Strengthening California's Steel Bridges by Prestressing

GUY D. MANCARTI

ABSTRACT

The Surface Transportation Assistance Act of 1982 that addresses increased truck sizes and weights has exacerbated maintenance problems of existing bridges designed to meet earlier loading criteria. In 1975 California implemented the Permit Design Live Load that allows substantial increases in live loads. Strengthening existing steel bridges on the highway system, in particular those bridges on California's State Highway Extra Legal Load network (SHELL routes), has assumed a high priority. Two steps can be involved: (a) All existing steel girder bridges are screened for potential overstress by a sophisticated computer program, CURVBRG. This program, which uses a plane grid analysis, was written at the University of California at Berkeley and adapted by the Structural Research Unit of the California Department of Transportation for use by the Office of Bridge Maintenance. For the heavier live loads, CURVBRG assesses stresses and deflections much more precisely than do usual design methods. If overstress is indicated, step (b) is implemented. (b) Longitudinal prestressing tendons are installed to enhance moment capacity in critical areas. Structural steel may be added as necessary to achieve balanced design stresses. This has been done on seven steel girder bridges to date and is planned for a dozen more. CURVBRG is described briefly, and several examples of prestressed installations are presented. Prestressing has proven to be a quick, economical, aesthetically pleasing method of strengthening steel bridges.

The Surface Transportation Assistance Act of 1982 mandated, among other things, increased truck sizes and weights. With this increase, many bridges designed by earlier live-loading standards became structurally inadequate. Several states, including California, have established even higher permit-loading criteria for special heavy-hauler routes. California's system, known as the State Highway Extra Legal Load or SHELL system, is being designed to accommodate California's maximum permit loads--trucks with up to 13 axles and gross weight of 314,000 lb (Figure 1).

Steel girder bridges, with relatively small dead-to-live load ratios, are especially affected by increases in live loads. Although California does not have a high percentage of steel bridges in its highway system, there are enough steel bridges, particularly on SHELL routes, to warrant comprehensive studies of system bridges to determine permit live-load ratings and identify bridges in need of strengthening on key routes. Several other methods have been used in unique cases, but the best developed technique thus far for increasing live-load capacity has been to strengthen steel girder bridges by prestressing.

BRIDGE INVENTORY RATING

All bridges on California's state highways have been inventoried by means of standard rating techniques

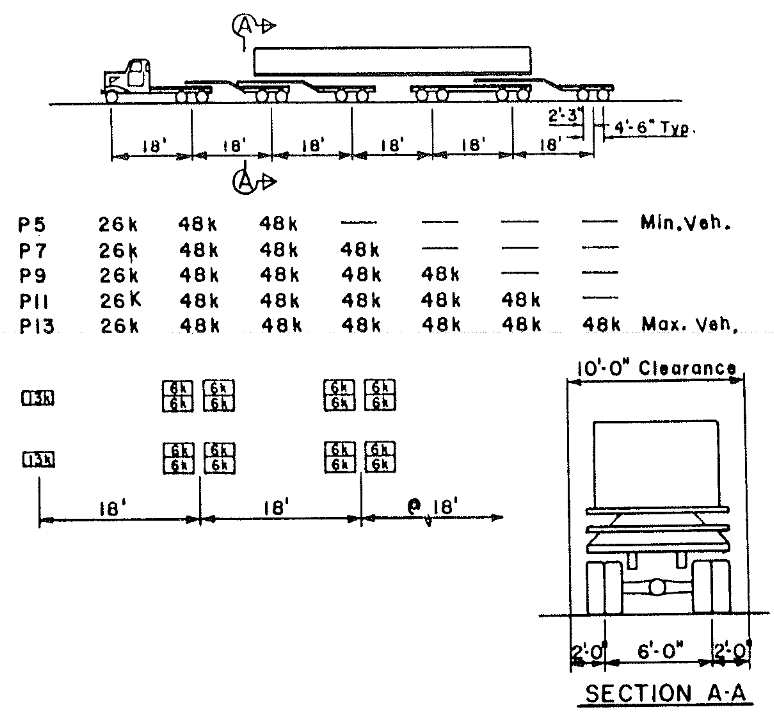

FIGURE 1 California permit loads.

to identify those with lower capacities. The computer program CURVBRG has been adapted by the Office of Bridge Maintenance for second-level analysis of more precise stresses and deflections under increased live load on bridges previously identified as overstressed.

The CURVBRG program was written in 1974 by Mondkar and Powell (1) at the University of California, Berkeley, and was modified as required for California Department of Transportation (Caltrans) computer equipment by the Structural Research Unit of the Office of Structures Design under the direction of R.E. Davis, Bridge Research Engineer. The program was introduced to the Office of Bridge Maintenance by Davis in 1977. For the benefit of engineers unfamiliar with computer technology, a second volume (2) provided annotated input forms and input and output for sample Caltrans problems.

Subsequent studies made in conjunction with field tests of instrumented structures subjected to measured loads clearly demonstrated that (a) CURVBRG could provide maximum envelope stresses at all points in a structure for any combination of loadings designated by the rater; (b) the program could readily account, with appropriate load factors, for dead loads, construction stages, arbitrary configurations of geometry and articulation, and arbitrary configurations of vehicle axles and combinations of load cases; (c) theoretical strains agreed closely with measured ones, and correlations were significantly better than those obtained by other methods; and (d) stresses obtained by the current AASHTO distribution factors were ultraconservative. For these reasons CURVBRG was adopted for day-to-day use and has been consistently demonstrating that steel girder bridges previously identified as substandard, based on current AASHTO criteria, are actually capable of carrying the new permit loadings without costly rehabilitation or replacement. Currently projected savings to the highway fund are large.

When refined analysis by CURVBRG demonstrates that bridges deemed substandard in the first-level screening have adequate load capacity to sustain permit loadings they are re-rated on the inventory and no further work is done.

Bridges found to be deficient by CURVBRG analysis are scheduled in systemwide priority for the strengthening program. Results of the detailed analyses, identifying critical areas and amounts of overstress, are made available to designers for preparation of contract plans.

STRENGTHENING BY PRESTRESSING

Steel girder structures are frequently found adequate for permit loadings in all respects except moment capacity, a deficiency susceptible to alleviation by prestressing. Compressive force is applied to tension flanges to provide a resisting moment sufficient to accommodate permit loadings. Deficiencies in negative moment areas of continuous structures may require the addition of steel to compression flanges to balance the sections. Concrete decks usually provide enough area in positive moment strengthening to keep compressive stresses within normal limits. These refinements will be illustrated in the examples.

CRITERIA FOR DESIGN

Normal prestressing criteria are used for the design of prestress tendons. Special tendon prestressing sequences are seldom required because applied forces are nominal in comparison with superstructure capacity. Special attention is paid to tendon paths, tendon encasement, and fastening devices, which are designed to match tendon ultimate values. These devices should not fail under any loading condition including seismic or accidental loading, and they are proportioned so that they will not cause failure of components of the structure to which they are attached.

Tendon paths are generally straight, although haunched girders may require angle points to align forces with girder flanges. Tendon paths must clear girder stiffeners and lateral bracing, which may require relocation or, if allowable, creation of an opening to accommodate tendons. Tendons are kept free from corrosion by encasement in galvanized pipes and grouting after tensioning. Anchorages are also sealed.

All strengthening by prestressing in California to date has employed strands, although specifications also permit use of high-strength rods. Only tendon forces and paths are shown on the plans. All prestressing systems and anchorage hardware must be tested and approved by the Caltrans Transportation Laboratory prior to installation.

DESIGN PROCESS FOR A SIMPLE SPAN

The steps of the design process are

1(a). Determine moments for applied dead load + live load + inertia (DL+LL+I) at center of span.

1(b). Calculate girder stresses.

2(a). Determine allowable girder stresses based on as-built material.

2(b). Calculate stressing force required to compensate for the difference between the allowable stresses and the DL+LL+I stresses in the tension flange. Assume an eccentricity for the stressing force that will allow adequate space for mounting the stressing anchorage brackets. Check compression flange steel and concrete stresses.

3(a). Repeat the process for other critical points within the span at flange reduction locations.

3(b). Determine location where stressing force may be terminated based on allowable unit stresses. Termination point must be between existing transverse stiffeners if anchorage brackets are mounted on the girder web.

4(a). Design anchorage brackets. Use sufficient transverse offset to clear girder stiffeners if brackets are mounted on the girder web. Check bracket size to ensure that its dimensions are consistent with the available space and the assumed stressing eccentricity.

4(b). Check the existing girder web for bearing stresses generated by the anchorage bracket.

EXAMPLES

Pit River Bridge and Overhead on I-5

One of the earliest strengthening jobs using prestressing was done in conjunction with the complete rehabilitation of the Pit River deck truss over Shasta Lake. Constructed to 1941 standards, the structure served for many years until wear and tear due to increasing truck traffic and deterioration due to salts necessitated complete deck replacement. Addition of a safety median barrier, replacement of portions of deck previously widened with lightweight concrete, addition of a deck seal and wearing course, and an increase in roadway width to accommodate exterior safety barriers required strengthening the stringer system and the cantilevered portions of floor beams.

Stringers were strengthened by prestressing tendons, affixed as shown in Figure 2, to reduce tensile stresses in negative moment areas over the

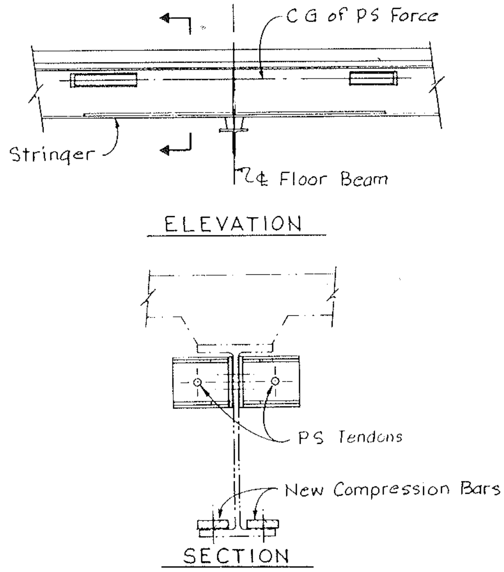

FIGURE 2 Pit River bridge stringers.

floor beams. Because prestressing increased compressive stress in the bottom (compression) flange, it was necessary to add the compression bars shown.

Floor-beam cantilevers were strengthened at their bases by fastening tension straps with tie plates alongside the original floor-beam cover plates before adding superstructure dead load (see Figure 3). The finished work is shown in Figure 4.

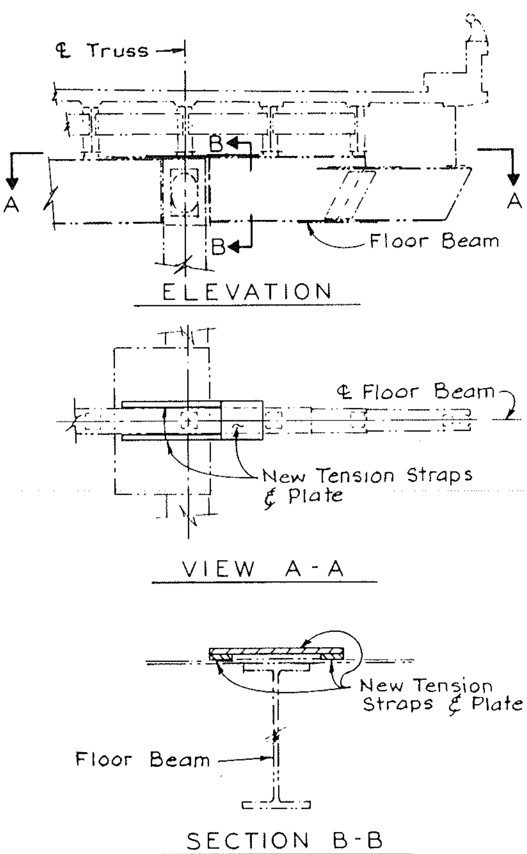

FIGURE 3 Pit River bridge floor beams.

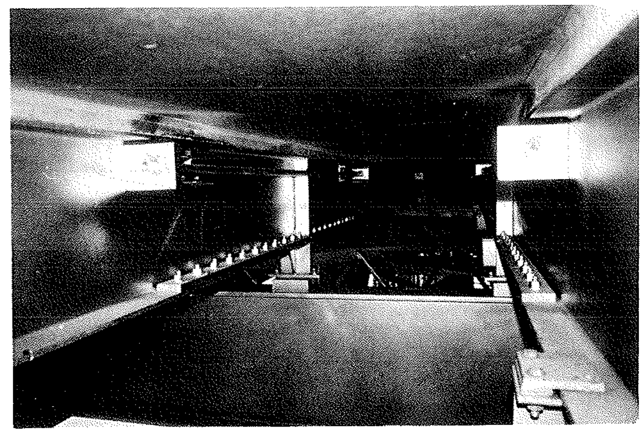

FIGURE 4 Pit River bridge—strengthened interior stringers.

Avenue 328 Overcrossing on CA-99

This composite steel girder structure, with six simple spans and five lines of girders, was designed for AASHTO HS20-44 live loading. The bridge was found to be deficient in moment capacity for permit loadings in the three central, 90-ft spans.

Strengthening was accomplished by adding 120 kips of force to each of the fifteen girders by means of two 60-kip tendons, 60 ft long, symmetrically placed on either side of the web 6 in. above the bottom flange. The attachment (Figure 5) was secured to the girder web by fourteen 7/8-in. high-strength bolts. All hardware was galvanized. Creep loss in the prestressing system was assumed to be 5,000 psi plus any losses characteristic of the prestressing and anchorage system. The tendons of each girder web were stressed simultaneously and enclosed in 2-in., standard, all galvanized pipe, which was grouted after stressing. The longitudinal centerline of the tendons was placed outboard of the girder stiffeners, and tendon supports (Figure 6) were placed at 15-ft intervals.

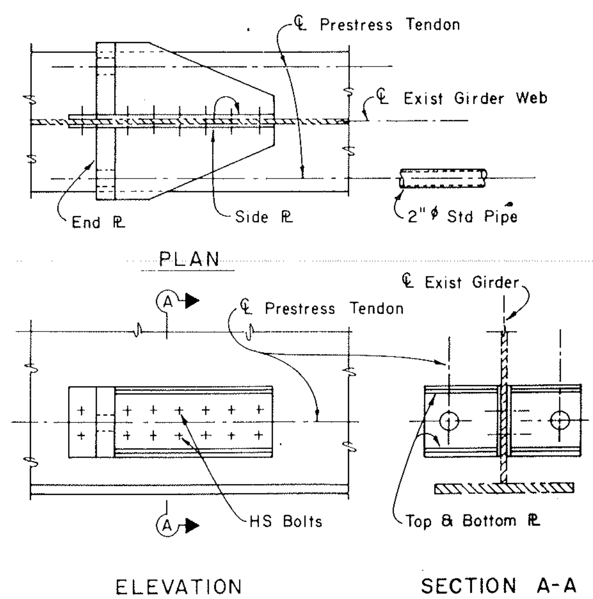

FIGURE 5 Prestress tendon anchorage—positive moment zone.

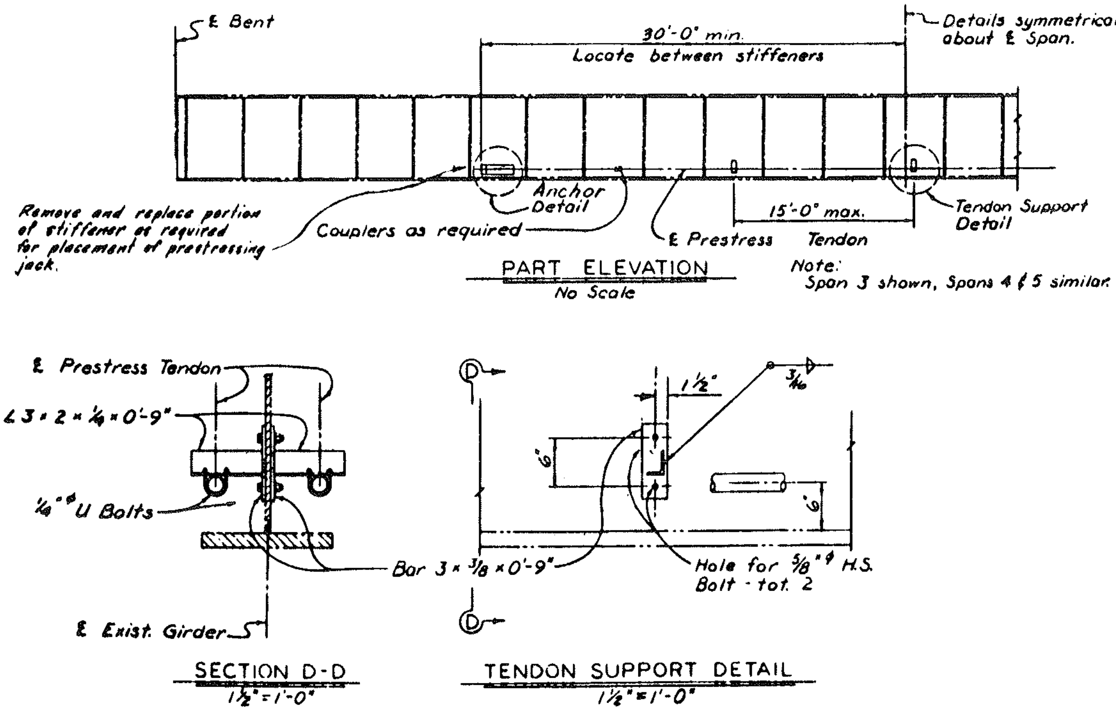

FIGURE 6 Avenue 328 overcrossing tendon supports.

Bid items and total bid amounts for the contract were

Traffic control system (lump sum)	$ 3,000
Prestressing steel girder (15 girders)	30,000
Miscellaneous metal (6,100 lb)	20,000
Contract total	$53,000

Drilling of bolt holes for the anchorages was included in the price of miscellaneous metal. All other work, including prestressing steel and grouting, was included in prestressing steel girder.

After anchorages were installed, prestressing was completed in less than a week; the contract allowed 50 days. Figures 7 through 9 are photographs of the installation during and after construction.

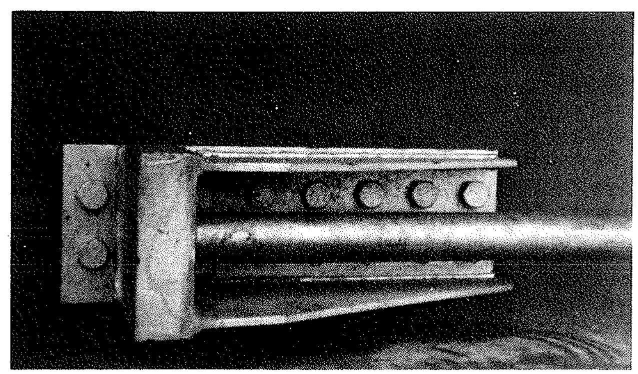

FIGURE 8 Tendon anchorage.

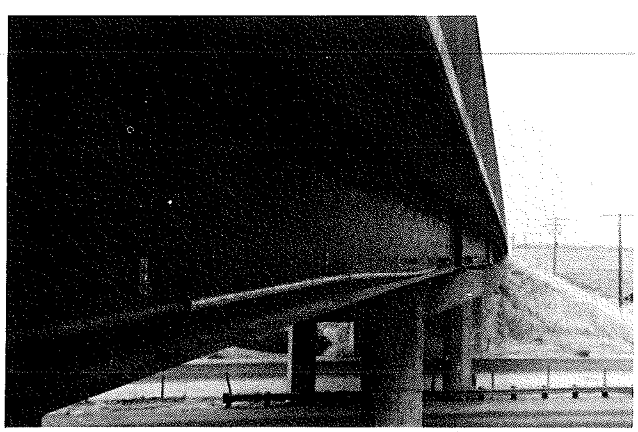

FIGURE 7 Two-inch pipe encasement for prestress tendon.

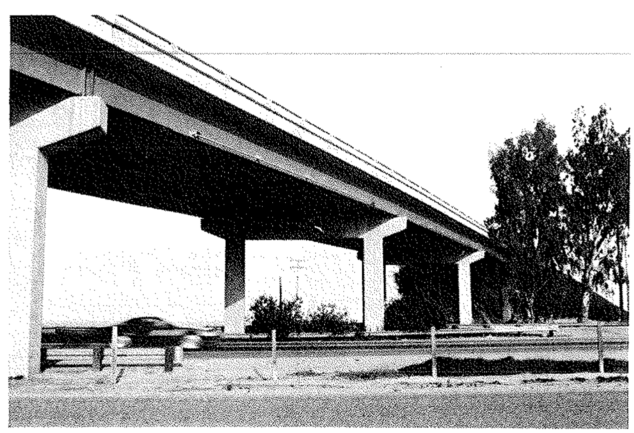

FIGURE 9 Completed exterior girder tendon.

Truckee River Bridges and Overheads on I-80

When I-80 was constructed through the Truckee River Canyon in 1955, high falsework for cast-in-place structures over deep canyons and segmental cantilever construction had not been developed to the present state of the art. Welded-steel girder structures were the best alternative for such sites. Seven crossings of the Truckee River and two high railroad overheads were constructed of steel. The Southern Pacific Transportation Company main line, which occupies the canyon, was used for the delivery of the girders. Designed for HS20-44 live loading, the majority of steel structures on this main truck route into California became deficient in load-carrying capacity with the introduction of the California permit load. Widening, deck replacements, seismic retrofitting, and upgrading to permit capacity for most of the steel structures from Auburn to the Nevada border are now under way. Spans shorter than 90 feet usually meet permit live-load requirements, but spans longer than 100 feet invariably have to be strengthened. The total anticipated cost of these improvements over the next 5 years will be more than $20 million.

TABLE 1 California Bridges Strengthened by Prestressing

Bridge	Route	County	Strengthened Date	Strengthened Span (ft)	Force per Girder (kip)
Pit River bridge	I-5	Shasta	1979	35	70-100
Salinas River bridge	CA-101	Monterey	1980	89	190
Milpas Street separation	CA-101	Santa Barbara	1980	122	360
Bridge-street undercrossing	CA-101	San Luis Obispo	1980	74	75
Avenue 328 overcrossing	CA-99	Tulare	1982	90	120
Truckee River bridges	I-80	Nevada	1983	100	110
Route 43/5 separation	CA-43	Kern	1984	145	350

Route Separations

Route separations, which are points of interchange on the SHELL system, are carefully screened and must be upgraded to permit live-load capacity. The route separation of CA-43 and CA-5 in Kern County is a typical steel girder structure that has been strengthened by prestressing. The two 145-ft spans have been strengthened by putting 350 kips of prestress force into each of the girders. For the four-girder section, a total force of 1,400 kips has been introduced into the superstructure. The largest force used in a steel girder superstructure thus far is at the Milpas Street separation structures in Santa Barbara. These composite, four-girder, dual structures, with single spans 122 ft long and 6 ft deep, have 360 kips of force in each girder, which makes a total of 1,440 kips on the cross section.

CONSTRUCTION

Construction problems reported by resident bridge engineers are minimal. Field adjustments and coping of intermediate interior web stiffeners may be required at some locations. Because California does not use intermediate stiffeners on exterior exposed webs, installation problems at those locations are nonexistent. Care, however, must be taken in placing tendons and encasements in position over traffic. Prestressing is checked by measuring both deformations and gauge pressures. Properly equipped and qualified prestressing contractors perform the work.

MAINTENANCE

Bridge maintenance engineers inspect the strengthened structures annually. They report no performance problems and all strengthened bridges are carried at full-permit live loading. No corrosion problems have been discovered even though several of the structures are located in aggressive mountain environments.

CONCLUSION

All structures strengthened by prestressing (see Table 1) have performed well thus far. There has been no evidence of loss of prestress due to slippage in the anchor systems. Permit loads on the SHELL system routes do not appear to pose a fatigue problem. Encasement of the tendons and anchorages has proven to be a wise precaution, particularly in coastal California and in the High Sierra where salting of bridges may expose unprotected prestress hardware and tendons to corrosive elements.

As structures have been identified and scheduled for strengthening in California's priority program, new problems in unique situations have been encountered. Innovative approaches taken by both designers and prestressors have solved these problems. Prestressing to upgrade the load-carrying capacity of steel girder structures has become the mainstay of California practice.

REFERENCES

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