High Performance Steel Cost Comparison Study

ACEC / NCDOT Bridge Committee
HPS Bridge Workshop
October 22, 2007

Edward Power, P.E.
Acknowledgements:

Joint Study between HDR Engineering and University of Nebraska at Lincoln

Sponsored by FHWA

Coauthors:

Richard Horton, P.E.
Gary Krupicka, P.E.
Atorod Azizinamini, Ph.D., P.E.
HPS Cost Comparison Study

HPS has been used successfully now on many projects in several states.

Tennessee – One of the first applications
State Route 53 Bridge over Martin Creek,
Jackson County
Weight Savings 24%
HPS 70W provides significant advantages over conventional Grade 50W Steel.

<table>
<thead>
<tr>
<th>Material</th>
<th>Strength</th>
<th>Weldability</th>
<th>Toughness</th>
<th>Weathering</th>
</tr>
</thead>
<tbody>
<tr>
<td>50W</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPS 70W</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

```
<table>
<thead>
<tr>
<th>Performance</th>
<th>50W</th>
<th>HPS 70W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```
HPS Cost Comparison Study

HPS 70W material cost is greater than conventional Grade 50W Steel.
When does greater strength and performance outweigh material unit cost to achieve overall economy?

Study showed the economy of hybrid girders.
COST COMPARISON STUDY GOALS

Compare girder weight and fabrication cost associated with designs using Grade 50W and HPS 70W steel.

Develop relative trends considering variable:
- Span length
- Girder spacing
- Material combinations + Hybrids
- Girder depth
Cost Comparison Study

Cost Comparison Study Goals

- Develop fabrication cost comparisons with Fabricator input
- Determine deflection effects (L/800)
- Determine fatigue effects
- Determine trends for box girders
Two-Span bridge arrangement considered for study

- Positive and negative moment regions
- Simple design approach
- Popular grade separation structure
HPS Cost Comparison Study

Design for Interior Girder

4 SPA. @ 9'- 0"

5 Girders @ 9’ Spacing
HPS Cost Comparison Study

Design for Interior Girder

3 SPA. @ 12'- 0"

4 Girders @ 12’ Spacing
Design Flowchart

HPS COST COMPARISON

SPAN LENGTHS

100’-100’

150’-150’

200’-200’

250’-250’

GIRDER SPACING

12’ SPA

9’ SPA

12’ SPA
Design Flowchart

HPS COST COMPARISON

SPAN LENGTHS

100'-100'
150'-150'
200'-200'
250'-250'

GIRDER SPACING

12' SPA
9' SPA
12' SPA

YIELD STRESS

50 W
HPS 70 W
HYBRIDS 1-5

WEB DEPTH OPTIMIZATION

L/25
L/30
L/35
Consider Hybrid 1 for shorter spans where Fatigue can control at positive moment bottom flanges.
HPS Cost Comparison Study

HYBRID 2

70 ksi 70 ksi 70 ksi

50 ksi 50 ksi 50 ksi

70 ksi 70 ksi 70 ksi
HPS Cost Comparison Study

HYBRID 3
HPS Cost Comparison Study

HYBRID 4

Hybrid 4 was typically the most cost effective
HPS Cost Comparison Study

HYBRID 5
HPS Cost Comparison Study

Design Criteria

AASHTO LRFD 2nd Edition with 2000 Interim

Design parameters:

• Interior girder
• 25 ft. max cross frame spacing
• 12” x 3/4” minimum flange
Girder Optimization

No thickness transitions

Partially stiffened web design
Stiffener cost 4x web plate cost

One thickness transition - 800# min weight savings

Plate width transition at field splices

HPS Cost Comparison Study
HPS Cost Comparison Study

HPS 70W mill lengths

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Process</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;= 2”</td>
<td>Thermo Mechanical Controlled Processing (TMCP)</td>
<td>120’</td>
</tr>
<tr>
<td>&gt; 2”</td>
<td>Quenching and Tempering (Q&amp;T)</td>
<td>50’</td>
</tr>
</tbody>
</table>
Performance Characteristics

HPS Cost Comparison Study

Girder Weight

Web Depth

Optimal Depth

Grade 50W

Grade HPS 70W
HPS Cost Comparison Study

Performance Characteristics

Girder Weight

Web Depth

Deflection L/800

Grade 50W

Grade HPS 70W
Performance Characteristics

Girder Weight

Web Depth

Deflection L/800

Fatigue

Grade 50W

Grade HPS 70W

Phases 1 & 2

49 design combinations

170 girder designs

HPS Cost Comparison Study
Optimal Depth and Deflection

Web Depth Corresponding to $L/D=25$
Optimal Depth and Deflection

Optimal Depth 50W

Span Length (ft.)

Web Depth (in.)
Optimal Depth and Deflection

Web Depth (in.)

Span Length (ft.)

L/D=25  50W  HPS70W

Optimal Depth HPS 70W
Optimal Depth and Deflection

Optimal Depth HY 4
Optimal Depth and Deflection

\[ \Delta = \frac{L}{800} \]
## HPS Cost Comparison Study

### Optimal Girder Depths

<table>
<thead>
<tr>
<th>Bridge Spans</th>
<th>Girder Spacing</th>
<th>50W</th>
<th>HPS 70W</th>
<th>Hybrid - 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>100’-100’</td>
<td>12’</td>
<td>42</td>
<td>40</td>
<td>41</td>
</tr>
<tr>
<td>150’-150’</td>
<td>9’</td>
<td>63</td>
<td>56</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>71</td>
<td>60</td>
<td>61</td>
</tr>
<tr>
<td>200’-200’</td>
<td>9’</td>
<td>76</td>
<td>70 (68)</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>78</td>
<td>72 (69)</td>
<td>76 (70)</td>
</tr>
<tr>
<td>250’-250’</td>
<td>9’</td>
<td>90</td>
<td>77 (84)</td>
<td>86 (86)</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>95</td>
<td>87 (91)</td>
<td>94 (93)</td>
</tr>
</tbody>
</table>

( ) – Depth where deflection equals L/800
Fatigue

When does Fatigue affect the cost effectiveness of HPS 70W steel?
HPS Cost Comparison Study

Fatigue

When does Fatigue affect the cost effectiveness of HPS 70W steel?

Fatigue resistance is a variable based on:

- detail category
- average daily truck traffic
HPS Cost Comparison Study

Fatigue

Two Fatigue Detail Categories Considered

- Stud Shear Connector Category C
- Welded Cross Frame Stiffener Category C'
Fatigue

Limiting value of Average Daily Truck Traffic (ADTT) used for study

- Results in conservative lower bound fatigue resistance.
- Corresponds to Interstate roadway or urban arterial.
- Ramps, overpasses, rural roads, etc. with lower ADTT will have higher fatigue resistance limits.
Fatigue Performance Ratio

Span Lengths (ft.)

Load Induced Fatigue
Bottom Category C’ - 12 ft. Girder Spacing
HPS Cost Comparison Study

Girder Weight Comparisons

Girder Weight

Web Depth

Deflection L/800

Grade 50W

Grade HPS 70W
Girder Weight Comparisons
100 ft. Spans & 12 ft. Girder Spacing

Girder Weight (lb. x1000) vs. Web Depth (in)

- Optimal Depth
- 50 ksi
- 70 ksi

14% difference
13% difference

Optimal Depth at approximately Web Depth = 41 in.
Girder Weight Comparisons
100 ft. Spans & 12 ft. Girder Spacing

Girder Weight (lb. x1000)

Web Depth (in)

- 50 ksi Fatigue
- 70 ksi Fatigue
- Optimal Depth

- 6% (FAT)
- 14% (FAT)
- 8% (FAT)
- 13% (FAT)
Girder Weight Comparisons
150 ft. Spans & 12 ft. Girder Spacing

Girder Weight (lb. x1000) vs. Web Depth (in)

Optimal Depth

50 ksi
70 ksi

23%
21%
17%
Girder Weight Comparisons
150 ft. Spans & 12 ft. Girder Spacing

- 50 ksi Fatigue
- 70 ksi Fatigue

Optimal Depth

Girder Weight (lb. x1000) vs. Web Depth (in)
Girder Weight Comparisons
200 ft. Spans & 12 ft. Girder Spacing

Girder Weight (lb. x1000)

Web Depth (in)

Optimal Depth

50 ksi

70 ksi
Girder Weight Comparisons
200 ft. Spans & 12 ft. Girder Spacing

Girder Weight (lb. x1000)

Web Depth (in)

“L/D”

Optimal Depth

Δ=L/800

Optimal Depth

50 ksi

70 ksi

L/40

L/35

L/30

L/25

55 60 65 70 75 80 85 90 95 100
Girder Weight Comparisons
250 ft. Spans & 12 ft. Girder Spacing

Web Depth (in)

Girder Weight (lb. x1000)

50 ksi

70 ksi

Optimal Depth

22%

21%
Girder Weight Comparisons
250 ft. Spans & 12 ft. Girder Spacing

Girder Weight (lb. x1000)

Web Depth (in)

Optimal Depth

50 ksi

70 ksi

L/40

L/35

L/30

“L/D” 25

Δ=L/800

22%

21%
Girder Weight Comparisons
Weight Savings from 50W

Span Length (ft.)

% Weight Savings

70W
HY4
Girder Weight Comparisons
Weight Savings from 50W
## HPS Cost Comparison Study

### Weight Savings at Optimal Depth from 50W

<table>
<thead>
<tr>
<th>Bridge Spans</th>
<th>Girder Spacing</th>
<th>HPS 70W</th>
<th>Hybrid - 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>100’-100’</td>
<td>12’</td>
<td>13% (8%)</td>
<td>13% (8%)</td>
</tr>
<tr>
<td>150’-150’</td>
<td>9’</td>
<td>17% (13%)</td>
<td>11% (9%)</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>17% (15%)</td>
<td>16% (14%)</td>
</tr>
<tr>
<td>200’-200’</td>
<td>9’</td>
<td>17%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>17%</td>
<td>15%</td>
</tr>
<tr>
<td>250’-250’</td>
<td>9’</td>
<td>17%</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>21% (19%)</td>
<td>20%</td>
</tr>
</tbody>
</table>

( ) - Weight savings considering fatigue

( ) - Weight savings considering deflection
Goal: Determine relative cost effectiveness of HPS 70W steel over Grade 50W

Fabricator participation requested for cost comparison
• Costs requested for 16 designs
• 10 Fabricators selected to represent entire country

Costs included material and labor
## HPS Cost Comparison Study

### Fabricator Cost Estimates

### Fabricator Average Unit Costs ($/lb.)

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>Phase I 2000</th>
<th>Phase II 2002</th>
<th>Phase III 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>50W</td>
<td>$0.61/lb</td>
<td>$0.52/lb</td>
<td>$0.70/lb</td>
</tr>
<tr>
<td>HPS 70W</td>
<td>$0.75/lb</td>
<td>$0.66/lb</td>
<td>$0.87/lb</td>
</tr>
<tr>
<td>Difference</td>
<td>$0.14/lb</td>
<td>$0.14/lb</td>
<td>$0.17/lb</td>
</tr>
</tbody>
</table>

Note: The difference in costs is reflected in the final row.
# HPS Cost Comparison Study

## Fabricator Average Cost Estimates ($/lb.)

<table>
<thead>
<tr>
<th>Bridge Spans</th>
<th>Girder Spacing</th>
<th>50W</th>
<th>HPS 70W</th>
</tr>
</thead>
<tbody>
<tr>
<td>150’ - 150’</td>
<td>9’</td>
<td>N.R.</td>
<td>N.R.</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>0.56</td>
<td>0.71</td>
</tr>
<tr>
<td>200’ - 200’</td>
<td>9’</td>
<td>0.53</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>0.51</td>
<td>0.63</td>
</tr>
<tr>
<td>250’ - 250’</td>
<td>9’</td>
<td>N.R.</td>
<td>N.R.</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>0.48</td>
<td>0.61</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td>0.52</td>
<td>0.66</td>
</tr>
</tbody>
</table>
Girder Cost Comparisons

Typical Cost Comparison for All Hybrid Alternatives

Girder Cost (x1000) vs. Web Depth (in)

- 50 ksi
- 70 ksi
- Hybrid-1
- Hybrid-2
- Hybrid-3
- Hybrid-4
- Hybrid-5
Girder Cost Comparisons
100 ft. Spans & 12 ft. Girder Spacing

Girder Cost (x1000)

50 ksi
70 ksi
Hybrid-4

Optimal Depth

Optimal Depths

Web Depth (in)
Girder Cost Comparisons
100 ft. Spans & 12 ft. Girder Spacing
Girder Cost Comparisons
150 ft. Spans & 12 ft. Girder Spacing

50 ksi Fatigue

70 ksi Fatigue

HY-4 Fatigue

Optimal Depth

Optimal Depth

5% (FAT)

8%

Girder Cost (x1000)

Web Depth (in)

L/35

L/30

L/25
Girder Cost Comparisons
250 ft. Spans & 12 ft. Girder Spacing

70 ksi Deflection (L/800)

Optimal Depth

HY-4 Deflection (L/800)

Girder Cost (x1000)

Web Depth (in)
Girder Cost Comparisons
Cost Savings from 50W

% Cost Savings vs. Span Length (ft.)

HY4

70W
Girder Cost Comparisons
Cost Savings from 50W

% Cost Savings vs. Span Length (ft.)

- HY4
- HY4 FAT
- 70W
- 70W FAT
## HPS Cost Comparison Study

### Relative Girder Fabrication Cost Savings w.r.t. Grade 50W

<table>
<thead>
<tr>
<th>Spans</th>
<th>Girder Spacing</th>
<th>HPS 70W</th>
<th>Hybrid - 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>100’-100’</td>
<td>12’</td>
<td>-8% (-14%)</td>
<td>2% (-4%)</td>
</tr>
<tr>
<td>150’-150’</td>
<td>9’</td>
<td>-4% (-8%)</td>
<td>4% (2%)</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>-2% (-6%)</td>
<td>8% (5%)</td>
</tr>
<tr>
<td>200’-200’</td>
<td>9’</td>
<td>-4%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>-3%</td>
<td>6%</td>
</tr>
<tr>
<td>250’-250’</td>
<td>9’</td>
<td>-3%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>12’</td>
<td>1%</td>
<td>9%</td>
</tr>
</tbody>
</table>

( ) – Cost savings considering fatigue
The study compared weight, depth and cost of 49 girder configurations for a range of span lengths, girder spacing, and steel types.
HPS Cost Comparison Study

Summary and Conclusions

Performance Issues:
- Use of homogenous HPS 70W steel resulted in weight savings of 13% to 20% relative to 50W. Hybrid 4 had 11% to 20% savings.
- Greater weight savings occur at shallower depths.
- Optimal girder depths were shallower by an average of 8% to 9% in all spans except 100’.
- Fatigue affected 100’ and 150’ spans. Truck volume is a factor.
- Deflection (L/800) affected 70W design at 250’ spans at optimal depth. In 200’ spans, depths below optimal were affected.
Summary and Conclusions

Cost Issues:

• At optimal depths, homogenous Grade 50 designs were typically more economical than HPS 70W designs. Advantage reduces with span length.

• At shallower depths, HPS 70W designs were typically more economical.
Hybrid designs were the most economical with cost savings of 2% to 9% at optimal depths. Savings increase with span length.

Hybrid 4 was the most economical with:
- HPS 70W top and bottom flanges in negative moment region
- HPS 70W bottom flanges in positive moment region
- Grade 50 top flanges in positive moment region and all webs

Additional cost savings can be realized with HPS 70W in shipping and erection, foundations, and reduced approach fill heights.
High Performance Steel Box Girder Study
HPS Box Girder Study

2 Box Girder Section

Longitudinal Stiffener (LS) when used
HPS Box Girder Study

Compression Flange Resistance (ksi)

E.Q. 6.11.8.2-2
(70)

E.Q. 6.11.8.2-3
(70)

E.Q. 6.11.8.2-2
(50)

E.Q. 6.11.8.2-3
(50)

50W

Spans 300 250 200 150

50 ksi

70 ksi

Flange b/t Ratio
HPS Box Girder Study

Hybrid B1

150 ft Spans – HY, HY LS
200 ft Spans – HY
250 ft Spans – HY
HPS Box Girder Study

Hybrid B2

200 ft Spans – HY LS
250 ft Spans – HY LS
HPS Box Girder Study

Hybrid B3

300 ft Spans – HY
HPS Box Girder Study

Hybrid B4

70 ksi
Top Flange

50 ksi

70 ksi
Bottom Flange

50 ft Spans – HY LS
Box Girder Weight Comparisons

Weight Savings from 50W

% Weight Savings

Span Length (Feet)
Box Girder Weight Comparisons
Weight Savings with Longitudinal Stiffener

% Weight Savings vs. Span Length (Feet)

- HY to HY LS
- 50 to 50 LS
Fabricator participation requested for cost comparison

- Costs obtained for 16 designs
- 4 Fabricators participated

Costs included material and labor
## Fabricator Cost Estimates

### Fabricator Average Unit Costs ($/lb.)

<table>
<thead>
<tr>
<th>Span</th>
<th>50W</th>
<th></th>
<th>HPS 70W</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Material</td>
<td>Labor</td>
<td>Total</td>
<td>Material</td>
</tr>
<tr>
<td>150 - 150</td>
<td>0.48</td>
<td>0.36</td>
<td>0.84</td>
<td>0.63</td>
</tr>
<tr>
<td>200 - 200</td>
<td>0.49</td>
<td>0.30</td>
<td>0.79</td>
<td>0.62</td>
</tr>
<tr>
<td>250 - 250</td>
<td>0.48</td>
<td>0.26</td>
<td>0.74</td>
<td>0.63</td>
</tr>
<tr>
<td>300 - 300</td>
<td>0.49</td>
<td>0.25</td>
<td>0.74</td>
<td>0.63</td>
</tr>
<tr>
<td>Average</td>
<td>0.49</td>
<td>0.29</td>
<td>0.78</td>
<td>0.63</td>
</tr>
</tbody>
</table>
## HPS Box Girder Study

### Fabricator Cost Estimates

### Fabricator Average Unit Costs ($/lb.)

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>Phase I 2000</th>
<th>Phase II 2002</th>
<th>Phase III 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I-Girder</td>
<td>Box</td>
<td></td>
</tr>
<tr>
<td>50W</td>
<td>$0.61/lb</td>
<td>$0.52/lb</td>
<td>$0.70/lb</td>
</tr>
<tr>
<td>HPS 70W</td>
<td>$0.75/lb</td>
<td>$0.66/lb</td>
<td>$0.87/lb</td>
</tr>
<tr>
<td>Difference</td>
<td>$0.14/lb</td>
<td>$0.14/lb</td>
<td>$0.17/lb</td>
</tr>
</tbody>
</table>
Box Girder Cost Comparisons
Cost Savings from 50W

% Cost Savings

Span Length (Feet)

HY LS

50 LS

HY
Box Girder Cost Comparisons
Cost Savings with Longitudinal Stiffener

Span Length (Feet)

% Cost Savings

HY to HY LS  
50 to 50 LS
Summary and Conclusions

- Hybrid design with bottom flange longitudinal stiffening is the most economical use of HPS 70W in box girders.
- Effectiveness of HY increases with increasing span length.
- Effectiveness of bottom flange negative moment longitudinal stiffening decreases with increasing span length.
- The optimal HY combination varies. All optimal hybrids had HPS 70W in negative moment top flanges, and 50W for all webs. Bottom flanges had varying use of HPS 70W according to span length and use of bottom flange longitudinal stiffening.
High Performance Steel Cost Comparison Study

Edward Power, P.E.