Direct Analysis Method – Part II

Design of a Three Bay Frame

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Introduction

As shown in Part One, S-FRAME's implementation of P-Delta analysis is rigorous and accurate enough for use in the Direct Analysis Method (DM) according to the requirements of ANSI/AISC 360-10. Part One showed this by comparing S-FRAME's calculated moment and deflection to those predicted by theory for two columns.

In *Design Steel Your Way II: Efficient Analysis for Steel Design Using the 2005 AISC Specification*, Carter and Geschwindner present a two-dimensional, three-bay unbraced frame and conduct its design using DM. In this paper, S-FRAME will be used to analyze the same frame, also using DM.

Structure

The structure is composed of two internal columns with fixed bases and two external leaning columns, as shown in Figure A. The columns are pin connected at the top to three rigid horizontal elements. The only lateral stiffness is provided by the two internal columns. The columns are 15 feet in height.
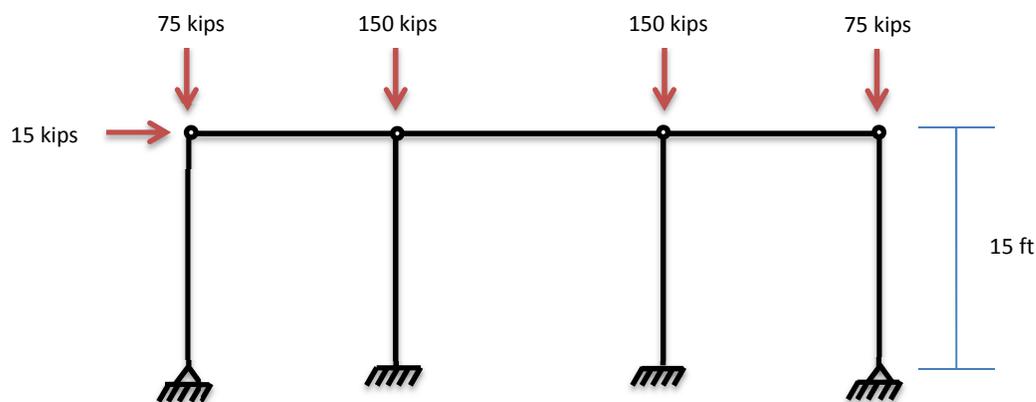

Figure A: Frame Geometry

Each column is loaded vertically and the system is loaded laterally at one of the horizontal rigid members.

A preliminary design has been performed to choose a section based on drift limits alone. The chosen section, W14x109 from ASTM A992 is applied to all columns. More details on this can be found in *Design Steel Your Way II.*

Direct Analysis Method

An introduction to the Direct Analysis Method was provided in Part One:

> *Specifications for Structural Steel Buildings*, *ANSI/AISC 360-10, published by the American Institute of Steel Construction, outlines the Direct Analysis Method (DM) and specifies its use in the design of steel structures. DM is defined by AISC as "a design method that captures the effects of residual stresses and initial out-of-plumbness of frames by reducing stiffness and applying notional loads in a second order analysis." DM also accounts for uncertainty in material strength and stiffness as well as stiffness reduction due to inelasticity.*

Perhaps the main advantage of DM is that it does not require calculation of effective length factors, which can be time consuming and computationally expensive. Furthermore, DM is applicable to all structures and does not distinguish between structural systems. According to Carter and Geschwindner, "the Direct Analysis Method was developed as the most accurate approach" for stability analysis and design.

While this paper does not aim to provide guidance on the use of the DM outside of S-FRAME, it would be prudent to discuss the steps undertaken in the AISC design guide en route to a solution. This will also provide some insight into what takes place behind the scenes in S-FRAME, although, as one would expect, the procedure in S-FRAME does vary in some respects to allow for automation when appropriate

Carter and Geschwindner began by computing the reduced stiffness of the W14x109 sections and using it to determine B_2: the ratio of second order to first order drift. Next the notional loads were calculated as 0.2% of the total vertical load. As B_2 was found to be less than 1.5 and the notional loads were found to be less than the 15 kip lateral load already applied, no notional loads were applied to the structure.

Next, the design guide uses the first order amplification method to take second order effects into account by increasing the magnitude of the axial and moment loads experienced by the columns. Finally, a compression check, bending stability check, and flexure and compression interaction check were performed to determine the adequacy of the chosen section.

S-FRAME Model

The model was constructed in S-FRAME using the same four W14x109 columns. Rather than use a rigid member to span the columns, a rigid diaphragm was used to constrain the four nodes at the top of the columns to each other. The supports prevented out of plane translation and rotation. For proper application of the DM, it was necessary to identify steel as a material to be applied to Lateral Force Resisting Members (LFRM) in the material properties. The steel with the LFRM option active was applied to the two internal columns, while steel with this option turned off was applied to the exterior, leaning columns. Other than this option, the material properties were identical.
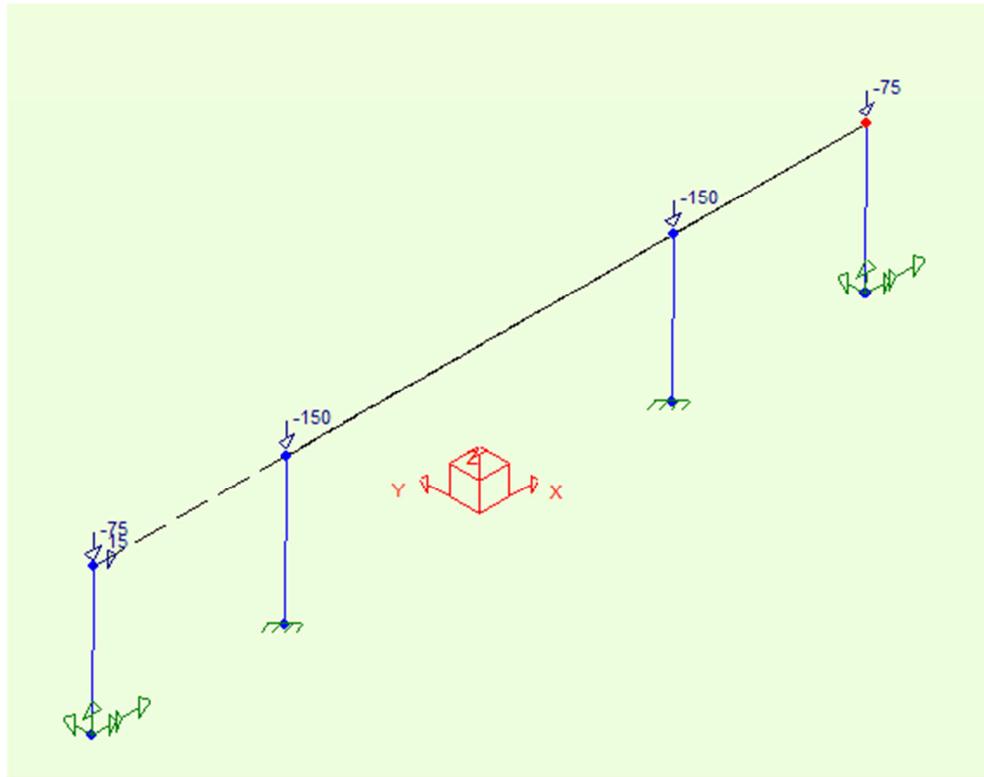

Figure B: S-FRAME Model

After the loads were applied, notional load factors were defined by hand as 0.2% and added to a load combination containing axial and lateral loads. S-FRAME will automatically calculate notional loads from the notional load factor and apply the larger of lateral loads and notional loads if it finds B_2 to be less than 1.7[1]. Otherwise, it will combine lateral and notional loads.

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[1] The discrepancy in B_2 cutoff between *Design Steel Your Way II* and S-FRAME is related to how the check is performed. *Design Steel Your Way II* performs the check with the unreduced stiffness EI while S-FRAME uses the reduced stiffness, EI*, and hence a larger cutoff is expected.

The AISC 360-05 LFRD design code was selected with the "DAM + 0.8 + τ_b" option. This automatically scales the stiffness of all LFRMs by 0.8 plus τ_b. τ_b is calculated based on the following:

If

$$\alpha P_r/P_y > 0.5 \quad \text{then} \quad \tau_b = 4(\alpha P_r/P_y*(1-\alpha P_r/P_y))$$

else

$$\tau_b = 1$$

where

P_r = axial force in member
$P_y = F_y$ x Area
$\alpha = 1.0$ for LFRD and 1.6 for ASD

Next, the model was run with P-Delta analysis. As S-FRAME offers rigorous P-Delta analysis, it was not necessary to use the amplified first order effects method used in *Design Steel Your Way II*; S-FRAME calculates the actual P-Delta effects. Unlike some software implementations of the Direct Analysis Method, S-FRAME only requires one run through analysis to calculate results.

To perform the three checks (compression, bending stability, and flexure and compression interaction) performed in the design guide, the analyzed model was opened in S-STEEL to take advantage of its code check features. Before performing a code check, it was necessary to change the design settings to match the example. The effective length factors in S-STEEL were set to $K_x = 1.0$ and $K_y = 1.0$ for all members as the Direct Analysis Method specifies. B_1 and bending coefficients C_b and C_m were all set to unity to reflect that P-delta effects were already taken into account in S-FRAME. Finally, A992 High Strength Low Alloy steel was selected.

Once complete, a code check was run for the load combination containing the axial and lateral loads, and the notional load factors.

Results

To check the accuracy of S-FRAME's Direct Analysis Method, the results are compared to those computed by hand in *Design Steel Your Way II*. The AISC design guide presents the results of three checks: a compression check, a bending stability check, and a flexure and compression interaction check. These are calculated as follows:

Compression Check

$$\frac{required\ axial\ compressive\ strength}{availible\ axial\ compressive\ strength} = \frac{P_r}{P_c}$$

Bending Stability Check

$$\frac{required\ moment\ resistance}{availible\ flexural\ strength} = \frac{M_{rx}}{\phi_b M_{nx}}$$

Flexure and Compression Interaction Check

$$\frac{required\ axial\ compressive\ strength}{twice\ the\ availalbe\ axial\ compressive\ strength} + \frac{required\ moment\ resistance}{availalbe\ flexural\ strength} = \frac{P_r}{2P_c} + \frac{M_{rx}}{M_{cx}}$$

The results of S-FRAME's analysis and the design guide are compared in Table 1.

Table 1: Results Comparison

Check	S-FRAME	Design Guide
Compression	0.123	0.123
Bending Stability	0.174	0.174
Flexure and Compression Interaction	0.236	0.235

In all three checks, S-FRAME's results are very close to those calculated in the design guide, differing by at most 0.4%. In fact, because the guide uses amplification of first order effects, while S-FRAME actually performs P-Delta analysis, it is possible that S-FRAME's results are closer to the 'true' values.

Conclusion

In version 10.0, S-FRAME has added support for the Direct Analysis Method, as specified by AISC. Part One of this paper demonstrated that S-FRAME's P-Delta analysis is more than accurate enough for use in DM. The second part of this paper used S-FRAME's implementation of DM to determine the required and available strengths of columns in a three bay frame. The frame had already been analyzed by hand in the AISC design guide: *Design Steel Your Way II*. Comparing the results from S-FRAME to those calculated in the design guide yielded very close agreement, demonstrating that S-FRAME is a reliable tool for use in the Direct Analysis Method.