# Short to Medium Span Precast Prestressed Concrete Bridges in Japan

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*Nearly 40 years have elapsed since precast, prestressed concrete was first introduced to the Japanese construction industry. During this period, precast, prestressed members have been utilized mainly in bridge systems. The need for prefabricated bridges has resulted from field labor shortages in Japan. The high quality of precast, prestressed concrete makes it the material of choice for short to medium span bridges. The objective of this paper is to present the Japanese state-of-the-art of design and construction using precast, prestressed concrete girders for bridges with spans ranging from 5 to 40 m (16 to 131 ft). Four national standard girders and one regional standard girder are presented. Also included are details of diaphragms, deck, bearing devices, and seismic resistant systems. Comparisons are made between Japanese and equivalent American systems relative to such factors as weight of precast members, amount of cast-in-place concrete, unit cost and design load capacity.*

For the past three decades, bridges with precast, pretensioned concrete girders spanning up to 21 m (69 ft) have accounted for more than 97 percent of the total number of prestressed concrete bridges constructed in Japan.[1] During the period between 1985 and 1989 alone, 6151 precast, pretensioned bridges were built.

Many 20- to 30-year old bridges have become obsolete or

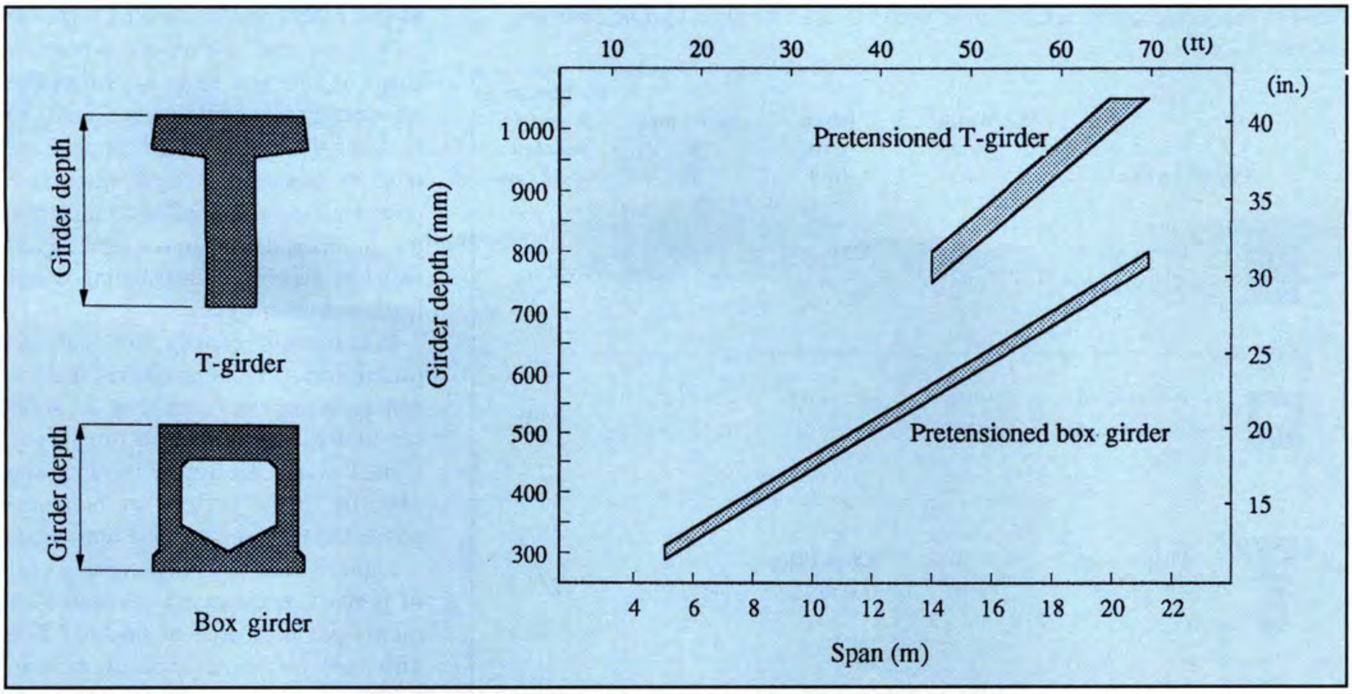



Fig. 1. Span-to-depth relationship for precast, pretensioned concrete girders for short span bridges as used in Japan.

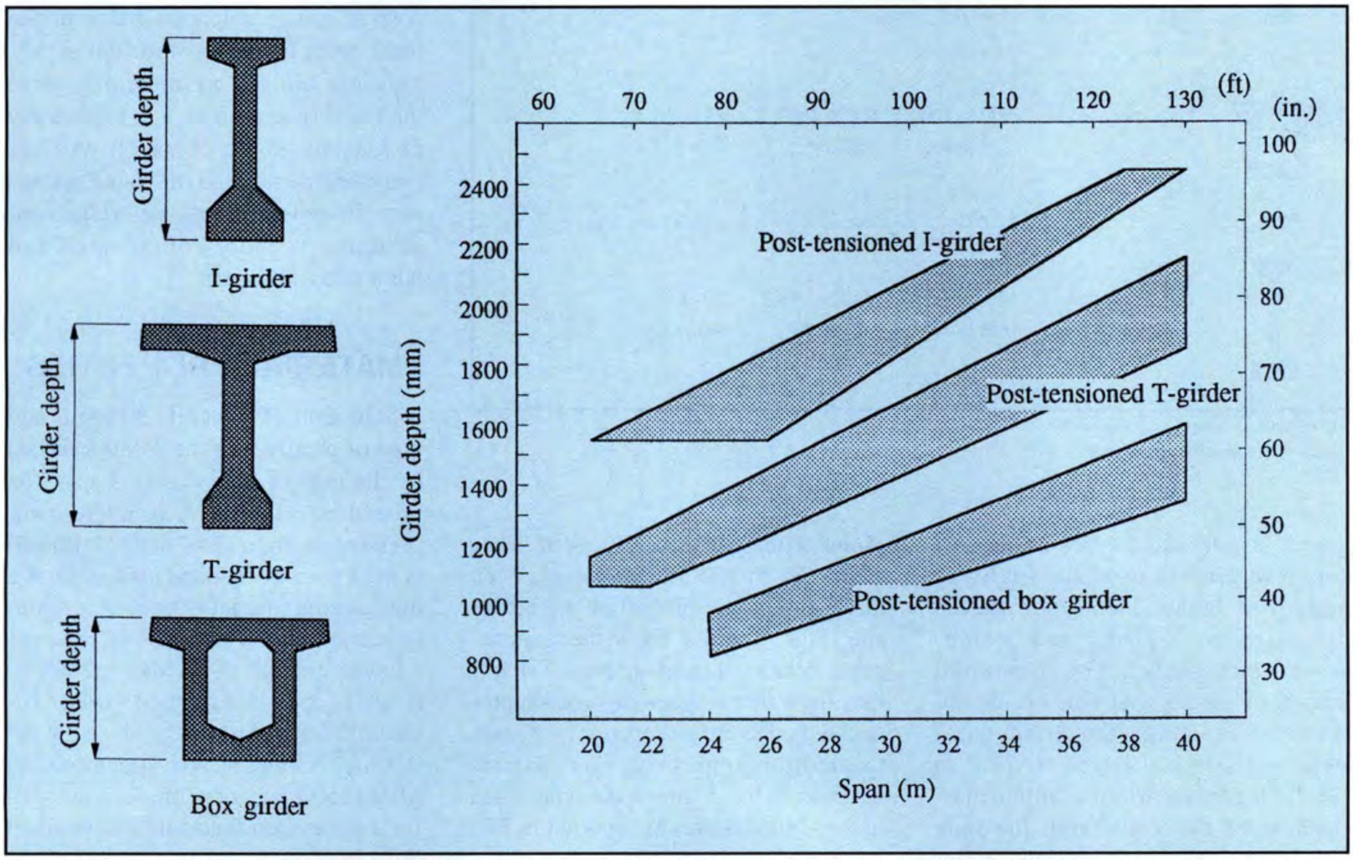



Fig. 2. Span-to-depth relationship for precast, post-tensioned concrete girders for medium span bridges as used in Japan.

unsafe due to the rapid growth of traffic volume and increased use of heavy transportation trucks as a result of the unprecedented economic growth in Japan. Replacement or widening of these bridges, as well as construction of new bridges, has demanded careful planning and execution. Cooperation between the precast concrete industry and Japanese transportation authorities has produced highly successful standardized bridge systems. In the following sections, Japanese design and construction details of typical precast, prestressed concrete bridges are discussed and compared with equivalent American practices.

There are four national and one re-

Table 1. Precast, prestressed concrete sections used for short to medium span bridges in Japan.

| Typical section | | Width mm (in.) | Depth mm (in.) | Span range m (ft) | Cast-in-place to precast concrete weight ratio |
|---|---|---|---|---|---|
|  | Pretensioned solid box girder* | 700 (28) | 325 to 400 (13 to 16) | 5 to 9 (16 to 30) | 0.10 |
|  | Pretensioned voided box girder* | 700 (28) | 425 to 800 (17 to 32) | 10 to 21 (33 to 69) | 0.10 |
|  | Pretensioned T-girder* | 750 (30) | 800 to 1050 (32 to 41) | 14 to 21 (46 to 69) | 0.25 |
|  | Post-tensioned T-girder* | 1500 (59) | 1050 to 2150 (41 to 85) | 20 to 40 (66 to 131) | 0.23 |
|  | Post-tensioned box girder* | 1000 to 1600 (39 to 63) | 800 to 1600 (32 to 63) | 24 to 40 (79 to 131) | 0.14 |
|  | Post-tensioned I-girder† | 650 to 1050 (26 to 41) | 1550 to 2450 (61 to 97) | 20 to 40 (66 to 131) | 0.60 to 1.20 |

* Used with noncomposite bridge deck.
† Used with composite bridge deck.

gional standardized types of precast concrete girders used for highway bridges in Japan. Two types are the pretensioned T-girder and pretensioned box girder. The maximum length of girder that can be moved from a precasting yard to any construction site is limited to 21.7 m (71 ft) by transportation authorities. Because of this constraint, the span length of precast, pretensioned girder bridges is limited to 21.0 m (69 ft). In unusual cases, longer girders have been utilized. In such circumstances, a special permit is obtained from the transportation authority.

Three other types of standardized bridge girders are the precast, post-tensioned I-girder, T-girder and box girder with span capabilities of 20 to 40 m (66 to 131 ft). However, even these girders are precast at the bridge site. Figs. 1 and 2 show the span-to-depth relationship of girders. Table 1 lists the various types of precast, prestressed concrete girders used for short to medium span bridges in Japan, whereas Table 2 shows the types used in the United States as reported in PCI literature.[2,3]

Of the systems described here, only post-tensioned I-girders are used with structural cast-in-place slabs to produce a composite bridge deck system. In this system, the cross-sectional area ratio of cast-in-place to precast concrete varies between 0.6 and 1.2.

In noncomposite construction, cast-in-place concrete is used to form diaphragms and to complete narrow strips of slab and shear keys between adjacent girders as shown in Figs. 3 to 6. After the cast-in-place concrete attains its specified strength, transverse post-tensioning is applied to integrate the girders and slabs into a rigid superstructure capable of distributing wheel loads and other forces.

In composite construction, cast-in-place concrete is used for the diaphragms and deck slab (Fig. 7), similar to I-girder construction in the United States. However, in Japan the majority of the bridges are noncomposite and transversely post-tensioned.

Table 3 compares the average cost of precast, prestressed concrete elements per unit area of bridge.[4] The unit cost for short to medium span bridge construction in Japan is three to four times that of bridges in the United States. However, precast concrete costs a comparable percentage of the total bridge cost in both countries. Japanese bridges are more expensive than American bridges due to a variety of reasons, some of which will become apparent in the following discussion. In general, Japanese bridge construction is more complicated and labor rates are higher.

## MATERIAL PROPERTIES

Selection of concrete strength and type of prestressing steel is influenced by the type of girder and construction procedure adopted. A concrete compressive strength of 49 MPa (7100 psi) is used for pretensioned girders since a high degree of quality control is maintained at the precasting plant, whereas a lower strength of 39 MPa (5700 psi) is used for post-tensioned girders because these girders are produced at the job site. A compressive strength of 59 MPa (8500 psi) or more is employed for factory-produced post-tensioned box girders.

Most precast concrete bridges built in the United States have a concrete strength in the 34 to 41 MPa (5000 to 6000 psi) range. Several initiatives are underway in the United States to produce bridge girders with a concrete strength as high as 83 MPa (12,000 psi). Cast-in-place deck strength in the United States is generally specified as 24 to 34 MPa (3500 to 5000 psi).

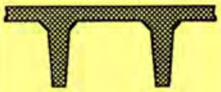
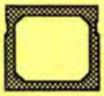
Prestressing steel used for pretensioned girders is either 15.2 or 12.7 mm (0.6 or 0.5 in.) diameter low relaxation strand with an ultimate strength of 1860 MPa (270 ksi). The choice is influenced by economy and span length. A multi-strand or multi-wire system with $f_{pu}$ of 1620 to 1720 MPa (235 to 250 ksi) is used for post-tensioned girders.

For post-tensioned girders, the standard practice in Japan is to use 12 - 7 mm (0.28 in.) diameter multi-wire systems for girders with span lengths up to 27 m (89 ft) and 12 - 12.4 mm (0.49 in.) multi-strand systems for longer spans. In the United States, 12.7 mm (0.5 in.) diameter strands are used almost exclusively for pretensioned girders, and 15.2 mm (0.6 in.) diameter strands are often employed in post-tensioning applications. Research is underway at several institutions in the United States to develop formulas for development and transfer lengths of 15.2 mm (0.6 in.) diameter strands in pretensioned concrete applications.

## DESIGN CONCEPT

Flexural design of prestressed concrete girders is primarily based on the working stress method with the flexural strength checked, similar to the approach taken by the American Association of State Highway and Transportation Officials (AASHTO) Specifications.[5] Design for shear and diagonal tension involves both working stress and strength design calculations. The formulas are somewhat similar to those used in the United States. If the section requires shear reinforcement, it may be provided in the form of mild steel reinforcement. Vertical post-tensioning is often used for shear reinforcement of long span girders but seldom used in short span bridges.

Table 2. Precast, pretensioned concrete beam sections used for short span bridges in the United States (Ref. 3).

| Typical section | Width mm (in.) | Depth mm (in.) | Span range m (ft) | Cast-in-place to precast concrete weight ratio |
|---|---|---|---|---|
|  Solid slab | 910 to 2440 (36 to 96) | 250 to 460 (10 to 18) | up to 9.1 (up to 30) | 0.0* |
|  Voided slab | 910 to 1220 (36 to 48) | 380 to 530 (15 to 21) | 7.6 to 15.2 (25 to 50) | 0.0* |
|  Multistem | 1220 (48) | 410 to 530 (16 to 21) | 7.6 to 16.8 (25 to 55) | 0.0* |
|  Double stem | 1520 to 2440 (60 to 96) | 410 to 580 (16 to 23) | 6.1 to 18.3 (20 to 60) | 0.0† |
|  Single stem | 1220 to 1830 (48 to 72) | 610 to 1220 (24 to 48) | 12.2 to 24.4 (40 to 80) | 0.0† |
|  Box girder | 910 to 1220 (36 to 48) | 690 to 1070 (27 to 42) | 18.3 to 30.5 (60 to 100) | 0.0* |
|  Deck bulb tee ‡ | 1220 to 2130 (48 to 84) | 740 to 1040 (29 to 41) | 18.3 or more (60 or more) | 0.0† |
|  I-girder ‡ | 460 to 660 (18 to 26) | 910 to 1370 (36 to 54) | 12.2 to 30.5 (40 to 100) | 0.6 to 1.2 |
|  AASHTO/PCI bulb tee‡ | 1070 (42) | 1370 to 1830 (54 to 72) | 24.4 to 42.7 (80 to 140) | 0.6 to 1.2 |
|  Local standard I-girder‡ | 610 to 1520 (24 to 60) | 710 to 2740 (28 to 108) | up to 50.9 (up to 167) | 0.6 to 1.2 |

* Bridges built without topping concrete or diaphragms.
† In some cases, with topping concrete and cast-in-place concrete diaphragms.
‡ When post-tensioning is used in combination with pretensioning, these girders may be spliced to reach longer spans up to 76 m (250 ft).

## LOADS ON BRIDGE GIRDERS

In Japan, similar to American practice, bridge girders are designed for dead and live load, impact or dynamic effect due to live load, wind forces, and other forces. These forces include the effect of thermal movement, shrinkage and creep of concrete, and seismic loads. As described next, the live loads used in Japan differ significantly from those used in the United States.

## LIVE LOADS

Two different types of live loads, namely TL and TT loads, are used to determine the live load effect on all highway bridges in Japan.[6] TL loadings are designated by the letters TL followed by a number indicating the gross weight in metric tons of the truck.

TL loading consists of two types: "T" represents a truck and "L" represents a distributed load equivalent to the T load. A T-20 truck is shown in Fig. 8a and an L-20 load is shown in Fig. 8b. TL-20 means T-20 or L-20, whichever controls the design. TT designates a truck-trailer loading, as shown in Fig. 9.

For major bridges, TT-43, in combination with TL-20, is used in design. For secondary bridges, only TL-14 is used, which is 70 percent of the weight of TL-20.

L-20 load consists of a uniform load and a transverse line load as shown in Fig. 8b. Uniform load comprises a high intensity load, $p$, spread over a 5.5 m (18 ft) width and $p/2$ for the remaining area, where $p = 4.9$ kN/m$^2$ (102 lbs per sq ft) for spans less than 80 m (262 ft). The transverse concentrated line load consists of 49 kN/m (3400 lbs per ft) in the high intensity loading area, and 24.5 kN/m (1700 lbs per ft) over the remaining width.

L-20 loading must be placed in such a way as to produce maximum stress. When TT-43 is used in combination with L-20, L-20 is increased by a $K$ factor which varies with the span length. Different procedures and $K$ factors are used for bridges depending on the owner. Table 4 shows the typical factors used for bridges owned and operated by the Japan Highway Public Corporation.[7]

In contrast, the United States system requires a 3 m (10 ft) wide uniform lane loading of 93 kN/m (640 lbs per ft) plus a moving point load. The point load used is 80 kN (18,000 lbs) for flexure and 116 kN (26,000 lbs) for shear. These values are to be used when HS-20 truck load is the design loading. For other loading levels, the intensity of the lane loading is adjusted proportionately. Bridges supporting U. S. interstate highways are also designed for an alternate military loading of two axles, 1.2 m (4 ft) apart, with each axle weighing 107 kN (24,000 lbs).

Table 3. Approximate cost of precast concrete bridges (Ref. 4).

| Type | United States | | Japan | |
|---|---|---|---|---|
| | Cost of total bridge (\$/ft$^2$) | Cost of precast concrete delivered (\$/ft$^2$) | Cost of total bridge (\$/ft$^2$) | Cost of precast concrete delivered (\$/ft$^2$) |
| Short (< 60 ft) | 35 to 50 | 15 to 20 (40 percent) | 150 to 200 | 30 to 55 (25 percent) |
| Medium (60 to 150 ft) | 50 to 70 | 15 to 20 (30 percent) | 200 to 250 | 30 to 55 (20 percent) |

**Note:** 1 ft = 0.3048 m; 1 \$/ft$^2$ = \$10.76/m$^2$.

Table 5 presents the computed maximum moments and shear forces for a typical bridge with a span length of 20 m (66 ft) for both Japanese and AASHTO loading. In computing moments and shear forces per lane due to live loads, TL-20 and combined TL-20 and TT-43 were fully imposed on a four-lane roadway bridge, and then the resulting values were divided by four.

It should be noted that in design practice in Japan, the maximum live load effect on a bridge girder is computed using a complex wheel load distribution analysis. As shown in Table 5, the service load moment due to the Japanese loading is 1190 kN-m (878.0 kip-ft) and AASHTO loading is 1240 kN-m (914.0 kip-ft), which are comparable values.

In comparing ultimate moments per lane due to live load, the live load is multiplied by a factor $\gamma = 2.5$, whereas in the United States $\gamma\beta_L = 1.3 \times 1.67 = 2.17$ is applied before the impact factor is incorporated in the computation. The impact factor used in Japan for the bridges under discussion is $I = 10/(25 + L)$, where $L$ is the span in meters. The impact factor in AASHTO is $50/(125 + L)$, where $L$ is in feet. A span of 20 m (66 ft) corresponds to $I = 0.22$ in Japan and $I = 0.26$ in the United States. Thus:

Table 4. Loading factors for live load TT–43 [span ≤ 40 m (131 ft)] (Ref. 7).

| Moment and shear force | Span (m) | Factor $K$ |
|---|---|---|
| Positive moment | 15 | 1.08 |
| | 20 | 1.13 |
| | 25 | 1.20 |
| | 30 | 1.24 |
| | 40 | 1.26 |
| Negative moment | 10 | 1.57 |
| | 12 | 1.53 |
| | 15 | 1.43 |
| | 18 | 1.34 |
| | 20 | 1.28 |
| | 22 | 1.23 |
| | 40 | 1.20 |
| Shear force | 15 | 1.36 |
| | 20 to 30 | 1.42 |
| | 40 | 1.39 |

**Note:** 1 m = 3.28 ft.

Table 5. Comparison of moments and shears due to Japanese and American live loading for a 20 m (66 ft) simple span bridge.

| Live load | Japan | | United States | |
|---|---|---|---|---|
| | TL-20 | TL-20, TT-43 | HS20-44 | HS25-44 |
| Moment due to service load* per lane: $M_s$ | 1120 kN-m (826 kip-ft) | 1190 kN-m (878 kip-ft) | 1240 kN-m (914 kip-ft) | 1550 kN-m (1143 kip-ft) |
| Shear force due to service load* per lane: $V_s$ | 220 kN (49.5 kips) | 270 kN (60.7 kips) | 280 kN (63.0 kips) | 340 kN (76.5 kips) |
| Moment due to ultimate load per lane: $M_u$ | 3400 kN-m (2507 kip-ft) | 3640 kN-m (2684 kip-ft) | 3400 kN-m (2507 kip-ft) | 4240 kN-m (3127 kip-ft) |
| Shear force due to ultimate load per lane: $V_u$ | 680 kN (153 kips) | 830 kN (187 kips) | 760 kN (171 kips) | 940 kN (211 kips) |

* Impact factor is not included.

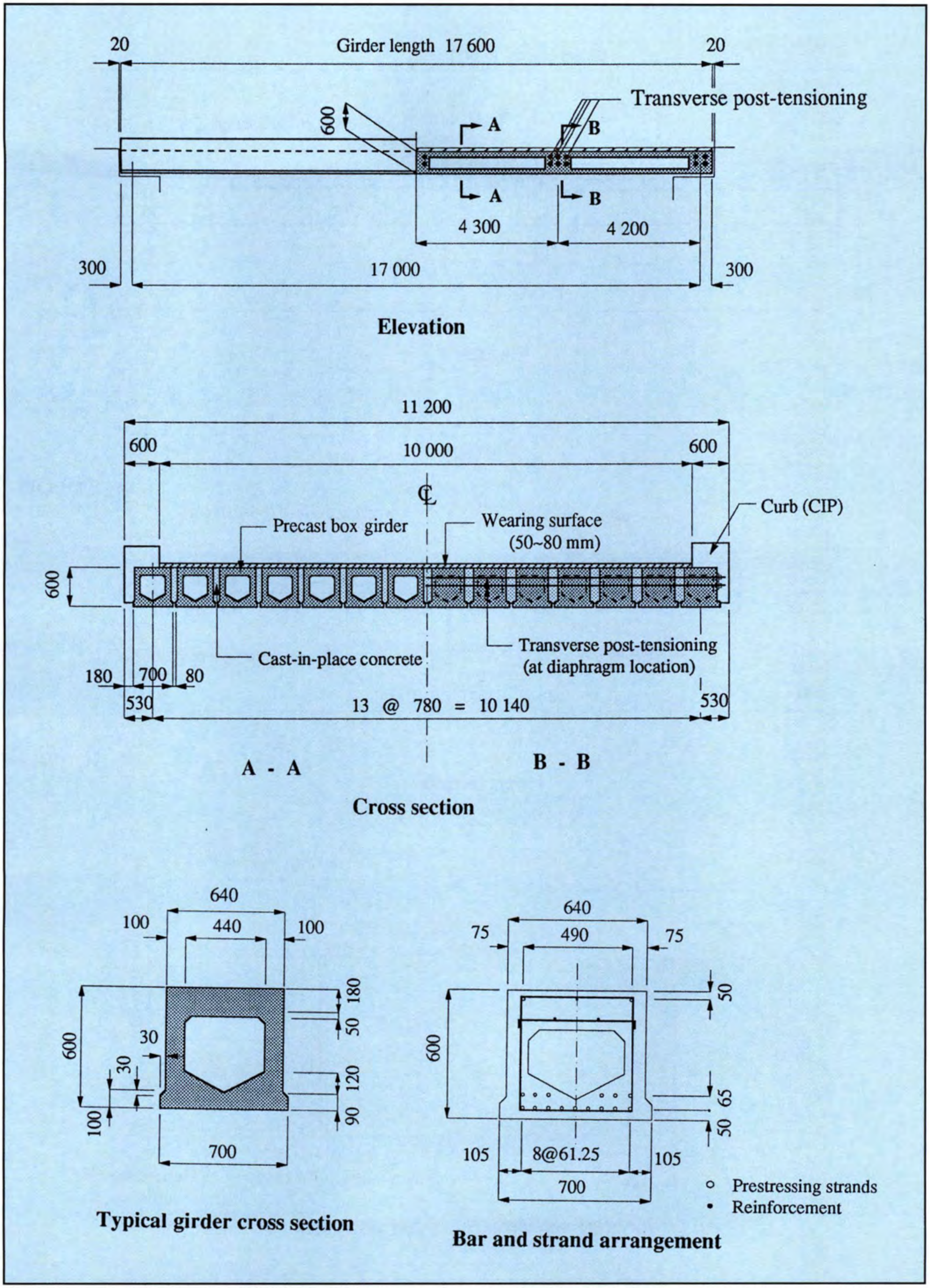



Fig. 3. Precast, pretensioned concrete box girder bridge system for simple short span. Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.

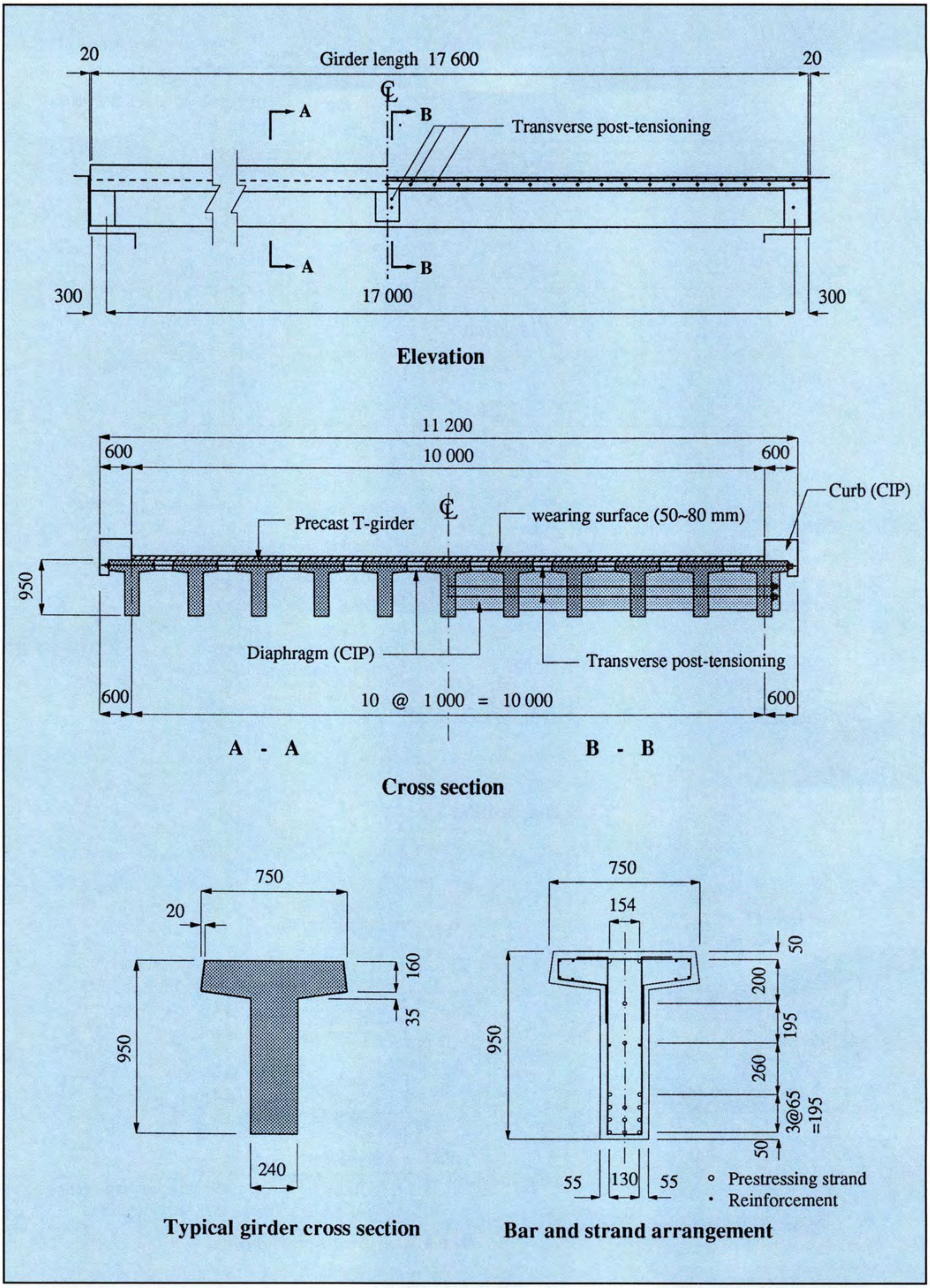



Fig. 4. Precast, pretensioned concrete T-girder bridge system for simple short span. Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.

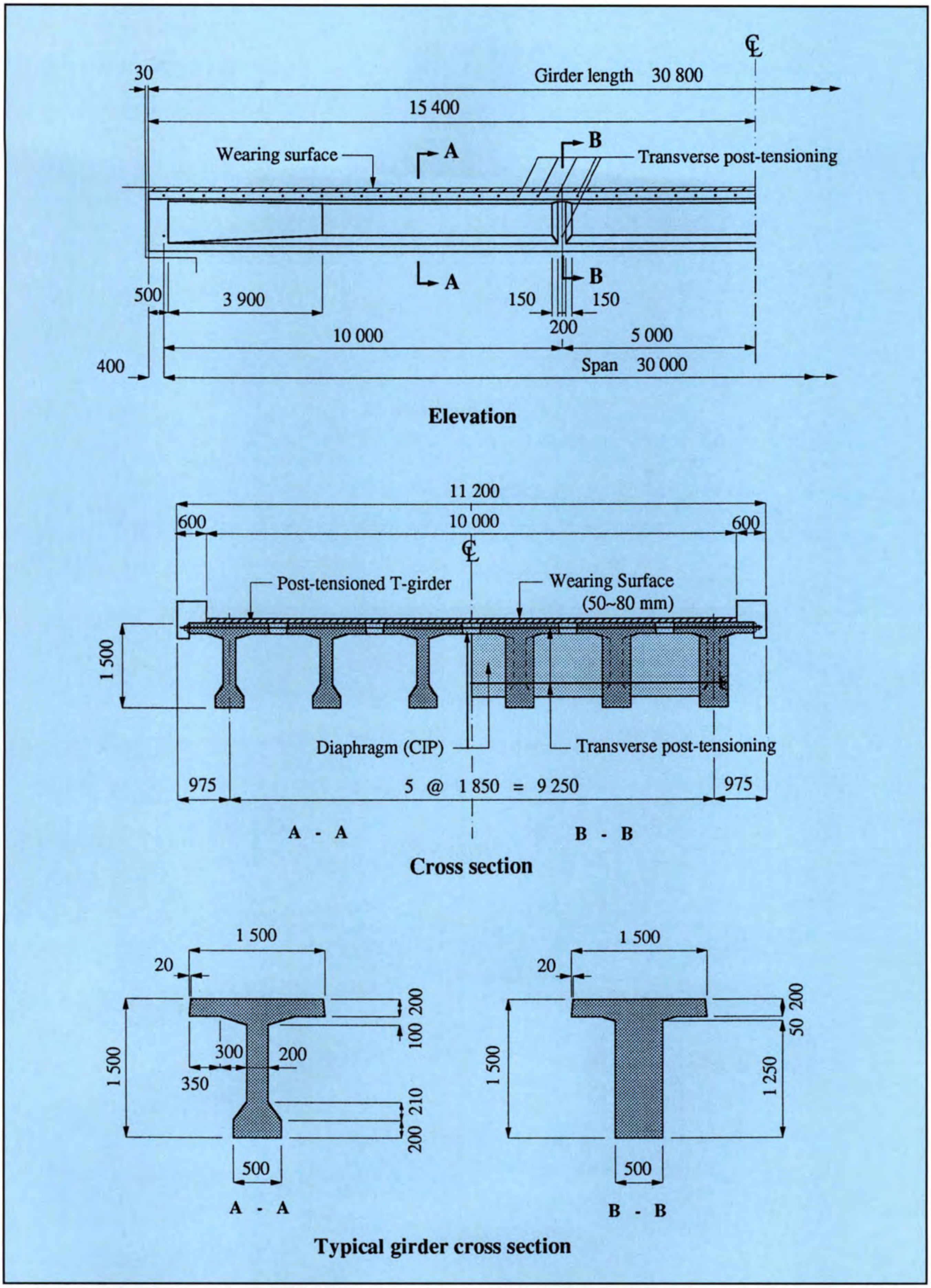



Fig. 5. Precast, post-tensioned concrete T-girder bridge system for simple medium span. Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.

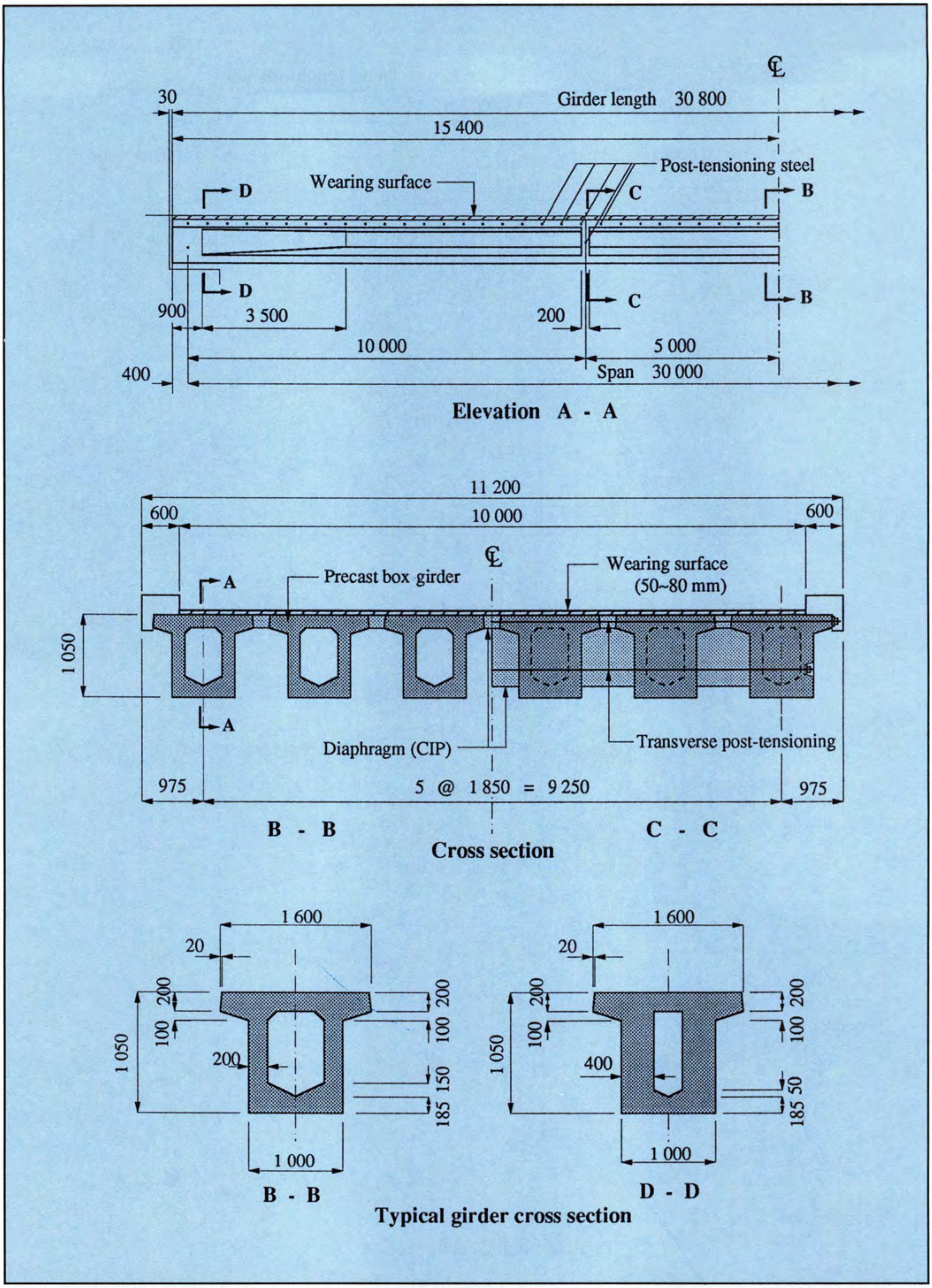



Fig. 6. Precast, post-tensioned concrete box girder bridge system for simple medium span. Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.

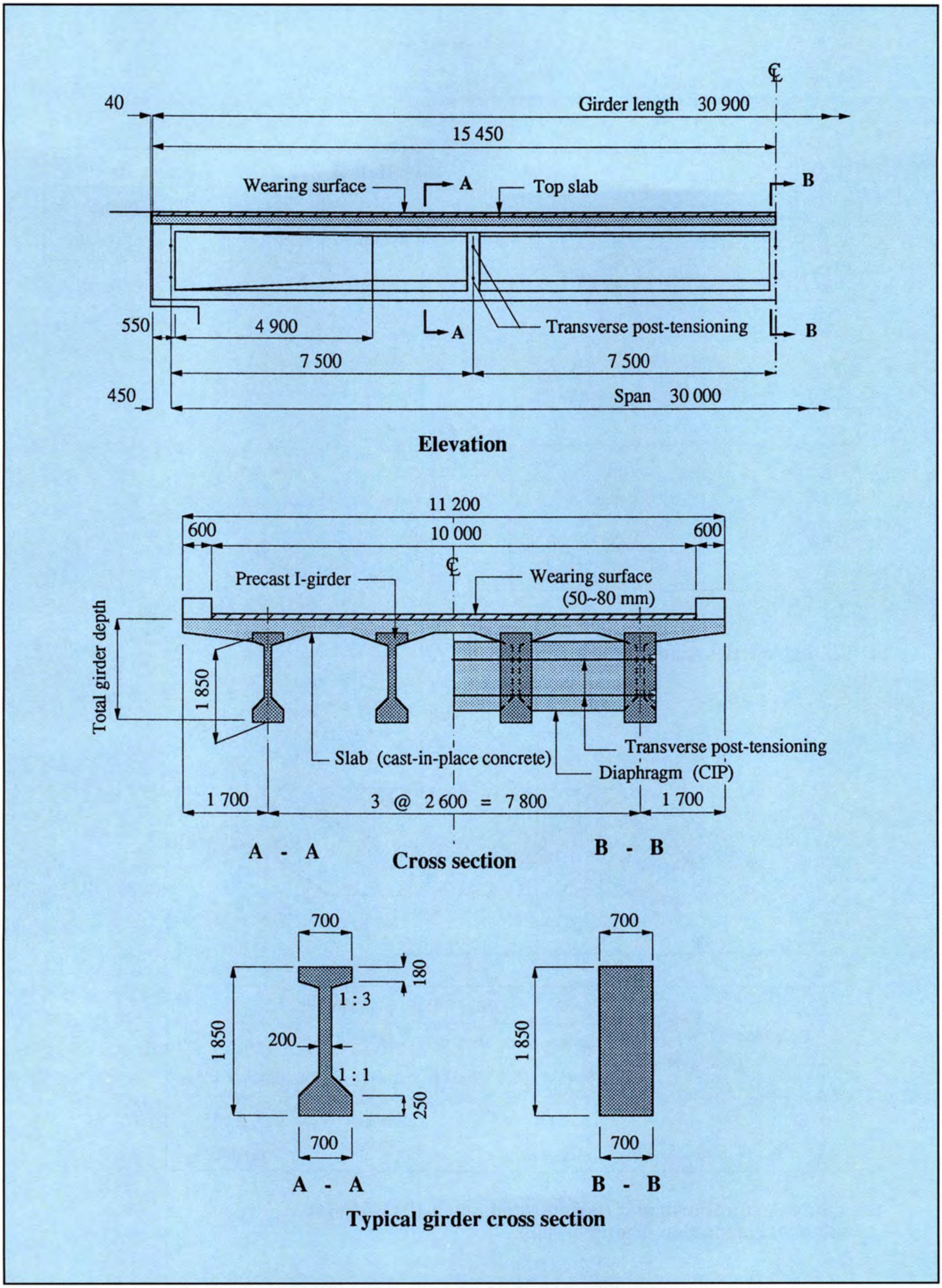
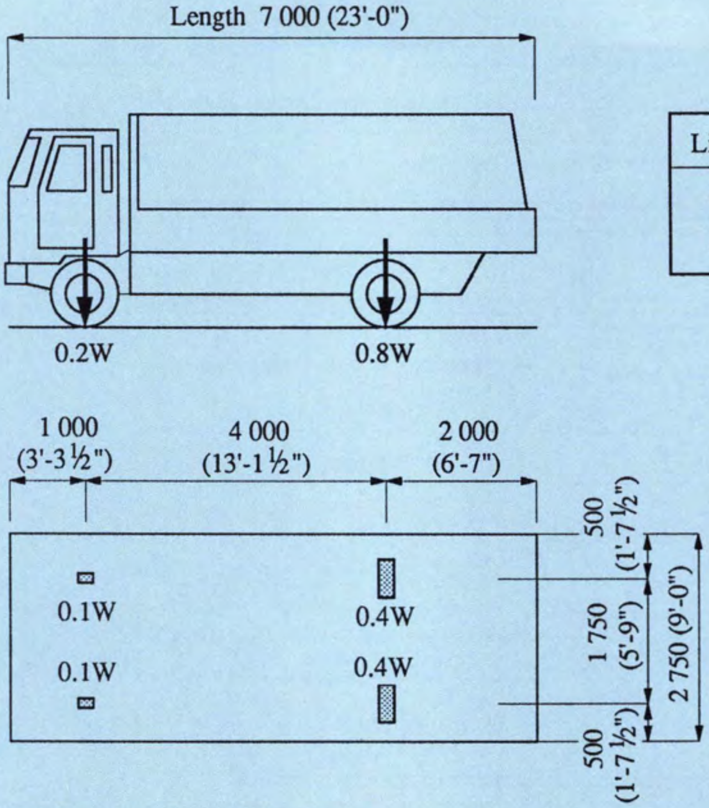
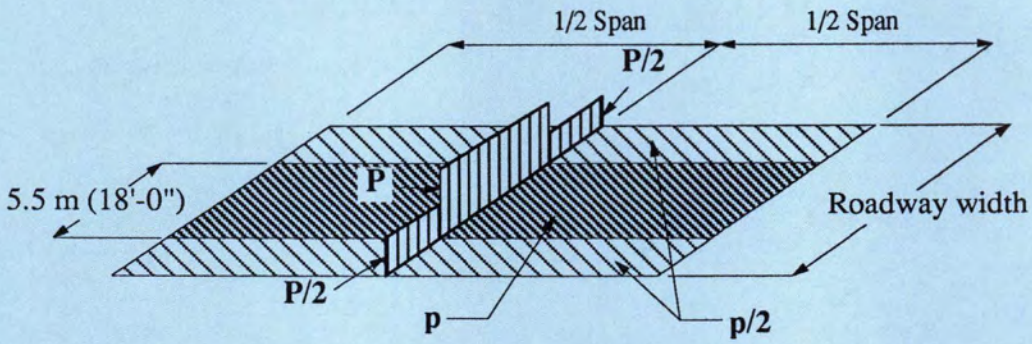



Fig. 7. Precast, post-tensioned concrete I-girder bridge system for simple medium span - composite section.
Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.




| Live load | TL-14 | TL-20 |
|---|---|---|
| Total load | 137 kN (30 800 lb) | 196 kN (44 100 lb) |

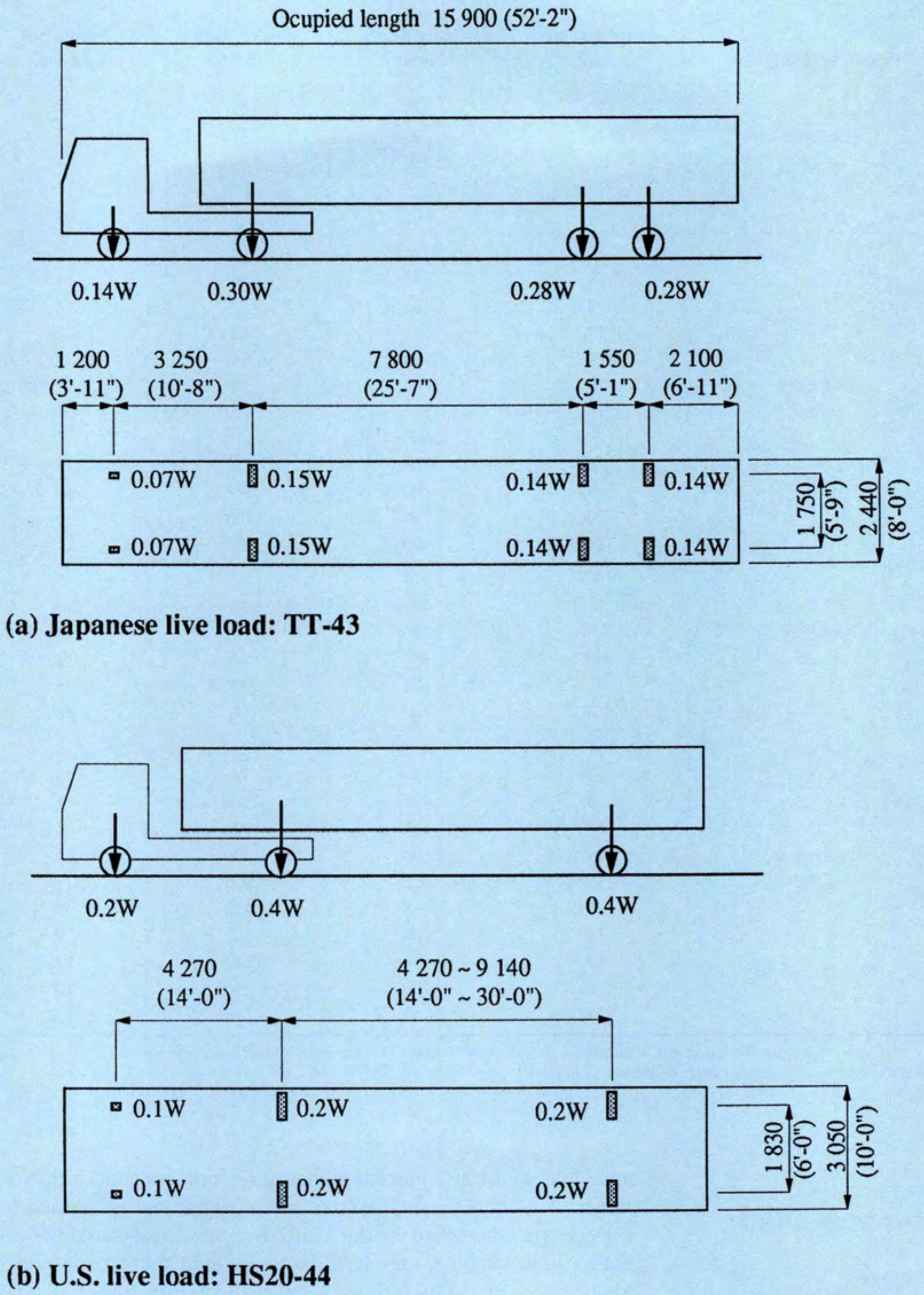
**(a) Standard truck load.**




| Live load | Line load P (kN/m) | Uniform load p (kN/m²) | | |
|---|---|---|---|---|
| | | Span ≤ 80 m (Span ≤ 262 ft) | 80 m ≤ Span < 130 m (262 ft ≤ Span < 426 ft) | Span > 130 m (Span > 426 ft) |
| L-20 | 49 (3.4 kips/ft) | 4.9 (102 ib/ft²) | Use linear interpolation | 2.9 (60 lb/ft²) |

**(b) Equivalent uniform and concentrated line load (L-20) for moment calculation of simple span.**

Fig. 8. Japanese bridge live load: TL-20 loading (Ref. 6).




| Live load | Japan | U.S. |
|---|---|---|
| | TT-43 | HS20-44 |
| Total load | 422 kN (94 900 lb) | 320 kN (72 000 lb) |

Fig. 9. Comparison of Japanese and American bridge live load (Refs. 5 and 6).

Table 6. Strand selection table for precast, pretensioned concrete box girders.

| Load | Type of bridge girder | Standard span (m) | Girder depth (mm) | Girder weight (kN) | 7-wire strand: Number of strands | 7-wire strand: Diameter (mm) |
|---|---|---|---|---|---|---|
| TL-20 loading | Ordinary girder | 5 | 325 | 27 | 9 | 12.7 |
| | | 6 | 325 | 32 | 12 | |
| | | 7 | 350 | 40 | 13 | |
| | | 8 | 375 | 50 | 16 | |
| | | 9 | 400 | 59 | 17 | |
| | Debonded girder | 10 | 425 | 58 | 10 | 15.2 |
| | | 11 | 450 | 66 | 11 | |
| | | 12 | 475 | 73 | 11 | |
| | | 13 | 500 | 82 | 13 | |
| | | 14 | 525 | 90 | 15 | |
| | | 15 | 550 | 99 | 15 | |
| | | 16 | 575 | 110 | 17 | |
| | | 17 | 600 | 120 | 17 | |
| | | 18 | 650 | 132 | 17 | |
| | | 19 | 700 | 148 | 19 | |
| | | 20 | 750 | 163 | 19 | |
| | | 21 | 800 | 177 | 19 | |
| TL-14 loading | Ordinary girder | 5 | 275 | 23 | 9 | 12.7 |
| | | 6 | 300 | 30 | 9 | |
| | | 7 | 325 | 37 | 10 | |
| | | 8 | 350 | 46 | 11 | |
| | | 9 | 375 | 55 | 15 | |
| | | 10 | 400 | 66 | 16 | |
| | Debonded girder | 11 | 425 | 64 | 10 | 15.2 |
| | | 12 | 450 | 71 | 10 | |
| | | 13 | 475 | 80 | 11 | |
| | | 14 | 475 | 85 | 13 | |
| | | 15 | 500 | 96 | 15 | |
| | | 16 | 525 | 106 | 15 | |
| | | 17 | 575 | 118 | 15 | |
| | | 18 | 600 | 127 | 17 | |
| | | 19 | 650 | 142 | 17 | |
| | | 20 | 700 | 156 | 17 | |
| | | 21 | 750 | 170 | 17 | |

Ordinary girder: A girder in which the prestressing strands are bonded to the concrete throughout the span and is arranged in a straight line.
Debonded girder: A girder which contains partly debonded strand.
**Note:** 1 m = 3.28 ft; 1 mm = 0.0394 in.; 1 kN = 225 lbs.

In Japan:

$$M_u = 2.5(1.22)M_s = 3.05M_s$$

In the United States:

$$M_u = 2.17(1.26)M_s = 2.74M_s$$

Referring to Table 5, the final ultimate moment due to live load in accordance with the Japanese loading is 3640 kN-m (2684 kip-ft) whereas AASHTO HS20-44 load would produce a moment of 3400 kN-m (2507 kip-ft). This example shows that both practices give comparable results with the service load moment 4 percent larger in the United States and the ultimate load moment 7 percent higher in Japan.

Recently, the trend in the United States is toward heavier live loads. Many states, including Nebraska, have adopted an HS-25 truck loading for major bridges, a 12.5 percent increase over HS-20. The draft NCHRP 12-33 Code, which is expected to be finalized by mid-1994, proposes to place the HS-20 truck loading in combination with the uniform portion of the lane live loading. Such a combination has been found to be approximately equivalent to the HS-25 truck loading alone.

The Japanese Ministry of Construction announced in November 1993 the approval of revised live loading. The new loads would essentially be 25 percent greater than the loads described in this paper. The impact of this change on actual bridges has not yet been determined.

## SYSTEM SELECTION

Each of the precast, prestressed concrete girders has its own properties and features. Thus, it is imperative for bridge engineers to choose an optimum type of girder which can be designed and constructed economically. Tables 1 and 2 show typical girder

Table 7. Strand selection table for precast, pretensioned concrete T-girders.

| Load | Type of bridge girder | Standard span (m) | Girder depth (mm) | Girder weight (kN) | 7-wire strand | |
|---|---|---|---|---|---|---|
| | | | | | Number of strands | Diameter (mm) |
| TL-20 loading | Debonded girder | 14 | 800 | 100 | 13 | 15.2 |
| | | 15 | 850 | 111 | 14 | |
| | | 16 | 900 | 124 | 14 | |
| | | 17 | 950 | 136 | 15 | |
| | | 18 | 1000 | 149 | 16 | |
| | Draped girder | 19 | 1050 | 163 | 13 | |
| | | 20 | 1050 | 171 | 15 | |
| | | 21 | 1050 | 180 | 17 | |
| TL-14 loading | Debonded girder | 14 | 750 | 96 | 11 | 15.2 |
| | | 15 | 800 | 107 | 11 | |
| | | 16 | 850 | 119 | 12 | |
| | | 17 | 900 | 131 | 13 | |
| | | 18 | 950 | 144 | 13 | |
| | | 19 | 1000 | 157 | 14 | |
| | Draped girder | 20 | 1050 | 171 | 11 | |
| | | 21 | 1050 | 180 | 13 | |

Debonded girder: A girder which contains partly debonded strand.
Draped girder: A girder in which the prestressing strands are bonded to the concrete throughout the span and some of the strands are draped.
**Note:** 1 m = 3.28 ft; 1 mm = 0.0394 in.; 1 kN = 225 lbs.

sections popular in Japan and the United States, respectively.

The following observations are noted from these tables:

- Cast-in-place concrete is used in all Japanese bridges, mostly in the form of longitudinal joints. American "all-precast" bridges, such as those using box girders, utilize special grouts in relatively small shear keys.
- In Japan, precast concrete members are limited in length to 21.7 m (71 ft), which severely restricts the ability to pretension longer girders and limits the use of I-girder shapes. In the United States, maximum girder length is nearly double that in Japan. Girders as long as 51 m (167 ft) have been plant produced and shipped in the states of Minnesota, Pennsylvania and Washington.
- Diaphragms in Japan are usually cast-in-place, while in the United States they may be cast-in-place concrete, structural steel bracing, or occasionally precast concrete.

## Pretensioned Girder Bridges

The majority of short span bridges are built with pretensioned T- and box girders. These two types of precast concrete girders are standardized by both the Ministry of Construction and the Japan Standards Association.[8,9] They are classified in span increments of 1 m (3 ft). The procedure in using these girders in short span bridges is highly standardized. Tables 6 and 7 show examples of such standardized designs.

T-girders are more popular than box girders since they result in structurally and economically efficient bridge systems. Fig. 10 shows an example of prestressing strand arrangement for a 20 m (66 ft) span pretensioned concrete T-girder with draped strands. Strand draping in T-girders is used only for spans of 19 to 21 m (62 to 69 ft). Figs. 11 and 12 show pretensioned T-girders in a precasting plant.

The precast, pretensioned box girder is designed to achieve a low depth-to-span ratio by using more girders for a given bridge width and using more prestressing strands per girder than for a T-girder system. All box girder strands are straight. They are fully bonded for a span range of 5 to 9 m (16 to 30 ft) and partially debonded at the ends for a span range of 10 to 21 m (33 to 69 ft). Solid box girders are popular for short spans up to 9 m (30 ft) in length and hollow boxes for longer spans. Fig. 13 is an example of a prestressing arrangement for a 20 m (66 ft) span box girder with debonded strands.

Since construction of precast, pretensioned box girder bridges does not require any field formwork or falsework, they are popular for bridges which span heavily traveled highways and railways. Figs. 14 and 15 show general views of pretensioned box girders in a precasting plant.

In general, bridges built with T-girders are approximately 5 percent lighter and more economical than those built with box girders. However, construction work to form T-girder bridges is complicated and the duration of construction after girder erection is longer than that for box girder bridges. Therefore, T-girders are usually employed when there are no site constraints on girder depth or construction period.

Continuous span bridges are constructed using T-girders by splicing reinforcing bars in the upper flange (slab) of the girders at the interior supports. Box girders are not normally used for continuous span construction.

## Post-Tensioned Girder Bridges

Precast, post-tensioned T-girder bridges are also standardized by the Ministry of Construction in Japan. As shown in Fig. 5, the web thickness is tapered for a distance of $0.15L$ to

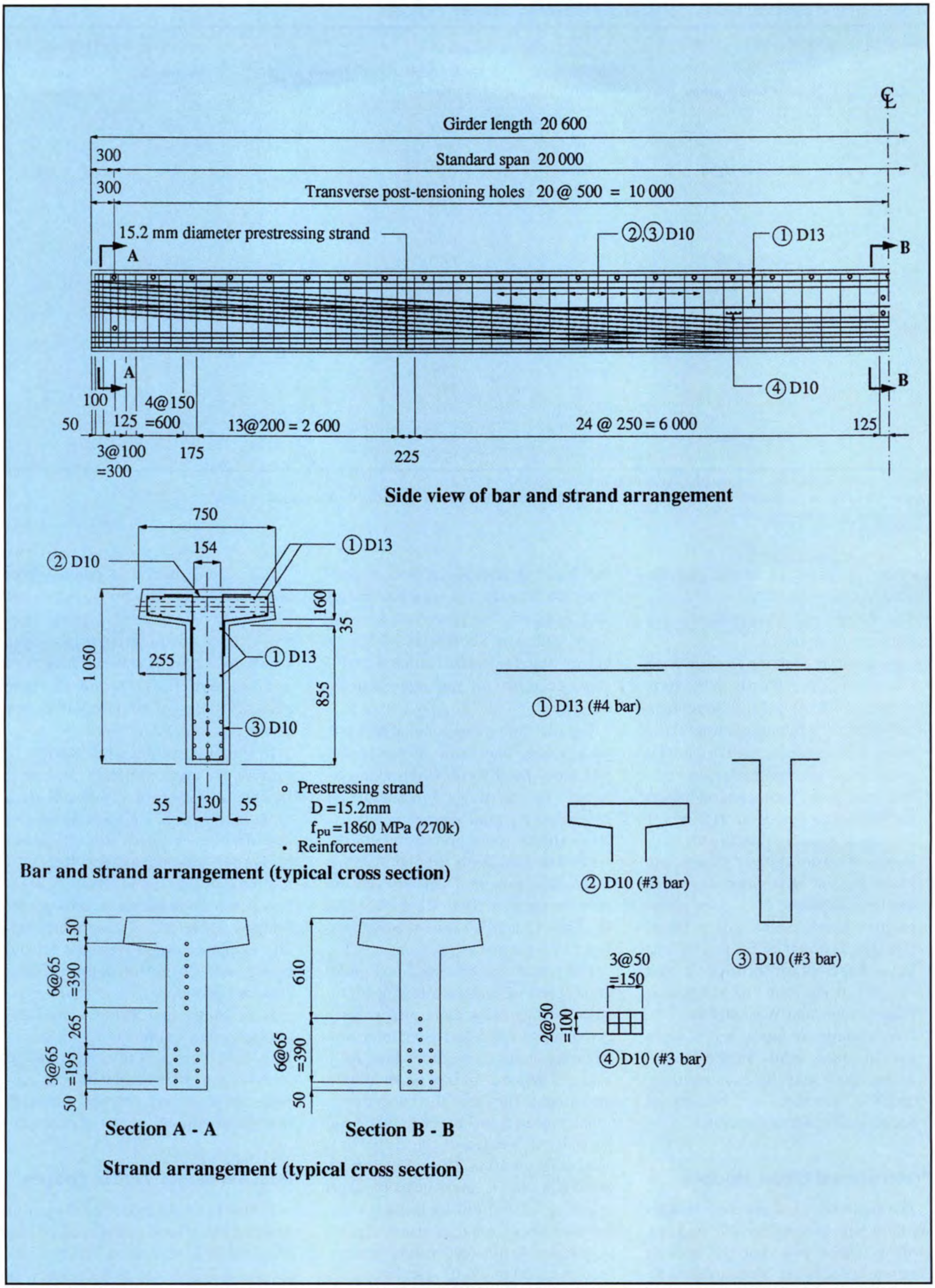



Fig. 10. Bar and strand arrangement of precast, pretensioned concrete T-girder (Ref. 9). Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.

Fig. 11. Pretensioned T-girder; shear reinforcement is epoxy coated.

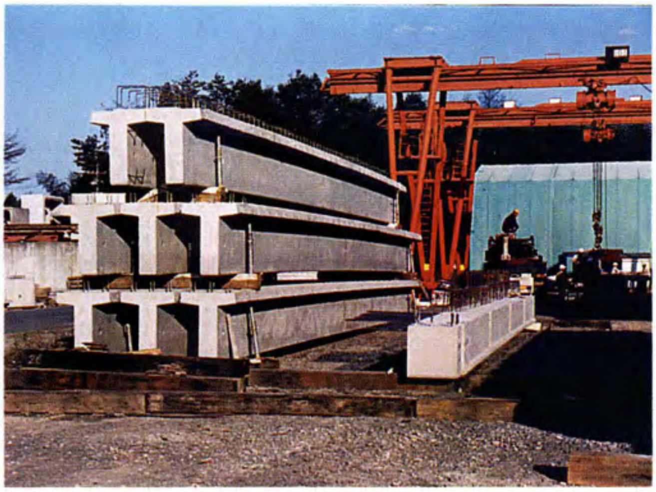


Fig. 12. Completed T-girders in storage.

0.20*L* from both ends of the girder to enhance shear capacity and to provide post-tensioning anchorage in these regions. Construction of the girder includes placement of bars projecting from the sides of the girders to tie into the cast-in-place concrete deck and diaphragms. Also included are ducts for transverse post-tensioning.

Bundles of 12 - 7 mm (0.28 in.) diameter multi-wire tendons are used for longitudinal post-tensioning of T-girders with span ranges of 20 to 27 m (66 to 89 ft). As shown in Fig. 16, about one-half of all tendons are anchored at the top surface of the girder to save steel and to avoid concentration of anchorages.

Bundles of 12 - 12.4 mm (0.49 in.) diameter multi-strand tendons are used for girders with span ranges of 28 m (92 ft) or more. All such tendons are anchored at the end face of the girders as shown in Fig. 17. Fig. 18a shows a typical reinforcing bar detail for T-girders.

Similar to pretensioned T-girders, post-tensioned T-girders are usually used for bridges with no constraints on superstructure depth or construction

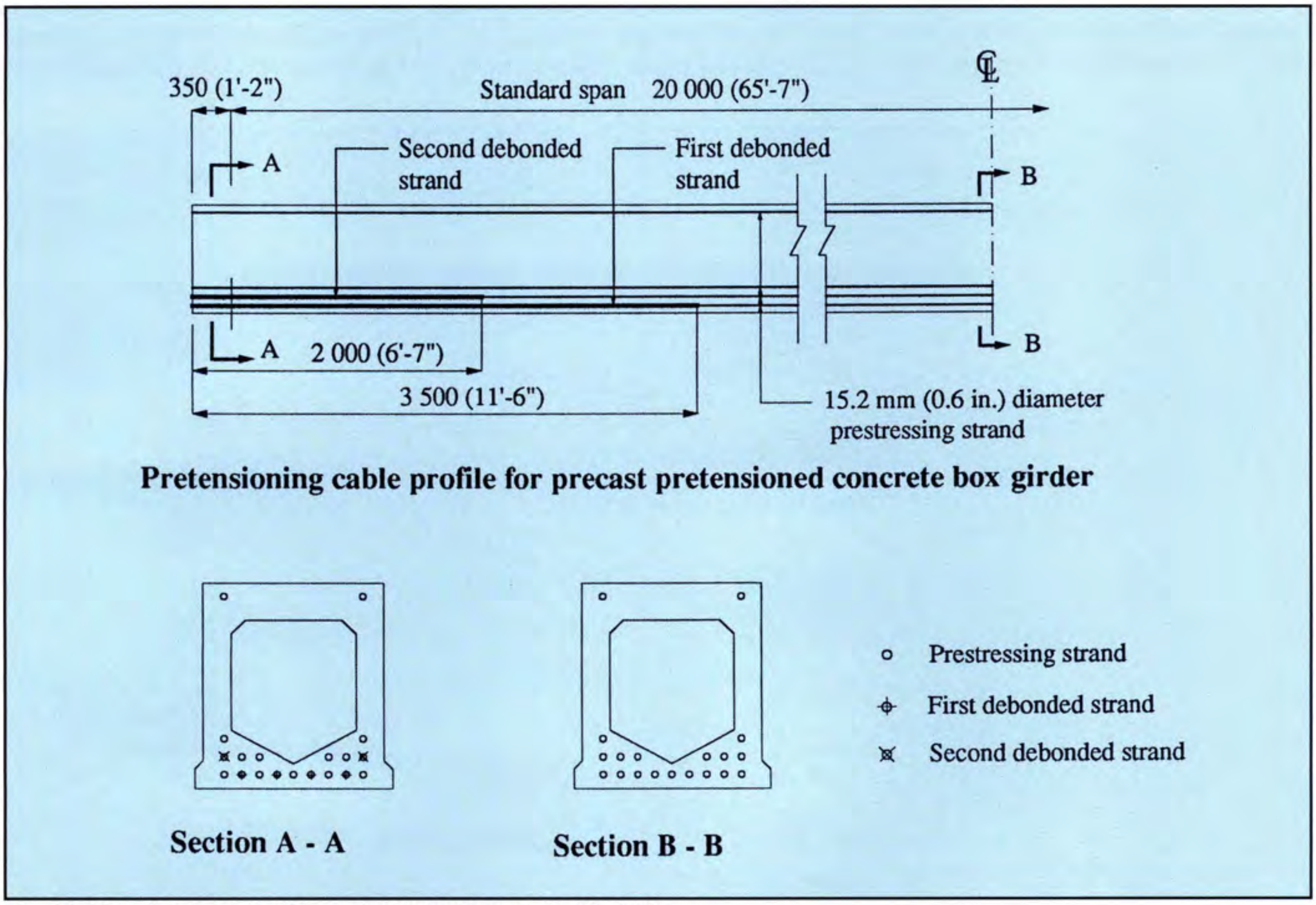



Fig. 13. Strand arrangement in pretensioned box girder (Ref. 8).

Fig. 14. Reinforcement of box girder. Note: Formation of void using expanded polystyrene, location of diaphragm and positioning of shear reinforcement on a skew angle.

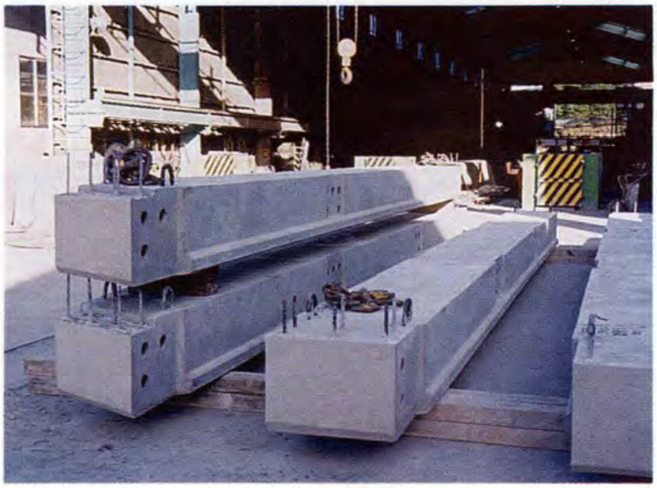


Fig. 15. Completed box girders. Note: Large depth of shear key, size and location of transverse post-tensioning.

time. When continuous span bridges are constructed using T-girders, each span length is generally limited to around 30 m (98 ft). Fig. 19 shows a completed bridge using post-tensioned T-girders.

Precast, post-tensioned I-girders are standardized by the Japan Highway Public Corporation. This girder type is used for composite bridge systems that are very similar to systems used in the United States. Prestressing steel is either 12 - 7 mm (0.28 in.) diameter multi-wire tendons or 12 - 12.4 mm (0.49 in.) multi-strand tendons depending on cost and structural detailing considerations.

All tendons are anchored at both ends of the girder. The reinforcing bar and prestressing steel details are shown in Fig. 18b. The web thickness of I-girders is increased gradually toward the end of the span and ducts for transverse post-tensioning are provided only in the web at diaphragm locations.

The cost of a bridge built with post-tensioned I-girders is about the same as that of a bridge built with T-girders. I-girders are used for major highway bridges in Japan. In general, they are versatile and can be used for bridges with various geometric conditions, especially for curved and variable width bridges, since the entire deck slab is cast-in-place.

There are two popular methods used in Japan to build continuous span bridges with post-tensioned I-girders. The first is similar to the method used

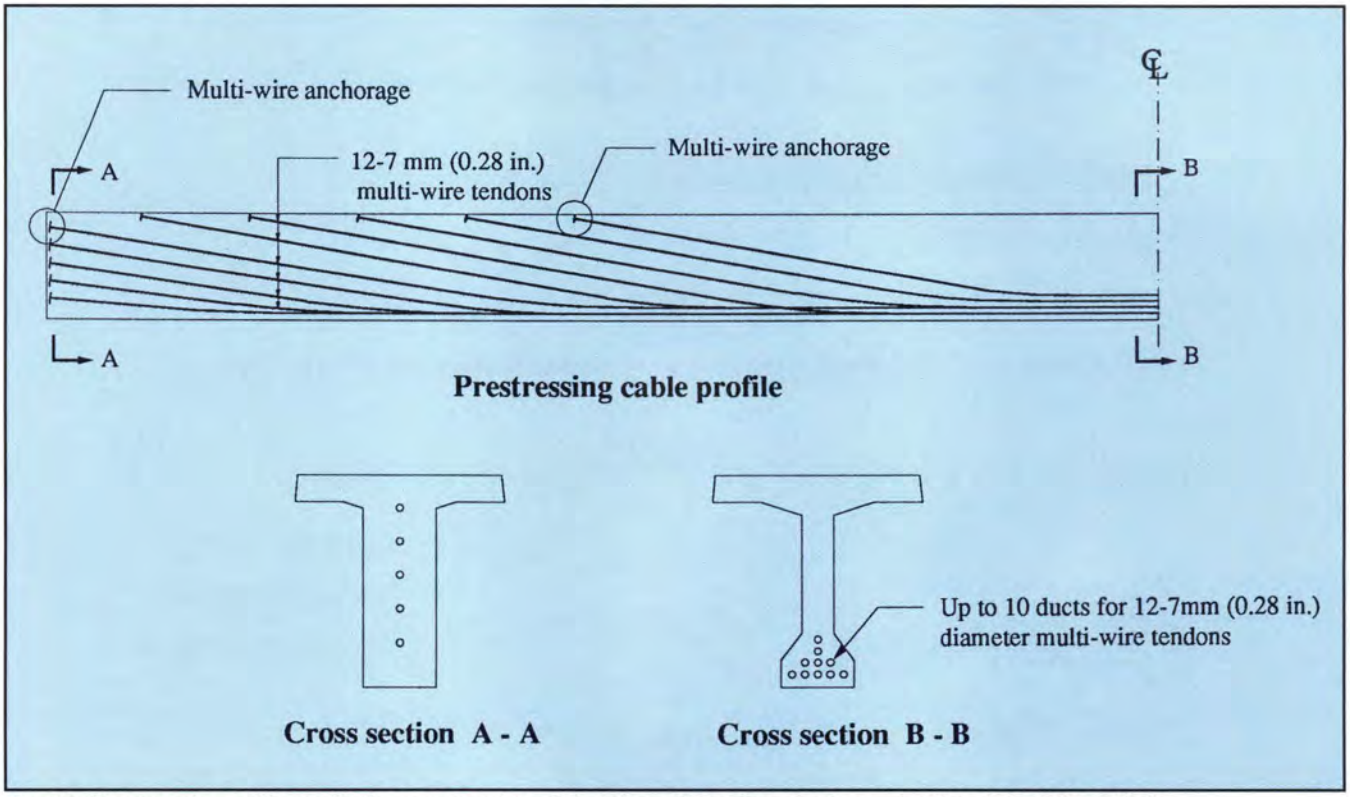



Fig. 16. Prestressing cable profile for post-tensioned T-girders. Note: Standard span is 20 to 27 m (66 to 89 ft).

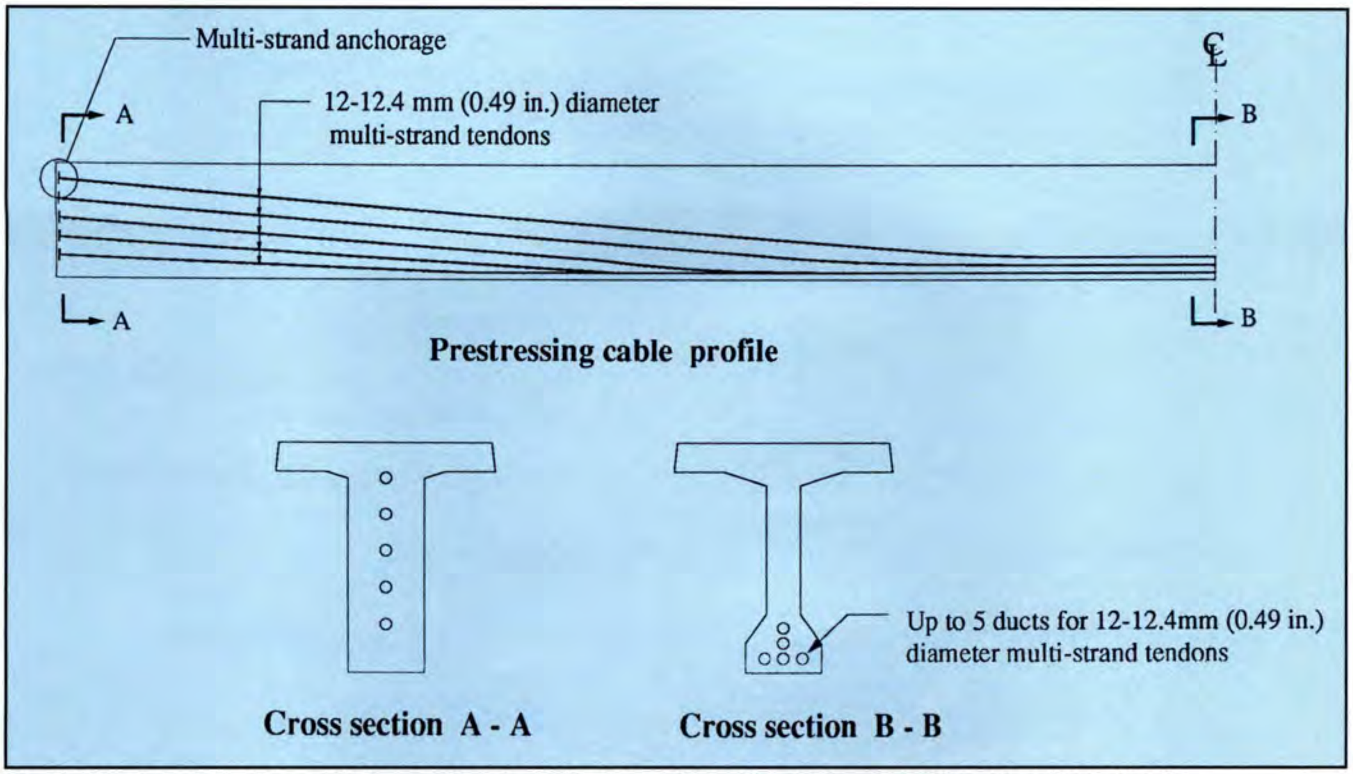



Fig. 17. Prestressing cable profile for post-tensioned T-girders. Note: Standard span is 28 to 40 m (92 to 131 ft).

for the T-girder system described previously. It is accomplished by splicing the reinforcement in the top slab at the interior support of I-girders. The maximum span achieved by this method is about 28 m (92 ft). The second method is used for longer spans. Continuity is achieved by post-tensioning girders and the top slab in the interior support zones only (see Fig. 20).

Precast, post-tensioned box girders are standardized only by regional authorities or by some prestressed concrete companies. The main purpose of the box girder is to build shallow bridges in the medium span range. Box girders can be 20 to 30 percent shallower than T-girders. This is achieved by employing high strength concrete, e.g., 59 MPa (8500 psi) or higher, using more prestressing steel per girder, and reducing girder spacing. The reinforcing bar arrangement and post-tensioning profile are shown in Fig. 18c.

Similar to the other post-tensioned girders, web thickness increases gradually toward the supports, and ducts are provided in the upper flange and in the web for lateral post-tensioning at diaphragm locations. In general, the weight of each box girder is considerably heavier than the other systems. Bridges built with box girders are 10 to 30 percent more expensive than those built with I- or T-girders. Consequently, post-tensioned box girders are often used when a shallow superstructure is required under site specific constraints.

## GIRDER SPLICING

Girder splicing is a concept in which more than one segment is spliced to produce span lengths greater than the girder segment length. This is used for the above mentioned girder types under some or all of the following conditions:

- When the precasting plant and transportation limitations do not allow full span segment lengths.
- When the construction yard for post-tensioned concrete girders near the bridge site does not permit one member per span.
- When the construction period is limited.

Splicing of segments can be achieved by full-length post-tensioning or by other methods.[10,11] In the United States, a recent study by Geren and Tadros[12] has resulted in a new series of I-girder shapes. The shapes are the first introduced in the United States in "hard" metric units, i.e., with rounded metric dimensions. The proposed girder shapes were optimized for continuous span construction and for uniform safety margin against flexural failure. Their depths vary from 750 to 2400 mm (30 to 94 in.) and the spans range from 15 to 51 m (49 to 167 ft) when used unspliced within each span and when the girder spacing is 3 m (10 ft). The span capabilities of the new shapes can be extended to 75 m (246 ft) if the post-tensioned, spliced girder concept is used.

## COMPARISON OF WEIGHT OF PRECAST GIRDERS IN BRIDGES

Fig. 21 compares the weight of precast concrete girders per unit area of bridge deck, as used both in Japan and the United States. The figure shows that the weight of precast girders per unit area of bridge deck in Japan is more than that in the United States, particularly for I-girders. This difference is due to the larger girder web and flange thicknesses generally used in Japan.

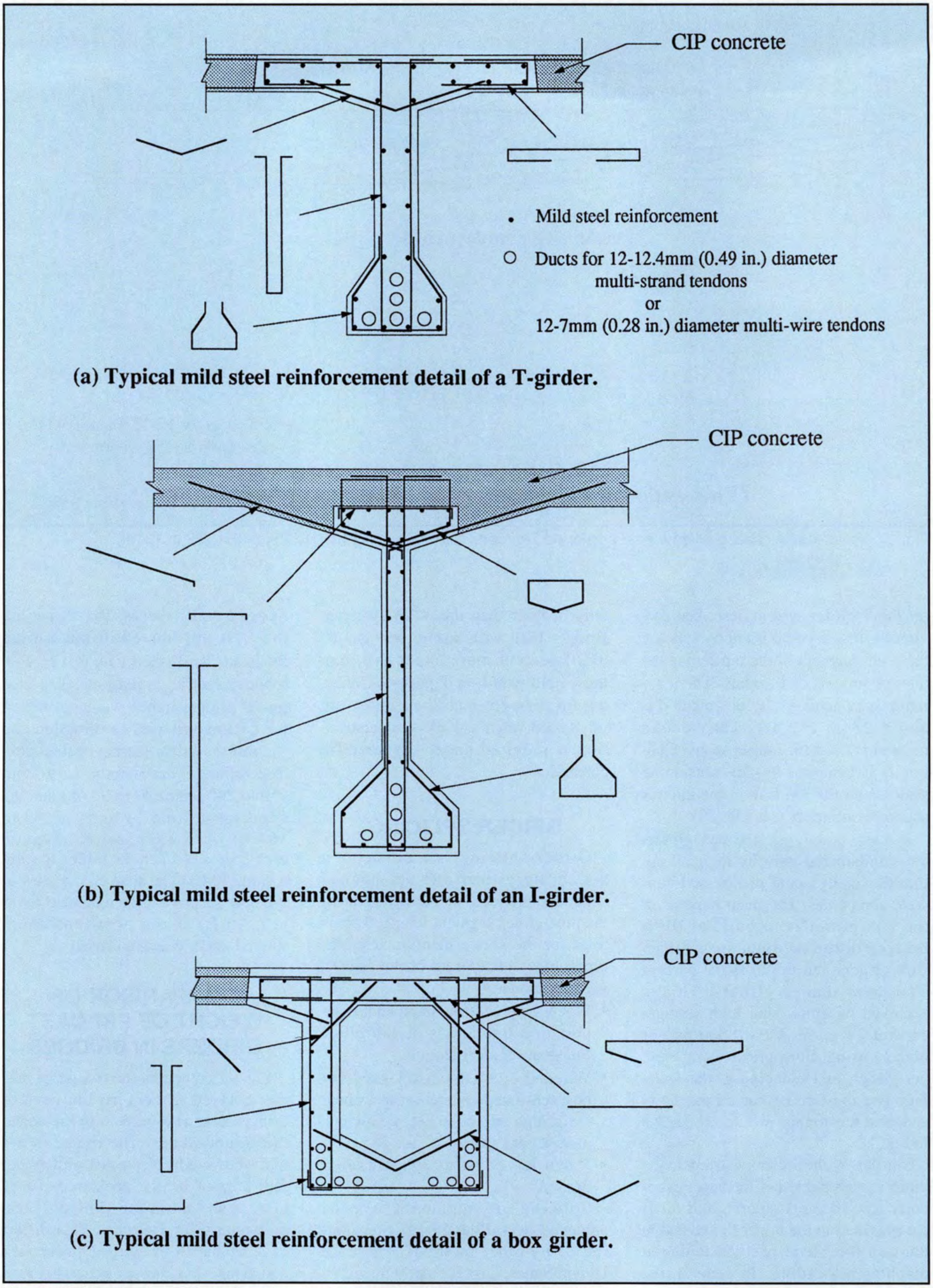



Fig. 18. Reinforcing bar and prestressing steel arrangement for post-tensioned girders.

Fig. 19. Completed bridge using post-tensioned T-girders. Note: Cast-in-place diaphragms and narrow girder spacing.

## DECK SLAB AND DIAPHRAGM DETAILS

Unlike the United States, cast-in-place concrete diaphragms are usually required for all types of precast multi-girder bridges in Japan. As shown in Figs. 4 through 6, pretensioned T-girders and post-tensioned T- and box girders are part of the integral deck system. Cast-in-place concrete is placed between adjacent girders to complete the prestressed concrete deck. On the other hand, a variety of non-cast-in-place concrete diaphragms are used in the United States, such as precast concrete diaphragms connected by welded plates and steel K-bracing.

The Japanese design philosophy is that cast-in-place concrete diaphragms with transverse post-tensioning produce a more durable system and more efficient load distribution among girders. Cast-in-place concrete diaphragms, however, result in complicated and expensive field work. The fabrication system used in the United States is advantageous in reducing field work and in simplifying replacement and widening of bridge superstructures. However, corrosion problems at the connections of these fabricated bridge elements can be considerable and their impact on the service life of the bridge deck should be taken into account.

Of all diaphragm construction methods used in Japanese precast multi-girder bridge systems, the procedure for constructing diaphragms for pretensioned box girder bridges is the easiest and the most economical method as shown in Fig. 22.

The construction process after erecting the girders consists of the following steps:

**1.** Connect ducts between adjacent girders.

**2.** Insert prestressing tendons through girders.

**3.** Place stay-in-place forms made of galvanized thin steel panels between girders.

**4.** Pour cast-in-place concrete between the girders.

**5.** Apply transverse post-tensioning when the specified concrete strength is achieved.

Steps 1 through 4 are done from the top of the girders. These steps can be performed by workers with relatively low skills to make a durable, highly efficient transverse connection system. For 20 m (66 ft) spans, the total amount of post-tensioning is 3300 kN (740 kips) or 165 kN/m (11 kips per ft). This is a much larger post-tensioning force than is traditionally used in the United States.

Slabs and diaphragms of pretensioned T-girders and post-tensioned T- and box girders are designed as a prestressed concrete member. The basic spacing of transverse post-tensioning in the slabs of these systems is 500 mm (20 in.). Prestressing steel is placed straight through the slab such that the eccentricity at midspan of the slab is zero or downward, and the eccentricity at negative moment section is upward because of change in slab thickness. Fig. 23 shows an example of transverse post-tensioning for a pretensioned T-girder bridge.

Unlike the United States, all highway bridge decks are covered with a 50 to 80 mm (2 to 3 in.) concrete or asphaltic concrete layer which has the following additional advantages:

- Provides a uniform wearing surface and better riding quality.
- Acts as a moisture barrier, and hence reduces deicing salt effect during the winter season.
- Reduces traffic noise.

## BEARING AND SEISMIC RESISTING DETAILS

Since Japan is located in a high seismic risk area, bridges must be designed for seismic resistance. For short to medium span prestressed concrete bridges, rubber pads are used for bearing while steel bars are used as dowels as shown in Figs. 24 and 26. A dowel consists of a steel bar placed within a steel pipe filled with elastic, rust proof material. It is placed in the space between the superstructure elements and embedded in the substructure.

A space between the dowel and pipe is provided at hinge supports to allow for rotation due to live load, and to accommodate construction tolerances. The oval pipe shape at sliding, or "roller," supports allows for movements due to temperature, shrinkage and creep. For simple span bridges, the dowel bars at the hinge supports are designed to transmit horizontal seismic force due to full dead load, and at the roller supports due to one-half of the dead load effect.

Special measures are used to prevent the superstructure from falling off the substructure due to earthquake motions for bridges on main highways. Many types of seismic resistant systems are available. They include the use of:

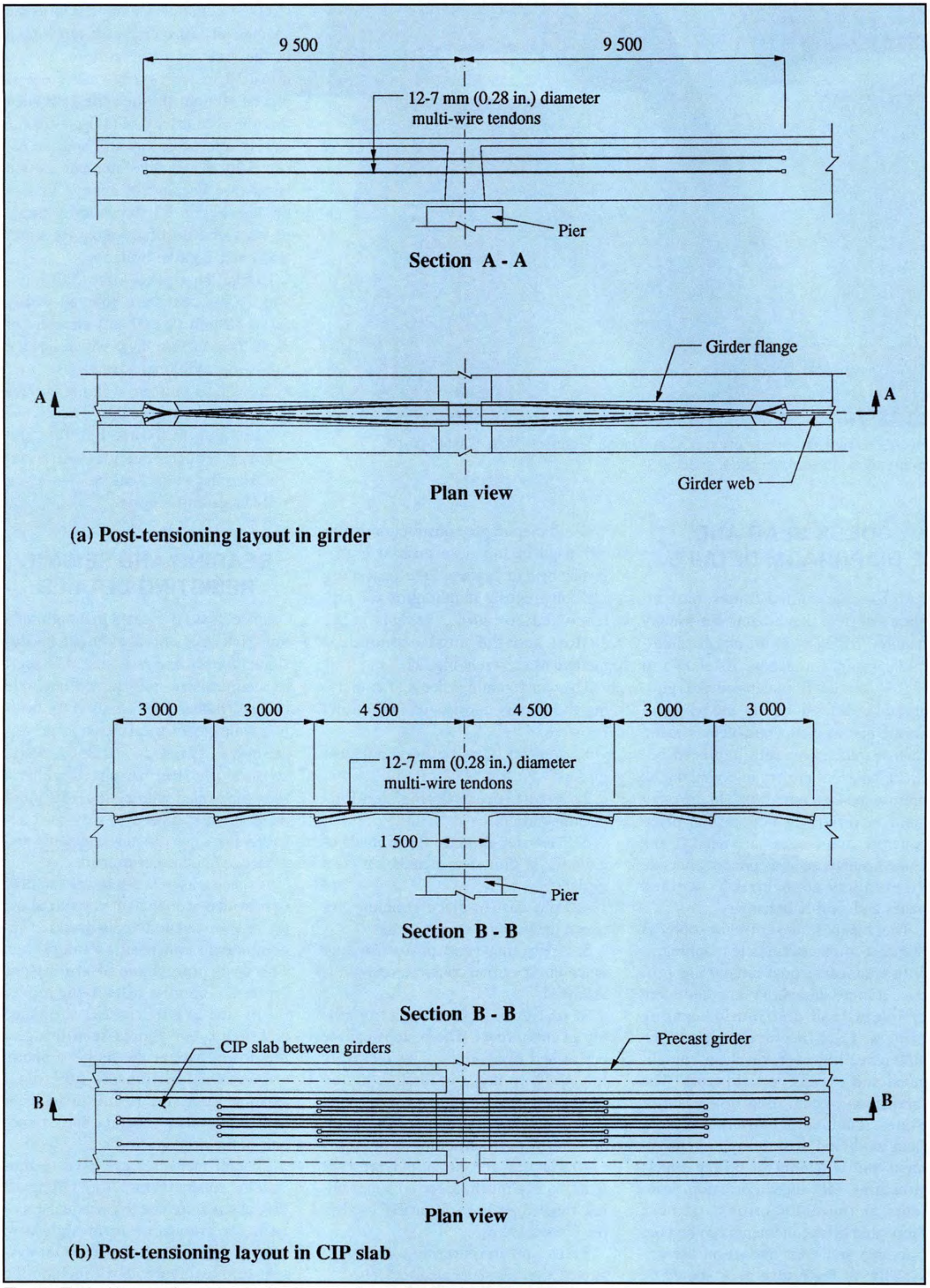



Fig. 20. Typical layout of post-tensioning tendons for continuity of I-girder bridges.

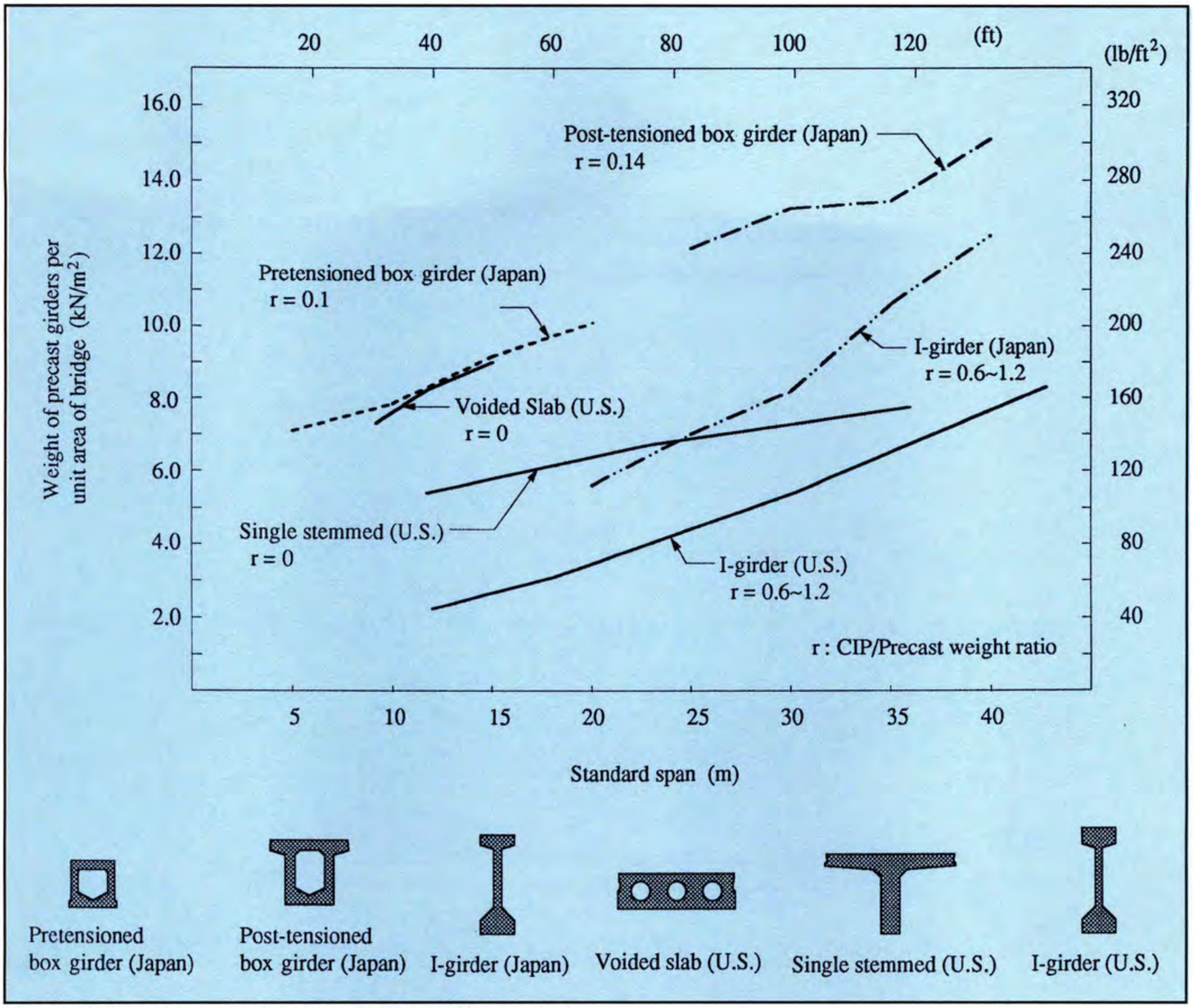



Fig. 21. Weight of precast girders per unit area of bridge deck.

- Larger size dowels which can resist a larger portion of horizontal forces.
- High strength bars, such as prestressing bars, to tie the abutment back wall to the end diaphragms of the superstructure. This system allows limited movement of the superstructure (see Fig. 25a).
- Reinforced concrete or steel brackets. These brackets are designed to resist horizontal forces due to earthquakes and prevent the movement of girders during an earthquake (see Fig. 25b).

## CONCLUDING REMARKS

Over 97 percent of the bridges being built in Japan with span lengths of up to 21 m (69 ft), are made of precast, prestressed concrete girders. Due to transportation restrictions, longer girders are not precast in a plant. This necessitates site-cast precast, post-tensioned concrete girder production in the span range of 20 to 40 m (66 to 131 ft). Much larger girders have traditionally been shipped in the United States, with lengths up to 51 m (167 ft) and weights up to 68 t (75 tons).

Precast, prestressed girders in Japan are either T- or box-shaped. The T-shape is more economical when structural depth and construction time are not restricted. For both shapes, the transverse girder spacing is very small, similar to American butted box systems. However, unlike American practice, cast-in-place concrete is used in relatively large shear keys or longitudinal strips.

Also, all bridge decks are transversely post-tensioned at relatively high levels of prestressing force. Most bridges in Japan do not incorporate cast-in-place structural slabs in composite action with the girders. However, a wearing surface is required on all bridge decks.

Site-cast precast girders ranging from 20 to 40 m (66 to 131 ft) in length are post-tensioned on the ground. They are more closely spaced in the superstructure than the American I-girder system. Also, they are connected together with large cast-in-place diaphragms and transverse post-tensioning.

Short and medium span bridge design and detailing is standardized in Japan. The live load moments, shears and other effects are comparable to those specified by AASHTO. How-

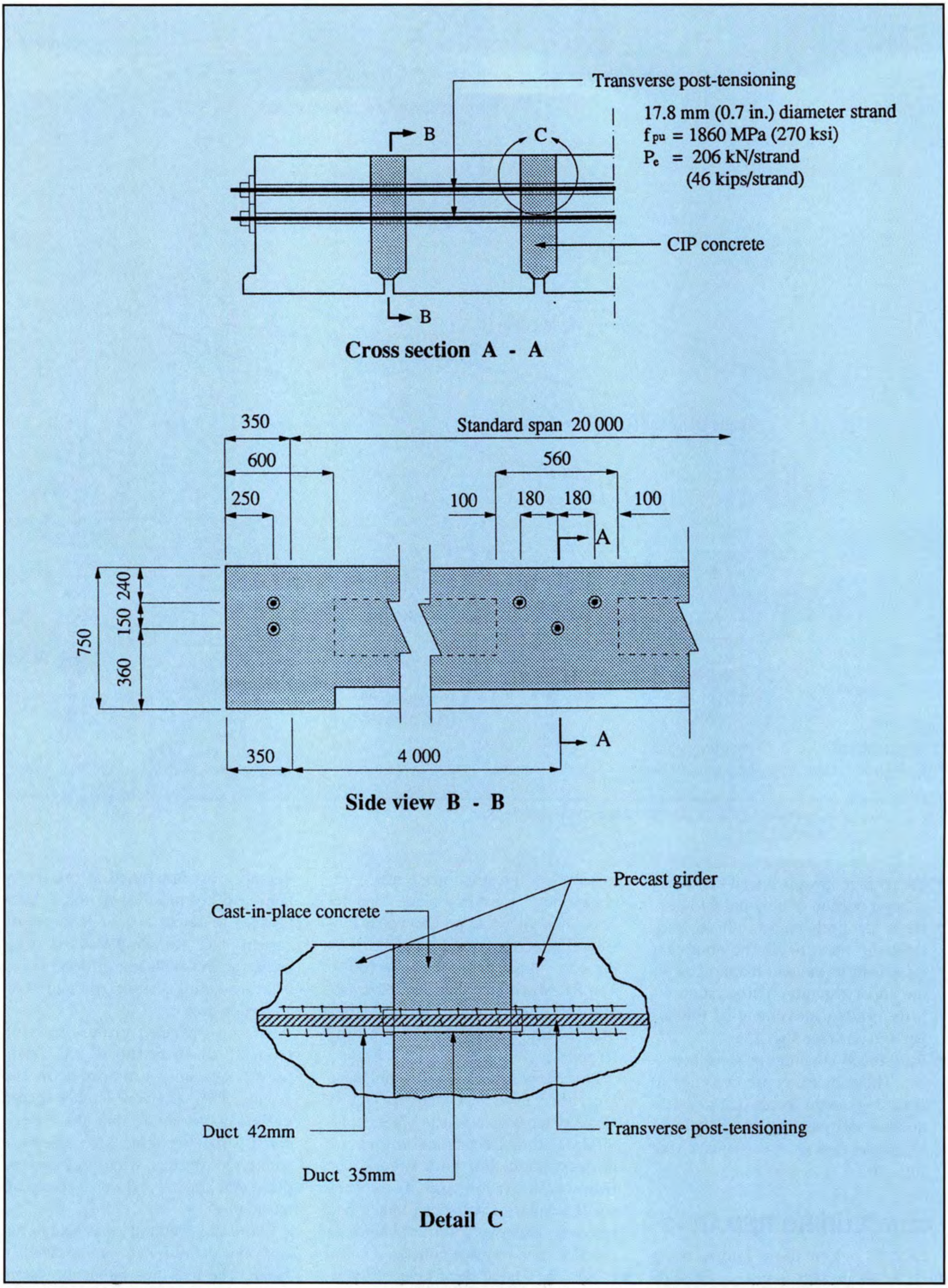



Fig. 22. Example of transverse post-tensioning for pretensioned box girder bridge with span of 20 m and TL-20 loading.
Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.

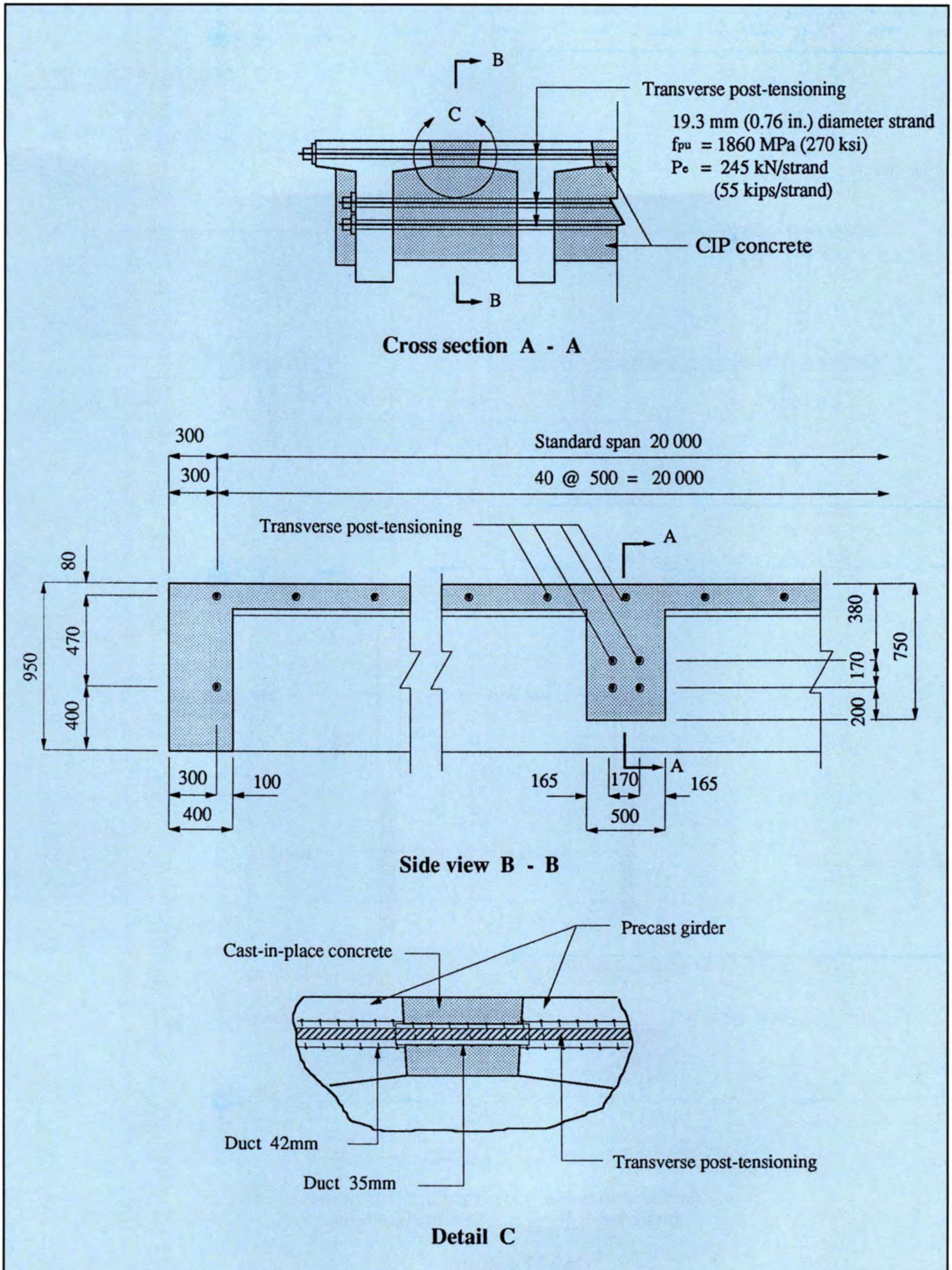



Fig. 23. Example of transverse post-tensioning for pretensioned T-girder bridge with span of 20 m and TL-20 loading.
Note: 1 m = 3.28 ft; 1 mm = 0.0394 in.

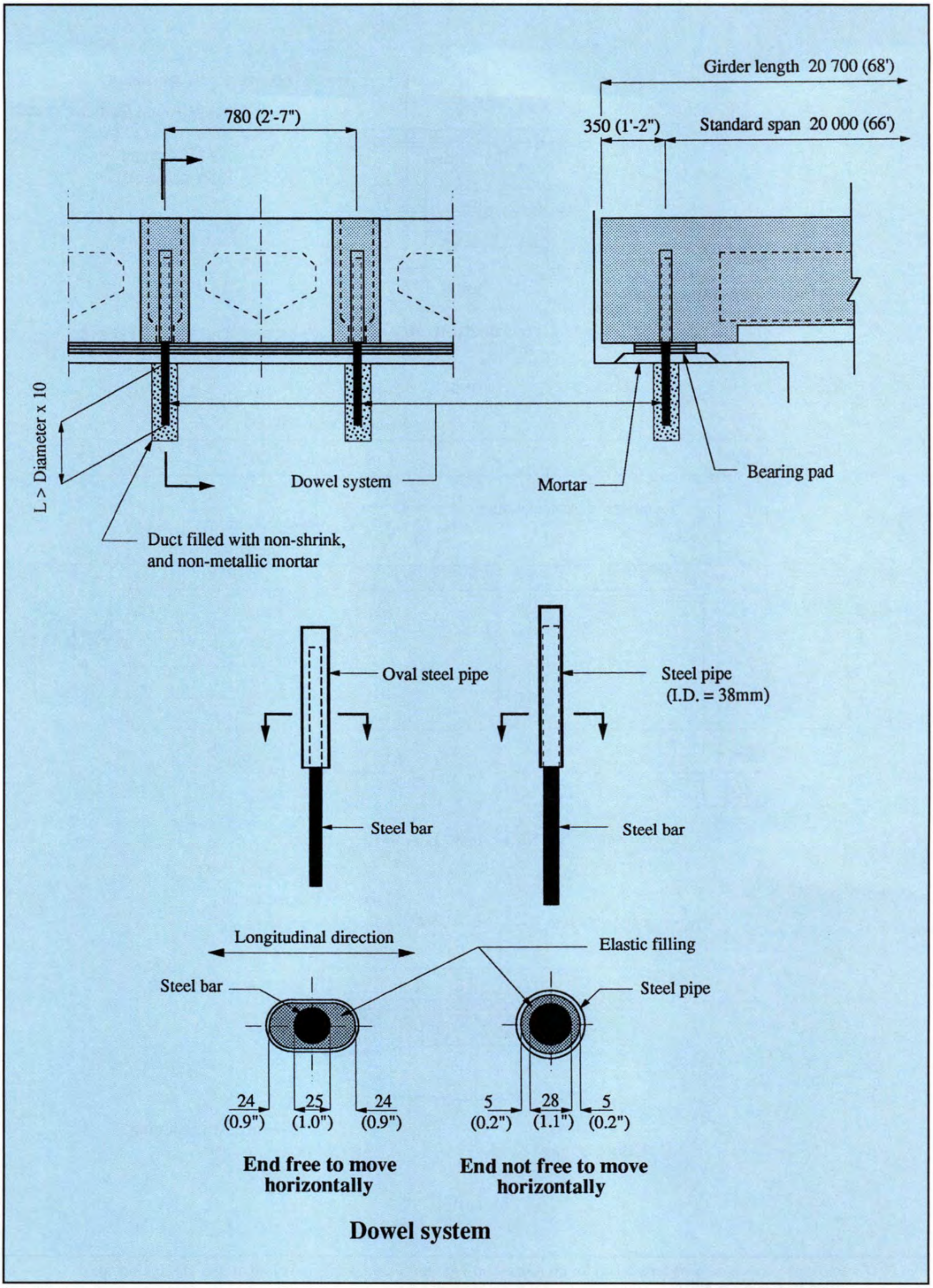



Fig. 24. Bearing and seismic dowel details for a pretensioned box girder bridge [span of 20 m (66 ft) for TL-20 loading].

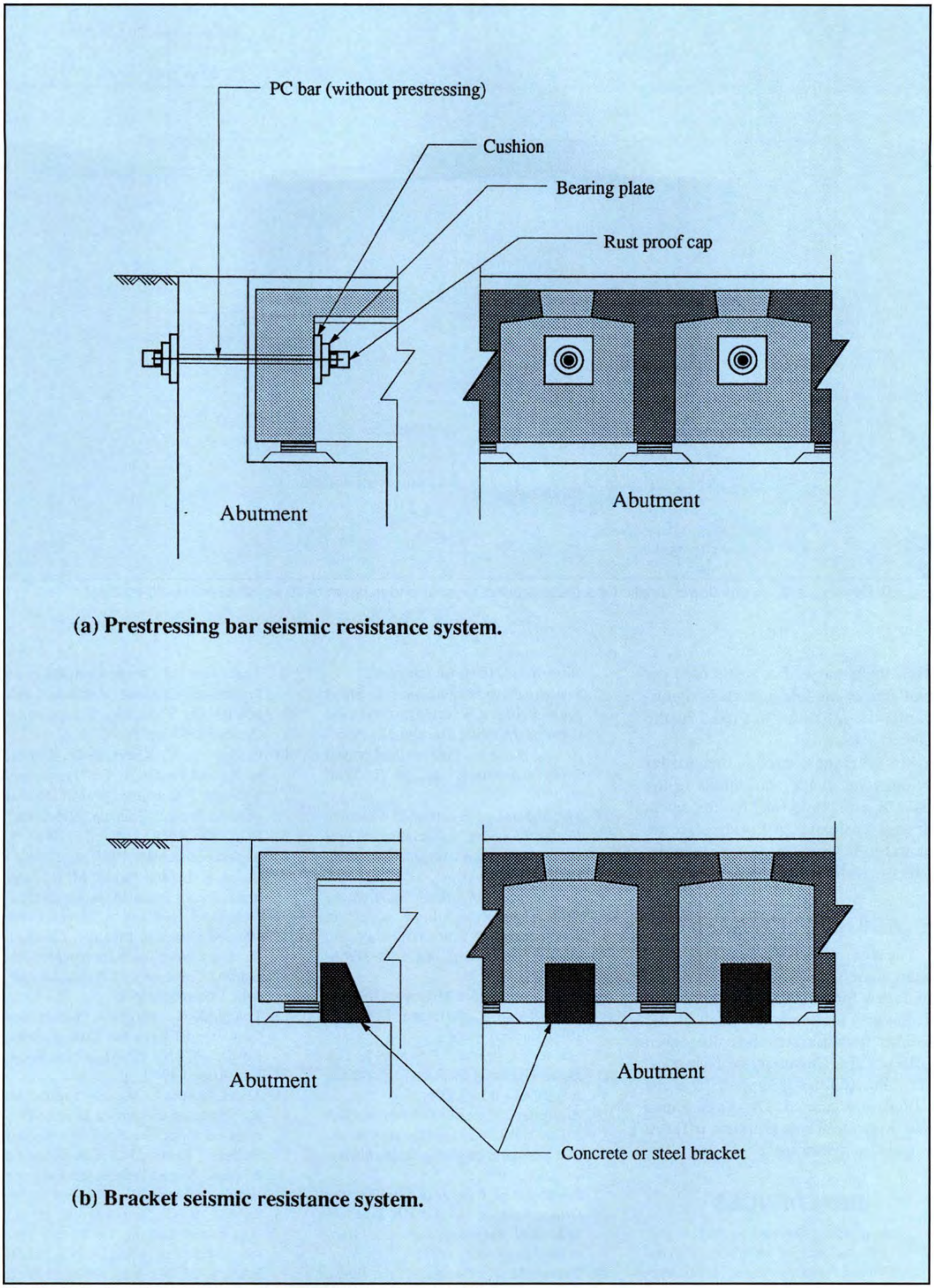



Fig. 25. Seismic resisting systems, at superstructure - abutment joint.

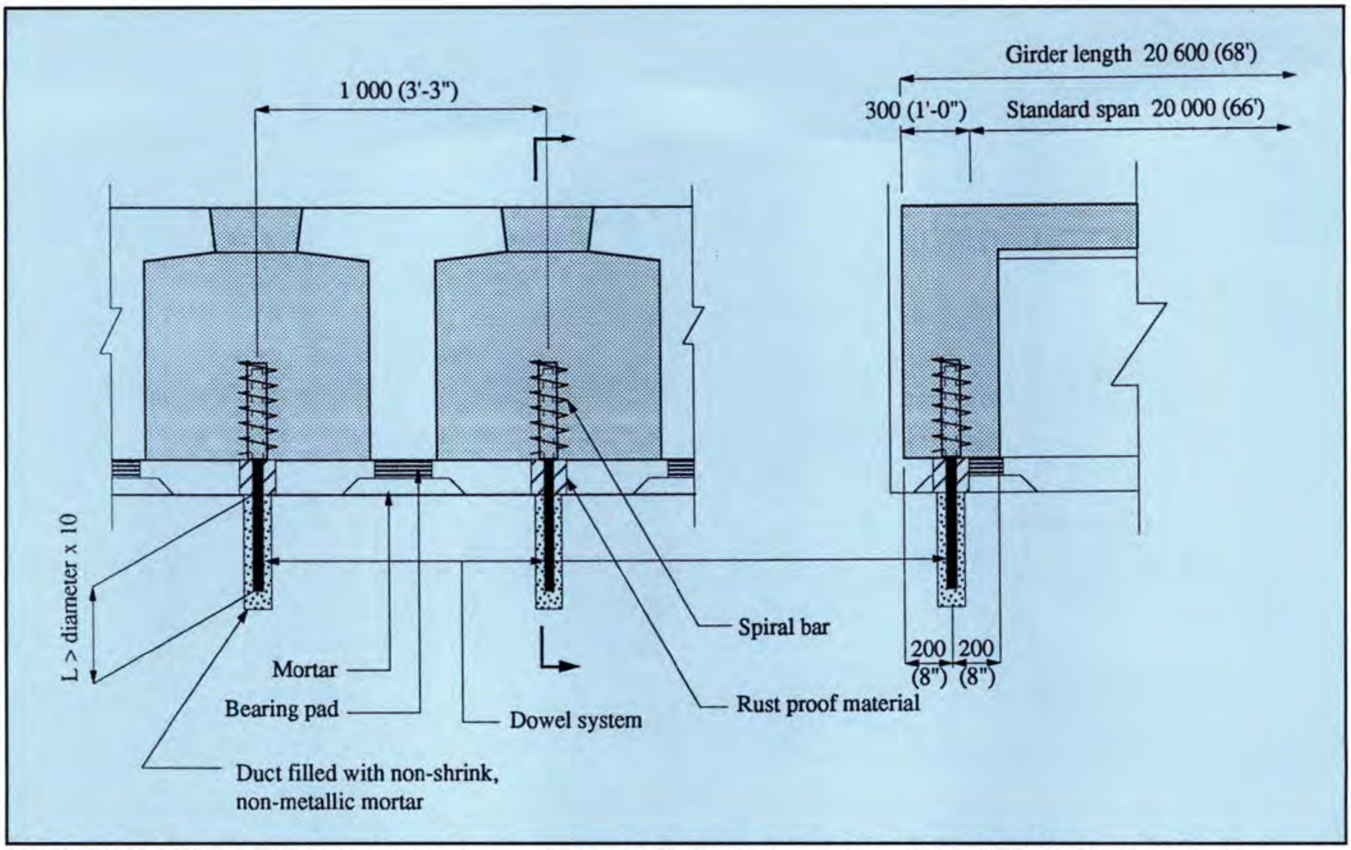



Fig. 26. Bearing and seismic dowel details for a pretensioned T-girder bridge [span of 20 m (66 ft) for TL-20 loading].

ever, the amount of concrete used per unit area of the bridge deck is significantly larger than that used in the United States.

Most bridges, except box girder bridges, are made continuous in the field by using mild steel reinforcement or post-tensioning. All bridges are required to have seismic connection details as given in the paper.


## ACKNOWLEDGMENT

The authors wish to express their appreciation to Kyokuto Corporation of Japan for its financial support of Takashi Yamane's research at the Center for Infrastructure Research (CIR) of the University of Nebraska-Lincoln. Additional support from the CIR is appreciated. Dr. Amin Einea and Ms. Deborah Derrick offered valuable suggestions.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