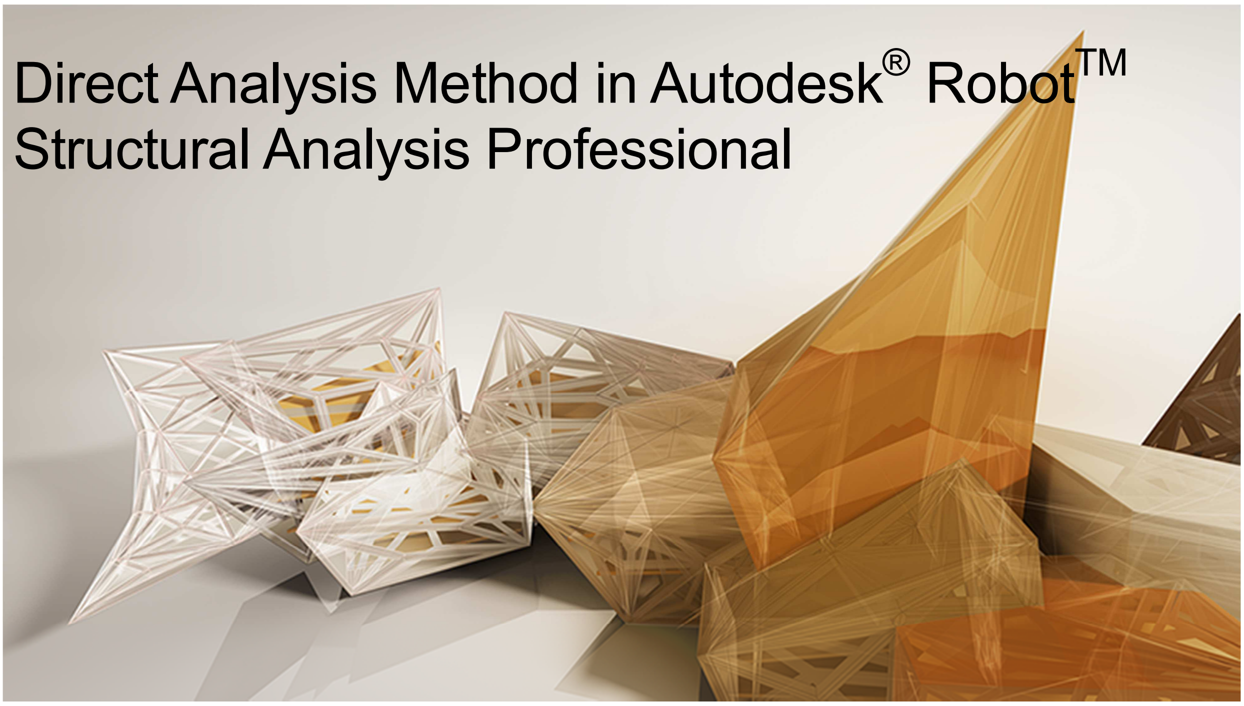
Autodesk® Robot™ Structural Analysis Professional 2015

Direct Analysis Method in Autodesk® Robot™ Structural Analysis Professional



Souza, True and Partners:

Souza and True was founded in 1959 by Edward K. True and Richard W. Souza, with the goal to provide superior structural engineering advice and design services to architects, owners, and contractors. We work closely with our clients to provide them the most efficient and optimum results while staying on schedule and on budget. Our design experience spans a long history of both publicly and privately funded projects, from new construction to historic renovations. While we design all types of structures, our specialty is designing structures in the following industries: health care, research, museum, theatre, academic, housing, laboratory, commercial, municipal, parking, residential, and industrial. We use the latest analysis, design, and documentation tools, including FEA, BIM, and LEED, and have extensive experience with various project delivery methods, such as IPD. We offer a full range of structural engineering services, including:

- Analysis and design
- Construction administration
- Comparative studies and feasibility studies
- Structural evaluations
- Peer reviews
- Expert witness

Lin Gallant:

Lin Gallant is an associate at Souza, True and Partners, with more than eight years of experience in structural engineering design. As a registered professional structural engineer in Massachusetts, Lin is focused on providing structural engineering solutions to clients in the building industry. Lin's design experience spans all industries and building types, from hospitals and research facilities to intermodal transportation centers. With a strong background in IT, Lin is the technology leader at his firm, responsible for researching and implementing new technology aligned to his company's business strategy and client demands. Prior to joining Souza True, Lin has worked at both large and small multidisciplinary engineering firms and in the public sector at a regional planning agency. Lin's college education focused on structural engineering and technology at UMass Amherst, where he obtained his bachelor's and master's degrees in civil engineering.

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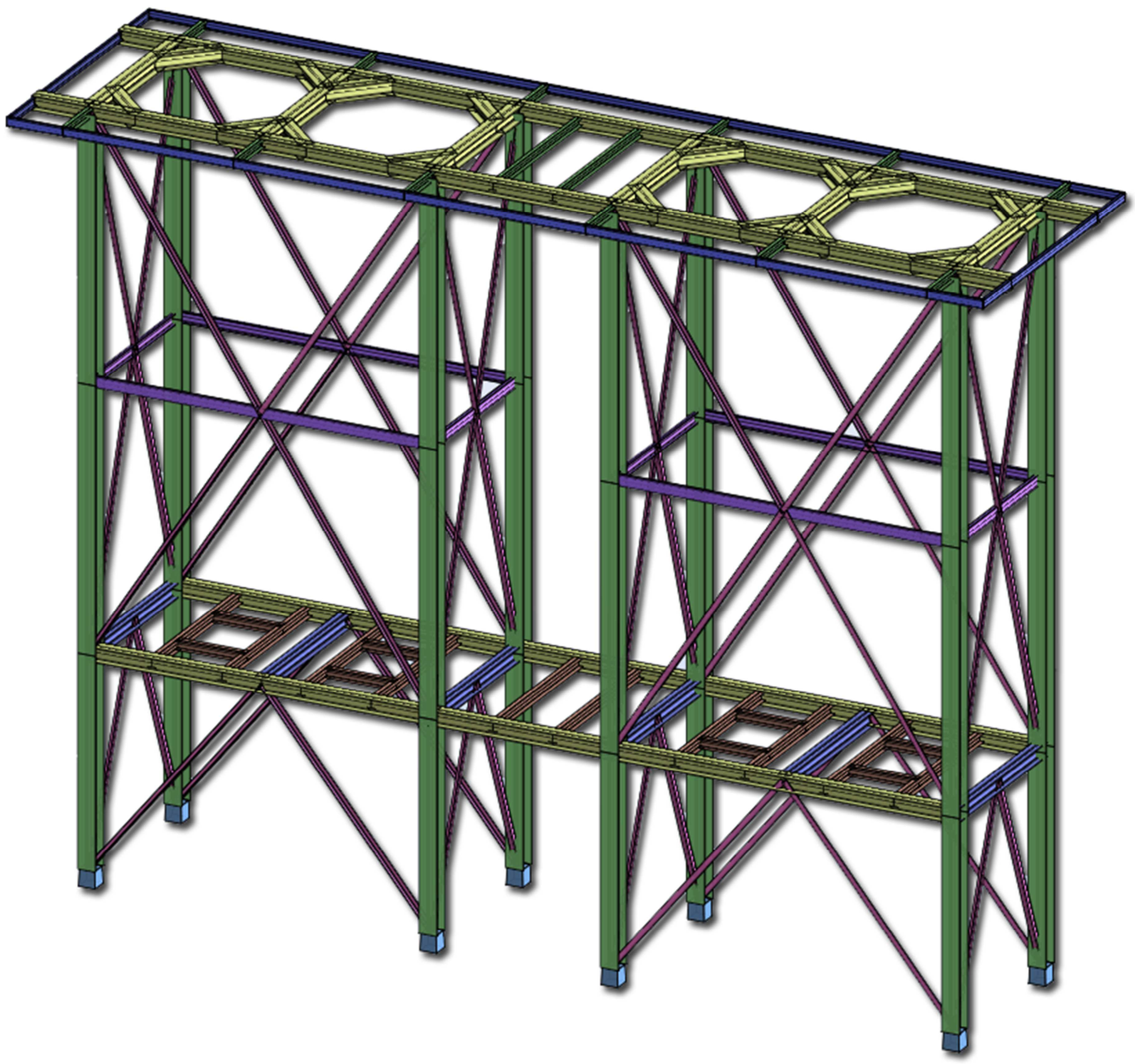
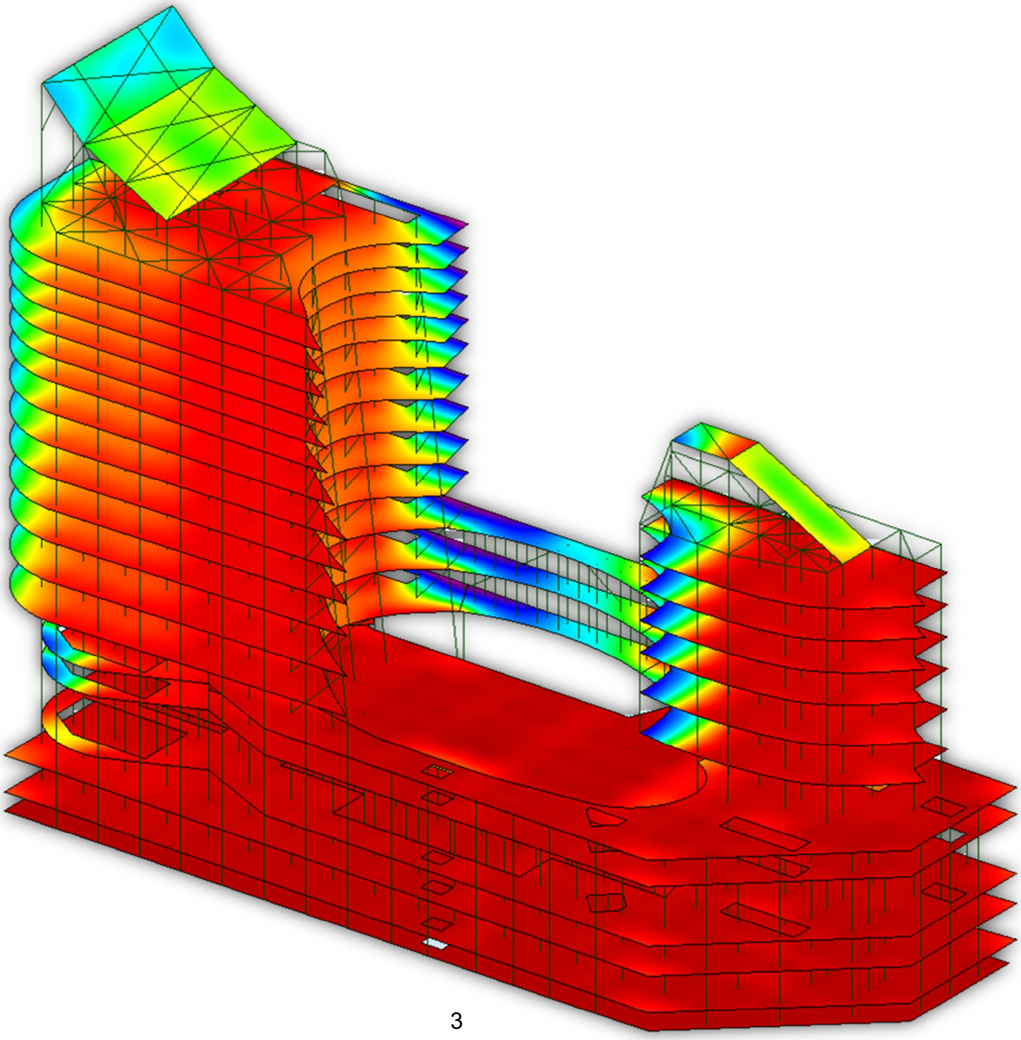


Introduction

Designing for stability is a critical requirement for all steel structures, but implementing the latest stability analysis methods into engineering workflows can be challenging and have significant negative effects if done improperly. With the release of the *AISC Specification for Structural Steel Buildings (AISC 360-05)* in 2005, AISC introduced the Direct Analysis Method and imposed new requirements for stability analysis and design. These changes represent a fundamental shift in how engineers consider destabilizing effects, shifting the accounting of these effects from member capacity calculations to member demand (analysis) calculations. Utilizing the Direct Analysis Method results in greater accuracy, simplified member capacity calculations, and greater applicability to more types of structures.

However, these benefits come at the expense of a more complex and rigorous structural analysis than was required with previous methods. For structures designed with structural analysis and design software, this requires significant changes to how the software conducts its analysis. The new requirements also require that engineers have a clear understanding of the Direct Analysis Method, how their software handles these analysis modifications, and when they should apply these new provisions. Improper implementation and user input can lead to significant overestimation or underestimation of the demands imposed on structures and their response to those demands.

To complicate matters further, the variation of programming and user workflows with different programs has led to a diversity of Direct Analysis Method implementations available, with many programs making different compromises in analysis accuracy, flexibility, and user experience to implement the Direct Analysis Method.



Background

The latest AISC stability analysis requirements have an impact on nearly all parameters of structural analysis. In order to be considered a valid stability analysis per AISC 360-05 and 360-10, the analysis must consider:

1. **All deformations** – flexural, shear, and axial deformations and all other component and connection deformations
2. **Second-order effects**
   - P-Δ effects – loads acting on globally displaced joints or nodes in a structure
   - P-δ effects – loads acting on locally deformed member shapes between nodes
3. **Initial imperfections** – due to fabrication and erection tolerances
4. **Material imperfections** – due to residual stresses imposed during fabrication
5. **Inelasticity** – as members are stressed beyond the elastic range, material softening occurs that reduces axial and flexural stiffness, which can amplify second-order effects

While AISC provides clear guidance on how to account for these effects, implementing them into analysis-design software is not a trivial task. Prior to the release of *AISC 360-05*, structural analysis using first-order elastic analysis was the most popular method used by design software due to its ease of implementation and relatively low computational demand. It was understood that the destabilizing effects occur in real structures, but they were accounted for in very different ways. Effective length (k) factors were applied to member strength calculations, which indirectly included the effects for member imperfections and material inelasticity. However, these factors represent idealized conditions not often found in real structures, and are applied only to the column axial load capacities and not included in other member design equations. Amplification factors were used to scale first-order elastic results to account for second-order effects, but in 2005 AISC placed limitations on the use of these factors for structures that are sensitive to second-order effects. These structures include those subject to high vertical loads with low lateral load resisting requirements, such as heavily loaded structures located in regions of low seismicity and low wind demand. The use of a second-order analysis was previously permitted by older versions of the AISC Specification, but little guidance was provided and member capacities still required the use of k factors. Logistically, these effects were accounted for after completion of the analysis, during post-processing and member design calculations. Accounting for these effects during the analysis requires major modifications be made to the software's programming.

To account for all five effects listed above, many modifications are required, including member stiffness reductions, the creation of notional load cases, and iterative analysis to capture second-order effects. To complicate matters further, not all analysis and design concerns have been calibrated to be compatible with these stability modifications, including serviceability, vibrations, dynamic response, and so on. Generally, this means at least two analysis models are required, one for stability design and another for everything else. Depending on how the program is structured, this can create a disjointed and cumbersome user experience. In order to implement these changes without a significant overhaul, software designers often make concessions to reduce computational complexity and the number of analysis iterations required, and they often limit the amount of control users have over stability analysis parameters. All of these decisions directly impact the accuracy of designs and the productivity of engineers who use these tools.

A review of currently available software solutions reveals typical concessions made to implement the latest stability analysis requirements:

- A common concession made is not conducting a true second-order analysis. Typically, this means considering P-Δ effects directly in the analysis but not P-δ effects, which are calculated using amplification factors. This approach can provide reasonably accurate results for most structures, but can be overly conservative or under conservative for structures sensitive to geometric imperfections.

- Many programs require multiple analysis runs, which is primarily due to the inability to create, store, and display the results from multiple analysis models. This increases analysis time and creates user workflow issues by requiring users keep track of numerous parameters, changing between stability analysis runs and other analysis runs.
- To simplify the analysis, some programs elect to make certain stability analysis and design parameter decisions for the user, without the ability to customize. An example of this is flexural stiffness reduction and notional load application. Some programs elect to apply additional notional loads to all load combinations, as is allowed by the AISC Specification, rather than enable the user to use alternate stiffness reduction factors, because the former is computationally less complicated. While this approach can be reasonable for many structures, it is not a flexible approach and can be overly conservative.

While not all programs have all of the above issues, each program we've used and reviewed makes some concessions. With this in mind, what are the qualities of a good Direct Analysis Method implementation? The primary goals should be to provide the most accurate results, flexibility to change analysis parameters to meet project specific requirements, an intuitive and transparent interface to understand what the analysis is actually doing, all while minimizing the additional burden placed on engineers.

Review of Robot Structural Analysis Professional 2015 Direct Analysis Method implementation

With the 2015 release version of Autodesk® Robot™ Structural Analysis Professional software, Autodesk has made significant enhancements to the program's stability analysis capabilities, including a robust implementation of AISC's Direct Analysis Method. Based on our knowledge of AISC's stability requirements and the shortcomings observed with other analysis software solutions, let's review Robot Structural Analysis Professional to see if it meets our criteria for a successful stability analysis method.

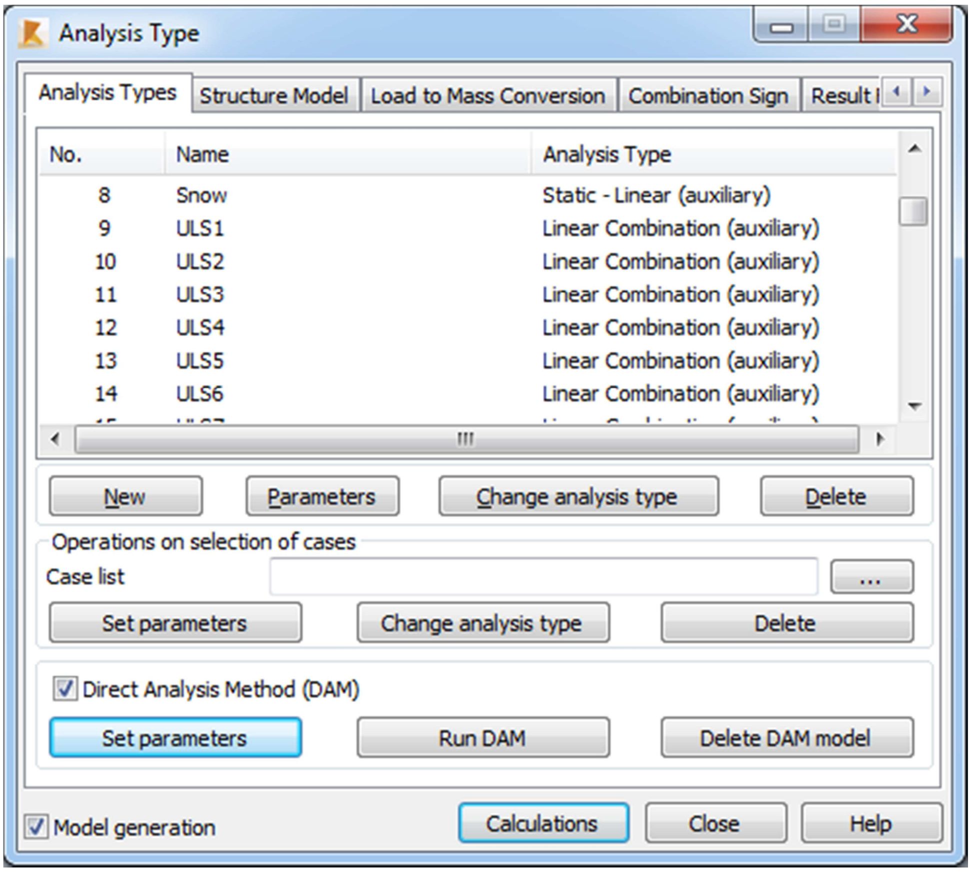


Figure 1. The user can activate the Direct Analysis Method analysis type in the Analysis Type dialog box.

With Robot Structural Analysis Professional's powerful analysis capabilities and programming structure, the software is able to offer users a stability analysis experience that meets all of AISC's requirements, is customizable, and is easy to use. The software achieves this by generating a separate Direct Analysis Method model, which automatically conducts the analysis per the stability analysis parameters specified by the user and uses the results in the appropriate design equations without the need for additional user input.

To conduct a valid stability analysis, Robot Structural Analysis Professional employs the following features:

1. **Deformations** – software calculates and considers all flexural, shear, and axial deformations for each member
2. **Second-order effects** – software calculates both P-Δ effects and P-δ effects using a rigorous second-order analysis
3. **Initial imperfections** – software automatically generates notional load cases for all gravity loads, and magnitudes, directions, and load combination of the notional loads are fully customizable
4. **Material imperfections** – software includes stiffness reduction factors to account for material imperfections, which can be customized by the user
5. **Inelasticity** – the same stiffness reductions for material imperfections are applied in software to account for material inelasticity

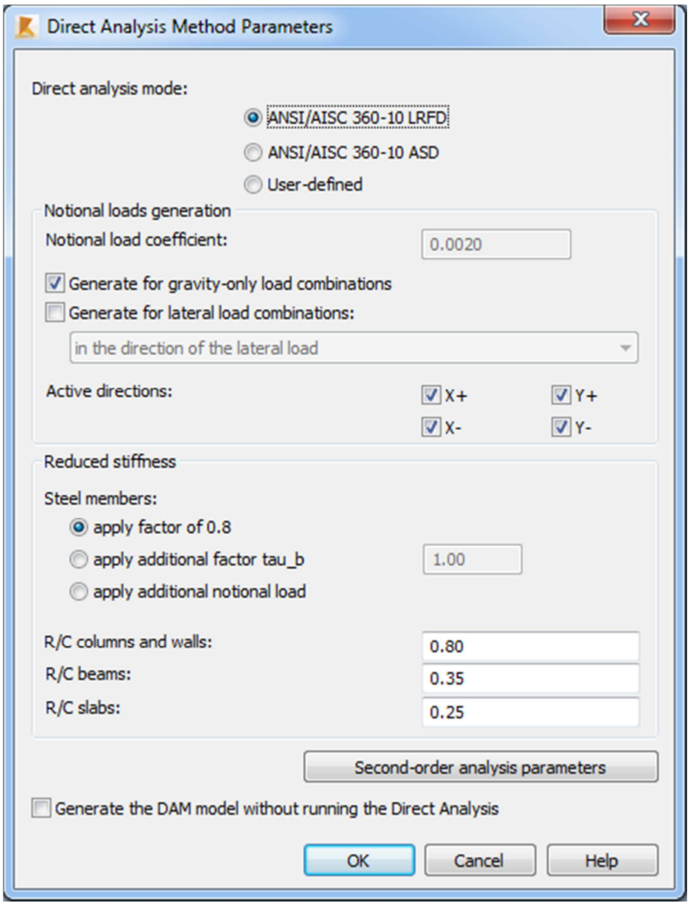


Figure 2. Direct Analysis Method parameters.

Since the program creates a separate Direct Analysis Method model, it has the ability to make the above modifications without compromises. Using a true second-order analysis helps ensure accurate results without the need to scale linear elastic results with amplification factors. A separate stability model gives the user confidence that their other design concerns, such as serviceability, are carried out with the appropriate unaltered parameters. This will significantly reduce errors made for non-stability calculations and eliminate the need for multiple analysis runs or manually creating and maintaining separate analysis files for different analysis types.

Conducting a stability analysis using the Direct Analysis Method in Robot Structural Analysis Professional is simple. Only two actions are required by users to run an analysis. First, the user must activate the Direct Analysis Method analysis type and then they must set Direct Analysis Method parameters. For convenience, both of these tasks are accessed from the Analysis Type window and all parameters specific to the Direct Analysis Method are conveniently located in a single parameters window. These parameters are completely customizable by the user, but for convenience and quick implementation, typical values and default values are provided for use (see Figure 2). With the analysis parameters established, the user can run the stability analysis, which can be run simultaneously with the original analysis model. Users have the option to run and delete the Direct Analysis Method analysis independently from other analysis types. Deleting the Direct Analysis Method results removes the separate analysis model from the project without affecting the original model or other analysis results.

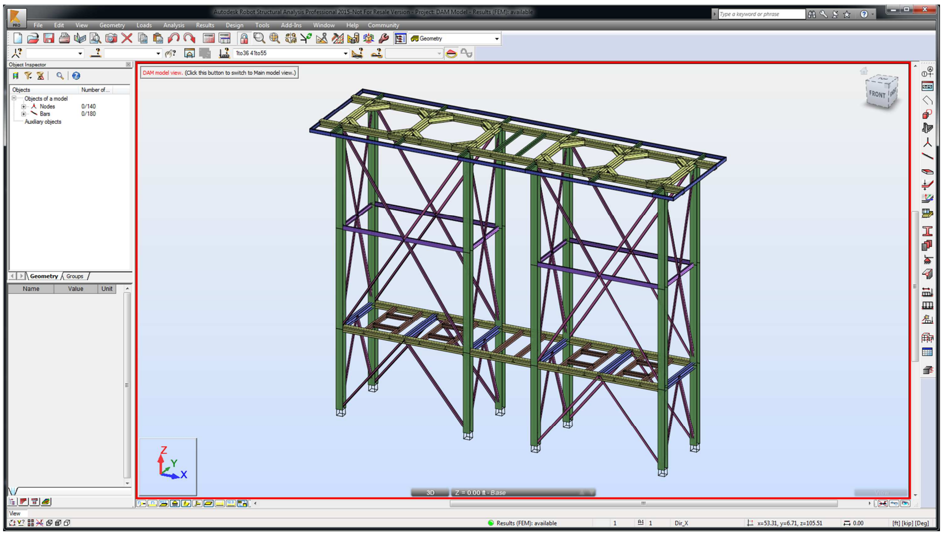


Figure 3. Direct Analysis Method model activated in the viewer.

Once the analysis is complete, the user has several options to view and validate their analysis. These options include viewing a comprehensive Direct Analysis Method validation report and switching to the Direct Analysis Method model view in the project window. The validation report provides the user with useful analysis option information and model results, including information on notional load application, stiffness reductions, second-order analysis verification, a second-order to first-order drift ratio comparison, and axial force demand capacity ratios. These are important values every engineer should review to help ensure their parameters assumptions result in a valid AISC stability analysis.

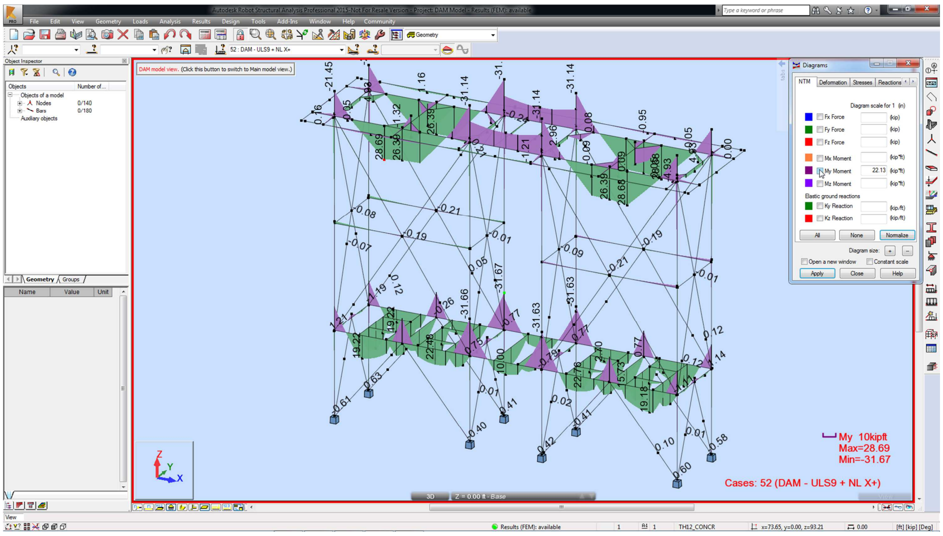


Figure 4. Results of the calculation of the Direct Analysis Method model.

Switching to the Direct Analysis Method model view from the main model view is accomplished by clicking a toggle button on the top left corner of the viewing window. When working with the Direct Analysis Method model results, a red border surrounds the viewing window or table, providing an obvious visual cue to eliminate confusion when switching between model types. In this view, the user is able to see specific analysis results, both on the model itself and in tabular form. When the user is satisfied with the results, they can proceed to the member design calculations. Since Robot Structural Analysis Professional automatically utilizes the Direct Analysis Method results in the appropriate design equations, there is no need for additional user input to quickly use stability analysis results for code checking. The user can quickly validate the proper analysis results were used in design by reviewing the member design summary and member design reports.

Conclusion

The Direct Analysis Method presents an opportunity for engineers to produce more accurate, safer, and more transparent designs for a wider range of steel structures. The cost of these benefits comes in the form of increased analysis requirements and complexity. As engineers need to adjust to this fundamental change, so to do structural analysis and design programs. The implementation challenges are significant, but the benefits of the Direct Analysis Method warrant dealing with these difficulties. While many programs can state that they comply with the stability requirements of *AISC 360-05* and have a working implementation of the Direct Analysis Method, tradeoffs in various aspects of the analysis and user experience are often made to implement these requirements. With Robot Structural Analysis Professional we find a powerful analysis and design platform with an approach to stability analysis that is rigorous, practical, and customizable. This Direct Analysis Method implementation produces easy-to-use, reliable results, with negligible increases in analysis and design time. Engineers can be assured that their analysis and designs completed in Robot Structural Analysis Professional will consider all code-required stability effects, with results that will never be unconservative or overly conservative.

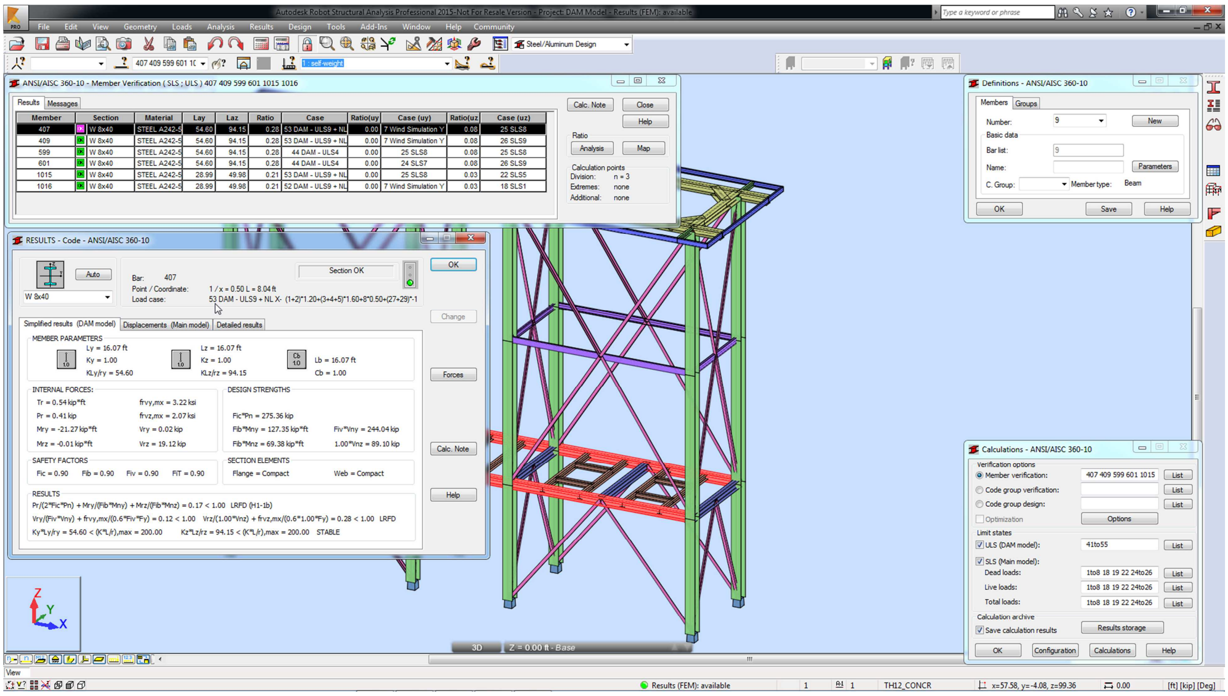


Figure 5. Stability analysis results are used for code checking.