

# A How-To Approach to Notional Loads

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Accounting for initial imperfections is as simple as modeling them with the loads.

**IN THE 2005 AISC** *Specification for Structural Steel Buildings*, AISC introduced significant changes to the stability design requirements. Clear requirements for stability design and three straight-forward methods of satisfying those requirements have been introduced. One of these, the direct analysis method, is the premier method and is found in Appendix 7 of the 2005 *Specification*, but will move to Chapter C as the default method in the 2010 *AISC Specification*. The basics of the direct analysis method include the following:

- **Second-Order Analysis:** A second-order analysis which considers both  $P-\Delta$  and  $P-\delta$  effects is required. This can be accomplished through a rigorous second-order analysis or by using the approximate method presented in the specification.
- **Initial Imperfections:** The effects of initial imperfections of the structure geometry are considered either by applying notional loads or directly modeling the imperfections in the geometry of the model.
- **Inelasticity:** The axial and flexural stiffnesses of members that contribute to the stability of the structure are required to be reduced to account for inelastic behavior in the members.
- **Effective Length Factor:** One major benefit of the direct analysis method is that  $K = 1.0$ . No more calculating  $K$  when determining the nominal strength of columns.

This article focuses on the idea behind using notional loads in a computer model to account for initial geometric imperfections. It is extracted from a larger white paper, which can be found in its entirety at [www.cscworld.com](http://www.cscworld.com).

## Using Notional Loads

To account for the effect of initial imperfections, the specification allows the designer to directly model the imperfections within the model. The set of initial displacements modeled need to consider displacements due to loading and anticipated buckling modes of the structure.

One consequence of this requirement is that the out-of-plumbness of the columns and the out-of-straightness of each member must be modeled. This must be done in a way to capture the most destabilizing effect on the structure, which means at least four different sets of displacements applied in the four principal directions at each level, with a corresponding set of member out-of-straightness selected to add to the effect of the out-of-plumbness.

This method can quickly become difficult and may require several separate models. In addition, if sharing project information through BIM, maintaining a single model with the “real” geometry has many advantages. Therefore, generally the best alternative may be to add notional loads to the structure as specified by AISC.

Notional loads are horizontal forces added to the structure to account for the effects of geometric imperfections. Figure 7, right, illustrates a simple version of the concept. The notional loads ( $N_i$ ) are calculated as a portion of the gravity loads ( $Y_i$ ) and applied at each level. The guidance included below will help you to calculate the magnitude of the notional loads, decide where to place them on the model and in which direction(s).

### Magnitude

The notional load,  $N_i$ , is 0.2% of the total factored gravity load at each level,  $Y_i$ , and can be written as:

$$N_i = 0.002 Y_i$$

Note that the value 0.002 is equal to  $1/500$ , which is the maximum tolerance for out-of-plumbness in steel structures as indicated in the AISC *Code of Standard Practice* (see Figure 8). Note that a smaller value can be used if the actual out-of-plumbness of the structure is known.



▲ Fig. 8: AISC *Code of Standard Practice* Tolerance for Column Out-of-Plumbness

Gravity loads are defined in the AISC *Specification* as “Load such as that produced by dead and live loads, acting in the downward direction.” The value  $Y_i$  is the total factored gravity load in each load combination. Therefore, the value of the notional loads will change from combination to combination. Also, the total factored gravity load includes all gravity loads on a level, not just those loads that are vertically supported by lateral framing members. Therefore the effect of leaning columns is included in the notional loads.

When using ASD with a direct second-order analysis, the total gravity load (and therefore the notional loads) are multiplied by 1.6. This is the same factor that is required for the second-order analysis with ASD. The loads are not multiplied by 1.6 twice.

### When to Apply

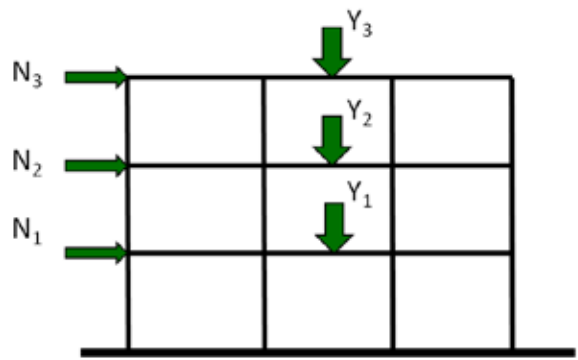
Notional loads are required to be added to all load combinations. For combinations including lateral loads, the notional loads are added to the other lateral loads. However, when the ratio of second-order deflection to the first-order deflection ( $2/1$ ) is less than 1.5, the notional loads only need to be added to gravity only combinations. The limit of 1.5 applies to structures that have been analyzed using the nominal (unreduced) stiffness of lateral members. If reduced stiffness is used, the limit is 1.7.

### Distribution

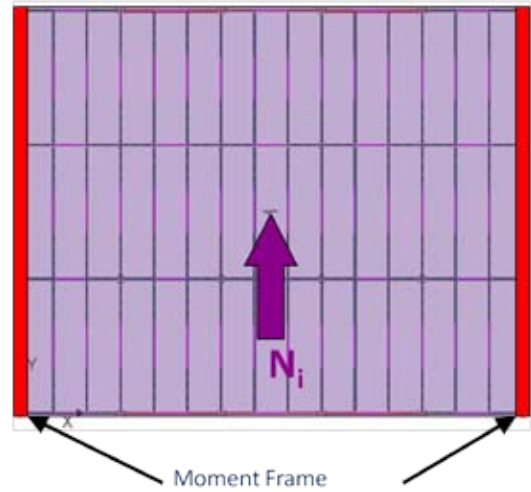
Now that you have the magnitude of the notional loads for each level and load combinations, you have to decide where on plan to apply them to the structure. AISC requires that they be distributed on each level in the same manner as the gravity load. This would indicate you could apply a single notional load (at each level for each load combination) at the location of the resultant of the total factored gravity loads, otherwise known as the center of gravity. The direction of the loads will be discussed in the next section.

If the gravity loads are distributed uniformly (in plan) on the level, it is easy to calculate where the notional load should be placed. Assuming the lateral framing is symmetric, it is easy to determine what portion of the notional loads each frame resists. See Figure 9.

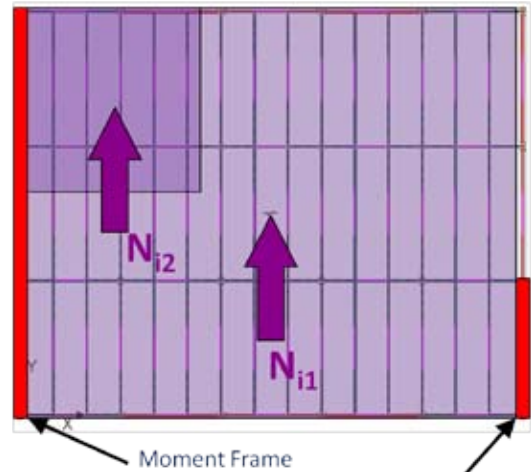
As areas with different gravity loads are introduced to the structure (such as a heavy storage area) the calculation of the center of gravity becomes more complicated. You would more likely add a notional point load at the center of gravity of each loading area. If there are only a few loading conditions and your lateral framing is still simple, the distribution of the notional loads to the frame is still manageable. See Figure 10.



▲ Fig. 7: Notional Loads



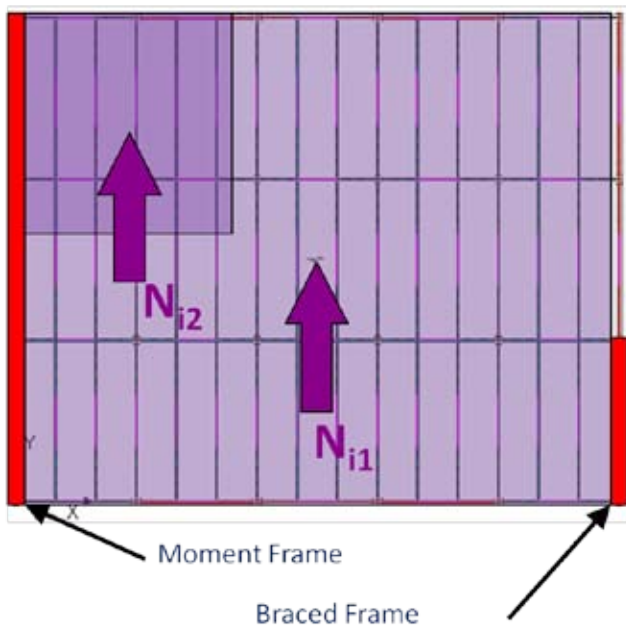
▲ Fig. 9: Notional Load for Uniform Loading and Symmetric Lateral Framing



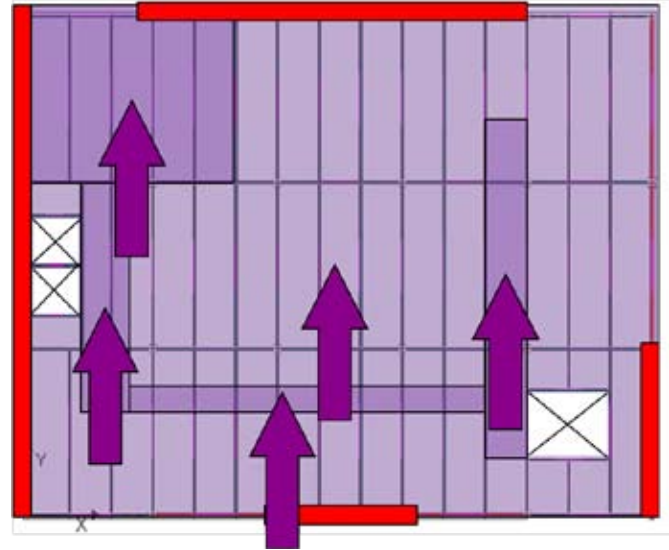
▲ Fig. 10: Multiple Loading Areas with Asymmetric Lateral Framing

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▲ Fig. 11: Multiple Loading Areas and Asymmetric Lateral Framing



▲ Fig. 12: "Real" Building with Complex Loading and Lateral Framing

As soon as a bit more complexity is added to the lateral framing, the distribution of the notional loads to the framing becomes more complicated. See Figure 11.

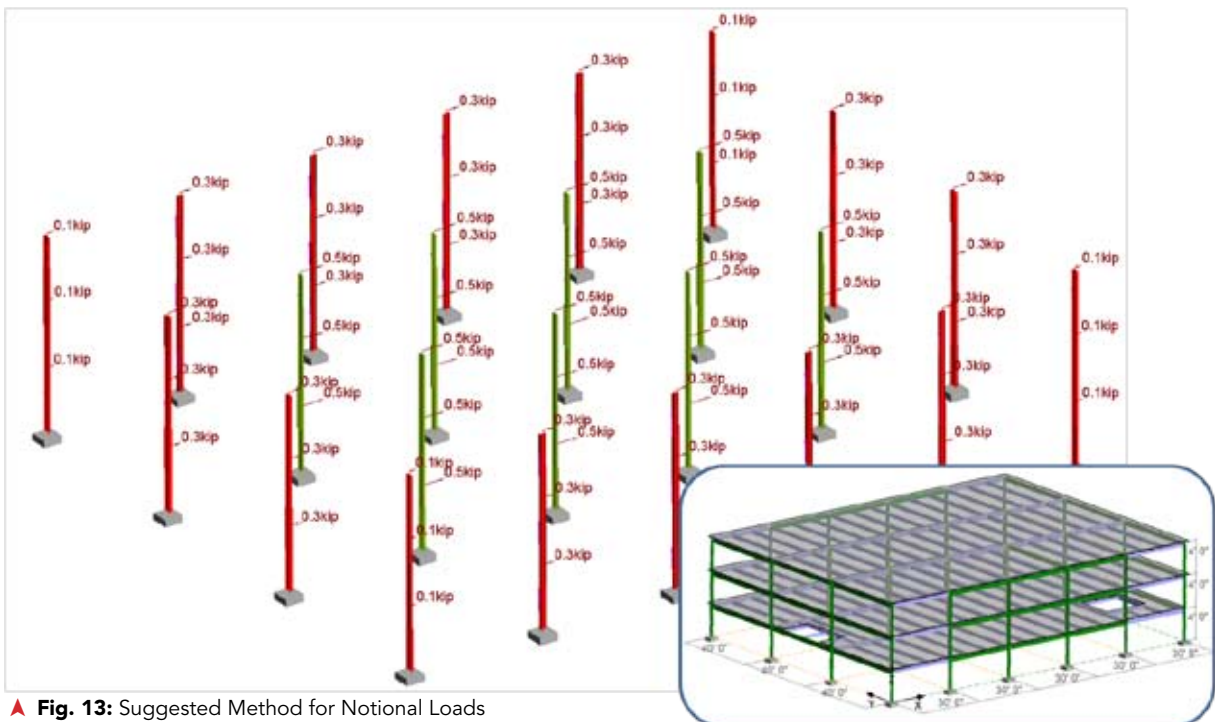
In a real building there are multiple loads on the levels and usually unsymmetrical framing. This makes placing and distributing the notional loads more and more complex. See Figure 12.

These more complex situations obviously lend themselves to computer analysis. The following suggested method works well with and without computer software, assuming you are able to accurately distribute the notional loads to the lateral framing by hand.

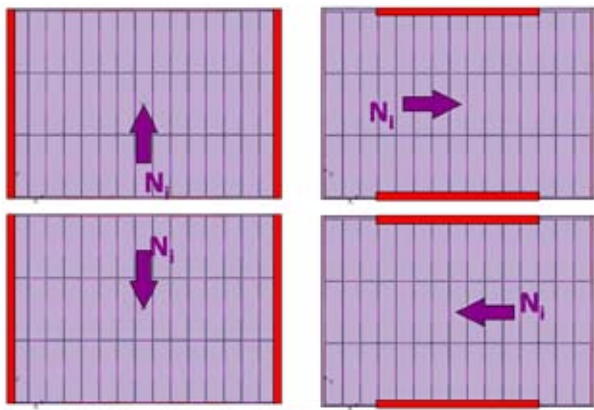
- Calculate the total factored gravity load transferred to each column at each level.
- Calculate the corresponding magnitude of the notional load for each appropriate load combination.

- Apply the notional load as a point load at each column at each level. See Figure 13 for a sample set of notional loads.
- Include the set of notional loads in each appropriate load combination.
- Perform a 3D analysis of the structure for the load combinations. Consider all framing, both lateral and gravity, in the analysis.

The point loads represent the notional load effect on each column. By applying the loads to all columns and including all framing in the model, the effect of leaning columns is directly included as part of the analysis. This method correctly distributes the notional loads in the same manner as the total factored gravity load and through the 3D analysis allows the effects of those loads to be distributed accurately to the lateral framing. This method can be easily automated and included as part of the structural analysis.



▲ Fig. 13: Suggested Method for Notional Loads



▲ Fig. 14: Notional Load Direction for Gravity Load Combinations

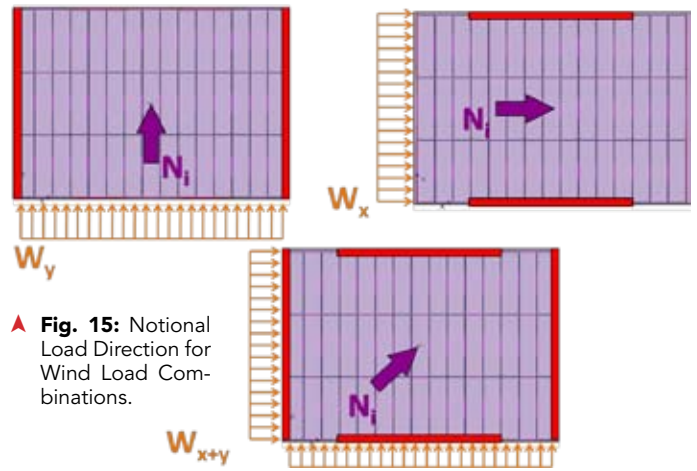
### Direction

Now we have a good method for calculating and applying notional loads in the proper location in the model. The next step is to determine in which direction or directions to apply them. The requirement in the AISC *Specification* is to apply the notional loads in the direction that adds to the destabilizing effects.

For gravity load combinations you will generally not know which direction is critical and different directions will be critical for different members within the framing. Therefore you will have to apply the notional loads in two orthogonal directions in both the positive and negative sense. See Figure 14. You can apply the notional loads in the same direction on all levels. Therefore, you will now have four load combinations for each gravity load combination each with the notional loads applied in a different direction.

For lateral load combinations (when notional loads are required) the notional loads are applied in the direction that adds to the destabilizing effects. This would be in the same direction as the resultant of all lateral loads. So if you are adding notional loads to a wind load case where the wind loads are applied in the +X direction, the notional loads would also be placed in that direction. If you have a combination of X and Y wind loads (as is often required by ASCE 7), then you would apply the notional loads in the resultant direction of the wind loads. See Figure 15 for an illustration of simple examples.

To read the full white paper from which this article was extracted, go to [www.cscworld.com](http://www.cscworld.com). MSC



▲ Fig. 15: Notional Load Direction for Wind Load Combinations.