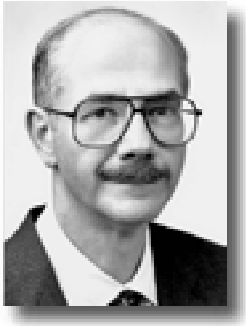
Design of Prestressed Concrete Bridges to Accommodate Future Widening



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This paper discusses how a two-lane prestressed concrete bridge can be designed and constructed so that it can be widened easily into a three- or four-lane bridge in the future. The methods presented are the strutted box widening method (SBWM), which applies to concrete box girder bridges, and the strutted girder widening method (SGWM), which applies to precast concrete girder bridges. Two design examples are given. The first is a detailed example that demonstrates how the SBWM can be applied to the popular case of a span-by-span precast segmental bridge. The second example shows how the SGWM can be used to double the traffic capacity of an existing bridge. Four "what-if" studies are included to demonstrate how two elevated median-based expressways and two major long-span crossings could have been designed and constructed using the SBWM to allow for future widening. The paper concludes with a discussion of a proposed precast segmental extradosed bridge that is to be constructed and widened using the SBWM.

A previous paper[1] introduced the strutted box widening method (SBWM), a system that allows a two-lane segmental bridge to be designed and constructed so that it can be widened easily into a three- or four-lane bridge in the future. Two examples demonstrated how the SBWM could be used to widen a variable-depth cast-in-place segmental bridge and a constant-depth precast segmental bridge, both built using the balanced cantilever method of construction. The current paper presents a detailed design example (complete longitudinal and transverse analysis) for the popular case of a constant-depth precast segmental bridge built using the span-by-span method of construction.

The previous paper[1] suggested that two particularly appealing potential applications of the SBWM are elevated median-based expressways and major long-span crossings. This paper considers two elevated median-based expressways in Texas and Florida, as well as two major long-span crossings in Hawaii and Canada. These "what-if" studies demonstrate how the SBWM can be applied during planning, design, and construction to allow for future widening to achieve increased traffic capacity.

The strutted girder widening method (SGWM) is a variation of the SBWM. The SGWM allows a two-lane precast concrete girder bridge to be designed and constructed so that it can be widened easily into a three- or four-lane bridge in the future. The SGWM is an attractive alternative to the conventional widening of an existing bridge because no additional foundation or substructure work needs to be done to widen the bridge to double the traffic capacity.

This paper concludes with a discussion of a proposed precast segmental extradosed bridge that is to be constructed and widened using the SBWM. This bridge has extradosed (cable-stayed) segmental main spans as well as traditional segmental transition and approach spans. What is interesting here is that the entire bridge consists of similar constant-depth precast segments that are assembled using the balanced cantilever method. Economy is achieved by having repetition in both the casting and erection operations. The example demonstrates that the SBWM can be applied to cable-supported and conventional segmental bridges in a similar manner.

STRUTTED BOX WIDENING METHOD (SBWM)

The strutted box widening method (SBWM) allows a two-lane segmental bridge (or other prestressed concrete box girder bridge) to be designed and constructed so that it can be widened easily into a three- or four-lane bridge at any time. Let us define three stages of construction (see Fig. 1): (1) Stage 1, two lanes plus shoulders, (2) Stage 2, three lanes plus shoulders, and (3) Stage 3, four lanes plus shoulders.

Thus, the bridge will initially be constructed to have two 3.66 m (12 ft) lanes plus two 3.05 m (10 ft) shoulders. The intention is to widen the bridge to three lanes plus shoulders as traffic volumes increase. Further widening to four lanes plus shoulders will occur as traffic volumes continue to increase. This gives a deck width of 14.33 m (47 ft) in Stage 1, 17.99 m (59 ft) in Stage 2, and 21.65 m (71 ft) in Stage 3.

What makes the SBWM such an attractive solution is that it is completely flexible. Widening only needs to be done when traffic volumes warrant it. If the traffic volumes do not increase as fast as projected, widening can be delayed as long as necessary. If the traffic volumes increase faster than expected, the bridge can be widened from two to four lanes directly (i.e., it is not necessary to have an intermediate three-lane bridge). The configuration of the bridge at the end of its service life can be two, three, or four lanes.

Conceptually, the SBWM is quite simple. During Stage 2 construction, exterior compression struts are installed and the deck slab is widened. Additional transverse internal prestressing tendons and longitudinal external prestressing tendons are installed and stressed. Widening from Stage 2 to Stage 3 construction is similar. The deck slab is again extended (cantilevered), and additional transverse internal prestressing

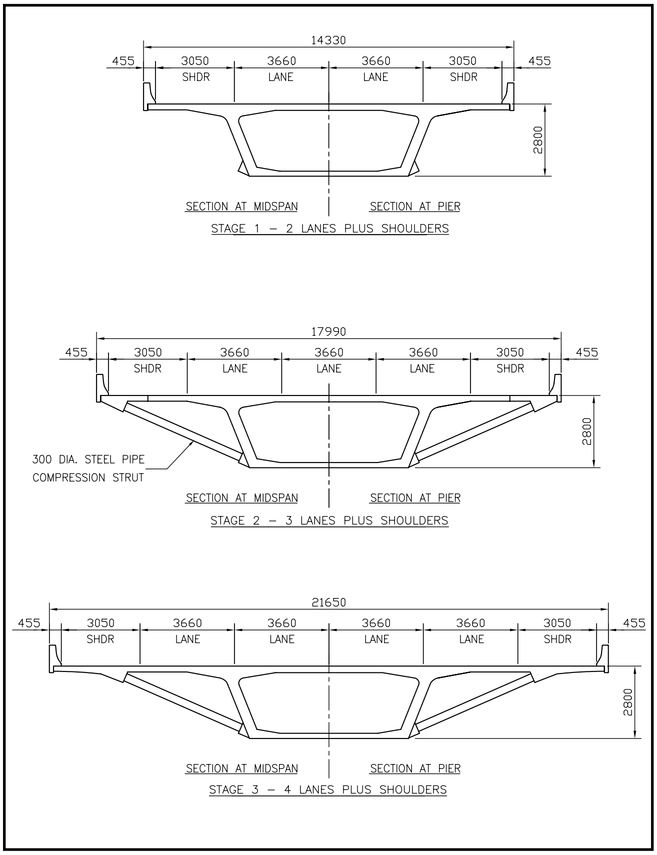

Fig. 1. Cross section widening for span-by-span precast segmental bridge.

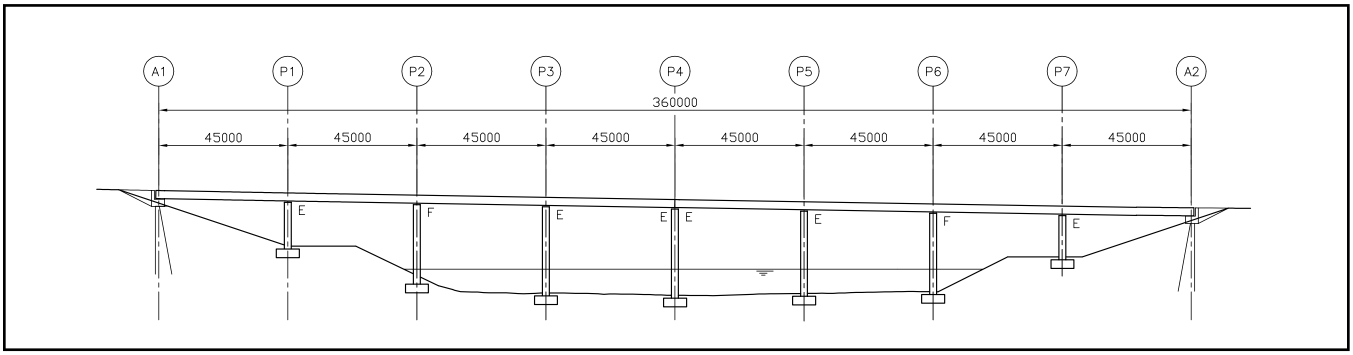

Fig. 2. Bridge elevation, eight-span span-by-span precast segmental bridge.

tendons and longitudinal external prestressing tendons are installed and stressed.

Consider an eight-span constant-depth precast segmental bridge built by the span-by-span method of construction (see Fig. 2). All span lengths are 45 m (148 ft), and the overall length of the structure is 360 m (1180 ft). The bridge consists of two four-span units that have an expansion joint at the interface (Pier P4) as well as at the abutments. Each structural unit is supported by fixed bearings at the middle pier (Piers P2 and P6) and expansion bearings at the other piers.

The depth of the section is 2.8 m (9.2 ft) (see Fig. 1), which gives a span-to-depth ratio of 16 and a strut angle of 24 degrees. The compression struts consist of 300 mm (12 in.) diameter steel pipes with end plates that frame into concrete buildouts (blisters) and transfer the load directly to the bottom slab from triangular-shaped exterior longitudinal T-beams at the deck level.

The segment layout and strut locations are shown in Fig. 3. Each span has fourteen 3.0 m (9.8 ft) long typical segments that are joined to 2.7 m (8.9 ft) long pier segments by virtue of 150 mm (6 in.) cast-in-place closure joints. The struts are located 1.5 m (4.9 ft) from the match-cast face of the segment. This gives a uniform spacing of 3.0 m (9.8 ft) for the length of the bridge and simplifies casting because the struts are always at

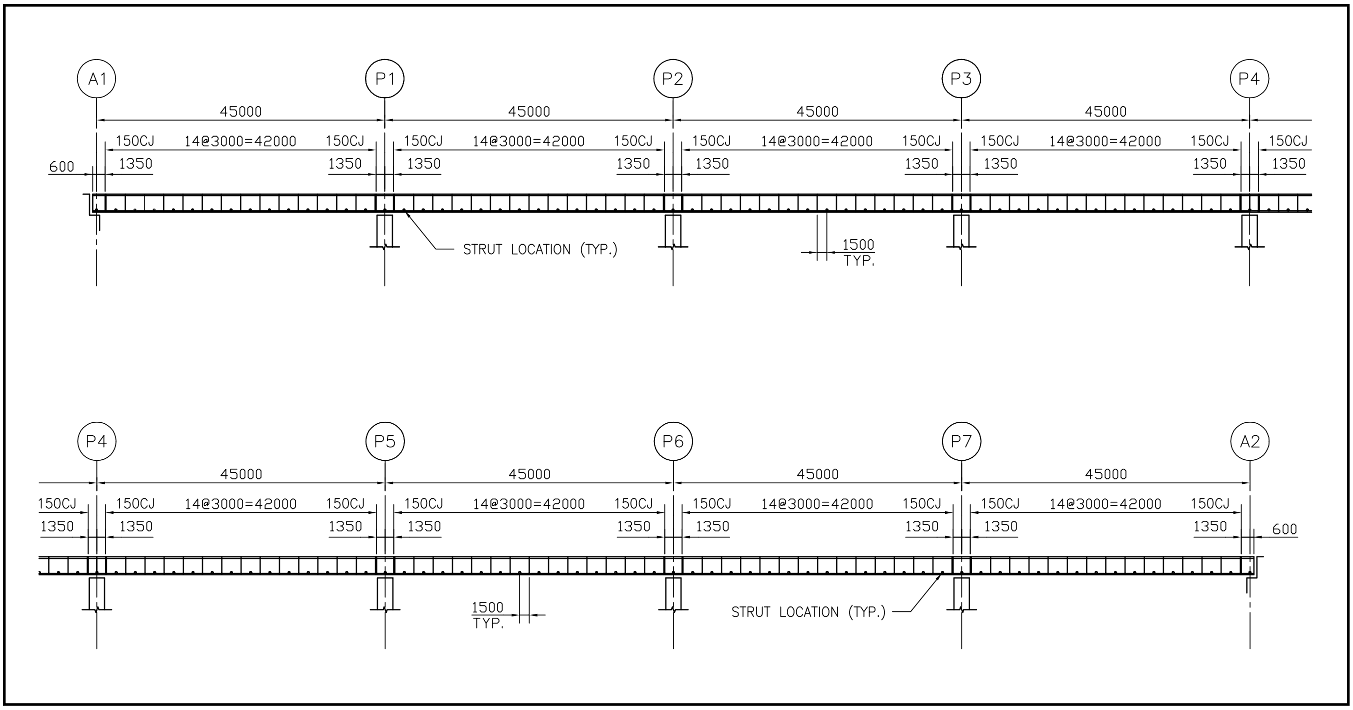

Fig. 3. Segment layout and strut locations.

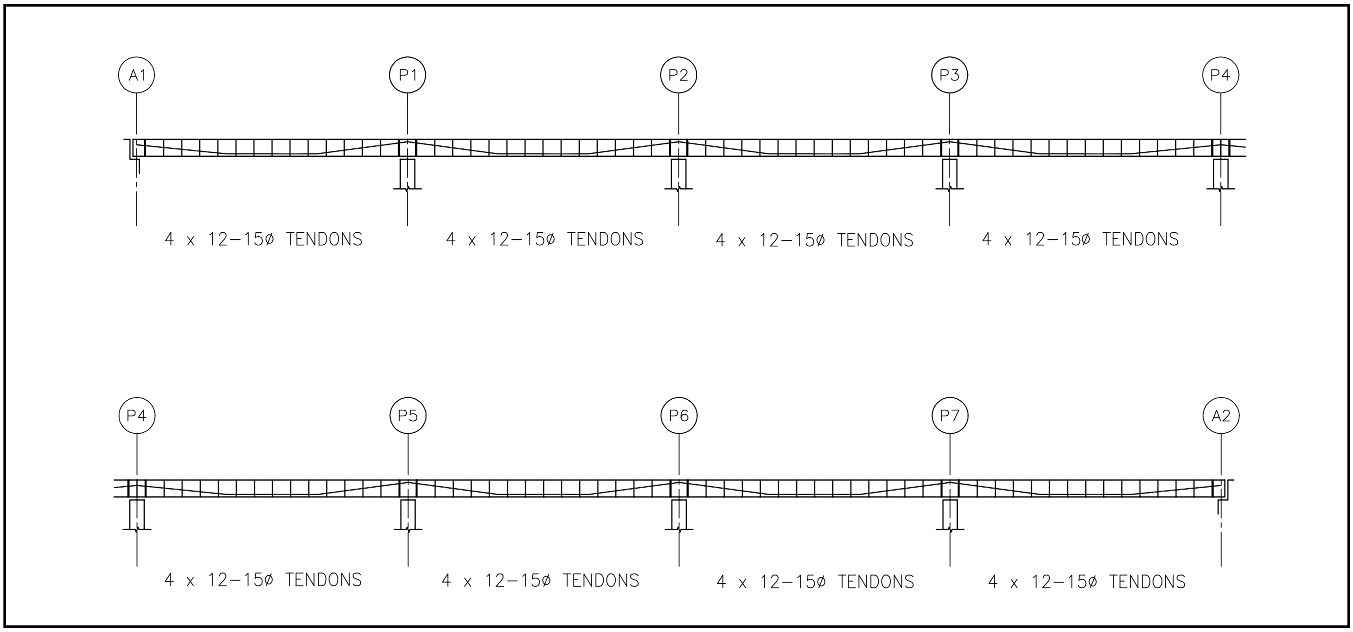

Fig. 4. Longitudinal external prestressing tendon layout.

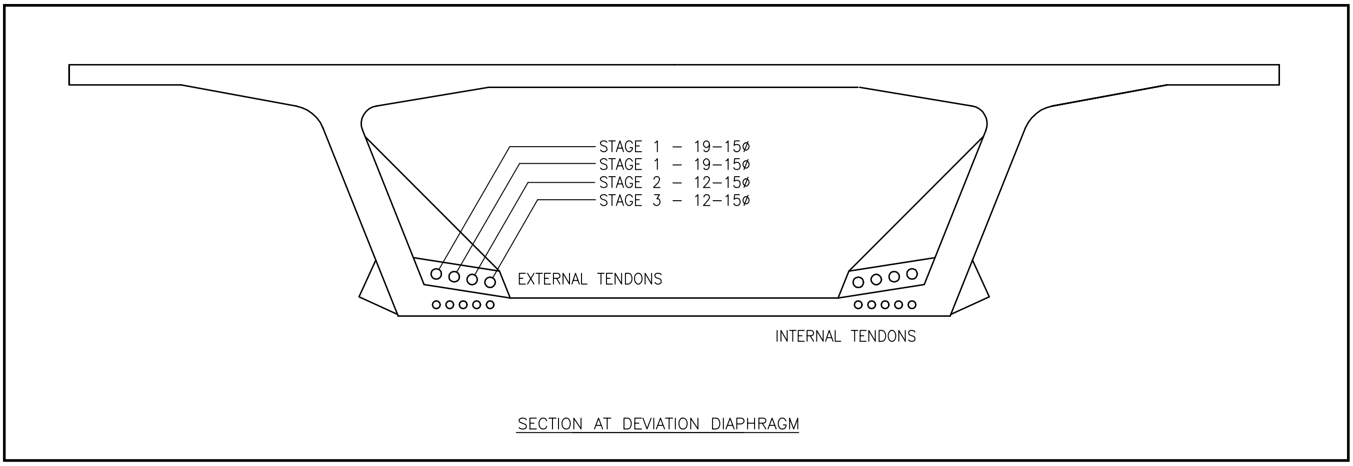

Fig. 5. Bulkhead details at the deviation diaphragm.

the same location in the casting cells. The construction sequence proceeds from one end of the bridge to the other.

Fig. 4 shows the longitudinal external prestressing tendon layout. Stage 2 and Stage 3 construction each require two 12-strand tendons in each span. These draped tendons are held down at the deviation diaphragms and anchored at the pier/abutment diaphragms.

The bulkhead details at the location of the deviation diaphragm are given in Fig. 5. There are five interior tendons per web (which are anchored in anchor blocks located in segments between the deviation diaphragm and the pier/abutment diaphragm). There are four external tendons per web. Stage 1 requires two 19-strand tendons while Stage 2 and Stage 3 each require one 12-strand tendon. Future contingency tendons are provided for by allowing the 12-strand tendons to be replaced by 19-strand tendons.

Fig. 6 shows the transverse internal prestressing tendon layout in plan and section for the three stages of construction. Each tendon consists of four strands in a flat duct. There are eight transverse prestressing tendons in each 3.0 m (9.8 ft) typical segment. Two tendons are stressed in Stage 1, two tendons are stressed in Stage 2, and four tendons are stressed in Stage 3. Note that the Stage 3 tendons have only two strands, which allows for some future contingency prestressing.

The transverse prestressing ducts for Stage 2 and Stage 3 widenings need to be installed during Stage 1 and Stage 2 construction. These plastic ducts need to be protected against moisture intrusion, which can lead to freezing and cracking of the deck concrete. One suggestion is to fill the ducts with grease or foam and cap the ends. The grease or foam would be flushed out when widening occurs.

The bending moment diagrams and shear force diagrams for the Stage 2 and Stage 3 widenings are shown in Figs. 7 and 8, respectively. Individual plots for dead load, superimposed dead load, positive live load, negative live load, and prestressing force are shown. The prestressing has been proportioned so that (1) there is a reserve of compression at the top and bottom of the section for the entire bridge, and (2) the vertical component of the draped tendons offsets the demand for an increased web thickness in Stage 1 to carry the Stage 3 shear forces. The flexural stress diagrams for the Stage 2 and Stage 3 widenings are shown in Fig. 9. The stresses at the top and bottom of the section are shown. Note that the reserve of compression varies from approximately 0 to 0.6 MPa (0 to 90 psi). The shear stress diagrams for the Stage 2 and Stage 3 widenings are shown in Fig. 10. Note that the increase in shear stress is on the order of 0.2 MPa (30 psi).

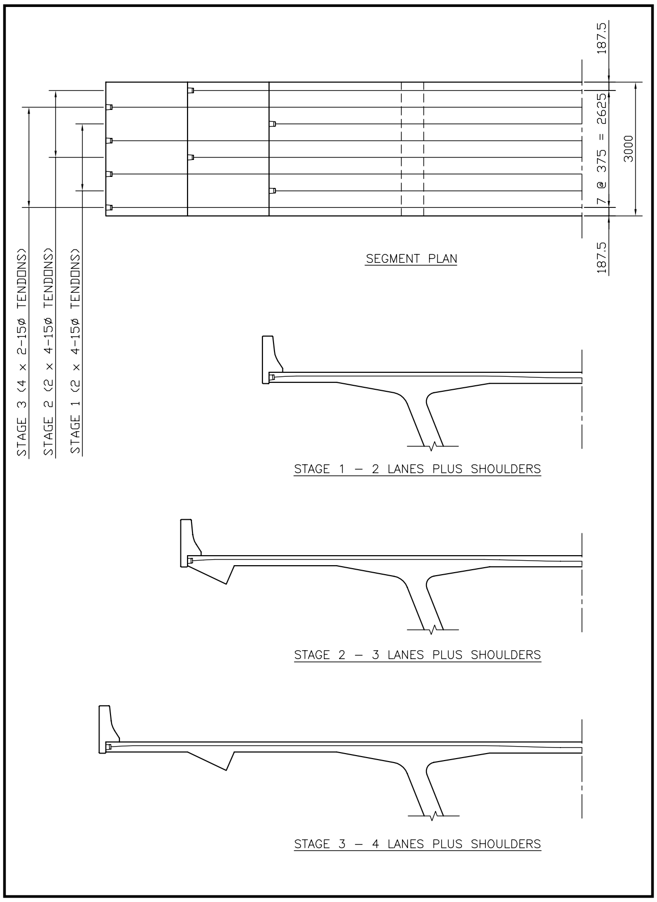

Fig. 6. Transverse internal prestressing tendon layout.

A simple computer program based on folded plate theory has been developed for the transverse analysis of strutted box girder bridges.[2] The program STRUTBOX is as simple to use as a plane frame computer program, and allows the prestressing and reinforcing steel to be proportioned for transverse flexure, as well as the stirrups to be proportioned for longitudinal shear and torsion.

The program also allows the compression struts to be designed. Loadings considered are self-weight, superimposed dead load, truck load (i.e., concentrated wheel loads), lane load, and transverse prestressing. Some simple methods of hand calculation for the transverse analysis of strutted box girder bridges are also presented in Reference 2.

The STRUTBOX computer models for the three stages of construction are shown in Fig. 11. The nodes for the top and bottom slab are kept at a constant elevation, and variations in the deck thickness are accounted for when entering the element thickness at each end. The compression struts are modeled to have only axial stiffness in the transverse direction. The compression struts frame into the bottom slab concentrically and are modeled as such (despite the fact that they appear to be eccentric in Fig. 11).

The bending moment diagrams and axial force diagrams due

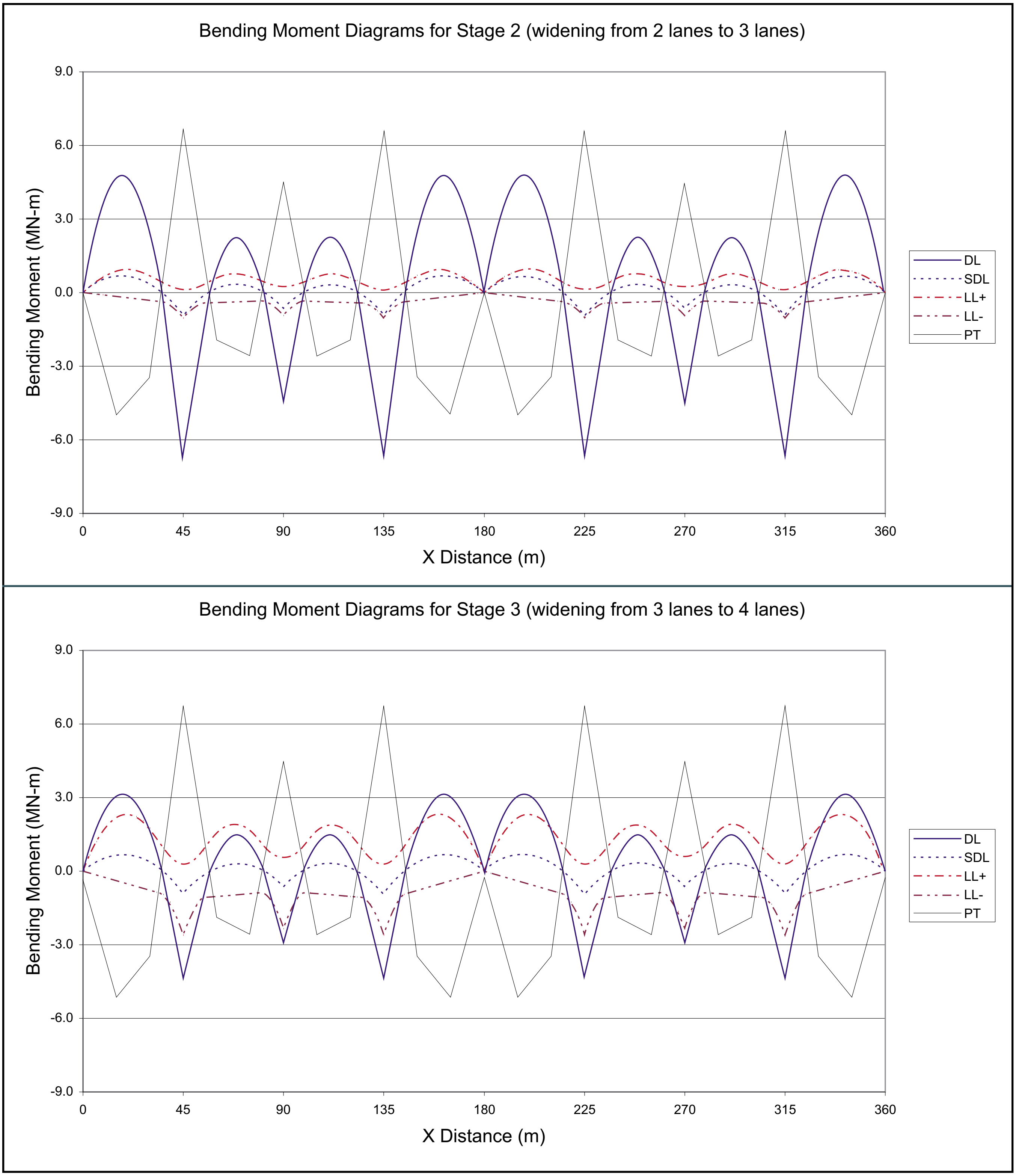

Fig. 7. Longitudinal bending moment diagrams.

to self-weight for the three stages of construction are shown in Fig. 12. The negative and positive moments between the webs for both the top and bottom slabs remain largely unchanged for the three stages of construction. The addition of the compression strut in Stage 2 creates a propped cantilever and introduces positive moment near the location of the compression strut. The addition of the cantilever in Stage 3 introduces negative moment, which reduces this positive moment. The axial tension in the bridge deck increases as the compression struts pick up axial force in Stage 2 and Stage 3.

There is danger in using a plane-frame analysis (as is commonly done) to approximate the results of a folded-plate analysis for strutted box girder bridges. This is because there are significant differences in the axial force diagrams given by the two methods, although the shear force and bending moment diagrams are virtually identical. It is, however, pos-

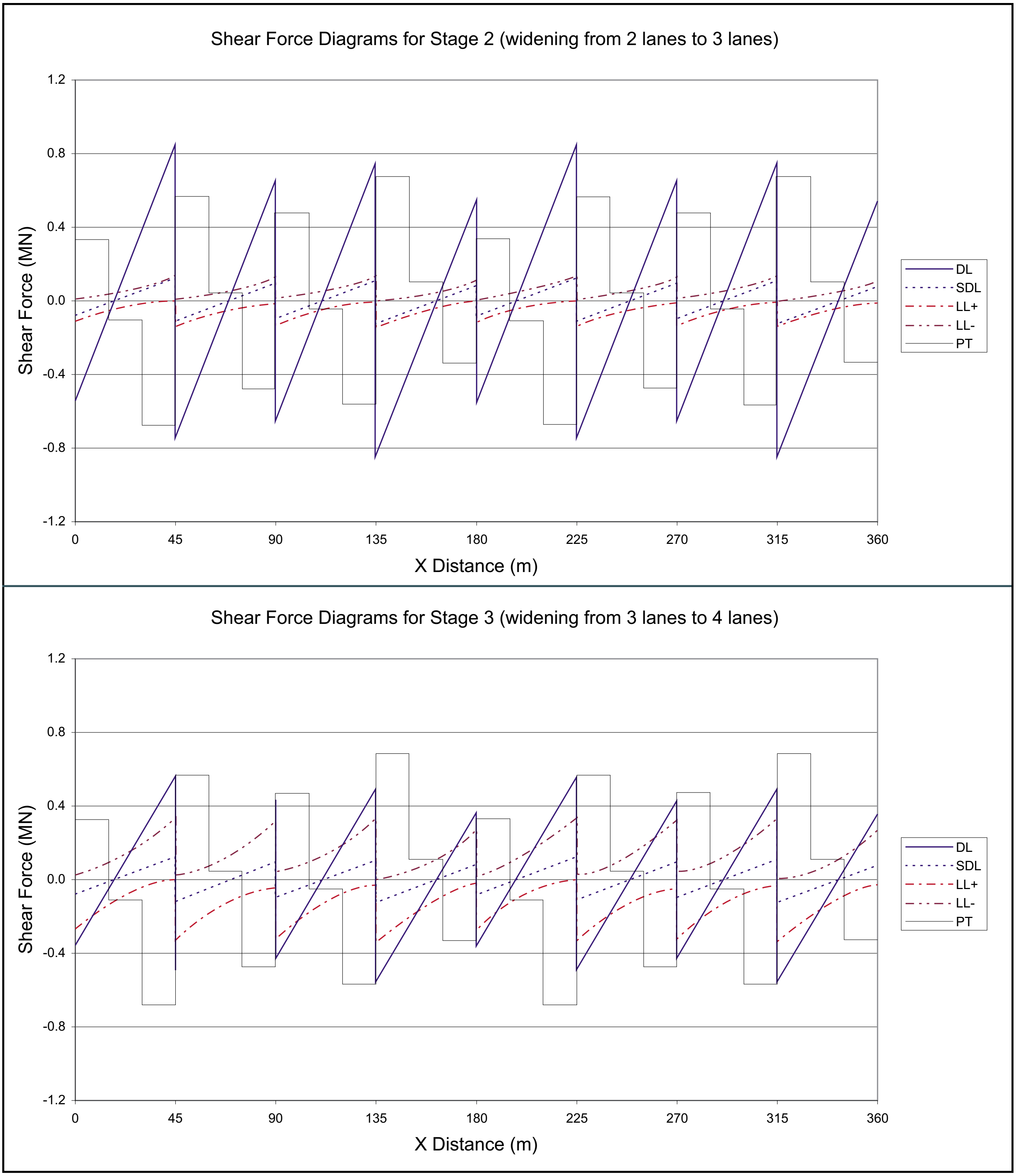

Fig. 8. Longitudinal shear force diagrams.

sible to approximate the actual three-dimensional behavior as predicted by a folded-plate analysis by using some simple membrane force equations in conjunction with a plane-frame analysis.[3,4] (These membrane equations are summarized in Appendix I of Reference 4.)

Fig. 13 demonstrates that the axial force diagram due to self-weight for Stage 3, as given by a folded-plate analysis, can be approximated by taking the membrane force equations diagram (which assumes loads over the webs), subtracting the plane-frame analysis diagram for loads over the webs, and adding the plane-frame analysis diagram for self-weight. The final diagram shows that the results are remarkably close to those given by a folded-plate analysis (which is shown dashed).

The results of the plane-frame analysis and the folded-plate analysis for self-weight are shown in the third and fourth diagrams, respectively, of Fig. 13. The plane-frame analysis

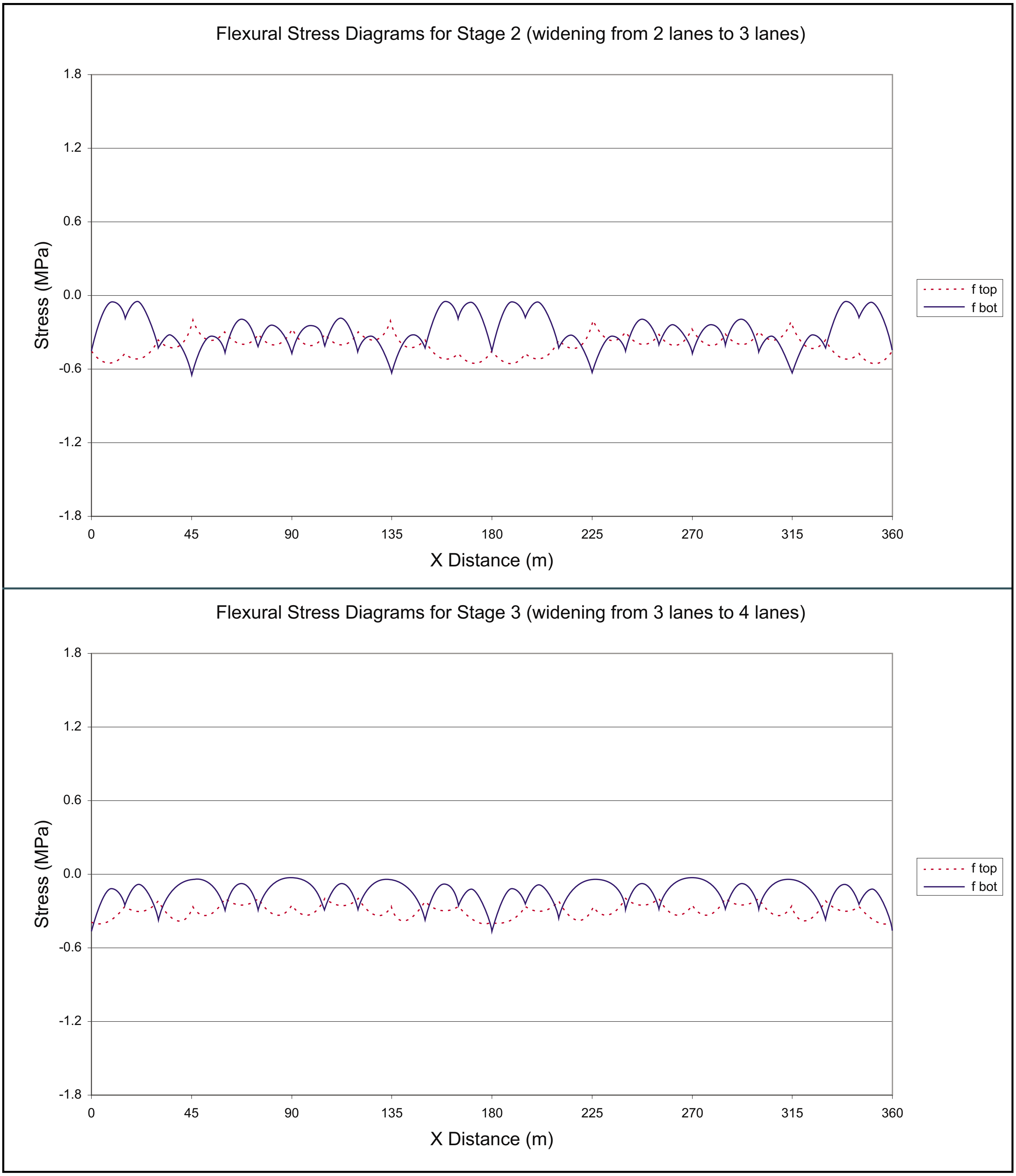

Fig. 9. Longitudinal flexural stress diagrams.

completely misses the magnitude and distribution of the large tension in the top slab as given by the folded-plate analysis.

Reference 2 gives complete examples for transverse flexure and longitudinal shear and torsion. Loadings considered include self-weight, superimposed dead load, and various truck and lane loads for each stage of construction. An important truck load position for Stage 2 and Stage 3 is to have the trucks adjacent to both barrier curbs, as this case introduces the largest compression force in both struts and, consequently, the largest tension force in the entire deck.

ELEVATED MEDIAN-BASED EXPRESSWAYS

The preceding example of a span-by-span precast segmental bridge can be applied directly to the design and construction of long elevated median-based expressways in congested

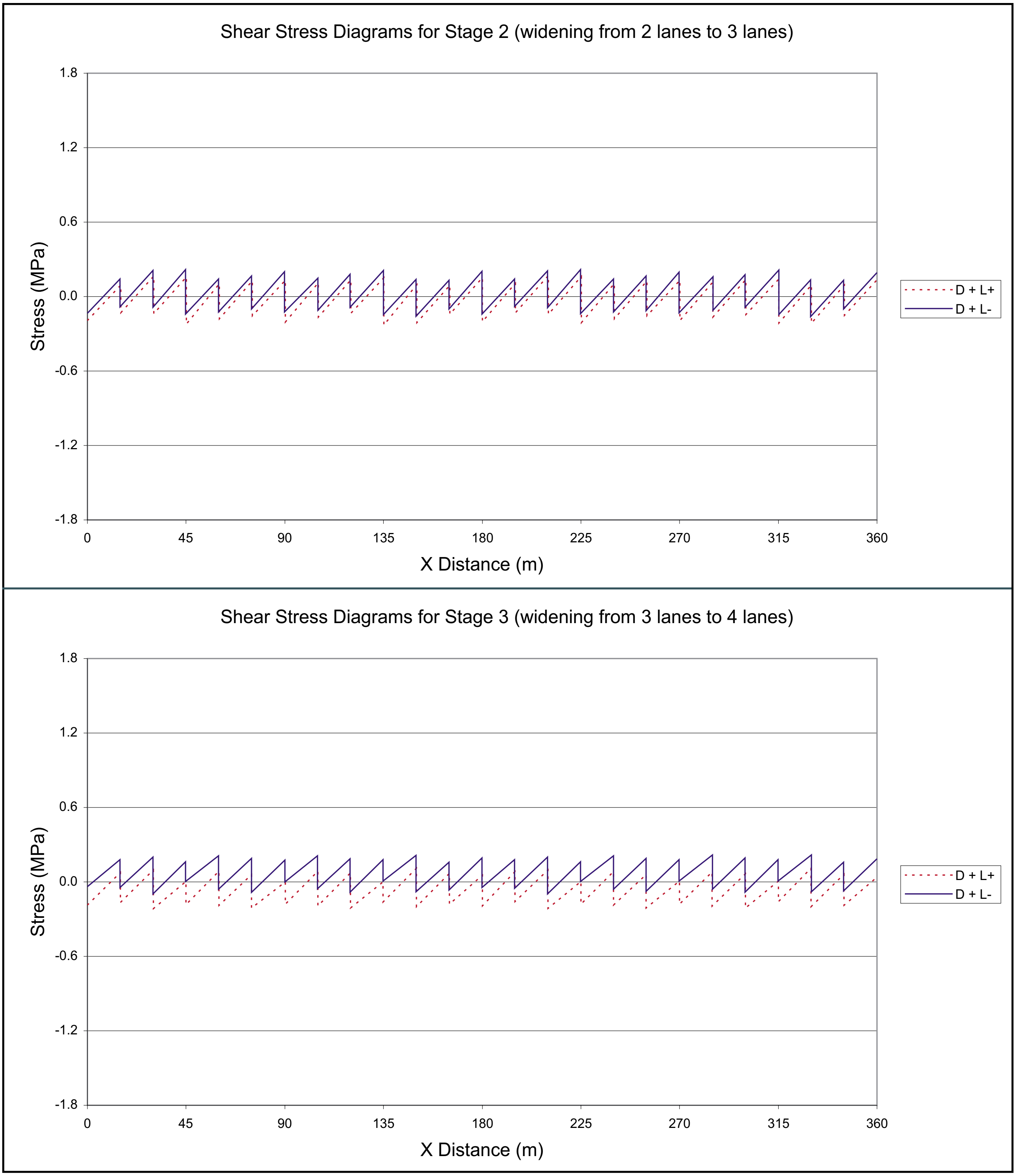

Fig. 10. Longitudinal shear stress diagrams.

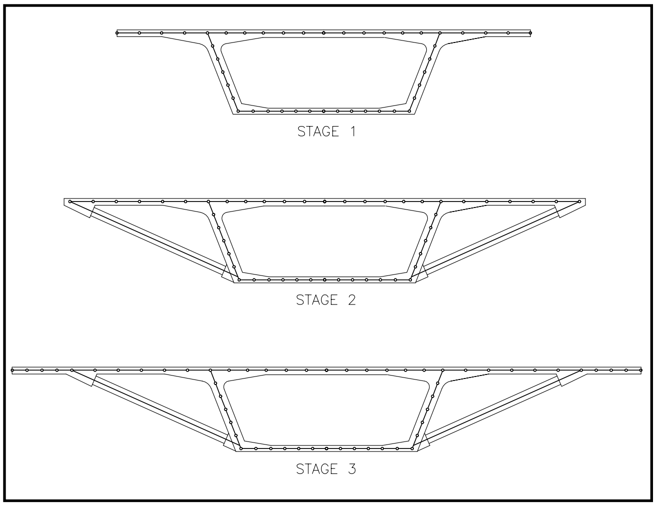

Fig. 11. STRUTBOX computer models.

urban environments where right-of-way acquisition is prohibitive. The elevated structure can be constructed and widened in the future as discussed in the example, or it can be constructed directly to its ultimate configuration. The SBWM allows a very wide elevated superstructure to be constructed while having a relatively small substructure footprint in the median. In addition, construction and widening can proceed without disrupting existing at-grade traffic.

The U.S. 183 Elevated Viaduct[5] in Austin, Texas (see Fig. 14), and the Lee Roy Selmon Crosstown Expressway[6] in Tampa, Florida (see Fig. 15), are considered for this "what-if" study. These two projects are similar in that they are both span-by-span precast segmental bridges. They are also different because one consists of twin bridges in the median carrying traffic in both directions while the other consists of a single bridge in the median with reversible traffic lanes.

The U.S. 183 Elevated Viaduct consists of twin elevated structures in the median that cantilever over the frontage roads. Each structure has a width of 17.68 m (58.0 ft) and carries three lanes plus shoulders. The maximum span length is 41.1 m (135 ft). The project has a total of 3332 precast segments, which are used to construct 206 spans. The viaduct was designed by the Texas Department of Transportation and was completed in 1997.

The Lee Roy Selmon Crosstown Expressway has a single elevated structure in the median, which allows for a future at-grade lane in each direction under the bridge. The 17.99 m (59.0 ft) wide Downtown Expressway has three lanes plus shoulders, while the 14.33 m (47.0 ft) wide Brandon Parkway has two lanes plus shoulders. The maximum span length is 43.3 m (142 ft). The project has a total of 3032 precast concrete segments, which are used to build 196 spans. The expressway was designed by Figg Engineering Group, and is presently being constructed by PCL Civil Constructors Inc.

The SBWM offers a number of attractive advantages over a conventional box girder scheme: (1) the traffic capacity of three lanes can be increased by one-third (i.e., to four lanes) by using the SBWM, (2) the span of the long heavy canti-

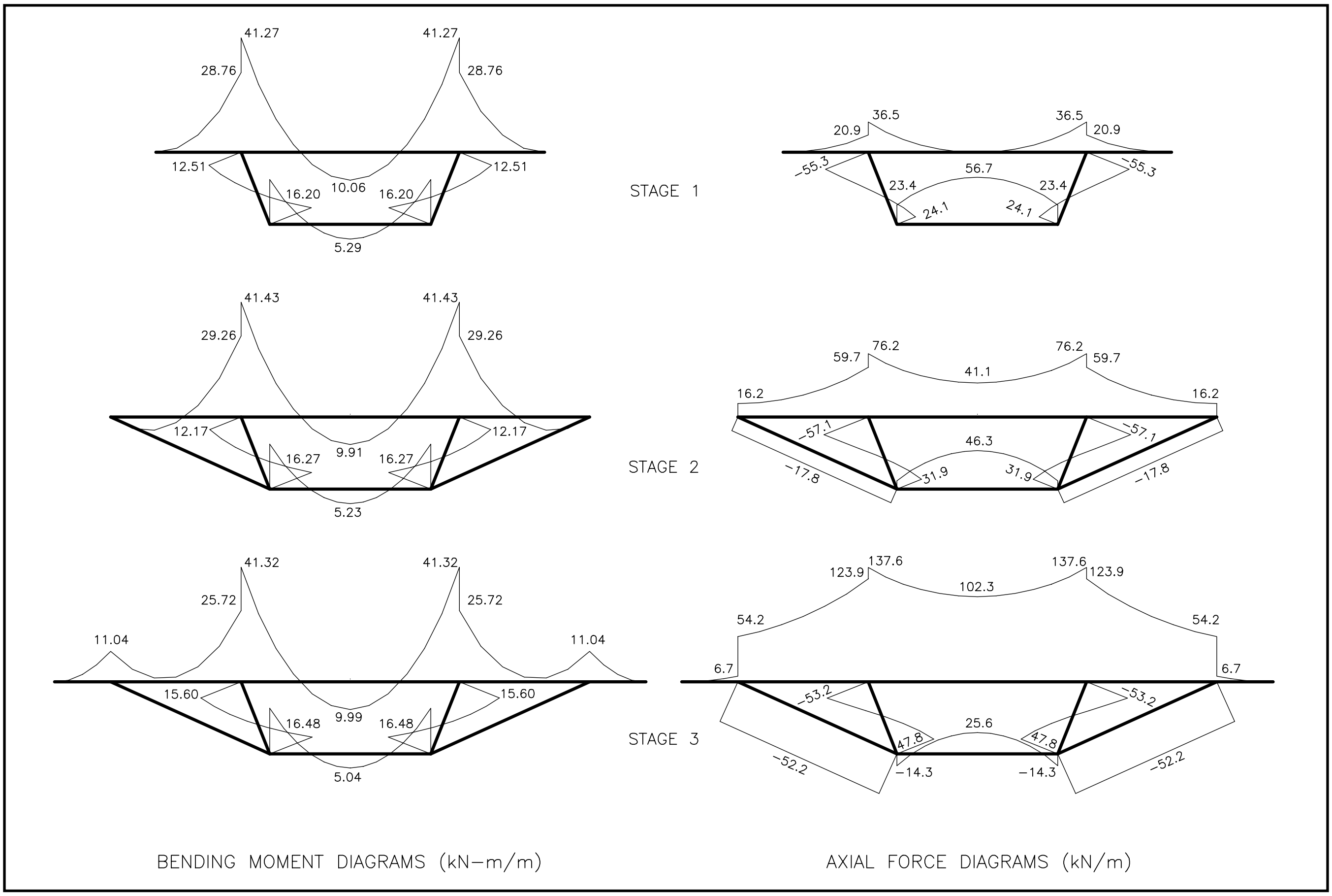

Fig. 12. Transverse bending moment diagrams and axial force diagrams for self-weight.

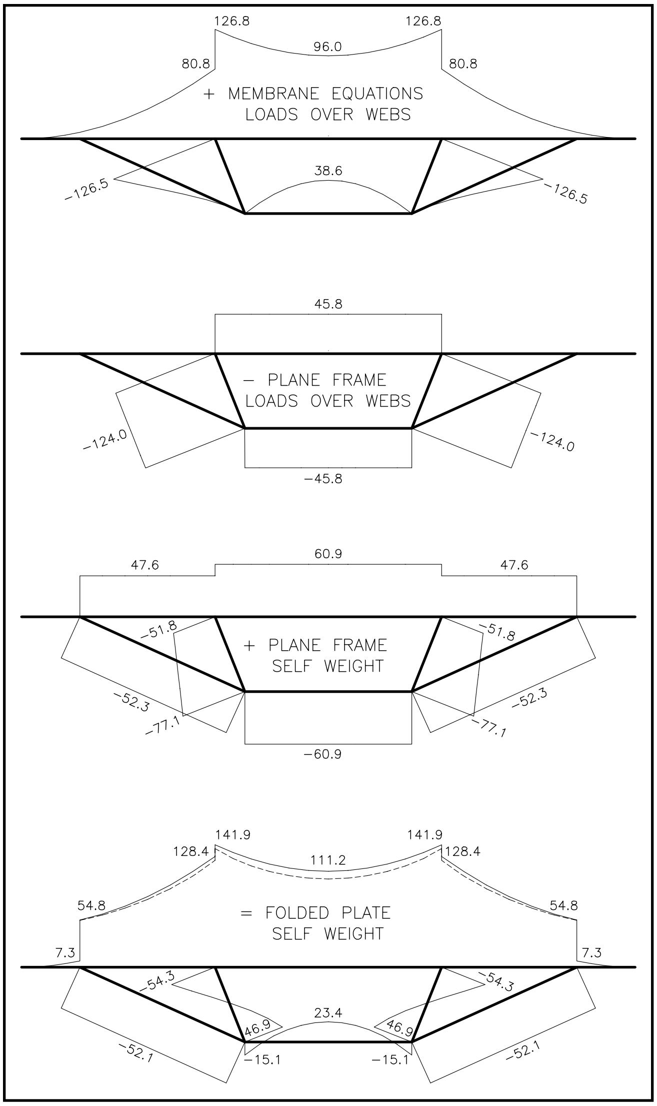

Fig. 13. Determination of transverse axial force diagram for self-weight.

Fig. 14. U.S. 183 elevated viaduct.

Fig. 15. Lee Roy Selmon Crosstown Expressway (from Reference 6).

levers can be reduced by using compression struts, which translates directly into weight savings and, hence, cost savings, and (3) the expressway can initially be built to three lanes and still be widened to four lanes in the future (or two lanes widened to three or four lanes in the future).

A major advantage of the SBWM is that it is possible to construct a single elevated median-based expressway with a central barrier curb to have two lanes plus a shoulder in each direction. Having the capability to construct an elevated four-lane bridge may offer traffic planners an alternative to constructing twin structures or reversing traffic lanes for this type of project.

Aesthetics played a very important role in the design of both projects.[5,6] The U.S. 183 Elevated Viaduct has elegant flared piers, with the central portion of the flare being removed and replaced with tension struts at the top. The Lee Roy Selmon Crosstown Expressway superstructure has a sculpted shape with curves in the webs and corners in the bottom slab. Aesthetics can also play a prominent role in a design using the SBWM. Special architectural treatments to the piers and superstructure can be easily featured in the design.

In conclusion, the SBWM offers substantial flexibility while retaining the advantages of traditional span-by-span segmental construction in congested urban environments, namely, rapid superstructure construction with minimum disruption to at-grade traffic.

MAJOR LONG-SPAN CROSSINGS

Suppose that a major long-span crossing needs to be designed and constructed. It will take a significant budget and construction effort to build this bridge. Let us consider two different "what-if" studies for this crossing:

1. Twin bridges—Present traffic estimates are that each bridge requires only two lanes (Stage 1). The owner can construct the bridges to have the lowest initial cost or can spend slightly more to allow each bridge to be widened in the future to have three lanes (Stage 2) or four lanes (Stage 3). The North Halawa Valley Viaduct in Hawaii is considered for this "what-if" study.

2. Single bridge—Present traffic estimates are that the bridge requires only one lane in each direction (Stage 1). The

Fig. 16. North Halawa Valley Viaduct (from Reference 7).

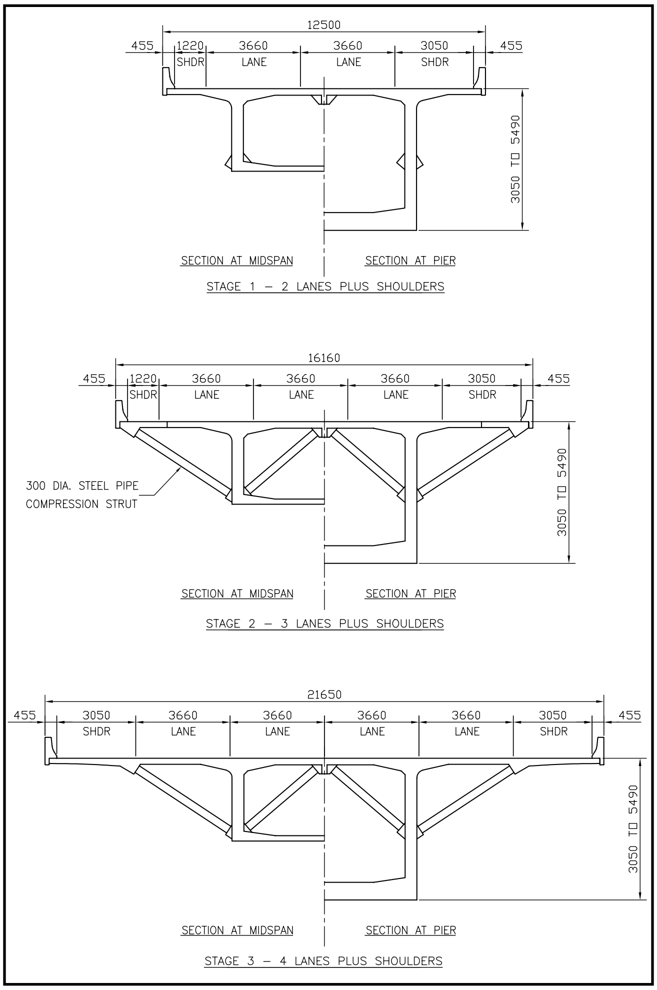

Fig. 17. Proposed cross section widening at midspan and pier for North Halawa Valley Viaduct.

owner can construct this bridge to have the lowest initial cost or can spend slightly more to allow the bridge to be widened in the future to have two lanes in each direction (Stage 3). The Confederation Bridge in Canada is considered for this "what-if" study.

The North Halawa Valley Viaduct[7] (see Fig. 16) consists of twin prestressed concrete segmental bridges. The 1720 m (5640 ft) inbound viaduct carries traffic to Honolulu, while the 1667 m (5740 ft) outbound viaduct carries traffic to Kaneohe. The maximum span length is 110 m (360 ft), and the depth of the section varies from 5.49 m (18.0 ft) at the pier to 2.44 m (8.0 ft) at midspan. This cast-in-place segmental bridge was built using the balanced cantilever method of construction using form travelers in conjunction with a launching truss. The bridge was designed by T.Y. Lin International/Nakamura and Tyau and constructed by Kiewit Pacific.

Fig. 17 shows the proposed widening for the three stages of construction. The Stage 1 cross section has been adapted from the actual cross section of the bridge to have an interior longitudinal beam and blisters for the compression struts. Furthermore, the section depth at midspan has been increased from 2.44 to 3.05 m (8.0 to 10.0 ft) to allow the compression struts to have an angle of 33 degrees with the bridge deck.

Note that it would be possible to keep the original midspan section depth and decrease the compression strut angle, but the resulting design of the widened bridge would not be as efficient. The section depth at the pier has not been changed. All other dimensions of the proposed cross section in Stage 1 remain the same as the actual cross section.

The Confederation Bridge[8,9] (see Fig. 18) is a 12.9 km (8.0 mile) long-span bridge that crosses the Northumberland Strait in Canada and joins the province of Prince Edward Island to New Brunswick and the rest of the mainland. The entire structure consists of the 1300 m (4264 ft) west approach bridge (in the foreground), the 11,000 m (36,080 ft) main bridge (in the background), and the 600 m (1968 ft) east approach bridge. The main bridge has 250 m (820 ft) spans while the approach bridges have 93 m (305 ft) spans.

The main bridge was erected using only 175 precast concrete components. The approach bridges were erected as precast segmental balanced cantilever bridges using a launching truss. This design-build project was designed by Jean Muller International/Stanley Joint Venture and constructed by Strait Crossing Joint Venture. The author was involved in this project as the design project manager for the west approach bridge.

Fig. 19 shows the proposed cross section widening for the approach bridges (the proposed cross section widening for the main bridge would be similar). Stage 1 has one lane plus a shoulder in each direction, while Stage 3 has two lanes plus a shoulder in each direction. The Stage 1 cross section shown is virtually identical to the actual cross section of the bridge, except that an interior longitudinal beam is provided along with blisters at the top and bottom for the future compression struts. Note that because Stage 2 construction (three lanes plus shoulders) is not relevant for this bridge, there is some flexibility in choosing the compression strut angle in Stage 3 (30 degrees has been chosen in this case).

The previous paper[1] emphasized that in order to gain the advantages of the SBWM (flexibility in widening, structural efficiency, low initial cost, reduced incremental cost and schedule, reduced prestressing for cantilever construction, and potential to satisfy FHWA performance objectives), a designer also has to deal with its disadvantages (increased design effort, greater substructure capacity, greater shear ca-

Fig. 18. Confederation Bridge. (Courtesy of Boily)

pacity, provision for future prestressing, and possible need to close the bridge during widening).

Consider each of the key disadvantages as they would apply to these bridges. The additional substructure capacity is not significant because balanced cantilever construction already provides increased capacity for the unbalanced moments. The additional shear capacity can be a costly issue if it requires additional web thickness for Stage 1 construction. However, an effective solution is to drape the Stage 2/Stage 3 external tendons to balance the increased shear demand so that an increased web thickness is not required.

Note that it is not necessary to close these bridges during widening. For the North Halawa Valley Viaduct, widening can proceed by diverting traffic from one bridge to the other and using the erection truss described in the previous paper.[1] Widening of the Confederation Bridge can proceed while allowing traffic to pass by using traveling underslung formwork attached to the web and cantilever.

Consider the key advantages that would apply to these bridges. There is complete flexibility in widening. The number of lanes on the bridge at the conclusion of its 100-year service life is solely a function of future traffic. The solution is structurally efficient. In order to have an increase of 100 percent in traffic capacity, the required increase in structural superstructure moment and shear capacity is on the order of

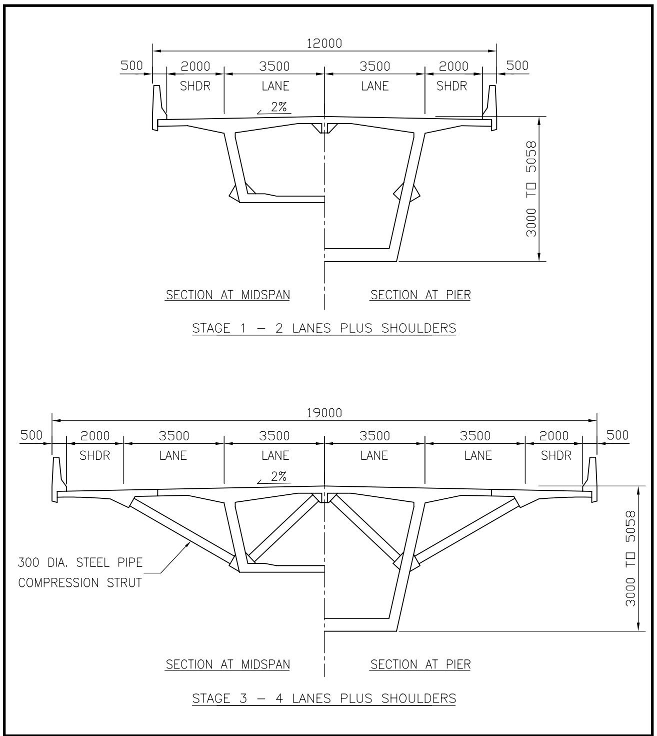

Fig. 19. Proposed cross section widening at midspan and pier for Confederation Bridge.

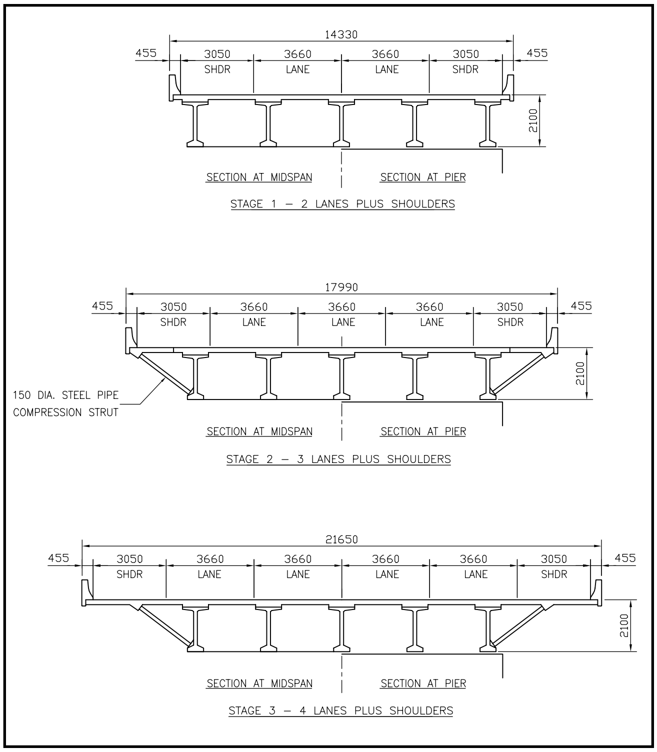

Fig. 20. Cross section widening for an AASHTO-PCI precast girder bridge.

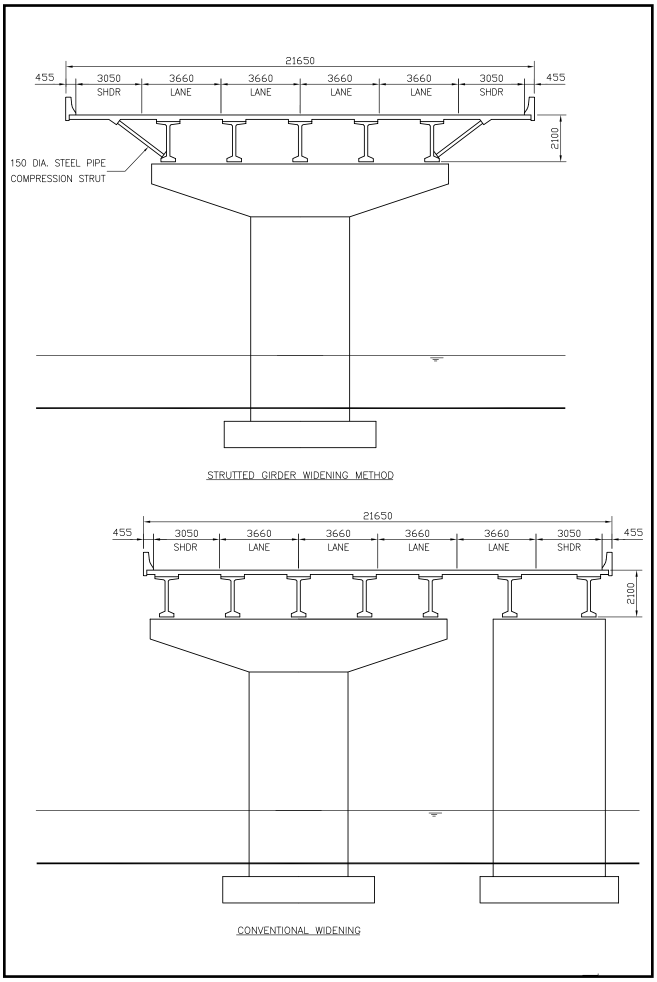

Fig. 21. Strutted girder widening method versus conventional widening of a bridge.

25 percent (significantly less for the main bridge of the Confederation Bridge). The initial cost is kept low by constructing only the bridge that is initially required. The incremental cost and schedule of doubling the traffic capacity by using the SBWM is substantially reduced over that of constructing additional major long-span crossings.

STRUTTED GIRDER WIDENING METHOD (SGWM)

Widening an AASHTO-PCI BT72 precast girder bridge (see Fig. 20) using the strutted girder widening method (SGWM) is similar to widening a precast segmental box girder bridge (see Fig. 1) using the strutted box widening method (SBWM). Exterior compression struts are installed and an additional deck slab is formed and placed. Both transverse internal prestressing tendons and longitudinal external prestressing tendons are installed and stressed.

Note that the lane configurations and overall deck dimensions in both these figures are the same for all three stages of construction. A new bridge can be designed and constructed so that it can be widened in the future, but, more importantly, an existing bridge can be widened at any time to double the traffic capacity.

As an example, consider the widening of an existing two-lane bridge to a four-lane bridge using the SGWM (see Fig. 21). The key to widening an existing bridge is to reduce the total weight by using a thinner deck and lightweight concrete. Because transverse prestressing is used, the 200 mm (8 in.) deck can be reduced to 150 mm (6 in.) (assuming that a sacrificial layer of concrete is not required in the deck as an overlay). If the deck thickness is reduced by 25 percent and the concrete density is reduced by 20 percent, a net reduction of 40 percent in the deck weight is achieved.

For this bridge, the Stage 1 dead load is 65.14 kN/m (4.46 kips/ft), while the Stage 3 dead load is 59.47 kN/m (4.08 kips/ft). This 10 percent reduction in dead load suggests that the substructure capacity may be adequate for the widened bridge, and that some of the existing girder capacities may be adequate, although some existing girders may need to be strengthened.

A detailed finite element analysis should be made for the widened bridge. The computer model would include plate elements for the deck slab, offset beam elements with rigid links for the precast girders (and longitudinal beams), and beam elements for the compression struts, along with diaphragm elements for the lateral bracing. The purpose of this finite element analysis is to determine the actual distribution of the concentrated truck wheel loads to the various girders.

The effect of increasing the number of diaphragms can be investigated with respect to (1) the load sharing of the precast girders, and (2) the transfer of the lateral compression strut forces through the structural system. Once an appropriate diaphragm spacing has been selected, the design can proceed.

The design procedure starts with checking the shear capacity of *each* existing girder for the widened dead load, superimposed dead load, and live load. If the shear capacity is not adequate, then draped external prestressing tendons are suggested for the girders, so that the vertical component of the

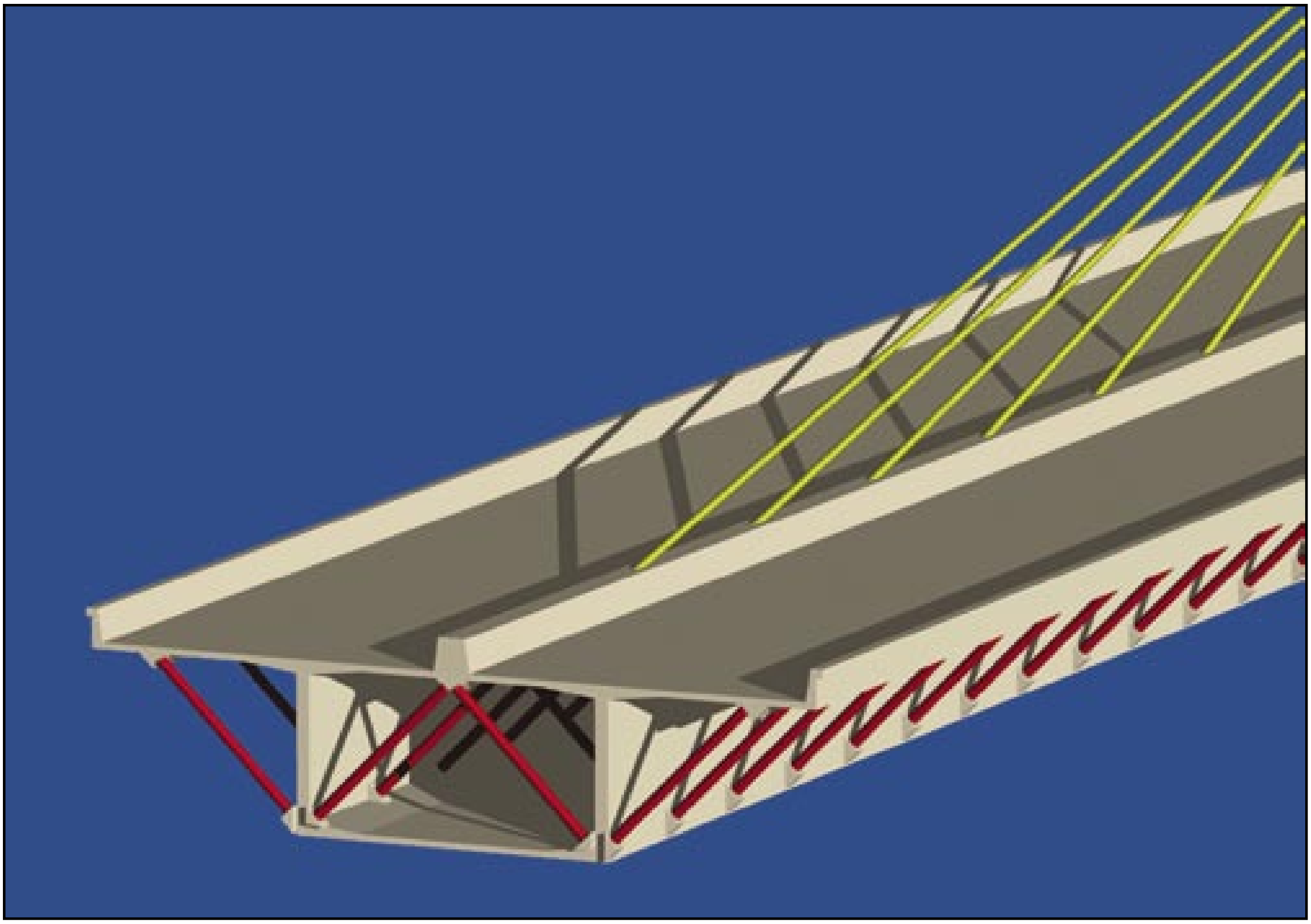

Fig. 22. Fraser River Crossing proposal.

prestressing force can balance the increased shear demand. If the shear capacity is adequate, then simple straight external prestressing tendons can be used for the girders.

The external tendons are proportioned to bring the flexural stresses to within the allowable limits, and the girder design is checked for ultimate strength, as well as camber and deflection. The diaphragm bracing system is checked to ensure that the compression strut forces can be transferred laterally. The pier and foundation capacity are checked to ensure that they can carry the additional load.

The major advantage of using the SGWM to widen an existing bridge is that no additional substructure work has to be done. This means that environmental permits do not have to be obtained to work in the water. This also means that cofferdams do not have to be built in the water to allow the substructure to be constructed. Furthermore, a workbridge does not have to be built in the water to allow the additional lines of girders to be erected. The SGWM does not require any construction in the water; in fact, the method does not even require water access. All construction is carried out from above on the existing bridge.

Another advantage of the SGWM is that the existing alignment is maintained (see Fig. 21). The conventional widening has the centerline of the roadway shifted over by 3.66 m (12 ft). If alignment and right-of-way are issues, widening on both sides of the existing bridge would be required. This would require water access on both sides of the existing bridge to build new substructures, and also to erect new lines of girders. This would essentially double the cost of conventional widening.

The design procedure using the SGWM is much more demanding than that for a typical precast girder bridge. The increased design effort, however, can be justified if the construction cost is greatly reduced. The designer should consider both the SGWM and conventional widening for a particular application. In most cases, conventional widening will be the more reasonable solution, but in certain instances (such as tall bridges over water), the SGWM may be a better solution.

A new bridge can be designed and constructed using the SGWM to allow for future widening. Although it appears to make more sense to construct extra-wide piers to allow new girder lines to be erected rather than applying the SGWM, there are still instances where the future delivery and erection of additional girders becomes very expensive or difficult (such as built-up locations). For cases such as these, the SGWM may offer a viable solution.

PRECAST SEGMENTAL EXTRADOSED BRIDGES

A precast segmental extradosed bridge that is constructed and widened using the strutted box widening method (see Fig. 22) has been proposed by the author for the new Fraser

River Crossing in Vancouver, Canada. The bridge elevation (along with the segment layout and strut locations) is shown in Fig. 23, while the cross section is shown in Fig. 24. The requirements of this design-build project are that the 1835 m (6021 ft) long bridge have three 225 m (738 ft) spans in the navigation channel and that it have three lanes plus a shoulder in each direction.

The proposed 12-span solution (see Fig. 23) has three 225 m (738 ft) main spans flanked on each side by one 175 m (574 ft) transition span and a number of 125 m (410 ft) approach spans. The main spans have stay cables that are draped over 20 m (66 ft) high towers to connect every second segment in the central portion of the span. What is interesting here is that the entire bridge comprises 367 similar constant-depth 5.0 m (16.4 ft) long precast segments, which are assembled using the balanced cantilever method of construction. Thus, the same solution applies to both the traditional segmental and cable-supported segmental spans. Economy is achieved by having repetition in both the casting and erection operations.

The 16.0 m (52.5 ft) wide cross section (see Fig. 24) is built by the balanced cantilever method in Stage 1, and then the SBWM is used to complete the 27.9 m (91.5 ft) wide cross section in Stage 2. (The SBWM is used here for construction purposes only and not as the basis for future widening.) The section depth is 6.25 m (20.5 ft), which gives a span-to-depth ratio of 20 for the approach spans and a strut angle of 45 degrees. The 400 mm (15.75 in.) diameter steel pipe compression struts are spaced at 5.0 m (16.4 ft) along the length of the bridge.

This Fraser River Crossing proposal demonstrates that the SBWM can be applied to cable-supported and conventional segmental bridges in a similar manner.

CONCLUDING REMARKS

The strutted box widening method (SBWM) and the strutted girder widening method (SGWM) allow two-lane prestressed concrete bridges to be designed and constructed so that they can be easily widened into three- or four-lane bridges at any time. These are attractive solutions since widening only needs to be done if and when traffic volumes warrant it.

This paper and the previous paper[1] have elaborated upon eight different applications of the SBWM and the SGWM. These are:

1. Precast/prestressed concrete girder bridge.

2. Constant-depth precast segmental bridge, built by the span-by-span method of construction.

3. Constant-depth precast segmental bridge, built by the balanced cantilever method of construction.

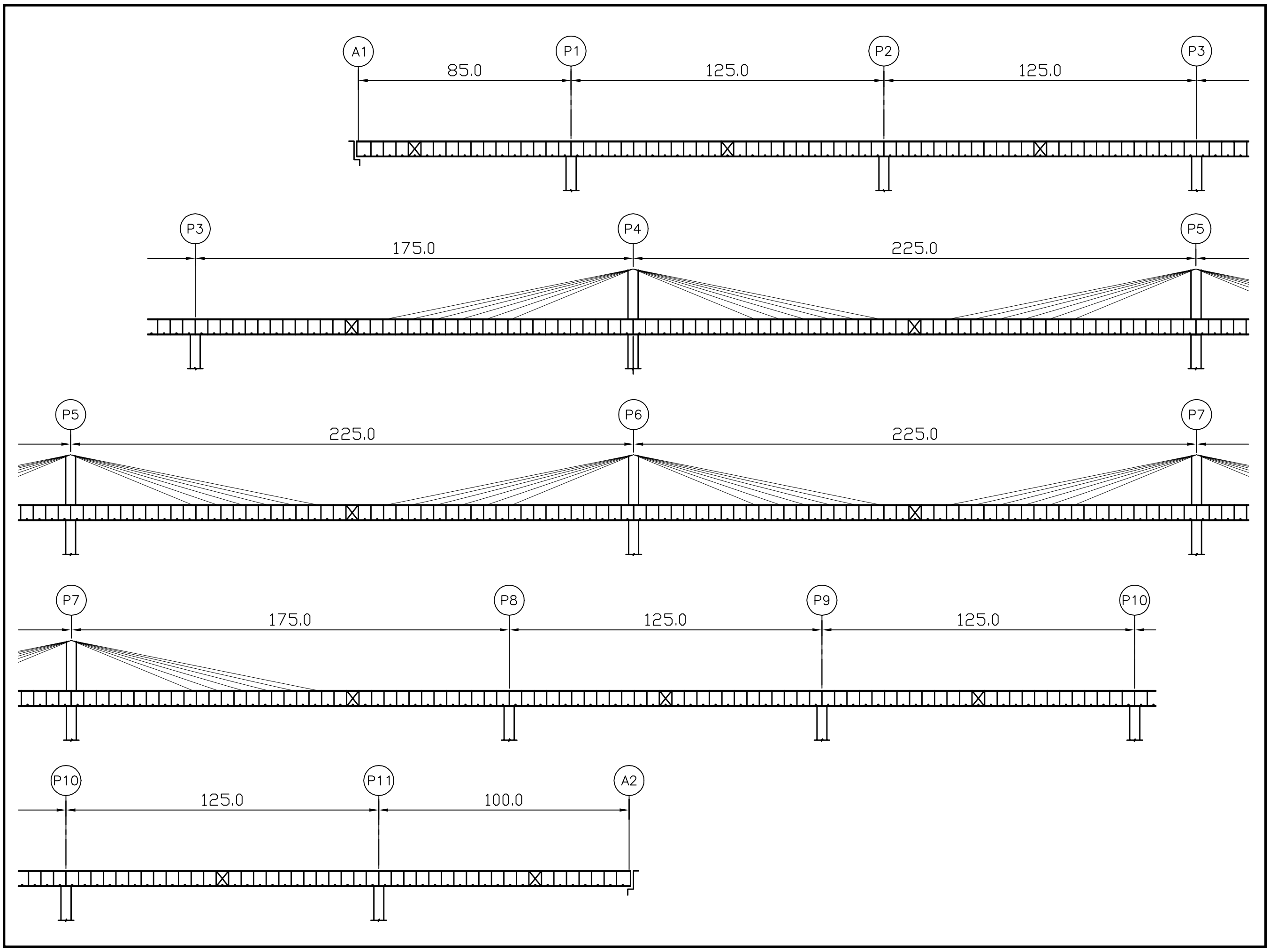

Fig. 23. Elevation of Fraser River Crossing.

4. Variable-depth cast-in-place segmental bridge, built by the balanced cantilever method of construction.

5. Elevated median-based expressway "what-if" study —U.S. 183 Elevated Viaduct in Texas and Lee Roy Selmon Crosstown Expressway in Florida.

6. Major long-span crossing "what-if" study—North Halawa Valley Viaduct in Hawaii.

7. Major long-span crossing "what-if" study—Confederation Bridge in Canada.

8. Precast segmental extradosed bridge—Fraser River Crossing proposal.

These are excellent solutions for constructing economic and efficient bridges to handle current traffic volumes, while simultaneously offering an effective "head start" on cost- and schedule-effective bridge widenings to handle future traffic volumes.

The introduction of the SBWM and SGWM has effectively added a new bridge type to the repertoire that bridge designers and constructors can consider in search of the best possible solution for any particular application.

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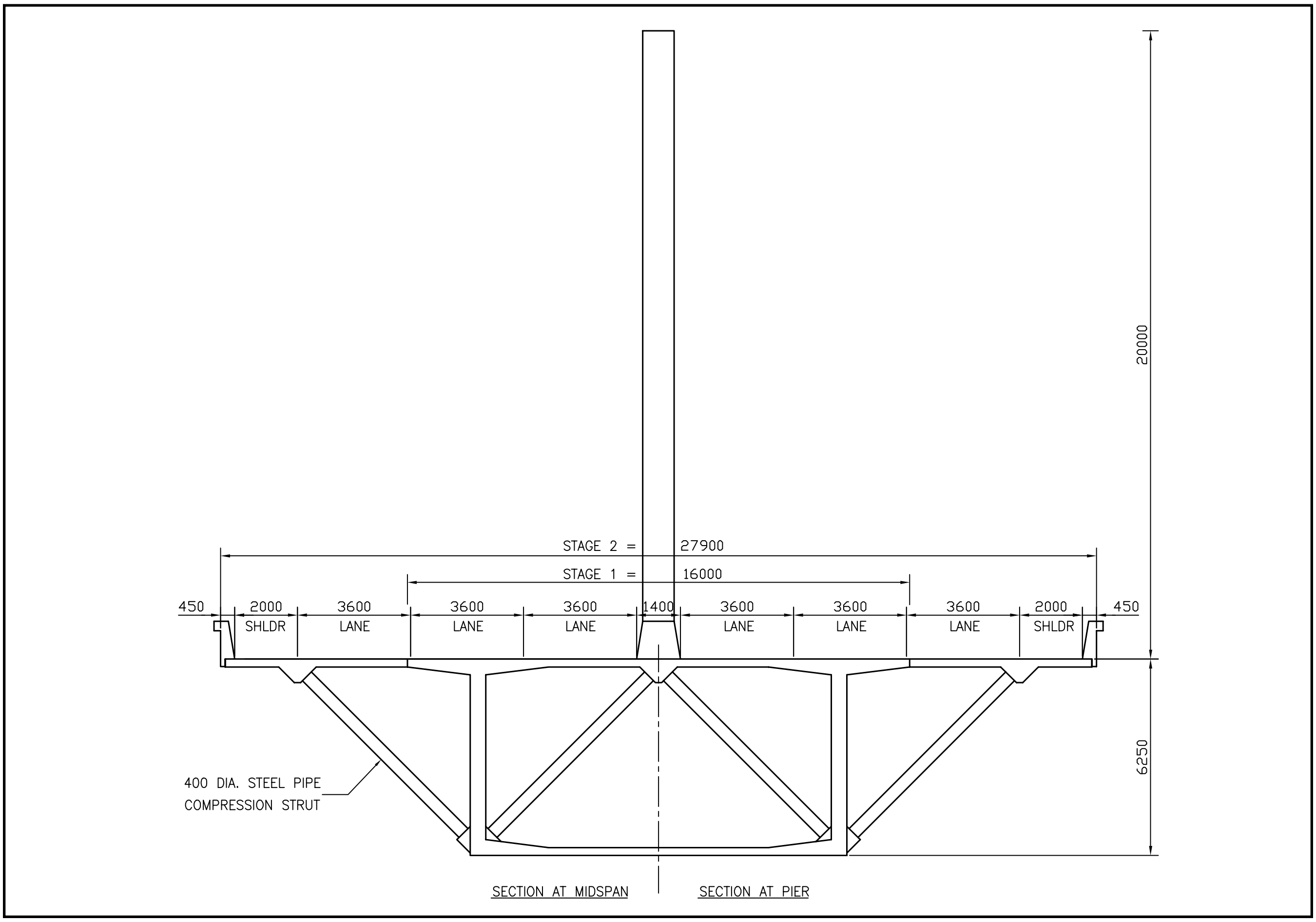

Fig. 24. Cross section of Fraser River Crossing.