Genuine Ingenuity

Enhancing Bridge Load Rating Analysis: Key Considerations – Part 2

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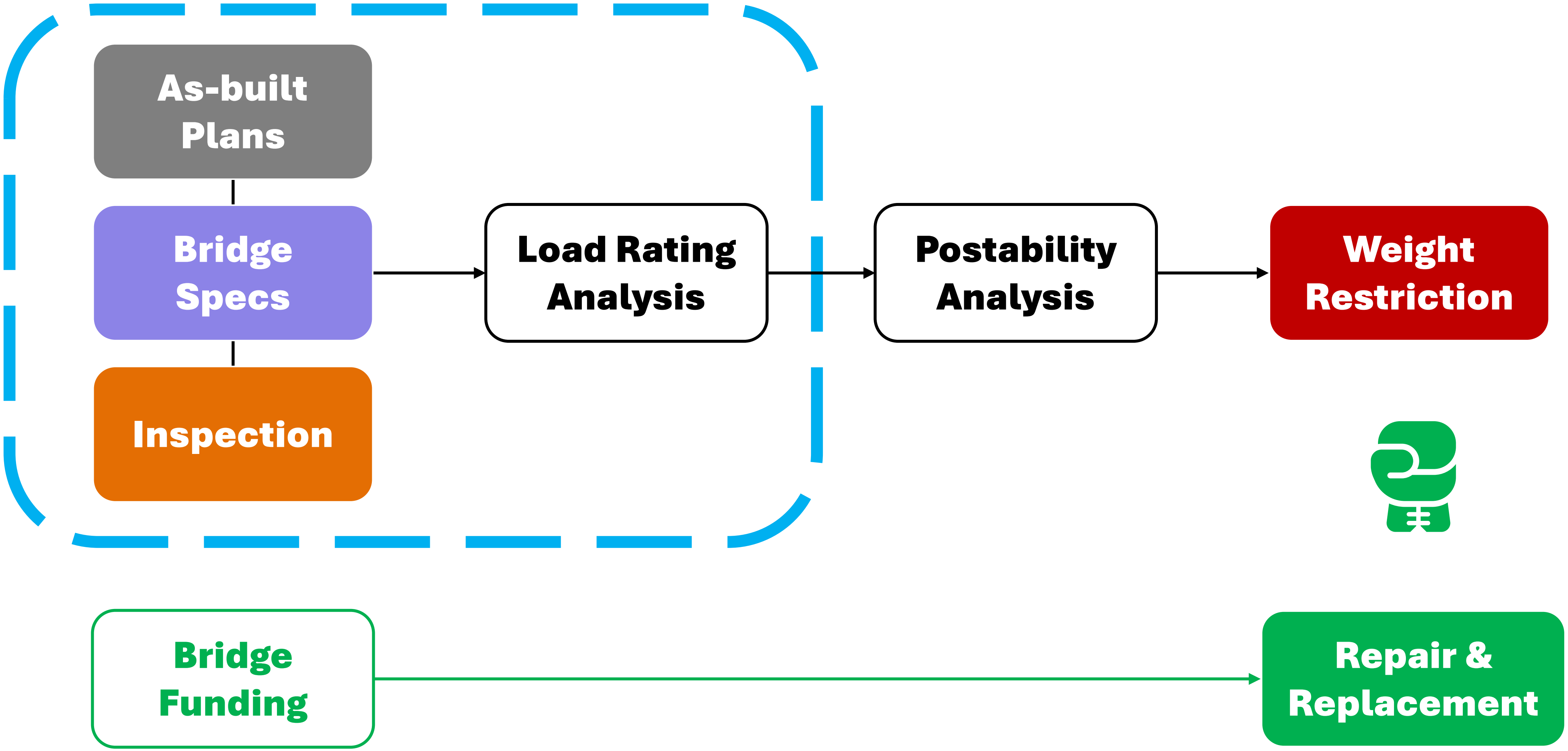
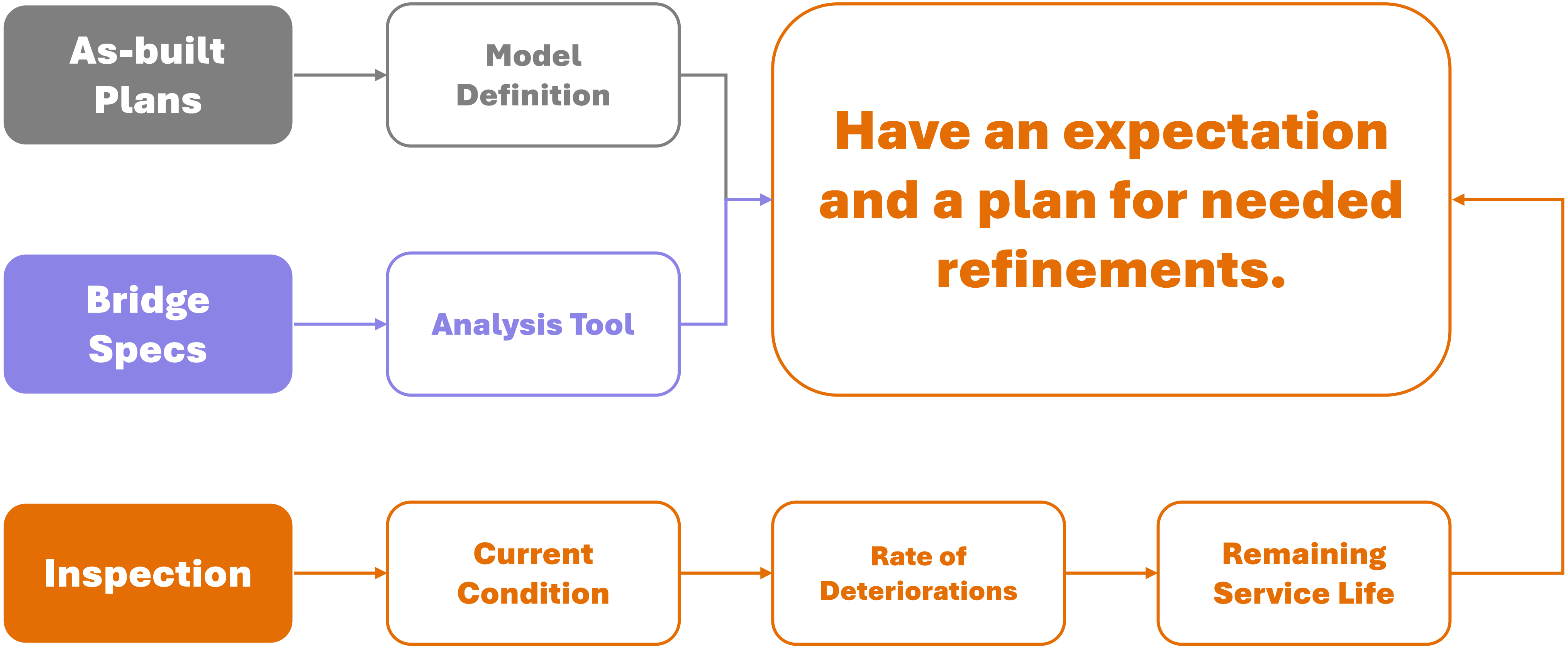
8/8/ 2023

Gresham Smith

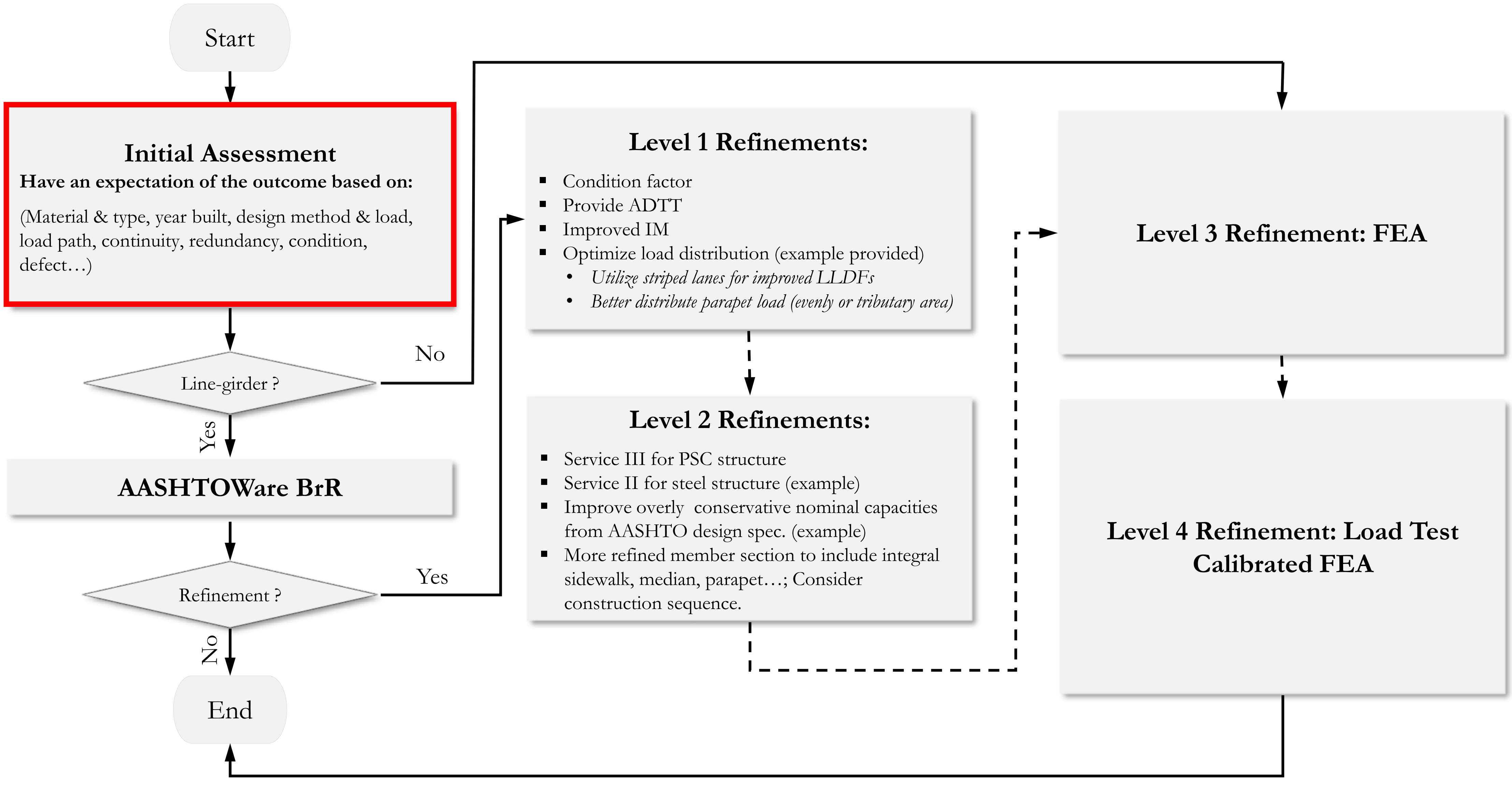
Maintaining a Healthy Bridge Program



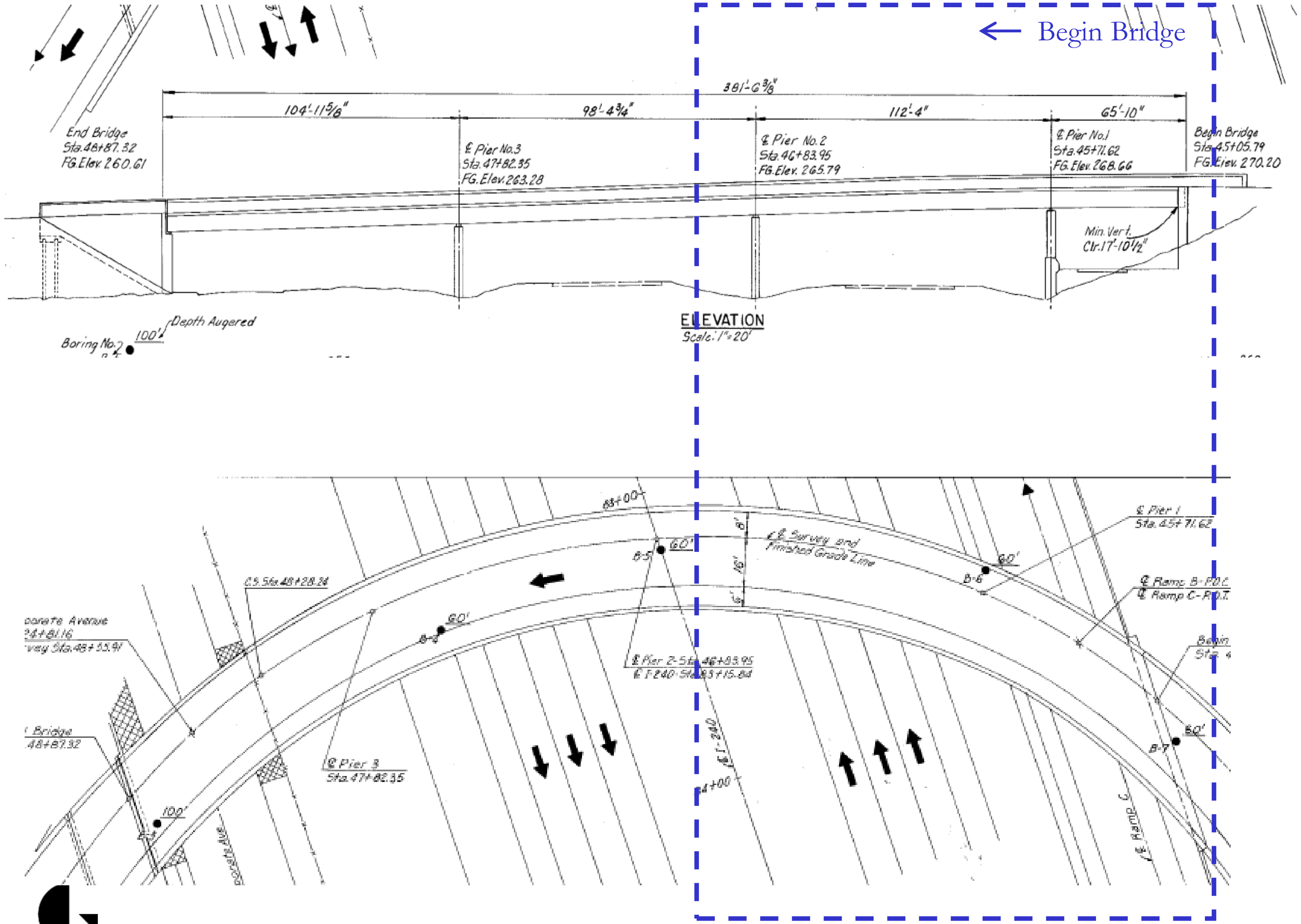
Components of load rating



Workflow for Bridge Load Ratings with Improvement Options



Initial Evaluation - Steel multi-girder



Steel Multi-I-Beam (Year built: 1982)

4-Span-Cont.: 105 ft, 98 ft, 112 ft & 66ft

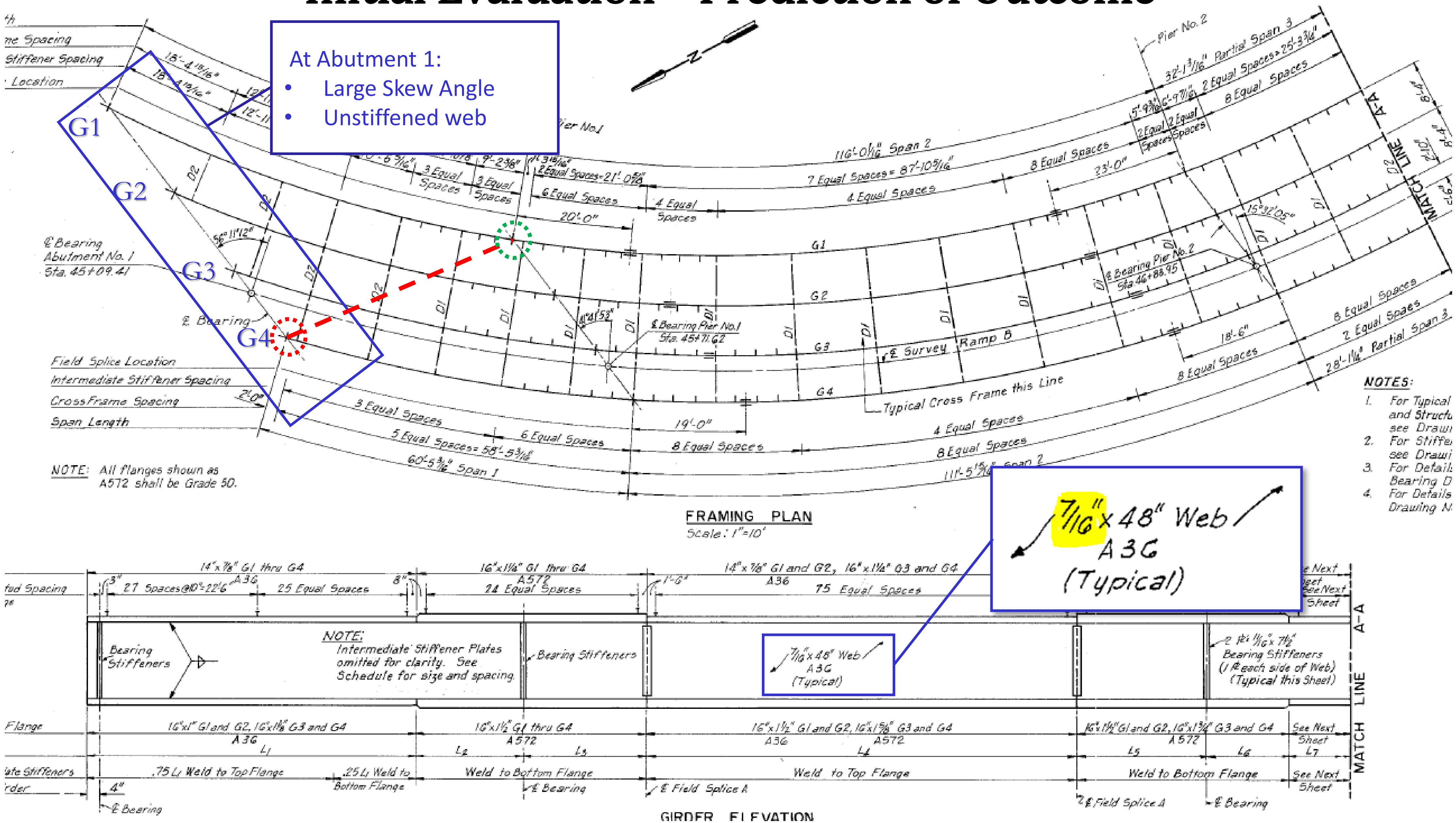
Interstate exit ramp

ADT: 113,227 (ADTT: 14,720)

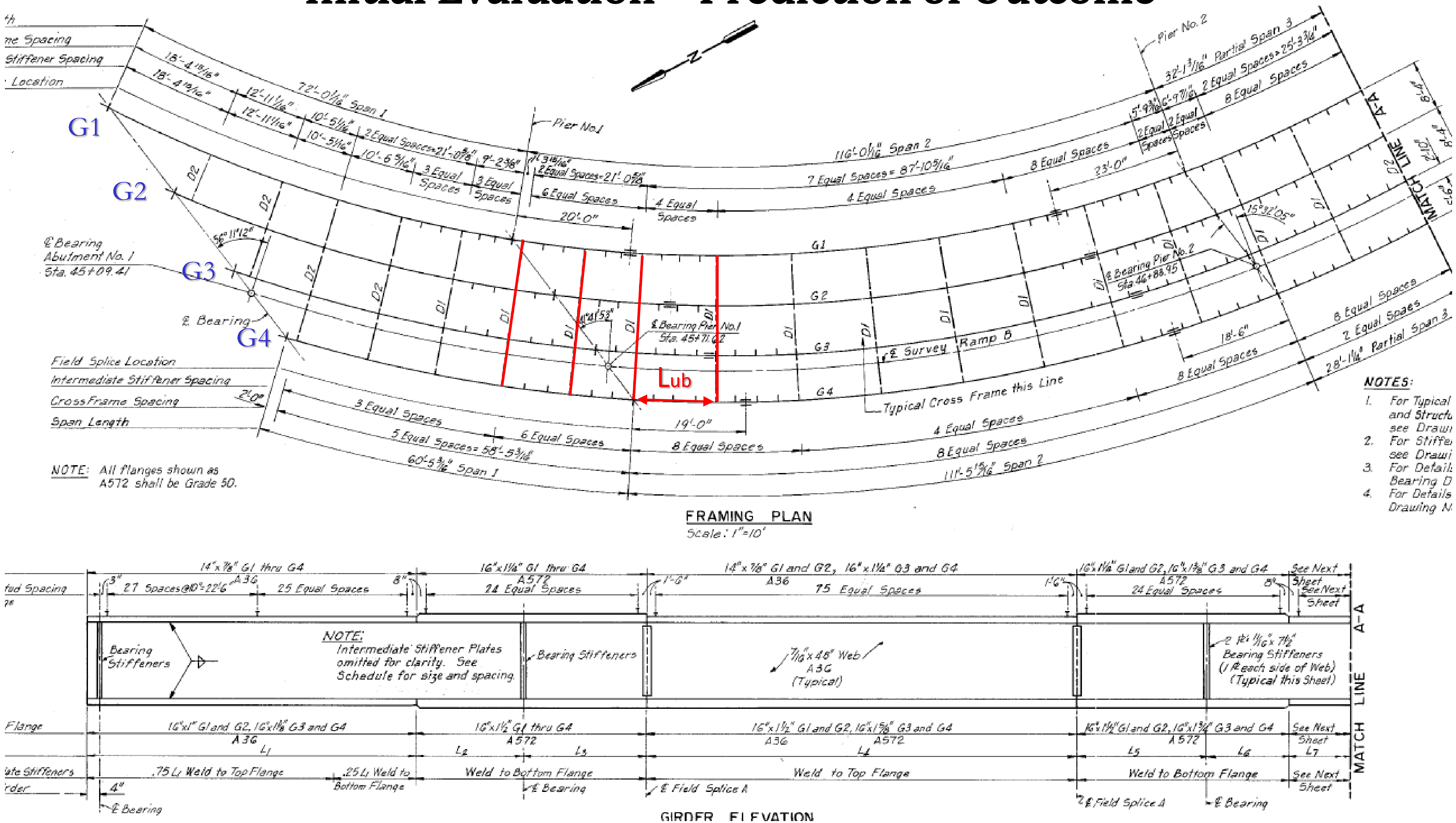
GCR (deck-super-sub): 6-8-6

- *Good & satisfactory condition*
- *Not postable*

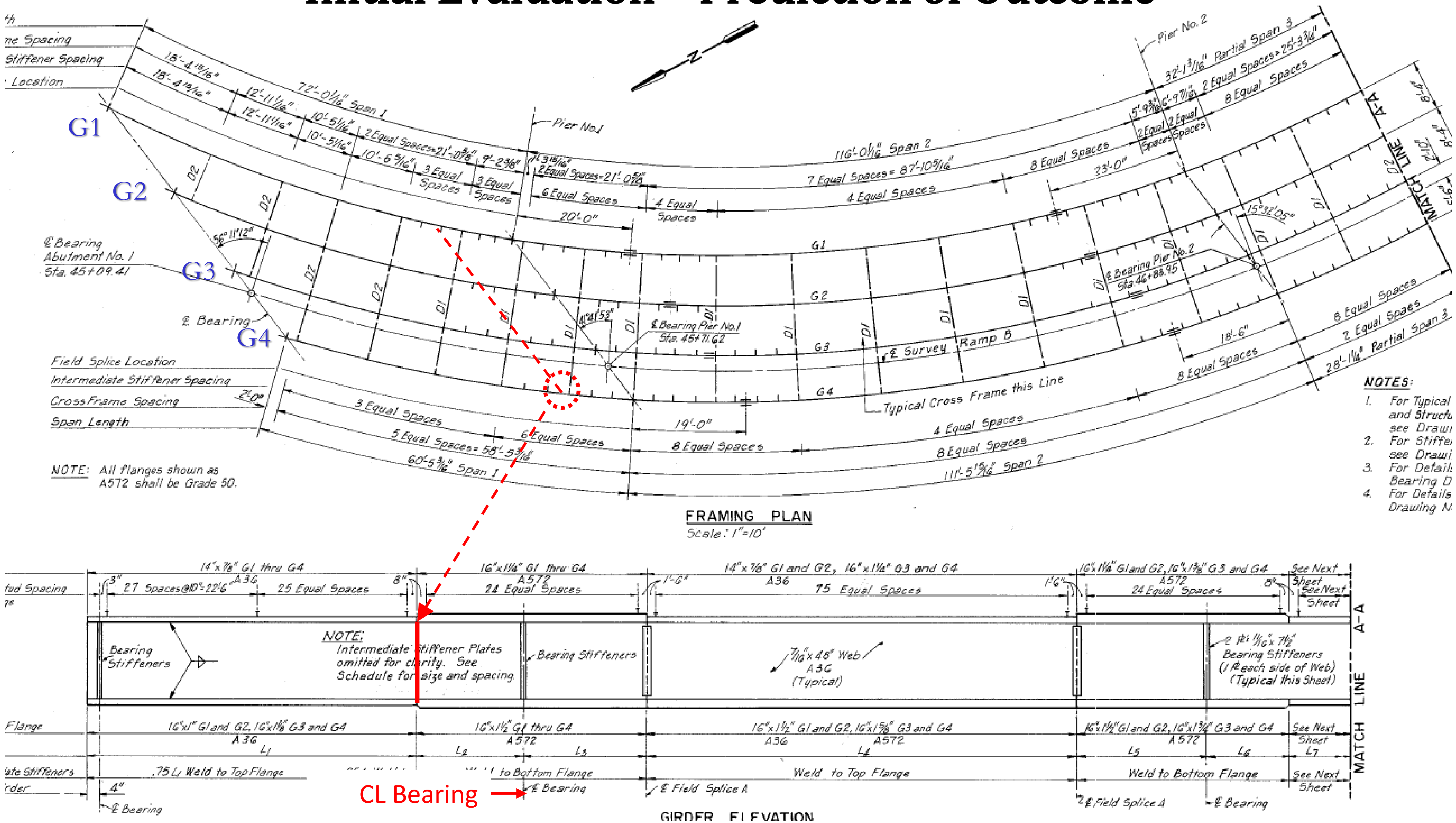
Initial Evaluation – Prediction of Outcome



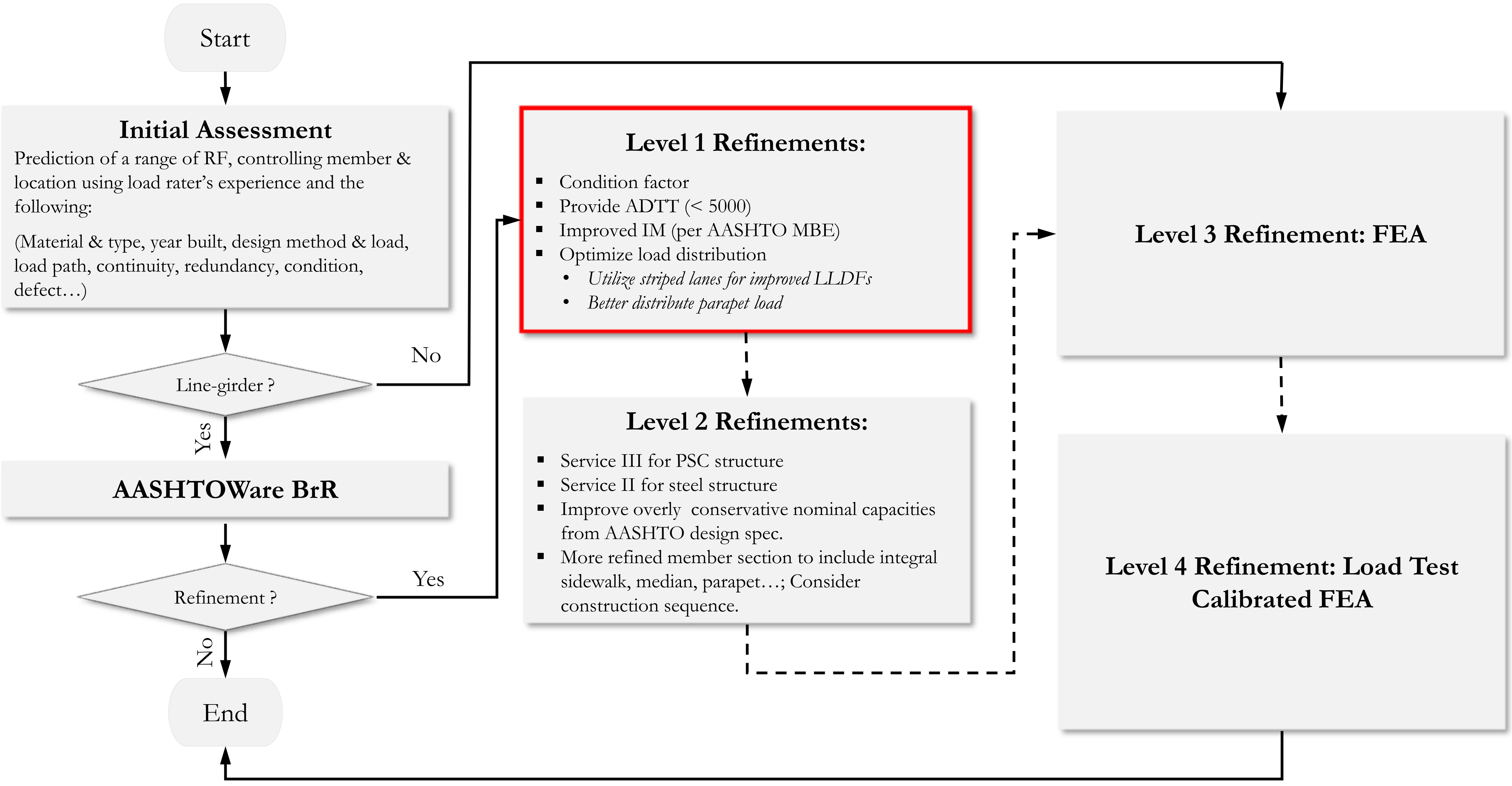
Initial Evaluation – Prediction of Outcome



Initial Evaluation – Prediction of Outcome

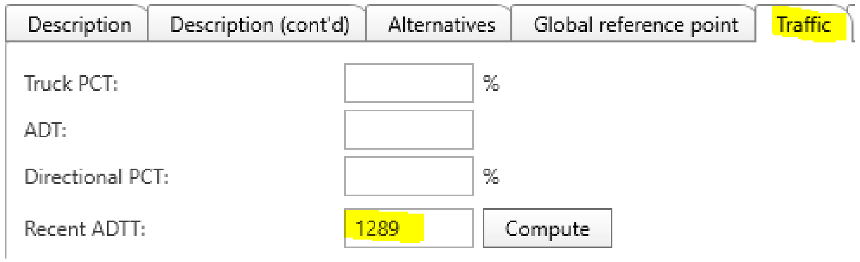


Workflow for Bridge Load Ratings with Improvement Options

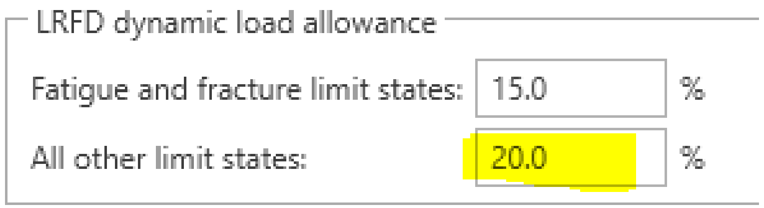


Level 1 Refinements:

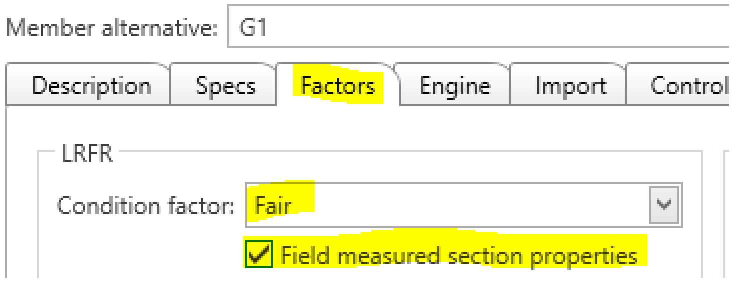
- Provide ADTT (< 5000)



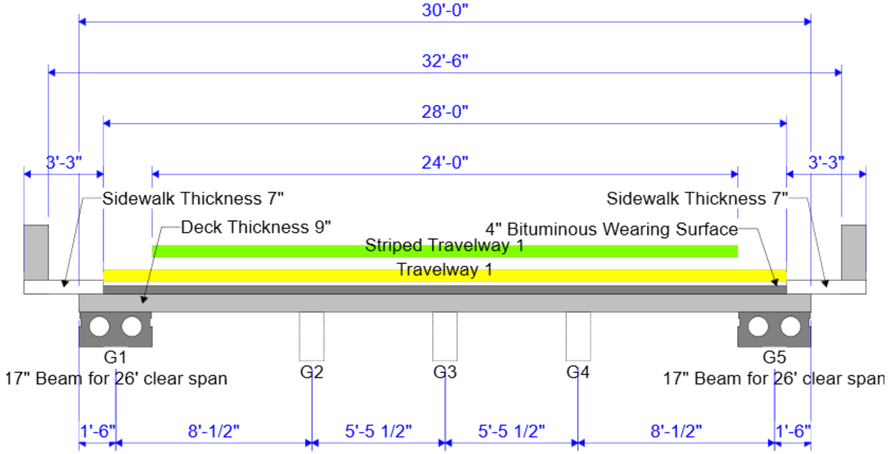
- Improved IM (per AASHTO MBE)

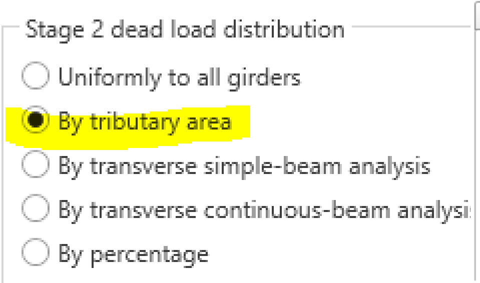


- Condition factor (verified defect)

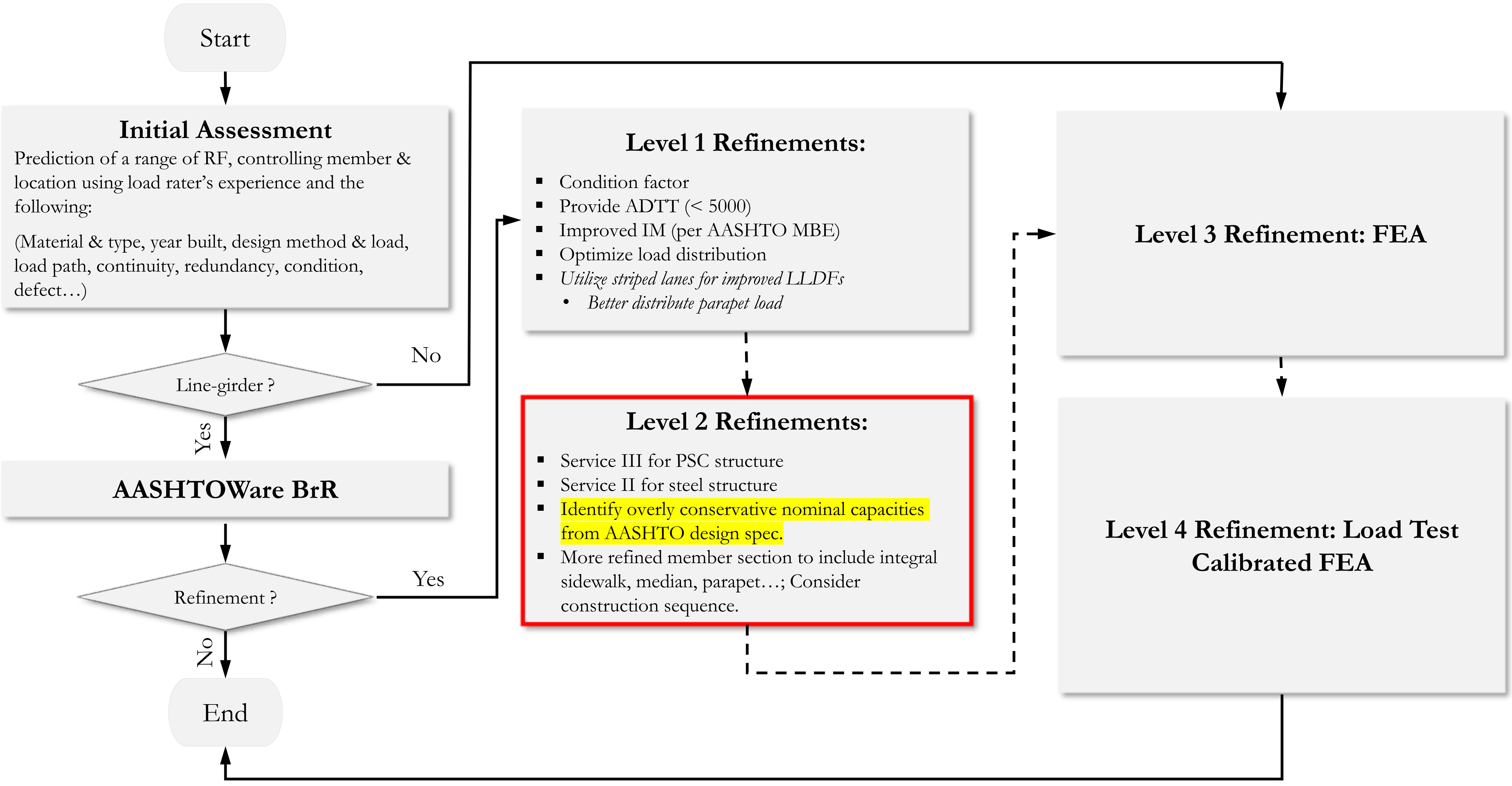


- Optimize load distribution
  - *Utilize striped lanes for improved LLDFs*
  - *Better distribute parapet load (tributary area)*

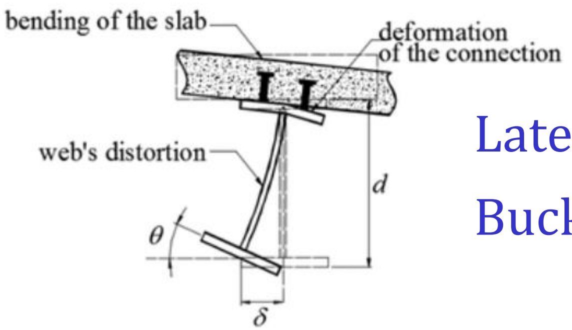




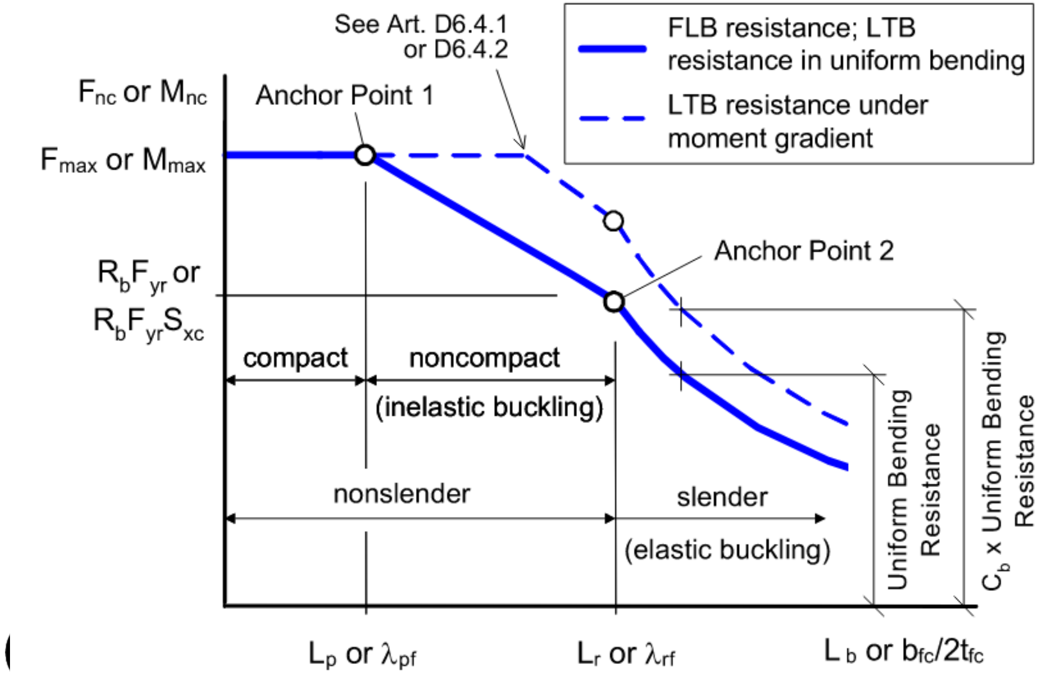
Workflow for Bridge Load Ratings with Improvement Options

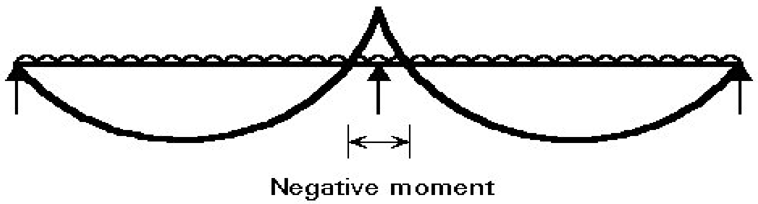


Level 2 Refinement: Overly Conservative Capacity



Lateral Torsional Buckling (TBL)





$$F_{nc} = C_b\left[1-\left(1-\frac{F_{yr}}{R_h F_{yc}}\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] R_b R_h F_{yc} \leq R_b R_h F_{yc} \quad (6.10.8.2.3\text{-}2)$$

C_b = moment gradient modifier. In lieu of an alternative rational analysis, C_b may be calculated as follows:

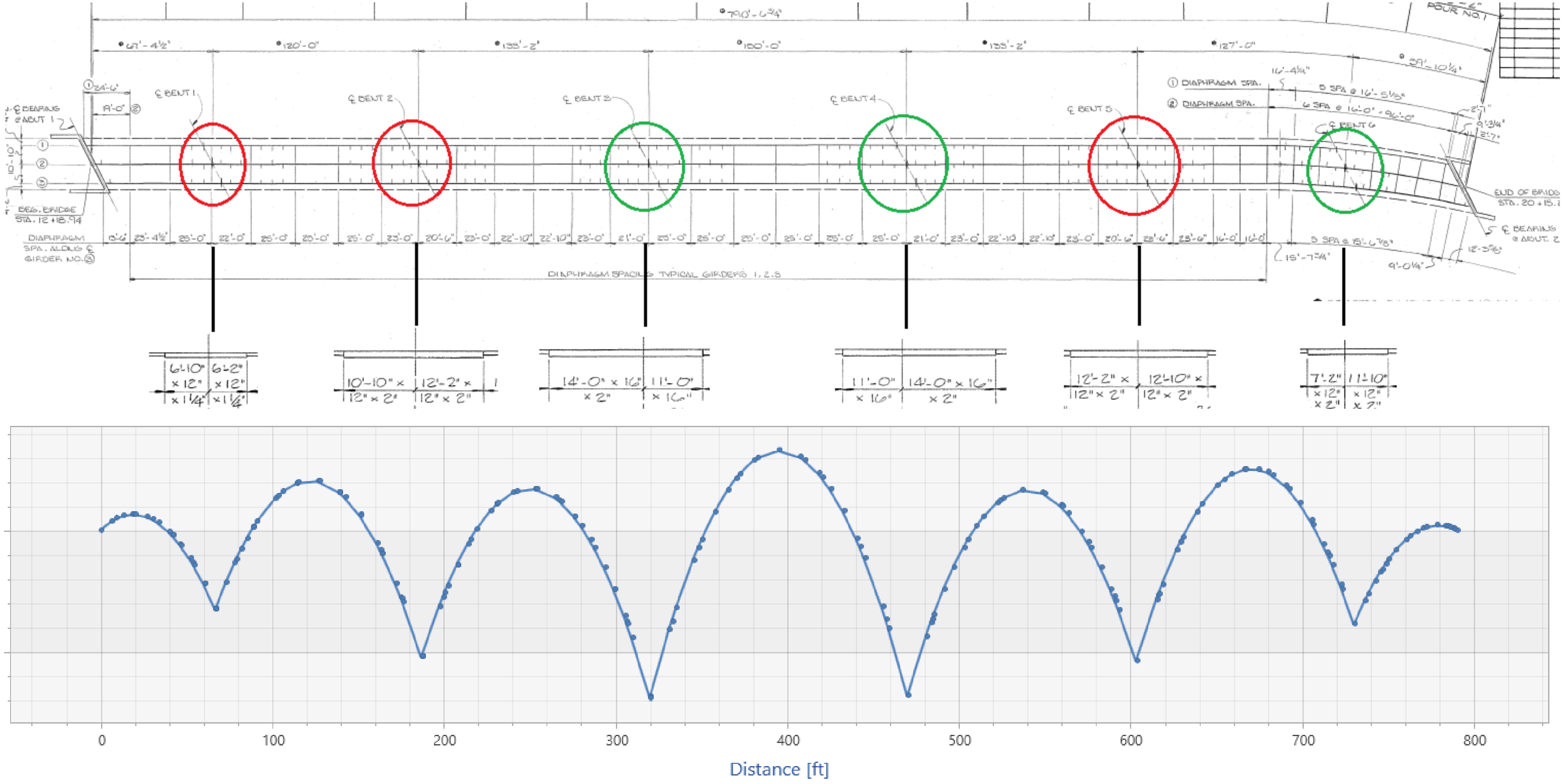
- For unbraced cantilevers and for members where $f_{mid}/f_2 > 1$ or $f_2 = 0$

$$C_b = 1.0 \quad (6.10.8.2.3\text{-}6)$$

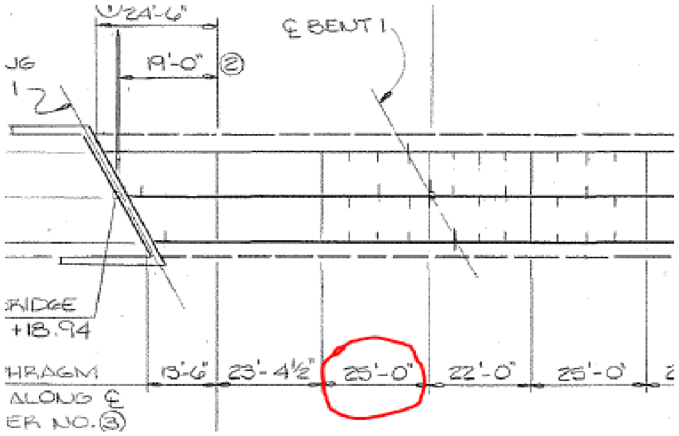
- For all other cases:

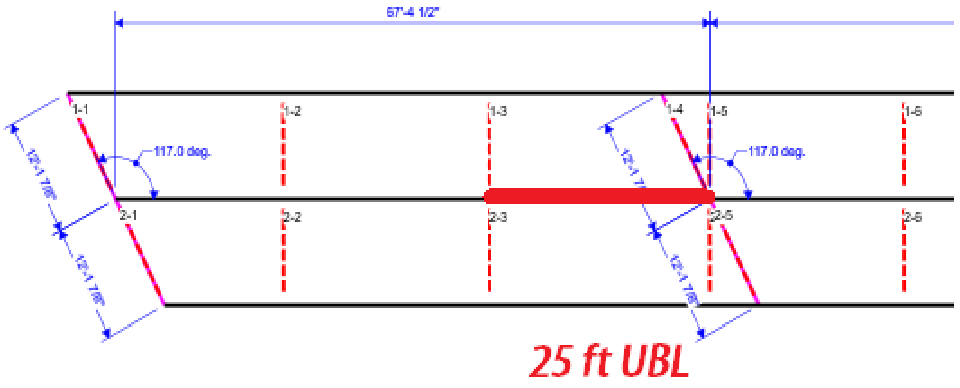
$$C_b = 1.75 - 1.05\left(\frac{f_1}{f_2}\right) + 0.3\left(\frac{f_1}{f_2}\right)^2 \leq 2.3 \quad (6.10.8.2.3\text{-}7)$$

Level 2 Refinement: Overly Conservative Capacity



Level 2 Refinement: Overly Conservative Capacity





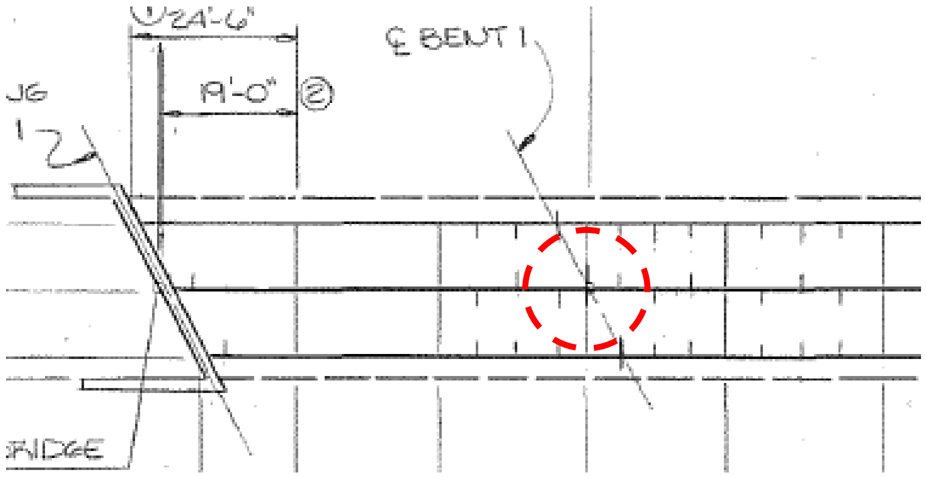
SUMMARY:

Cb = 1.0 (6.10.8.2.3-6)

Cb = 1.75 - 1.05*(f1/f2) + 0.3*(f1/f2)^2 <= 2.3 (6.10.8.2.3-7)

		Input			Output					
Limit State	Load Comb	Left Stress (ksi)	Mid Stress (ksi)	Right Stress (ksi)	Concave Moment	fmid (ksi)	f2 (ksi)	f1 (ksi)	Eq.	Cb
STR-I	1, LegalR~	5.54	-7.02	-14.29	No	7.02	14.29	-0.25	6*	1.0000
STR-I	1, LegalR~	-9.09	-18.68	-24.02	No	18.68	24.02	13.33	6*	1.0000
SER-II	1, LegalR~	5.13	-5.28	-11.23	No	5.28	11.23	-0.67	6*	1.0000
SER-II	1, LegalR~	-6.28	-14.29	-18.76	No	14.29	18.76	9.81	6*	1.0000

Level 2 Refinement: Overly Conservative Capacity



$$F_{nc} = C_b \left[1 - \left(1 - \frac{F_{yr}}{R_h F_{yc}} \right) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] R_b R_h F_{yc} \le R_b R_h F_{yc}$$

$$F_r = \varphi_c \varphi_s \varphi F_{nc} = 19.1\ ksi$$

$$f_{DL} = 15.8\ ksi \quad f_{LL} = 9.07\ ksi$$

$$RF = \frac{C - DL}{LL}$$

$$\mathrm{RF} = 0.37$$

Level 2 Refinement: Overly Conservative Capacity

LRFR

- For unbraced cantilevers and for members where

  $f_{mid}/f_2 > 1$ or $f_2 = 0$

  $$C_b = 1.0 \qquad (6.10.8.2.3\text{-}6)$$

- For all other cases:

$$C_b = 1.75 - 1.05\left(\frac{f_1}{f_2}\right) + 0.3\left(\frac{f_1}{f_2}\right)^2 \leq 2.3 \qquad (6.10.8.2.3\text{-}7)$$

LFD/LFR

$$C_b = 1.75 + 1.05\left(\frac{M_1}{M_2}\right) + (\frac{M_1}{M_2})^2$$

$$C_b = 1.75\ (end\ span)$$

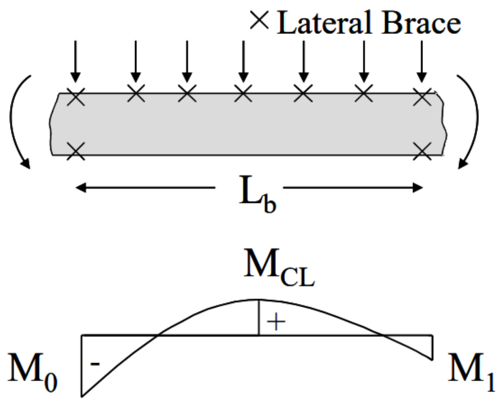
AISC

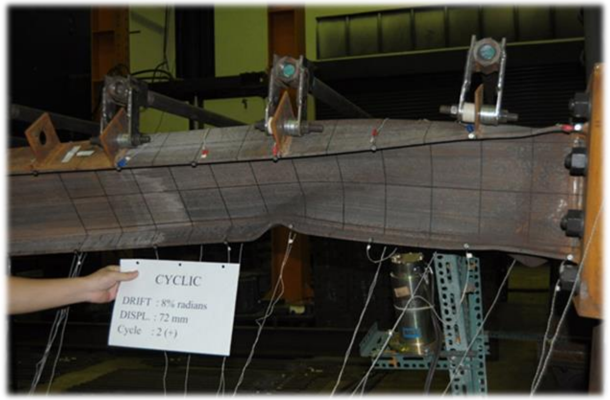
$$C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_C}$$

	f_r	DL	LL	RF
LRFR	19.1	15.8	9.07	0.37
LFR	25.6	15.8	9.07	1.08
AISC	25.1	15.8	9.07	1.02

Level 2 Refinement: Yura & Helwig Approach

- Restrain against twist at support
- Restrain against lateral displacement along the length at top flange



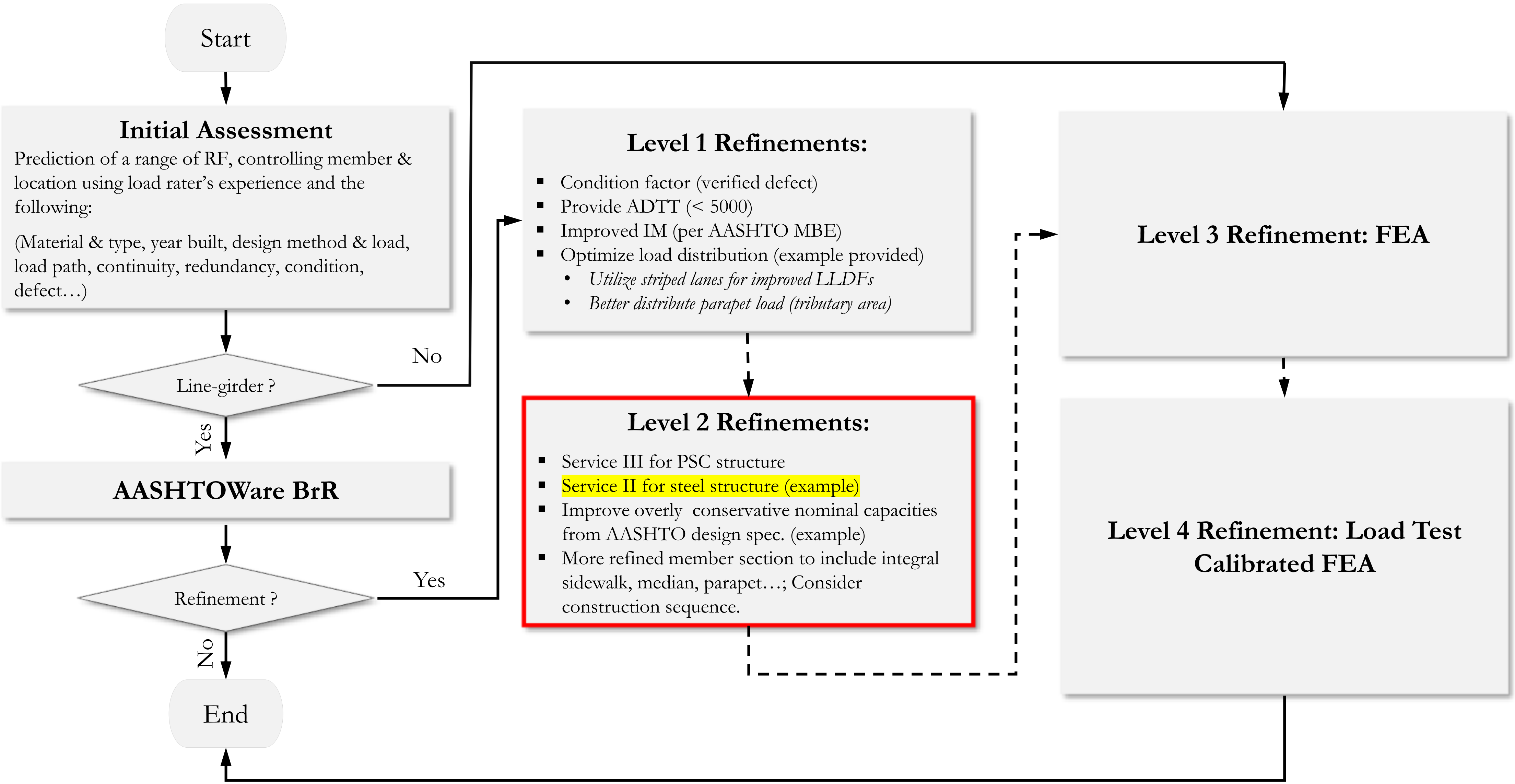


Yura & Helwig Equation:

$$C_b = 3.0 - \frac{2}{3}\left(\frac{M_1}{M_o}\right) - \frac{8}{3}\frac{M_{CL}}{(M_o + M_1)^{*}}$$

	fr	DL	LL	RF
Yura & Helwig	44.0	15.8	9.07	3.11

Workflow for Bridge Load Ratings with Improvement Options



Service II / Web Proportion/Web Bend-Buckling

Service II—Load combination intended to control yielding of steel structures and slip of slip-critical connections due to vehicular live load. [3.4.1]

For the top steel flange of composite sections:

$$f_f \leq 0.95 R_h F_{yf} \quad (6.10.4.2.2\text{-}1)$$

For the bottom steel flange of composite sections:

$$f_f + \frac{f_\ell}{2} \leq 0.95 R_h F_{yf} \quad (6.10.4.2.2\text{-}2)$$

$$f_c \leq F_{crw} \quad (6.10.4.2.2\text{-}4)$$

6.10.2—Cross-Section Proportion Limits

6.10.2.1—Web Proportions

6.10.2.1.1—Webs without Longitudinal Stiffeners

Webs shall be proportioned such that:

$$\frac{D}{t_w} \leq 150 \quad (6.10.2.1.1\text{-}1)$$

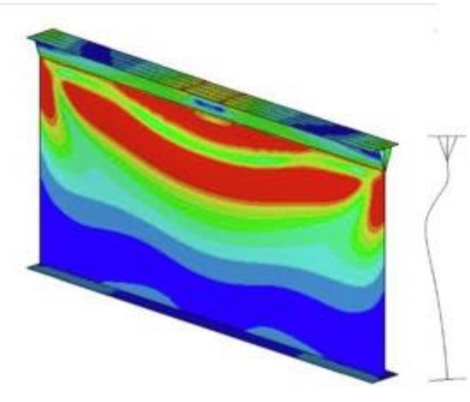
Web Bend-Buckling Resistance

6.10.1.9—Web Bend-Buckling Resistance

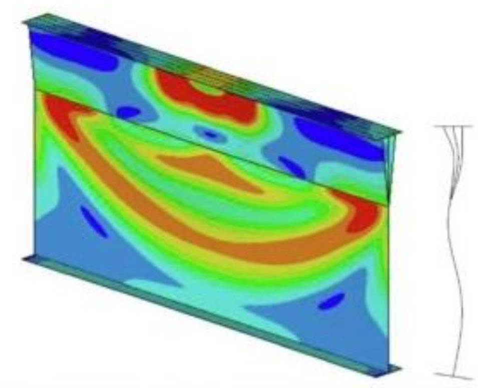
6.10.1.9.1—Webs without Longitudinal Stiffeners

The nominal bend-buckling resistance shall be taken as:

$$F_{crw} = \frac{0.9Ek}{\left(\frac{D}{t_w}\right)^2} \qquad (6.10.1.9.1\text{-}1)$$



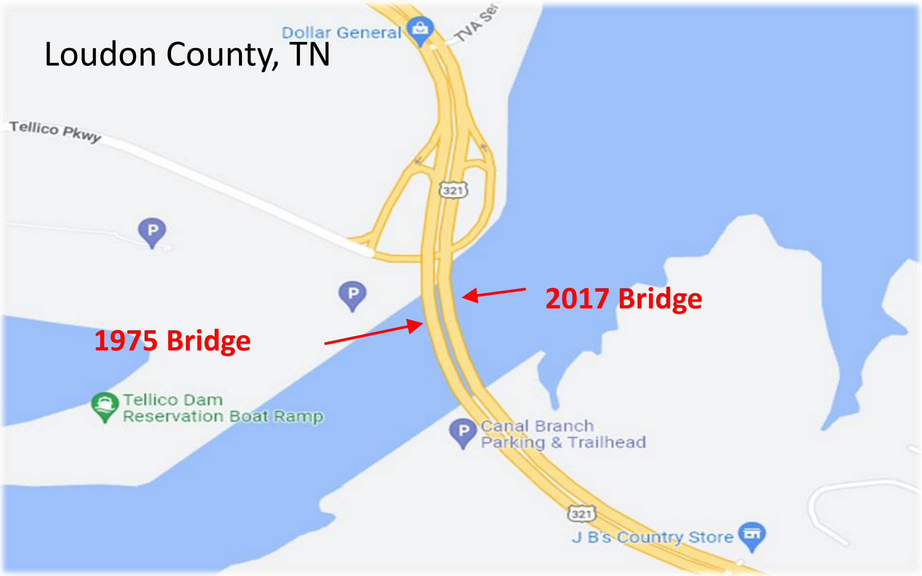
Unstiffened Web

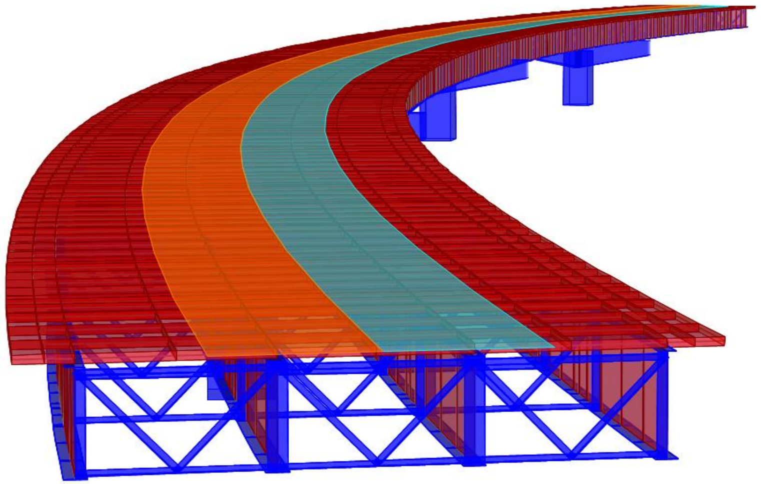


Stiffened Web

- ASCE (1968) recommends that web bend-buckling does not need to be considered in hybrid sections with *Fyc* up to 100 ksi as long as the web slenderness does not exceed 5.87√*E*/*Fyc*. [C6.10.1.9.1]
- The flexural resistance equations of these Specifications give somewhat conservative predictions for the strengths of hybrid members without longitudinal stiffeners tested by Lew and Toprac (1968) that had *D/tw* and 2*Dc/tw* values as high as 305 and *Fyw/Fyc* = 0.32. Therefore, no additional requirements are necessary at the strength limit state for all potential values of *Fyw/Fyc* associated with the steels specified in Article 6.4.1. [C6.10.1.9.1]
- In many experimental tests, noticeable web plate bending deformations and associated transverse displacements occur from the onset of load application due to initial web out-of-flatness. Because of the stable postbuckling behavior of the web, there is no significant change in the rate of increase of the web transverse displacements as a function of the applied loads as the theoretical web bend-buckling stress is exceeded (Basler et al., 1960). [C6.10.1.9.1]
- Due to unavoidable geometric imperfections, the web bend-buckling behavior is a load-deflection rather than a bifurcation problem. The theoretical web-buckling load is used in these Specifications as a simple index for controlling the web plate bending strains and transverse displacements. [C6.10.1.9.1]

Web Bend Bucking in Service II





$$\frac{D}{t_w} = \frac{105in}{\left(\frac{9}{16}\right) in} = 186 > 150$$

- Slender web without longitudinal stiffener
- f_{crw} controlled limiting stress resulted a RF of ZERO.

- Field weld a longitudinal stiffener
  - Preheating and welding at compression side of the web
  - Curbed surface
  - Interference with vertical stiffener
- Can an engineering judgement be made?

Did You Know?

“ In general, bridge capacities has increased by more than 9% from 2009 to 2019. ”

Reference: https://www.fhwa.dot.gov/bridge/lrfd/webinar.cfm

Summary

- **Have an Expectation:** Begin with a well-defined expectation.
- **Refine Expectation:** Utilize inspection reports to enhance and adjust initial expectations.
- **Results Validation:** Use modeling results for validations.
- **Adaptive Approach:** Maintain an open mindset to incorporate refinements.

Questions?

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