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Design Aids of NU I-Girders Bridges

Kromel E. Hanna, Ph.D.
Department of Civil Engineering
University of Nebraska-Lincoln

George Morcous, Ph.D.
Associate Professor

Maher K. Tadros, Ph.D.
Professor Emeritus

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Nebraska Transportation Center
262 WHIT
2200 Vine Street
Lincoln, NE 68583-0851
(402) 472-1975

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Professor Emeritus
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16. Abstract

Precast prestressed concrete I-Girder bridges have become the most dominant bridge system in the United States. In the early design stages, preliminary design becomes a vital first step in designing an economical bridge. Within the state of Nebraska, the two standard precast prestressed products used are Inverted Tee (IT) girders and University of Nebraska (NU) I girders. In the early 1990s, Nebraska Department of Roads (NDOR) developed design charts for NU-I girders in order to assist in member selection and preliminary design. In 2004, design charts were developed for IT girders. However, the NU-I girder charts have since become obsolete because they were developed for low strength concrete (6 ksi) and 0.5 inch prestressing strands. In addition, the charts were based off of American Association of State Highway and Transportation Officials (AASHTO) standard specifications. Since then, NDOR has adopted AASHTO Load and Resistance Factor Design (LRFD) specifications for superstructure design and the Threaded Rod (TR) continuity systems in their standard practice. Therefore, the new design charts are based on the latest AASHTO LRFD Specifications for superstructure design and NDOR Bridge Operations, Policies, and Procedures (BOPP manual). With the increasing use of 0.6 and 0.7 inch diameter strands as well as increasing concrete strengths, there is a need for new preliminary design charts for NU-I girders. The new design aids provide bridge designers with different alternatives of girder section size (from NU900 to NU2000), girder spacing (from 6-12 ft), prestressing strands (up to 60), prestressing strand diameter (from 0.6 to 0.7 inch), and compressive strength of concrete (from 8 ksi to 15 ksi). Two sets of design charts are developed to cover simple span and two-span continuous bridges. Each set contains two different types of charts: summary charts and detailed charts. Summary charts give designers the largest possible span length allowed given girder spacing, concrete strength, and NU-I girder sections. Detailed charts give designers the minimum number of prestressing strands required given girder spacing, span length, and concrete strength. Both sets of charts provide designers with the limit state that controls the design. If needed, this allows the design to be optimized in an efficient manner.

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List of Abbreviations

American Association of State Highway and Transportation Officials (AASHTO)
Bridge Operations, Policies, and Procedures Manual (BOPP)
High Strength Concrete (HSC)
Inverted Tee Girders (IT)
Load and Resistance Factor Design (LRFD)
Nebraska Department of Roads (NDOR)
Threaded Rod (TR)
University of Nebraska I Girders (NU-I)

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Chapter 1 Introduction

Precast prestressed concrete girder bridges have become the most dominant bridge system in the United States. In the early design stages, preliminary design becomes a vital first step in designing an economical bridge. Within the state of Nebraska, the two standard precast prestressed products used are Inverted Tee (IT) girders and University of Nebraska I girders (NU-I). In the early 1990s, Nebraska Department of Roads (NDOR) developed design charts for NU-I girders in order to assist in member selection and preliminary design. In 2004, design charts were developed for IT girders. However, the NU-I girder charts have since become obsolete because they were developed for low strength concrete (6 ksi) and 0.5 inch prestressing strands. In addition, the charts were based off of American Association of State Highway and Transportation Officials (AASHTO) standard specifications. Since then, NDOR has adopted AASHTO Load and Resistance Factor Design (LRFD) specifications for superstructure design and the Threaded Rod (TR) continuity systems in their standard practice. Therefore, the new design charts are based on the latest AASHTO LRFD specifications for superstructure design and NDOR Bridge Operations, Policies, and Procedures Manual (BOPP).

With the increasing use of 0.6 and 0.7 inch diameter strands, as well as increasing concrete strengths, there is a need for new preliminary design charts for NU-I girders. The new design aids provide bridge designers with different alternatives for girder section size (from NU900 to NU2000), girder spacing (from 6-12 ft), prestressing strands (up to 60), prestressing strand diameter (from 0.6 to 0.7 inch), and compressive strength of concrete (from 8 ksi to 15 ksi). Two sets of design charts are developed to cover simple span and two-span continuous bridges. Each set contains two different types of charts: summary charts and detailed charts. Summary charts give designers the largest possible span length allowed given girder spacing, concrete strength, and NU-I girder sections. Detailed charts give designers the minimum number of prestressing strands required given girder spacing, span length, and concrete strength. Both sets of charts provide designers with the limit state that controls the design. If needed, this allows the design to be optimized in an efficient manner.

All design charts were developed using two different design methods for concrete strength at release: Strength Design Method and Working Stress Method. In the state of Nebraska, the designer is permitted to use the strength design method and/or the working stress method. This allowed for the comparison of the two methods and gave designers an option on which method to use based off of company policies. For two-span continuous girder bridges, the TR continuity system was used. This system allows the deck weight to act continuously throughout the bridge system whereas the conventional continuity system is continuous for live load only.[1] A comparison of TR continuity and the conventional bridge continuity system is shown later in this paper.

The new design aids provide bridge designers with an efficient and reliable tool to optimize the selection and preliminary design of NU-I girders. This will eliminate the tedious and time-consuming process of evaluating several alternatives to achieve a feasible and economical design. It is expected that the new design aids will save time, money, and effort spent in performing unnecessary design iterations. The developed design aids will satisfy both current and future needs of bridge designers.

1.1 Girder Section Properties

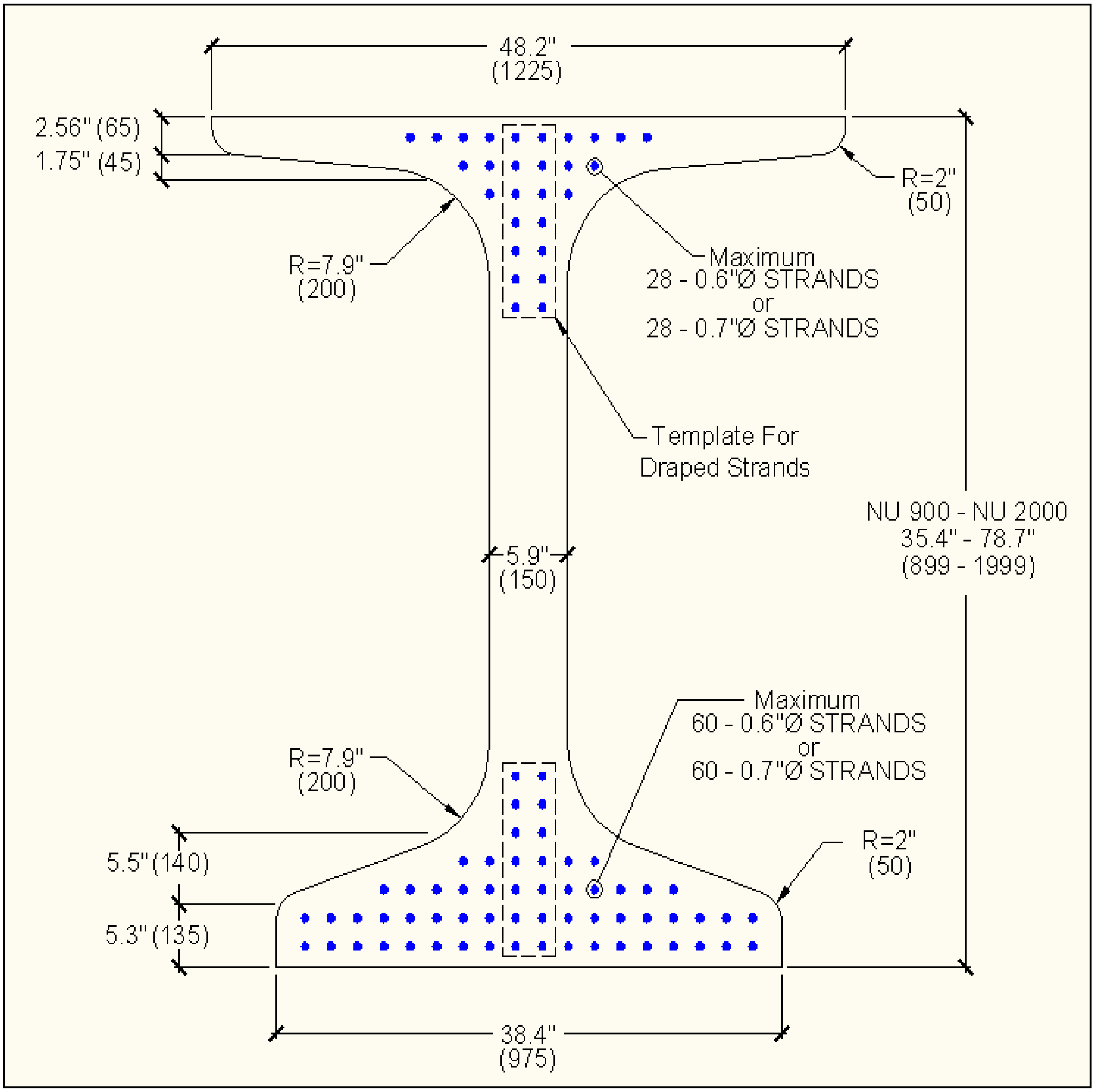

Figure 1.1 Pretensioned only Nebraska University I-girder with strand template

Table 1.1 NU girder properties of pre-tensioned only sections

NU GIRDER PROPERTIES OF PRE-TENSIONED ONLY SECTIONS								
Section	Height in (mm)	Web Width in (mm)	Top Flange Width in (mm)	Bottom Flange Width in (mm)	A in^2 (mm^2)	Y_b in (mm)	I in^2 ($mm^4 * 10^6$)	W_t Kips/ft KN/m
NU 900	35.4 (900)	5.9 (150)	48.2 (1225)	38.4 (975)	648.1 (418,111)	16.1 (410)	110,262 (45,895)	0.680 (9.85)
NU 1100	43.3 (1100)	5.9 (150)	48.2 (1225)	38.4 (975)	694.6 (448,111)	19.6 (497)	182,279 (75,870)	0.724 (10.56)
NU 1350	53.1 (1350)	5.9 (150)	48.2 (1225)	38.4 (975)	752.7 (485,610)	24.0 (608)	302,334 (126,841)	0.785 (11.44)
NU 1600	63.0 (1600)	5.9 (150)	48.2 (1225)	38.4 (975)	810.8 (523,111)	28.4 (722)	458,482 (190,835)	0.840 (12.33)
NU 1800	70.9 (1800)	5.9 (150)	48.2 (1225)	38.4 (975)	857.3 (553,111)	32.0 (814)	611,328 (254,454)	0.894 (13.03)
NU 2000	78.7 (2000)	5.9 (150)	48.2 (1225)	38.4 (975)	903.8 (583,111)	35.7 (906)	790,592 (329,069)	0.942 (13.74)

Chapter 2 Design Assumptions of NU-I Pretensioned Precast Girders

Design Code:

- AASHTO LRFD 2007.
- NDOR Bridge Office Policies and Procedures (BOPP) Manual 2009.

Design Criteria:

- Service III.
- Strength I Precast.
- Strength I Composite (Multiplier of 2.0 was used for the ultimate moment M_{LL+IM} and ultimate shear V_{LL+IM}).
- Release Stresses (Strength Design Method).
- Shear Limit.
- Negative Moment Fatigue.
- Crack Control.

Structural System:

- Simple Span.
- Two Span Continuous (Equal Spans).
- Three Span Continuous (0.8L, 1.0L, 0.8L).

Girder Sections:

- NU 900, NU 1100, NU 1350, NU 1600, NU 1800, NU 2000.
- Interior Girders.
- w_c = 0.150 kcf.

Girder Spacing:

- 6, 8, 10, and 12 ft.

Girder Compressive Strength at Final:

- 8, 10, 12, and 15 ksi.

Girder Compressive Strength at Release:

- $0.75*f'_c$ = 6, 7.5, 9, and 11.25 ksi.

Deck Concrete:

- 4 ksi (for 8 and 10 ksi final compressive concrete strength).
- 5 ksi (for 12 and 15 ksi final compressive concrete strength).

Deck Thickness:

- For Girder Spacing = 6-10ft, t_s = 7.5 in.
- For Girder Spacing = 12 ft, t_s = 8.0 in.
- Assume ½ inch reduction of deck slab thickness in computing composite properties to allow for long term wear.

Haunch:

- Width = 48 in.
- Thickness for simple span = 1 in.
- Thickness for continuous span.
    - Over positive section = 2.5 in.
    - Over negative section = 3.5 in.

Strand Type:

- Grade 270 low-relaxation, E_s = 28,500 ksi.
- Yield Strength = 243 ksi.
- Jacking Stress = 0.75*$f_{pu.}$

Strand Diameter:

- 0.6 in (for 8, 10, and 12 ksi final compressive concrete strength).
- 0.7 in (for 12 and 15 ksi for final compressive concrete strength).

Strand Arrangement:

- 60 strands – 7 rows (18,18,12,6,2,2,2) @ 2” x 2” grid spacing.
- Straight strands, two point draping allowed at 0.4*L.
- Debonding allowed for a maximum of 40% of any row and 25% of total.

Dead Load:

- Girder weight.
- Deck weight.
- Diaphragm = 0.25 k/ft.
- Haunch weight.
- Asphalt (2 inch wearing surface).

Live Load:

- HL-93 - Design Truck + Design Lane.

Misc:

- For continuous girders, 10 - 1 3/8”ø – 50 ft Threaded Rods are placed 0.75 in. above the top flange of the girder over the negative moment section.
- Minimum deck reinforcement plus #5 to 2-#8 bars may be placed in between the minimum reinforcement in order to obtain the maximum strength moment capacity over the negative section.

Chapter 3 Developed Charts

Two types of charts were developed: summary charts and detailed charts. The charts will provide the designer with an excellent starting point for preliminary design. Note that the charts also provide the governing limit state controlling the design. This will allow bridge designers to adjust various design parameters if needed to fit their specific design.

3.1 Summary Charts

Summary charts display the maximum attainable span versus girder spacing (6, 8, 10, and 12 ft) for different girder sizes (NU 900, 1100, 1350, 1600, 1800, and 2000). This type of chart is convenient to use in the early stages of design to identify the spacing and approximate girder size to use for a given span length. Figure 3.1 shows an example of a summary chart. A total of five summary charts were developed to represent different combinations of concrete strength: 8, 10, 12 (0.6” and 0.7” strands), and 15 ksi.

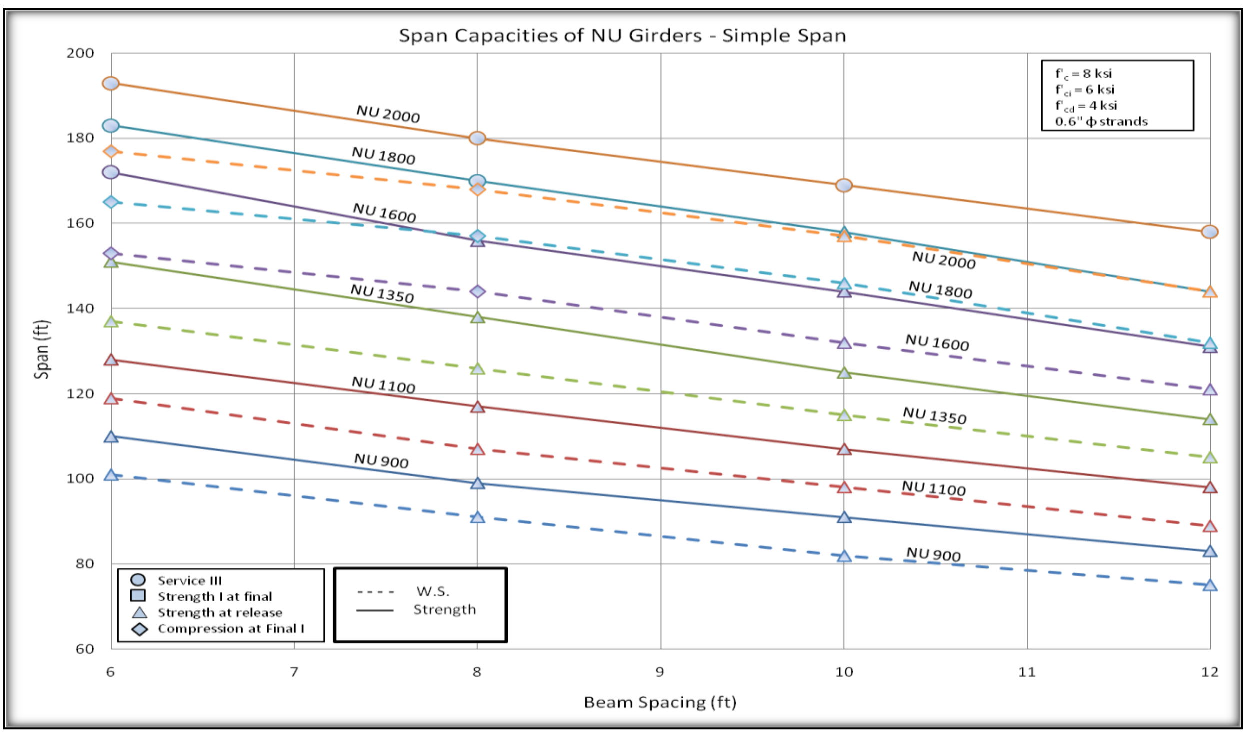

Figure 3.1 Example of a summary chart

3.2 Detailed Charts

Detailed charts display the required number of strands and concrete strength for a specific girder given the span length and the girder spacing. Figure 3.2 shows an example of a detailed chart. A total of 30 detailed charts were developed in order to represent different combinations of girder size (NU 900 – NU 2000) and concrete strengths (8, 10, 12, and 15 ksi).

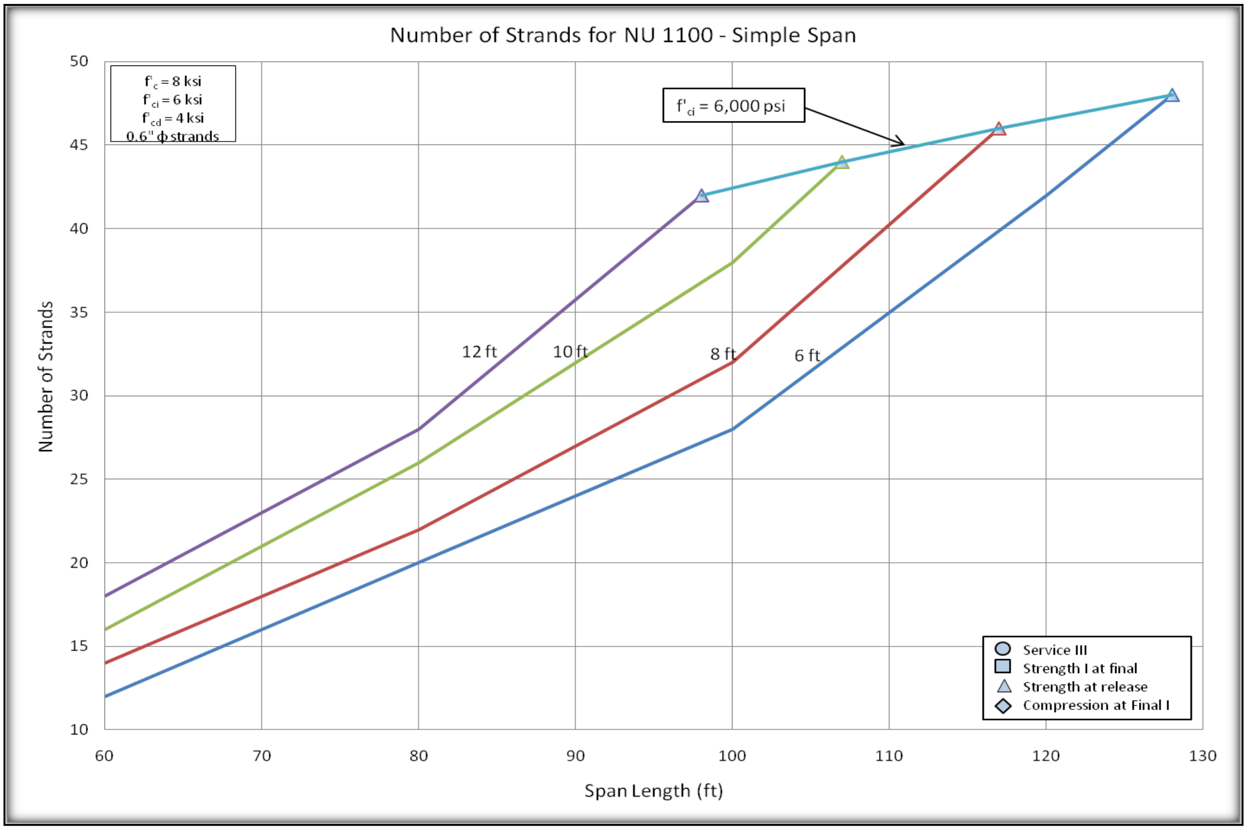

Figure 3.2 Example of detailed chart using Strength Design Method

Chapter 4 Effect of Design Parameters

While preparing the design charts, it was important to compare results obtained from the design and evaluate the effects that variation in design parameters had on the final results. The most important design aspects that affected the design include: girder type, prestressing strand diameter, concrete strength at release, concrete strength at final, and continuity for multi-span bridges.

4.1 Girder Type (NU-I Girder Compared with AASHTO)

NU-I prestressed precast girders have been adopted by NDOR and are used extensively within the state of Nebraska. The NU-I girders have even been used in other states such Missouri and Texas, as well as in the country of Canada. Figure 4.1 (below) shows a comparison of the maximum span lengths obtained using NU-I and AASHTO prestressed precast girders using constant design parameters. The girders were compared and matched using the height of the girders. For example, NU 1100 was compared with AASHTO Type III girder. It is evident from figure 4.1 that the NU-I girders provide a maximum span length of up to 10% longer over using a comparable AASHTO girder.

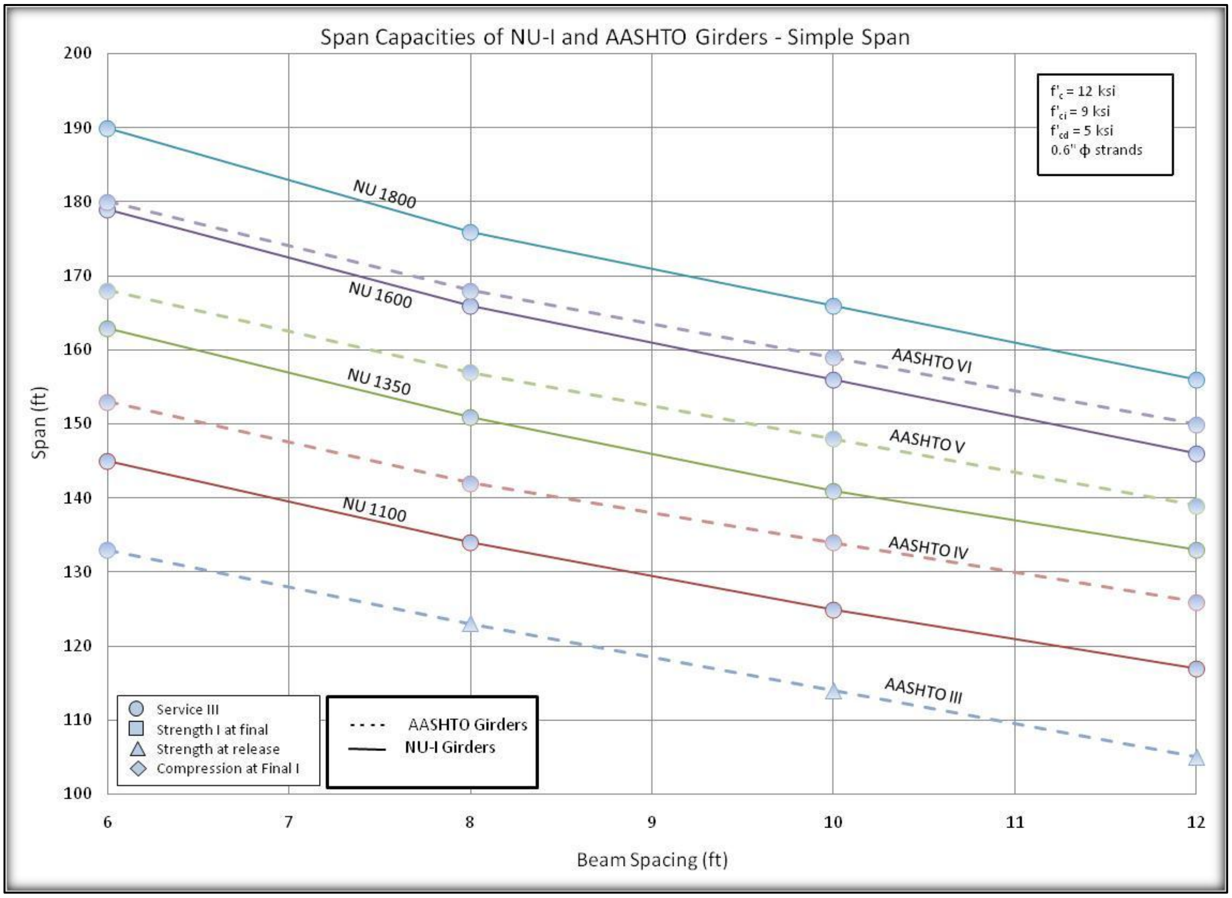

Figure 4.1 Example of summary chart comparing NU-I and AASHTO girders

4.2 Prestressing Strand Diameter (0.6 inch to 0.7 inch)

Presently, 0.7 inch strands are not commonly used in the industry. However, due to recent successful research, the future of prestressed precast concrete will embrace the use of 0.7 inch prestressing strands.

The use of 0.7 inch strands is in direct correlation with high strength concrete (HSC). There is a significant increase in the moment capacity when 0.6 and 0.7 inch strands are used in comparison with 0.5 inch strands. This increase occurs because the tensile force in the strands must reach equilibrium with the compressive forces occurring in the deck and girder. If the depth of the compression block in the top flange exceeds the deck thickness and reaches the top flange of the girder, the high concrete strength of the girder becomes an important factor in determining the moment capacity of the composite section.

The increase in strand diameter from 0.6 to 0.7 inches creates approximately 35% more prestressing area, which correlates to 35% more prestressing force. From 0.5 to 0.7 inches, there is a 92% increase in prestressing force. The use of larger prestressing strands allows for shallower section depths and longer span lengths. This would also result in significant savings in material and labor costs due to the decrease in the amount of prestressing strands. The use of fewer prestressing strands results in fewer number of chucks used in the pretensioning process, also resulting in a decrease in labor costs.

Figure 4.2 and figure 4.3 below show the comparison of 0.6 and 0.7 inch prestressing strands using 12 ksi concrete. The summary chart in figure 4.2 shows the maximum attainable span length vs. girder spacing. The detailed chart in figure 4.3 shows the minimum number of prestressing strands needed vs. span length for an NU 900 girder.

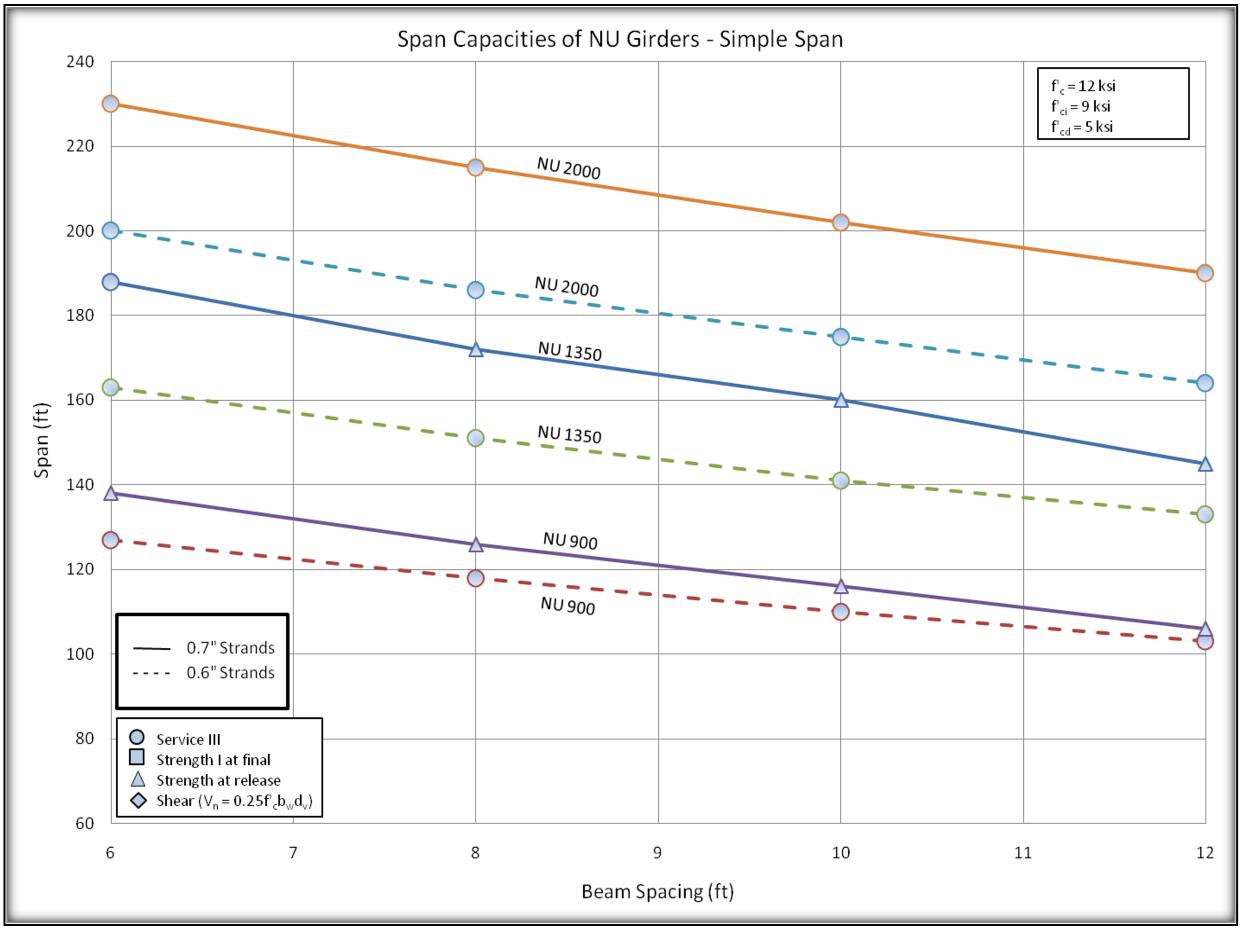

Figure 4.2 Summary chart comparison between 0.6 and 0.7 inch strands

For clarity purposes, only NU 900, 1350, and 2000 are graphed. However, it is still quite clear that the use of 0.7 inch strands over 0.6 inch strands allows for a significant increase in span capacity. The largest variation in span length occurs with NU 2000 at 6ft girder spacing with a 15% increase in maximum span length. It is important to note that for smaller sections such as NU 900, there is an increase of 9% in maximum span length. This distinction occurs due to the strength at release limit state controlling the design. However, there is still a significant increase in span length when comparing 0.6 to 0.7 inch strands.

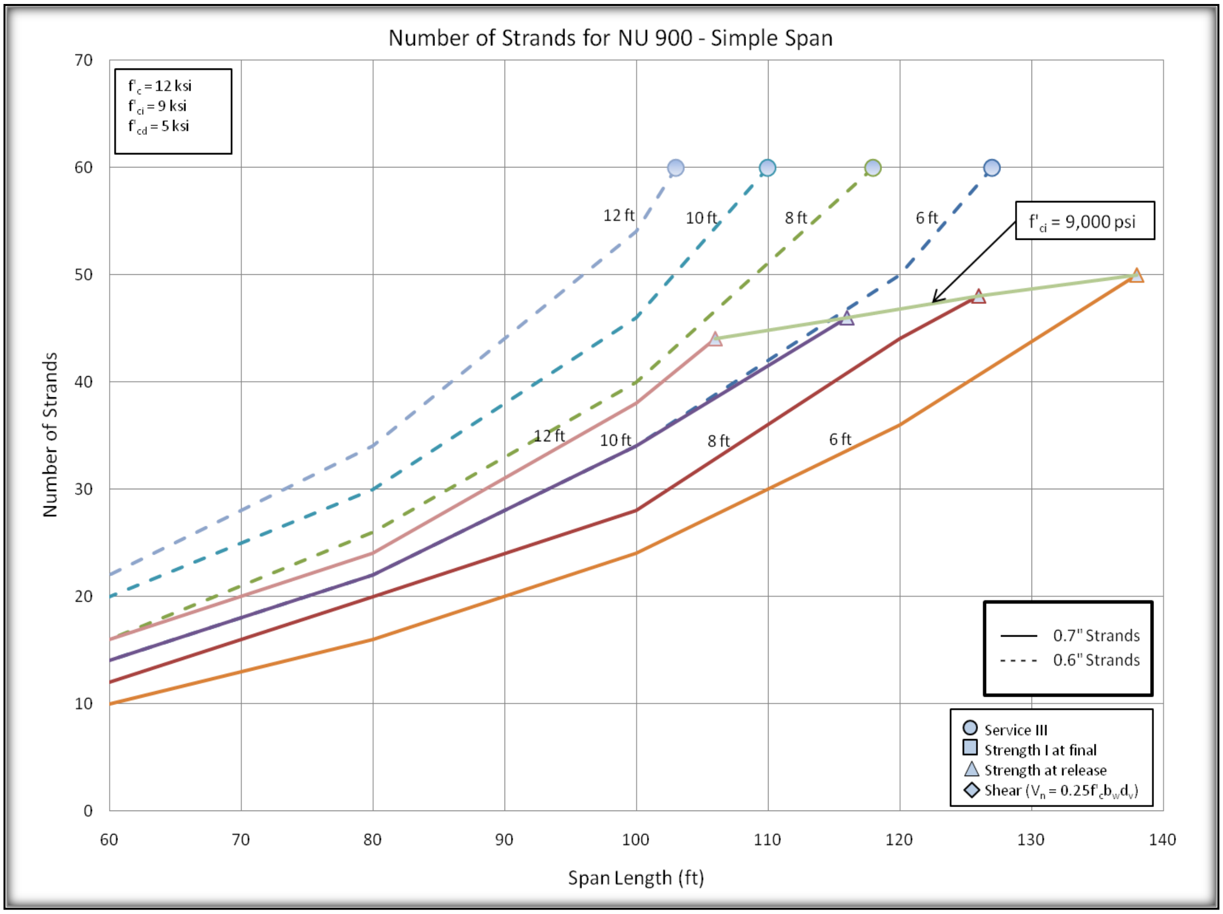

Figure 4.3 Detailed chart comparison between 0.6 and 0.7 inch strands

The detailed chart in figure 4.3 shows similarities to the summary chart in figure 4.2. The girders using 0.6 inch strands are all controlled due to Service III limit state and can utilize the maximum 60 prestressing strands. For 0.7 inch strands, Strength at Release limit state governs the design. However, longer span lengths are attainable with fewer prestressing strands, which results in a significant decrease in material and labor costs.

4.3 Compressive Strength of Concrete (8 ksi to 15 ksi)

The use of HSC is another significant aspect of precast/prestressed concrete design. Generally, standard concrete strength used in the state of Nebraska has been 8 ksi. HSC allows for higher compressive strength with very little increase in cost compared to 6 ksi. As stated before, HSC is especially important when used in correlation with 0.7 inch prestressing strands. The design charts created include concrete compressive strengths of 8, 10, 12, and 15 ksi. Compressive strengths of 8, 10, and 12 ksi include the use of 0.6 inch prestressing strands. Compressive strength of 12 and 15 ksi include the use of 0.7 inch prestressing strands. The compressive concrete strength at release is equivalent to 0.75*f'$_c$.

The summary chart in figure 4.4 and detailed chart in figure 4.5 show the relationship between different compressive concrete strengths of 8, 10, and 12 ksi using 0.6 inch prestressing strands. As seen in the chart, NU 2000 has approximately a 4% increase in span length between 8 and 12 ksi. However, NU 900 has a 24% increase in span length, mostly due to the strength at release limit state.

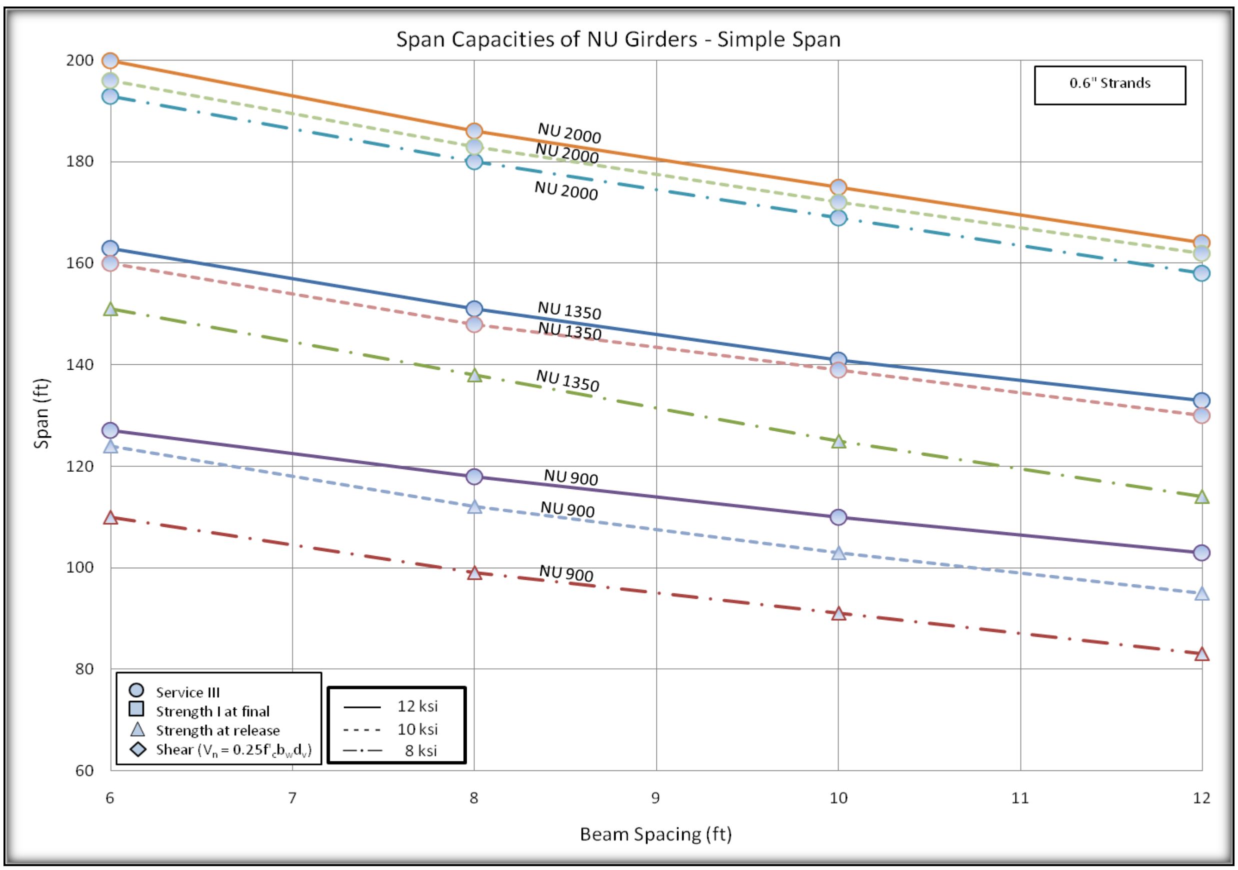

Figure 4.4 Summary chart for 8, 10, and 12 ksi concrete strengths

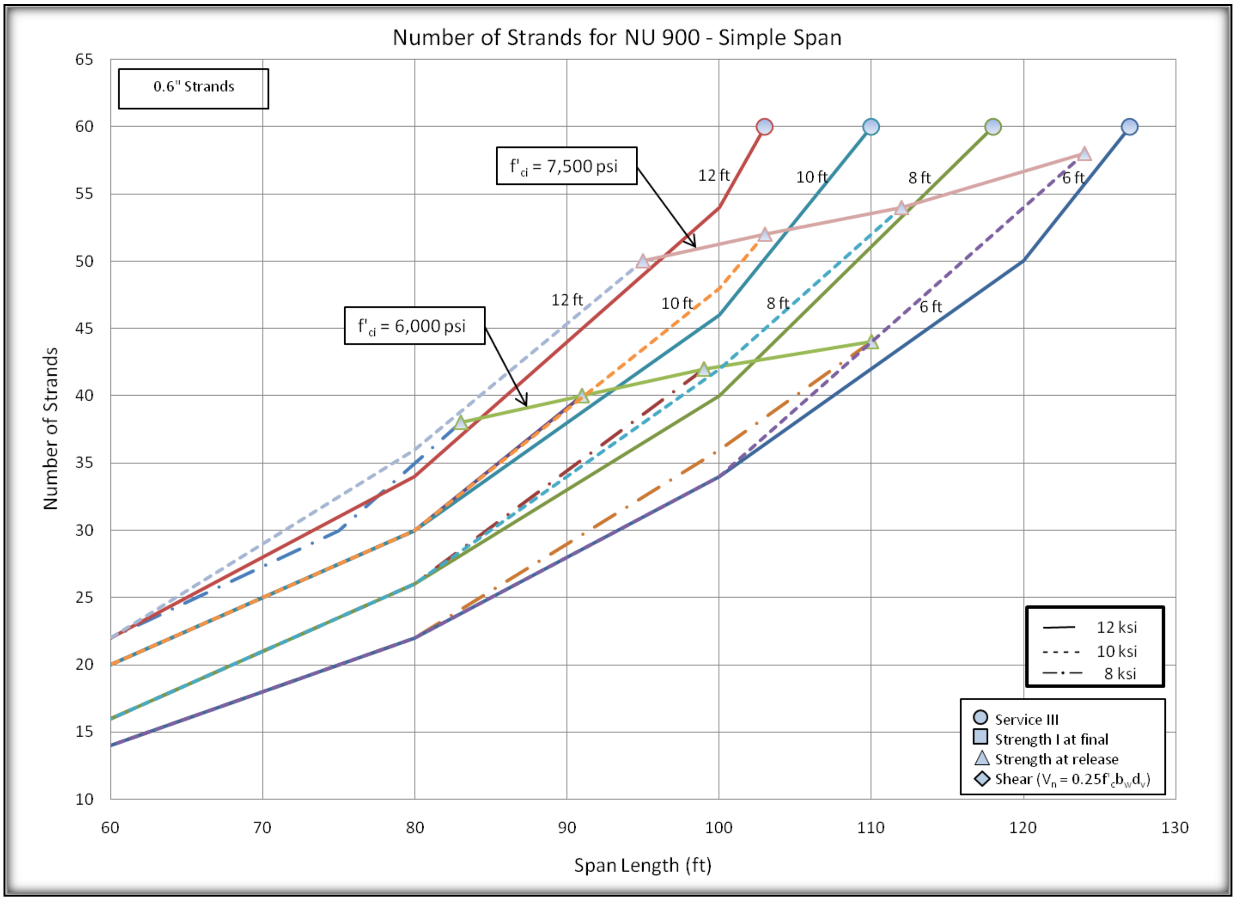

Figure 4.5 Detailed chart comparison between 8, 10, and 12 ksi concrete strengths

It can be concluded that the compressive strength at release and the depth of the girder controls the effect of high strength concrete. For shallower sections, the higher strength concrete of 12 ksi has a higher strength at prestress transfer. Therefore, it was not controlled by strength at release limit state and can obtain much higher maximum span lengths.

4.4 Strength Design Method vs. Working Stress Method for Concrete Strength at Release

The compressive strength at prestress transfer plays a vital role in the design of prestressed precast concrete bridge girders. Often times, the concrete strength at release can govern a design, thus preventing a more efficient design. This paper compares the results obtained from Strength at Release Method vs. Workings Stress Method based off of the simple span design charts. The strength design at release method allows for longer spans because of the elimination of unnecessary limits imposed by the working stress method on the concrete at release. This allows the design to be controlled by Service III rather than service at release. This approach permits the prestressing strands to be released at a lower concrete strength than the working stress method. Currently, NDOR leaves the decision of whether to use strength design or working stress design up to the bridge designer's discretion.

Using the strength design method, the precast members can be treated as a reinforced concrete column subjected to an axial compressive force and the moment that coincides.[3] The method will solve for f'_{ci} and the centroid axis by solving the force and moment equilibrium equations. Another advantage of the strength design method approach allows for the calculation of any top bonded reinforcement required to maintain strength at transfer with controlled tension cracking without using the uncracked section analysis of an already cracked section.[4]

As stated earlier, the strength design method allows the prestressing strands to be released at a lower concrete strength than the working stress method. This would allow for a more rapid production cycle. It would lower the cost for curing and demand for debonding and/or draping of strands. Overall, there would be a significant increase in efficiency for the precast/prestressing industry.

With a decrease in the required concrete strength at release, there is an allowance for higher span lengths, lower costs for accelerated curing, and lower demand for debonding and draping of strands at the ends of the girders.[4] The strength design method allows designers to eliminate the limit of $0.196 * \sqrt{f'_{ci}}$ as stated in the AASHTO LRFD 2007 code.[5] See figure 4.6 for a summary chart and figure 4.7 for a detailed chart comparison of strength design vs. working stress design methods for concrete strength at prestress transfer.

The summary chart in figure 4.6 shows a large difference in the maximum attainable span length between the strength design method and the working stress method. There is approximately 10% greater span lengths when using the strength design method. For the working stress method, the main governing limit is $0.6*f'_{ci}$, compression in the bottom fibers at prestress transfer.[4] This limit accounts for the decrease in maximum span length calculated, related to the strength design method. The detailed chart in figure 4.7 reiterates the same concepts, the strength design method allows for significantly larger maximum span lengths.

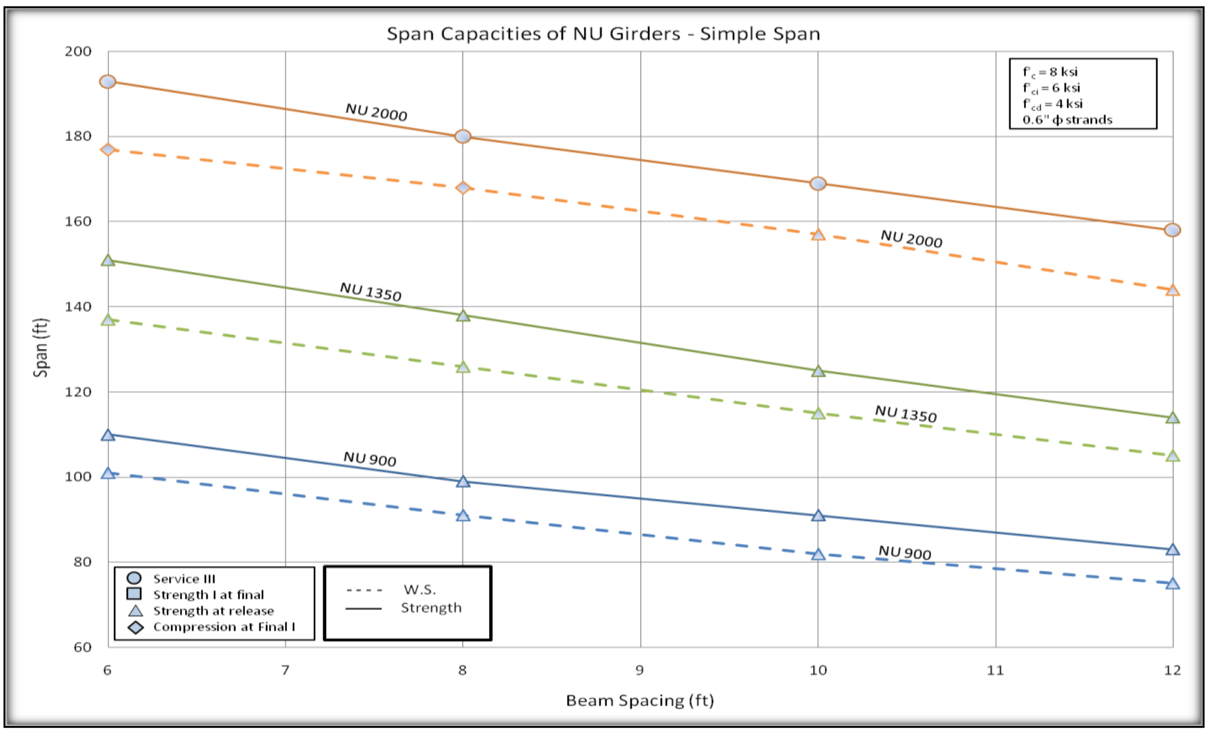

Figure 4.6 Summary chart comparing Strength Design Method and Working Stress Method

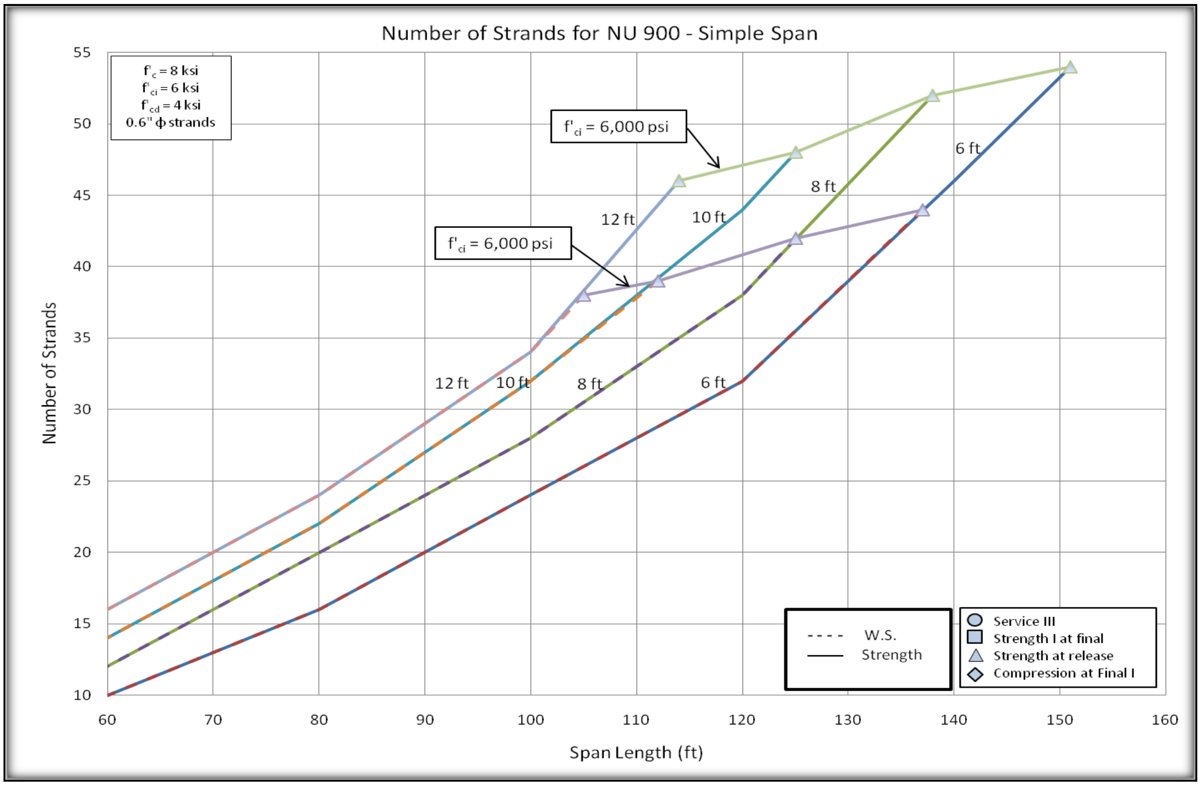

Figure 4.7 Detailed chart comparing Strength Design Method and Working Stress Method

<u>4.5 Threaded Rod Continuity System</u>

There are many advantages of the TR continuity system vs. the conventional bridge continuity system. TR continuity allows for longer span lengths, shallower girder depths, and a reduction in girder lines. The major advantages of this system are that the precast concrete girders are made continuous for about two-thirds of the total load, while the threaded rod system establishes continuity over the piers and resists the negative moment due to deck slab weight. The deflection and midspan bending moments are also greatly reduced, resulting in less prestressing and less camber. Lastly, this system allows designers to avoid post-tensioning. All of these advantages make for a more efficient and cost effective design.

A summary chart is shown below in figure 4.8 to compare the maximum span lengths obtained from TR continuity system and the conventional continuity system.

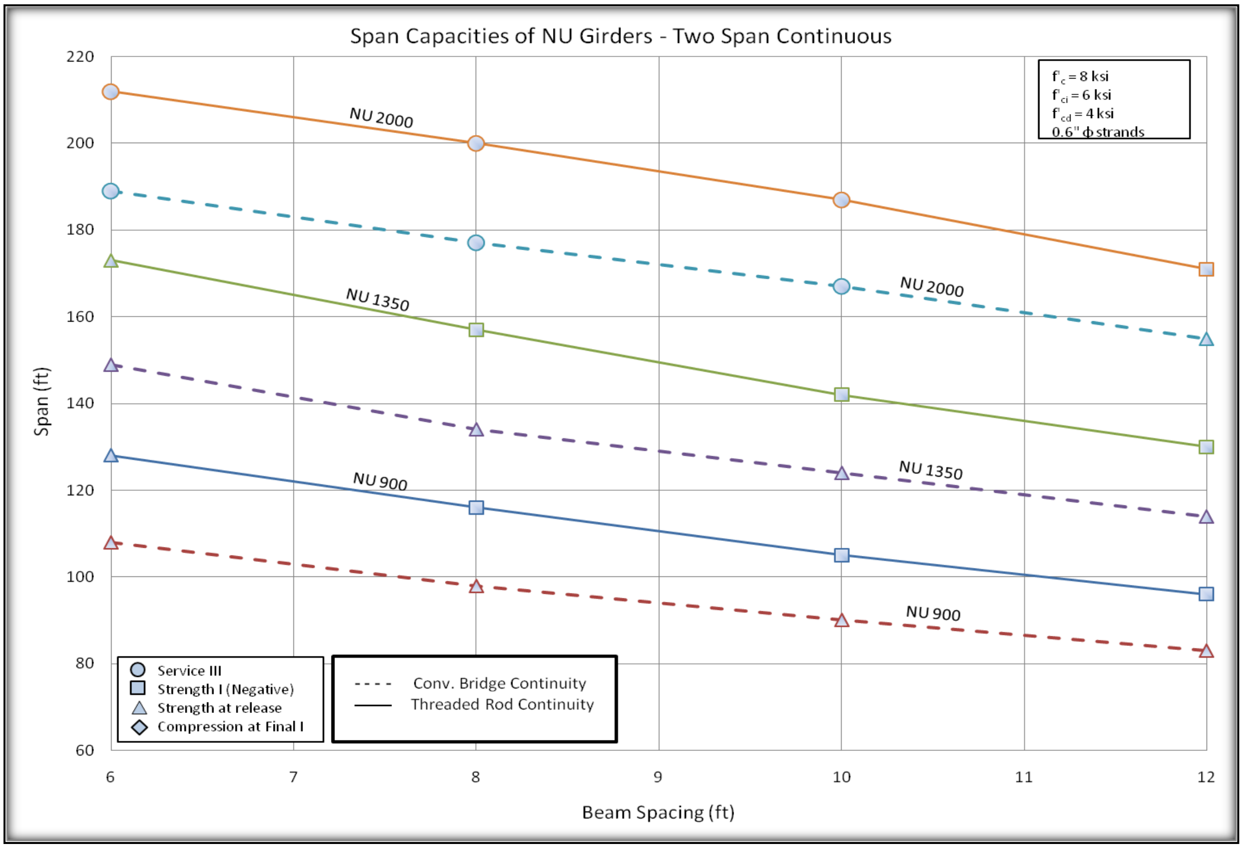

Figure 4.8 Summary chart comparison between TR continuity and conventional continuity

The summary chart in figure 4.8 shows the significant advantage in maximum attainable span length when using TR continuity versus the conventional bridge continuity method. The difference in span length can reach as high as 10-18% for any NU-I girder precast section. For the conventional bridge continuity system, the designs were governed by the positive moment section.

For the TR continuity system, designs using 6 ft girder spacing were typically governed by the positive moment. However, the majority of the designs were governed by the negative moment section by the Strength I (composite) limit state. To increase the maximum attainable span length for the TR continuity system, one could do the following to increase the negative moment capacity: add a steel plate to the bottom of the girder, add more threaded rods, increase the haunch thickness, increase top flange thickness, or increase web thickness. These options would allow for even higher span lengths than shown in figure 4.8.

Chapter 5 Design Aid Utilization Example

5.1 Design Example No. 1

The following example demonstrates how to use the design aids in an efficient manner: Design a simple span NU I-Girder bridge for HL93 loading with a 105 ft design span. The total width of the bridge is 46'-8". Use strength design method for concrete stresses at release. Assume depth requirements only allow use of NU 900 girders. Using the preliminary design charts, the various design alternatives are shown in table 5.1.

Table 5.1 Design alternatives – Example 1

I-Girder	Girder Depth (in.)	Deck t (in.)	Total Depth (in.)	Spacing (ft)	No. Girder Lines	Concrete Strength (ksi)	Strand Dia (in.)	Number of Strands
NU 900	35.4	7.5	43.9	6	8	8	0.6	40
NU 900	35.4	7.5	43.9	6	8	10	0.6	44
NU 900	35.4	7.5	43.9	8	6	10	0.6	50
NU 900	35.4	7.5	43.9	6	8	12	0.6	40
NU 900	35.4	7.5	43.9	8	6	12	0.6	48
NU 900	35.4	7.5	43.9	10	5	12	0.6	56
NU 900	35.4	7.5	43.9	6	8	12	0.7	28
NU 900	35.4	7.5	43.9	8	6	12	0.7	36
NU 900	35.4	7.5	43.9	10	5	12	0.7	40
NU 900	35.4	8.0	44.4	12	4	12	0.7	44
NU 900	35.4	7.5	43.9	6	8	15	0.7	28
NU 900	35.4	7.5	43.9	8	6	15	0.7	36
NU 900	35.4	7.5	43.9	10	5	15	0.7	42
NU 900	35.4	8.0	44.4	12	4	15	0.7	44

* A 1" Haunch thickness is added to the total depth thickness

For this example, only NU 900 girders were used. The alternative solutions were based on variations in girder spacing, concrete compressive strength, strand diameter, and number of strands. For the total depth, a haunch thickness of 1 inch was assumed. The number of girder lines is selected to prevent from exceeding the overhang length limits.

5.1.1 Recommendation

For this situation, it would be suggested to use the case highlighted in red. All of the cases are viable options and fit within the governing limits. However, due to the 12 ft spacing, only 4 girder lines are required. This alone will save a significant amount of money for cost of materials and cost of labor. Figure 5.1 and figure 5.2 show how the preliminary design charts are utilized in this design example.

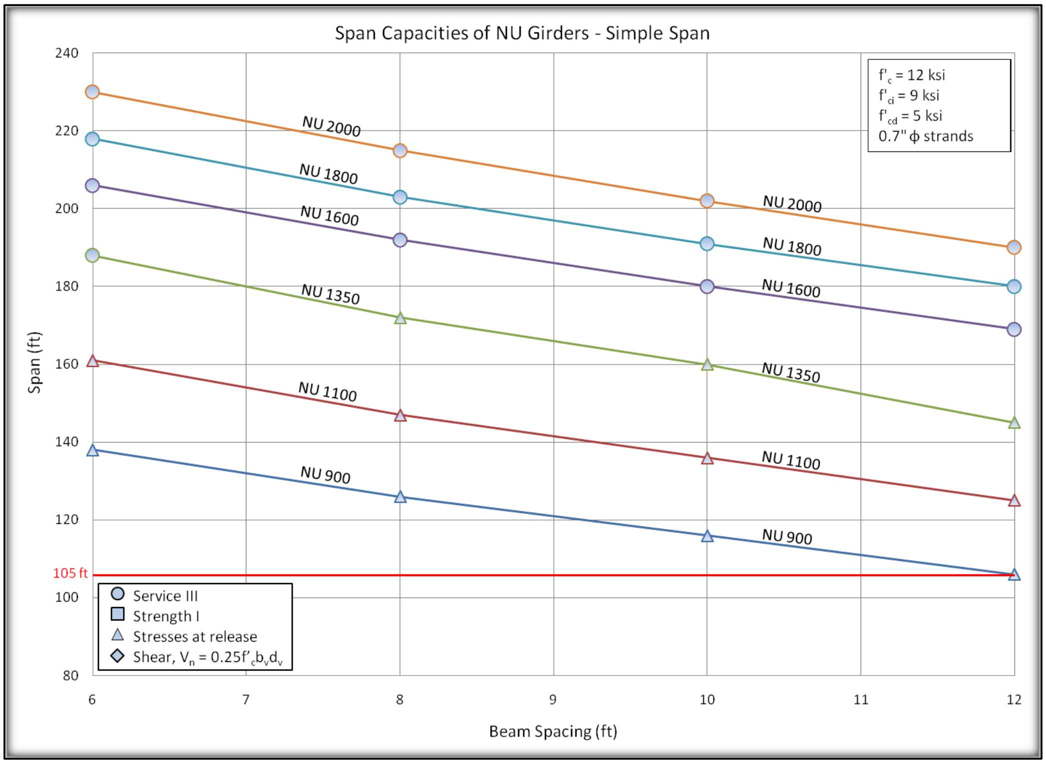

Figure 5.1 Summary chart – Example 1

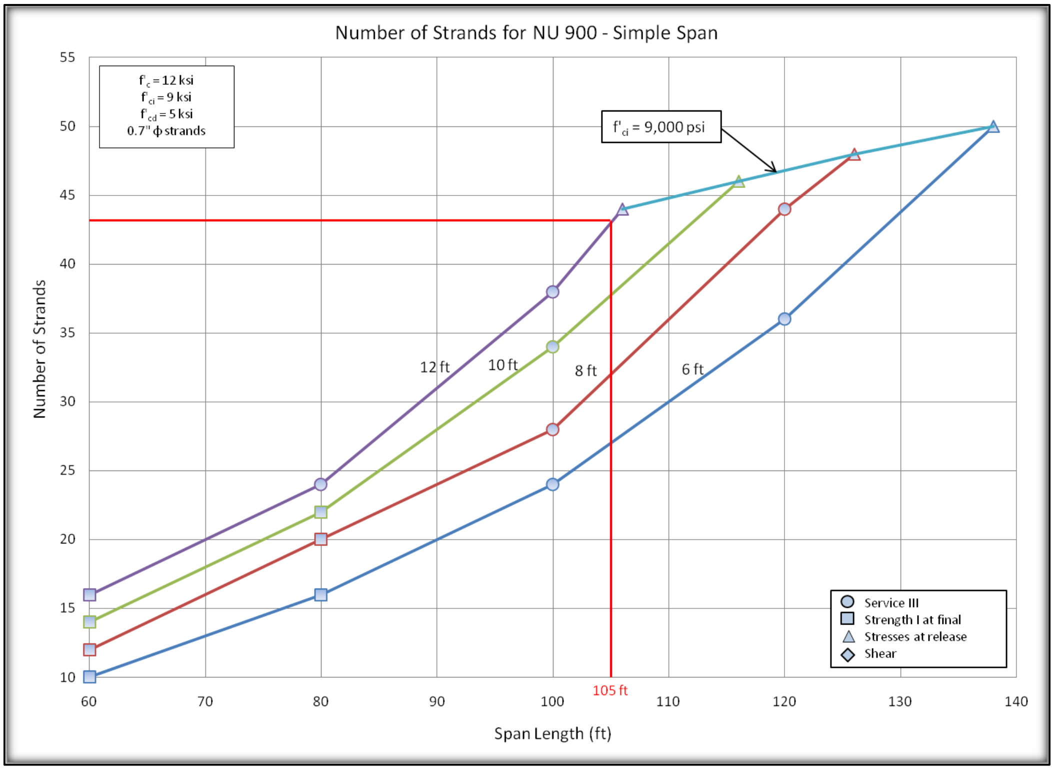

Figure 5.2 Detailed chart – Example 1

<u>5.2 Design example no. 2</u>

Design a two (equal) span NU I-Girder bridge for HL93 loading with a 150 ft design span. The total width of the bridge is 46'-8". Use the working stress method for concrete stresses at release. Assume there are no depth requirements. Using the preliminary design charts, the various design alternatives are shown in table 5.2.

Table 5.2 Design alternatives for Example 2

I-Girder	Girder Depth (in.)	Deck t (in.)	Total Depth (in.)	Spacing (ft)	No. Girder Lines	Concrete Strength (ksi)	Strand Dia (in.)	Number of Strands
NU 1100	43.3	7.5	53.3	6	8	15	0.7	28
NU 1100	43.3	7.5	53.3	8	6	15	0.7	32
NU 1100	43.3	7.5	53.3	10	5	15	0.7	36
NU 1100	43.3	7.5	53.3	6	8	12	0.7	28
NU 1100	43.3	7.5	53.3	8	6	12	0.7	32
NU 1100	43.3	7.5	53.3	10	5	12	0.7	36
NU 900	35.4	7.5	45.4	6	8	12	0.7	34
NU 900	35.4	7.5	45.4	8	6	12	0.7	38
NU 1100	43.3	7.5	53.3	6	8	12	0.6	38
NU 1100	43.3	7.5	53.3	8	6	12	0.6	44
NU 1100	43.3	7.5	53.3	10	5	12	0.6	48
NU 900	35.4	7.5	45.4	6	8	12	0.6	50
NU 900	35.4	7.5	45.4	8	6	12	0.6	58
NU 900	35.4	7.5	45.4	6	8	10	0.6	52
NU 1100	43.3	7.5	53.3	6	8	10	0.6	38
NU 1100	43.3	7.5	53.3	8	6	10	0.6	46
NU 1100	43.3	7.5	53.3	10	5	10	0.6	52
NU 1350	53.1	7.5	63.1	6	8	8	0.6	34
NU 1350	53.1	7.5	63.1	8	6	8	0.6	38
NU 1350	53.1	7.5	63.1	10	5	8	0.6	42
NU 1100	43.3	7.5	53.3	6	8	8	0.6	40

* A 2.5" Haunch thickness is added to the total depth thickness

For this example, many different combinations can be used to fulfill the 150 ft design span requirement. The alternative solutions are based off of variations in girder size, girder spacing, concrete compressive strength, strand diameter, and number of strands. For the total depth, assume a haunch thickness of 1 in. The number of girder lines is selected to prevent exceeding the overhang length limits. It is important to choose the solution that is the most practical and can save in material and labor cost.

5.2.1 Recommendation

For this situation, it would be suggested to use the case highlighted in red. All of the cases are viable options and fit within the governing limits. However, due to the 10 ft spacing, only 5 girder lines are required. There are five total cases using 10 ft spacing. Therefore, choosing concrete compressive strength of 12 ksi and 0.7 in. diameter strands is the most practical option, thus requiring less prestressing strands. Figure 5.3 and figure 5.4 show how the preliminary design charts are utilized in this design example.

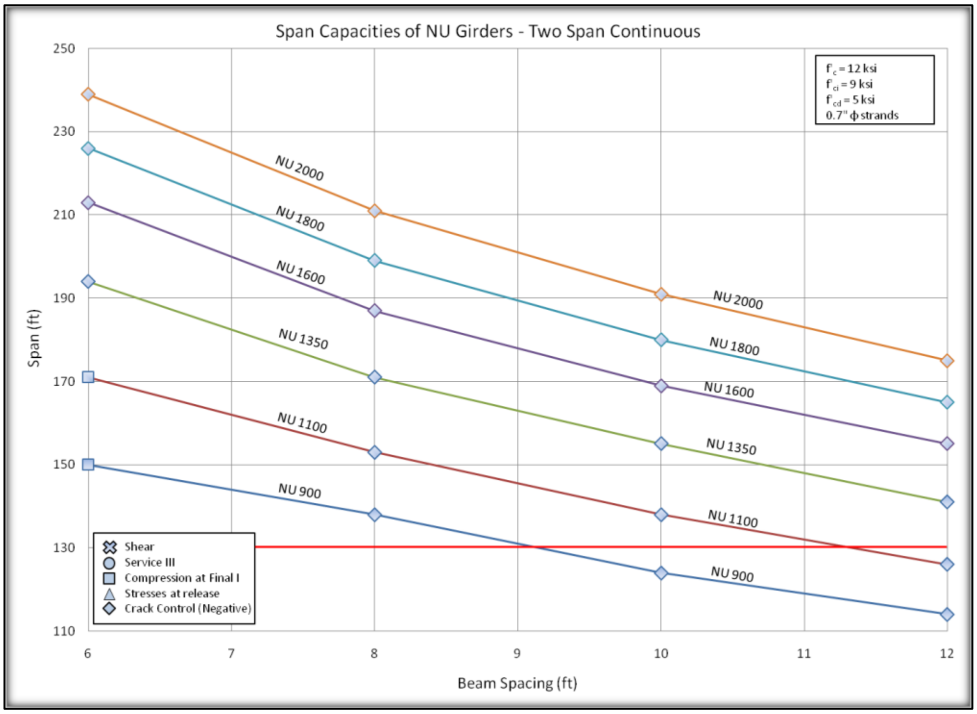

Figure 5.3 Summary chart – Example 2

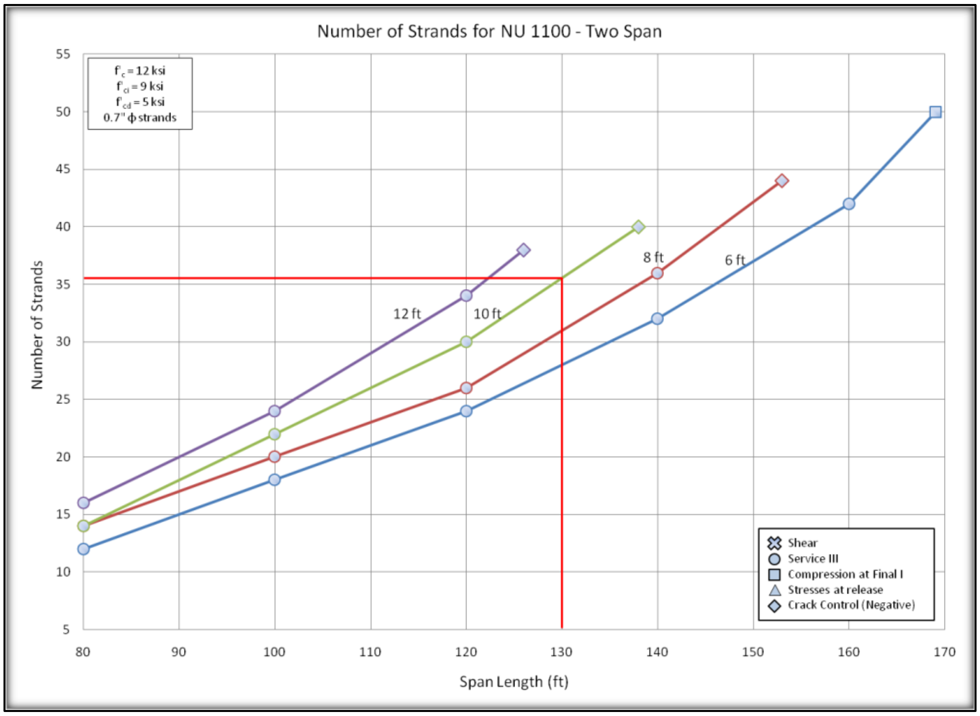

Figure 5.4 Detailed chart – Example 2

5.3 Design example no. 3

Design a three span continuous NU I-Girder bridge for HL93 loading. The span length outline is 0.8L, L, 0.8L.

(5.1)

Assume the middle span length is 200 ft long. The total width of the bridge is 46'-8". Assume depth requirements only allow use of NU 1600 girders. Also assume the precasting plant is only equipped to use 0.6 inch prestressing strands. Use the strength design method for stresses at release. Using the preliminary design charts, the various design alternatives are shown in table

5.3. Figure 5.5 and figure 5.6 show how the preliminary design charts are utilized in this design example.

Table 5.3 Design alternatives – Example 3

I-Girder	Girder Depth (in.)	Deck t (in.)	Total Depth (in.)	Spacing (ft)	No. Girder Lines	Concrete Strength (ksi)	Strand Dia (in.)	Number of Strands
NU 1600	63.0	7.5	73.0	6	8	8	0.6	54
NU 1600	63.0	7.5	73.0	8	6	8	0.6	60
NU 1600	63.0	7.5	73.0	6	8	10	0.6	52
NU 1600	63.0	7.5	73.0	8	6	10	0.6	58
NU 1600	63.0	7.5	73.0	6	8	12	0.6	52
NU 1600	63.0	7.5	73.0	8	6	12	0.6	56
* A 2.5" Haunch thickness is added to the total depth thickness								

For this example, only NU 1600 girders are used. The alternative solutions are based off of variations in girder spacing, concrete compressive strength, strand diameter, and number of strands. For the total depth, assume a haunch thickness of 2.5 in. The number of girder lines is selected to prevent from exceeding the overhang length limits.

5.3.1 Recommendation

For this situation, it would be suggested to use the case highlighted in red. All of the cases are viable options and fit within the governing limits. However, due to the 8 ft spacing, only six girder lines are required versus using 6 ft spacing. Higher strength concrete is used in this example, which requires less prestressing strands. The use of larger girder spacing and larger prestressing strands will save a significant amount of money for cost of materials and cost of labor.

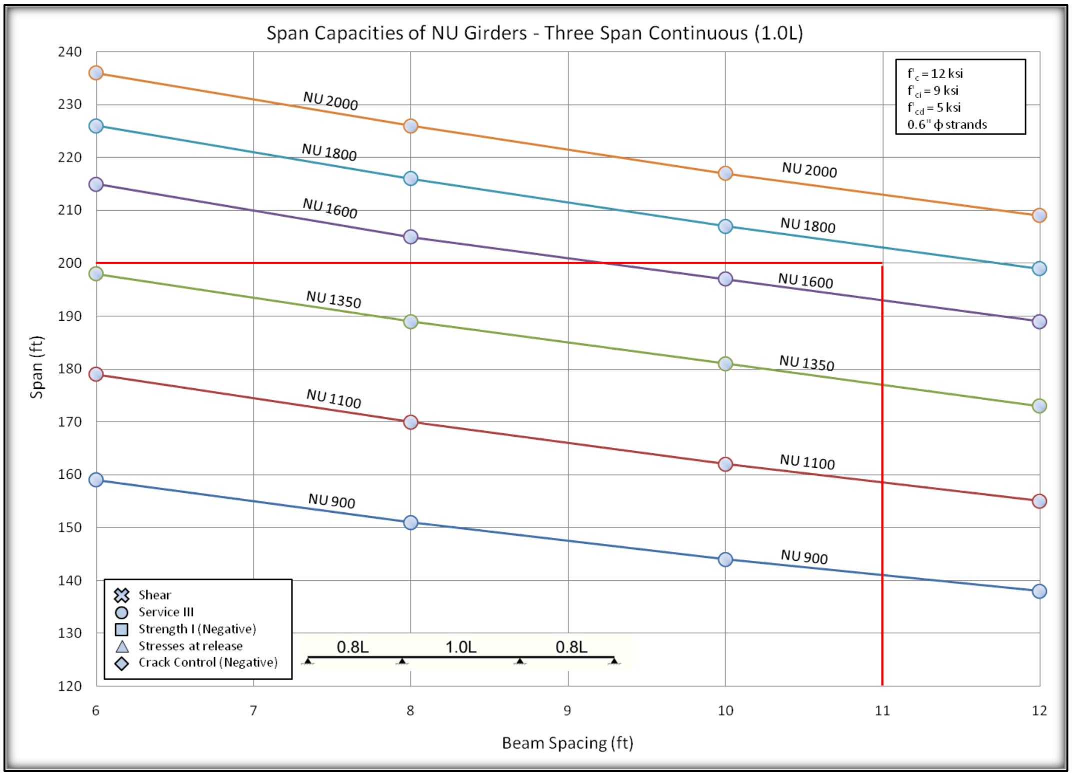

Figure 5.5 Summary chart – Example 3

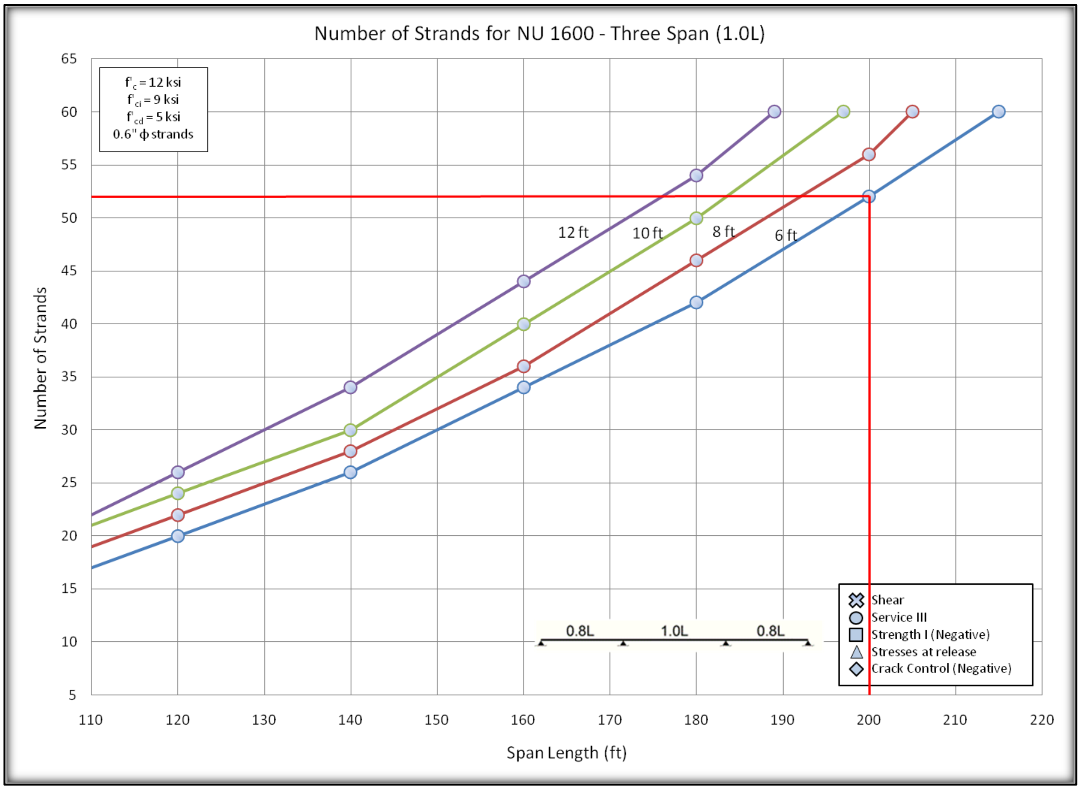

Figure 5.6 Detailed chart – Example 3

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