COMPARATIVE BRIDGE DESIGNS USING NORMALWEIGHT AND LIGHTWEIGHT CONCRETE

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ABSTRACT

A range of designs using normalweight and lightweight concrete for prestressed concrete bridge girders was performed using commercial bridge design software. Combinations of concrete types considered include a normalweight deck on normalweight girders, a lightweight deck on lightweight girders, a lightweight deck on normalweight girders, and a normalweight deck on lightweight girders. The effect of using lightweight concrete in barrier rails was examined briefly. Results of the designs are compared to demonstrate the differences in span capacity, number of strands required, required release strength, and camber. The first set of designs studies a wide bridge cross-section that allows comparison of maximum spans for different girder spacings, optimizing the use of a girder cross-section currently used in the southeast. The second set of designs considers a narrower bridge with a fixed span configuration that represents a typical overpass.

Keywords: Lightweight concrete, structural efficiency, maximum span, release strength, camber, barrier rail

INTRODUCTION

It is easily understood that the use of lightweight concrete (LWC) for bridge superstructure elements will provide improved structural efficiency over normalweight concrete (NWC). However, the quantity of the improvement has not been investigated using current design specifications. In this paper, the authors report the results of a comparative study of two bridge typical sections using prestressed concrete bridge girders that was performed using commercial bridge design software.

The following combinations of concrete types are considered in the study:

- NWC girder and NWC deck (NG + ND)
- LWC girder and NWC deck (LG + ND)
- NWC girder and LWC deck (NG + LD)
- LWC girder and LWC deck (LG + LD)

Design results are compared to demonstrate the differences in span capacity, number of strands required, required release strength and camber. The deck concrete type is also used for barrier rails and concrete diaphragms in each design combination.

Two bridge typical sections are considered in the comparisons. The first is a relatively wide bridge cross-section that is used to compare the maximum spans for different girder spacings, representing a long multi-span bridge where span lengths can be optimized. The second typical section represents a highway overpass, with a narrow bridge and a fixed span of 150 ft. For all designs considered in this study, the spans were simply supported.

The effect of using lightweight concrete in barrier rails is briefly examined.

The reader is referred to other papers for a discussion of the characteristics and properties of lightweight aggregates and lightweight concrete[1-3]. One of the authors has performed similar design comparisons several years ago[3, 4].

DESIGN METHODS, ASSUMPTIONS AND PARAMETERS

The approach and parameters used in the designs are presented in this section.

DESIGN METHODS

Designs are performed using the provisions of the current *AASHTO LRFD Bridge Design Specifications*[5]. Both service and strength limit state requirements were checked, but designs were governed in all cases by the service limit state. The concrete limiting stresses used in the design are shown in Table 1. Note: units shown in Table 1 are psi, rather than ksi used in the AASHTO LRFD Specifications.

Table 1 Limiting stresses used in design (psi)

Tensile stress at release	200 psi
Compressive stress at release	$0.6\ f'_{ci}$
Tensile stress at service limit state	$6\sqrt{f'_c}$
Compression at service limit state	$0.6\ f'_c$

Design calculations were performed using Version 3.13 of PSBeam from Eriksson Technologies, Inc. The graphic images of typical sections used in this paper were taken from program output. The load table generation feature of the program was used to obtain data for figures showing values of interest for a range of spans.

All spans were designed as simply supported. The girder length was taken as 1 ft greater than the design span, making the center of bearing 0.5 ft from each end of the girder.

Prestress losses were computed using the detailed method of the LRFD Specifications. No modifications were made to the procedure for LWC, except for the modulus of elasticity, which affected the elastic shortening loss. LRFD Equation 5.4.2.4-1, which includes a term for the density of concrete, was used to compute the modulus of elasticity using the densities listed in Table 2.

Erection and final cambers are computed using PCI deflection multipliers, but only the multipliers for erection are used. It is assumed that cambers will not significantly change after the composite connection between the deck and girder is achieved.

DESIGN LOADS

The standard loads specified in the AASHTO LRFD Specifications were used.

Other design parameters and dead loads were based on NCDOT design standards[6]:

- SIP steel forms (3 psf) with additional dead load for 1 in. of concrete in the flutes
- 2 in. deep haunch above flanges used for dead load only
- A 0.5 in. non-structural wearing surface
- A 30 psf allowance for future wearing surface
- Concrete diaphragms located at 3rd points of the span

The NCDOT standard barrier rail load of 406 plf was used for NWC. The weight of a LWC barrier rail was determined using the ratio of concrete densities, resulting in a load of 325 plf. The NCDOT barrier load distribution rules were used, which distribute barrier loads to all girders or the 3 outer girders on each side, depending on deck width and number of girders.

For the design comparisons, the barrier rails and concrete diaphragms are assumed to be the same type of concrete as the deck.

MATERIAL PROPERTIES

Typical concrete properties are used for the comparative designs, as shown in Table 2.

Table 2 Concrete Properties for Comparative Designs

	f'_{ci} (ksi)	f'_c (ksi)	Density, w_c (kcf)
Deck – NWC	–	4.5	0.145
Deck – LWC	–	4.5	0.120
Girder – NWC	7.0	8.5	0.1485
Girder – LWC	7.0	8.5	0.125

The LWC densities used represent typical values for the equilibrium density of sand lightweight concrete and include an allowance of 0.005 kcf for reinforcement. The NWC densities are determined using the expressions given in LRFD Table 3.5.1-1, but do not include an allowance for reinforcement. The compressive strengths shown can be achieved using a number of different sources of lightweight aggregate in the US.

For the deck concrete, the LWC density is 17.2% less than the NWC; for the girder concrete, the LWC density is 15.8% less than the NWC.

The prestressing steel used in the designs was 0.6-in. diameter Grade 270 seven-wire strand.

GIRDER CROSS-SECTION

All designs were performed using a 74-in. deep modified bulb-tee section. This section has been used in North Carolina and South Carolina when longer spans are needed. Dimensions of the girder section are shown in Figure 1.

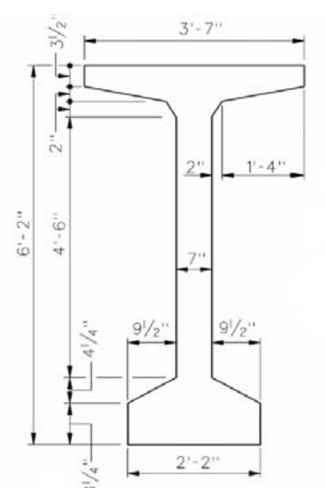

Fig. 1 Dimensions of 74-in. Deep Modified Bulb-Tee Girder Section

DECK DIMENSIONS

The girder spacings were determined based on the bridge width and the fixed overhang distance. The required thickness of the deck for each girder spacing, which was determined using the NCDOT Design Manual[6], is shown in Table 3.

Table 3 Deck thickness required

Maximum Span Designs			
Girder spacing (ft)	11.4	9.5	8.14
Deck thickness (in.)	9.00	8.50	8.25
Fixed Span Designs			
Girder spacing (ft)	10.0	8.0	
Deck thickness (in.)	8.50	8.25	

MAXIMUM SPAN COMPARISONS

The typical section for the maximum span designs is shown in Figure 2. The overhang was taken as 4 ft for all girder spacings.

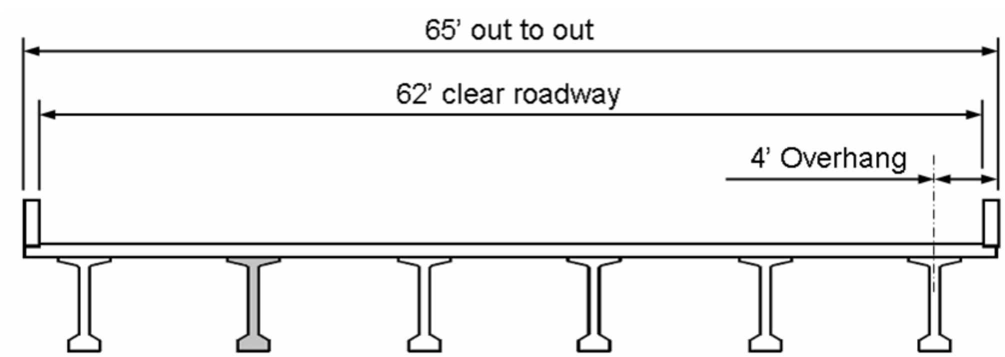

Fig. 2 Typical section for maximum span designs

Based on the typical section, three girder spacings were considered, which are shown in Figure 3:

- Six girders at 11.4 ft
- Seven girders at 9.5 ft
- Eight girders at 8.14 ft

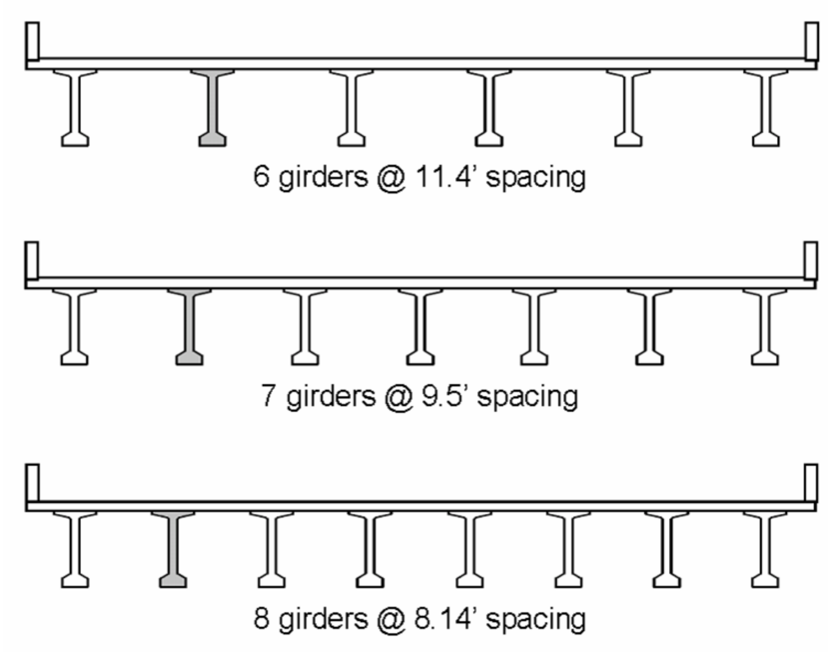

Fig. 3 Three typical sections considered for maximum span designs

Results from the designs are shown in Table 4 and are presented graphically in Figure 4. The results bear out the expected conclusion that using lightweight concrete will lead to longer maximum spans for a given typical section. It was found that using a LWC girder with a NWC deck (LG + ND) resulted in only a small increase in maximum span. However, putting a LWC deck on a NWC girder (NG + LD) resulted in a significant increase in span capability. Finally, using LWC for both girder and deck (LG + LD) provided the largest increase in span, but not much more than NG + LD. One of the most interesting findings was that the maximum span for the all lightweight concrete combination (LG + LD) was equal or very close to the maximum span for the all NWC combination (NG + ND) with one more girder line, i.e., using the all LWC option would allow the removal of a line of girders, which provides a significant reduction in cost.

Several other design parameters were examined from the results of the maximum span designs. However, because the span is increasing as lightweight concrete is being used, these comparisons are not very useful. The number of strands required and the minimum release strength, f'_{ci}, for each design combination is shown in Table 5. One can note that the number of strands is not changing significantly even though the span is increasing. It is clear that the release strength was governing designs for these girders since all of the minimum release strength values are very close to the specified limit of 7.00 ksi.

Table 4 Tabulated results from maximum span designs – maximum spans

Girder spacing	No. of Girders	Combination	Maximum Span	Change from NG + ND	
(ft)			(ft)	(ft)	(%)
11.4	6	NG + ND	137	0	0.0%
		LG + ND	139	2	1.5%
		NG + LD	147	10	7.3%
		LG + LD	149	12	8.8%
9.5	7	NG + ND	150	0	0.0%
		LG + ND	152	2	1.3%
		NG + LD	161	11	7.3%
		LG + LD	162	12	8.0%
8.14	8	NG + ND	162	0	0.0%
		LG + ND	165	3	1.9%
		NG + LD	174	12	7.4%
		LG + LD	175	13	8.0%

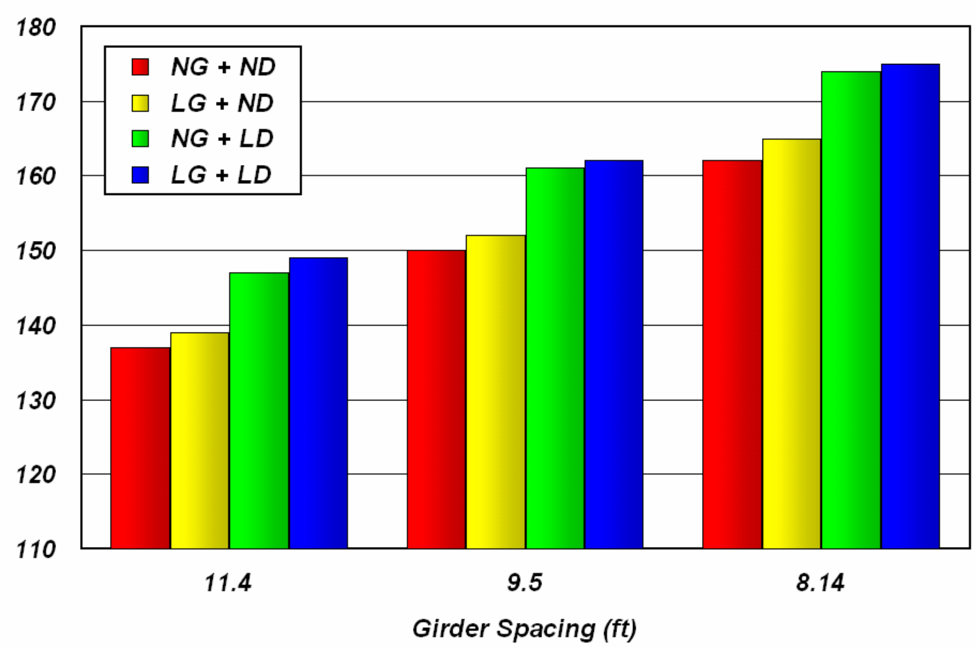

Fig. 4 Results for maximum span designs

Table 5 Tabulated results from maximum span designs – required number of strands and minimum release strength, f'_{ci}

Girder spacing	No. of Girders	Combination	Maximum Span	No. of Strands	Min. Rel. Strength, f'_{ci}
(ft)			(ft)		(ksi)
11.4	6	NG + ND	137	48	6.91
		LG + ND	139	48	6.98
		NG + LD	147	50	6.98
		LG + LD	149	50	6.98
9.5	7	NG + ND	150	50	6.97
		LG + ND	152	50	6.98
		NG + LD	161	54	6.97
		LG + LD	162	52	6.97
8.14	8	NG + ND	162	54	6.98
		LG + ND	165	54	6.97
		NG + LD	174	58	6.98
		LG + LD	175	56	6.97

An interesting comparison is made in Table 6, where the total superstructure dead load reactions at an interior bent are presented for two pairs of designs. For each pair, both design combinations achieve the same or nearly the same maximum span, but the all lightweight concrete design uses one less girder. The table demonstrates that, for the same span, using the all lightweight design combination will reduce the total superstructure dead load reaction at an interior bent by about 21%, or 450 to 525 kips. This can provide a significant reduction in project cost since fewer girders are required and the foundation loads are reduced, with a good potential for reducing foundation costs.

The final comparisons for the maximum span designs address the cambers for the pairs of girders just discussed. For these pairs of girders with essentially the same spans, the LWC girders have significantly greater cambers, as shown in Table 7. However, in the final condition, with all dead load in place, the difference in camber between the two designs is not as great, which is a result of the greater deflection of the LWC girders when the deck is placed. The cambers are compared graphically for the longer span pair of designs in Figure 5. Although the total change in deflection from erection to final conditions is large for the LWC girder designs, the final cambers are not large and can be accommodated by proper detailing for any of the designs.

Table 6 Tabulated results from maximum span designs – total dead load reaction at interior bent

Girder spacing	No. of Girders	Combination	Max. Span	Total DL Reaction at Interior Bent	
(ft)			(ft)	(kips)	(kips/%)
9.5	7	NG + ND	150	2187	-453
11.4	6	LG + LD	149	1734	-20.7%
8.14	8	NG + ND	162	2492	-523
9.5	7	LG + LD	162	1968	-21.0%

Table 7 Tabulated results from maximum span designs – cambers & deflection when deck is cast

Girder spacing	No. of Girders	Combination	Max. Span	Release	Erection	Defl. w/ Deck	Final DL
(ft)			(ft)	(in.)	(in.)	(in.)	(in.)
9.5	7	NG + ND	150	3.11	5.44	4.00	0.79
11.4	6	LG + LD	149	4.35	7.66	5.25	1.59
8.14	8	NG + ND	162	3.18	5.50	4.56	0.10
9.5	7	LG + LD	162	4.53	7.91	5.85	0.98

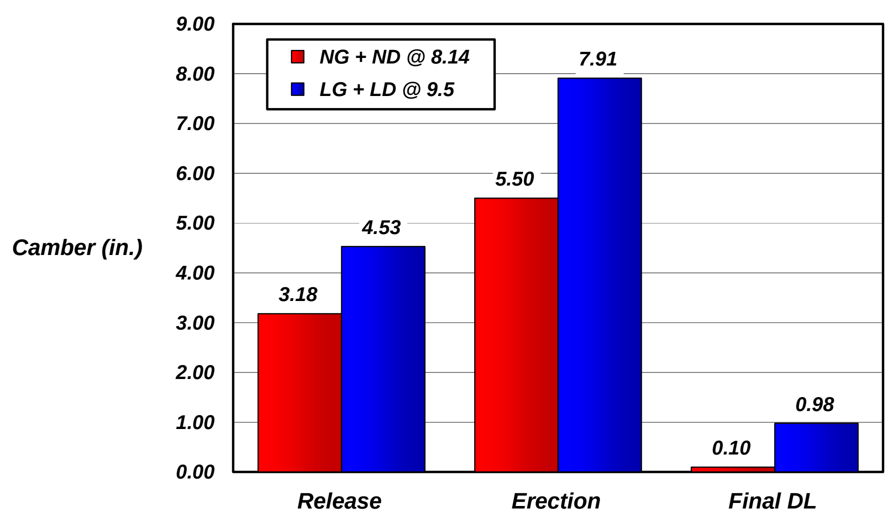

Fig. 5 Comparison of cambers for girder designs with 162 ft maximum spans

FIXED SPAN COMPARISONS

The fixed span design comparisons represent a two-span overpass structure, where a local route crosses a multi-lane highway. Both spans are simply supported and have a design span length of 150 ft for all of the fixed span design comparisons in this section. The typical section for the bridge is shown in Figure 6. The overhang is taken as 3.5 ft for the two girder spacings considered.

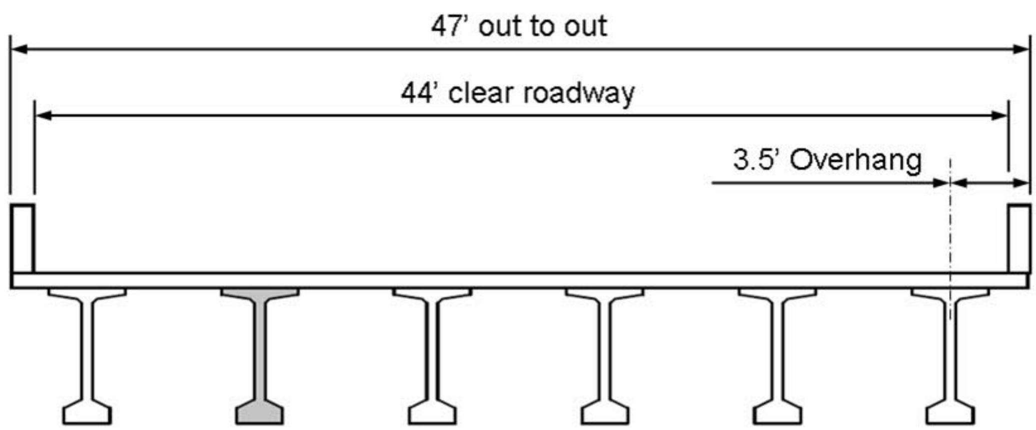

Fig. 6 Typical section for fixed span designs

Because the typical section was narrow, there were only two practical girder spacings to consider, as shown in Figure 7:

- Five girders at 10.0 ft
- Six girders at 8.0 ft

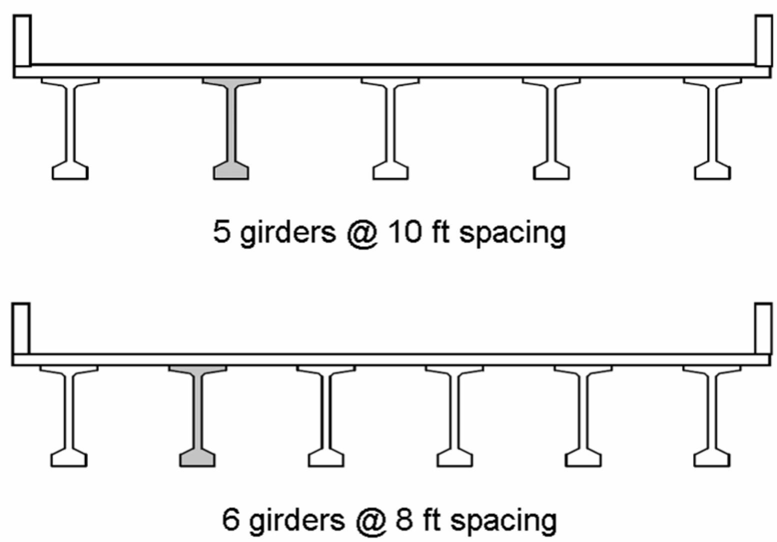

Fig.7 Typical sections considered for 150 ft fixed span designs

Since the girder length is fixed, the girder weights do not vary with the girder spacing. Table 8 gives the girder weights for the LWC and NWC girders. They differ by the ratio of the assumed concrete densities.

Table 8 Girder weights for 150 ft fixed span designs

Girder spacing	No. of Girders	Combination	Girder weight	Change from NG	
(ft)			(kips)	(kips)	(%)
8 or 10	6 or 5	NG	137.8	0	0.0%
		LG	116.0	-21.8	-15.8%

Several other design parameters were examined from the results of the maximum span designs. Because the span is held constant, direct comparisons can be made for the different combinations.

The number of strands required for each design combination is shown in Table 9. In all but one case, the number of strands decreases compared to the all normalweight concrete option as lightweight concrete is used. The same order of progression of reduction in strands is seen as was seen with the maximum spans: the all lightweight concrete option had the greatest reduction, the normalweight girder with lightweight concrete deck was slightly less, and the lightweight concrete girder with normalweight concrete deck had a small or no reduction in the number of strands. Reducing the number of strands for a project on the order of 10 to 15%, as demonstrated here, could provide a noticeable reduction in cost for a project.

Table 9 Tabulated results from 150 ft fixed span designs – required number of strands

Girder spacing	No. of Girders	Combination	No. of Strands	Change from NG + ND	
(ft)					(%)
10	5	NG + ND	52	0	0.0%
		LG + ND	52	0	0.0%
		NG + LD	48	-4	-7.7%
		LG + LD	46	-6	-11.5%
8	6	NG + ND	44	0	0.0%
		LG + ND	42	-2	-4.5%
		NG + LD	40	-4	-9.1%
		LG + LD	38	-6	-13.6%

Using the design table function in the program, the strand requirement was plotted as the span was increased. The resulting data are shown in Figure 8. In this figure and those that follow, a vertical line is placed at 150 ft, indicating the span used for the fixed span comparisons. This shows that the difference in number of strands is consistent through most of the range of achievable spans.

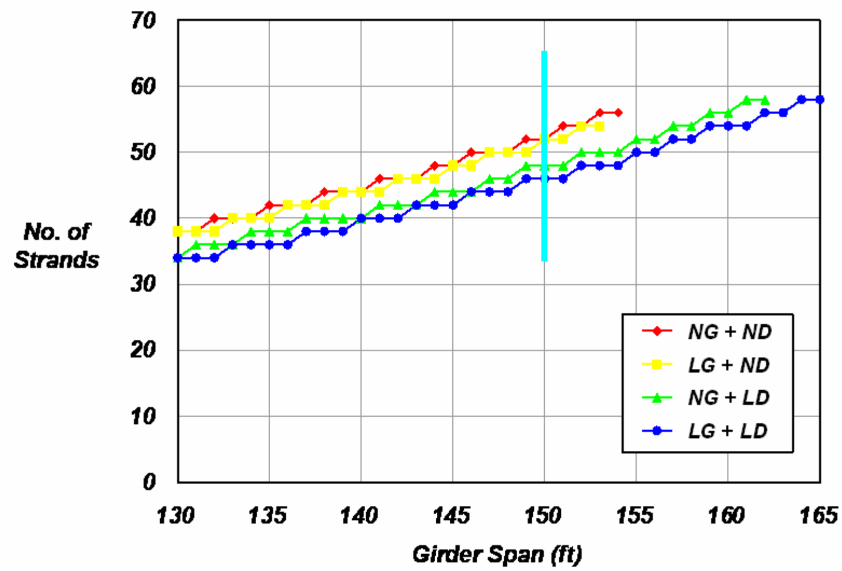

Fig. 8 Required number of strands with increasing span – 10 ft girder spacing

The minimum release strength, f'_{ci}, for each design combination is shown in Table 10. In all cases, the lightweight concrete combinations have lower release strengths, with the release strength for the all LWC option 11 to 13% lower than the all NWC option. A reduction in release strength is an important cost factor for a manufacturer of prestressed concrete girders.

Table10 Tabulated results from 150 ft fixed span designs –minimum release strength, f'_{ci}

Girder spacing	No. of Girders	Combination	Release Strength, f'_{ci}	Change from NG + ND	
(ft)			(ksi)	(ksi)	(%)
10	5	NG + ND	7.072	0	0.0%
		LG + ND	7.150	0.078	1.1%
		NG + LD	6.481	-0.591	-8.4%
		LG + LD	6.308	-0.764	-10.8%
8	6	NG + ND	5.842	0	0.0%
		LG + ND	5.696	-0.146	-2.5%
		NG + LD	5.166	-0.676	-11.6%
		LG + LD	5.059	-0.783	-13.4%

Results for the variation of the minimum release strength with increasing span are very similar to the results shown for number of strands in Figure 8.

The total superstructure dead load reactions at an interior bent are presented for the fixed span designs in Table 11. In this case, the LG + ND option provides a noticeable reduction in reaction, nearly as much as the NG + ND option. The all LWC option (LG + LD) provides the greatest reduction in total reaction, giving a reduction of 267 or 287 kips or 16.6%. As noted for the maximum span comparisons, the reduced interior bent reaction may result in foundation cost savings.

Table 11 Tabulated results from 150 ft fixed span designs – total dead load reaction at interior bent

Girder spacing	No. of Girders	Combination	Total DL Reaction	Change from NG + ND	
(ft)			(kips)	(kips)	(%)
10	5	NG + ND	1606.0	0.0	0.0%
		LG + ND	1496.9	109.0	-6.8%
		NG + LD	1447.9	158.1	-9.8%
		LG + LD	1338.8	267.1	-16.6%
8	6	NG + ND	1735.4	0.0	0.0%
		LG + ND	1604.6	130.9	-7.5%
		NG + LD	1578.8	156.6	-9.0%
		LG + LD	1447.9	287.5	-16.6%

As is evident in Figure 8, the NG + ND option at a 10 ft girder spacing is nearing its maximum span at 150 ft. Therefore, if the design span were slightly longer, the NG + ND option would no longer be available. In that case, as was seen for the maximum span designs, the all lightweight concrete option with one less girder would reduce the total dead load reaction at an interior bent significantly. Using the numbers in Table 11, the LG + LD option at a 10 ft girder spacing would reduce the reaction by nearly 400 kips or about 23% when compared to the NG + ND option at an 8 ft spacing.

The cambers of the girders at different stages of construction are shown in Table 12 for the fixed span designs. As was noted for the maximum span designs, the LWC girders have significantly greater cambers than the NWC girders, especially at release and erection. However, in the final condition with all dead load in place the difference in camber between the LWC girders and NWC girders is not as great. For this span, all of the final cambers are well within the range that can be accommodated by proper detailing.

The cambers for the 10 ft girder spacing designs at release, erection and final for the four design combinations are shown with increasing spans in Figures 9 – 11, respectively. The final cambers for the designs with 8 ft girder spacing are shown in Figure 12. In each figure, the curves end when the maximum span is reached for the design conditions, and a vertical line is drawn at 150 ft, the fixed span being considered.

Table 12 Tabulated results from 150 ft fixed span designs – release, erection and final cambers

Girder Spacing	No. of Girders	Combination	Release	Erection	Final
(ft)	(ft)		(in.)	(in.)	(in.)
10	10	NG + ND	3.17	5.54	0.72
		LG + ND	4.42	7.78	1.34
		NG + LD	3.05	5.33	1.22
		LG + LD	4.23	7.43	2.03
8	8	NG + ND	2.88	5.02	1.09
		LG + ND	3.80	6.66	1.49
		NG + LD	2.47	4.27	0.98
		LG + LD	3.30	5.76	1.43

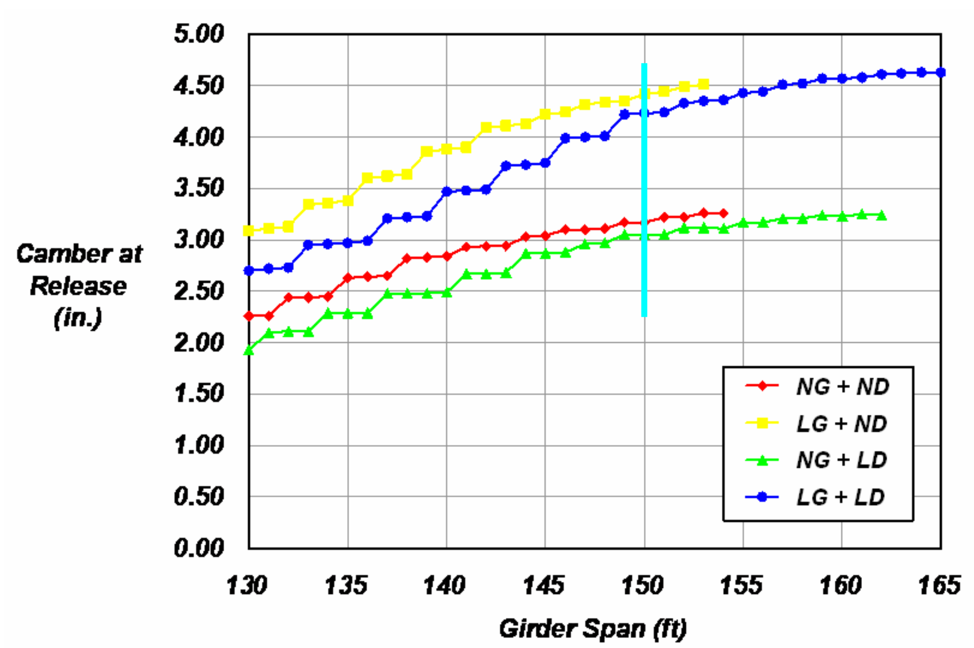

Fig. 9 Camber at release with increasing span – 10 ft girder spacing

These figures show that the difference in camber between LWC girders and NWC girders observed from the data in Table 12 for the 150 ft span applies for a wide range of spans, but is greater at longer spans.

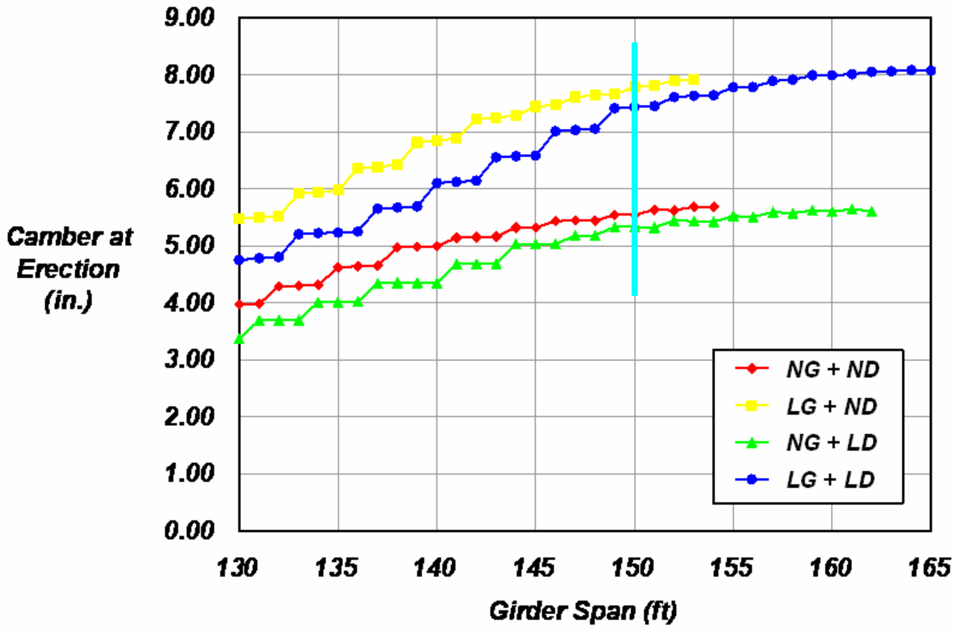

Fig. 10 Camber at erection with increasing span – 10 ft girder spacing

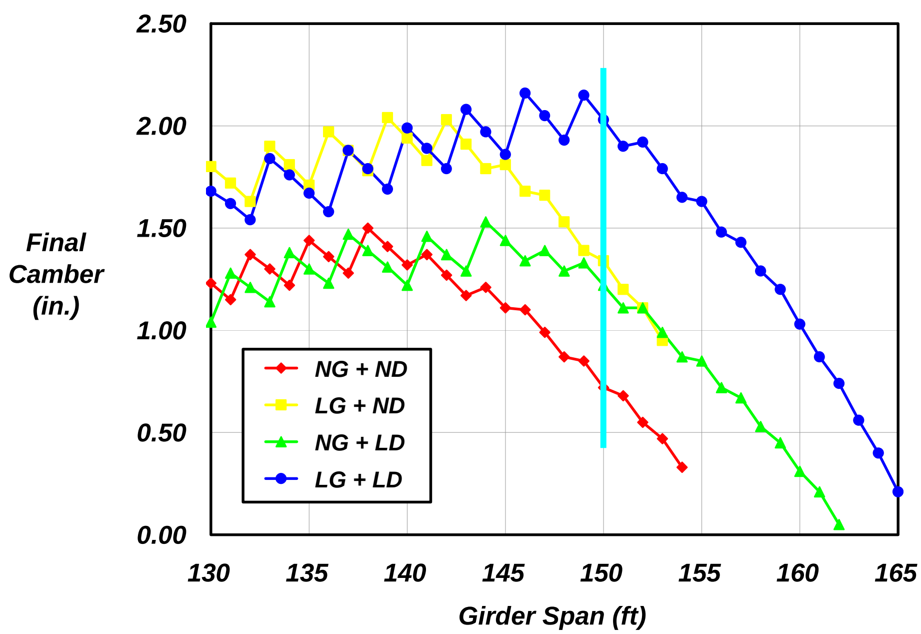

Fig. 11 Final camber with increasing span – 10 ft girder spacing

The trends seen in Figures 11 and 12 for final camber are interesting. At longer spans, the final camber begins to decrease markedly. While a single cause for this behavior is not easy to identify, it is probably affected by the governing stress conditions and by strand locations in the bottom flange being filled so that additional strands are not as effective in producing camber. As maximum spans are approached, the final camber can become fairly small. For the designs with an 8 ft girder spacing, the final camber becomes negative at spans close to the maximum span. This is usually not desirable, and is typically avoided in design. However, from these figures, it is seen that the designs with LWC maintain a positive camber for spans where the all NWC design has become small or negative. The all LWC design maintains the greatest final camber, with a 1.5 in. positive camber when the all NWC design final camber reaches zero at a span of 163 ft. Figure 12 also shows that the all LWC design has a greater maximum span for this case, and maintains a positive final camber for a span about 10 ft longer than the all NWC option.

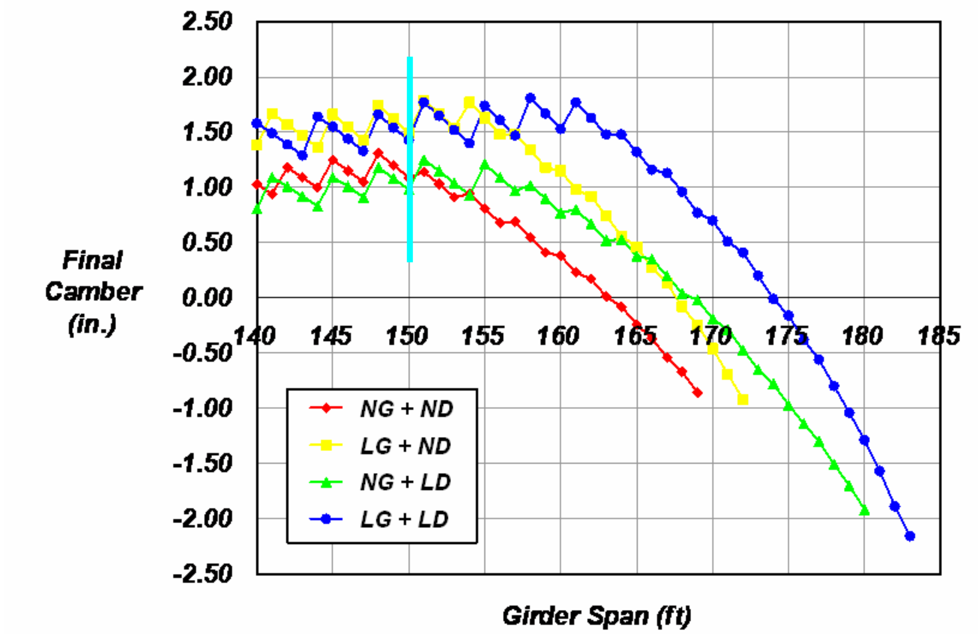

Fig. 12 Final camber with increasing span – 8 ft girder spacing

LIGHTWEIGHT CONCRETE BARRIERS

Lightweight concrete has been used for barrier rails on bridges to reduce the load on a bridge. In this application, it functions as well as normalweight concrete, since LWC can be designed to have the same strength as normalweight concrete.

A brief evaluation of the effect of using LWC for barriers for the maximum span and fixed span designs considered in this paper follows. In this evaluation, only the effect of using LWC or NWC for the barrier on the all NWC design (NG + ND) is considered, since the change would be most significant for this case.

MAXIMUM SPAN DESIGNS

The superstructure dead loads are summarized in Table 13 for the three girder spacings used in the maximum span designs. The relative magnitude of the barrier load compared to the total superstructure dead load is presented in Table 14 for the maximum span designs. In these tables, NB indicates a NWC barrier and LB indicates a LWC barrier.

Table 13 Superstructure dead loads for maximum span designs

Girder spacing	No. of Girders	NG + ND + Barrier	Max. Span	Girders	Deck	Barriers	Total DL
(ft)			(ft)	(kips)	(kips)	(kips)	(kips)
11.4	6	NB	137	755.7	1047.2	112.1	1914.9
		LB				92.7	1895.6
9.5	7	NB	150	964.7	1099.6	122.6	2186.9
		LB				101.5	2165.8
8.14	8	NB	162	1190.1	1169.1	132.4	2491.6
		LB				109.5	2468.8

The data in Table 14 show that for the relatively wide prestressed concrete girder bridge considered in the maximum span designs, the weight of the barrier rails constitutes a relatively small fraction of the total load. The data show that the NWC barrier is 5.3 to 5.9% of the total superstructure dead load, and the LWC barrier is 4.4 to 4.9% of the total superstructure dead load, with the higher fractions being for the wider girder spacings with fewer girders.

Table 14 Effect of barrier dead load for maximum span designs

Girder spacing	No. of Girders	NG + ND + Barrier	Max. Span	Barriers		Change in Total DL from NB	
(ft)			(ft)	(kips)	(% of Total)	(kips)	(%)
11.4	6	NB	137	112.1	5.9%	-	-
		LB		92.7	4.9%	-19.3	-1.0%
9.5	7	NB	150	122.6	5.6%	-	-
		LB		101.5	4.7%	-21.1	-1.0%
8.14	8	NB	162	132.4	5.3%	-	-
		LB		109.5	4.4%	-22.8	-0.9%

For any of the girder spacings, changing the barrier from NWC to LWC reduced the dead load by about 1%. This appears to be a rather insignificant change. However, maximum span designs using the two barriers were not performed, which would reveal the true significance of the reduction.

FIXED SPAN DESIGNS

The superstructure dead loads are summarized in Table 15 for the two girder spacings used in the fixed span designs. The relative magnitude of the barrier load compared to the total superstructure dead load is presented in Table 16 for the fixed span designs. In these tables, NB indicates a NWC barrier and LB indicates a LWC barrier.

Table 15 Superstructure dead loads for fixed span designs

Girder spacing	No. of Girders	NG + ND + Barrier	Span	Girders	Deck	Barriers	Total DL
(ft)			(ft)	(kips)	(kips)	(kips)	(kips)
10.0	5	NB	150	689.1	794.3	122.6	1606.0
		LB				101.5	1584.8
8.0	6	NB	150	826.9	785.9	122.6	1735.4
		LB				101.5	1714.3

The data in Table 16 show that for the narrower prestressed concrete girder bridge considered in the fixed span designs, the weight of the barrier rails still constitutes a relatively small fraction of the total load, although the fraction is higher than for the maximum span designs. The data show that the NWC barrier is 7.1 to 7.6% of the total superstructure dead load, and the LWC barrier is 5.9 to 6.4% of the total superstructure dead load, with the higher fractions being for the wider girder spacings with fewer girders.

Table 16 Effect of barrier dead load for fixed span designs

Girder spacing	No. of Girders	NG + ND + Barrier	Max. Span	Barriers		Change in Total DL from NB	
(ft)			(ft)	(kips)	(% of Total)	(kips)	(%)
11.4	6	NB	150	122.6	7.6%	-	-
		LB		101.5	6.4%	-21.1	-1.3%
9.5	7	NB	150	122.6	7.1%	-	-
		LB		101.5	5.9%	-21.1	-1.2%

For both of the girder spacings, changing the barrier from NWC to LWC reduced the dead load by slightly more than 1%. Again this appears to be a rather insignificant change, but may be found to be more important if the change were used in designs.

While this brief comparison does not show a significant advantage to using LWC barrier for typical prestressed concrete girder bridges, there are other applications where the use of LWC barriers has proven beneficial, such as narrow long-span ramp bridges where the barrier weight is a more significant fraction of the total superstructure dead load.

COST CONSIDERATIONS

Lightweight concrete costs more than normalweight concrete because of the additional cost for the high-temperature processing required to make lightweight aggregate. Transportation costs can also be a significant component of the cost of lightweight aggregate because of the limited number and distribution of plants manufacturing structural lightweight aggregates in the US. The higher cost of lightweight aggregate results in an increased cost of lightweight concrete compared to normalweight concrete. The additional cost for lightweight concrete over normalweight concrete (often referred to as the "cost premium" for lightweight concrete) will vary with location and cost of normalweight aggregate. The cost premium for lightweight concrete usually ranges from $15/cy to $40/cy, but may be more if transportation costs are high. However, in many cases the total cost savings for a project from using lightweight concrete can more than offset the additional cost.

CONCLUSIONS

The limited comparisons reported in this paper have demonstrated that the use of lightweight concrete in girders and decks for prestressed girder bridges can improve the structural efficiency of the structure. The four possible combinations of lightweight and normalweight concrete for girders and decks were considered in this study. Compared to the base case of NWC girders and a NWC deck (NG + ND), the following was found:

- The combination of LWC girders with a NWC deck (LG + ND) provides a minor improvement in maximum span, and reduced release strength with a possible reduction of strands for fixed span designs
- The combination of NWC girders with a LWC deck (NG + LD) provides a significant improvement in maximum span, and a reduction in release strength and strands for fixed span designs
- The combination of LWC girders with a LWC deck (LG + LD) provides the greatest improvement in maximum span, and the greatest reduction in release strength and strands for fixed span designs
- The combination of LWC girders with a LWC deck (LG + LD) may provide the opportunity to eliminate a girder line

It was found that the use of LWC provides a significant reduction in the total superstructure dead load reaction, which may allow a reduction in substructure and foundation costs.

For both maximum span and fixed span designs, it was observed that cambers for LWC girders are increased over NWC girders, but that the final cambers are reasonable for these designs. The additional camber in LWC girders provide better performance compared to NWC girders, where the NWC girders have little or no camber at final conditions.

The use of LWC for barriers on the maximum and fixed span designs considered in this paper was not found to significantly reduce the dead load of the structure. However, an analysis was not performed to determine the effect that the reduction had on the structural performance of the bridge.

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