Automated Production of Robust Owner-Specific Steel Bridge Design Details

Developed by West Virginia University and Marshall University

Researchers at West Virginia University (WVU) and Marshall University (MU) have developed software tools that allow for the automated production of standard rolled beam and plate girder designs for highway bridge applications. Resulting designs conform to both AASHTO as well as owner-specified criteria. The designs are also individually compared against external software programs to ensure their compliance with owner preferences and pertinent limit states.

Development of Design Criteria

The production of state-specific standard designs begins with establishing governing criteria for girder selection and design. These criteria include:

- Defining required vehicular loading (AASHTO HL-93 vs. state-specific trucks), permanent loads and limit states.
- Designating geometrical parameters, such as the transverse cross-sections (e.g., number of girders, girder spacing, deck overhangs) and span configurations (i.e., single spans vs. multi-span arrangements), which will be used to design a matrix of steel bridge solutions.
- Specifying secondary superstructure details, such as barrier/railing systems, traditional vs. empirical deck design methods, and bearing types (e.g., steel-reinforced elastomeric bearings, cotton-duck pads, etc.).

Formulation of Design Rules

Once a set of design criteria has been established with the owner agency, a matrix of girder designs is generated for each permutation of bridge cross-section and span increment. This is done by establishing rules for girder selection, based on both owner preferences and any current local best fabrication methods (geared toward overall efficiency and economy). Specifically, these include

- Selection of steel grades for both rolled beam and plate girder options.
- Fabrication methods, such as including flange transitions in plate girders (as opposed to using prismatic flanges), utilizing stiffened vs. unstiffened webs, and optimizing shear connector layouts.
- Establishment of maximum tolerable skew angles.
- Identifying ranges for resulting solutions
  - Span ranges for noncomposite vs. composite girder designs
  - Span ranges for rolled beam vs. plate girder options

Automated Design

After the criteria and rules have been established by the owner agency, the design tools developed by WVU and MU are then used to generate the fabrication details necessary to completely construct the superstructure for each permutation of bridge cross-section and span increment. These include all associated beam selections (W-sections, plate sizes, etc.), bracing layout, shear connector layouts, bearing selection, and associate deck designs (including overhang details).

An example set of output designs is illustrated in Fig. 1. These were taken from short-span steel bridge design standards developed for the Ohio Department of Transportation (ODOT). In this figure, composite, homogeneous plate girders are presented for simple spans in 5-ft increments. Design criteria were established based on both AASHTO and ODOT standards, and designs were conducted to employ commonly available steel products as well as preferred fabrication details (e.g., all plate girders webs were designed as unstiffened). For each span increment, girders were designed for six individual cross-sections; the designs in Fig. 1 are targeted for 7-foot girder spacings. As shown, all relevant plate sizes, diaphragm spacings, and shear connector layouts are provided.

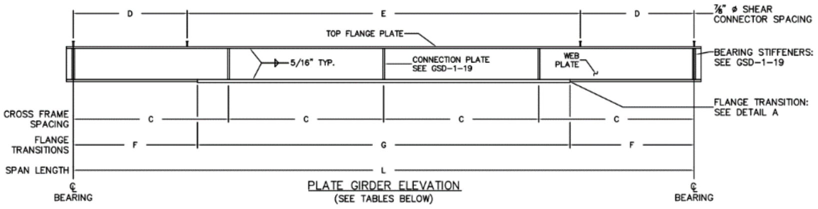

PLATE GIRDER ELEVATION
(SEE TABLES BELOW)

SPAN (L) – ft.	PLATE GIRDER SIZE						DIAPHRAGM SPACING (C) – ft.	SHEAR CONNECTOR MAX. SPACING	
	TOP FLANGE – in.	BOTTOM FLANGE (F)		BOTTOM FLANGE (G)		WEB PLATE – in.			
		PLATE – in.	LENGTH – ft.	PLATE – in.	LENGTH – ft.			D	E
60	14 x 0.750	–	–	14 x 1.250	60	24 x 0.5000	20.00	48 @ 6	9
65	16 x 0.750	–	–	16 x 1.250	65	24 x 0.5000	21.67	52 @ 6	9
70	16 x 0.875	–	–	16 x 1.250	70	26 x 0.5000	23.33	56 @ 6	9
75	16 x 0.875	–	–	16 x 1.375	75	28 x 0.5000	25.00	46 @ 6	9
80	16 x 0.875	–	–	16 x 1.375	80	30 x 0.5000	20.00	48 @ 6	9
85	16 x 0.875	–	–	16 x 1.500	85	32 x 0.5000	21.25	34 @ 6	9
90	16 x 0.875	16 x 0.875	18	16 x 1.500	54	34 x 0.5000	22.50	36 @ 6	9
95	16 x 0.875	16 x 0.875	19	16 x 1.625	57	36 x 0.5000	23.75	20 @ 6	9
100	18 x 0.750	18 x 0.750	20	18 x 1.500	60	38 x 0.5000	20.00	20 @ 6	9
105	18 x 0.875	18 x 0.875	21	18 x 1.500	63	40 x 0.5000	21.00	–	9
110	18 x 0.875	18 x 0.875	22	18 x 1.500	66	42 x 0.5000	22.00	–	9
115	20 x 0.875	20 x 0.875	23	20 x 1.375	69	44 x 0.5000	23.00	–	9
120	20 x 0.875	20 x 0.875	24	20 x 1.500	72	46 x 0.5000	24.00	–	9
125	20 x 0.875	20 x 0.875	25	20 x 1.500	75	48 x 0.5000	25.00	–	9
130	20 x 1.000	20 x 1.000	26	20 x 1.500	78	50 x 0.5000	26.00	52 @ 9	12
135	20 x 1.000	20 x 1.000	27	20 x 1.500	81	52 x 0.5000	27.00	54 @ 9	12
140	20 x 1.000	20 x 1.000	28	20 x 1.625	84	54 x 0.5625	28.00	38 @ 9	12

Fig. 1: Sample design standards (prepared for Ohio DOT). Complete drawing set can be downloaded here.

Validation of Standard Designs

Once the designs have been generated, they are then validated using two approaches. First, each resulting permutation is evaluated using external design software (populated, executed, and queried withing the WVU / MU program) to ensure that designs meet pertinent limit states. This is done by comparing performance ratios generated from the two software packages. In addition, the resulting weights of each girder design are plotted to ensure that the resulting designs will be economically competitive.

An example design comparison is shown in Fig. 2. For each iteration, a comparison of performance ratios for various limit states is shown. Specifically, performance ratios generated from in-house design tools are compared against those taken from NSBA LRFD Simon, a popular design and rating tool for steel I-girder bridges. As shown, the tools developed by WVU and MU are quite accurate when compared with industry-approved design software.

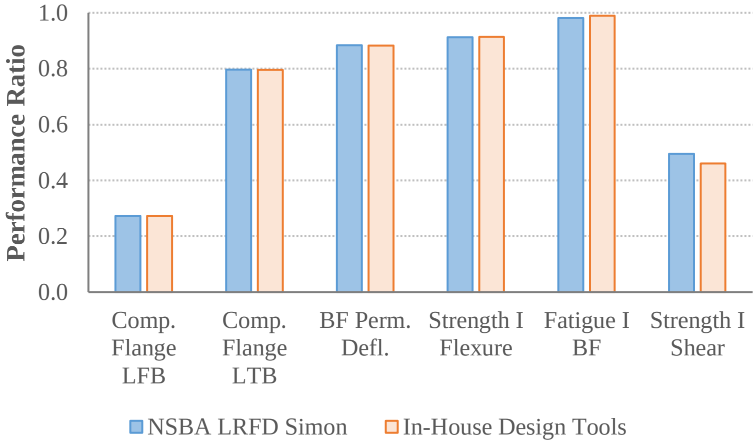

Fig. 2: Sample comparison of performance ratios for pertinent limit states.

An example weight comparison is shown in Fig. 3. For each cross-section, the resulting weights are plotted vs. span length to ensure that the suite of girder designs are economically competitive. As shown, both rolled beam and plate girder options are compared. The region of overlap (between 60 ft. and 110 ft.) illustrates that the two options have comparable weights, thereby demonstrating the economy of the suite of designs.

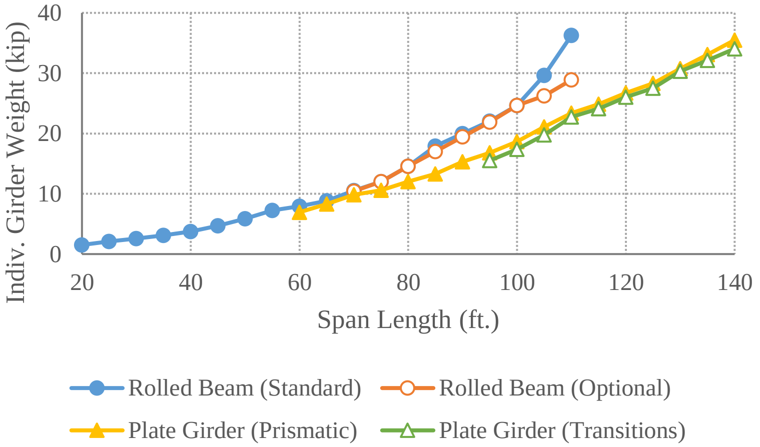

Fig. 3: Sample weight comparison between rolled beam and plate girder solutions.

Production of Final Output

Once reviewed and approved by the owner agency, a PDF containing all relevant design details, dimensions, and design notes (formatted according to owner preferences) will be furnished for review. An example can be downloaded for review here. Additionally, the owner agency can be supplied with a set of NSBA LRFD Simon design files for reference In addition, a comprehensive design example of a representative iteration can be furnished to the owner for review if desired.

Summary & Benefits of Standardized Designs

The software developed by researchers at West Virginia University and Marshall University afford owner agencies the ability to rapidly develop steel bridge design detail standards tailored for any specified cross section, span configuration, loadings, and state specific practices for various detailing items. The potential savings in material cost realized by designing each structure individually for every site situation are far outweighed by standardizing the design of these structures. That is, utilization of similar beam sizing across the board for similar span arrangements, utilization of common details, utilization of common fabrication practices far outweighs any negligible material savings associated with design on a site by site basis.

This has broad implications for improved quality and efficiency in our infrastructure. It allows owners to have a real time understanding of what cost may be, it allows the bridge inspection community to be better equipped to perform inspections on industry vetted an know details, it allows fabricators to have readily available approved design and detailing files to expedite project delivery, it allows contractors to be more fined tuned to successfully perform jobs with a minimum of problems related to design flaws or complicate to install pieces, and it affords transportation system users a more cost effective and efficient infrastructure system.