13. Resistant to extreme flooding;
14. Maximum use of local materials;
15. No bridge deck to deteriorate and no joints in road;
16. Low hazard from ice glazing;
17. Minimal inspection required by owner; and
18. Not sensitive to unequal settlement.

From the precasters and contractors viewpoints, the system has the following characteristics:

1. Meets load limitation and clearance standards for transporting in all states;
2. Requires no special processes (prestressing, steam curing, etc.);
3. Requires no special materials;
4. No special erection equipment needed;
5. Low initial capital investment;
6. Requires no new skills, but present skills must be augmented;
7. Precise pricing possible once operation established;
8. Increases construction season;
9. Not sensitive to backfilling when prescribed backfilling operations are used; and
10. Small on-site work force.

For the above reasons, it is believed that the Americanized version of the Swiss BEBO system will find many applications in the United States.

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Bridge Structure Construction System That Uses Treated Lumber

G. DUANE BELL AND KENNETH A. OLSON

For generations, timber has been considered an economical material for bridge construction. Although for years railroads made good use of treated timber in their bridges, little thought was given to design or permanence of timber for highway bridges, which resulted in timber being viewed as a second-class material. Even though preservative-treated wood was eventually used, it is only in recent years that serious consideration has been given to the design of treated timber for use in short-span highway bridges. Treated timber offers economical advantages, but it provides other advantages as well. Treated-timber material will not crack, crumble, or rot. It cannot be damaged by continuous freezing and thawing, and it is not affected by temperature, alkali soil, or acids. When properly designed, a timber bridge provides flexibility and lower costs in design, simplicity in construction, short construction duration, little or no maintenance, minimal weather considerations during construction, and compatability with the surrounding environment. One type of economical timber bridge is the longitudinal laminated-floor design, which is especially easy to construct. To form the superstructure, 3- or 4-in planks are set on edge in the direction of the span; they are offered in spans up to 38 ft in length. Deck planks are laminated together into panels approximately 6 ft wide by using ring shank dowels. Panels are attached to each other at the site by using dome head drive spikes through a shiplap joint. The structure, which is usually completed in a few days, minimizes cost and inconvenience to the taxpayer.

If the term "wood bridge" is mentioned, most of us immediately picture an old-fashioned covered bridge (Figure 1) or perhaps an old, broken down, poorly constructed wood crossing (Figure 2). Actually, the first wood bridge probably was a log laid across a chasm. For years thereafter wood was an important material used in the construction of bridges.

Railroads and their company engineers long ago recognized the value of wood as a basic bridge material. Wood was readily available. It was durable; easy to use; easily maintained, repaired, or modified; and the use of wood preservatives made it permanent. By applying engineering practices, treated wood became a predominate material. Virtually thousands of timber railroad bridges were built, and many still provide excellent service.

Wood bridges for roads or highways, however, were often built with little thought given to design or concern for permanence. Wood was usually a material put together quickly and cheaply to meet society's basic need of getting from one stream bank to another. Thus, for highway bridges, wood evolved as a second-class material. Gradually, data on timber construction offered by most engineering schools decreased. Many practicing engineers have had almost no background in timber construction. It is ironic that wood as a construction material has been around almost as long as man and yet is probably the least understood common building material. Wood is a highly desirable raw material because it is a renewable resource that is provided by significant amounts of forests in the United States. It is a long way from that small stream crossing for the horse and buggy compared with the demands that present-day traffic puts on major highway bridges. (You might say it is like comparing a Model T with a Cadillac. In between there are a lot of bridge needs, and a good many of them are on rural and township roads. The Model T is inadequate, but the Cadillac is more than is needed. The key is to match the solution to the need; i.e., adequate design, permanence and integrity, and economical cost. That is where treated timber can help.)

There is nothing second-class about timber bridges (Figure 3). Treated timber offers economical advantages over other materials. It will not crack, crumble, or rot. It cannot be damaged by continuous freezing and thawing. Salt will not pit it, water will not rust it, and it is not affected by temperature, alkalai soil, or acids. As a matter of fact, chemical companies such as DuPont have been using preservative-treated wood box culverts in effluent discharge systems for years. They found treated wood to be the best material available to withstand the chemical action of toxic wastes.

When properly designed, treated timber provides flexibility; it can be easily modified, expanded, dismantled, or moved from one location to another should needs change. Treated timber provides econ-

Figure 1. Typical old-fashioned wooden bridge.

Figure 2. Example of old wood crossing.

Figure 3. Example of timber bridge.

omy, simplicity in construction, longevity, dependable material availability, short construction duration, little or no maintenance, minimal weather considerations during construction, and compatability with the surrounding environment.

The departments of transportation in some North Central and Midwestern states now recognize the advantages of using treated timber for bridges on secondary roads. Many specifying engineers are requesting treated timber.

There are several variations in timber bridge design. Most of them have advantages, but the type that offers the greatest combination of desirable characteristics is the longitudinal laminated-deck design. Figures 4 and 5 show an abbreviated two-sheet drawing of a typical longitudinal laminated-deck timber bridge. This design accommodates spans up to 38 ft, is simple, and is easily constructed. It also conforms to American Association of State Highway and Transportation Officials (AASHTO) (1) standard specifications for highway bridges [Section 1.2.5 (for highway loadings)] and bridges designed for HS 20-44 loadings. Section 1.3.4 covers distribution of wheel loads on timber flooring. Paragraph B pertains to longitudinal flooring, normal to direction of span. We mention this because frequent questions from engineers are about that specification and about laminated floor versus splined or doweled floor. After several years of confusion about the definition of a doweled floor, an amendment came about as a result of extensive testing done on an actual timber bridge. Test results showed the design more than met the strength and deflection requirement as prescribed by AASHTO for a splined or doweled deck.

The longitudinal laminated-deck timber bridge consists of shop-assembled deck panels (Figure 6). Panels are about 6 ft wide, made up of 3- or 4-in-wide planks set on edge; the depth of the plank varies with the length of span. Span lengths are from 18 ft (where 10-in planks are used) to 38 ft (where 16-in planks are used). Planks are predrilled with holes at 12-in centers and are usually treated with creosote or penta in heavy oil, then attached to each other by means of 11- or 15-in ring shank dowels. Creosote or penta in heavy oil are preferred preservatives because they provide a higher and more uniform moisture content over a longer period. Adjacent deck panels are fastened to each other with drive spikes nailed vertically through a shiplap joint, which consists of one-half of a plank connected at the bottom of one panel and one-half of a plank connected at the top of an adjacent panel (Figure 7). Deck panels are supported on timber caps, which in turn are supported on piles (Figure 8). During deck installation, a 6x12-in wood-spreader beam is installed under the deck at midspan (Figure 9).

Two basic types of curbs and rails are used. Where 10-kip rail is required, a 6x12-in treated-timber curb is bolted through scupper blocks to the deck by using split ring connectors. The railing is a treated glu-lam timber connected to 8x12-in treated-timber rail posts. Posts are anchored with drive spikes to the deck and bolted to the curb (Figure 10). Where 10-kip rail is not a requirement, there is a simplified rail design that uses smaller timber curbs and posts with standard steel beam guardrail.

For the abutments and wings, timber piling is driven to a minimum of 15-ton bearing, then aligned for placement of the timber cap and timber backing. Then 3-in treated-timber backing planks are installed on the timber piling. A vertical timber functions as a pile stay, which helps keep the cap in place and prevents the abutment from moving forward after back-filling (Figure 11). The wing plank and abutment plank join at the corner pile to form an interlocking fingerlike connection (Figure 12). When abutments are placed farther back in the bank and 14x14-in caps are used, piles can be spaced farther apart, which results in savings in abutment construction (Figure 13). Piers can consist of either timber piling or cast-in-place concrete or steel piles, depending on site and ice conditions (Figure 14).

Testing of the bridge was done under the direction of an independent inspection agency. In the bridge used for testing, the deck consisted of four

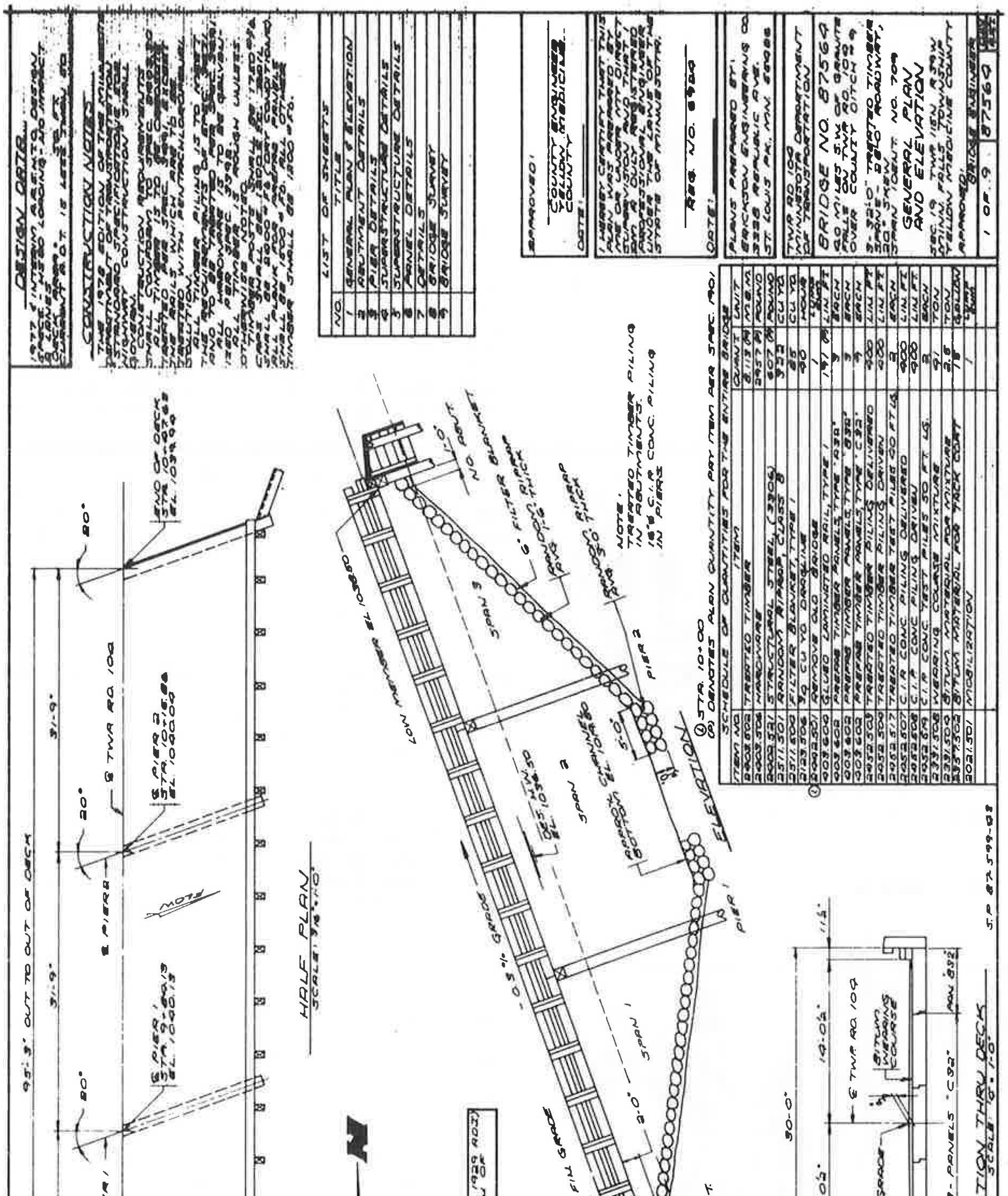


Figure 4. Plans for typical longitudinal deck timber bridge.

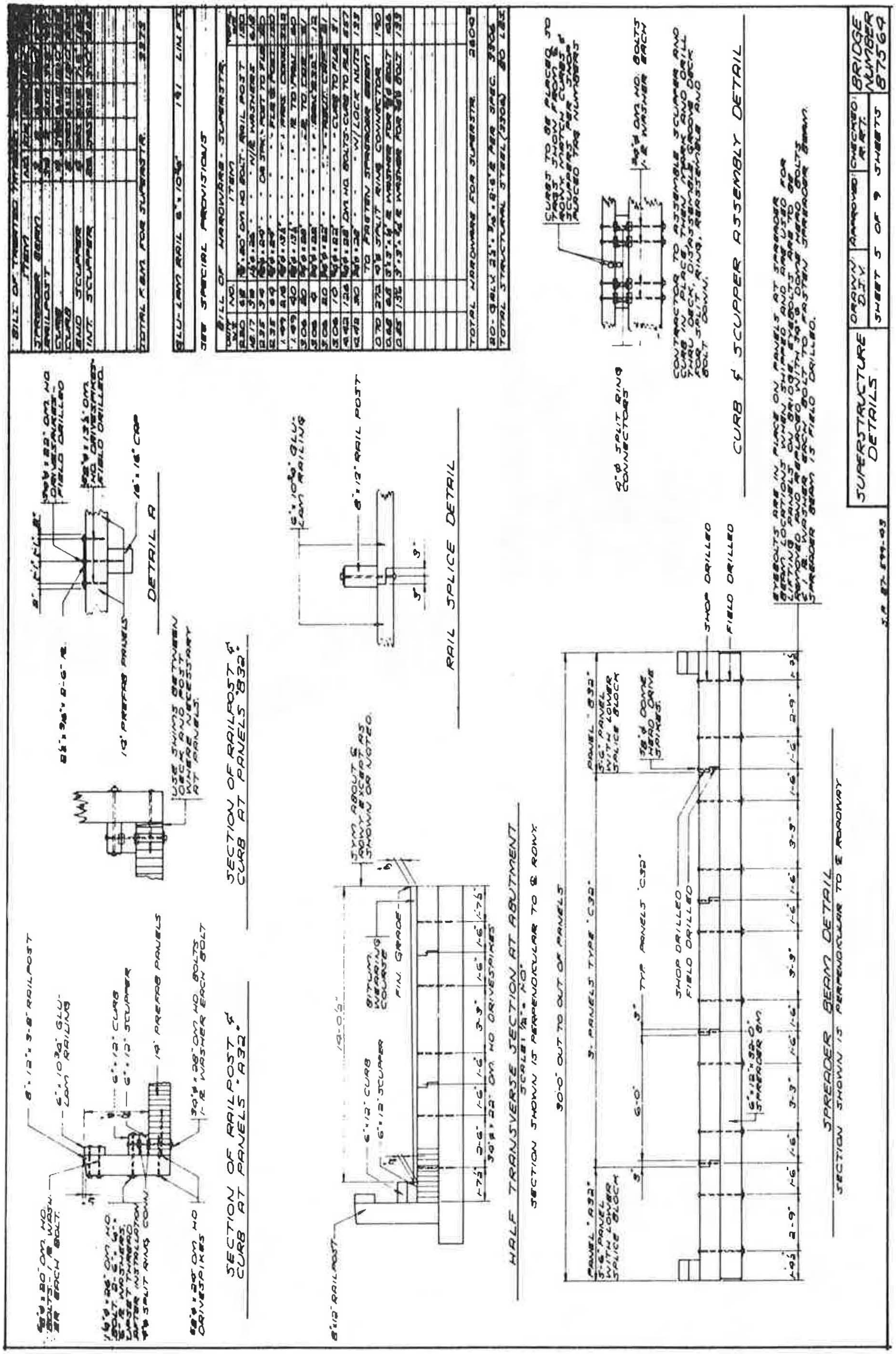


Figure 5. Superstructure details of longitudinal deck timber bridge.

deck panels that were 12 in deep, 6 ft wide, and 26 ft long. A timber-spreader beam was installed under the deck at midspan. A 10-kip railing was also installed. The testing of the deck was done by applying a load with bundles of steel to simulate wheels 20x10-in in dimension (Figure 15). The test series consisted of several sets of conditions, including tests for simulated single-axle loading (two wheels) and the single-wheel loadings (one wheel). A total superimposed load of more than 70 000 lb was applied in the single-axle test. That is more than twice the required loading. Yet the deflection was only one-half what the calculated deflection formula would indicate. The single-wheel test had even better results. For testing the 10-kip railing, a

Figure 6. Shop-assembled deck panels.

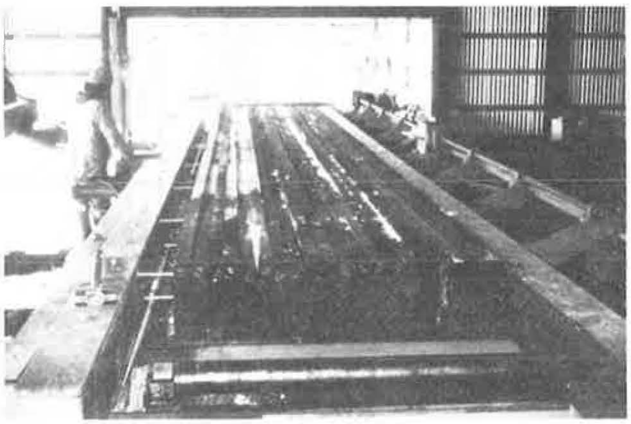


Figure 7. Fastening of deck panels.

Figure 8. Support for deck panels.

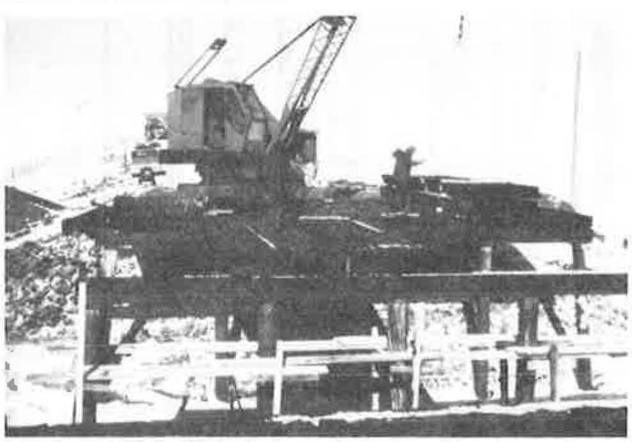


Figure 9. Installation of wood-spreader beam.

Figure 10. Bridge rail and curb.

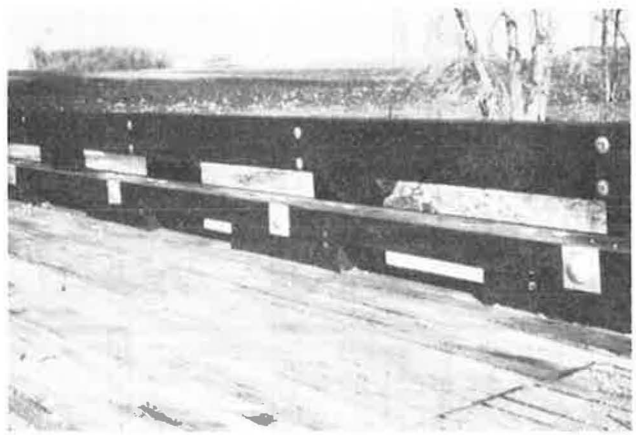
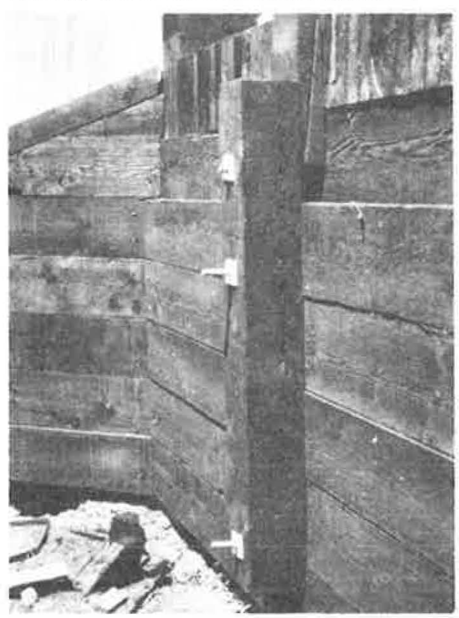


Figure 11. Vertical timber functioning as pile stay.

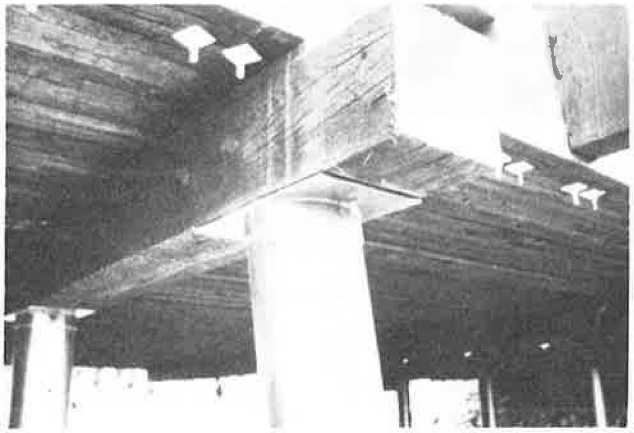


horizontal load of 10 000 lb was applied to the railing and to a rail post by using a calibrated hydraulic ram system and held for 1 min; it showed excellent results.

Figure 12. Wing and abutment planks.

Figure 13. Alternate abutment configuration.

Figure 14. Steel piles used in piers.



We have mentioned the advantages of the longitudinal laminated-deck timber bridge. Its simplicity in construction is a big one. It is not uncommon for a small contractor or a county crew to install a timber bridge by using one carpenter foreman, a machine operator, and one or two laborers. It does not take a lot of sophisticated equipment or many highly skilled workers to do the job (Figure 16). Minimal weather consideration is another ad-

Figure 15. Testing the deck.

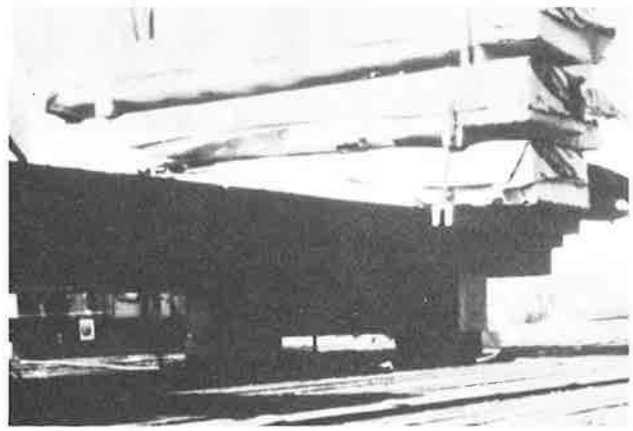


Figure 16. Construction of timber bridge.

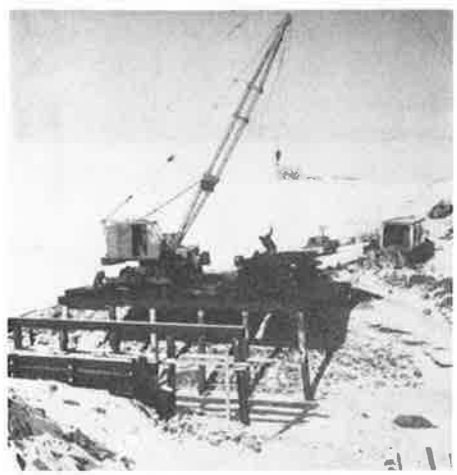


Figure 17. Work is easily done during winter months.

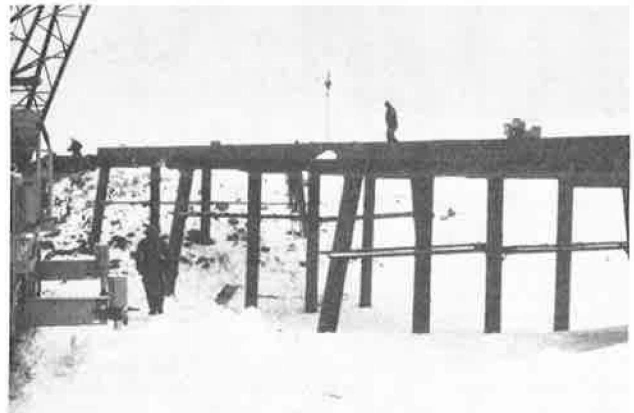


Figure 18. Panels are stockpiled at the job site.

Figure 19. Panels are quickly installed.

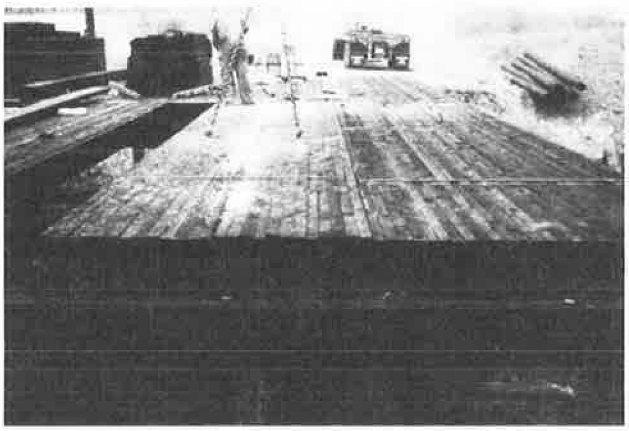


Figure 20. Completed timber bridge.

Figure 21. Timber bridge for vehicles.

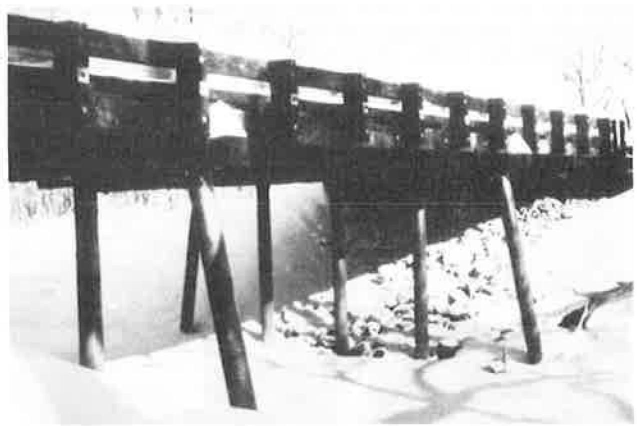


Figure 22. Timber bridge for pedestrians.

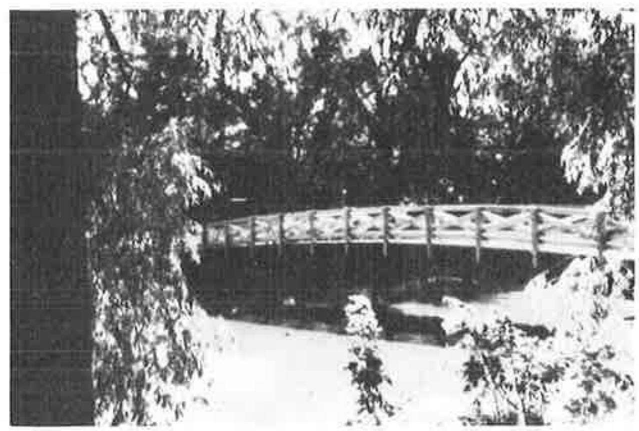


Figure 23. Treated-timber bridge.

vantage. It is not uncommon to build timber bridges during the month of January in Minnesota. We will not say that efficiency is at its best, but it sure beats trying to pour concrete (Figure 17). The need for only a short construction duration is another advantage. Very often complete timber bridges are installed in a matter of a few days, and a good part of that is spent in driving piles and building abutments and piers. In fact, complete decks are usually installed in less than a day. Panels are lifted directly from trucks or from a stock pile at the job site and set into place in a matter of minutes (Figures 18 and 19); before long the bridge is complete (Figure 20).

We do not believe that there is any bridge material that can provide the aesthetic qualities of a timber bridge (Figure 21). That is true, not only of vehicular bridges, but it is especially true at sites where timber pedestrian bridges have been installed (Figure 22).

Figure 24. Example of treated-timber bridge.

Like any new type of construction or material, contractors new to timber bridges may bid unrealistically high when bidding the first few times. With a little experience, however, the cost of treated timber becomes consistently equal to, or usually less than, other bridge materials.

Recently, a consulting engineering firm offered data on total in-place cost comparisons on approximately 200 county and/or township bridges built over a period of three years. Treated-timber bridges averaged about $30/ft². Their closest competitor--concrete Quad-T--was about 10 percent more. Other types of bridges were even higher. And, incidentally, most of those timber bridges were of the longitudinal deck design.

We do not have to remind you of the tremendous need for bridge replacement or that the need for new bridges will cost the taxpayer millions of dollars. Never has there been a time when economy was more important. Many of those bridges are in rural areas on county, township, or municipal roads and at sites where simple, multiple short-span, and economical bridges are ideal. With treated-timber bridges, there is an opportunity to have some of the best of all worlds (Figures 23 and 24).

REFERENCE

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Live Load Distribution in Concrete Box-Girder Bridges

RAYMOND E. DAVIS, VU DINH BON, AND FRANK M. SEMANS

Traditional methods for designing bridges that reduce the significant parameters affecting distribution of live loads to a single entity (e.g., stringer spacing or deck width) represent archaic oversimplifications. They are held over from the precomputer era and result in a spectrum of designs that range from ultraconservative to those that would be unsafe but for generous safety factors. Development of such distribution factors has usually been based on the assumption that all lanes on a structure are loaded with design vehicles, and such design methods become particularly meaningless when used in conjunction with hybrid loadings such as California's Permit-series, which comprises a single, heavy rating vehicle in combination with a single H-series design vehicle. Sophisticated analytical tools developed in the postcomputer era can provide very exact designs (perhaps more exact than warranted by live load specifications), but these tools are too cumbersome for use in a production environment. Presented here is an alternate, intermediate design method that combines relative exactness with a shortcut design approach that employs nomographic analysis for traditional designs and influence-line analysis for hybrid loadings.

For many years, the concrete box-girder bridge has enjoyed special popularity on California's freeway network. Prior to 1959, design of such structures for live load was based on a distribution-factor approach in which individual I-sections were assumed loaded with S/5 wheel lines of a standard H-series vehicle, where S is the spacing (in feet) between centerlines of webs.

In 1959, California design engineers, who appreciated the large torsional rigidity of the closed box section, suggested to the American Association of State Highway Officials (AASHO) a change in this distribution factor to S/7. Sophisticated techniques for analyzing such structures were unavailable at the time, and the recommendation had little scientific basis; nonetheless, the new specification was tentatively adopted, contingent on California's agreeing to embark on a research project to study box-girder load-distribution phenomena.

The research program began in 1960 with field testing of the Harrison Street Undercrossing (1,2), a 34-ft-wide structure that had a single span of 80 ft. The cross section comprised four cells spaced at 7 ft 3 in and provided a live load distribution of S/5 = 1.450 wheel lines according to the earlier specification and S/7 = 1.036 wheel lines according to the revised specification.

Field testing entailed heavily instrumenting the structure with strain- and deflection-measuring devices and running a Euclid truck across the span in 13 transverse positions while internal strains and deflections were recorded. The two-axle test vehicle was heavily ballasted with reinforcing bar ingots to 57 kips. Tests were run in three phases: with and without intermediate diaphragms and after addition of 3-ft-wide barrier curbs and rails.

Analytic techniques for data reduction involved plotting of individual strains as functions of transverse position of the test vehicle and, subsequently, hypothetical placement of more than one vehicle on these strain plots for superposition of strains and conversion to stresses and stress integration in individual I-sections for determination of stringer moments. These stringer moments were compared with computed moments on the span due to a single wheel line of the test vehicle to permit assessment of an S/D factor for hypothetical combinations of test vehicles critical for each stringer.

The 28-ft roadway between the 3-ft-wide barrier curbs permitted two lanes under the specifications