INDEPENDENT STRUCTURAL ANALYSIS FOR THE CORPUS CHRISTI NEW HARBOR BRIDGE PROJECT

Legacy Contract No. 88-0SDP5002 PS 10781

TECHNICAL MEMORANDUM

ERECTION LOADING

DOCUMENT NUMBER: TM1005

08/12/2022

Revision 0

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ORIGINATOR: Michael W. Smart, PE

Revision History

Revision	Date	Description
0	08/12/2022	Original Issue

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1. Introduction

This technical memorandum discusses a finding of the Independent Structural Analysis (ISA) concerning erection loadings, which take place during the construction of the Corpus Christi New Harbor Bridge, cable-stay main bridge. The current design does not meet the project requirements.

2. References

The following documents are referenced in this memorandum.

1. American Association of State Highway and Transportation Officials (AASHTO), "LRFD Bridge Design Specifications," 7th Edition, 2014 with 2015 Interim Revisions. ["AASHTO LRFD"]
2. "277609-NHB-PLN-MSUPER_A-0" ["Design Drawings" or "Current Design"]
3. "277609-NHB-REP-MWER-02: US181 Harbor Bridge Replacement Project: Wind Engineering Report," Revision 2, May 4, 2021 (First received by ISA Team June 7, 2022) ["Wind Report"]
4. "277609-NHB-MAN-MEM-01_01" ["Erection Manual"]
5. Independent Structural Analysis for the Corpus Christi New Harbor Bridge Project, Document Number: 1010 dated January 8, 2021 ["ISA Phase 1 Report"]
6. Independent Structural Analysis for the Corpus Christi New Harbor Bridge Project, Document Number: 2010 dated April 23, 2022 ["ISA Phase 2 Part 1 Report"]
7. Meeting Notes of 26 May 2022 meeting in Austin, TX between TxDOT, FDLLC, HNTB, ARUP-CFC, and IBT ["May 2022 Meeting"]
8. Meeting Notes and Presentations of 10 June 2022 meeting in Austin, TX between TxDOT, FDLLC, HNTB, ARUP-CFC, and IBT ["June 2022 Meeting"]

3. Background

AASHTO LRFD §5.14.2.3.1 requires that the partially built permanent structure shall be checked during construction with load combinations specified in Section 3. The ISA team has previously identified findings related to construction loadings, which have been presented in the ISA Phase 1 Report and the ISA Phase 2 Part 1 Report. The issues identified previously were related to the Service limit state requirements of AASHTO LRFD and to constructability. These findings have yet to be addressed by the Developer, and they have not been addressed by the change in wind input recently observed in the Rev. 2 Wind Report.

The revised Wind Report (Rev. 2) received June 7th, 2022 now provides more critical wind load cases during construction. The memorandum focuses on a Strength limit state finding that relates to the partially built structure subject to a design wind event during construction.

4. Summary of Finding

The current design of the bottom slab of the back span superstructure has insufficient post-tensioning to provide the flexural resistance necessary to withstand positive bending (tension at the bottom) caused by wind and other effects at a certain stage of construction. The state of the structure considered is shown in Figure 1 below. The loading considered occurs after the first-stage stressing of the Stay 12 pair of stays, just before the superstructure reaches the back span piers 1N and 1S.

The critical sections are located at the beginning of NB and SB segments 32. These segments are the first ones erected after the temporary bent has been connected to the deck.

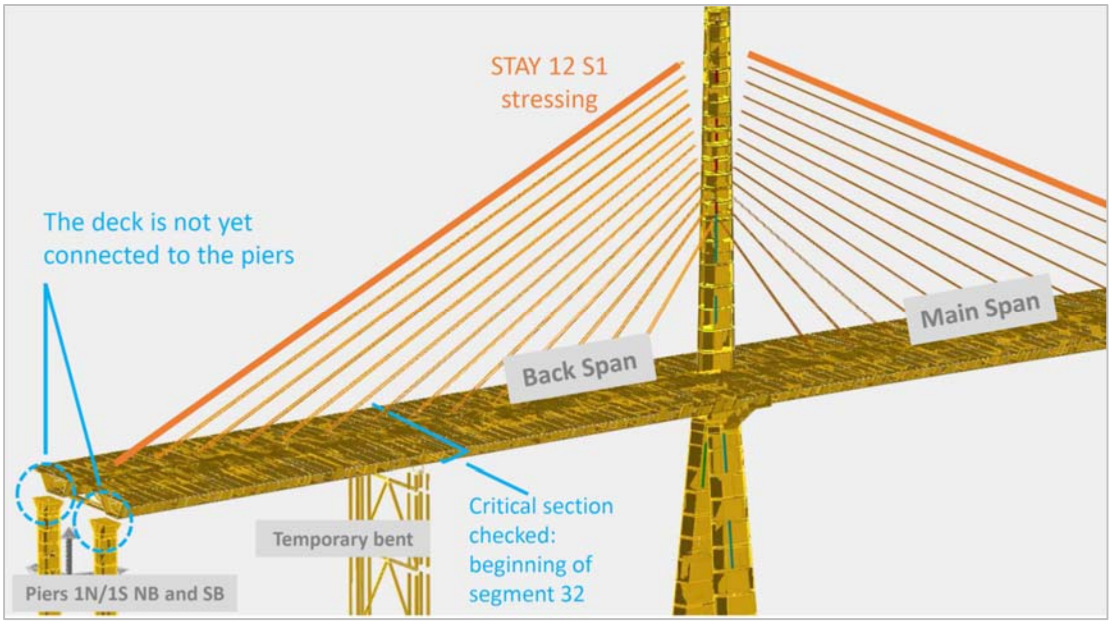

Figure 1: Stage 12 S1 Stressing Showing Erection Phase and Critical Section Investigated

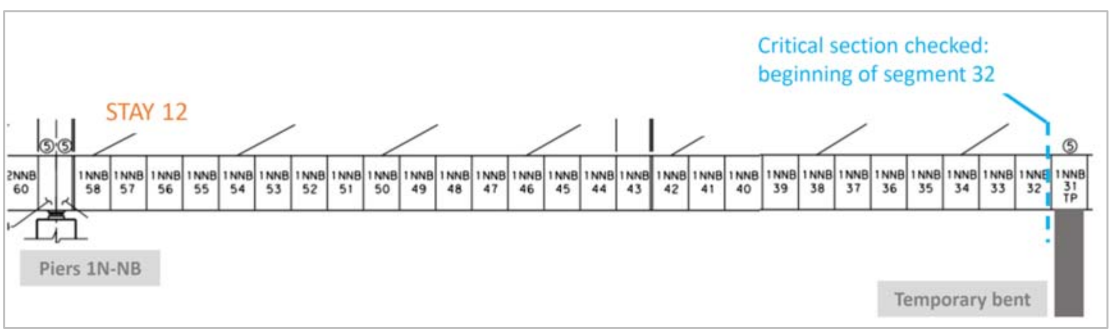

Figure 2: Elevation View Showing Critical Section Investigated (NB shown – SB similar)

At this phase of construction, these segments experience large positive bending moment (tension at the bottom) due to the first stage stressing and due to the factored wind demand for that configuration, identified as BLWTL's Wind Case 2 (originally named "Construction Case #2, free cantilever, before arrival to the back span pier (temporary pier still active), for West wind direction") with only five post-tensioning bars located in the bottom slab to provide resistance.

The governing combination is Strength III with the minimum required load factor of 1.25 applied to wind during construction, with either 1.25 or 0.90 applied to DC, EL, and CR/SH, and 1.00 applied to secondary post-tensioning (AASHTO LRFD §3.4.2.1), so the ISA considered the following two combinations:

Strength III-A: 1.25 DC + 1.25 EL + 1.00 PS2 + 1.25 CR/SH + 1.25 WS

Strength III-B: 0.90 DC + 0.90 EL + 1.00 PS2 + 0.90 CR/SH + 1.25 WS

Where:

- DC: Dead load of the structure and of the erection equipment
- EL: Stay load
- CR/SH: Creep and shrinkage
- WS: Wind on the structure for BLWTL's Wind Case 2

Demands for individual load effects, the Strength III-A and Strength III-B load combinations, and capacity interaction plots are presented in Appendix A. Table 1 below presents a summary of demand from these load combinations along with corresponding demand-to-capacity (D/C) ratios.

Table 1: Demand and D/C Ratios for Segments 32 NB/SB

	Deck SB/NB	FX (kips)	MY (kip-ft)	MZ (kip-ft)	D/C
Strength III-A	**SB**	-10,548	-43,744	136,277	**2.16**
Strength III-B	**SB**	-7,146	-32,070	122,071	**2.55**
Strength III-A	**NB**	-12,656	69,409	126,006	**1.90**
Strength III-B	**NB**	-8,698	49,205	115,585	**2.37**

Where:

- FX: axial demand in the deck, negative in compression
- MY: transverse bending moment
- MZ: longitudinal bending moment (positive for tension at the bottom of the section)

Appendix B presents similar computations using available demands provided in the Erection Manual by others. D/C ratios using these demands ranged from 1.74 – 2.20.

5. Conclusion

The ISA has identified insufficient post-tensioning in the bottom slab of sections in the back span superstructure over 121' due to wind during construction. Flexural demand exceeds capacity at this location subject to Strength limit state loadings. The applicable requirements are AASHTO LRFD §1.3.2.1, §5.14.2.3.1, §3.4.2.1, and §5.7.3.2. Mitigation measures to address this finding were not documented in the Erection Manual nor in any of the other Current Design documents.

Other findings related to construction loadings caused by excessive torsional loadings considering shear lag have been presented previously in the following reports and meetings:

- ISA Phase 1 Report
- ISA Phase 2 Part 1 Report
- May 2022 Meeting
- June 2022 Meeting

The findings related to construction presented previously have not yet been addressed by the Developer.

Appendix A. Calculations Considering ISA Computed Loadings

A.1 Section Investigated

The NB/SB section investigated is at the beginning of segment 32, which is located at station 1085+78.94 (at x=-1135 ft, where x = 0 at midspan of the main span). This is the most critical section, but the problem extends over 121 ft from stations 1084+57 to 1085+78. The cross-section for the critical section with its post-tensioning are as follows:

Table 2: Post-Tensioning Bars and Tendons

Position: top/bottom	Cable/Bar name	Nb	size SB	size NB
top	BT5	2	Tendon 25 strands 0.6''	Tendon 25 strands 0.6''
top	BT8	2	Tendon 27 strands 0.6''	Tendon 27 strands 0.6''
top	R4	2	PT bar 1.38 in diameter	PT bar 1.75 in diameter
top	R5	2	PT bar 1.75 in diameter	PT bar 1.75 in diameter
top	R6	2	PT bar 1.75 in diameter	PT bar 1.75 in diameter
top	R7	2	PT bar 1.75 in diameter	PT bar 1.75 in diameter
top	R8	2	PT bar 1.75 in diameter	PT bar 1.75 in diameter
top	R9	2	PT bar 1.75 in diameter	PT bar 1.75 in diameter
top	R10	2	PT bar 1.38 in diameter	PT bar 1.25 in diameter
top	R11	2	PT bar 1.38 in diameter	PT bar 1.25 in diameter
bottom	R1	1	PT bar 1.38 in diameter	PT bar 1.25 in diameter
bottom	R2	2	PT bar 1.38 in diameter	PT bar 1.25 in diameter
bottom	R3	2	PT bar 1.38 in diameter	PT bar 1.25 in diameter

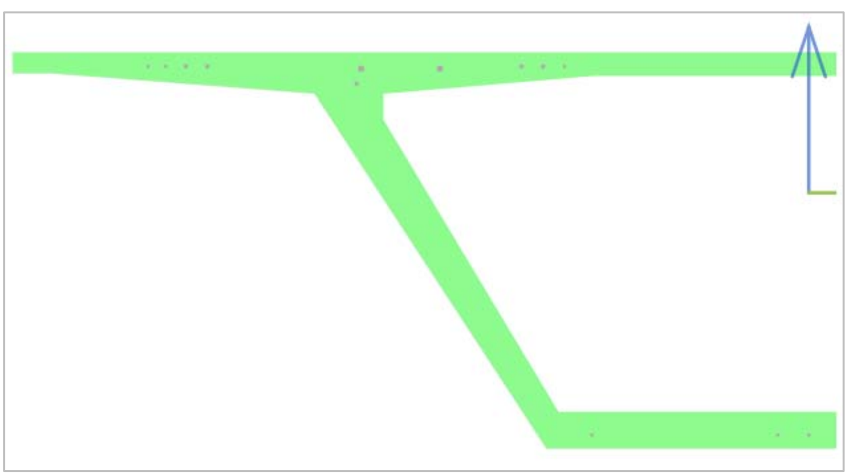

Figure 3: SB Section Investigated Showing PT Bars and Tendons

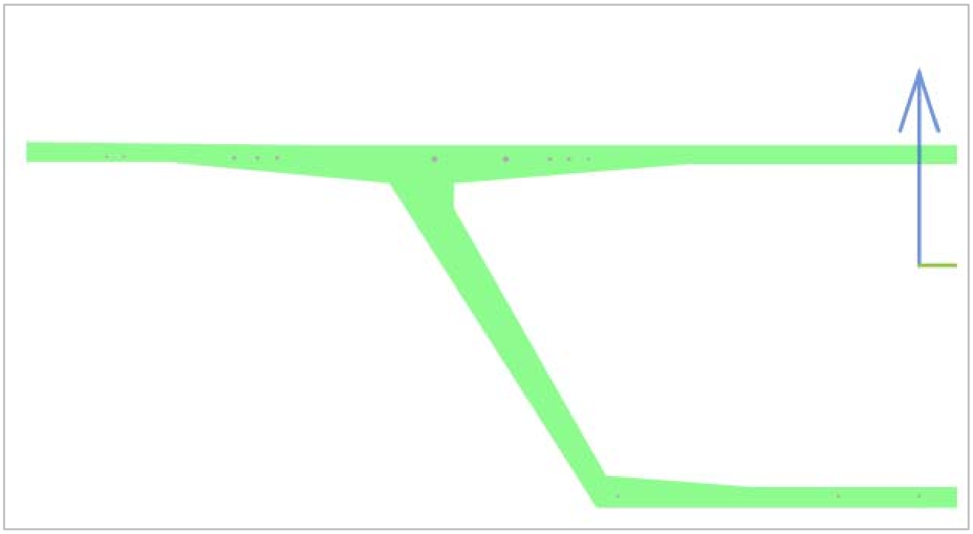

Figure 4: NB Section Investigated Showing PT Bars and Tendons

A.2 Load Combination - Demand

The governing combination is Strength III:

Strength III-A: 1.25 DC+ 1.25 EL + 1.00 PS2 + 1.25 CR/SH + 1.25 WS

Strength III-B: 0.90 DC+ 0.90 EL + 1.00 PS2 + 0.90 CR/SH + 1.25 WS

Unfactored demands are presented below along with the factored combinations Strength III-A and Strength III-B. The stage total demand (unfactored), after Stay 12 stage 1 stressing is also provided for information. DC demand includes the sum of DC-structure (self-weight) and DC-erection (all erection loads).

SB:

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	Comb A	Comb B
Stage total demand	-16,870	-36,821	60,462		
DC+EL	-9,079	-44,884	42,430	**1.25**	**0.90**
PS1	-7,432	11,656	21,874	**0.00**	**0.00**
PS2	282	-15,124	-2,001	**1.00**	**1.00**
CRSH	-641	11,531	-1,840	**1.25**	**0.90**
WS (governing case)	1,056	10,457	70,033	**1.25**	**1.25**

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	D/C
Strength III-A	**-10,548**	**-43,744**	**136,277**	**2.16**
Strength III-B	**-7,146**	**-32,070**	**122,071**	**2.55**

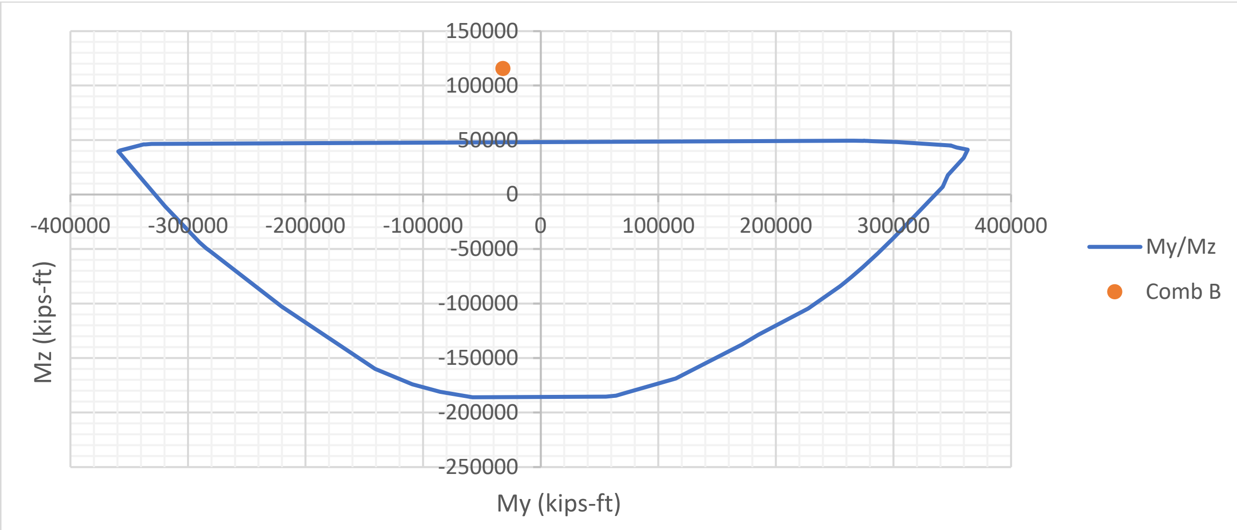

Figure 5: SB Interaction (Fx-My-Mz) Diagram for Governing Case (Fx=-7146 kips)

NB:

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	Comb A	Comb B
Stage total demand	-18,398	58,439	50,137		
DC+EL	-10,828	72,917	29,524	**1.25**	**0.90**
PS1	-7,295	-16,840	21,764	**0.00**	**0.00**
PS2	205	17,553	-1,401	**1.00**	**1.00**
CRSH	-480	-15,191	250	**1.25**	**0.90**
WS (governing case)	1,019	-16,242	72,152	**1.25**	**1.25**

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	D/C
Strength III-A	**-12,656**	**69,409**	**126,006**	**1.90**
Strength III-B	**-8,698**	**49,205**	**115,585**	**2.37**

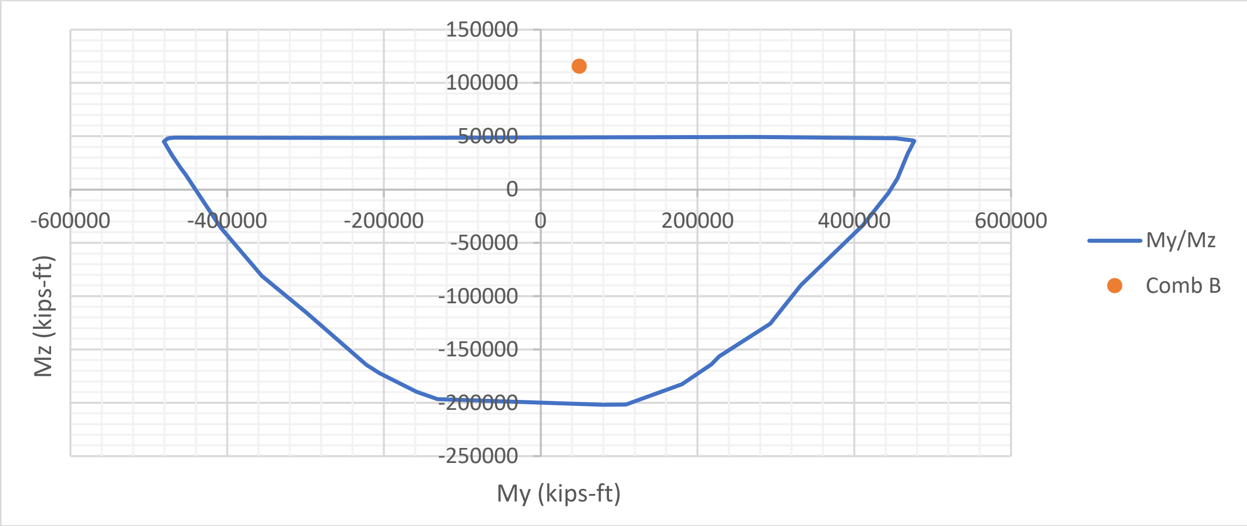

Figure 6: NB Interaction (Fx-My-Mz) Diagram for Governing Case (Fx=-8698 kips)

Where:

- FX: axial demand in the deck, negative in compression
- MY: transverse bending moment
- MZ: longitudinal bending moment, positive for sagging
- DC: Dead load of the structure and of the erection equipment
- EL: Stay load
- PS1: Primary PT effect, excluded from external loads
- PS2: Secondary PT effect
- CR/SH: Creep and shrinkage
- WS: Wind on the structure for BLWTL's Wind Case 2

Appendix B. Calculations Considering Erection Manual Loadings

B.1 Erection Manual Demand

The intent of this section is to investigate the same section as the one presented in Appendix A, considering the demand that is provided in the Erection Manual.

The construction demand is extracted from the Erection Manual plots for the stage under consideration (Stage C12_Stay 12 S1- Sheet 104 of 171).

This demand excludes primary PT, and it does not provide the breakdown between DC, EL, PS2, and CR/SH. Therefore, the Strength combination III cannot be calculated directly from the plots that are provided. Instead, the ISA used selected information from its analysis, so that it could apply load factors and calculate total demand consistently. Figures 7, 8, and 9 below shows axial load, longitudinal bending moment, and transverse bending moment demand for the NB and SB box girders from the Erection Manual. In the tabulation for SB, Figure 10 below shows the demand obtained from the Erection Manual along with ISA-computed primary PT and overall demand at this stage of construction. It also shows how total demand exceeds capacity with a biaxial interaction diagram (Fx-My-Mz). Figure 11 shows the same for NB.

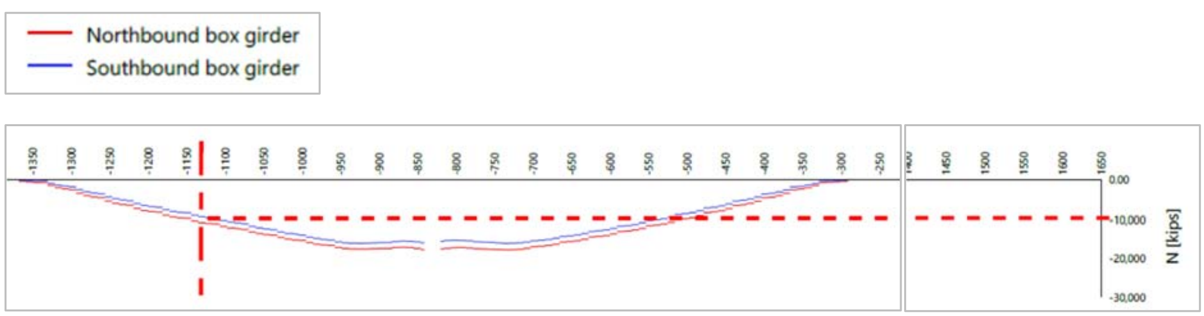

Figure 7: Erection Manual Axial Demand in NB/SB Decks for Stage Stay_12 S1

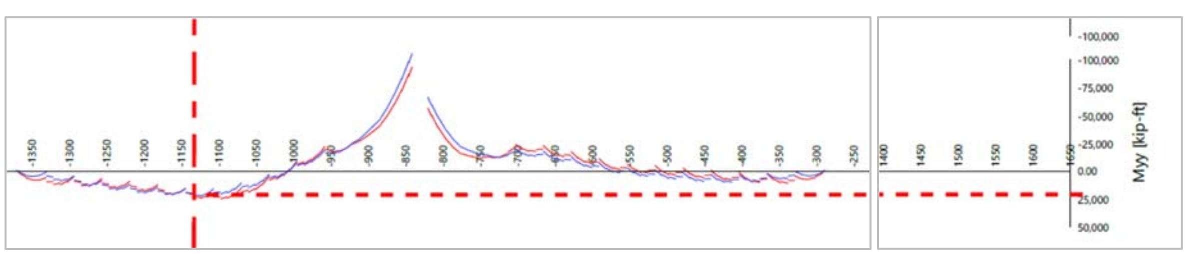

Figure 8: Erection Manual Longitudinal Bending Demand in NB/SB Decks for Stage Stay_12 S1

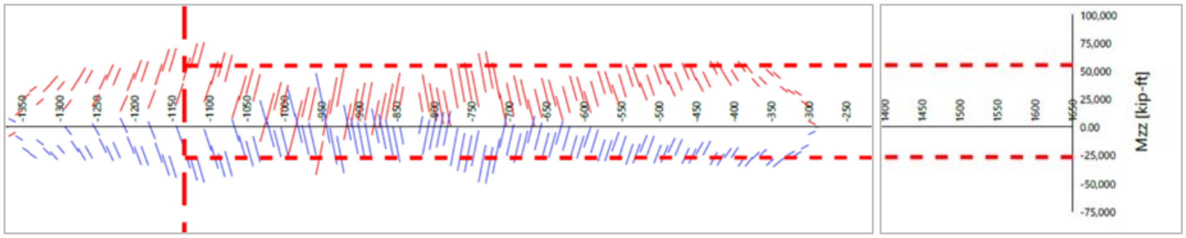

Figure 9: Erection Manual Transverse Bending Demand in NB/SB Decks for Stage Stay_12 S1

SB:

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	γ_A	γ_B
Stage Dmd_{ISA}	-16,870	-36,821	60,462		
Stage $Dmd_{Erect.Manual\ w/o\ PS1}$	-9,900	-28,000	21,000		
$PS1_{ISA}$	-7,432	11,656	21,874		
Stage $Dmd_{Erect.Manual\ w/o\ PS1}$+$PS1_{ISA}$-Stage Dmd_{ISA}	**-462**	**20,477**	**-17,589**	**1.25**	**0.9**

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	D/C
Strength III-A Dmd_{ISA}	-10,548	-43,744	136,277	**2.16**
Strength III-B Dmd_{ISA}	-7,146	-32,070	122,071	**2.55**
Strength III-A $Dmd_{Erection\ Manual}$	**-11,126**	**-18,148**	**114,291**	**1.74**
Strength III-B $Dmd_{Erection\ Manual}$	**-7,562**	**-13,641**	**106,241**	**2.13**

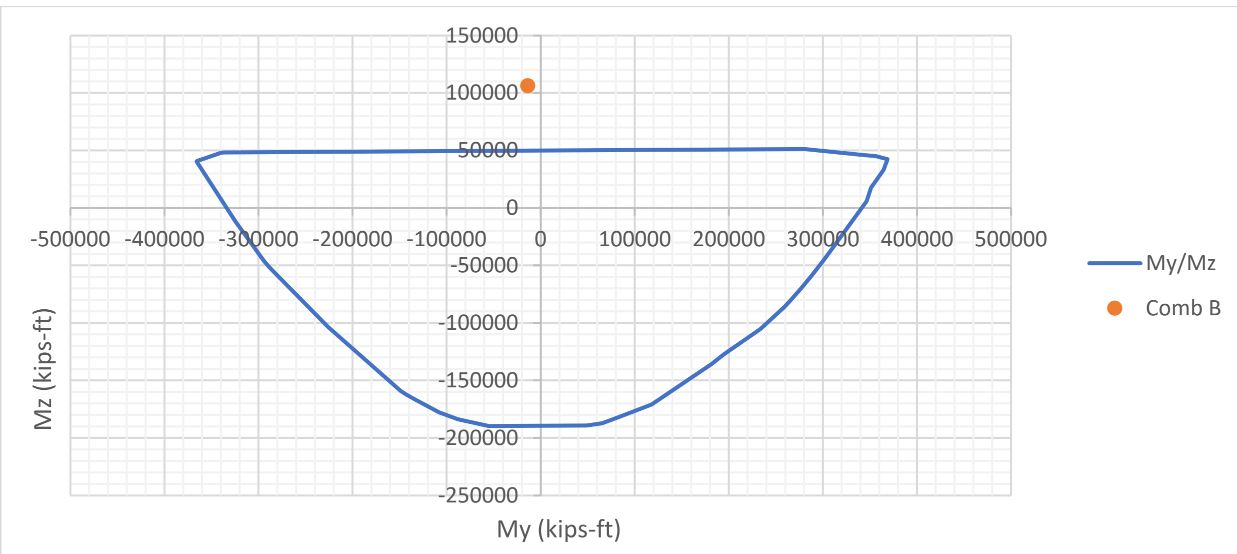

Figure 10: SB Interaction (Fx-My-Mz) Diagram for Governing Case (Fx = -7562 kips) with Demand from Erection Manual

NB:

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	γ_A	γ_B
Stage Dmd_{ISA}	-18,398	58,439	50,137		
Stage $Dmd_{Erect.Manual\ w/o\ PS1}$	-11,500	55,000	23,000		
$PS1_{ISA}$	-7,295	-16,840	21,764		
Stage $Dmd_{Erect.Manual\ w/o\ PS1}$+$PS1_{ISA}$-Stage Dmd_{ISA}	**-397**	**-20,279**	**-5,373**	**1.25**	**0.9**

	FX (kips)	MY (kip-ft)	MZ (kip-ft)	D/C
Strength III-A Dmd_{ISA}	-12,656	69,409	126,006	**1.90**
Strength III-B Dmd_{ISA}	-8,698	49,205	115,585	**2.37**
Strength III-A $Dmd_{Erection\ Manual}$	**-13,152**	**44,060**	**119,290**	**1.75**
Strength III-B $Dmd_{Erection\ Manual}$	**-9,055**	**30,953**	**110,750**	**2.20**

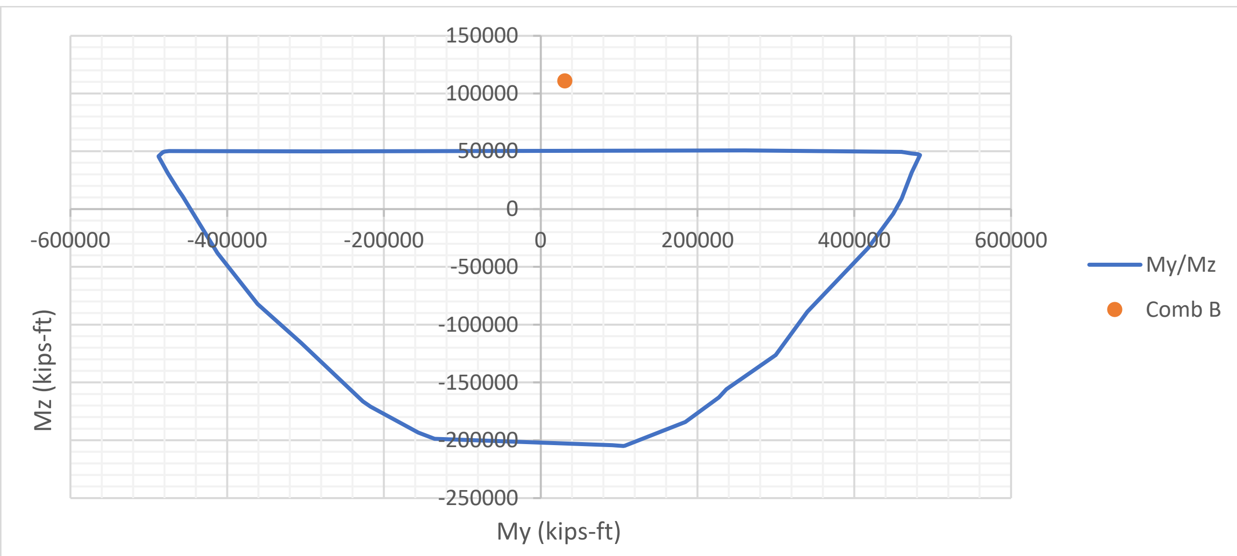

Figure 11: NB Interaction (Fx-My-Mz) Diagram for Governing Case (Fx=-9055 kips) with Demand from Erection Manual