ALTERNATIVE FRAMING STRATEGIES FOR STEEL I-GIRDER PHASE
CONSTRUCTION PROJECTS TO ALLEVIATE FIT-UP ISSUES

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ABSTRACT

This paper presents an investigation to determine the role and influence of the cross-frames between construction phases on closure pour region performances in steel I-girder bridges using phase construction. Use of phase construction can lead to fit-up issues and elevation differences between phases arising from sources such as construction errors and differential creep and shrinkage due to construction timing. To facilitate the construction and alleviate fit-up issues, an alternative cross-frame configuration between construction phases is investigated as well as the total elimination of the cross frame between construction phases.

A parametric study was conducted considering: girder spacing, deck thickness, girder depth, phase configuration and cross-frame spacing. Detailed 3D finite element models were created in order to perform the parametric study. The obtained results indicated that total elimination of cross-frames between construction phases increases the maximum live load distribution factor of girders up to 14%. The deck transverse moment in the closure region increased up to 67%. Use of horizontal struts between the phases provided performance similar to the use of full cross-frames and constitutes an attractive alternative. The results also indicated that the axial loads in the horizontal struts are almost similar to the corresponding component of the full cross-frame.

Key Words: Phase Construction, Cross Frame, Steel Bridges, Closure pour, parametric study, Finite element.
BACKGROUND

The term phase construction generally refers to any sequence of construction where a portion of the structure is being worked on while the remainder of the structure continues to remain in service. The concept of phase construction can be applied to the widening, complete structure replacement, and construction of new bridges. Generally, for steel I-girder bridges, two phases are connected by placing cross-frames and casting closure pour between the decks after completion of second phase.

Since the two phases are constructed independently, and at different times, there exists the possibility that they may not align properly when it comes time to connect them together. Significant differential elevation can result in major construction problems. The challenges are mainly related to fitting the cross-frames and splicing the transverse reinforcement in the closure pour region (1). This differential elevation can be caused by a number of factors, including: construction error, accumulated construction tolerance, time dependent effects such as creep and shrinkage, thermal or other meteorological effects, mismatched end restraint conditions and rotation of phases due to unequal loading or lack of symmetry (2). It should be noticed that the differential deflection due to different dead load conditions is assumed to be considered in camber calculations during the design phase.

When misalignment of phases does occur and regardless of the source, it must be accommodated. One of the major issues in accommodating misalignment is the presence of cross-frames between the two phases. In fact, even if the two phases are in perfect alignment, accessibility issues can create difficulties with regards to cross-frames between the two phases. When the deck elevations of the two phases do not match, a common practice is to force the phases into alignment. This practice can subject the deck and cross-frames in the closure pour region to additional stresses that are difficult to estimate. These locked in stresses can subject the girder webs in the closure pour regions to very high out of plane stresses resulting in fatigue cracking. Such practices may also jeopardize the service life of deck concrete (2).

THE INVESTIGATED METHODS TO ALLEVIATE FIT UP ISSUES

Elimination of cross-frames between construction phases may be considered as the most convenient method to alleviate the fit up issues, if it ensures acceptable performance of the bridge. There is some disagreement about the role of cross-frames in live-load distribution. Mertz notes that while the NCHRP Guide Specifications for Distribution of Loads for Highway Bridges has no provision regarding the presence of cross-frames, The AASHTO LRFD Specifications provides a provision to benefit bridges with cross-frames diaphragms (3). A study indicates that after the concrete has hardened, the stiffness of the deck is mainly responsible for distributing the wheel loads between the girders and the cross-frame contribution to load distribution is negligible (4). Other studies show that the presence of cross-frames after construction is even harmful due to fatigue cracking (5). As shown in this
study, the elimination of cross-frame, even in a single bay, may increase the strain in the concrete deck and consequently reduce the service life of the bridge. An alternative cross frame configuration may be able to alleviate the fit up issue, while still guaranteeing satisfactory performance.

The main objectives of this paper are: 1) to determine the role and influence of the cross-frames between construction phases on the performance of phase constructed steel I-girder bridges; 2) To identify an alternative cross-frame configuration to best achieve a smooth fit-up between construction phases with least construction difficulties. To this end, a parametric study was conducted to investigate the effects of both the cross-frame elimination and an alternative cross-frame configuration on bridge response.

Throughout the research, three different cross-frame configuration cases were considered, which are shown in FIGURE 1. The first considered the original bridge model and includes all cross-frames; during the discussions, this case is denoted WCF (With Cross-frames). The second case considered that the cross-frames in the closure pour bay are completely removed, denoted WOCF (Without Cross-frames). For WOCF case, stability consideration has to be taken into account when either phase includes less than three girders. The third, representing the suggested alternative configuration, considered the diagonal members of the original cross-frame configuration are eliminated. Since this alternative includes only the horizontal members, it is denoted WHCF (With Horizontal Cross-frame).

One possible installation processes for WHCF framing is to connect the phases through struts with single-bolt connections. Once construction of the phases is complete, additional bolts could be added; however, the additional holes would likely need to be field drilled, or at least reamed through. Small relative deflections would then be accommodated by bending of the struts. Alternatively, a connection detail could be devised that allows alignment without the need for field drilling.

FIGURE 1 Investigated framing strategies
BRIDGE MODELS AND FINITE-ELEMENT MODELING DESCRIPTION

To ensure realistic assumption about the model sizes and details, the structural models used in the parametric study correspond to actual phase construction projects constructed by the Florida Department of Transportation (FDOT). Two, single span, non-skewed (or slightly skewed) bridges – I-95 over SR-421 and SR-589 over Waters Avenue – were used to conduct the full parametric study. In addition, two other bridge models, SR-589 Bridge over Hillsborough Avenue and I-4 Bridge over SR-46, were analyzed to evaluate the effect of continuity and skew, respectively. The following table presents detailed information about the bridges.

TABLE 1 Geometrical Characteristics of Model Bridges

<table>
<thead>
<tr>
<th>Project</th>
<th>Span length</th>
<th>Ske w</th>
<th>Cross-frame spacing</th>
<th>Girder spacing</th>
<th>Thickness of the deck</th>
<th>Width of the deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-95 over SR-421</td>
<td>190 ft. (57.95m)</td>
<td>7°</td>
<td>22 ft. (6.71m)</td>
<td>12’ 6” (3.8m)</td>
<td>8.5 in (215.9 mm)</td>
<td>59’ 1” (18m)</td>
</tr>
<tr>
<td>SR-589 over Waters Avenue</td>
<td>250 ft. (57.95m)</td>
<td>-</td>
<td>25ft. (7.63m)</td>
<td>11’ 4”(3.46m) (phase1)</td>
<td>8.5in (215.9 mm)</td>
<td>71’ 1” (21.7m)</td>
</tr>
<tr>
<td>SR-589 over Hillsborough Ave.</td>
<td>Span 1: 95ft. (29 m)</td>
<td>-</td>
<td>23ft. (7m) (Average)</td>
<td>9’ 3” (2.82m) (phase1)</td>
<td>8.5in (215.9 mm)</td>
<td>71’ 1” (21.7m)</td>
</tr>
<tr>
<td></td>
<td>Span 2: 156ft. (47.58 m)</td>
<td>-</td>
<td></td>
<td>9’ 1 1/2 (2.17m) (phase2-left)</td>
<td>8.5in (215.9 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6’ 10 1/2 (2.1m) (phase2-right)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-4 over SR 46.</td>
<td>198 ft. (60.39m)</td>
<td>24°</td>
<td>25ft. (7.63m)</td>
<td>10’8” (3.25m) (phase1)</td>
<td>8.5in (215.9 mm)</td>
<td>138’ 1 1/4 (42.12m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11’ 2 7/8”(3.4m) (phase2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ANSYS 14.0 finite element software was used to perform the analyses. A full 3D model was used to represent the bridge system. The flanges, web, stiffeners, and deck were modeled with four-node shell elements (SHELL181), while the cross-frames are modeled with two-node 3D beam elements (BEAM188). Connectivity between the top flange and deck is accomplished by modeling them at the same elevation with coincident nodes and the actual eccentricity between the deck and top flange is handled in the element formulation. Linear elastic materials were assumed with the modulus of elasticity taken as 29000 ksi for steel and 3600 ksi for concrete. Poisson’s ratio was assumed 0.3 and 0.2 for steel and concrete respectively.

Loading

The focus of this study was on the change in bridge response under traffic loading for various structural configurations. As already described, in phase and widening construction approach, the phases are constructed separately and then become connected through closure.
pour and cross frames. Therefore, the phases already experienced the major dead load
displacements and the presence of dead load does not significantly affect the behavior of the
bridge using alternative framing strategies. Hence, the dead load was not considered in this
study. For the live loading, AASHTO LRFD suggests a design tandem load or a design truck
load both superimposed by a lane load. While the lane load is distributed uniformly and the
truck imposes larger load than the tandem, considering merely the truck load results in more
conservative assessment of change in the bridge response. Thus, a standard AASHTO HS-20
truck with two rear axles was used to simulate live loading on the bridge models. Six point
loads corresponding to the six wheels of a truck were considered to be applied to the model.
Each point load is distributed to the four nodes of a deck shell element using bi-linear shape
functions to calculate the portion of a point load to be applied to each node of the element.

To perform the study, it was necessary to find the combination of truck count and
positioning on the bridge deck creating the critical value of the desired response. For single-
span bridge models, mid-span was taken to be the point of interest for the response variables.
For the two-span bridge model, the longitudinal location of maximum response for all
response variables, and associated longitudinal positioning of load, was chosen to be the
locations for which maximum bending moment in the girders was observed, which was
typically near mid-span.

With the longitudinal location set, the next step was to determine the count and
positioning of trucks in the transverse direction. The available travel width, assuming 2 ft.
clear spacing from the face of each barrier to the nearest wheel load, was divided into regular
12 inch increments representing potential centerlines of a lane. A separate analysis was
performed with a single truck placed in each of the potential lane locations and all of the
results were saved. Superposition was used during post-processing to create scenarios
considering multiple loaded lanes. The post processing routine considered line every possible
combination that provided a spacing of at least 12 feet between loaded lanes. The results
obtained were multiplied by multiple presence factors as per the AASHTO LRFD (6), based
on the number of trucks in the particular combination.

**INVESTIGATED BRIDGE PERFORMANCES & VEHICLE LOAD OPTIMIZATION**

The deformed shapes obtained from the three models (WCF, WOCF and WHCF)
representing the bridge I-95 over SR-421 are shown in FIGURE 2. The view shown is
looking from the end of the structure. The applied load was a single truck longitudinally
positioned at mid-span and centered between girders G3 and G4 (middle of closure pour
bay). As shown in the figure, when the cross-frames are completely removed (FIGURE 2b),
the two phases tend to rotate independent of each other. This results in greater vertical
deflection of the girders immediately adjacent to the closure bay. Since this is a linear elastic
analysis of a simply supported structure, greater deflection is indicative of greater moment in
the deck and girders. Live load distribution factor and transverse moment, or stress in the
deck over the closure bay, were the two structural responses focused upon in this study. Note
that for the horizontal strut case (FIGURE 2c), the behavior is very similar to that of the fully
braced model. Complete removal of the frames (FIGURE 2b) allows the phases to rotate
independent of each other while the horizontal strut controls the rotation. This indicates the
potential of horizontal struts to be considered as an appropriate alternative framing method.

![Diagram](image)

**FIGURE 2** Bridge I-95 over SR421 deformed shapes in three different cases; a) WCF; b) WOCF; c) WHCF

The live load distribution factor can be obtained from the longitudinal stresses in the
bottom flanges. For each analysis, the live load distribution factor of a girder \(i\) was obtained
using EQ.

\[
DF_i = \sum_{l=1}^{L} \frac{\sigma_{il}}{(\sum_{j=1}^{N} \sigma_{lj})_l} \times m
\]

Where:

- \(DF_i\) = Distribution Factor for \(i^{th}\) girder,
- \(\sigma_{il}\) = Longitudinal stress at bottom flange of \(i^{th}\) girder due to \(l^{th}\) loaded lane,
- \(L\) = Number of loaded lanes,
- \(N\) = Number of girders,
- \(\sum_{j=1}^{N} \sigma_{lj}\) = Sum of longitudinal stress at bottom flange of all the girders due to \(l^{th}\) loaded lane,
- \(m\) = Multiple presence factor.

**FIGURE 3** presents the influence lines for the distribution factor of each girder in the
I-95 over SR421 Bridge. The influence lines correspond to the live load distribution factor of
each girder while the location of the truck is moved laterally across the bridge at mid-span.
Distribution factors for all different combinations trucks were obtained by superposition of
results for each individual truck represented in the influence lines. For each case considered
in the parametric study there were on average 150 possible combinations of truck positions
that were analyzed to get the maximum distribution factor corresponding to each girder.
The other response to be investigated was transverse deck stresses, or moment in the deck, over the closure bay. The interest is in evaluating the relative change due to the various framing configurations so either stress or moment would be an appropriate variable to consider. In the study, changes in deck stresses at different points over the closure pour bay for different framing strategies were evaluated. For each analysis, the transverse stresses were obtained at six locations on the concrete deck, as illustrated in FIGURE 4. These stresses were found to arise predominately due to flexural action with a negligible minimal membrane component such that at each location the value of stresses from the bottom side were simply the negative of the values obtained on the top side and in direct proportion to the transverse bending moment.

FIGURE 4 Position of the points where the stresses of deck obtained

FIGURE 5 presents the influence lines for transverse stress obtained for the I-95 over SR-421 Bridge. Similar to the procedure described for distribution factor, superposition was used to combine results from the individual analyses and generate the response due to any
combination of truck positioning. The multiple presence factor was applied corresponding to number of trucks for each combination. For each case considered in the parametric study, an average of 4000 combinations of truck positions were analyzed to get the maximum and minimum transverse stress.

**FIGURE 5** Influence lines of transverse deck stresses for Bridge I-95 over SR-421

Typical deck stress influence lines for the three cross-frame configurations are shown in FIGURE 6. The chart indicates an increase in the transverse moment and corresponding stresses over the closure pour bay due to the elimination of cross-frames between construction phases. While two traces of WCF and WHCF are shown almost coincident in the figure, for the WHCF case (with horizontal struts only), only very slight changes are observed.

**FIGURE 6** Influence Line of Transverse stress of the deck in three different cases for Bridge I-95 over SR-421
PARAMETRIC STUDY

A parametric study was conducted to comprehend the role that cross-frames in the closure pour region have on the performance of the structure. The specific responses examined were the live load distribution factors of the girders and transverse stresses in the deck. The five parameters investigated on each of the two base bridge models, I-95 over SR-421 and SR-589 over Waters Avenue, were: a) girder spacing, b) thickness of the deck, c) depth of the girders, d) number of girders in phases I and II, e) cross-frames spacing. During each analysis, the three previously mentioned cross-frame configuration cases (WCF, WOCF and WHCF) were considered. TABLE 2 presents the values of each parameter that was considered.

TABLE 2 Values of Parameters Investigated on Bridge Models.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>I95 over SR421</th>
<th>SR589 over Waters Avenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girder spacing&lt;sup&gt;1&lt;/sup&gt;</td>
<td>72in (1.83m), 90in (2.29m), 114in (2.90m), 132in (3.35m), 150in (3.81)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>50in-94in (1.27m-2.39m), 68in-112in (1.73m-2.84m), 92in-136in (2.34m-3.45m)&lt;sup&gt;1&lt;/sup&gt;, 110in-154in (2.79m-3.91m), 128in-172in (3.25m-4.37m)</td>
</tr>
<tr>
<td>Thickness of the deck</td>
<td>6.5in (165.1mm), 7.5in (190.5mm), 8.5in (215.9mm), 9.5in (241.3mm), 10.5in (266.7mm)</td>
<td>6.5in (165.1mm), 7.5in (190.5mm), 8.5in (215.9mm), 9.5in (241.3mm), 10.5in (266.7mm)</td>
</tr>
<tr>
<td>Depth of the girders&lt;sup&gt;1&lt;/sup&gt; 2</td>
<td>72in (1.83m), 78in (1.98m), 84in (2.13m), 90in (2.90m), 96in (2.44m)</td>
<td>84in-91in (2.13m-2.31m), 90in-97in (2.90m-2.46m), 96in-103in (2.44m-2.62m)&lt;sup&gt;1&lt;/sup&gt;, 102in-109in (2.59m-2.77m), 108in-115in (2.74m-2.92m)</td>
</tr>
<tr>
<td>Cross-frames spacing</td>
<td>17.1 ft. (5.22m), 19.25 ft. (5.87m), 22 ft&lt;sup&gt;1&lt;/sup&gt; (6.71m), 25.67 ft. (7.83m), 30.8 ft. (9.39m)</td>
<td>19.1 ft. (5.83m), 20.7 ft. (6.31m), 22.6 ft. (6.90m), 24.8 ft. (7.56m), 27.6 ft. (8.42m)</td>
</tr>
<tr>
<td>Number of girders in phases I and II&lt;sup&gt;1&lt;/sup&gt; 3</td>
<td>3-2&lt;sup&gt;1&lt;/sup&gt;, 3-3, 4-2, 4-3, 5-2, 5-3</td>
<td>2-3-2, 3-3-3, 4-3-4, 2-4-2&lt;sup&gt;1&lt;/sup&gt;, 2-3-3, 4-4-4, 2-5-2, 3-5-3, 4-5-4</td>
</tr>
</tbody>
</table>

<sup>1</sup> Base configuration

<sup>1</sup>(x-y), x: Amount of parameter in phase I, y: Amount of parameter in phase II

<sup>1</sup>(y-x-y), x: number of girders in existing bridge, y: number of girders of widening parts

TABLE 3 summarizes the results for the cases of cross-frames elimination (WOCF) and horizontal struts (WHCF) in comparison with the original bridge containing full bracing. The analysis results show that elimination of cross-frames between construction phases
increases the live load distribution factor of the girders immediately adjacent to the closure pour bay with the greatest increase occurring in the wider of the two phases. However, the girder displaying the maximum individual change is not necessarily the girder with the maximum value. Therefore, the values in TABLE 3 represent the change in the maximum value as obtained from all interior girders, not just the observed change in for any one individual girder. The maximum observed change in distribution factor was 13.5% due to elimination of cross frames between construction phases. Girder spacing and phase configuration (number of girders in each phase) are the most important parameters affecting the live load distribution factor. The remaining three parameters of deck thickness, girder depth, and cross-frame spacing have minimal effect on the results. For the alternative cross-frame configuration, which uses only horizontal struts, the results show less than a 2.5% increase in distribution factor.

### TABLE 3 Summarized Results of Parametric Study

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Model Bridge</th>
<th>DF* change (%)</th>
<th>Deck stress change – Bottom-Middle of the Bay (%)</th>
<th>Deck stress change – Top-Side of the Bay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>WOCF</td>
<td>WHCF</td>
<td>WOCF</td>
</tr>
<tr>
<td>Girder spacing</td>
<td>Bridge I95</td>
<td>5.2</td>
<td>0.8</td>
<td>50.7</td>
</tr>
<tr>
<td></td>
<td>Bridge SR589</td>
<td>13.5</td>
<td>2.3</td>
<td>46.3</td>
</tr>
<tr>
<td>Depth of girders</td>
<td>Bridge I95</td>
<td>4.4</td>
<td>0.2</td>
<td>46.5</td>
</tr>
<tr>
<td></td>
<td>Bridge SR589</td>
<td>11.0</td>
<td>1.2</td>
<td>45.9</td>
</tr>
<tr>
<td>Thickness of deck</td>
<td>Bridge I95</td>
<td>4.4</td>
<td>0.2</td>
<td>44.4</td>
</tr>
<tr>
<td></td>
<td>Bridge SR589</td>
<td>11.8</td>
<td>1.9</td>
<td>46.4</td>
</tr>
<tr>
<td>Cross frames spacing</td>
<td>Bridge I95</td>
<td>4.6</td>
<td>0.2</td>
<td>46.2</td>
</tr>
<tr>
<td></td>
<td>Bridge SR589</td>
<td>10.1</td>
<td>0.8</td>
<td>64.5</td>
</tr>
<tr>
<td>Number of girders in phases</td>
<td>Bridge I95</td>
<td>5.9</td>
<td>1.3</td>
<td>38.4</td>
</tr>
<tr>
<td></td>
<td>Bridge SR589</td>
<td>1.5</td>
<td>0.5</td>
<td>66.6</td>
</tr>
</tbody>
</table>
The deck transverse stress results shown in TABLE 3 indicate a significant increase (up to 67%) in stresses over the middle due to elimination of cross-frames while stresses near the sides, over the girders, actually decreased. The significant increases in deck stresses and distribution factor due to elimination of cross frames restrict the application of this alternative in widening projects where the Phase I is already designed without considering the required extra capacity. For the alternative configuration with horizontal struts only, the increase in deck stresses was limited to 4.4%. Therefore, using the horizontal strut alternative has a negligible effect on deck stresses. The observed deformation shapes of the deck in the two cases with and without cross-frames shown in FIGURE 2 suggest that the difference in results can be explained by considering the effective end restraint condition of the slab over the girders. Elimination of cross-frames allows rotation of the phases and effectively reduces the end restraint of slab resulting in greater stresses at middle and less stresses at the ends.

The parametric study results related to the alternative cross-frame (Horizontal Struts) indicate that it performs almost the same as the original bridge containing full cross frames. The increases in distribution factor and deck transverse stresses due to use of the alternative cross-frame are less than 5% for all values of the five investigated parameters, as shown in TABLE 3. This suggests that the Horizontal Struts option is an appropriate alternative in phase and widening projects that can facilitate construction with nearly the same performance.

Parameters Combinations

After completing the study of five parameters independently, a complementary study was conducted considering the possible compounding of effects due to the combination of parameters. As was concluded in the individual studies, girder spacing is the most important parameter of the five investigated parameters. To consider the worst combination of parameters, the largest girder spacing in combination with the worst case of the other four parameters for both model bridges, were considered. Although these combinations may not represent valid scenarios, such as large girder spacing combined with a thin deck, it allowed for a cursory check for potential interaction effects.

TABLE 4 summarizes the results from the parameter combination investigation. From the table it can be seen that the single largest increase in distribution factor was observed for the original configuration of I-95 Bridge. The combination of parameters, even these worst case scenarios, does not create a more severe condition.
TABLE 4 Summary Table of Parameters Combinations Result – WOCF

<table>
<thead>
<tr>
<th>Parameter combination</th>
<th>Model bridge</th>
<th>Distribution Factor max increase (%)</th>
<th>Deck stress max increase at middle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original bridge</td>
<td>Bridge SR589</td>
<td>5.2</td>
<td>42.3</td>
</tr>
<tr>
<td></td>
<td>Bridge I95</td>
<td>13.5</td>
<td>35.5</td>
</tr>
<tr>
<td>Max girder spacing+ max depth of girders</td>
<td>Bridge SR589</td>
<td>9.0</td>
<td>32.4</td>
</tr>
<tr>
<td></td>
<td>Bridge I95</td>
<td>7.3</td>
<td>29.6</td>
</tr>
<tr>
<td>Max girder spacing+ max deck thickness</td>
<td>Bridge SR589</td>
<td>8.5</td>
<td>38.3</td>
</tr>
<tr>
<td></td>
<td>Bridge I95</td>
<td>4.5</td>
<td>46.5</td>
</tr>
<tr>
<td>Max girder spacing+ max cross-frame spacing</td>
<td>Bridge SR589</td>
<td>10.2</td>
<td>26.8</td>
</tr>
<tr>
<td></td>
<td>Bridge I95</td>
<td>7.4</td>
<td>32.2</td>
</tr>
<tr>
<td>Max girder spacing+ max number of girders in phases</td>
<td>Bridge SR589</td>
<td>4.1</td>
<td>42.0</td>
</tr>
<tr>
<td></td>
<td>Bridge I95</td>
<td>5.2</td>
<td>40.6</td>
</tr>
</tbody>
</table>

Axial load in horizontal cross-frame members

As concluded from the results of the parametric study, the cross-frame configuration consisting of horizontal struts performs similar to the original bridge with full cross-frames. While the top chord does not significantly contribute due to presence of bridge deck, it might have an important role in constructability. One concern with the detail is the level of axial load in the bottom chord. An investigation was performed to find the change in axial load in the horizontal struts compared to the original configuration. To this end, the cases described in the previous section, the original bridge model and four parameter combination cases, were revisited and the resulting axial load in the bottom chord was obtained. FIGURE 7 shows the axial load in the bottom chord located in at mid-span for two cases full frame (WCF) and horizontal strut (WHCF). For each single model, different possible combinations of the number and position of trucks were considered to find the maximum tensile and compressive axial load. As illustrated in FIGURE 7 for compression load, which is important due to potential buckling, the change is very low (less than 6%). For tensile load, many cases actually displayed a decrease in force. These findings are discussed below.

Maximum compressive axial load occurs when trucks are located at each side of the structure. In this case, shear load is transferred through diagonal members in the outer bays and down to the bottom chords where it is then transmitted bay to bay. Therefore, the configuration of the closure frame does not affect the compressive load in the bottom chord. Maximum tensile axial load occurs in the case when the trucks are over the closure bay itself. In this case, shear loads would be transferred mainly through diagonal members of the frame within the closure bay. Since there are no diagonal members, less shear load is transferred and consequently less tensile load is imposed on the bottom chord of the bay.

FIGURE 7 Axial force at bottom chord over closure bay in two original and alternative cross-frame cases
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for Bridge SR-589 over Waters Avenue

EFFECT OF CONTINUITY AND SKEW

Two additional models were analyzed to evaluate the effect of continuity and skew on the performances of the bridges using alternative framing strategies.

The SR-589 Bridge over Hillsborough Avenue, a two-span continuous bridge was analyzed to evaluate the effect of continuity. Locating the location of maximum response and the critical truck positioning required to obtain the response was obtained by moving a line of trucks along the bridge and monitoring the stress along the bottom flanges to identify the load positioning creating the absolute maximum stress along the length. The trucks were laterally spaced at 12 ft. and centered on the bridge. The critical positions obtained from this study were then used in the subsequent analyses. For distribution factor, the maximum observed increase for the case of cross-frame removal was 3.2% compared to the original structure with full cross-frames and the maximum increase was only 0.1% for the case using horizontal struts. Considering transverse stress at middle of closure bay, the maximum observed increase for the case of cross-frame removal was 53.5% compared to the original structure with full cross-frames and the maximum increase was 1.74% for the case using horizontal struts.

The I-4 Bridge over SR46 was a single span bridge with a support skew of 24 degrees. This structure was used to evaluate implementing of the alternative framing strategies on bridges with skewed supports. The same modeling and analysis techniques were used for the skewed structure except the transverse loading locations follow the skew angle across the bridge. The obtained result showed a maximum 3.6% increase in distribution factor for the case of cross-frame removal, and only 0.2% increase for the case using horizontal struts, compared to the original structure with full cross-frames. For transverse stress at middle of the deck over the closure bay, there was an observed maximum 20.7% increase for the case
of cross-frame removal, and 0.1% increase for the case using horizontal struts, compared to
the original structure with full cross-frames.

For both analyzed models, the maximum observed increases in both distribution
factor and transverse deck stress were slightly lower than the values obtained from the
parametric study. Therefore, implementing alternative cross-frames in skewed or multi-span
bridges leads to changes in performance of the bridge in the same range obtained in
parametric study. This result was anticipated since both skew and continuity have minimal
effect of the distribution factor and transverse deck stress near mid-span.

SUMMARY AND CONCLUSION

This research investigated two alternative cross-frame configurations to be used between
construction phases to alleviate fit-up issues in phase construction steel I-girder bridges. The
first alternative was complete elimination of cross-frames between the phases and the second
was omission of the diagonal members leaving only the horizontal struts.

A parametric study was conducted to evaluate the alternatives. Two FDOT projects
were used as the source models in the parametric study. The five parameters considered
were: a) girder spacing, b) thickness of the deck, c) depth of the girders, d) number of girders
in Phases I and II, and e) cross-frame spacing. The major responses investigated were the live
load distribution factor and the transverse deck stresses to observe the influence of alternative
cross-frames. The following conclusions could be made from the parametric study:

- For elimination of cross frames between construction phases, the maximum observed
change in distribution factor was 13.5%. Girder spacing and phase configuration
(number of girders in each phase) were the most important parameters affecting the
live load distribution factor. For the alternative cross-frame configuration, which uses
only horizontal struts, the results show less than a 4.4% increase in distribution factor.
- The results indicate a significant increase (up to 67%) in stresses over the middle of
the closure region due to elimination of cross-frames while stresses near the sides,
over the girders, decreased. These changes are due to the effective end restraint
flexibility at the side of the closure bay. Elimination of cross-frames causes a more
flexible condition than for the case with full frames. For the alternative configuration
with horizontal strut only, the change in deck stresses is limited to 2.5%. Therefore
using the horizontal strut alternative has a negligible effect on deck stresses.
- Investigating parameter combinations showed that the combined effect of parameters
has only a slight compounding effect.
- The investigation on the force in horizontal struts indicates that the axial load is
similar for both the full frame and horizontal strut only cases. For loading patterns
that create compression load, the force in the strut is nearly identical for both cases
while loading patterns resulting in tension actually create lower forces.

Two additional analyses were also performed in order to evaluate the influence of
skew and continuity. The results show that the changes in the distribution factor and deck
stresses are within the range obtained in the parametric study, which considered non-skew
single span structures.

From the results obtained it was generally concluded that the alternative cross-frame
configuration which uses only horizontal struts results in similar performance of the bridge
using full cross-frames, while better facilitating the use of phase construction for steel I-
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girder bridges. Thus it suggests that the use of horizontal struts is an appropriate alternative in phase and widening projects.

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