C4-2'      'C5-1'      'C6-1'      'C7-1'      'C8-1'    -
   'C9-1'      'C9-2'
$ -------------------------------------------------------------------

$ ----------BEAMS and GIRDERS--------------------------------------

DEFINE GROUP '7Z-1' MEMBERS -
   'GZ701'      'GZ702'

DEFINE GROUP '7Z-2' MEMBERS -
   'GZ703'      'GZ704'      'GZ705'      'GZ706'
                  .
                  .
                  .

$ --------------GROUP CONTAINING ALL BEAMS------------------------
DEFINE GROUP 'BEAMS' GROUPS -
   '7Z-1'      '7Z-2'      '7X-1'      '7X-2'      '6Z-1'    -
   '5X-1'      '5Z-1'      '4Z-1'      '4Z-2'      '4Z-3'    -
   '4X-1'      '4X-2'      '3Z-1'      '3Z-2'      '3Z-3'    -
   '3X-1'      '3X-2'      '2X-1'      '2X-2'      '2Z-1'    -
   '2Z-2'      '2Z-3'
$ -------------------------------------------------------------------


$ ------------------------------------------------------------------
DEFINE GRP 'ALLMEM' MEMBERS EXISTING MEMBERS ONLY
$ ------------------------------------------------------------------

MEMBER PROPERTIES TABLE 'W-AISC13'
   GRP 'COLUMNS' T 'W14X90'
   GRP 'BEAMS'   T  'W21X101'
$ ------------------------------------------------------------------

SAVE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

FINISH
```

APPENDIX AK

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 2. STATIC_LOADS_with_Notional_LOAD_Command.gti

```
RESTORE '1. IndustrialStructure_NoBracing_13th_Ed_AISC.gts'

LARGE PROBLEM SIZE 5

$ Define static loading conditions

UNITS KIPS FEET

SELF WEIGHT 'SW' 'SELF WEIGHT' DIRECTION -Y ALL MEMBERS

LOADING 'DL' 'ADDITIONAL DEAD LOADS'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.915
'GX704' FOR Y GLOB UNI W -0.889
'GX706' FOR Y GLOB UNI W -0.863
        .
        .
        .

$
LOADING 'LL' 'Live Loads'

MEMBER LOAD
'GX702' FOR Y GLOB UNI W -0.295
'GX704' FOR Y GLOB UNI W -0.287
'GX706' FOR Y GLOB UNI W -0.278
        .
        .
        .

JOINT LOADS
305 FORCE Y -100
308 FORCE Y -100


LOADING 'WLW' 'Wind Loads West'

JOINT LOADS

709     FOR     X       -9.48
708     FOR     X       -9.48
707     FOR     X       -9.48
        .
        .
        .


LOADING 'WLE' 'Wind Loads East'

JOINT LOADS

701     FOR     X       5.93
703     FOR     X       5.93
403     FOR     X       4.58
        .
        .
        .


LOADING 'WLN' 'Wind Loads North'

JOINT LOADS

704     FOR     Z       -6
701     FOR     Z       -6
317     FOR     Z       -6
        .
        .
        .
```

```
LOADING 'WLS' 'Wind Load South'

JOINT LOADS

709    FOR    Z      6
706    FOR    Z      6
703    FOR    Z      6
        .
        .
        .

$ -------------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                  FROM 'SW' 1.0 'DL' 1.0 -
                                  GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                  FROM 'SW' 1.0 'DL' 1.0 -
                                  GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NX_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                  FROM 'LL' 1.0          -
                                  GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_LL'    'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                  FROM 'LL' 1.0          -
                                  GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ -------------------------------------------------------------------------------------------
$ 13th Edition LRFD Load Combinations

FORM LOADING '11-1' '1.4*(SW+DL)' -
       FROM 'SW' 1.4 'DL' 1.4
FORM LOADING '11-2' '1.4*(SW+DL) + NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL'  1.4
FORM LOADING '11-3' '1.4*(SW+DL) - NOTIONAL_X' -
       FROM 'SW' 1.4 'DL' 1.4 'NX_SW+DL' -1.4
FORM LOADING '11-4' '1.4*(SW+DL) + NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL'  1.4
FORM LOADING '11-5' '1.4*(SW+DL) - NOTIONAL_Z' -
       FROM 'SW' 1.4 'DL' 1.4 'NZ_SW+DL' -1.4

FORM LOADING '12-1' '1.2*(SW+DL)+1.6*(LL)' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6
FORM LOADING '12-2' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL'  1.6
FORM LOADING '12-3' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL' -1.6
FORM LOADING '12-4' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL'  1.2 'NX_LL' -1.6
FORM LOADING '12-5' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NX_SW+DL' -1.2 'NX_LL'  1.6
```

```
FORM LOADING '12-6' '1.2*(SW+DL)+1.6*(LL) ++ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  1.6
FORM LOADING '12-7' '1.2*(SW+DL)+1.6*(LL) -- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -1.6
FORM LOADING '12-8' '1.2*(SW+DL)+1.6*(LL) +- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -1.6
FORM LOADING '12-9' '1.2*(SW+DL)+1.6*(LL) -+ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  1.6

FORM LOADING 13 '1.2*(SW+DL)+0.8*(WLW) - NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'WLW' 0.8 'NX_SW+DL' -1.2
FORM LOADING 14 '1.2*(SW+DL)+0.8*(WLE) + NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'WLE' 0.8 'NX_SW+DL'  1.2
FORM LOADING 15 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL' -0.5
FORM LOADING 16 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL'  0.5
FORM LOADING 17 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLW) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLW' 1.6 'NX_SW+DL' -1.2 'NX_LL'  0.5
FORM LOADING 18 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLE) +- NOTIONAL_X' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLE' 1.6 'NX_SW+DL'  1.2 'NX_LL' -0.5
FORM LOADING 19 '0.9*(SW+DL)+1.6*(WLW) - NOTIONAL_X' -
       FROM 'SW' 0.9 'DL' 0.9 'WLW' 1.6 'NX_SW+DL' -0.9
FORM LOADING 20 '0.9*(SW+DL)+1.6*(WLE) + NOTIONAL_X' -
       FROM 'SW' 0.9 'DL' 0.9 'WLE' 1.6 'NX_SW+DL'  0.9

FORM LOADING 21 '1.2*(SW+DL)+0.8*(WLN) - NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'WLN' 0.8 'NZ_SW+DL' -1.2
FORM LOADING 22 '1.2*(SW+DL)+0.8*(WLS) + NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'WLS' 0.8 'NZ_SW+DL'  1.2
FORM LOADING 23 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL' -0.5
FORM LOADING 24 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) ++ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL'  0.5
FORM LOADING 25 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLN) -+ NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLN' 1.6 'NZ_SW+DL' -1.2 'NZ_LL'  0.5
FORM LOADING 26 '1.2*(SW+DL)+0.5*(LL)+1.6*(WLS) +- NOTIONAL_Z' -
       FROM 'SW' 1.2 'DL' 1.2 'LL' 0.5 'WLS' 1.6 'NZ_SW+DL'  1.2 'NZ_LL' -0.5
FORM LOADING 27 '0.9*(SW+DL)+1.6*(WLN) - NOTIONAL_Z' -
       FROM 'SW' 0.9 'DL' 0.9 'WLN' 1.6 'NZ_SW+DL' -0.9
FORM LOADING 28 '0.9*(SW+DL)+1.6*(WLS) + NOTIONAL_Z' -
       FROM 'SW' 0.9 'DL' 0.9 'WLS' 1.6 'NZ_SW+DL'  0.9

$ -------------------------------------------------------------------------------------
QUERY

$ PRINT LOAD DATA

SAVE '2. STATIC_LOADS_Notional.gts'

FINISH
```

APPENDIX AL

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 3a. LINEAR_STATIC_ANALYSIS_Notional.gti

```
RESTORE '2. Notional_Loads.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$  Perform linear static analysis for all currently
$  active factored limit state loading conditions.

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

UNITS INCH KIPS

OUTPUT DECIMAL 3
LIST DISPLACEMENTS JOINTS 'P2322' 'P2262' 'P1342' 'J1430'
$ LIST MAXIMUM JOINT DISPLACEMENT SUMMARY ONLY LOADS ACTIVE

OUTPUT BY JOINT $ ... and BY MEMBER
LIST SUM REACTIONS
LIST MAXIMUM REACTION ENVELOPE LOADS ACTIVE ONLY

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

FINISH
```

APPENDIX AM

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 4a. AISC13_LRFD_Design_LinearAnalysis_CodeCheck_Notional.gti

```
RESTORE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

LARGE PROBLEM SIZE 5

UNITS FT

$ -----------------------------------------
$ Steel design by the 13th Edition AISC code
$ -----------------------------------------
$ For all beams:
$     KY = KZ = 1.0
$
$ For all columns:
$     KY = KZ = 1.0
$
$ Use code units rather than:  UNITS ACTIVE ALL

$ ------------------------------------------------------------------

PARAMETERS
   CODE AISC13 ALL MEMEBERS
   METHOD LRFD ALL MEMBERS
   STEELGRD A992 ALL   $ 50 ksi STEEL
   CODETOL 0.0 ALL $ Unity check = 1.0

   TBLNAM   WBEAM-13 MEMBERS GRP 'BEAMS'   $ All beams
   TBLNAM   WCOL-13  MEMBERS GRP 'COLUMNS' $ All columns
   KZ       1.0      ALL MEMBERS
   KY       1.0      ALL MEMBERS
   SLENCOMP 300      MEMBERS GRP 'BEAMS'   $ All beams
   CB       1.0      ALL MEMBERS
   CM       1.0      ALL MEMBERS


$------------- UNLCF (Maximum unbraced length of compression flange) ----------------

UNLCF   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
UNLCF   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$------------------------------------------------------------------------------------

$--------------------------------LY GIRDERS------------------------------------------

LY   9.833  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LY   9.278  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$--------------------------------LZ GIRDERS------------------------------------------

LZ  29.500  MEMBERS 'GZ701' 'GZ702' 'GZ703'
LZ  27.833  MEMBERS 'GZ704' 'GZ705' 'GZ706'
                .
                .
                .

$---------------LZ (Unbraced length) of Columns--------------------------------------

$------------------------------------------------------------------------------------

LZ  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121' 'Cb101' 'Cb102' 'Cb103' -
                     'Cb104' 'Cb105' 'Cb106' 'Cb107' 'Cb108' 'Cb109' -
                     'Cb110' 'Cb111' 'Cb112' 'Cb113' 'Cb114' 'Cb115' -
                     'Cb116' 'Cb117' 'Cb118' 'Cb119' 'Cb120' 'Cb121'
```

```
LZ  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221' 'Cb201' 'Cb202' 'Cb203' -
                     'Cb204' 'Cb205' 'Cb206' 'Cb207' 'Cb208' 'Cb209' -
                     'Cb210' 'Cb211' 'Cb212' 'Cb213' 'Cb214' 'Cb215' -
                     'Cb216' 'Cb217' 'Cb218' 'Cb219' 'Cb220' 'Cb221'
                .
                .
                .

$-------------------------------------------------------------------------------------


$---------------------------------LY of Columns--------------------------------------

LY  20.73    MEMBERS 'Ca101' 'Ca102' 'Ca103' 'Ca104' 'Ca105' 'Ca106' -
                     'Ca107' 'Ca108' 'Ca109' 'Ca110' 'Ca111' 'Ca112' -
                     'Ca113' 'Ca114' 'Ca115' 'Ca116' 'Ca117' 'Ca118' -
                     'Ca119' 'Ca120' 'Ca121' 'Cb101' 'Cb102' 'Cb103' -
                     'Cb104' 'Cb105' 'Cb106' 'Cb107' 'Cb108' 'Cb109' -
                     'Cb110' 'Cb111' 'Cb112' 'Cb113' 'Cb114' 'Cb115' -
                     'Cb116' 'Cb117' 'Cb118' 'Cb119' 'Cb120' 'Cb121'

LY  19.27    MEMBERS 'Ca201' 'Ca202' 'Ca203' 'Ca204' 'Ca205' 'Ca206' -
                     'Ca207' 'Ca208' 'Ca209' 'Ca210' 'Ca211' 'Ca212' -
                     'Ca213' 'Ca214' 'Ca215' 'Ca216' 'Ca217' 'Ca218' -
                     'Ca219' 'Ca220' 'Ca221' 'Cb201' 'Cb202' 'Cb203' -
                     'Cb204' 'Cb205' 'Cb206' 'Cb207' 'Cb208' 'Cb209' -
                     'Cb210' 'Cb211' 'Cb212' 'Cb213' 'Cb214' 'Cb215' -
                     'Cb216' 'Cb217' 'Cb218' 'Cb219' 'Cb220' 'Cb221'
                .
                .
                .
$-------------------------------------------------------------------------------------

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL -7.0 ALL $ 7% overdesign to improve design iteration convergence
$                    (i.e., Unity check = 0.93)

SELECT MEMBERS GRP 'BEAMS'    $ All beams
SELECT MEMBERS GRP 'COLUMNS'  $ All columns

UNITS KIP
STEEL TAKE OFF
$ --------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0.smooth.gti'
$ --------------------------------------------------------------
STEEL TAKE OFF

$ -------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
```

```
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix 7 states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION X JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLF 0.003 NLDIRECTION Z JOINTS EXISTING
$ -----------------------------------------------------------------------------------------

FORM LOAD REFORM $ Reform all FORM LOADS with the updated notional loads
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ -----------------------------------------------------------------
$ Perform a code check for all members for design loads
$ -----------------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '4a. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX AN

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '4a. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -------------------------------------------------------
$ Design all members that failed the previous code check
$ -------------------------------------------------------
PARAMETERS
   CODETOL -15.0 ALL $ Require a 15% overdesign to improve design iteration convergence
$                     (i.e., Unity check = 0.85)

SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

$ ------------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design.
$ ------------------------------------------------------------------
UNITS KIP

STEEL TAKE OFF $ All members
$ --------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0.smooth.gti'
$ --------------------------------------------------------------
STEEL TAKE OFF

$ ----------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ ----------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

QUERY
STIFFNESS ANALYSIS

$ ------------------------------------------------------
$ Perform a code check for all members for design loads
$ ------------------------------------------------------
PARAMETERS
   CODETOL  0.0  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.00)
CHECK CODE ALL MEMBERS

UNITS KIP
STEEL TAKE OFF

SAVE '5c. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX AO

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

```
RESTORE '5b. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ --------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ --------------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

SAVE '6. NonlinearAnalysis_Original_Notional.gts'
FINISH
```

APPENDIX AP

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

```
RESTORE '6. NonlinearAnalysis_Original_Notional.gts'

LARGE PROBLEM SIZE 5

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

CHECK CODE ALL MEMBERS

UNITS KIP FEET
STEEL TAKE OFF

SAVE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX AQ

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '7c. CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

UNITS KIP
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

SELECT MEMBERS GRP 'FAILCK'

UNITS KIP FEET
STEEL TAKE OFF

$ -------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0.smooth.gti'
$ -------------------------------------------------------------

STEEL TAKE OFF

$ -------------------------------------------------------------------------------------
DELETE; LOAD 'NX_SW+DL' 'NZ_SW+DL'; ADDITIONS

FORM NOTIONAL LOAD 'NX_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NZ_SW+DL' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Z-DIRECTION' -
                                   FROM 'SW' 1.0 'DL' 1.0 -
                                   GRAVITY AXIS Y NLDIRECTION Z NLF 0.003 JOINTS EXISTING
$ -------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 13 TO 28

$ -----------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ -----------------------------------------------------------------------------------

LIST SUM REACTIONS

UNITS INCH KIPS
CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

SECTION FR NS 5 0.0 0.25 0.5 0.75 1.0 MEMBERS GRP 'BEAMS'  $ All beams
SECTION FR NS 2 0.0 1.0 MEMBERS GRP LIST 'COLUMNS'         $ All columns and bracing

PARAMETERS
   CODETOL 0.0 ALL $ Unity check = 1.0

CHECK CODE ALL MEMBERS
```

```
UNITS KIP FEET
STEEL TAKE OFF

SAVE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX AR

Model 1 - Case 4: With Smoothing and Extra Joints at Mid-Column
File: 99. NotionalLoadAnalysis_SupportJointReactions.gti

```
RESTORE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

$ -----------------------------------------------------
$ This is the last analysis run based on the following:
$ -----------------------------------------------------
$ ---------------------------------------------------------------------------------------
$ Paper by Dr. R. Shankar Nair, "Stability and Analysis Provisions of the 2005 AISC
$ Specification", Page 9 "2.2 Consideration of Initial Imperfections:  User Note: The
$ notional loads do not cause a net horizontal reaction on the foundation but may, in
$ some cases, cause horizontal reactions on the individual foundation components. A
$ horizontal force of Sum(Ni), opposite in direction to the notional loads, may be
$ applied in the analysis at the bases of all columns to yield the correct reactions at
$ the foundation."
$ ---------------------------------------------------------------------------------------
$ Therefore, perform a linear static analysis for the notional loads, output the support
$ reactions, and then use the notional load reaction components to subtract from the
$ reactions of the most recent nonlinear analyses.
$ ---------------------------------------------------------------------------------------

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST 'NX_SW+DL' 'NZ_SW+DL' 'NX_LL' 'NZ_LL'

QUERY
STIFFNESS ANALYSIS

OUTPUT DECIMAL 3
OUTPUT BY JOINT
LIST REACTIONS

LOAD LIST ALL

SAVE '99. NotionalLoadAnalysis_SupportJointReactions.gts'

FINISH
```

APPENDIX AS

Model 1 – Simple Industrial Structure
File: 0.smooth.gti

```
TAKE MEMBERS GRP 'C1-1' AS LARGEST 'AX' OF MEMBERS GRP 'C1-1'
TAKE MEMBERS GRP 'C2-1' AS LARGEST 'AX' OF MEMBERS GRP 'C2-1'
TAKE MEMBERS GRP 'C3-1' AS LARGEST 'AX' OF MEMBERS GRP 'C3-1'
TAKE MEMBERS GRP 'C3-2' AS LARGEST 'AX' OF MEMBERS GRP 'C3-2'
TAKE MEMBERS GRP 'C4-1' AS LARGEST 'AX' OF MEMBERS GRP 'C4-1'
TAKE MEMBERS GRP 'C4-2' AS LARGEST 'AX' OF MEMBERS GRP 'C4-2'
TAKE MEMBERS GRP 'C5-1' AS LARGEST 'AX' OF MEMBERS GRP 'C5-1'
TAKE MEMBERS GRP 'C6-1' AS LARGEST 'AX' OF MEMBERS GRP 'C6-1'
TAKE MEMBERS GRP 'C7-1' AS LARGEST 'AX' OF MEMBERS GRP 'C7-1'
TAKE MEMBERS GRP 'C8-1' AS LARGEST 'AX' OF MEMBERS GRP 'C8-1'
TAKE MEMBERS GRP 'C9-1' AS LARGEST 'AX' OF MEMBERS GRP 'C9-1'
TAKE MEMBERS GRP 'C9-2' AS LARGEST 'AX' OF MEMBERS GRP 'C9-2'

TAKE MEMBERS GRP '7Z-1' AS LARGEST 'SZ' OF MEMBERS GRP '7Z-1'
TAKE MEMBERS GRP '7Z-2' AS LARGEST 'SZ' OF MEMBERS GRP '7Z-2'
TAKE MEMBERS GRP '7X-1' AS LARGEST 'SZ' OF MEMBERS GRP '7X-1'
TAKE MEMBERS GRP '7X-2' AS LARGEST 'SZ' OF MEMBERS GRP '7X-2'
TAKE MEMBERS GRP '6Z-1' AS LARGEST 'SZ' OF MEMBERS GRP '6Z-1'
TAKE MEMBERS GRP LIST '5Z-1' '5X-1' AS LARGEST 'SZ' OF MEMBERS GRP LIST '5Z-1' '5X-1'
TAKE MEMBERS GRP '4Z-1' AS LARGEST 'SZ' OF MEMBERS GRP '4Z-1'
TAKE MEMBERS GRP '4Z-2' AS LARGEST 'SZ' OF MEMBERS GRP '4Z-2'
TAKE MEMBERS GRP '4Z-3' AS LARGEST 'SZ' OF MEMBERS GRP '4Z-3'
TAKE MEMBERS GRP '4X-1' AS LARGEST 'SZ' OF MEMBERS GRP '4X-1'
TAKE MEMBERS GRP '4X-2' AS LARGEST 'SZ' OF MEMBERS GRP '4X-2'
TAKE MEMBERS GRP '3Z-1' AS LARGEST 'SZ' OF MEMBERS GRP '3Z-1'
TAKE MEMBERS GRP '3Z-2' AS LARGEST 'SZ' OF MEMBERS GRP '3Z-2'
TAKE MEMBERS GRP '3Z-3' AS LARGEST 'SZ' OF MEMBERS GRP '3Z-3'
TAKE MEMBERS GRP '3X-1' AS LARGEST 'SZ' OF MEMBERS GRP '3X-1'
TAKE MEMBERS GRP '3X-2' AS LARGEST 'SZ' OF MEMBERS GRP '3X-2'
TAKE MEMBERS GRP '2Z-1' AS LARGEST 'SZ' OF MEMBERS GRP '2Z-1'
TAKE MEMBERS GRP '2Z-2' AS LARGEST 'SZ' OF MEMBERS GRP '2Z-2'
TAKE MEMBERS GRP '2Z-3' AS LARGEST 'SZ' OF MEMBERS GRP '2Z-3'
TAKE MEMBERS GRP '2X-1' AS LARGEST 'SZ' OF MEMBERS GRP '2X-1'
TAKE MEMBERS GRP '2X-2' AS LARGEST 'SZ' OF MEMBERS GRP '2X-2'
```

APPENDIX AT

Model 2: Nuclear Power Plant Boiler Building
File: 1. Model&Indloads.gti

```
STRUDL 'BOILER' 'BOILER STEEL STRUCTURE'

$ ------------------
LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES
$ ------------------

OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

LARGE PROBLEM SIZE 5

TYPE SPACE FRAME
UNIT MM DEGREE
$
JOINT COORDINATE
 'P1'         0.          0.       7300.
 'P2'      1500.          0.       7300.
 'P3'      9430.          0.       7300.
              .
              .
              .

$ Declare support joint
STATUS SUPPORT 'P1' TO 'P59'
$
MEMBER INCIDENCES
  'E1'  'P71'  'P73'
  'E2'  'P73'  'P75'
  'E3'  'P75'  'P77'
          .
          .
          .

$====================================

MEMBER PROPERTIES TABLE 'NewHSS'
  EXISTING T 'HSS16x16x1/2'

MEMBER RELEASE
$ EL18650
'E22' 'E36' 'E49' 'E62' 'E75' 'E76' 'E77' 'E85' 'E86' TO 'E91' 'E95' TO 'E98' -
'E102' TO 'E104' 'E108' TO 'E110' 'E114' TO 'E117' 'E121' TO 'E124' 'E128' -
'E129' TO 'E145' 'R4154' 'R4071' 'B65' TO 'B68' -
START MOM Y Z END MOM Y Z
'E23' 'E25' 'E27' 'E30' 'E32' 'E34' 'E37' 'E39' 'E41' 'E43' 'E45' 'E47' -
'E50' 'E52' 'E54' 'E56' 'E58' 'E60' 'E63' 'E65' 'E67' 'E69' 'E71' 'E73' -
'E78' 'E82' 'E92' 'E99' 'E105' 'E111' 'E118' 'E125' -
START MOM Y Z
'E24' 'E26' 'E29' 'E31' 'E33' 'E35' 'E38' 'E40' 'E42' 'E44' 'E46' 'E48' -
'E51' 'E53' 'E55' 'E57' 'E59' 'E61' 'E64' 'E66' 'E68' 'E70' 'E72' 'E74' -
'E81' 'E84' 'E94' 'E101' 'E107' 'E113' 'E120' 'E127' -
END MOM Y Z
          .
          .
          .
$
$===================================

$ CONSTANTS OF MATERIAL PROPERTY
UNIT INCH POUND
CONSTANT E 30000000.0 ALL
CONSTANT G 12000000.0 ALL
CONSTANT POISSON .2700 ALL
CONSTANT DENSITY .2830 ALL

$===================================

$ BETA CONDITION
UNITS DEGREES
CONSTANTS
```

```
BETA 90 ALL

$ CHANGE BETA FOR COLUMN ONLY
CONSTANT
BETA 0 -
'C1' TO 'C58' 'E3961' TO 'E4196' 'E4300' TO 'E4316' -
'C3967' 'C3968' 'C3972' 'C3978' 'C3979' 'C3983' -
'C3989' 'C3990' 'C3994' 'C4000' 'C4001' 'C4005' -
'C4011' 'C4012' 'C4016' 'C4022' 'C4023' 'C4027' -
'C4033' 'C4034' 'C4038' 'C4068' 'C4089' 'C4110' 'C4131' 'C4151'
          .
          .
          .

$================= CREATE MEMBER GROUPS ====================
DEFINE GRP '1a' MEMBERS -
'B1260' 'B1258' -
'E1663' 'E1700'

DEFINE GRP '1b' MEMBERS -
'E1440' 'E1441' 'E1511' 'E1512' 'E1573'
          .
          .
          .

$===================================
$
$ ----------------  LOADING CONDITION ----------------------------$
UNIT MTOM METER
SELF WEIGHT LOADING 'SW' 'STEEL SELF WEIGHT' -Z ALL MEMBERS

$**********************************
LOADING '1X' 'ADDITIONAL DEAD LOAD'
$**********************************
$ PLATFORM DEAD LOAD
JOINT LOADS
$ 11598
'P141'  FOR Z -3.125
'P143'  FOR Z -3.125
'P145'  FOR Z -3.125
          .
          .
          .

$ CONCRETE FLOOR
'P409'   FOR Z -9.520
'P274'   FOR Z -9.520
'P410'   FOR Z -19.
          .
          .
          .

$ ROOF (BOILER)
'P2254'   FOR Z -0.500
'P2262'   FOR Z -0.500
'P2264'   FOR Z -3.250
          .
          .
          .

$ ROOF (COAL SILO)
'P1418'   FOR Z -3.280
'P1430'   FOR Z -3.280
'P1431'   FOR Z -3.280
          .
          .
          .

$ ROOF (A/H)
'P1307'   FOR Z -2.100
'P1313'   FOR Z -2.100
```

```
          .
          .
          .

$ SKY ROUNGE PLATFORM
'J2083'   FOR Z -0.500
'P2081'   FOR Z -0.500
'P2074'   FOR Z -0.700
          .
          .
          .

$ ----- END OF PLATFORM DEAD

$ GIRT & SIDING ( 42.5 kg)
JOINT LOADS
'P96'   FOR Z -0.53
'P97'   FOR Z -2.07
'P409'   FOR Z -0.92
          .
          .
          .

$ -- END OF GIRT & SIDING

$ ------------------------ELEVATOR LOAD
$ EL.109900
$ PLATFORM DEAD LOAD
'P2263' 'P2264' 'P2273' 'P2274' FOR Z -2.8

$ EQUIPMENT DEAD LOAD
'P2263' 'P2264' 'P2273' 'P2274' FOR Z -5.5


$ ----------------------CRITICAL PIPE (M/S, H/R, C/R)
$ EL.46900
'P910' FOR Z -20.0
'P911' FOR Z -38.0
'P912' FOR Z -10.0
          .
          .
          .

$ -------------------------MISCELLANEOUS PIPE
$ EL.16100
'P94' FOR Z -1.3
'P86' FOR Z -0.8
          .
          .
          .

$ ----------------------- WIND BOX LOAD
$ EL.39900
'P863' 'P864' 'P868' 'P869' FOR Z -17.0
          .
          .
          .


$ ------------------------COAL FEEDER LOAD
$ EL.23540
'P409' 'P415' FOR Z -3.0
'P410' TO 'P414' FOR Z -5.5
'P274' 'P284' FOR Z -4.0
'P276' 'P278' 'P279' 'P280' 'P282' FOR Z -7.0


$ ----------------------DUST COLLECTOR
$ EL.59700
'P1239' 'P1236' 'P1252' 'P1256' FOR Z -5.0
'P1238' 'P1254' FOR Z -10.0
```

```
$ -----------------------COAL PIPE LOAD
$ EL. 23540
MEMBER LOADS
'E455' FOR Z GLO CON P -6.3 L 3.3 / -6.3 5.8 / -2.8 7.8 / -2.2 9.3
'E465' FOR Z GLO CON P -4.9 L 3.3 / -4.9 5.8 / -1.6 7.6 / -1.6 9.3
'E480' FOR Z GLO CON P -1.7 L 3.3 / -3.9 5.8
          .
          .
          .

JOINT LOAD
'P275' FOR Z -4.2
'P287' FOR Z -1.9
'P301' FOR Z -2.7
'P296' FOR Z -1.0
'P295' FOR Z -4.4
          .
          .
          .

$ --------------------------AIR HEATER LOAD
$ EL.35300
MEMBER LOAD
'E1049' 'E1023' FOR Z GLO CON P -134.5 L 2.74
'E1050' 'E1024' FOR Z GLO CON P -134.5 L 1.095
'E1034' 'E1039' FOR Z GLO CON P -129.6 L 2.14
          .
          .
          .

$ --------------------------COAL SILO LOAD
$ EL.35750
$ SILO STEEL WEIGHT (63.5 TON/SET)
JOINT LOAD
'P759' 'P735' FOR Z -14.5
'P739' 'P743' 'P747' 'P751' 'P755' FOR Z -29.0
'P785' 'P795' FOR Z -17.3
'P787' 'P789' 'P790' 'P791' 'P793' FOR Z -34.6

$ -------------------------CONDENSATE TANK LOAD
$ EL.16100
'P94' 'P86' FOR Z -10.0
'P87' FOR Z -15.0
'P309' FOR Z -15.0

$ --------------------------FLASH TANK
$ EL.29550
MEMBER LOAD
'E714' 'E718' 'E769' 'E785' FOR Z GLO CON P -20.0 L 2.0

$ ------------------------TRIPPER LOAD
$ EL.52050
$ DEAD LOAD (EQUIPMENT)
JOINT LOAD
'P1109' 'P1115' 'P1129' 'P1141' FOR Z -10.0
'P1110' TO 'P1114' 'P1131' 'P1133' 'P1135' 'P1137' -
'P1139' FOR Z -20.0

$ ------------------------------SOOT BLOWER LOAD
$ EL.93600
MEM LOAD
'E2834' 'E2891' FOR Z GLO CON P -1.0 L 2.0
'E2833' 'E2890' FOR Z GLO CON P -1.0 L 3.0
'E2832' 'E2889' FOR Z GLO CON P -1.0 L 0.7
'E2831' 'E2888' FOR Z GLO CON P -1.0 L 0.5
          .
          .
          .
```

```
JOINT LOAD
'P1936' 'P1937' FOR Z -1.0
          .
          .
          .

$ ----------------------------DUCT LOAD
$ PRIMARY AIR TO A/H
$ EL.23540
MEMBER LOADS
'E387' FOR Z GLO CON P -7.3 L 4.575
'E388' FOR Z GLO CON P -7.3 L 1.735
'E400' FOR Z GLO CON P -10.4 L 8.225
          .
          .
          .

JOINT LOAD
'P1362' 'P1363' FOR Z -2.3
'P1278' 'P1279' FOR Z -0.4
'P1368' 'P1369' FOR Z -0.4
          .
          .
          .

$ ------------------------------------SILENCER LOAD
$ EL.116500
'P2266' 'P2270' FOR Z -5.0
'P2293' 'P2296' FOR Z -11.0


$ ------------------------------------CABLE TRAY
$ COL. "M"
'P2003' FOR Z -5.3
'P1885' FOR Z -5.4
'P1800' FOR Z -5.7
          .
          .
          .

$ ###################################################
FORM LOADING 1 'ADDITIONAL DEAD LOAD' FROM '1X' 0.15 $ <<<----Reduce Load values by 85%
$ ###################################################

$******************************************
LOADING '2X' 'BOILER HANGING LOAD'
$******************************************
$ EL.109900
JOINT LOADS
  'P2085' 'P2095' FOR Z -5.0
  'P2090' FOR Z -4.0
  'P2116' 'P2124' 'P2173' 'P2181' FOR Z -35.
          .
          .
          .

$ ###################################################
FORM LOADING 2 'BOILER HANGING LOAD' FROM '2X' 0.15 $ <<<----Reduce Load values by 85%
$ ###################################################

$********************************************
LOADING '3X' 'LIVE LOAD'
$********************************************
$ PLATFORM LIVE LOAD
$ 11598
JOINT LOADS
'P141'   FOR Z -12.500
'P143'   FOR Z -12.500
'P145'   FOR Z -12.500
          .
          .
```

```
          .

$ CONCRETE FLOOR
'P409'   FOR Z -9.520
'P274'   FOR Z -9.520
'P410'   FOR Z -19.
          .
          .
          .

$ CONCRETE FLOOR
'P1109'   FOR Z -9.520
'P1115'   FOR Z -9.520
'P1129'   FOR Z -9.520
          .
          .
          .

$ ROOF (BOILER)
'P2254'   FOR Z -0.500
'P2262'   FOR Z -0.500
'P2264'   FOR Z -3.250
          .
          .
          .

$ ROOF (COAL SILO)
'P1418'   FOR Z -3.280
'P1430'   FOR Z -3.280
'P1431'   FOR Z -3.280
          .
          .
          .

$ ROOF (A/H)
'P1307'   FOR Z -2.100
'P1313'   FOR Z -2.100
'P1309'   FOR Z -8.970
          .
          .
          .

$ SKY ROUNGE
'J2083'   FOR Z -2.
'P2081'   FOR Z -2.
'P2074'   FOR Z -2.800
          .
          .
          .

$  END OF PLATFORM LIVE

$ ------------------------ELEVATOR LOAD
$ EL.109900
$ PLATFORM LIVE LOAD
   'P2263' 'P2264' 'P2273' 'P2274' FOR Z -2.8
   'P2263' 'P2264' 'P2273' 'P2274' FOR Z -2.8


$ ------------------------COAL FEEDER LOAD
$ EL.23540
$ LIVE LOAD
  'P409' 'P415' FOR Z -1.5
  'P410' TO 'P414' FOR Z -2.8
  'P274' 'P284' FOR Z -2.0
  'P276' 'P278' 'P279' 'P280' 'P282' FOR Z -3.5


$ ------------------------TRIPPER LOAD
$ EL.52050
$ LIVE LOAD (EQUIPMENT)
```

```
JOINT LOAD
'P1109' TO 'P1115' 'P1129' 'P1131' 'P1133' 'P1135' -
'P1137' 'P1139' 'P1141' FOR Z -20.0


$ #######################################
FORM LOADING 3 'LIVE LOAD' FROM '3X' 0.15 $ <<<----Reduce Load values by 85%
$ #######################################

$***********************************************************
LOADING '4X' 'MATERIAL LOAD (ASH & COAL)'
$***********************************************************
$ ASH LOAD
JOINT LOAD
$ EL.19300
'P166' 'P177' FOR Z -2.0
          .
          .
          .

$ COAL WEIGHT (720 TON/SET)
JOINT LOAD
'P759' 'P735' FOR Z -164.
'P739' 'P743' 'P747' 'P751' 'P755' FOR Z -328.0
'P785' 'P795' FOR Z -196.0
'P787' 'P789' 'P790' 'P791' 'P793' FOR Z -392.0

$ ########################################################
FORM LOADING 4 'MATERIAL LOAD (ASH & COAL)' FROM '4X' 0.15 $ <<<----Reduce Load values by
85%
$ ########################################################

$************************************************
LOADING '5X' 'CONTINGENCY LOAD'
$************************************************
JOINT LOAD
$ COL. "G"
'P1418' 'P1420' 'P1422' 'P1424' 'P1426' 'P1428' 'P1430' FOR Z -20.0
          .
          .
          .

$ ##############################################
FORM LOADING 5 'CONTINGENCY LOAD' FROM '5X' 0.15 $ <<<----Reduce Load values by 85%
$ ##############################################

$***************************************
LOADING 'WLN-X' 'SOUTH TO NORTH WIND'
$***************************************
MEMBER LOADS
$ WINDWARD
$ COL G
'C1' 'C2'    FOR Y GLO UNI 0.97
'C3'         FOR Y GLO UNI 0.99
'C4' 'C5'    FOR Y GLO UNI 1.02
          .
          .
          .

$ LEEWARD
$ COL J
'E4271' TO 'E4287' FOR Y GLO UNI 0.4
'E4300' TO 'E4316' FOR Y GLO UNI 0.48
          .
          .
          .
```

```
$ SIDEWARD
$ COL 10
'C1' TO 'C7'          FOR X GLO UNI -0.4
'E3962' TO 'E3972'    FOR X GLO UNI -1.14
'C3967' 'C3968'       FOR X GLO UNI -1.14
          .
          .
          .

$ UPWARD
JOINT LOAD
$ ROOF (BOILER)
'P2254'   FOR Z 1.0
'P2262'   FOR Z 1.0
'P2264'   FOR Z 6.5
          .
          .
          .


$ ROOF (COAL SILO)
'P1418'   FOR Z 5.48
'P1430'   FOR Z 5.48
'P1431'   FOR Z 5.48.
          .
          .
          .

$ ROOF (A/H)
'P1307'   FOR Z 3.4
'P1313'   FOR Z 3.4
'P1309'   FOR Z 14.55
          .
          .
          .

$ GALLERY BRIDGE
'P1115' 'P1231' FOR Y 17.84
'P1109' 'P1239' FOR Y 17.84

$ ########################################################
FORM LOADING 'WLN' 'SOUTH TO NORTH WIND' FROM 'WLN-X' 0.15 $ <<<----Reduce Load values by
85%
$ ########################################################

$***************************************
LOADING 'WLS-X' 'NORTH TO SOUTH WIND'
$***************************************
MEMBER LOADS
$ WINDWARD
$ COL R
'E4892' 'E4893'       FOR Y GLO UNI -0.79
'E4894' 'E4895'       FOR Y GLO UNI -0.82
'E4896'               FOR Y GLO UNI -0.86
          .
          .
          .

$ LEEWARD
$ COL J
'E4183' TO 'E4196'    FOR Y GLO UNI -0.58
'E4214' TO 'E4223'    FOR Y GLO UNI -0.48
'C4223'               FOR Y GLO UNI -0.48
          .
          .
          .
```

```
$ SIDEWARD
$ COL 10
'C1' TO 'C7'          FOR X GLO UNI -0.4
'E3962' TO 'E3972'    FOR X GLO UNI -1.14
'C3967' 'C3968'       FOR X GLO UNI -1.14
          .
          .
          .

$ UPWARD
JOINT LOAD
$ ROOF (BOILER)
'P2254'   FOR Z 1.0
'P2262'   FOR Z 1.0
'P2264'   FOR Z 6.5
          .
          .
          .

$ ROOF (COAL SILO)
'P1418'   FOR Z 5.48
'P1430'   FOR Z 5.48
'P1431'   FOR Z 5.48
          .
          .
          .

$ ROOF (A/H)
'P1307'   FOR Z 3.4
'P1313'   FOR Z 3.4
'P1309'   FOR Z 14.55
          .
          .
          .

$ GALLERY BRIDGE
'P1244' 'P1141' FOR Y -17.84
'P1256' 'P1129' FOR Y -17.84

$ ##########################################################
FORM LOADING 'WLS' 'NORTH TO SOUTH WIND' FROM 'WLS-X' 0.15 $ <<<----Reduce Load values by
85%
$ ##########################################################

$****************************************
LOADING 'WLE-X' 'WEST TO EAST WIND'
$****************************************
MEMBER LOADS
$ WINDWARD
$ COL 10
'C1' TO 'C7'     FOR X GLO UNI 0.4
'E3962'          FOR X GLO UNI 1.05
'E3963'         FOR X GLO UNI 1.07
          .
          .
          .

$ LEEWARD
$ COL 15.2
'C5011' TO 'C5019' 'C5021' FOR X GLO UNI 1.
'E4271' TO 'E4299' FOR X GLO UNI 1.11
'C4297'            FOR X GLO UNI 1.11
          .
          .
          .

$ SIDEWARD
$ COL GFZ
'C1' TO 'C7'   FOR Y GLO UNI -0.92
'C12' TO 'C18' FOR Y GLO UNI -1.65
'C21' TO 'C27' FOR Y GLO UNI -1.65
```

```
          .
          .
          .

$ UPWARD
JOINT LOAD
$ ROOF (BOILER)
'P2254'   FOR Z 1.0
'P2262'   FOR Z 1.0
'P2264'   FOR Z 6.5
          .
          .
          .

$ ROOF (COAL SILO)
'P1418'   FOR Z 5.48
'P1430'   FOR Z 5.48
'P1431'   FOR Z 5.48
          .
          .
          .

$ ROOF (A/H)
'P1307'   FOR Z 3.4
'P1313'   FOR Z 3.4
'P1309'   FOR Z 14.55
          .
          .
          .

$ ######################################################
FORM LOADING 'WLE' 'WEST TO EAST WIND' FROM 'WLE-X' 0.15 $ <<<----Reduce Load values by
85%
$ ######################################################

$****************************************
LOADING 'WLW-X' 'EAST TO WEST WIND'
$****************************************
MEMBER LOADS
$ WINDWARD
$ COL 15.7
'C52' TO 'C58'     FOR X GLO UNI -0.4
'E4028'            FOR X GLO UNI -1.05
'E4029'            FOR X GLO UNI -1.07
          .
          .
          .

$ LEEWARD
$ COL 10.4
'C5001' TO 'C5010' 'C5020' FOR X GLO UNI -0.71
'E4343' TO 'E4367' FOR X GLO UNI -0.71
'C4365'            FOR X GLO UNI -0.71
          .
          .
          .

$ SIDEWARD
$ COL GFZ
'C1' TO 'C7'   FOR Y GLO UNI -0.92
'C12' TO 'C18' FOR Y GLO UNI -1.65
'C21' TO 'C27' FOR Y GLO UNI -1.65
          .
          .
          .
```

```
$ UPWARD
JOINT LOAD
$ ROOF (BOILER)
'P2254'   FOR Z 1.0
'P2262'   FOR Z 1.0
'P2264'   FOR Z 6.5
          .
          .
          .

$ ROOF (COAL SILO)
'P1418'   FOR Z 5.48
'P1430'   FOR Z 5.48
'P1431'   FOR Z 5.48
          .
          .
          .

$ ROOF (A/H)
'P1307'   FOR Z 3.4
'P1313'   FOR Z 3.4
'P1309'   FOR Z 14.55
          .
          .
          .

$ #####################################################
FORM LOADING 'WLW' 'EAST TO WEST WIND' FROM 'WLW-X' 0.15 $ <<<----Reduce Load values by
85%
$ #####################################################

BYPASS $
<<<*************************************************************************<<<<<<<<<<
$****************************************
LOADING 100 'SOUTH TO NORTH SEISMIC'
$****************************************
JOINT LOAD
'P554' 'P553' FOR Y 60.0 $ (EL29550)
'P1491' 'P1495' FOR Y 80.0 $ (EL71200,EL74200)
'P1796' 'P1799' FOR Y 25.0 $ (EL85550)
MEMBER LOAD
'E2746' FOR Y GLO CON P 80.0 L 0.96 $ (EL90200,EL93600)
'E2749' FOR Y GLO CON P 80.0 L 3.39 $ (EL90200,EL93600)
'E2783' FOR Y GLO CON P 25.0 L 0.92 $ (EL93600)
'E2784' FOR Y GLO CON P 25.0 L 8.83 $ (EL93600)
          .
          .
          .

$
$****************************************
LOADING 110 'NORTH TO SOUTH SEISMIC'
$****************************************
JOINT LOAD
'P554' 'P553' FOR Y -60.0 $ (EL29550)
'P1522' 'P1524' FOR Y -80.0 $ (EL71200,EL74200)
'J1827' 'J1828' FOR Y -25.0 $ (EL85550)
MEMBER LOAD
'E2783' FOR Y GLO CON P -80.0 L 0.96 $ (EL90200,EL93600)
'E2784' FOR Y GLO CON P -80.0 L 8.79 $ (EL90200,EL93600)
'E2810' FOR Y GLO CON P -25.0 L 0.92 $ (EL93600)
'E2815' FOR Y GLO CON P -25.0 L 2.33 $ (EL93600)
          .
          .
          .

$****************************************
LOADING 120 'WEST TO EAST SEISMIC'
$****************************************
JOINT LOAD
'P540' 'P567' FOR X 60.0   $ (EL29550)
```

```
'P1517' FOR X 80.0         $ (EL71200,EL74200)
'P1877' FOR X 80.0         $ (EL90200,EL93600)
'P1804' 'P1822' FOR X 25.0 $ (EL85550)
'P1903' FOR X 25.0         $ (EL93600)
MEMBER LOAD
'E2257' FOR X GLO CON P 80.0 L 1.51 $ (EL71200,EL74200)
'E2841' FOR X GLO CON P 80.0 L 1.51 $ (EL90200,EL93600)
'E2847' FOR X GLO CON P 25.0 L 1.34 $ (EL93600)
          .
          .
          .

$***************************************
LOADING 130 'EAST TO WEST SEISMIC'
$***************************************
JOINT LOAD
'P540' 'P567' FOR X -60.0     $ (EL29550)
'P1518' FOR X -80.0           $ (EL71200,EL74200)
'P1878' FOR X -80.0           $ (EL90200,EL93600)
'P1805' 'P1823' FOR X -25.0   $ (EL85550)
'P1904' FOR X -25.0           $ (EL93600)
MEMBER LOAD
'E2271' FOR X GLO CON P -80.0 L 1.51 $ (EL71200,EL74200)
'E2875' FOR X GLO CON P -80.0 L 1.51 $ (EL90200,EL93600)
'E2881' FOR X GLO CON P -25.0 L 1.34 $ (EL93600)
          .
          .
          .

BYPASS $ <<<****************************************************************<<<<<<<<<<

$----------------------------------------------------------------

UNIT TONS FEET
STEEL TAKE OFF

UNITS INCH KIPS

SAVE '1. Model&Indloads.gts'

FINISH $
<<<**************************************************************************<<<<<<<<<<
```

APPENDIX AU

Model 2: Nuclear Power Plant Boiler Building
File: 2. Notional_Loads.gti

```
RESTORE '1. Model&Indloads.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$ Define Notional Loads

UNIT MTOM METER

$ ----------------------------------------------------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix 7 states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

FORM NOTIONAL LOAD 'NX_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' –
                                  FROM 'SW' 1.0 1 1.0 2 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Y-DIRECTION' -
                                  FROM 'SW' 1.0 1 1.0 2 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NX_3+4+5'  'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                  FROM 3 1.0 4 1.0 5 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_3+4+5'  'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Y-DIRECTION' -
                                  FROM 3 1.0 4 1.0 5 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
$ ----------------------------------------------------------------------------------------
$ 13th Edition LRFD Load Combinations

FORM LOADING '11-1' '1.4*(SW+1+2)' -
       FROM 'SW' 1.4 1 1.4 2 1.4
FORM LOADING '11-2' '1.4*(SW+1+2) + NOTIONAL_X' -
       FROM 'SW' 1.4 1 1.4 2 1.4 'NX_SW+1+2'  1.4
FORM LOADING '11-3' '1.4*(SW+1+2) - NOTIONAL_X' -
       FROM 'SW' 1.4 1 1.4 2 1.4 'NX_SW+1+2' -1.4
FORM LOADING '11-4' '1.4*(SW+1+2) + NOTIONAL_Y' -
       FROM 'SW' 1.4 1 1.4 2 1.4 'NY_SW+1+2'  1.4
FORM LOADING '11-5' '1.4*(SW+1+2) - NOTIONAL_Y' -
       FROM 'SW' 1.4 1 1.4 2 1.4 'NY_SW+1+2' -1.4

FORM LOADING '12-1' '1.2*(SW+1+2)+1.6*(3+4+5)' -
       FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6
FORM LOADING '12-2' '1.2*(SW+1+2)+1.6*(3+4+5) ++ NOTIONAL_X' -
       FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2'  1.2 'NX_3+4+5'  1.6
FORM LOADING '12-3' '1.2*(SW+1+2)+1.6*(3+4+5) -- NOTIONAL_X' -
       FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' -1.2 'NX_3+4+5' -1.6
FORM LOADING '12-4' '1.2*(SW+1+2)+1.6*(3+4+5) +- NOTIONAL_X' -
       FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2'  1.2 'NX_3+4+5' -1.6
FORM LOADING '12-5' '1.2*(SW+1+2)+1.6*(3+4+5) -+ NOTIONAL_X' -
       FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NX_SW+1+2' -1.2 'NX_3+4+5'  1.6
FORM LOADING '12-6' '1.2*(SW+1+2)+1.6*(3+4+5) ++ NOTIONAL_Y' -
       FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NY_SW+1+2'  1.2 'NY_3+4+5'  1.6
FORM LOADING '12-7' '1.2*(SW+1+2)+1.6*(3+4+5) -- NOTIONAL_Y' -
```

```
        FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NY_SW+1+2' -1.2 'NY_3+4+5' -1.6
FORM LOADING '12-8' '1.2*(SW+1+2)+1.6*(3+4+5) +- NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NY_SW+1+2'  1.2 'NY_3+4+5' -1.6
FORM LOADING '12-9' '1.2*(SW+1+2)+1.6*(3+4+5) -+ NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 1.6 4 1.6 5 1.6 'NY_SW+1+2' -1.2 'NY_3+4+5'  1.6

$ FORM LOADING 13 '1.2*(SW+1+2)+0.8*(WLW) - NOTIONAL_X' -
        FROM 'SW' 1.2 1 1.2 2 1.2 'WLW' 0.8 'NX_SW+1+2' -1.2
FORM LOADING 14 '1.2*(SW+1+2)+0.8*(WLE) + NOTIONAL_X' -
        FROM 'SW' 1.2 1 1.2 2 1.2 'WLE' 0.8 'NX_SW+1+2'  1.2

BYPASS $ <<<*******************************************************************<<<<<<<<<<
FORM LOADING 15 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLW) -- NOTIONAL_X' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLW' 1.6 'NX_SW+1+2' -1.2 -
             'NX_3+4+5' -0.5
FORM LOADING 16 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLE) ++ NOTIONAL_X' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLE' 1.6 'NX_SW+1+2'  1.2 -
             'NX_3+4+5' 0.5
FORM LOADING 17 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLW) -+ NOTIONAL_X' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLW' 1.6 'NX_SW+1+2' -1.2 -
             'NX_3+4+5' 0.5
FORM LOADING 18 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLE) +- NOTIONAL_X' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLE' 1.6 'NX_SW+1+2'  1.2 -
             'NX_3+4+5' -0.5
FORM LOADING 19 '0.9*(SW+1+2)+1.6*(WLW) - NOTIONAL_X' -
        FROM 'SW' 0.9 1 0.9 2 0.9 'WLW' 1.6 'NX_SW+1+2' -0.9
FORM LOADING 20 '0.9*(SW+1+2)+1.6*(WLE) + NOTIONAL_X' -
        FROM 'SW' 0.9 1 0.9 2 0.9 'WLE' 1.6 'NX_SW+1+2'  0.9
BYPASS $ <<<*******************************************************************<<<<<<<<<<

FORM LOADING 21 '1.2*(SW+1+2)+0.8*(WLN) - NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 'WLN' 0.8 'NY_SW+1+2' -1.2
$ FORM LOADING 22 '1.2*(SW+1+2)+0.8*(WLS) + NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 'WLS' 0.8 'NY_SW+1+2'  1.2

BYPASS $ <<<*******************************************************************<<<<<<<<<<
FORM LOADING 23 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLN) -- NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLN' 1.6 'NY_SW+1+2' -1.2 'NY_3+4+5'
-0.5
FORM LOADING 24 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLS) ++ NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLS' 1.6 'NY_SW+1+2'  1.2 'NY_3+4+5'
0.5
FORM LOADING 25 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLN) -+ NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLN' 1.6 'NY_SW+1+2' -1.2 'NY_3+4+5'
0.5
FORM LOADING 26 '1.2*(SW+1+2)+0.5*(3+4+5)+1.6*(WLS) +- NOTIONAL_Y' -
        FROM 'SW' 1.2 1 1.2 2 1.2 3 0.5 4 0.5 5 0.5 'WLS' 1.6 'NY_SW+1+2'  1.2 'NY_3+4+5'
-0.5
FORM LOADING 27 '0.9*(SW+1+2)+1.6*(WLN) - NOTIONAL_Y' -
        FROM 'SW' 0.9 1 0.9 2 0.9 'WLN' 1.6 'NY_SW+1+2' -0.9
FORM LOADING 28 '0.9*(SW+1+2)+1.6*(WLS) + NOTIONAL_Y' -
        FROM 'SW' 0.9 1 0.9 2 0.9 'WLS' 1.6 'NY_SW+1+2'  0.9
BYPASS $ <<<*******************************************************************<<<<<<<<<<

$ -----------------------------------------------------------------------------------------

QUERY

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

$ PRINT LOAD DATA

SAVE '2. Notional_Loads.gts'

FINISH
```

APPENDIX AV

Model 2: Nuclear Power Plant Boiler Building
File: 3a. LINEAR_STATIC_ANALYSIS_Notional.gti

```
RESTORE '2. Notional_Loads.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$  Perform linear static analysis for all currently
$  active factored limit state loading conditions.

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS


UNITS INCH KIPS

OUTPUT DECIMAL 3
LIST DISPLACEMENTS JOINTS 'P2322' 'P2262' 'P1342' 'J1430'
$ LIST MAXIMUM JOINT DISPLACEMENT SUMMARY ONLY LOADS ACTIVE

OUTPUT BY JOINT $ ... and BY MEMBER
LIST SUM REACTIONS
LIST MAXIMUM REACTION ENVELOPE LOADS ACTIVE ONLY

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

FINISH
```

APPENDIX AW

Model 2: Nuclear Power Plant Boiler Building
File: 4a. AISC13_LRFD_LinearAnal_Design&CodeChk_Notional.gti

```
RESTORE '3a. LINEAR_STATIC_ANALYSIS_Notional.gts'

LARGE PROBLEM SIZE 5
ACTIVE SOLVER GTSES
OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

$ ----------------------------------------
$ Steel design by the 13th Edition AISC code
$ ----------------------------------------
$ For all beams:
$     FRUNLCF = 0.5 (Maximum unbraced length of compression flange = 0.5 x Member Length)
$     KY = KZ = 1.0
$
$ For all columns:
$     KY = KZ = 1.0
$
$ Use code units rather than:  UNITS ACTIVE ALL

UNITS KIPS INCHES
PARAMETERS
   CODE AISC13 ALL MEMBERS
   METHOD LRFD ALL MEMBERS

   FY 50 ALL $ Conflicting steel grades for box shapes and Wide flange shapes for
             $ purposes of smoothing set yield stress to 50ksi for all members
   FU 70 ALL

   CODETOL 0.0 ALL $ Unity check = 1.0

   KZ       1.0      ALL MEMBERS
   KY       1.0      ALL MEMBERS
   SLENCOMP 1000.0   ALL MEMBERS
   SLENTEN  1000.0   ALL MEMBERS
$  FRUNLCF  0.5      MEMBERS GRP 'BEAMS'   $ All beams: Maximum unbraced length of
compression flange
$  SLENCOMP 300      MEMBERS GRP 'BEAMS'   $ All beams
   Cb       1.0      ALL MEMBERS


   'TBLNAM'   'W-AISC13' ALL MEMBERS

   'TBLNAM' '2L-EQ-13' MEMBERS 'R1' TO 'R34'
   'nConnect' -1       MEMBERS 'R1' TO 'R34'

   'TBLNAM' 'NewHSS' MEMBERS -
                'E3763' TO 'E3768'    'E3769' TO 'E3772'     'E3773' TO 'E3778' -
                'E3779' TO 'E3784'    'E3785' TO 'E3788'     'E3789' TO 'E3794' -
                'E3795' TO 'E3800'    'E3801' TO 'E3804'     'E3811' TO 'E3814' -
                         .
                         .
                         .

$==============Unbraced Lengths=======================
UNITS MTONS MM

PARAMETERS

'LZ' 11350  MEM  'E4051' 'E4071' 'E4092' 'E4113' 'C4051' 'C4071' 'C4092' 'C4113'
'LY' 6010   MEM  'E4030' 'E4031' 'E4019' 'E4020' 'E4008' 'E4009' 'E3997' -
                 'E3998' 'E3986' 'E3987' 'E3975' 'E3976' 'E3964' 'E3965'
'LZ' 12210  MEM  'E4030' TO 'E4032' 'E4019' TO 'E4021' 'E4008' TO 'E4010' -
                 'E3997' TO 'E3999' 'E3986' TO 'E3988' 'E3975' TO 'E3977' -
                 'E3964' TO 'E3966'
                         .
                         .
                         .

$====================================================

SECTION FR NS 3 0.0 0.5 1.0
```

```
$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ Design all members

UNITS KIPS IN
SELECT ALL MEMBERS

UNITS TONS FT
STEEL TAKE OFF
$ -------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0. SmoothMemberProperties.gti'
$ -------------------------------------------------------------
STEEL  TAKE  OFF

$ ---------------------------------------------------------------------------------------
-------------------------------------------
$ Reference the 13th Edition AISC Specification, Appendix 7, Pages 16.1-196 to 16.1-198:
$ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
$ The CASE Center believes the 13th Edition AISC Provision for the additional tau_b (tb)
$ reduction of flexural stiffness (i.e., [0.8 x tb x EI]) is only applicable to frame
$ structures whose behavior is similar to the behavior of the simple plane frames for
$ which the mathematical formulations of stability were developed.

$ Appendix 7 states that, "In lieu of using tb less than 1.0 ....., tb = 1.0 may be used
$ for all members, provided that an additive notional load 0f 0.001 Yi is added to the
$ notional load requirement in (2)."

$ It is the opinion of the CASE Center that the behavior of most, if not all, industrial
$ structures and modern high-rise commercial buildings will rarely, if ever, be the same
$ as the behavior of the overly simplified frames upon whose behavior the tb factor was
$ developed, and thus the calculation and use of the tb factor is considered to be NOT
$ justified.

$ Therefore, GTSTRUDL does not calculate the tb factor. Rather, the user may simply use
$ the AISC option of tb = 1.0 by specifying the notional load factor (NLF) to be 0.003 Yi
$ as shown in the following FORM NOTIONAL LOAD commands:

DELETE; LOAD 'SW' 'NX_SW+1+2' 'NY_SW+1+2'; ADDITIONS

SELF WEIGHT LOADING 'SW' 'STEEL SELF WEIGHT' -Z ALL MEMBERS

FORM NOTIONAL LOAD 'NX_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 1 1.0 2 1.0 -
                                   GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Y-DIRECTION' -
                                   FROM 'SW' 1.0 1 1.0 2 1.0 -
                                   GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM $ Reform all "FORM LOADS" with the updated notional loads
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

$ ----------------------------------------------------------------
$ Perform a code check for all members for design loads
$ ----------------------------------------------------------------
PARAMETERS
   CODETOL  0.5  ALL  $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.005)

UNITS KIPS INCH
CHECK CODE ALL MEMBERS

SAVE '4a. AISC13_LRFD_Notional.gts'
FINISH
```

APPENDIX AX

Model 2: Nuclear Power Plant Boiler Building
File: 5a. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '4a. AISC13_LRFD_Notional.gts'

LARGE PROBLEM SIZE 5

OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ -------------------------------------------------------
$ Design all members that failed the previous code check
$ -------------------------------------------------------
PARAMETERS
   CODETOL -10.0 ALL $ Require a 10% overdesign to improve design iteration convergence
$                     (i.e., Unity check = 0.90)

UNITS KIPS INCH
SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

$ ------------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design.
$ ------------------------------------------------------------------
$ STEEL TAKE OFF MEMBERS EXISTING ITEMIZE BY PROFILE NAMES   $ All members

UNITS TONS FT
STEEL TAKE OFF
$ --------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0. SmoothMemberProperties.gti'
$ --------------------------------------------------------------
STEEL TAKE OFF

$ ---------------------------------------------------------------------------------------
DELETE; LOAD 'SW' 'NX_SW+1+2' 'NY_SW+1+2'; ADDITIONS

SELF WEIGHT 'SW' 'SELF WEIGHT' DIRECTION -Z ALL MEMBERS

FORM NOTIONAL LOAD 'NX_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM ‘SW’ 1.0 1 1.0 2 1.0 -
                                   GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Y-DIRECTION' –
                                   FROM ‘SW’ 1.0 1 1.0 2 1.0 -
                                   GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM $ Reform all "FORM LOADS" with the updated notional loads
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

$ ------------------------------------------------------
$ Perform a code check for all members for design loads
$ ------------------------------------------------------
PARAMETERS
   CODETOL 1.0 ALL $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                       (I.E., UNITY CHECK = 1.01)

UNITS KIPS INCH
CHECK CODE ALL MEMBERS

SAVE '5c. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX AY

Model 2: Nuclear Power Plant Boiler Building
File: 5b. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '5c. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ -----------------------------------------------------------------
$ Calculate the length, volume, and weight of the current design of
$ all beams and columns after design smoothing.
$ -----------------------------------------------------------------
UNITS TONS FT
STEEL TAKE OFF    $ All members

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ ------------------------------------------------------
$ Design all members that failed the previous code check
$ ------------------------------------------------------
PARAMETERS
   CODETOL -15.0 ALL $ Require a 10% overdesign to improve design iteration convergence
$                      (i.e., Unity check = 0.85)

UNITS INCH KIPS
SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

CHANGE
MEMBER PROPERTIES TABLE 'W-AISC13'
'E1269' 'E1270' 'E1273' 'E1274'  TABLE 'W10x19'

UNITS TONS FT
STEEL TAKE OFF
$ -------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0. SmoothMemberProperties.gti'
$ -------------------------------------------------------------
STEEL TAKE OFF

$ ---------------------------------------------------------------------------------------
DELETE; LOAD 'SW' 'NX_SW+1+2' 'NY_SW+1+2'; ADDITIONS

SELF WEIGHT 'SW' 'SELF WEIGHT' DIRECTION -Z ALL MEMBERS

FORM NOTIONAL LOAD 'NX_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                  FROM 'SW' 1.0 1 1.0 2 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Y-DIRECTION' -
                                  FROM 'SW' 1.0 1 1.0 2 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

$ -----------------------------------------------------
$ Perform a code check for all members for design loads
$ -----------------------------------------------------
PARAMETERS
   CODETOL 1.0 ALL $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                      (I.E., UNITY CHECK = 1.01)
UNITS INCH KIPS
CHECK CODE ALL MEMBERS

SAVE '5b. REDESIGN AND CODE_CHECK_Notional.gts'
FINISH
```

APPENDIX AZ

Model 2: Nuclear Power Plant Boiler Building
File: 5c. Redesign, LinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '5b. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

UNITS TONS
STEEL TAKE OFF    $ All members

LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ -------------------------------------------------------
$ Design all members that failed the previous code check
$ -------------------------------------------------------
PARAMETERS
   CODETOL -20.0 ALL $ Require a 20% overdesign to improve design iteration convergence
$                      (i.e., Unity check = 0.80)

UNITS INCH KIPS
SELECT MEMBERS GRP 'FAILCK'    $ All members that failed code check

UNITS TONS FT
STEEL TAKE OFF
$ --------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0. SmoothMemberProperties.gti'
$ --------------------------------------------------------------
STEEL TAKE OFF

$ ---------------------------------------------------------------------------------------
DELETE; LOAD 'SW' 'NX_SW+1+2' 'NY_SW+1+2'; ADDITIONS

SELF WEIGHT 'SW' 'SELF WEIGHT' DIRECTION -Z ALL MEMBERS

FORM NOTIONAL LOAD 'NX_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                  FROM 'SW' 1.0 1 1.0 2 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZONTAL GLOBAL Y-DIRECTION'
                                  FROM 'SW' 1.0 1 1.0 2 1.0 -
                                  GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

QUERY
STIFFNESS ANALYSIS

$ ------------------------------------------------------
$ Perform a code check for all members for design loads
$ ------------------------------------------------------
PARAMETERS
   CODETOL 1.0 ALL $ NO OVERSTRESS PERMITTED DURING CODE CHECK
$                        (I.E., UNITY CHECK = 1.01)
UNITS INCH KIPS
CHECK CODE ALL MEMBERS

SAVE '5c. REDESIGN AND CODE_CHECK_Notional.gts'

FINISH
```

APPENDIX BA

Model 2: Nuclear Power Plant Boiler Building
File: 6a. NonlinearAnalysis_Original_Notional&AE_EI.gti

```
RESTORE '5c. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ ------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ ------------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '6. NonlinearAnalysis_Notional.gts'
FINISH
```

APPENDIX BB

Model 2: Nuclear Power Plant Boiler Building
File: 4b. AISC13_LRFD_DESIGN_Notional.gti

```
RESTORE '5c. REDESIGN AND CODE_CHECK_Notional.gts'

LARGE PROBLEM SIZE 5
ACTIVE SOLVER GTSES
OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

$ Factored limit state loading conditions (i.e., the FORM LOADS
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ Redesign all members
PARAMETERS
   CODETOL -30.0 ALL $ Unity check = 0.70

UNITS KIPS IN
SELECT ALL MEMBERS

UNITS TONS FT
STEEL TAKE OFF
$ -------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0. SmoothMemberProperties.gti'
$ -------------------------------------------------------------
STEEL TAKE OFF

$ ---------------------------------------------------------------------------------------
DELETE; LOAD 'SW' 'NX_SW+1+2' 'NY_SW+1+2'; ADDITIONS

SELF WEIGHT LOADING 'SW' 'STEEL SELF WEIGHT' -Z ALL MEMBERS

FORM NOTIONAL LOAD 'NX_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                FROM 'SW' 1.0 1 1.0 2 1.0 -
                                GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Y-DIRECTION' -
                                FROM 'SW' 1.0 1 1.0 2 1.0 -
                                GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
$ ---------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

SAVE '4b. LRFD3_DESIGN_Notional.gts'
FINISH
```

APPENDIX BC

Model 2: Nuclear Power Plant Boiler Building
File: 6c. NonlinearAnalysis_Notional&AE_EI.gti

```
RESTORE '4b. LRFD3_DESIGN_Notional.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ -------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ -------------------------------------------------------------------------------------

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

LIST SUM REACTIONS

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '6. NonlinearAnalysis_Notional.gts'
FINISH
```

APPENDIX BD

Model 2: Nuclear Power Plant Boiler Building
File: 7a. AISC13_LRFD_CHECK_UsingNonlinear_Notional.gti

```
RESTORE '6. NonlinearAnalysis_Notional.gts'

LARGE PROBLEM SIZE 5
ACTIVE SOLVER GTSES
OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

PARAMETERS
   CODETOL 1.0 ALL $ Unity check = 1.01

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

UNITS INCH KIPS
CHECK CODE ALL MEMBERS

UNITS TONS FT
STEEL TAKE OFF

SAVE '7c. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'
FINISH
```

APPENDIX BE

Model 2: Nuclear Power Plant Boiler Building
File: 7b. Redesign, NonlinearAnalysis, & CodeCheck_Notional.gti

```
RESTORE '7c. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5
ACTIVE SOLVER GTSES
OPEN USERDATA FILE '0. HSS_New_Table.ds' READ EXISTING

$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

UNITS TONS FT
STEEL TAKE OFF

$ Redesign all members
PARAMETERS
   CODETOL -20.0 ALL $ Unity check = 0.80

UNITS KIPS INCH
SELECT MEMBERS GRP 'FAILCK'

UNITS TONS FT
STEEL TAKE OFF
$ ---------------------------------------------------------------
$ Input file called that will smooth the member groups
CINPUT '0. SmoothMemberProperties.gti'
$ ---------------------------------------------------------------
STEEL TAKE OFF

$ -----------------------------------------------------------------------------------------
DELETE; LOAD 'SW' 'NX_SW+1+2' 'NY_SW+1+2'; ADDITIONS

SELF WEIGHT LOADING 'SW' 'STEEL SELF WEIGHT' -Z ALL MEMBERS

FORM NOTIONAL LOAD 'NX_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL X-DIRECTION' -
                                   FROM 'SW' 1.0 1 1.0 2 1.0 -
                                   GRAVITY AXIS Z NLDIRECTION X NLF 0.003 JOINTS EXISTING
FORM NOTIONAL LOAD 'NY_SW+1+2' 'NOTIONAL LOADS APPLIED IN HORIZ GLOBAL Y-DIRECTION' -
                                   FROM 'SW' 1.0 1 1.0 2 1.0 -
                                   GRAVITY AXIS Z NLDIRECTION Y NLF 0.003 JOINTS EXISTING
$ -----------------------------------------------------------------------------------------

FORM LOAD REFORM
LOAD LIST '11-1' TO '11-5', '12-1' TO '12-9', 14, 21

$ ---------------------------------------------------------------------------------------
$ DEFINE NONLINEAR ANALYSIS PARAMETERS

NONLINEAR EFFECTS
  GEOMETRY ALL MEMBERS

MAXIMUM NUMBER OF CYCLES 100
CONVERGENCE TOLERANCE EQUIL 0.001

$ ----NONLINEAR STATIC ANALYSIS--------------------------------
UNITS INCH KIPS
CONSTANTS E 23200 ALL   $ Reduced E (0.8E) for Reduced AE, EIy, and EYz
          G  9280 ALL   $ Reduced G (0.8G) for Reduced GIx, GAy, and GAz

QUERY
NONLINEAR ANALYSIS $ NONLINEAR STATIC ANALYSIS
$ ---------------------------------------------------------------------------------------

LIST SUM REACTIONS

CONSTANTS E 29000 ALL   $ Return E to its original value
          G 11600 ALL   $ Return G to its original value

PARAMETERS
   CODETOL 1.0 ALL $ Unity check = 1.01

CHECK CODE ALL MEMBERS
```

```
SAVE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'

FINISH
```

APPENDIX BF

Model 2: Nuclear Power Plant Boiler Building
File: 99. NotionalLoadAnalysis_SupportJointReactions.gti

```
RESTORE '7b. REDESIGN AND CODE_CHECK_UsingNonlinear_Notional.gts'

LARGE PROBLEM SIZE 5

ACTIVE SOLVER GTSES

$ ----------------------------------------------------
$ This is the last analysis run based on the following:
$ ----------------------------------------------------
$ ------------------------------------------------------------------------------------------
$ Paper by Dr. R. Shankar Nair, "Stability and Analysis Provisions of the 2005 AISC
$ Specification", Page 9 "2.2 Consideration of Initial Imperfections:  User Note: The
$ notional loads do not cause a net horizontal reaction on the foundation but may, in
$ some cases, cause horizontal reactions on the individual foundation components. A
$ horizontal force of Sum(Ni), opposite in direction to the notional loads, may be
$ applied in the analysis at the bases of all columns to yield the correct reactions at
$ the foundation."
$ ------------------------------------------------------------------------------------------
$ Therefore, perform a linear static analysis for the notional loads, output the support
$ reactions, and then use the notional load reaction components to subtract from the
$ reactions of the most recent nonlinear analyses.
$ ------------------------------------------------------------------------------------------
$ Factored limit state loading conditions (i.e., the FORM LOADS)
LOAD LIST 'NX_SW+1+2' 'NY_SW+1+2' 'NX_3+4+5' 'NY_3+4+5'

QUERY
STIFFNESS ANALYSIS

OUTPUT DECIMAL 3
OUTPUT BY JOINT
LIST REACTIONS

LOAD LIST ALL

UNITS TONS FEET
STEEL TAKE OFF
UNITS KIPS INCH

SAVE '99. NotionalLoadAnalysis_SupportJointReactions.gts'

FINISH
```

APPENDIX BG

Model 2: Nuclear Power Plant Boiler Building
File: 0. SmoothMemberProperties.gti

```
TAKE MEMBERS GRP '1a' AS LARGEST 'SZ' OF MEMBERS GRP '1a'
TAKE MEMBERS GRP '1b' AS LARGEST 'SZ' OF MEMBERS GRP '1b'
TAKE MEMBERS GRP   2 AS LARGEST 'AX' OF MEMBERS GRP   2
TAKE MEMBERS GRP   3 AS LARGEST 'SY' OF MEMBERS GRP   3
TAKE MEMBERS GRP   4 AS LARGEST 'SZ' OF MEMBERS GRP   4
TAKE MEMBERS GRP   5 AS LARGEST 'AX' OF MEMBERS GRP   5
TAKE MEMBERS GRP '6a' AS LARGEST 'SZ' OF MEMBERS GRP '6a'
TAKE MEMBERS GRP '6b' AS LARGEST 'SZ' OF MEMBERS GRP '6b'
TAKE MEMBERS GRP '6c' AS LARGEST 'SZ' OF MEMBERS GRP '6c'
TAKE MEMBERS GRP '6d' AS LARGEST 'SY' OF MEMBERS GRP '6d'
TAKE MEMBERS GRP '6e' AS LARGEST 'SZ' OF MEMBERS GRP '6e'
TAKE MEMBERS GRP '7a' AS LARGEST 'SY' OF MEMBERS GRP '7a'
TAKE MEMBERS GRP '7b' AS LARGEST 'SZ' OF MEMBERS GRP '7b'
TAKE MEMBERS GRP '7c' AS LARGEST 'SZ' OF MEMBERS GRP '7c'
TAKE MEMBERS GRP '7d' AS LARGEST 'SY' OF MEMBERS GRP '7d'
TAKE MEMBERS GRP '7e' AS LARGEST 'SZ' OF MEMBERS GRP '7e'
TAKE MEMBERS GRP   8 AS LARGEST 'SZ' OF MEMBERS GRP   8
TAKE MEMBERS GRP   9 AS LARGEST 'SZ' OF MEMBERS GRP   9
TAKE MEMBERS GRP  10 AS LARGEST 'SZ' OF MEMBERS GRP  10
TAKE MEMBERS GRP  11 AS LARGEST 'SZ' OF MEMBERS GRP  11
TAKE MEMBERS GRP  12 AS LARGEST 'SZ' OF MEMBERS GRP  12
TAKE MEMBERS GRP  13 AS LARGEST 'SZ' OF MEMBERS GRP  13
TAKE MEMBERS GRP  14 AS LARGEST 'SZ' OF MEMBERS GRP  14
TAKE MEMBERS GRP  15 AS LARGEST 'SZ' OF MEMBERS GRP  15
        .
        .
        .
```

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