research report

Estimating the Response of Cold-Formed Steel Frame Shear Walls

RESEARCH REPORT RP03-7

2003
REVISION 2006

American Iron and Steel Institute

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PREFACE

This report was developed by Dr. Reynaud Serrette for the Lateral Design Task Group of the AISI Committee on Framing Standards. The objective of this project was to develop elastic shear stiffness coefficients and general (piece-wise linear or continuous) deflection expressions for the shear wall configurations to be included in the AISI *Standard for Cold-Formed Steel Framing - Lateral Design*.

This project developed a method to estimate the drift deflection of cold-formed steel frame shear walls recognized in the 2003 ICC *International Building Code* (IBC) and 2003 NFPA *Building Construction and Safety Code* (NFPA 5000). The method was based on a simple model for the behavior of shear walls and incorporated empirical factors to account for nonlinear behavior. The empirical factors were based on regression and interpolation analyses of the reversed cyclic test data used in development of the IBC and NFPA 5000 cold-formed steel shear wall design values. The findings provided a basis for the AISI Committee on Framing Standards to include an expression for the deflection of a blocked wood structural panel or sheet steel shear wall in the AISI *Standard for Cold-Formed Steel Framing - Lateral Design*.

Research Team
Steel Framing Alliance

Estimating the Response of Cold-Formed Steel Frame Shear Walls

Prepared for
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Submitted

November 29, 2003
(Revised: December 17, 2003)

INTRODUCTION

This paper describes a method that was recently developed to estimate the drift deflection of cold-formed steel (CFS) frame shear walls recognized in the 2003 International Building Code (IBC) and 2003 National Fire Protection Association (NFPA) Building Construction and Safety Code (NFPA 5000). The method is based on a simple model (illustrated in Figure 1) for the behavior of shear walls and incorporates empirical factors to account for nonlinear behavior. The empirical factors are based on regression and interpolation analyses of the reversed cyclic test data used in development of the IBC and NFPA CFS shear wall design values. Specifically, the peak response envelope data illustrated in Figure 2 was used.

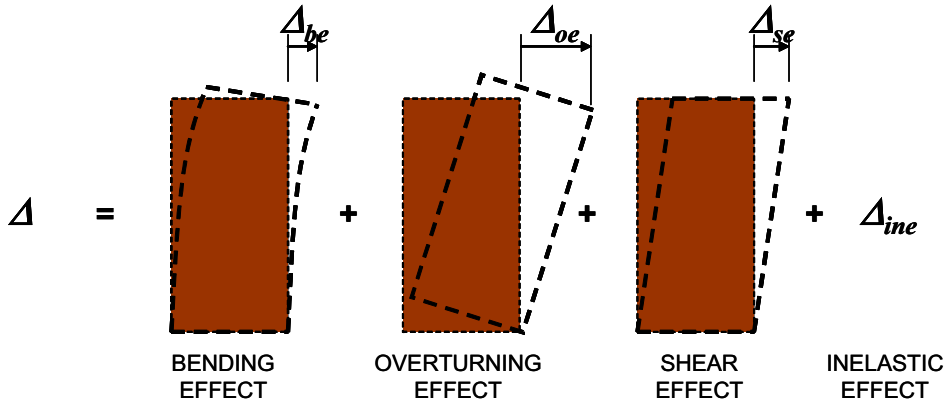


Figure 1. Modeling of drift deflection, Δ

In reviewing the accuracy and applicability of the formulation/method presented, it is important to keep in mind that the response of light frame shear walls is relatively complex and the proposed semi-empirical method is intended to provide an estimate, not an exact prediction, of drift deflection. To the extent feasible, the method was developed to be as general as possible. However, the specific application of the method is geared toward the CFS shear wall configurations referenced in the IBC and NFPA building codes. The method should not used to estimate capacities nor should it be used to estimate drift deflection beyond the nominal strengths tabulated in the referenced building codes.

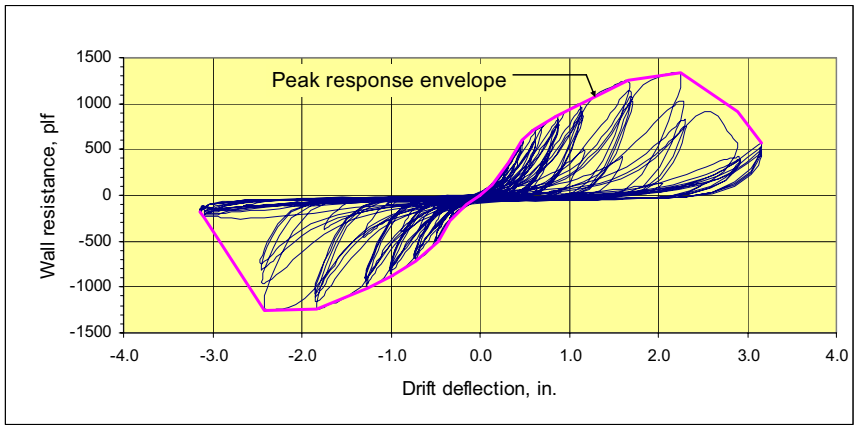


Figure 2. Example of a peak response envelope from a reversed cyclic test

DRIFT DEFLECTION FORMULATION

The formulation described below approximates the drift deflection (lateral displacement), Δ, of cold-formed steel frame shear walls sheathed with plywood, OSB or sheet steel. This formulation does not apply to gypsum-sheathed walls and is similar to the method used in wood-frame construction. The total deflection (Δ) of a uniformly fastened, blocked wood structural panel or sheet steel panel shear wall is permitted to be calculated using the following formula:

$$\Delta = \Delta_{be} + \Delta_{oe} + \Delta_{se} + \Delta_{ine} \qquad \textit{(Equation 1)}$$

where Δ = total wall deflection, Δ_{be} = deflection due to cantilever bending, Δ_{oe} = deflection due to overturning anchor deformation, Δ_{se} = deflection due to shear deformation in the plane of the sheathing and Δ_{ine} = empirical inelastic deflection component (derived from regression analysis of reversed cyclic test data). These four components of deflection are defined in the following sections.

Δ_{be} : Deflection due to cantilever bending (in.)

$$\Delta_{be} = \frac{8qh^3}{E_s A_C w} \qquad \textbf{(Equation 2)}$$

E_s = elastic modulus of steel (29,500,000 psi)

A_C = gross cross-sectional area of chord stud (in^2)

$q = V/w$ (lb/ft)

V = total lateral load applied to the wall (lb)

w = width of the wall--measured between chord center lines (ft)

h = wall height--out-to-out from top to bottom plate (ft)

Δ_{oe} : Deflection due to overturning anchorage deformation (in.)

$$\Delta_{oe} = \frac{12qh^2 L}{E_s A_a w_a} \qquad \textbf{(Equation 3)}$$

L = "deformable" length of the anchor bolts (ft)

A_a = cross-sectional area of the anchor bolts (in^2)

w_a = centerline distance between anchor bolts (ft)

This deflection component only includes deformation of the anchor bolt itself. Other sources of anchorage deformation (example: contributions from the holdown device) are not included.

Δ_{se} : Deflection due to shear deformation in the plane of the sheathing (in.)

$$\Delta_{se} = \omega_1 \frac{q}{\rho G t_{sheathing}} \qquad \textbf{(Equation 4)}$$

$$\omega_1 = \left(\frac{s}{6} \cdot \frac{0.033}{t_{stud}}\right)\left(\frac{h}{8}\right)$$

ρ = 0.23 for plywood, 0.13 for OSB and $0.009\left(\frac{t_{sheathing}}{0.018}\right)$ for sheet steel

G = shear modulus of the sheathing material (psi)

$t_{sheathing}$ = nominal panel thickness (in.)

t_{stud} = nominal stud thickness (in.)

s = fastener spacing at panel edges (in.)

Δ_{se} is essentially the product of the classic expression for elastic in-plane shear deformation ($\gamma = \tau / G$, where $\gamma = \Delta / h$ and $\tau = V / \left(w \cdot t_{sheathing}\right)$) multiplied by empirical adjustment factors derived from regression analyses of thirty-two of the reversed cyclic tests used in development of Code (IBC and NFPA) nominal shear values. The adjustment factors account for wall heights greater than 8 ft. (only eight foot walls were tested), screw spacings other that 6 inches on center at panel edges, stud thickness greater than 33 mil and the type of sheathing.

Δ_{ine} : Empirical inelastic deflection component (in.)

$$\Delta_{ine} = \omega_2 \omega_3 \omega_4 \left(\frac{q}{\beta}\right)^2 \qquad \textbf{(Equation 5)}$$

$$\omega_2 = \left(\frac{s}{6}\right)^{1.25}\left(\frac{0.033}{t_{stud}}\right)$$

$$\omega_3 = \sqrt{\frac{\left(h/w\right)}{2}}$$

$\omega_4 = 1$ for wood structural panels, $\sqrt{\frac{33}{F_y}}$ for sheet steel

$\beta = 810$ for plywood, 660 for OSB and $500\left(\frac{t_{sheathing}}{0.018}\right)$ for sheet steel

Δ_{ine} is a purely empirical term that accounts for the complex nonlinear response evident in cold-formed steel frame shear walls. In wood frame construction, this term is commonly referred to as "nail slip." Δ_{ine} was developed by comparing envelope results from regression analyses of thrity-two reversed cyclic tests (see the Appendix).

The expressions given above are not sensitive to different fastener sizes (diameters). Recent tests ("Performance of Cold-Formed Steel-Framed Shear Walls: Alternative Configurations," LGSRG-06-02, submitted to NAHB Research Center, July 12, 2002) have shown that larger screws (No. 10 versus No. 8) tend to increase the stiffness of a wood panel shear wall. Given the limited scope of the recent tests (LGSRG-06-02) and the approximate nature of the proposed equations, adjustments for increased stiffness from larger fastener sizes were not included in the expressions recommended above.

The attached appendix compares the estimated drift deflections using the method described in this paper with the peak response envelope curves derived from tests. There are two peak response curves per plot (one for the positive (push) data and one for the negative (pull) data). The estimated deflections ignore the Δ_{be} and Δ_{oe} terms. The Δ_{be} term is a relatively small contributor due to the high value of the elastic modulus compared to lumber, and the Δ_{oe} contribution, measured in tests, was relatively small.

NOTES:

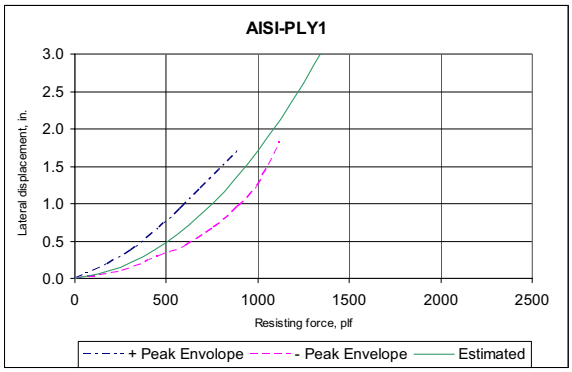
1. *It is the responsibility of the designer to include any other contribution to drift that was not explicitly addressed in the method presented.*
2. *The method presented should not be used to estimate capacities nor should it be used to estimate drift beyond nominal strengths tabulated in applicable building codes.*

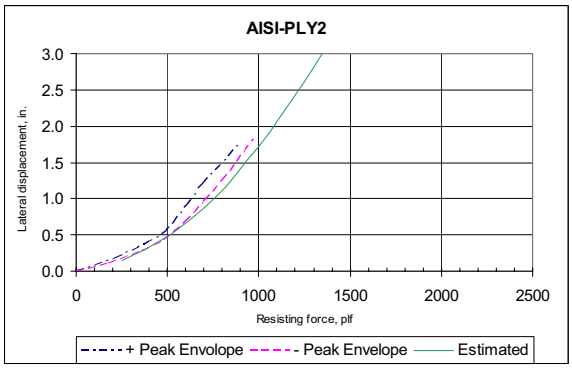
APPENDIX

In the following graphs, the term framing refers to the chord members (stud sections), and top and bottom tracks members (track sections).

The values of G used to predict the drift deflections are given below:

- *Plywood: 50,000 psi (actual value may be between 35,000 to 110,000 psi: Diaphragms and Shear Walls: Design/Construction Guide, 2001, APA-The Engineered Wood Association, Tacoma, WA)*
- *OSB: 77,500 psi (actual value may be between 110,000 to 210,000 psi: Diaphragms and Shear Walls: Design/Construction Guide, 2001, APA-The Engineered Wood Association, Tacoma, WA)*
- *Steel: 11,300,000 psi (2001 North American Specification for the Design of Cold-Formed Steel Structural Members)*





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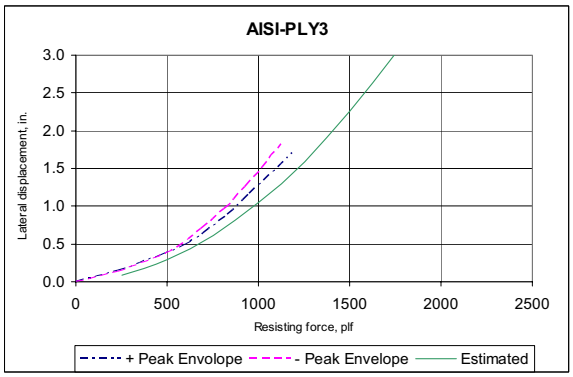

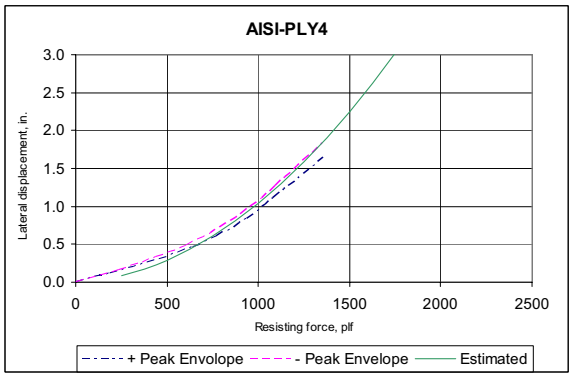

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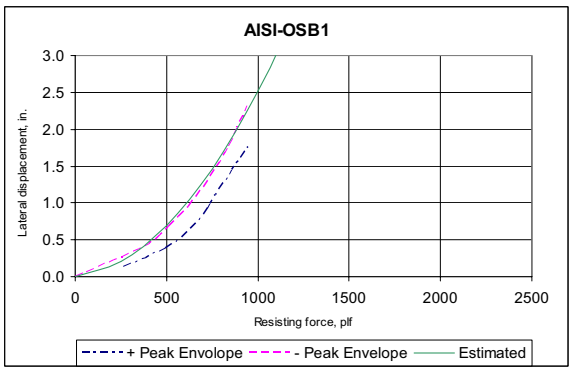

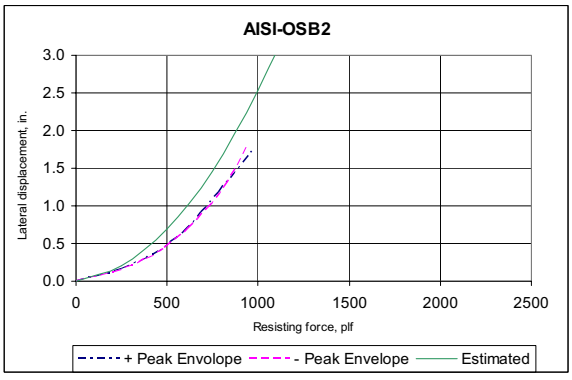

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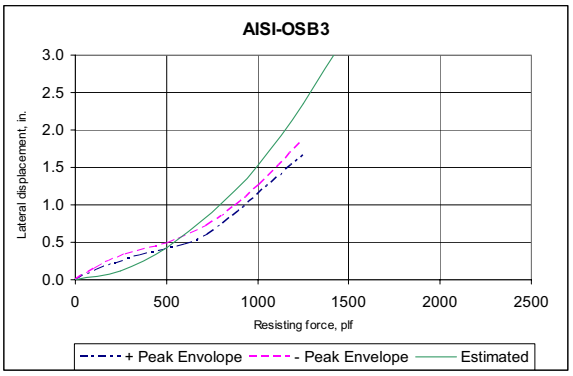

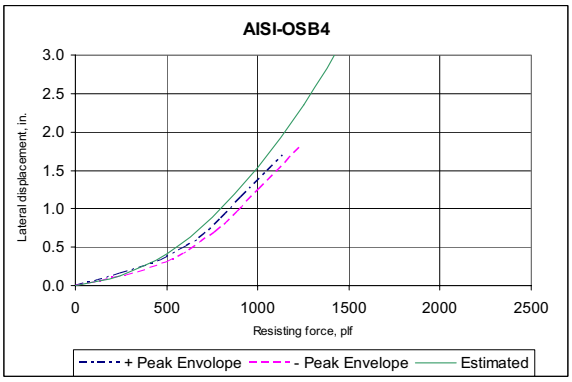

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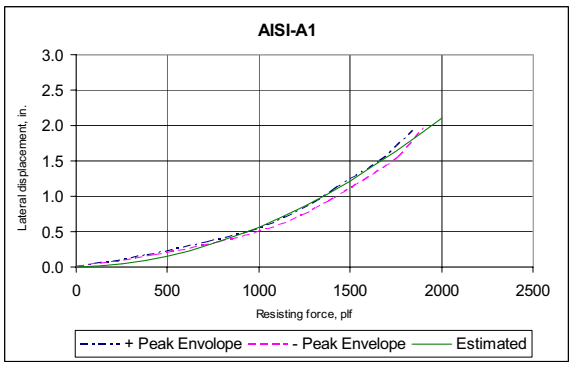

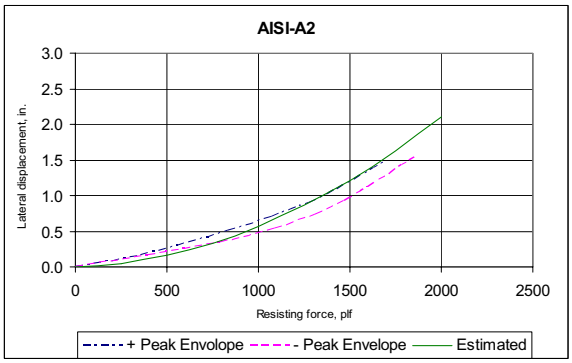

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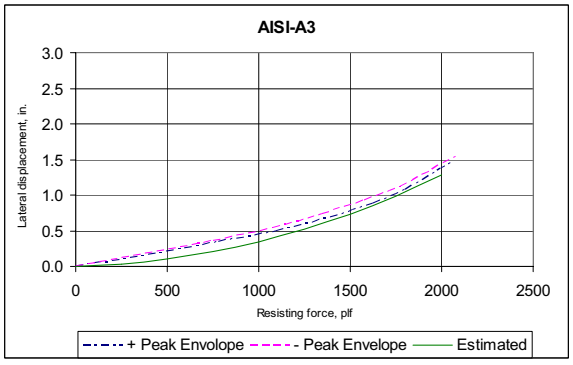

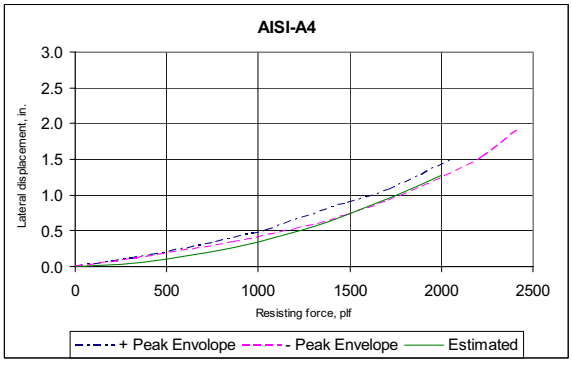

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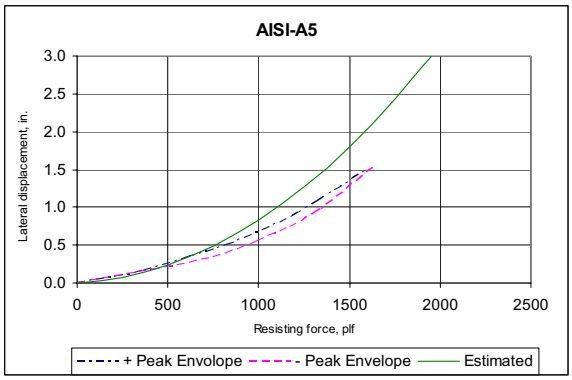

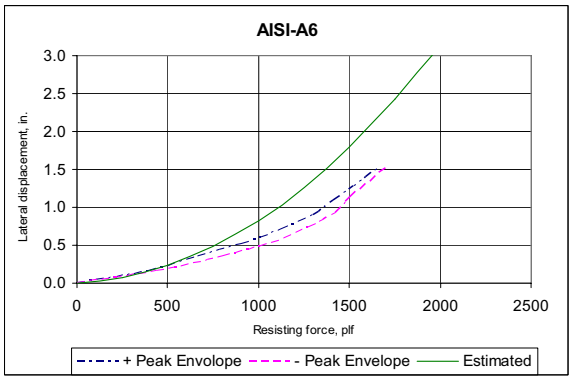

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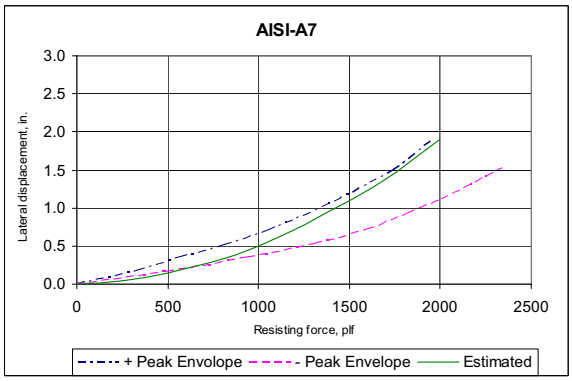

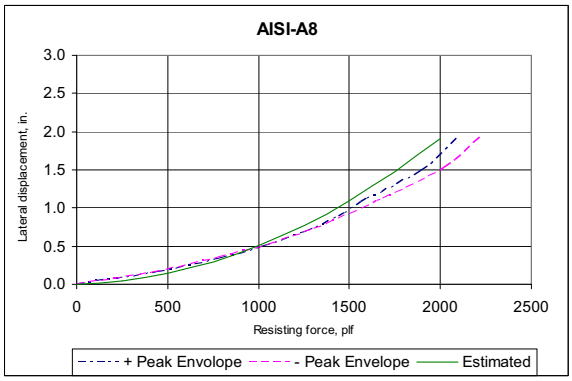

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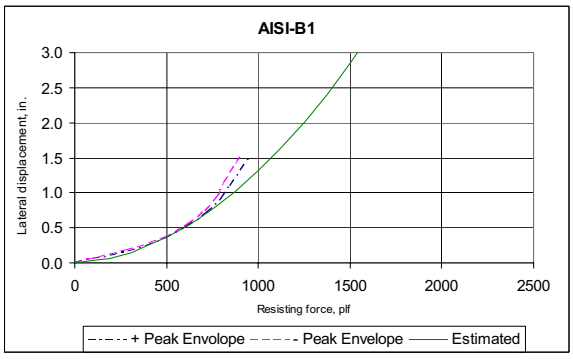

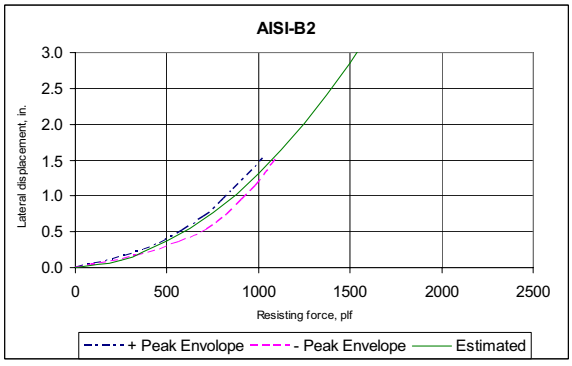

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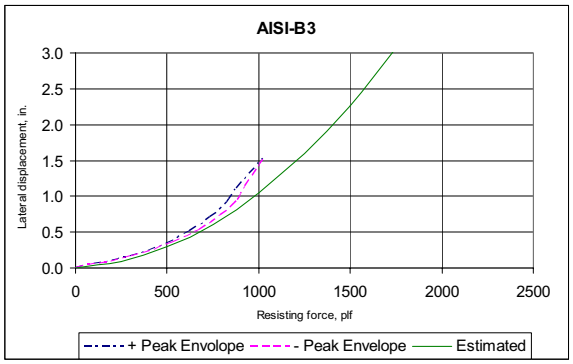

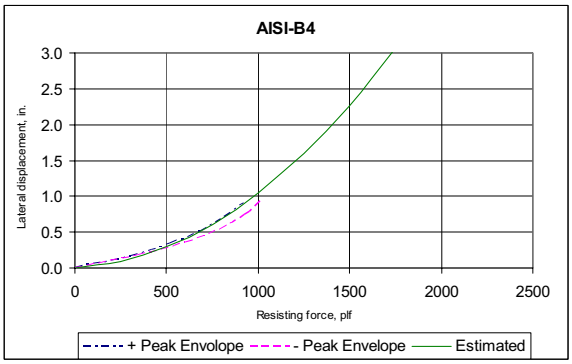

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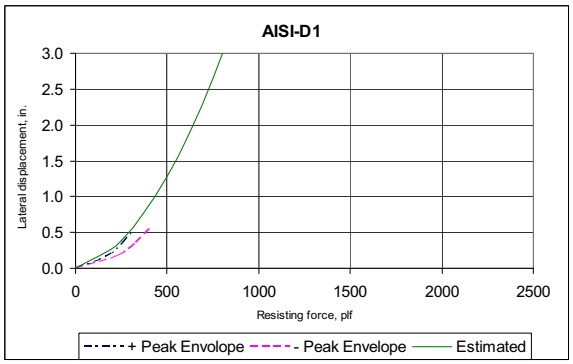

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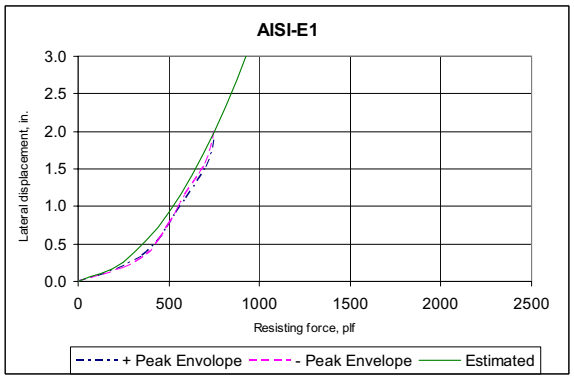

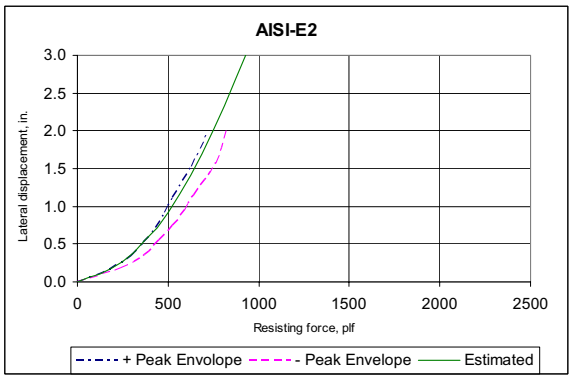

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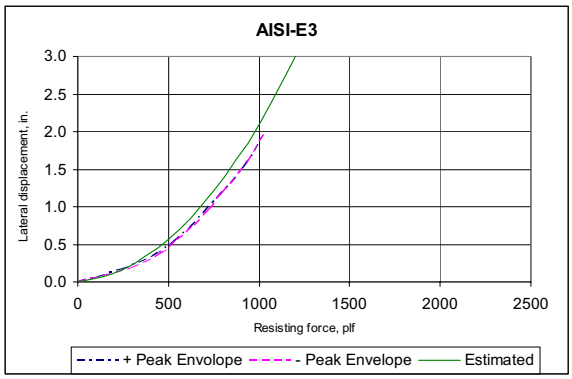

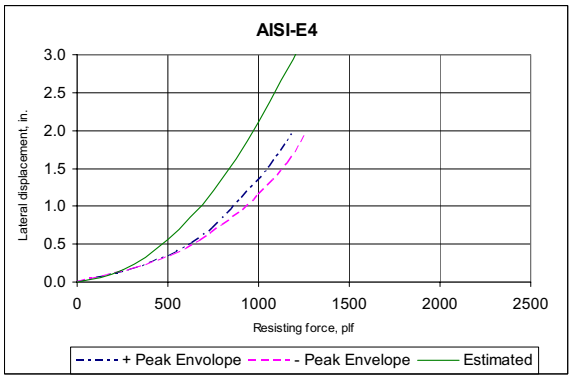

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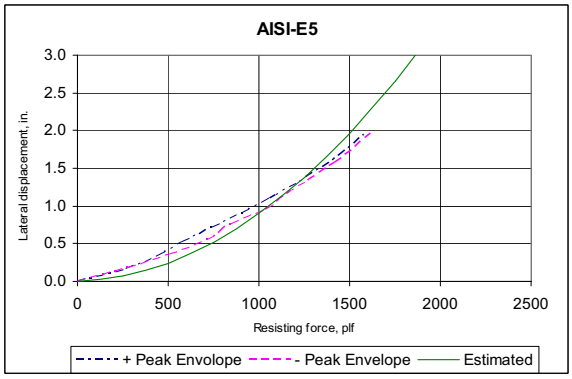

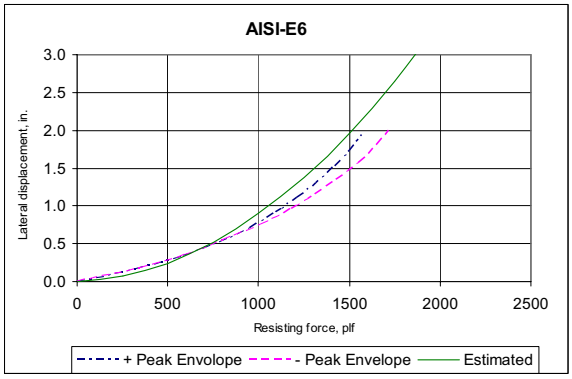

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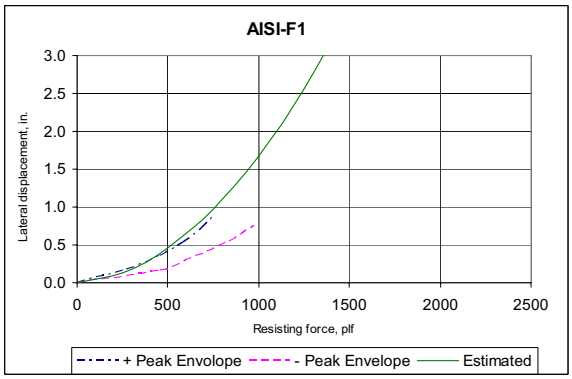

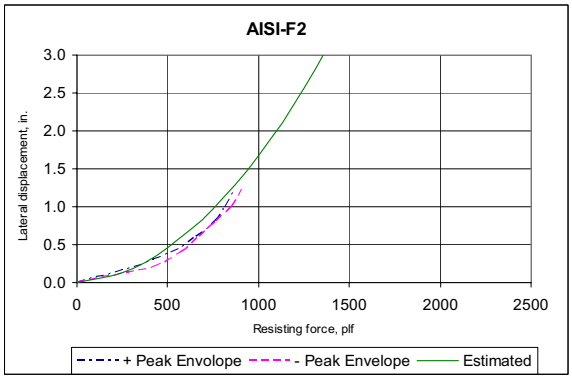

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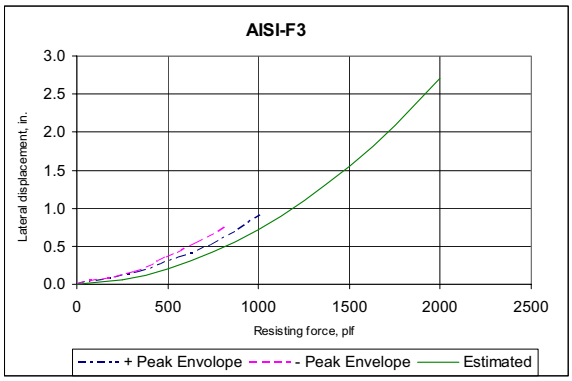

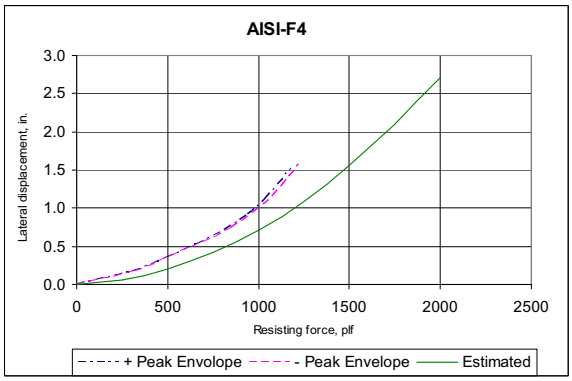

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