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Strategies for Economy

4.0 INTRODUCTION

The use of precast, prestressed concrete products for the construction of bridges results in very economical, high quality structures. This is due to several factors:

- Mass production of standardized, low maintenance sections
- A factory environment that includes quality control
- Speed of erection and construction
- The use of high quality, inexpensive and locally available materials for production

This chapter discusses some considerations for the designer to further enhance the cost effectiveness of precast, prestressed concrete bridge construction.

4.1 GEOMETRY

All bridges must meet the specific geometric constraints for each unique site. The length of the bridge must be sufficient to cross the features below. This can be accomplished by providing fewer longer spans or a larger number of shorter spans. Pier/bent placements may be restricted by roadway or railway systems and their necessary horizontal clearances. Likewise, specific requirements for ships or barges may dictate the placement of piers on either side of a main channel. Existing utilities may limit the locations of foundations. At other locations, such as stream and creek crossings, the designer may have more control over placement of the substructure. The choice of span length can also be affected by the cost of substructure units. Where the foundation conditions are poor or the piers are tall, it could be more economical to use longer spans. The choice of span length should result from the lowest combined cost of the superstructure and substructure. Each site must be evaluated to determine the most appropriate span arrangement to accommodate the necessary horizontal and vertical clearances of the system below the bridge.

4.1.1 Span Length vs. Structure Depth

The depth of the bridge superstructure increases with the span length. As a general rule, this is also true for precast, prestressed concrete. However, the structural efficiency of deeper sections may not always result in cost efficiency.

Raw bridge cost is not the only basis for selecting structure type. Hydraulics and/or gradeline constraints may require very shallow superstructures. Structures that can be constructed rapidly might be justified if detour time, and therefore user costs, can be minimized. Environmental considerations could justify the extra cost of special aesthetic structural designs.

Superstructure depth is frequently controlled by minimum vertical clearance requirements. These are typically established by the functional classification of the highway and the construction classification of the project. As discussed in Chapter 1, a common requirement is that the bridge superstructure be as shallow as possible to satisfy both minimum vertical clearance requirements and to minimize approach grades. Therefore, a high span-to-depth ratio is desired.

4.1.1.1 Shallow Sections

Shallower systems may require more strands and a higher release strength, but, as a rule, are less expensive, since less concrete is required. In addition to the reduced direct material cost, reduced costs can be realized by lower shipping and handling weights. Spans of up to 40 ft can be achieved using solid slabs, voided slab beams or stemmed members placed side-by-side. For a given span length, voided slab beams or stemmed members may use less material and be relatively lightweight. However, solid slabs may be less expensive, since the forms are very inexpensive and the fabrication of the solid slab is relatively uncomplicated.

4.1.1.2 Deeper Sections

As span length increases, there is the need to increase section properties of the superstructure components, while reducing their weight. Deeper sections such as box beams and deeper stemmed sections, placed side-by-side, become advantageous. The greater depth contributes to an increased moment of inertia, while the reduction of the concrete in the voided portion of the beam helps to keep the weight of the section to a minimum. As span length continues to increase, the use of superstructure components not placed side-by-side become the more cost-effective solution. These types of systems, such as spread box beams and I-beams, require the use of a cast-in-place concrete deck to span between beams.

4.1.1.3 Water Crossings

For typical stream or creek crossings where the foundation conditions are good, it may be more economical to use a larger number of shorter spans. The cost of additional substructure units must be weighed against savings associated with the use of smaller cranes which can be used with shorter, lighter beams. Physical constraints on the location of substructures generally are few and are probably restricted only to hydraulic considerations. The balance between the number and costs of substructure units and the size of the superstructure members becomes the primary factor in minimizing construction costs.

4.1.1.3.1 Vertical Profile at Water Crossings

Superstructure depth is important when freeboard of the stream must be maintained, while reducing the impact on the vertical profile of the bridge and approach roadways. Increased structure depth may increase the volume of fill for the approach roadways and have an effect on right-of-way requirements to accommodate roadway fill.

4.1.1.4 Grade Crossings

At grade crossings, span lengths are generally dictated by horizontal clearance requirements and other safety considerations. The span lengths usually are such that the use of spread box beams or I-beams is effective. Depth of structure becomes a consideration in establishing the bridge profile while maintaining the required vertical clearance for the transportation system below. As with water crossings, the structure depth will have a direct impact on the volume of approach roadway fill and the measures necessary to accommodate that fill.

4.1.1.5 Wearing Surface

The use of a wearing surface may be desirable to improve durability and enhance the quality of the ride. A cast-in-place concrete composite topping is a superior wearing surface for high traffic volumes and can also increase the load carrying capacity of the superstructure. On rural bridges with low traffic volumes, especially when deicing salt is not used, the precast concrete surface provides outstanding durability and lowest possible construction cost. In other cases, a waterproof membrane and asphalt surface can be used effectively.

4.1.2 Member Spacing

As span length increases, it becomes necessary to evaluate the use of various beam types, plus evaluating the depth of beams against the number of beams required. For a given span length, a 54 in. deep beam and a 63 in. deep beam may both be acceptable. The number of 54 in. deep beams required in the cross-section will likely be more than 63 in. deep beams. As with shorter span bridges, depth of structure versus the effect on the roadway/bridge profile and the vertical clearance below must be evaluated.

4.1.2.1 Wider Spacings

Generally, the use of fewer beams at a greater spacing will prove to be more economical than more beams at a lesser spacing. The use of fewer members means reduced volume of beam concrete required to be cast and fewer beams to fabricate, ship and erect. Other savings result from the reduction in the number of bearing devices, fewer end diaphragms/edge beams to form and cast, fewer bays between the beams in which to install and remove deck forms and fewer manhours to inspect. Very wide beam spacings (in excess of 12 ft) must be carefully considered, since the cost of the deck and its forming may override the savings of the reduced number of beams. Future deck replacement and staged construction should also be considered in selecting beam spacing.

4.1.3 Maximizing Span Lengths

For a given beam depth, it is often advantageous to use the beam at its maximum span length, even if closer spacings are required.

4.1.3.1 Advantages of Maximum Spans

By using a beam at its maximum span capability, the designer can achieve a longer span without increasing the depth of the structure. This can provide for better horizontal and vertical clearances for the roadway, railway or waterway below. Additionally, for longer bridges, the use of extended spans means fewer substructures must be constructed. Often, longer spans are necessary and consideration of superstructure cost versus substructure cost must be evaluated. For example, when very expensive substructures are required, such as those which must resist ship impact or which require deep or massive foundations, the cost of the superstructure with longer spans becomes more economical.

4.1.3.2 Limitations of Maximum Spans

Designers must be cognizant of the limitations of production facilities, handling, shipping and erection applicable to longer beams. The use of beam sections not available through local producers will usually be more expensive if the forms must be purchased for a small number of beams. Local producers may not have prestressing beds capable of withstanding larger prestressing forces. Longer beams are heavier and may require larger cranes for handling and erection and special truck/trailer systems may be required to transport the beams to the job site. Generally, increased weights are not an issue for erection over water if the beams can be transported to the site by barge.

4.1.4 Splicing beams to Increase Spans

To increase span capabilities of precast, prestressed concrete beams, designers should consider the technique of splicing. Through the use of post-tensioning or other splicing methods, continuity and its inherent benefits relative to moment reduction in the superstructure and a reduction in the number of expansion joints can be achieved. Splicing beams also reduces the size and weight of the segments, allowing easier handling and erection, and lighter weights for shipping. Splicing does, however, have additional costs associated with the time to splice the sections, possible need for temporary supports and the splicing system itself. For more detailed information on the use of spliced beams, see Chapter 11.

4.1.5 Special Geometry Conditions

Overall bridge geometry is very often dictated by the roadway designers. The bridge location within a roadway system frequently establishes the bridge within a horizontal curve, a vertical curve, with skewed substructures, or with flared spans to accommodate ramps.

4.1.5.1 Horizontal Curves

Straight precast, prestressed concrete beams can usually be used for horizontally curved bridges. The beam placement must take into account the degree of curvature and the span length. The primary impact of the curve is on the location of the exterior beams. The overhang of the deck must be evaluated at the beam ends and at midspan to ensure that proper consideration is given to the loading of the beam under both dead and live loads.

4.1.5.2 Vertical Curves

The profile of the deck may include crest or sag vertical curves. The designer must consider the camber of the beam relative to the deck profile to establish the proper build-up of concrete or haunch over the beam (**Figure 4.1.5.2-1**). The volume of concrete in the build-up is larger in wider beams such as bulb-tees (**Figure 4.1.5.2-2**). Horizontal curves also affect the volume of concrete in the build-up due to the superelevation of the roadway. However, this build-up concrete is inexpensive since costs are almost exclusively a function of the concrete material cost. No additional forming, placement or curing costs result from the build-up. In some locations, producers have successfully fabricated beams with a specified top profile and cross slope (within reasonable limits) to accommodate a certain vertical profile and superelevation. This is often done with deck bulb-tees, which are wide, erected with their top flanges touching, and using no cast-in-place topping or asphalt wearing surface.

Figure 4.1.5.2-1
Beam Camber/Deck Relationship

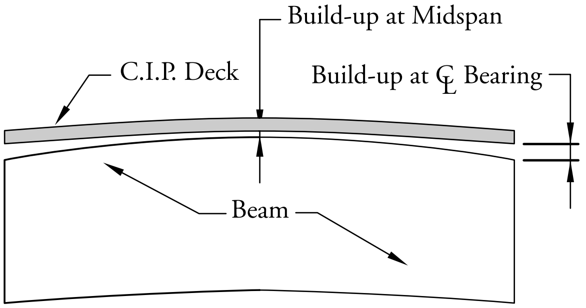
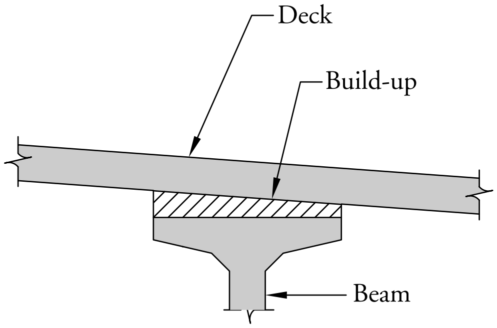
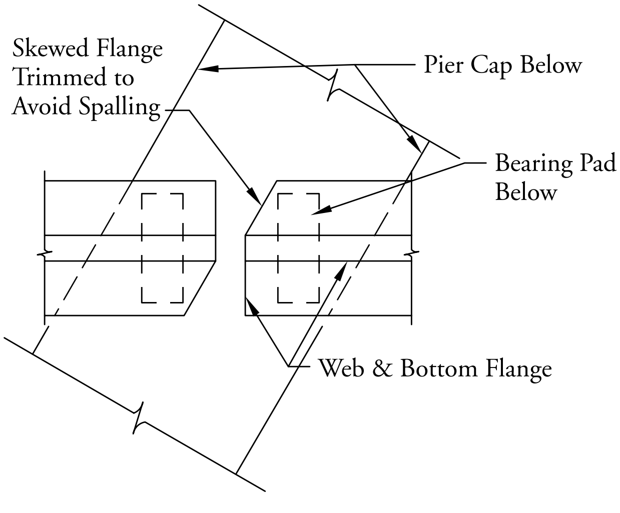


Figure 4.1.5.2-2
Build-up over Beam



4.1.5.3 Skews

Figure 4.1.5.3-1
Beam Ends at Support
with Large Skew

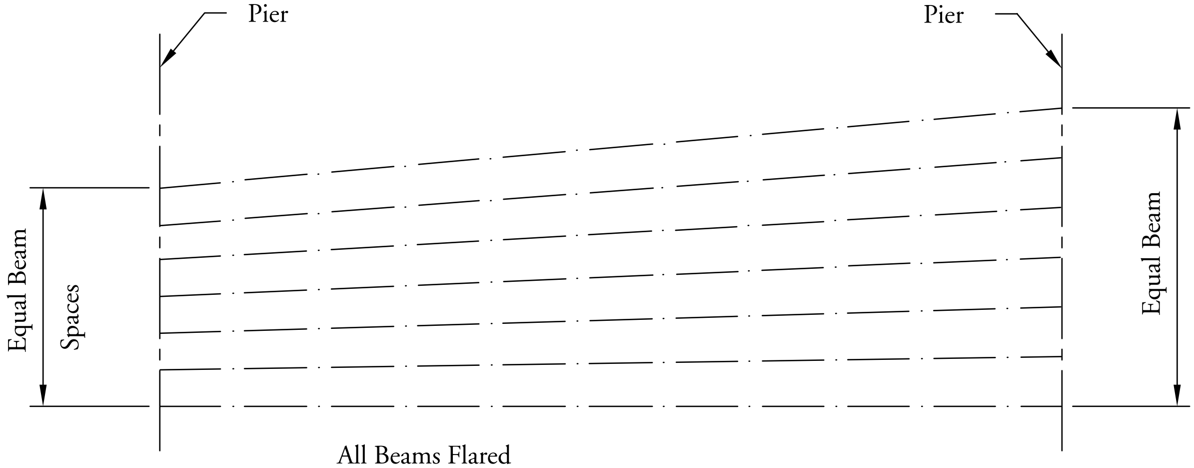


Substructures which are skewed to the beam require some consideration. If possible, avoid skewed supports. The *LRFD Specifications* modify the live load distribution factor for skewed superstructures. Additionally, beam ends are usually skewed so that the ends of the beams are parallel to the substructure. Small skews normally will not affect the cost of precast, prestressed concrete beams. Extreme skews usually require the producer to take measures to reduce spalling of the beam end during the strand detensioning operation. Otherwise, the "point" on the beam end must support the dead weight of the beam when in the prestressing bed. This, combined with elastic shortening, usually results in spalling. One method of reducing the spalling is to trim the point of the skew from the beam as depicted in **Figure 4.1.5.3-1**. If a spall does occur, it is generally minor and can be easily repaired without affecting the integrity of the bearing area.

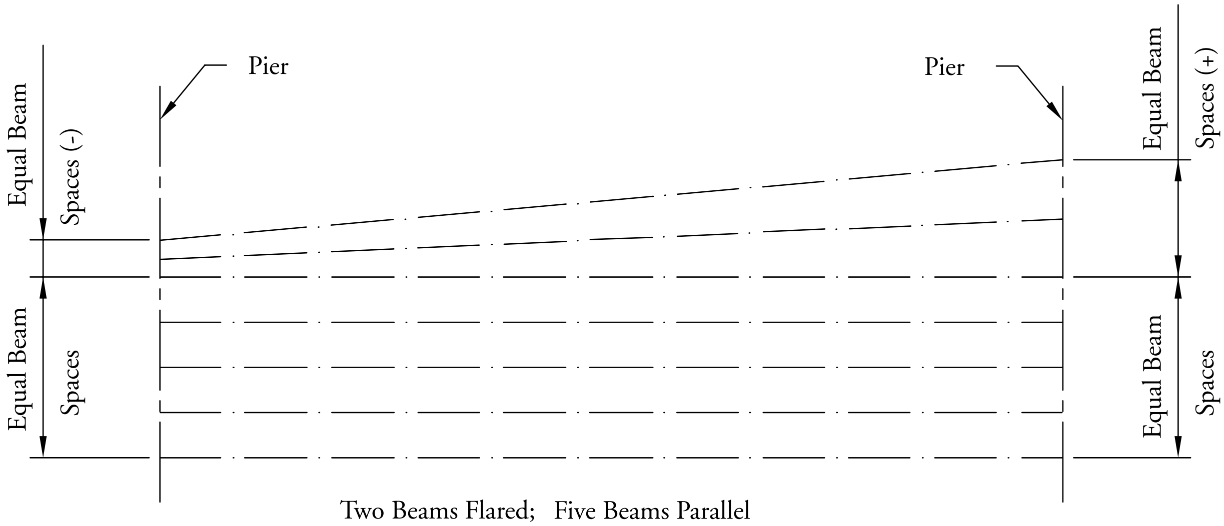
4.1.5.4
Flared Structures

Flared spans are those structures which have one end wider than the other. By using as many parallel beams within the span as possible, the designer can reduce the fabrication and construction costs of the superstructure. This results from maintaining more uniform beam lengths, typical beam end skews and reduced deck forming costs. **Figure 4.1.5.4-1** depicts two beam layouts which could be used for a flared span. Note that with all beams flared, each of the beams is unique. The alternate with five parallel beams has three unique beams and the deck forming will be more uniform.

Figure 4.1.5.4-1
Span Configurations
For a Flared Structure



All Beams Flared



Two Beams Flared; Five Beams Parallel

4.1.5.5
Varying Span Lengths

When possible, design precast beams with the same cross section and strand pattern. Economy in precasting results from the production of identical sections. If a bridge consists of different span lengths, it may be better to design all of the precast units with the same cross-section rather than to design each span for the minimum depth-span ratio.

4.1.6 Product Availability

Designers must determine the availability of precast products in the local area. If the product selected for the project is not available within 200 to 500 mi, depending on the geographic region, a premium for shipping from a distant precaster or for local form purchase may be added to the project. Designs using local and readily available member types will result in lower bid prices.

4.1.6.1 Economy of Scale

If a single project uses a large quantity of a specific product, or if a new product will be used as a standard for future bridges, the considerable cost of new forms, when amortized over a large volume, becomes far less significant. Designers should consult local producers early in the study phase of a bridge project to determine the available precast products or the costs associated with new products for a specific application. Many times it is possible to create a new section by making small, inexpensive modifications to existing forms, such as casting a 3'-6" deep box beam in a 4'-0" deep form, or placing AASHTO Type II beam side forms on a wider Type IV bottom form.

4.2 DESIGN

Many decisions made during the design of precast, prestressed concrete bridges have a direct economic impact on the bridge construction cost. Some of these decisions are:

- Structural system (simple spans versus continuity)
- Integral caps and/or abutments
- Use of intermediate diaphragms
- Prestressing systems
- Durability systems
- Bearing systems
- Use of lightweight aggregate concrete
- Special construction techniques

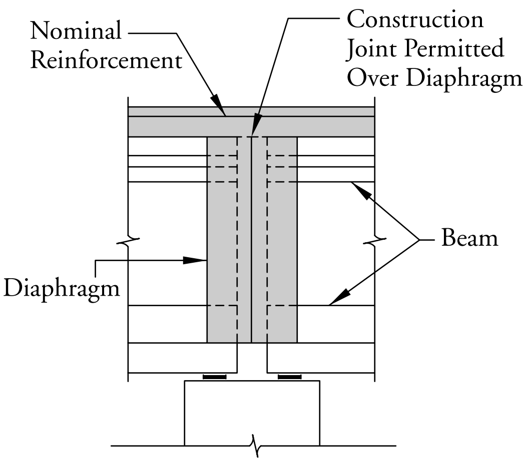
4.2.1 Advantages of Simple Spans

Simple span prestressed concrete superstructures can result in very economical bridges. Many designers rely almost exclusively on simple spans for this very reason. With simple spans, end diaphragms and end connections are greatly simplified. There is a significant reduction in the volume of reinforcement required over interior supports. There are also substantially reduced structural effects of short and long term volume changes due to temperature variations and creep and shrinkage.

4.2.2 Limitations of Simple Spans

Use of simple spans may, however, limit the span length for a particular product or require more beams for a particular span. The use of more prestressing strands may allow for an increased span length, but may create a need for increased concrete strength at release of the prestress force. This may force the cycle time of the prestressed bed to be increased, reducing the efficiency of the plant. There may also be more joints over substructures which can affect deck ride quality. Also, joints must be maintained to reduce premature deterioration of the substructure and bearing devices caused by road salts and deicers. Some designers have successfully eliminated this problem by casting the deck continuous over supports and placing additional nominal reinforcing steel in the deck to reduce deck cracking (**Figure 4.2.2-1**).

Figure 4.2.2-1
Detail to Eliminate Deck Joint



4.2.3 Continuity

In designing continuous superstructures, designers can take advantage of increased span lengths or reduce the number of beams required for a span. The smaller positive moments which occur in continuous systems will reduce the required number of prestressing strands. Continuity will reduce the number of joints in the superstructure and enhance redundancy of the structure.

The continuous superstructure also increases the resistance of the structure to horizontal forces, particularly seismic loads and ship impact forces.

4.2.3.1 Achieving Continuity

Continuity is usually achieved through the use of enhanced, positive beam connections over supports and reinforcing the deck over the substructure to withstand the negative moments due to composite dead and live loads. Longitudinal post-tensioning of the beams may be expensive, but can also be used to achieve continuity. Refer to Chapter 11 for a full discussion of these issues.

4.2.3.2 Limitations of Continuity

Proper detailing of continuous superstructures over the supports should be provided to avoid diaphragm cracking. Some end diaphragms with improper details have resulted in cracks from volumetric changes in the concrete. Use of continuity without post-tensioning requires a significant increase in the amount of mild steel reinforcement in the deck. Some states design beams as simple spans and use continuous slabs over the supports to eliminate joints and reduce the negative effects of the volumetric changes.

4.2.4 Integral Caps and Abutments

Integral caps and abutments have been used successfully in several areas. By creating proper connections between the superstructure and substructure, moments from the superstructure are distributed to the substructure components. More information on integral bridges is found in Chapter 13 and PCI Bridges Committee Report on "Integral Bridges" (1997).

4.2.4.1 Advantages

In addition to the benefits of reduced positive moments in the span, there are also significant increases in the resistance to horizontal forces and redundancy of the structure. Transverse joints and bearing devices are virtually eliminated. Integral abutments are flexible and tolerate a wide range of temperature movements. Integral abutments can be used for precast concrete bridges with lengths up to 1,000 ft. There is also strong potential to reduce the overall construction cost of the substructure.

4.2.4.2 Disadvantages

Design for this type of system is somewhat more difficult than for a continuous superstructure since substructure stiffness must be considered in the distribution of forces. Very stiff substructures make the system sensitive to volumetric changes. Also, connection design and construction requires more attention.

4.2.5 Intermediate Diaphragms

Intermediate diaphragms are a significant cost in the construction of prestressed concrete bridges. When used, intermediate diaphragms may be constructed of either concrete or structural steel. If concrete is used for these diaphragms, it will probably be permanent and its weight must be considered in the design of the beams.

4.2.5.1 Need for Intermediate Diaphragms

Although AASHTO implies that intermediate diaphragms are necessary, several research papers have concluded they are not required. References are cited in Chapter 3, Section 3.7. The cost to construct and install forms and reinforcement for diaphragms is very high, as is the connection to the beams. Several states have eliminated the use of intermediate diaphragms without negative impact on the performance of their prestressed concrete bridges.

4.2.5.2 Steel Diaphragms

Structural steel diaphragms are usually bolted to inserts in the beams, eliminating field forming and casting expense. However, accurate detailing of the steel and placement of the inserts are necessary to ensure proper fit in the field. Connections must allow for fabrication and construction tolerances. Steel diaphragms may also be more susceptible to corrosion, resulting in higher maintenance costs.

4.2.5.3 Precast Concrete Diaphragms

Precast concrete diaphragms have been successfully used. Precast diaphragms reduce the field labor costs associated with forming and placing of cast-in-place concrete. However, as with steel diaphragms, care must be taken in the detailing and fabrication of the precast diaphragms to accommodate fabrication and construction tolerances. Connection schemes for precast diaphragms must also be carefully considered. Recent development and tests in Pennsylvania have resulted in Penn DOT acceptance of a standard for precast diaphragms (Penn DOT, 1996).

4.2.5.4 Temporary Diaphragms

For some longer spans and deeper beams, temporary intermediate diaphragms may be desirable to increase the stability of the beams prior to and during placement of the concrete deck. Typically, these temporary diaphragms are steel.

4.2.6 Prestressing

Selection of either stress-relieved (normal-relaxation) or low-relaxation strands and the size of prestressing strand has a direct impact on the cost of prestressed products. Section 7 of Chapter 2 discusses the various types of prestressing strand materials which are available. Currently, the most common strand used in beams is seven-wire, low-relaxation, Grade 270 strand. The steel used in this strand can be pulled to a higher initial stress and exhibits lower losses than normal relaxation strand.

4.2.6.1 Strand Considerations

The use of fewer strands with larger diameter is generally more cost effective than the use of a larger number of smaller diameter strands. The cost of the strand is usually not directly proportional to the area of the strand (larger strands are proportionately slightly less expensive). But even if it were, the labor to install the larger number of smaller diameter strands will almost always make the use of the larger size strands more cost effective. As concrete design strength increases, the use of larger strands and their associated larger forces becomes more desirable. The use of larger strand enables the designer to place a larger prestressing force at the same eccentricity as the same number of smaller strands. This will increase the capacity of the beam. Using a lesser number of larger strands may also reduce congestion and facilitate concrete placement.

Designers are urged to avoid using more strands or prestressing force than required by design. Excessive strand is costly and can significantly increase camber.

Beams may be designed with strands having either a straight or harped trajectory.

4.2.6.2 Harped Strands

Very often, some of the prestressing strands are placed in a harped (deflected or sometimes draped) profile along the length of the beam. By harping the strands, designers are able to place the strands at the lowest position at midspan where the positive moment is largest, but raise the center of gravity of the prestress force near the end of the beam where the moments are reduced (see **Figure 3.3.2.4-1**). Raising the strands reduces the eccentricity and therefore the negative moment associated with the prestress force. The reduced negative moment results in lower compressive stresses in the bottom of the beam and lower tensile stresses in the top of the beam near its ends. In Chapter 3, detailed information on harping strands is contained in Section 3.3.2.

4.2.6.2.1
Harped Profiles

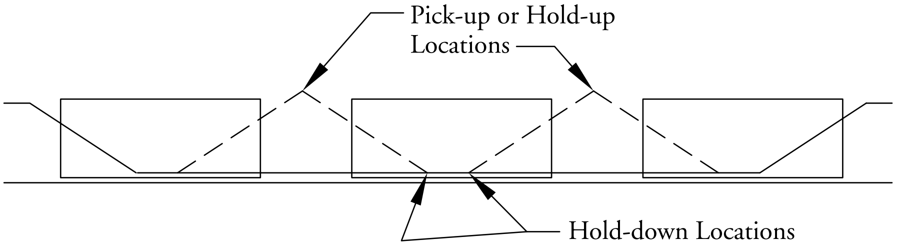
The method of achieving a harped strand profile requires the use of hold-down devices and either hold-up or pick-up devices. The location of the hold-down should be near a point that is approximately 0.4 to 0.45 of the beam length from the ends. Some designers have located the hold-down points as close to the ends as 0.3L; others have used a single point at midspan. Based on the shape of the typical positive moment envelope, the use of the 0.4L to 0.45L location may be the most appropriate choice. Use of a location closer to the end does not appear to provide increased capacity, and increases the forces in the hold-up/hold-down devices. When using a single hold-down at the center of the beam, the load transmitted to the anchorage for the hold-down sometimes becomes excessive.

4.2.6.2.2
Harping Methods

A hold-down device normally consists of rollers attached to a vertical rod, which passes through the bottom form and is anchored to the form substructure or foundation to resist the vertical component of the prestress force. The force which must be resisted by the hold-down device, and therefore its size, depends on the number of harped strands and the trajectory angle of the strands. There is a cost associated with the hold-down devices since they remain in the beam and are not reused. Additionally, when the hold-down locations along the length of the prestress bed are moved to accommodate different beam lengths, the bottom form must be patched.

Frequently, precast concrete producers use hold-up devices to raise the profile of the strand at the ends of beams and then tension the strands in their already harped profile. Others lift the harped strand to the proper elevation after tensioning the strands. Again, the number of harped strands and their angle directly influence the size and cost of the hold-up/pick-up device. **Figure 4.2.6.2.2-1** shows a typical harped strand profile in a prestressing bed. The designer can reduce the cost of the prestressed product by minimizing both the number of harped strands and the heights of the hold-up points.

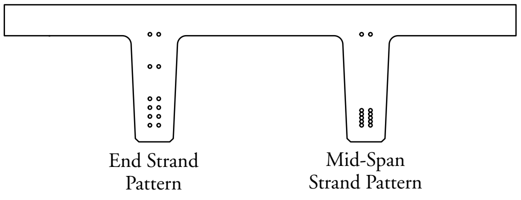
Figure 4.2.6.2.2-1
Harped Strand Profile



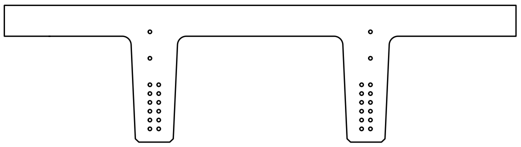
4.2.6.3
Straight Strands

The use of straight strand offers some advantages in the fabrication of prestressed concrete products. There are instances when the addition of a few straight strands can eliminate the need for harped strands. This option should be seriously evaluated, since the straight strand option, while using more strands, results in easier fabrication. **Figure 4.2.6.3-1** depicts a harped strand pattern and an alternate straight strand pattern. The increase in stresses due to more strands may be reduced by debonding some of the strands in the ends of the beams (see also Chapter 3, Section 3.3.2.9).

Figure 4.2.6.3-1
Straight vs. Harped Strands



Harped Strand Pattern - 24 strands required



Alternate Straight Strand Pattern - 28 strands required

4.2.6.3.1 Advantages of Straight Strands

Use of straight strands is generally less expensive than harped strands for several reasons:

- Hold-down/hold-up devices are not required
- Placement of beams within the bed is less restricted
- The stressing operation is made simpler and safer
- Detensioning operations are also simplified (hold-down/hold-up devices do not have to be released)
- Varying beam lengths will not require moving hold-down locations
- The cost of repairing the bottom form is eliminated

4.2.6.3.2 Debonding Strands

The effect of harping on stresses can be approximated by using straight strands located as required for the maximum positive moment and debonding some of the strands near the ends of the beam. Debonding is achieved by sheathing the strand in plastic tubing. By selectively debonding strands, the designer can effectively control the prestress force and eccentricity, achieving results similar to harping strands.

4.2.6.3.3 Limitations of Straight Strands

When increasing the number of strands, it may become necessary to increase the release strength and/or the final design strength of the concrete in order to resist the larger compressive force. Disadvantages of using debonded strands include the elimination of the vertical components of the prestressing force which may result in a slight increase in shear reinforcement. Design effort may be increased to determine proper debonding patterns, shear reinforcement and camber. Designers should consult precast producers in the project area to determine strand harping capability and debonding preference.

4.2.6.4 Strand Spacing

The *Standard Specifications* currently require that strands be spaced, center-to-center equivalent, no closer than four strand diameters. Several research projects have demonstrated that closer strand spacings do not adversely affect bond between concrete and strand. In fact, some states have successfully used smaller strand spacings for many years. Most plants have constructed stressing headers that provide for a strand grid spacing of 2 inches. Before adjusting strand spacing, it should be determined whether the change will require the producer to adjust plant equipment. Designers should consult producers in the geographic area of the project to determine strand patterns and configurations being used (see Chapter 3, Section 3.2.2.3).

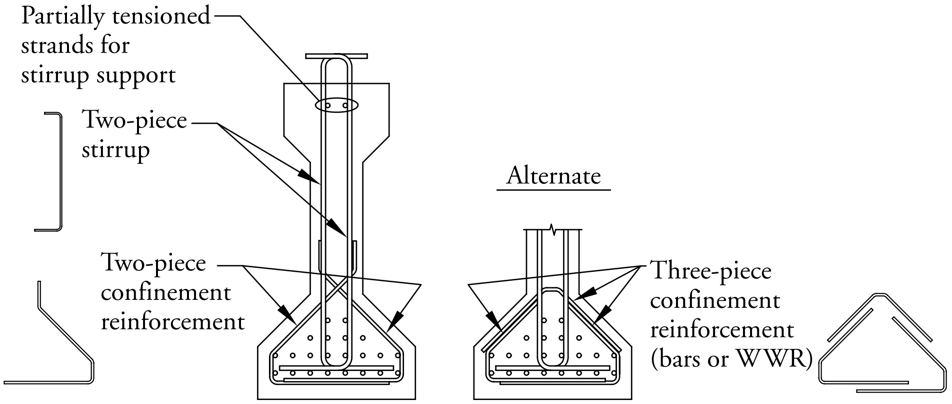
4.2.7 Nonprestressed Reinforcement

Proper detailing of mild reinforcing steel offers the designer an important opportunity to contribute to cost savings. As discussed in Chapter 3, the reinforcing steel is generally placed within the beam after the strands have been tensioned.

4.2.7.1 Detailing for Ease of Fabrication

If the reinforcement is detailed closed around the strands, it requires that the strands be threaded through the closed bars. By using two-piece bars that can be placed after the strand is tensioned, the fabrication process is simplified. **Figure 4.2.7.1-1** illustrates two-piece stirrups and two-piece confinement reinforcement in an I-beam. When specifying concrete cover and spacing of strands and bars, the designer must consider reinforcing bar diameters and bend radii to avoid conflicts. In order to support reinforcing steel located in the tops of some beams and the stirrups in all beams, some producers may prefer to locate one or two strands near the top of the beams (see **Figure 4.2.6.3-1**). Some support could be provided by longitudinal reinforcing bars, but strand is slightly less expensive than mild steel reinforcement and is readily available at precast plants. This strand may be fully tensioned (if considered in the design), or tensioned to a force of 5,000-10,000 lbs. The producer can then tie the reinforcement to the strand which will provide firm support.

Figure 4.2.7.1-1
Multi-Piece Reinforcement



4.2.7.2 Excessive Reinforcement

Minimize the amount of reinforcing steel in prestressed concrete members. There appears to be a tendency to add more reinforcement than is needed "just to be safe." Often, the added reinforcement merely creates congestion making consolidation of the concrete difficult without contributing significantly to the structural strength or behavior.

4.2.7.3 Welded Wire Reinforcement

Welded wire reinforcement (WWR) can be a very cost-effective way to place mild reinforcing steel in precast, prestressed components. WWR is a prefabricated reinforcement consisting of parallel, cold-drawn wires welded together in square or rectangular grids. Each wire intersection is electrically resistance-welded by a continuous automatic welder. The use of WWR is particularly advantageous where large areas have uniform reinforcing spacings, such as flanges of double tees and web shear steel in beams. Although the material cost of the WWR is normally greater than that of reinforcing bars, cost of installation will normally be substantially less. An example of WWR details for a precast concrete I-beam is shown in **Figure 4.2.7.3-1** for the Nebraska University (NU) metric beam section.

4.2.8 Durability

Prestressed concrete products have an excellent durability record. Review of data in the National Bridge Inventory compiled by the Federal Highway Administration has confirmed the performance of precast, prestressed bridges in all regions of the country. There are several reasons for this excellent record.

4.2.8.1 Benefits of the Fabrication Process

Most prestressed concrete products are fabricated in certified manufacturing plants where strict quality control is maintained. The quality of the concrete is exceptional, and it generally has a higher density and strength than field-placed concrete. Curing procedures, especially those during the first several hours after the concrete is cast, contribute to higher concrete quality. The concrete is almost always maintained in compression due to prestressing, and is therefore essentially crack free. These factors reduce the penetration of water and chloride ions into the concrete, increasing its life. In addition, many precast plants use heat to accelerate curing of the concrete. Recent tests have shown that this further increases the concrete's ability to resist chloride penetration (Pfeifer et al, 1987 and Sherman et al, 1996).

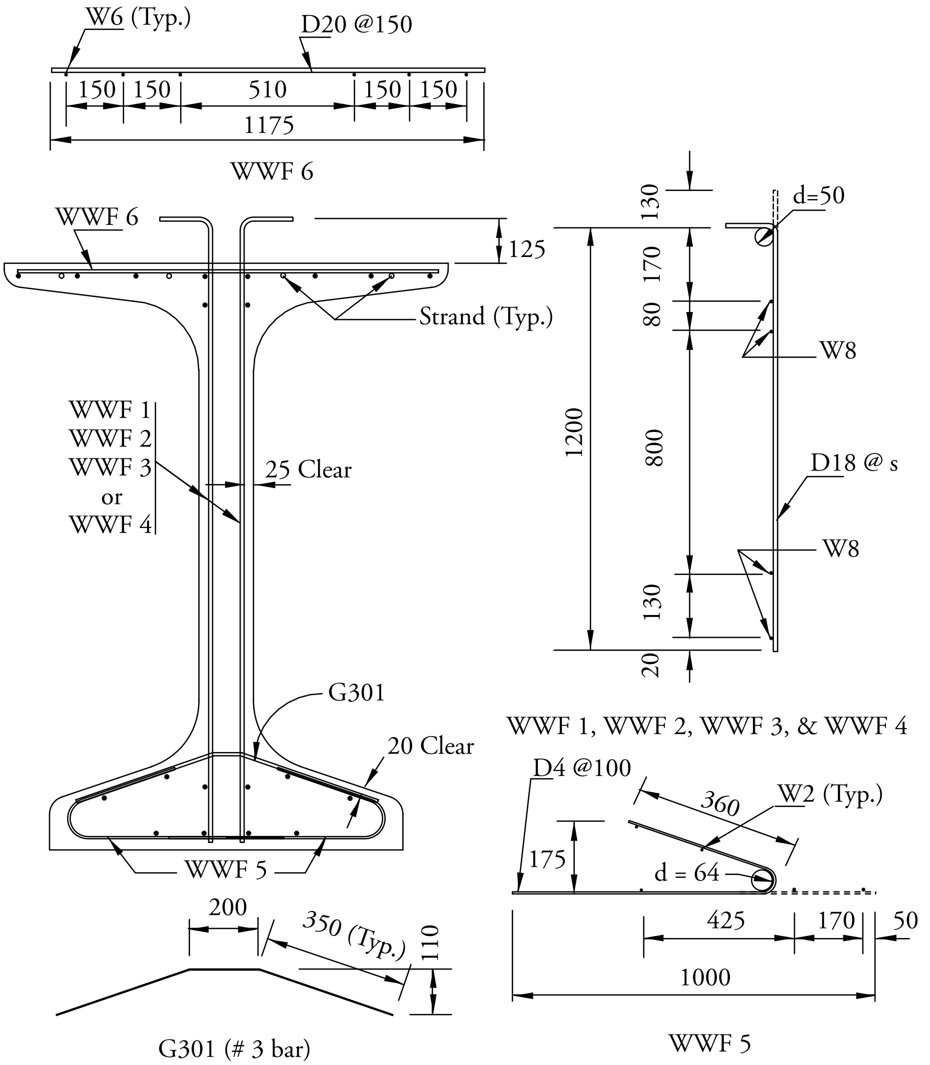


Figure 4.2.7.3-1
Welded Wire Reinforcement Details used by Nebraska Department of Roads

Fabric Designation	WWF1	WWF2	WWF3	WWF4
Spacing, s (mm)	50	100	200	300

Notes:
Dimensions in mm
1 inch = 25.4 mm
D18 designates a deformed wire whose area is 0.18 in.^{2}
W designates a smooth wire

4.2.8.2 Additional Protection

Additional measures can be taken to further enhance the durability of prestressed concrete. Chapter 2 discusses several measures that can be taken to enhance the material properties of the concrete, e.g., using low water/cementitious materials ratios and certain concrete additives. Providing the proper concrete cover over the reinforcement is essential, but excessive cover does little to enhance durability of the product. If the ends of the precast product are not encased in cast-in-place concrete it is important to seal or coat exposed prestressing strand and mild reinforcing steel with an appropriate coating.

4.2.9 Bearing Systems

Bearing systems for precast, prestressed concrete products can be very simple. The bearings need to be designed to transfer the design vertical and horizontal forces to the substructure.

4.2.9.1 Embedded Bearing Plates

In most cases, embedded bearing plates are not needed. If large horizontal forces, such as seismic loads, must be transmitted from the superstructure to the substructure, bearing plates may be necessary on some beams. Beams erected on a steep grade may also need bearing plates. In lieu of costly tapered bearing plates, elastomeric bearing pads placed directly between the precast product and the substructure are commonly used.

4.2.9.2 Bearing Devices

Elastomeric bearing pads are very economical. The bearing pad must be properly designed to accommodate the bearing pressure and the volumetric changes in the superstructure. If necessary, laminated pads can be used, but they cost substantially more than plain pads. Tapered bearing pads have been used in several places to accommodate roadway grades of up to 5%. These pads are more expensive to manufacture than flat pads, but much less expensive than tapered plates. For shallow grades, many states slope the concrete cap at the bearing to provide full contact between the bearing pad and the cap/beam. Pot bearings have been used in conjunction with bearing plates on precast products, but their expense must be carefully considered. They are normally not recommended.

4.2.9.3 Bearing Replacement

Provision for future replacement of bearing devices may be required in some locations. This requires the designer to provide a suitable and practical means for raising the superstructure for removal and replacement of the bearing device. End diaphragms, when used on bridges, can often be designed and detailed to serve this purpose.

4.2.10 Concrete Compressive Strengths

Concrete strength requirements can significantly affect costs. Strength required at release of prestress force is likely to be a predominant concern to the producer. Precast concrete plants rely on daily use of the prestressing beds. Therefore, the concrete strength at release of prestress should be kept to the minimum required to stay within allowable temporary stresses. Local fabricators are the best source of information on details related to optimum concrete strength.

4.2.11 Lightweight Concrete

Lightweight concrete has been successfully used on many bridges in the United States since the early 1950s. Its earliest applications were in lightweight concrete deck slabs. Lighter weight beams can and could allow longer spans or greater beam spacings for the same strand and concrete strength. Lightweight concrete use has become more popular in seismic areas where reductions in weight will reduce seismic forces transmitted to the substructure elements, resulting in substantial savings.

4.2.11.1 Material Properties

Concrete strengths of structural-grade ESCS (expanded shale, clay and slate produced by the rotary kiln method) lightweight aggregate concrete are in the same range as those for normal weight concrete with the same cementitious materials content. Contact a local producer of ESCS aggregate for assistance with mix designs. The modulus of elasticity for a lightweight concrete will be significantly less than that of a normal weight concrete with same strength. For detailed material properties, refer to ASTM STP 169C (1995). Obtaining concrete strengths in lightweight concrete comparable to the commonly used strengths of normal weight concrete is not difficult. Creep, shrinkage and deflection must be appropriately evaluated and accounted for when lightweight concrete is employed.

4.2.11.2 Major Bridges with Lightweight Concrete

There are many notable bridges constructed with lightweight concrete. Some of these include:

- Suwanee River Bridge on U.S. Route 19 at Fanning Springs, Fla. Built in 1964 with Type IV AASHTO I-beams, it uses 5,000 psi lightweight concrete at 120 pcf to achieve six, 121-ft spans. These were constructed in three, 2-span continuous units.
- Chesapeake Bay Bridges near Annapolis, Md.
- Napa River Bridge on State Route 29 near Napa, Calif. This is a segmental, prestressed concrete bridge 2,230-ft long with 250 ft spans. It was constructed in 1978.
- Sebastian Inlet Bridge over the Indian River, Fla. Approach spans are 73 ft long and main spans are 100, 180, 100 ft long. A drop-in I-beam of lightweight concrete, 72 in. deep, is supported by 2 cantilevered pier beams. Built in 1964, the cast-in-place deck, curbs and parapets are also lightweight concrete.
- Full-depth deck panels of lightweight concrete were used on the Woodrow Wilson Bridge in Washington, DC, and the Governor Nice Bridge on Maryland Route 301 over the Potomac River.

4.2.12 Touch Shoring

Touch shoring is a technique that has been used to further extend the capacity of precast, prestressed concrete beams. The process is to provide proper temporary supports during construction to carry a predetermined portion of the weight of the cast-in-place concrete deck when it is cast. After curing of the deck slab concrete, the temporary shoring is removed and the slab weight is transferred to the composite system rather than the prestressed beam alone. This additional capacity of the beams provide for wider beam spacing or longer span lengths compared to a similar unshored system.

4.2.12.1 Example Project

In 1988, touch shoring was used for the main span carrying twin structures of the Florida Turnpike over I-595 in Ft. Lauderdale. For this project, a Type V I-beam, which normally is limited to simple spans of approximately 135 ft, was used for a 150 ft span. This scheme was used in lieu of a spliced beam system and saved over $100,000.

4.2.12.2 Limitations

The drawbacks of the touch shoring system are additional cost of the temporary support and the sensitivity of the system to possible shoring settlements during construction. Touch shoring should be utilized cautiously, with proper attention given to the temporary support design and construction. Subsequent deck replacement will also require specific design and construction provisions; this may be a deterrent to the use of touch shoring in some applications.

4.3 PRODUCTION

Several decisions made by designers can affect production costs adversely. Specific topics include concrete finishes, aesthetic requirements and elements projecting from beams. Refer to Chapter 3 for detailed discussion of precast, prestressed concrete product manufacture.

4.3.1 Beam Top Finish

If the precast product is to be covered with a concrete topping, the top surface of the precast member should be intentionally roughened. This can be done by using a rough float, heavy broom or raked finish to provide a proper bonding surface for the cast-in-place concrete. If this concrete topping is to act compositely with the beam, the designer should provide for the proper volume of mild steel reinforcement extending from the top of the beam into the deck. However, the projection of this steel should be kept to the minimum required since it interferes with the leveling and finishing of the top of the beam. If stay-in-place (SIP) concrete panels are to be used for a deck, a smooth edge of an appropriate width should be provided as a bearing surface for the SIP panel supports.

4.3.2 Side and Bottom Finishes

Precast, prestressed concrete products used as bridge components are normally cast in steel forms. The resulting finish is typically excellent. However, as with all concrete products, there can be minor blemishes or voids which are generally not considered to be defects. Major flaws in the finish should be repaired. Since bridges are usually viewed from some distance, minor surface flaws cannot easily be seen, especially on interior beams. A requirement to eliminate all minor blemishes in these surfaces adds unnecessary cost to the products. It may be desirable to provide special treatment only to products on the exteriors of bridges. Although costly, the aesthetic qualities of bridges have been enhanced through the use of exposed aggregate concrete and special form liners to create distinctive designs or finishes.

4.3.3 Appurtenances

It is sometimes necessary to connect appurtenances to the surfaces of precast units. To reduce the cost, it is necessary to eliminate projections from the beams. Most precast, prestressed concrete members are cast in precision-made steel forms. Projections can be accommodated only by modifying the forms. It is better practice to utilize details that permit attachment through use of threaded inserts, weld plates, or through bolts, as shown in Chapter 3, Section 3.2.4.

4.4 DELIVERY AND ERECTION

Transportation of precast, prestressed concrete bridge products to the bridge site can represent a significant portion of the construction cost. The transportation system from the plant to the site and the means for erecting the product at the bridge must be considered in the design.

4.4.1 Transportation

Construction of bridges over navigable waterways normally makes product delivery by barge possible. Inland bridges will necessitate delivery of components by truck or rail.

4.4.1.1 Water Delivery

Manufacturing plants located on waterways which are also accessible to the project site can load products directly on barges for delivery. When direct delivery by barge from plant to jobsite is possible product weight is a relatively minor concern, since it will be limited only by barge capacity and plant and erection crane sizes. Direct delivery by barge will usually be more economical than overland delivery.

4.4.1.2 Truck Delivery

When shipping overland, several issues will affect the cost. The most dominant consideration is product weight. Smaller products (up to 45 tons) will normally not require special equipment or permits for shipping. Larger components may require special trailers with multiple axles, dual steering systems and load distribution systems to reduce and equalize the loads to the axles. These larger components may also require the shipping agency to obtain special permits for hauling over highways and bridges. Arrangements for lead and trail vehicles and coordination with local traffic control agencies may be required. Evaluation of the highway between the bridge site and precast plant should include horizontal and vertical geometry limitations and capacity of bridges which must be crossed. Additionally, the contractor must provide adequate access to the bridge site by furnishing a suitable haul road. The haul road must be sufficient to support the loaded weight of the truck and be relatively smooth so as not to induce excessive twisting in the precast members.

4.4.1.3 Rail Delivery

Another mode of transportation for finished products is by rail. Rail transport may be especially advantageous for heavy products where rail access is available at both the precast plant and jobsite. Placement limitations of loads on the rail cars, as well as load capacities of the cars themselves may also determine the feasibility of rail shipment.

Short products may be accommodated on one car. Long products may require several cars to be attached into a "set" which will carry a single product. If more than one car is used to carry a product, special attention must be given to the support bolsters on the cars to provide for horizontal rotation. The products must be tied down well in all directions to overcome significant transportation-induced loads. Rail shipment should always be coordinated with precast producers and the railroad.

4.4.2 Handling and Erection

Generally, precast plants have cranes and other equipment for handling products in the plant. At the bridge site, the contractor must have the necessary crane(s) to provide adequate lifting capability at the required working radius. Unstable soil conditions may necessitate the use of mats for crane support. Longer beams may require special handling or a supplemental bracing system to provide proper lateral stability during lifting and shipping. Environmental constraints may require that special techniques be used for erection of precast components. For long or heavy precast products, the designer should discuss shipping and erection methods with both producers and contractors during the design phase.

4.4.2.1 Lifting Devices

For most precast products, the producer will provide means for attaching the precast component to the crane. Usually, the producer will use loops of prestressing strands embedded in the concrete. This is often the most cost effective lifting device. Other specialty lifting devices may be required, but the producer should be allowed to select the means of handling the product.

4.4.2.2 Support and Lift Locations

When prestressed concrete products are resting on supports, it is usually desirable for the supports to be located near the ends of the product. Long prestressed piles may require several points of support and lifting. The location of the lifting points must consider the stability of the product. It may be desirable to locate the lifting device some distance from the ends of long slender members. The bending stresses associated with the resulting cantilevers must be considered when locating lifting points more than 2 to 3 ft from the ends. Chapters 3 and 8 discuss this topic in detail. Designers should consult local fabricators to determine the preferred method of providing stability while maintaining stresses within acceptable limits.

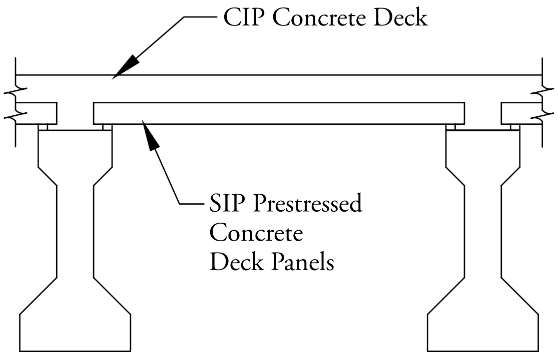
4.5 OTHER PRODUCTS

In addition to using precast, prestressed concrete beams, designers can further increase the cost effectiveness of their designs by considering the use of other manufactured concrete components for bridges. Chapter 16 contains more detailed descriptions of these products and their applications.

4.5.1 Stay-in-Place Panels

Cast-in-place (CIP) concrete bridge decks are used on a variety of bridge superstructures and usually require the use of forms. Stay-in-place (SIP) composite concrete deck panels, schematically shown in **Figure 4.5.1-1**, offer several advantages over the use of traditional removable form systems or SIP metal forms. Since the lower portion of the deck (SIP panel) is prestressed, all of the advantages associated with plant-cast concrete are made available to the deck. The deck durability is enhanced

Figure 4.5.1-1
Typical Deck Configuration with SIP Concrete Panels



since the SIP panel is virtually crack free. The SIP concrete panel is not subject to the corrosion susceptibility of the metal SIP form. Cost advantages result from the elimination of the bottom mat of reinforcing in the deck and a reduction in the volume of concrete which must be field cast. Field labor is not required to remove the forms after the deck cures. For further information, refer to "Precast Prestressed Concrete Bridge Deck Panels" (1988) published by PCI.

4.5.2 Full Depth Precast Decks

In addition to using precast concrete as deck forms, full depth precast bridge decks have been used successfully on many projects. The main advantages associated with this type of construction are the speed with which the deck is placed, and the previously enumerated benefits that are associated with plant-cast concrete. Connection of this type of deck to the beams and connections between the individual deck units must be properly designed to include bearing of the slab on the beams as well as proper shear transfer if composite action is desired. A special report, "Precast Bridge Deck Design Systems" by Biswas (1986), discusses the use of this product in detail.

4.5.3 Precast Substructures

Economic designs of bridge substructures can be achieved using precast components, especially when there is the possibility of form reuse. The precast components are generally simple to form and fabricate. Precast substructures have been successfully used on both large and small bridges.

4.5.3.1 Advantages of Precast Substructures

Increased speed of construction can decrease costs through reduced traffic maintenance requirements, enhanced safety and reduced overhead for the contractor. For construction over water, using smaller crews working less time not only reduces labor costs, but can significantly decrease workman's compensation expenses. Plant-cast concrete will normally be of high quality, and, hence, very durable.

4.5.3.2 Components

Precast substructure components include prestressed concrete piles, abutment walls, caps for pile bents, pier columns and caps. Piles are normally prestressed to resist the stresses that result from driving. The other components listed are normally reinforced with mild steel. Pile bents with prestressed piles and concrete caps have been used in lieu of piers, especially for short span bridges. Precast bent caps are very simple to fabricate and have been used widely. For grade crossings, precast pier caps eliminate the need for erecting and removing expensive form work, installing the reinforcing cage and curing the cap at an elevation above grade. Major bridges successfully built using precast columns and caps include the Sunshine Skyway Bridge in Tampa Bay, Fla, and the Edison Bridge in Ft. Myers, Fla, shown in **Figure 4.5.3.2-1**.

Figure 4.5.3.2-1
Edison BridgeFt. Meyers, Fla, showing precast concrete columns and caps

4.5.3.3 Connections

A primary concern for designers of economical precast substructures is to provide effective and durable, yet reasonably simple means of connecting precast components to other precast and CIP components. The connections between precast elements must be designed and detailed for full transfer of all applicable forces. Bent caps normally provide a socket in the cap into which the piles are set and subsequently grouted. Other connection schemes use reinforcing bar splices such as mechanical splices, or grouted sleeves, and post-tensioning.

4.5.4 Barriers

Precast concrete railings or barriers are frequently used as bridge components. Cast-in-place railings are normally cast independent of the bridge deck requiring separate delivery of concrete. Precasting the railing or barrier eliminates this requirement and speeds the construction process. Barriers have been attached to bridges by bolted connections or with the use of bar splicing devices and mechanical anchors.

4.6 ADDITIONAL CONSIDERATIONS

When compared to other bridge systems, the direct cost of precast concrete components alone can be significantly less. There are other benefits that can be achieved with the use of specific products or materials.

4.6.1 Wide Beams

Over the past several years, the use of precast, prestressed concrete beams with wide top flanges has grown in use. The increased width provides a smaller area requiring deck forming, probable reduction in the amount of deck reinforcing steel, improved lateral stability for handling and shipping longer beams and a wider work surface for construction crews prior to installation of deck forms. Excessive width may, however, increase the volume of haunch concrete over the beam and, for very thin flanges, increase the difficulty of deck replacement.

4.6.2 Adjacent Members

By placing precast concrete beams side-by-side, the need for a CIP concrete deck may be eliminated, further reducing the cost of construction. This is especially beneficial at remote construction sites where transporting concrete to the site is difficult or too time consuming. Cost savings related to the deck include forming, placing, finishing, curing, form stripping, and the material and delivery expense. By eliminating the deck, total construction can be completed in significantly less time.

4.6.3 High Strength Concrete

The use of higher concrete strengths has been increasing. With the higher strength, comes the ability to increase the span length for given beam depths and the associated economy of longer spans. These longer spans are accompanied by increases in the amount of prestressing force in the products. Designers must take into account the potential increase in beam camber and also increased concrete release strengths that could preclude casting on a daily cycle. The ability of prestressing beds to withstand the larger prestress force should also be investigated. The stability of long, slender members during handling and shipping must be considered as part of the member design. Precast producers in most areas are familiar with these parameters and can provide assistance.

4.6.4 Contract Considerations

During the planning phase of projects, agencies should evaluate contract procedures and use one that gives the best opportunity to save money. When a number of small bridges are to be constructed or replaced in one area, significant savings can be realized by grouping several bridges in one contract.

4.7 SUMMARY AND REFERENCES

4.7.1 Summary

There are several keys to the economical use of prestressed concrete for bridges. These include proper design and detailing, local availability of products, repetitive use of products and open communications between designers, contractors and manufacturers starting with the concept of the design through final construction. As noted several times in this chapter, designers should contact local precast, prestressed concrete fabricators to obtain information vital to the design of a cost-effective structure.

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