CONTINUATION METHOD FOR DESIGN OF ECCENTRICALLY LOADED WELD GROUP

November 14, 2019

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10th International Symposium on Steel Structures, Jeju, Korea

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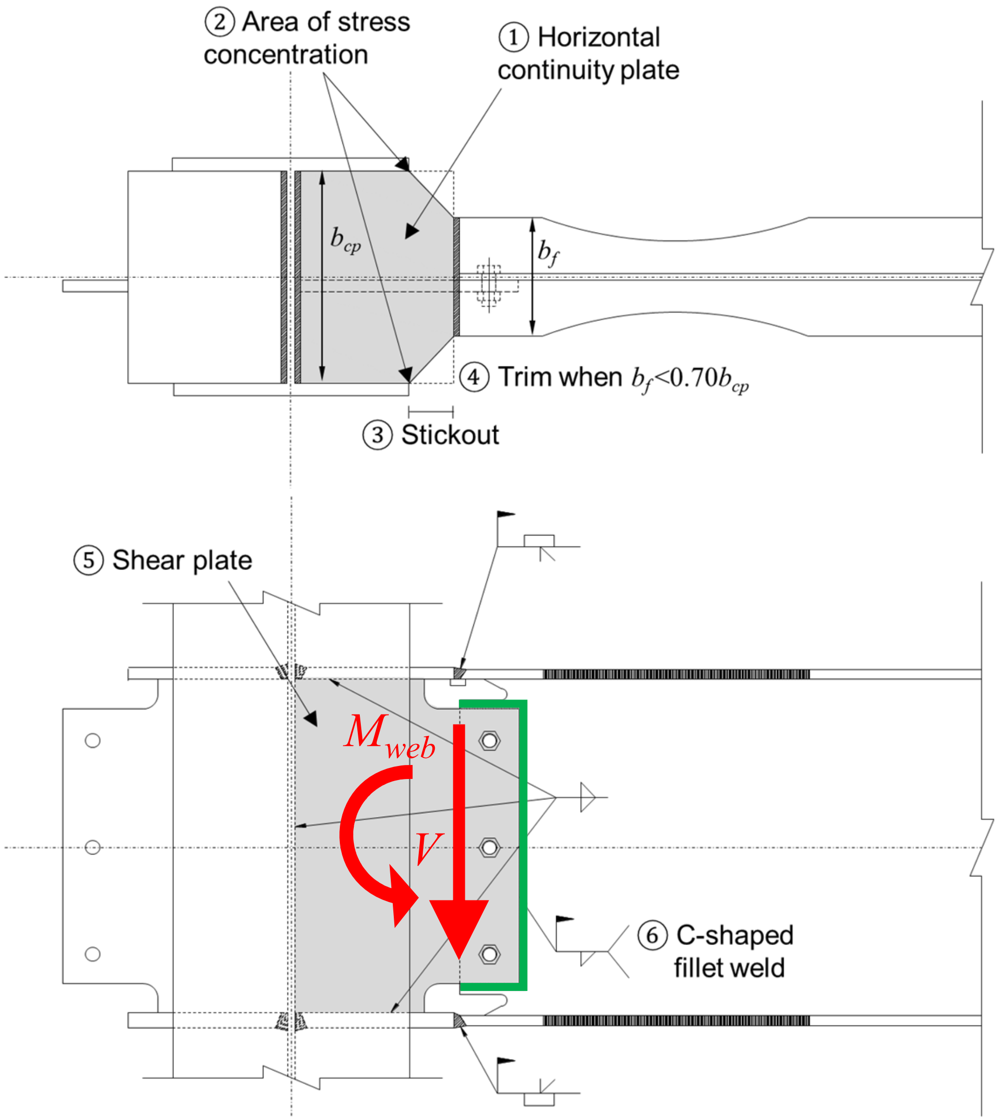
Continuation Method for Design of Eccentrically Loaded Weld Group

01. INTRODUCTION

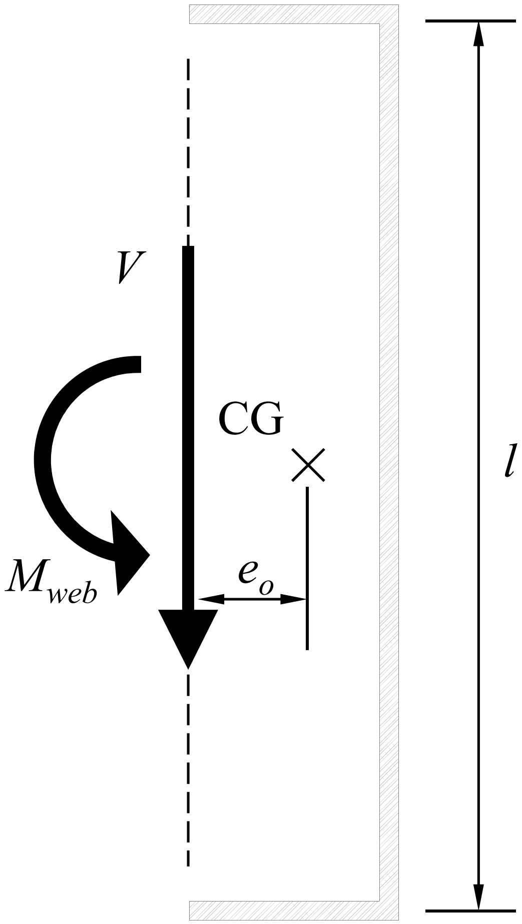
TYPICAL WEAK-AXIS RBS CONNECTION

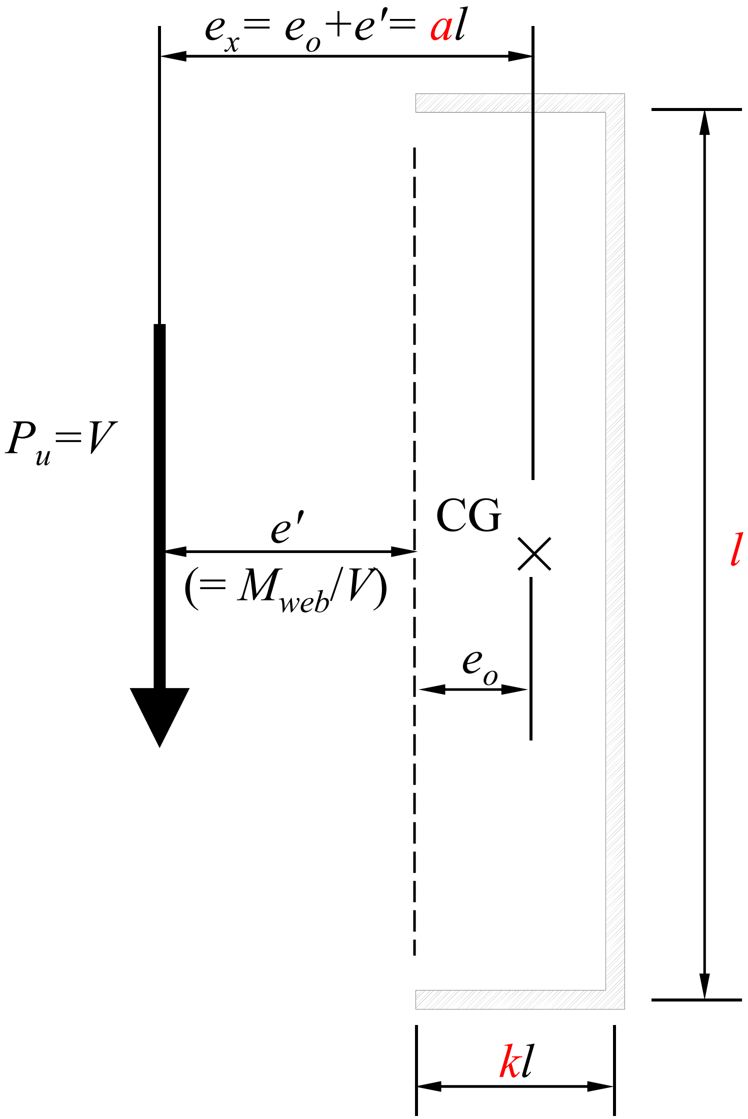


Key details of weak-axis RBS moment connection proposed by Gilton and Uang (2002)

01. INTRODUCTION

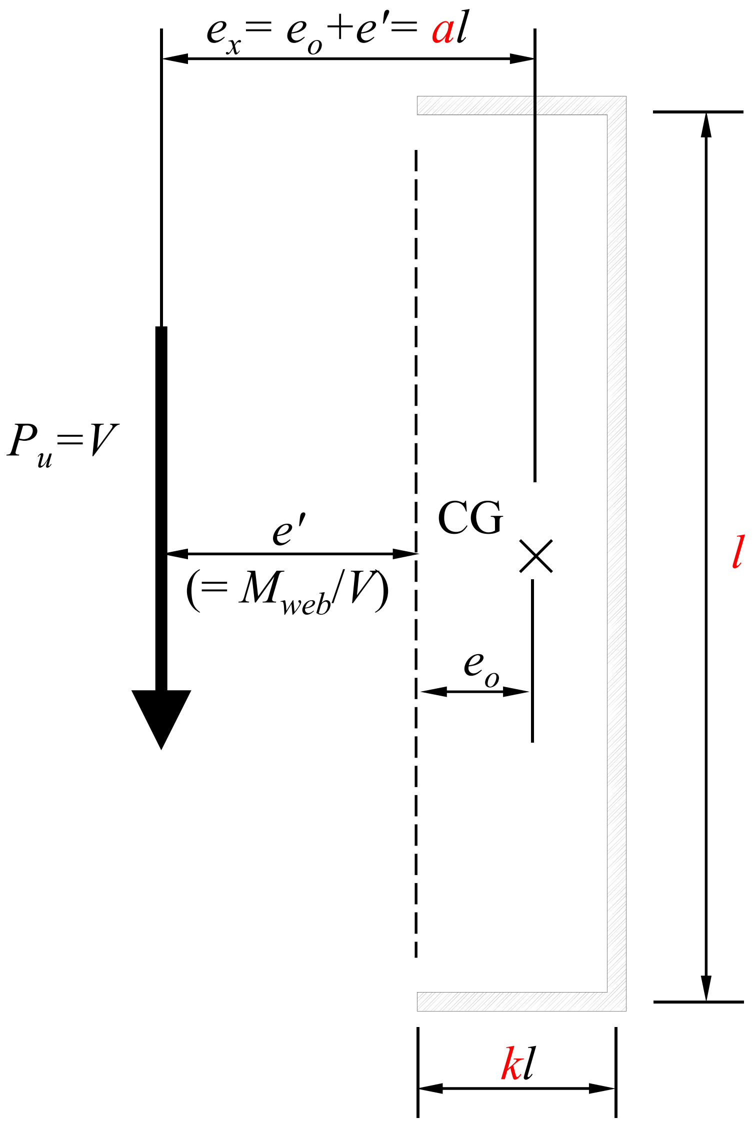
ECCENTRICALLY LOADED WELD GROUP





01. INTRODUCTION

ECCENTRICALLY LOADED WELD GROUP



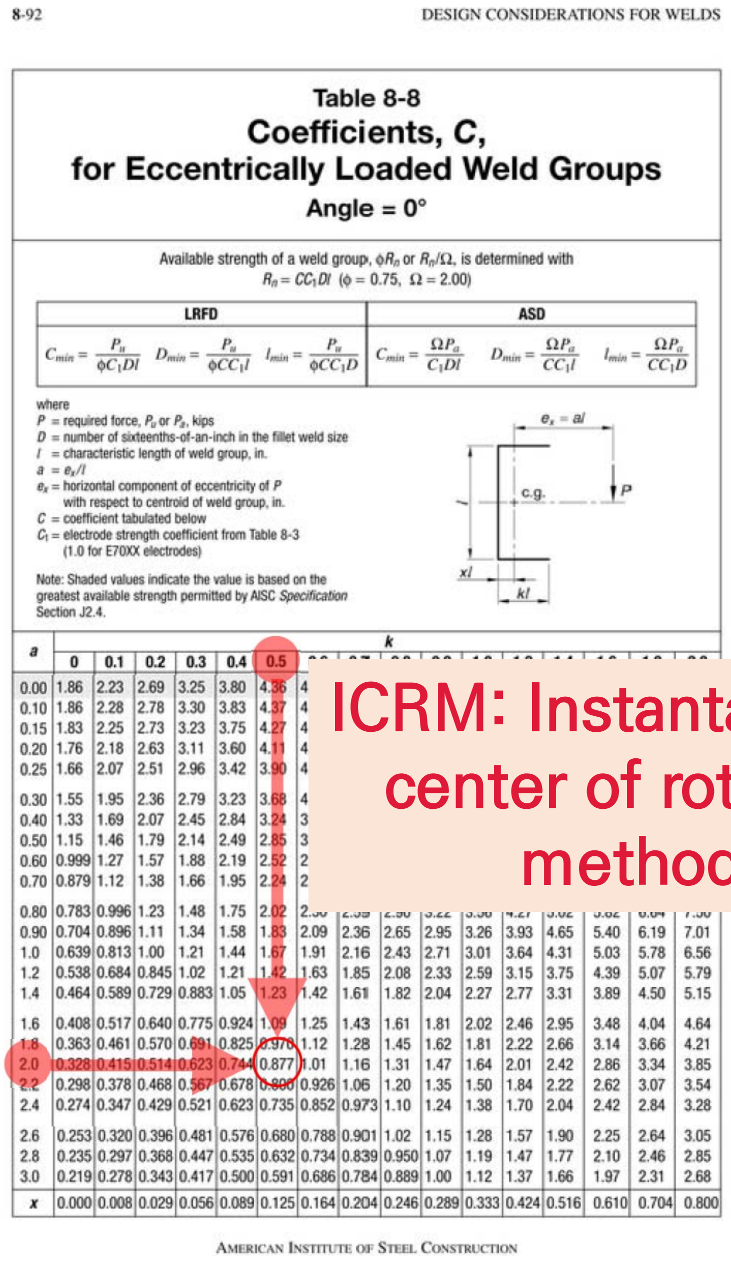

8-92 DESIGN CONSIDERATIONS FOR WELDS

Table 8-8
Coefficients, C, for Eccentrically Loaded Weld Groups
Angle = 0°

Available strength of a weld group, ϕR_n or R_n/Ω, is determined with
$R_n = CC_1Dl$ ($\phi = 0.75$, $\Omega = 2.00$)

LRFD	ASD
$C_{min} = \frac{P_u}{\phi C_1 D l}$ $D_{min} = \frac{P_u}{\phi C C_1 l}$ $l_{min} = \frac{P_u}{\phi C C_1 D}$	$C_{min} = \frac{\Omega P_a}{C_1 D l}$ $D_{min} = \frac{\Omega P_a}{C C_1 l}$ $l_{min} = \frac{\Omega P_a}{C C_1 D}$

where
P = required force, P_u or P_a, kips
D = number of sixteenths-of-an-inch in the fillet weld size
l = characteristic length of weld group, in.
a = e_x/l
e_x = horizontal component of eccentricity of P with respect to centroid of weld group, in.
C = coefficient tabulated below
C_1 = electrode strength coefficient from Table 8-3 (1.0 for E70XX electrodes)

Note: Shaded values indicate the value is based on the greatest available strength permitted by AISC *Specification* Section J2.4.

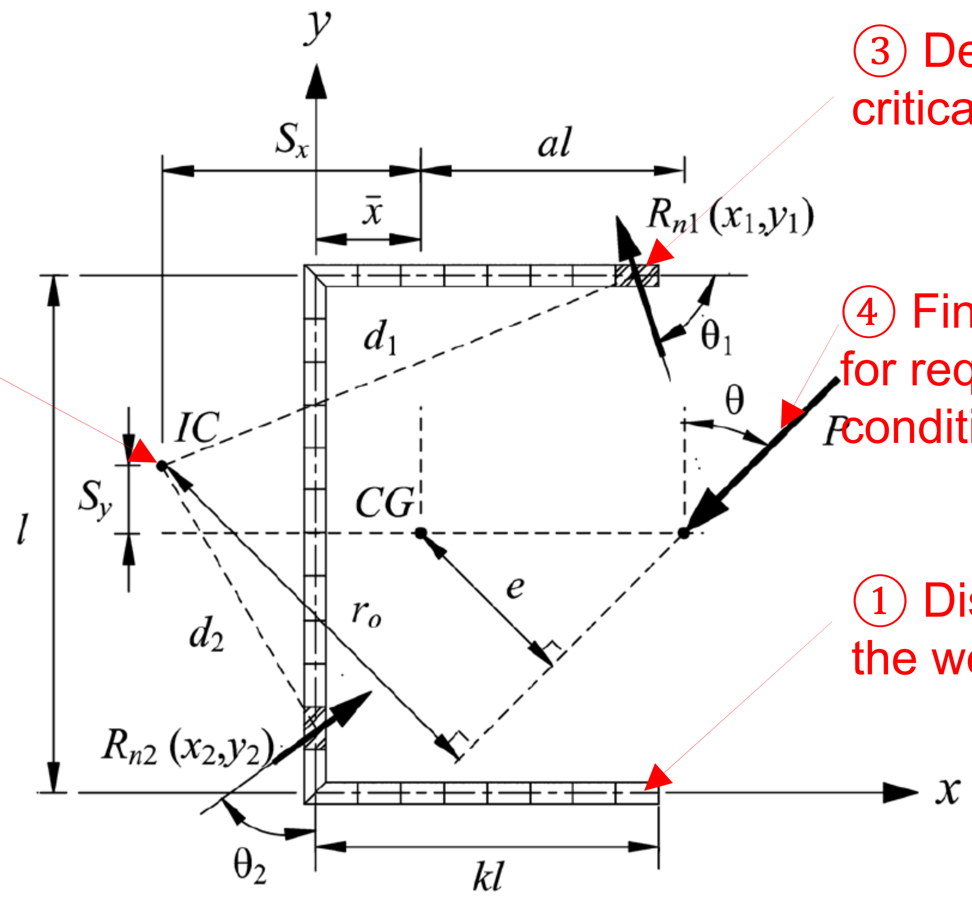
a	k															
	0	0.1	0.2	0.3	0.4	0.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.00	1.86	2.23	2.69	3.25	3.80	4.36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.10	1.86	2.28	2.78	3.30	3.83	4.37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.15	1.83	2.25	2.73	3.23	3.75	4.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.20	1.76	2.18	2.63	3.11	3.60	4.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.25	1.66	2.07	2.51	2.96	3.42	3.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.30	1.55	1.95	2.36	2.79	3.23	3.68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.40	1.33	1.69	2.07	2.45	2.84	3.24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.50	1.15	1.46	1.79	2.14	2.49	2.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.60	0.999	1.27	1.57	1.88	2.19	2.52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.70	0.879	1.12	1.38	1.66	1.95	2.24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.80	0.783	0.996	1.23	1.48	1.75	2.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.90	0.704	0.896	1.11	1.34	1.58	1.83	2.09	2.36	2.65	2.95	3.26	3.93	4.65	5.40	6.19	7.01
1.0	0.639	0.813	1.00	1.21	1.44	1.67	1.91	2.16	2.43	2.71	3.01	3.64	4.31	5.03	5.78	6.56
1.2	0.538	0.684	0.845	1.02	1.21	1.42	1.63	1.85	2.08	2.33	2.59	3.15	3.75	4.39	5.07	5.79
1.4	0.464	0.589	0.729	0.883	1.05	1.23	1.42	1.61	1.82	2.04	2.27	2.77	3.31	3.89	4.50	5.15
1.6	0.408	0.517	0.640	0.775	0.924	1.09	1.25	1.43	1.61	1.81	2.02	2.46	2.95	3.48	4.04	4.64
1.8	0.363	0.461	0.570	0.691	0.825	0.970	1.12	1.28	1.45	1.62	1.81	2.22	2.66	3.14	3.66	4.21
2.0	0.328	0.415	0.514	0.623	0.744	0.877	1.01	1.16	1.31	1.47	1.64	2.01	2.42	2.86	3.34	3.85
2.2	0.298	0.378	0.468	0.567	0.678	0.800	0.926	1.06	1.20	1.35	1.50	1.84	2.22	2.62	3.07	3.54
2.4	0.274	0.347	0.429	0.521	0.623	0.735	0.852	0.973	1.10	1.24	1.38	1.70	2.04	2.42	2.84	3.28
2.6	0.253	0.320	0.396	0.481	0.576	0.680	0.788	0.901	1.02	1.15	1.28	1.57	1.90	2.25	2.64	3.05
2.8	0.235	0.297	0.368	0.447	0.535	0.632	0.734	0.839	0.950	1.07	1.19	1.47	1.77	2.10	2.46	2.85
3.0	0.219	0.278	0.343	0.417	0.500	0.591	0.686	0.784	0.889	1.00	1.12	1.37	1.66	1.97	2.31	2.68
x	0.000	0.008	0.029	0.056	0.089	0.125	0.164	0.204	0.246	0.289	0.333	0.424	0.516	0.610	0.704	0.800

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

ICRM: Instantaneous center of rotation method

01. INTRODUCTION

INSTANTANEOUS CENTER OF ROTATION METHOD



① Discretize the weld line(s)

② Assume the location of IC

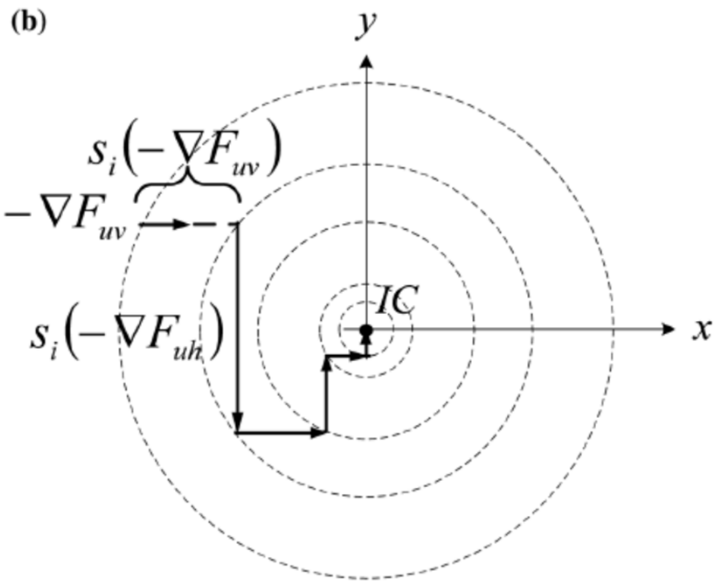
③ Determine the critical element

④ Find the ultimate strength for required force equilibrium conditions

1) Discretization, 2) Ultimate strength

01. INTRODUCTION
ECCENTRICALLY LOADED WELD GROUP

Lue et al. (2017) – Ultimate strength



At static equilibrium ($\sum F_x = 0,\ \sum F_y = 0$), the resultants are expressed as:

$$\sum F_x = F_{uh} = P_{nx} + \sum R_{nix}, \text{ and} \tag{11}$$

$$\sum F_y = F_{uv} = P_{ny} + \sum R_{niy}, \tag{12}$$

where F_{uh} and F_{uv} are called the unbalanced forces if $\sum F_x \neq 0$ or $\sum F_y \neq 0$.

Let F be the magnitude of the unbalanced force at a trial IC point (x_o, y_o).

$$\nabla F(x_o, y_o) = \frac{\partial F}{\partial x}\hat{\mathbf{i}} + \frac{\partial F}{\partial y}\hat{\mathbf{j}} = \Sigma F_x\,\hat{\mathbf{i}} + \Sigma F_y\,\hat{\mathbf{j}} = F_{uh}\hat{\mathbf{i}} + F_{uv}\hat{\mathbf{j}} \tag{13}$$

where $F = \sqrt{F_{uh}^2 + F_{uv}^2}$.

each direction of descent. Gradient is perpendicular to the force vector. Accordingly, the direction of descent opposes the normal to the force vector, so F_{uv} declines in the positive x direction and F_{uh} falls in the negative y direction. Then, step length, $s_i F_{uv}$ or $s_i F_{uh}$, is adjusted as a shift along each direction of descent, with reference to Figure 3(b). The positive s_i is the step-length parameter, which can be set for each iterative process. Therefore, the iterated coordinates are given by:

$$x_{i+1} = x_i + s_i(-\nabla F_{uv}) = x_i + s_i F_{uv}, \text{ and} \tag{14}$$

$$y_{i+1} = y_i + s_i(-\nabla F_{uh}) = y_i - s_i F_{uh}. \tag{15}$$

The algorithm requires that the initially guessed IC position is the centroid of the section; the iterative process generates the next point by moving one step length in the direction of negative gradient from the preceding IC point. The computational

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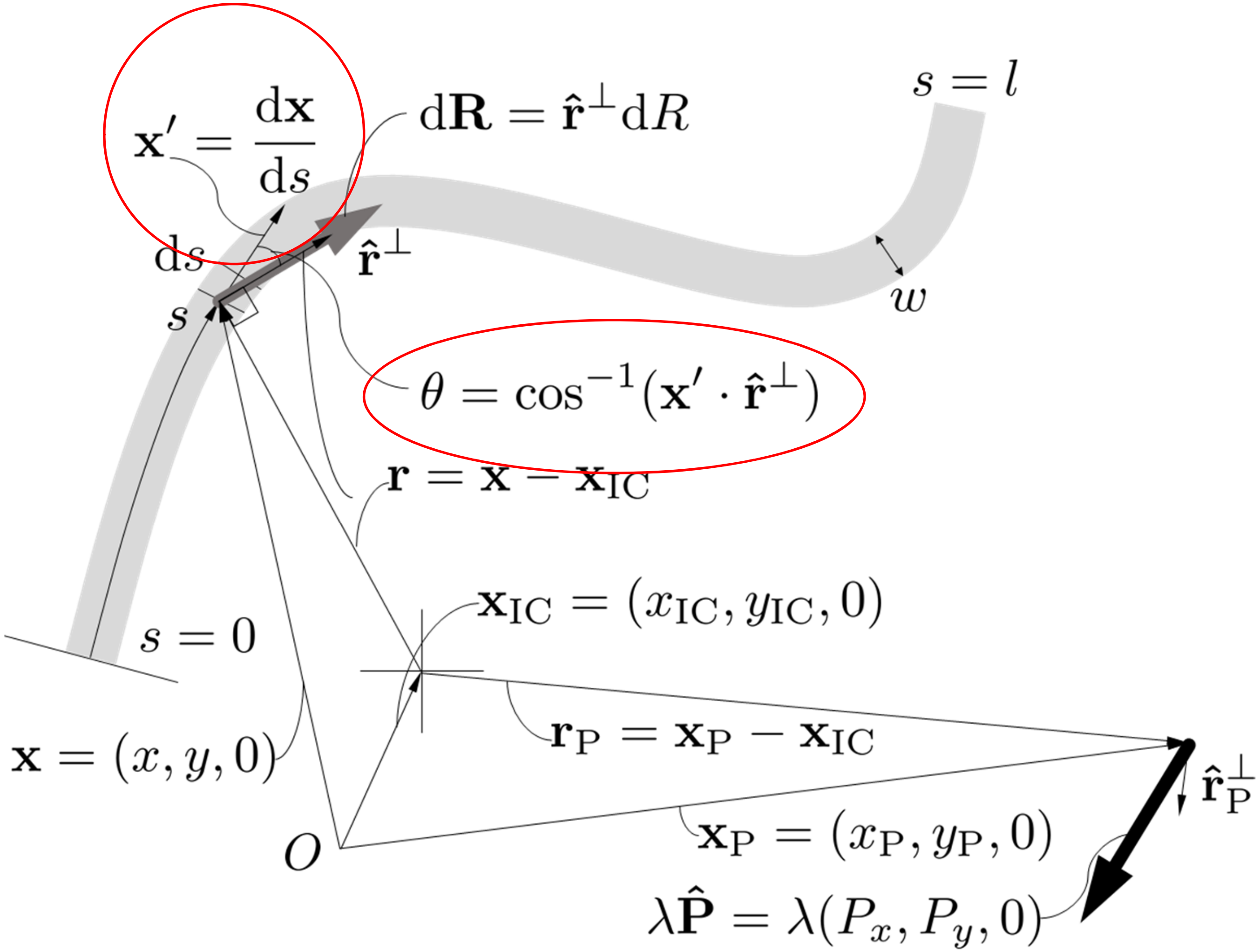
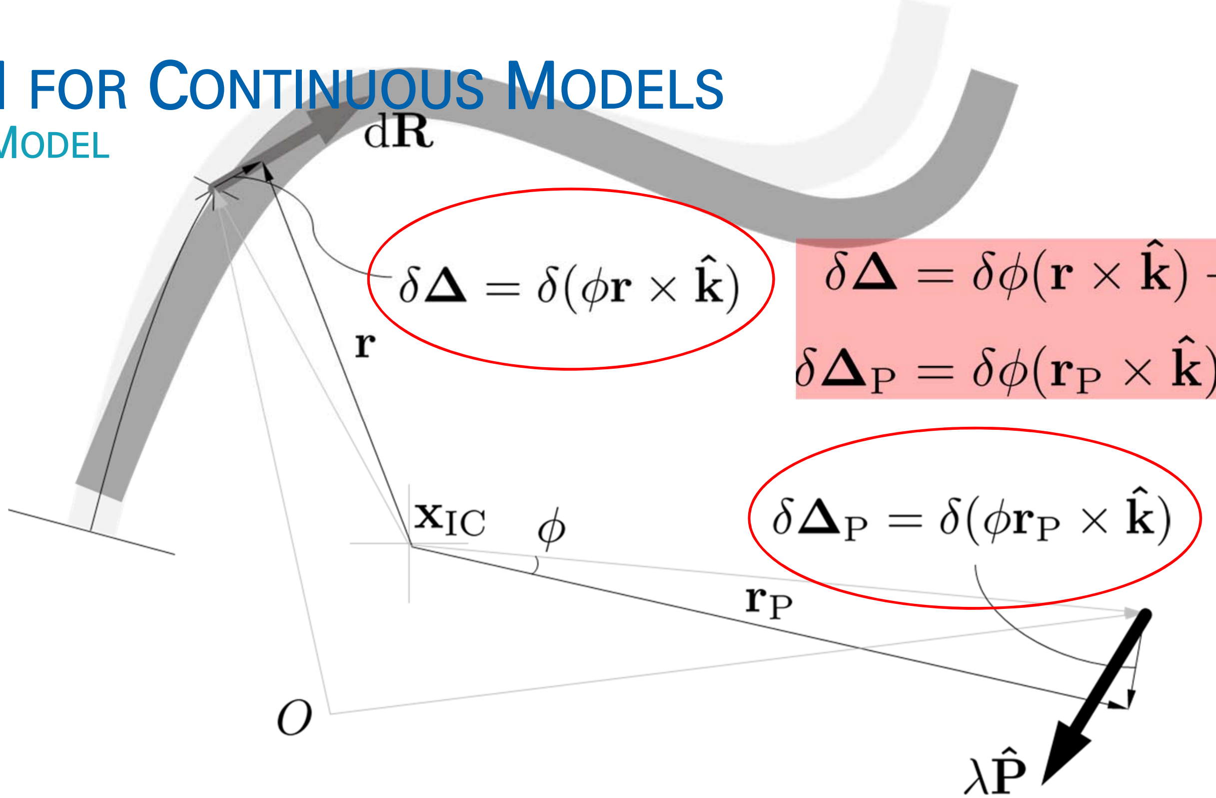
02. ICRM for Continuous Models

Continuous Model



02. ICRM FOR CONTINUOUS MODELS

CONTINUOUS MODEL



$$\delta\boldsymbol{\Delta} = \delta\phi(\mathbf{r}\times\hat{\mathbf{k}}) + \phi(\delta\mathbf{x}_{\mathrm{IC}}\times\hat{\mathbf{k}})$$

$$\delta\boldsymbol{\Delta}_{\mathrm{P}} = \delta\phi(\mathbf{r}_{\mathrm{P}}\times\hat{\mathbf{k}}) + \phi(\delta\mathbf{x}_{\mathrm{IC}}\times\hat{\mathbf{k}})$$

$$\delta\Pi = \delta(U+V) = 0$$

$$\lambda\hat{\mathbf{P}} - \int_0^l \frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s = \mathbf{0}$$

$$\left(\hat{\mathbf{r}}_{\mathrm{P}}^{\perp}\times\lambda\hat{\mathbf{P}} - \int_0^l \mathbf{r}\times\frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s\right)\cdot\hat{\mathbf{k}} = 0$$

Equilibrium equations

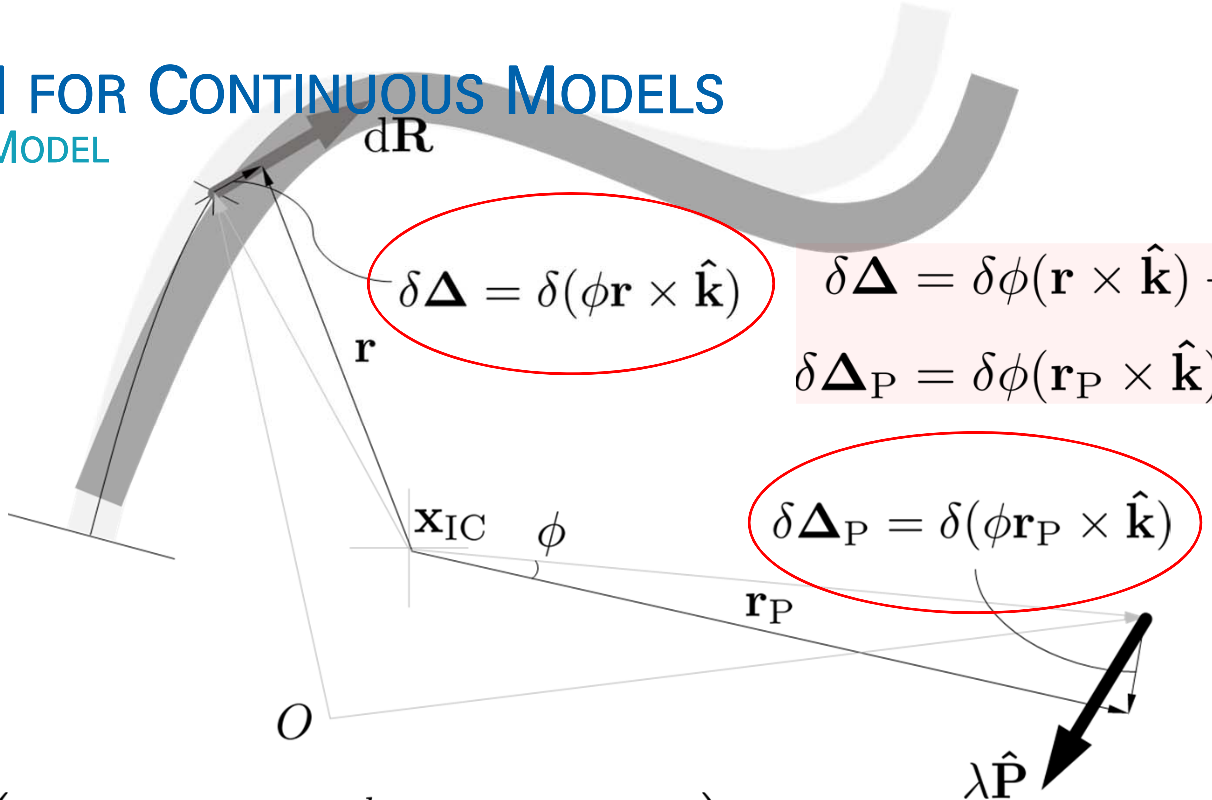
$$\delta\mathbf{x}_{\mathrm{IC}}\cdot\left[\lambda\hat{\mathbf{P}} - \int_0^l \frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s\right] = 0,$$

$$\delta\phi\left(\mathbf{r}_{\mathrm{P}}\times\lambda\hat{\mathbf{P}} - \int_0^l \mathbf{r}\times\frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s\right)\cdot\hat{\mathbf{k}} = 0,$$

Virtual displacements introduced

02. ICRM FOR CONTINUOUS MODELS

CONTINUOUS MODEL



$$\delta\boldsymbol{\Delta} = \delta(\phi\mathbf{r} \times \hat{\mathbf{k}})$$

$$\delta\boldsymbol{\Delta}_{\mathrm{P}} = \delta(\phi\mathbf{r}_{\mathrm{P}} \times \hat{\mathbf{k}})$$

$$\delta\boldsymbol{\Delta} = \delta\phi(\mathbf{r} \times \hat{\mathbf{k}}) + \phi(\delta\mathbf{x}_{\mathrm{IC}} \times \hat{\mathbf{k}})$$

$$\delta\boldsymbol{\Delta}_{\mathrm{P}} = \delta\phi(\mathbf{r}_{\mathrm{P}} \times \hat{\mathbf{k}}) + \phi(\delta\mathbf{x}_{\mathrm{IC}} \times \hat{\mathbf{k}})$$

$$\mathbf{f}(\mathbf{y}, \lambda) = \begin{pmatrix} \lambda\hat{\mathbf{P}} - \int_0^l \frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s \\ \hat{\mathbf{r}}_{\mathrm{P}}^{\perp} \times \lambda\hat{\mathbf{P}} \cdot \hat{\mathbf{k}} - \int_0^l \mathbf{r} \times \frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s \cdot \hat{\mathbf{k}} \end{pmatrix} = \mathbf{0}$$

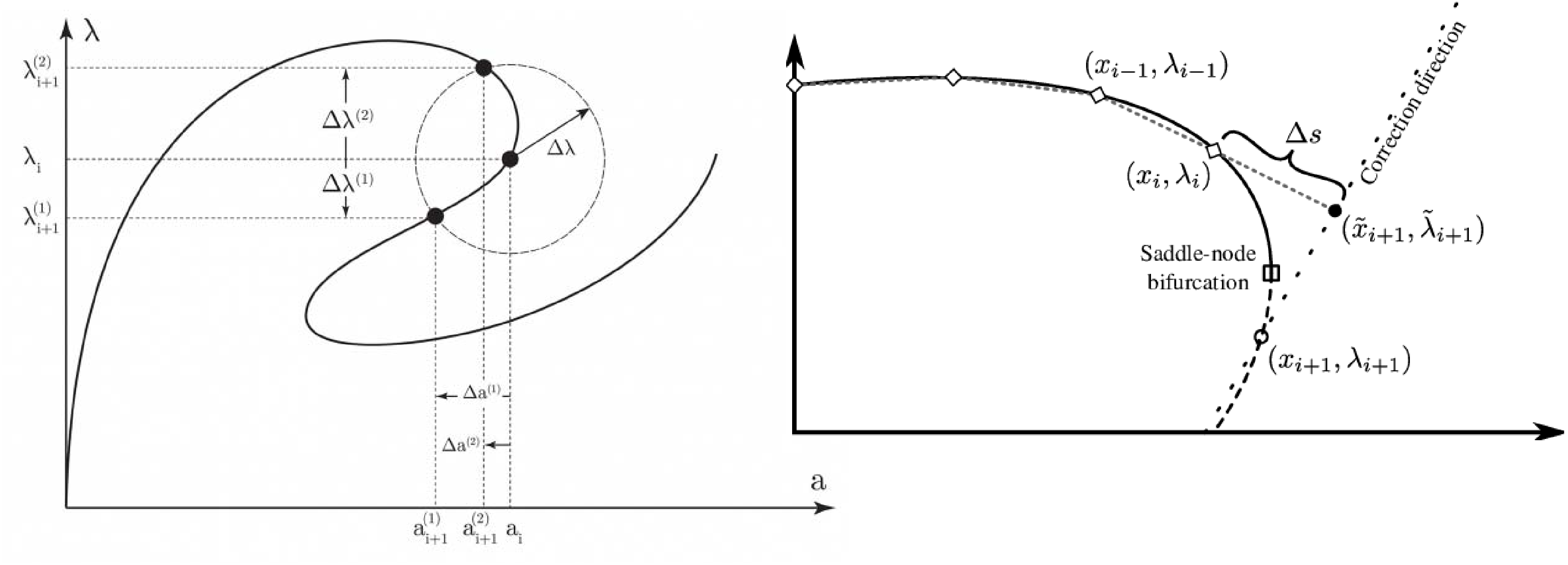
Parameterized algebraic equation

→ Continuous method can be applied for solving the parameterized equation.

02. ICRM FOR CONTINUOUS MODELS

CONTINUOUS MODEL

$$\mathbf{f}(\mathbf{y},\lambda) = \begin{pmatrix} \lambda\hat{\mathbf{P}} - \int_0^l \frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s \\ \hat{\mathbf{r}}_{\mathrm{P}}^{\perp} \times \lambda\hat{\mathbf{P}} \cdot \hat{\mathbf{k}} - \int_0^l \mathbf{r} \times \frac{\mathrm{d}\mathbf{R}}{\mathrm{d}s}\,\mathrm{d}s \cdot \hat{\mathbf{k}} \end{pmatrix} = \mathbf{0}$$



Arc-length method is applied to find the continuous trajectory of the location of IC and rotation angle.

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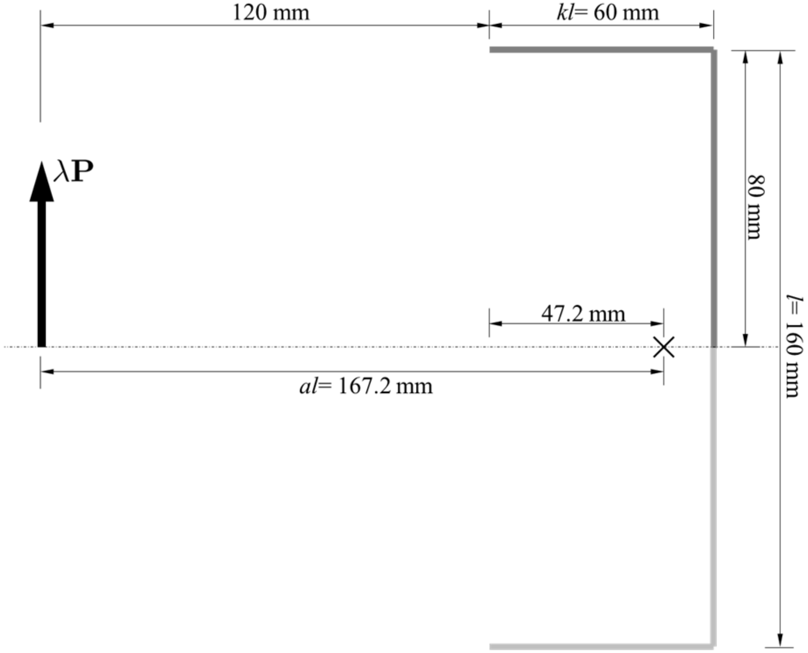
Continuation Method for Design of Eccentrically Loaded Weld Group

03. NUMERICAL EXAMPLE

ECCENTRICALLY LOADED C–SHAPED WELD GROUP



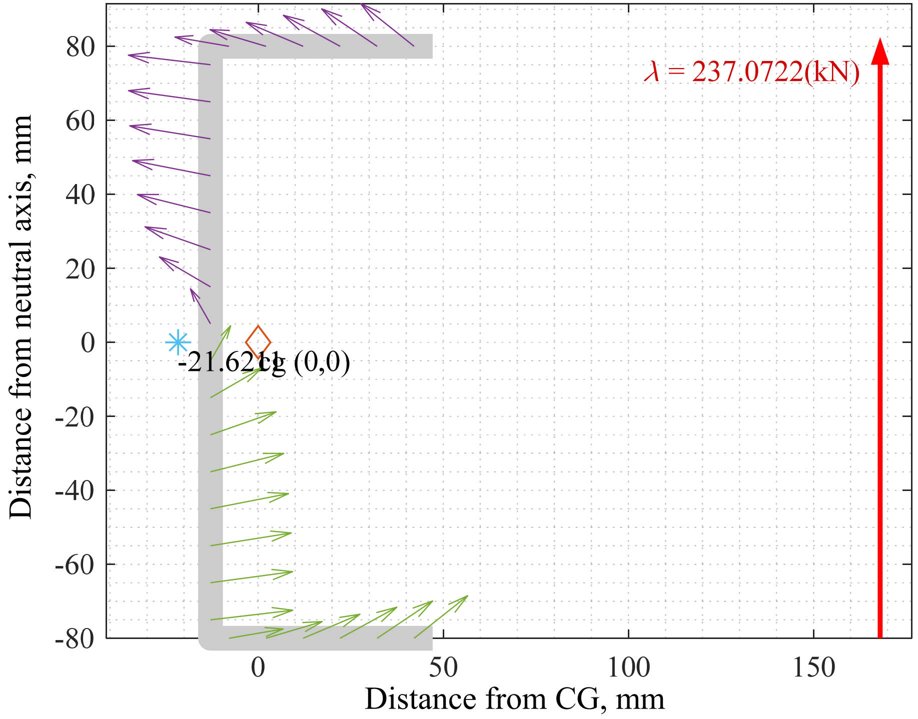
$l = 160$ mm, $k = 0.375$, and $a = 1.05$

$F_{EXX} = 490$ MPa and $w = 10$ mm

- The location of C.G.: 47.2 mm from the far left of the weld group
- The eccentric load is applied to the vertical direction (i.e. $P_x=0$ and $P_y=1$) at 120 mm from the far left of the weld group (i.e. the distance from the C.G. to the nodal load point, *al*, is 120+47.2=167.2 mm and thus *a*= 1.05).

03. NUMERICAL EXAMPLE

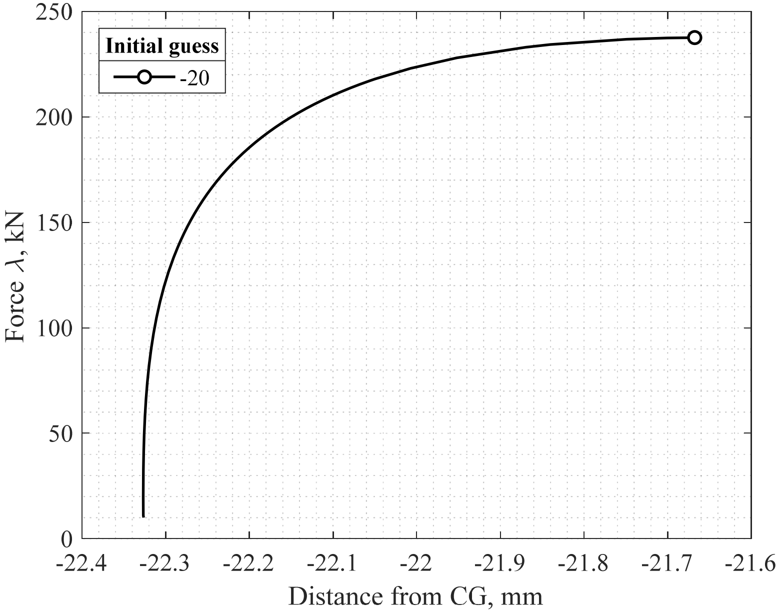
ECCENTRICALLY LOADED C–SHAPED WELD GROUP

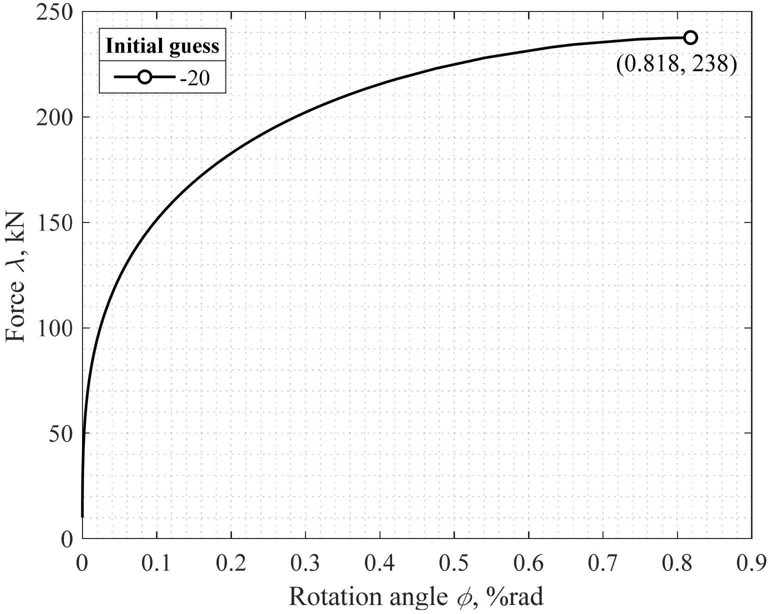


The nominal strength of the weld group examined was calculated as 237 kN, and the value was only about 1% different from the strength obtained using the AISC table method.

03. NUMERICAL EXAMPLE

ECCENTRICALLY LOADED C–SHAPED WELD GROUP





The trajectories of the location of IC and rotation angle for the examined weld group are applicable for the investigation of the incremental nonlinear behavior of the eccentrically loaded weld group.

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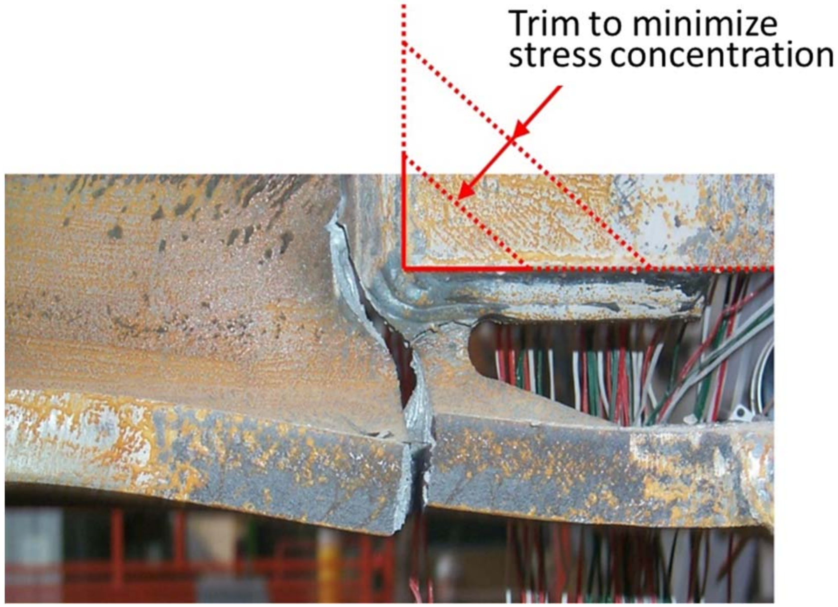
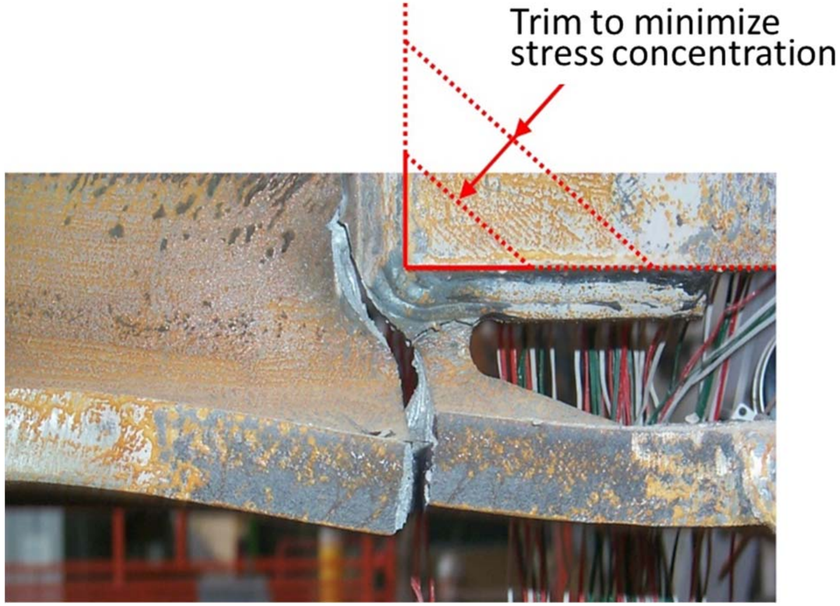
ECCENTRICALLY LOADED C-SHAPED WELD GROUP

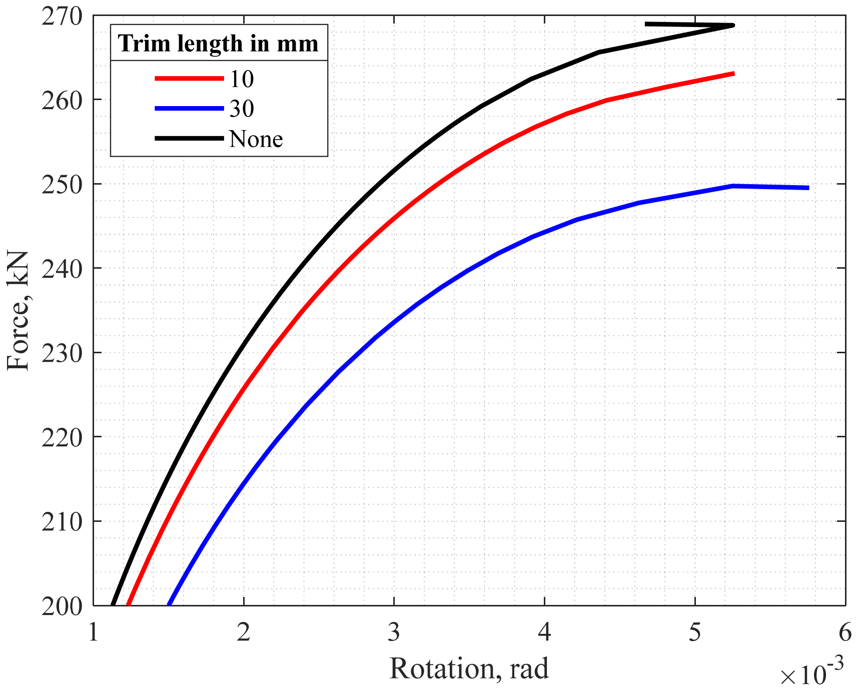


Improved shape of C-shaped fillet weld proposed by Lee et al. (2019)

03. NUMERICAL EXAMPLE

ECCENTRICALLY LOADED C–SHAPED WELD GROUP





Increase in the trim length yields to decrease in the ultimate strength, but yields to more ductile behavior.

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04. SUMMARY AND CONCLUSIONS

1. The ICRM is reformulated from minimum potential method, and a continuation method is applied for the design of weld group.

2. The reformulated ICRM enables the designer to be able to track the path or trajectory of designated parameters such as location of IC and rotation angle.

3. The continuous method applied in this study would be helpful in understanding the incremental nonlinear behavior of the weld group.

THANKS FOR YOUR ATTENTION!

This research was supported by Young Researcher Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (No. NRF-2018R1C1B6009196).