ECONOMICAL STRUCTURES FOR LOW-VOLUME ROADS

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Sharp increases in prices and a concurrent decline in highway revenues have forced a re-evaluation of highway projects. Most seriously affected are the old bridges since, unlike the rest of the highway, their life cannot be indefinitely extended by maintenance. A national bridge survey reveals that 105,000 bridges in the U.S. are structurally deficient and/or functionally obsolete and 72,000 of these are on roads that are not on the federal-aid system. The needs on our low-volume roadway system far exceed program funds available. The potential economies suggested in this paper will hopefully lead to better utilization of the funds available. This paper investigates the economics of low-volume structures. It discusses the most economical bridge types being constructed in the Northwest. Although, not primarily addressed to the hydraulics involved in stream crossings, the paper discusses some of the hydraulic considerations that should be made. Attention is directed to actual practice of agencies constructing bridges on low-volume roads. The three principal structural materials of concrete, timber, and steel are discussed. Certain structural details are suggested for economy, as well as structural types. The comments and recommendations contained in this paper are based on a survey made in the Northwestern United States.

For many years our highway and bridge engineers have been well aware that this country has a major bridge problem which daily grows worse, particularly on our low-volume roads. Time has taken its toll, so we are now surrounded by large numbers of deteriorated and dilapidated bridges. Fortunately, as the result of the widespread publicity given to the problem in the past few years, other people - from layman to congressman - have finally been awakened to the seriousness of the situation. Congress is now recognizing this by increasing the funds for bridge replacement to the point where significant progress can be made in years ahead. The present amounts proposed vary from $450 million to $2 billion per year. This is a welcome contrast to the previous allocations which averaged only $120 million per year over the seven-year life of this program. Other improvements in the current bills before Congress would permit rehabilitation of existing bridges as well as replacement and, for the first time would allow bridge replacement funds to be spent on both federal-aid and non-federal aid (off-system routes.) It is estimated that there are 33,500 deficient bridges on federal-aid routes and 72,000 on off-system routes. Estimated replacement cost of these deficient bridges is in excess of $25 billion.

The problem with old deficient bridges is most critical on low-volume roads because that is where the largest percentage of very old narrow bridges are found. Many of these old bridges on the back roads are collapsing, but we hear little or nothing about most of them. Unless the bridge is large or involves fatalities, it is considered just another "fact-of-life" occurrence. An example of one such collapse is shown in Figure 1. It has been estimated that 200 bridges in the U.S. collapse every year.

Figure 1. Collapsed log bridge in Oregon.

In order to determine what was being done in the Northwest, questionnaires were sent to counties and other local jurisdictions in the States of Idaho, Oregon, and Washington. The total number of bridges built, over a three year period, by some 100 responding agencies was 790. Of these 72% were prestressed concrete, 15% were timber, 5% were steel, and 8% were other types including long span culverts. A further breakdown of the prestressed concrete bridges showed 57% were slab or "rib deck", 39% were bulb tees, and 4% were box beams.

Interestingly, the questionnaire revealed that, of the 790 bridges reported only 55% were contracted. The other 45% were built with the agencies' own forces. These numbers are misleading of the total picture though because the large bridges were contracted and those built by day labor often involved contract purchases of beams and other components.

The initial statement in this paper to the effect that the problem of old deteriorating bridges daily grows worse, needs clarification. While the statement is true of a large number of counties and cities there are many others that are making good progress in replacing their old bridges. In an effort to get an indication of the progress being made we selected Washington State, since the County Road Administration Board (CRAB) in that State maintains good records of all county bridges including the number that are deficient and the number replaced each year. Although our previous survey indicated that most counties in Washington were making good progress replacing deficient bridges, CRAB's bridge inventory records reveal some surprising statistics. The total number of bridges being maintained by the 39 counties in Washington is about 4100. In 1972, 514 of these were rated as structurally deficient. In the ensuing five years 443 of these deficient bridges were replaced. Simple arithmetic would indicate that few deficient bridges remained. Yet in 1977, five years later, the CRAB tabulation shows that the number of structurally deficient bridges had increased by 26, to 540. This makes it appear as though they are losing ground but this is not necessarily true. While most of the increase in the number of deficient bridges is undoubtedly due to the continuing deterioration of the older structures, part of the increase can be attributed to an improved bridge inspection program and a more thorough rating analysis which has caused many older structures, that were previously considered adequate, to now be classified as deficient.

Planning

The first step in planning a bridge replacement program is to establish needs. Since the national bridge inspection program for federal-aid routes has now been in existence for several years, counties and other agencies should be aware of their needs on the federal-aid system. With the new highway bill including funds for off-system bridges, the inspection program will have to be extended to include all bridges and thus needs for the entire highway system will be established. Many counties, at least many of those surveyed in the Northwest, already have an inspection program covering all bridges and thus are well aware of their entire needs. Those who are not that fortunate should get going fast if they hope to get their share of the expanded bridge replacement funds. As the replacement program is planned, the first question should be, how many of the old bridges can be replaced with culverts? If a commercially available size culvert up to 4.6 m (15 ft.) can handle the runoff, and if drift is not a serious problem, the culvert should save money and require minimum maintenance. Other advantages to culverts include: no bridge rails to run into head-on, no bridge icing, and no deck deterioration. Also, the culvert can carry heavier loads and the continuity of riding surface over a culvert eliminates the bump that is often found at bridge ends. For the larger sizes, with spans up to 15 m (50 ft.), the culvert requires special site conditions including adequate depth of embankment to allow space for the structure plus some 1.5 m (5 ft.) of fill over the pipe. (Figure 2.) Over 600 of these larger culverts (termed long-span) have been installed in North America since 1960. They are being used as drainage structures and as grade separations. Six major companies are producing long-span culverts. Culverts can be constructed faster than most bridges and often at substantially less cost. When site conditions are right for these large culverts careful study should be made to determine the relative merits of a culvert or bridge. Structure choice at these locations should be based on comparative cost of construction and maintenance, risk of failure, risk of property damage, traffic safety, fish passage requirements, and environmental and aesthetic considerations. At some sites the culvert seems to be an ideal structure from an environmental standpoint. In other locations, especially in urban areas, the openness of a bridge and the smaller right-of-way make it more desirable.

Figure 2. Horizontal arch-shaped culvert with 12 m (40 ft.) span.

Although this paper is not primarily addressed to the hydraulics involved in stream crossings, this is an area which needs more attention. Such items as skew angle, possible channel changes, streamlining of intermediate piers and bents to avoid excessive scouring and drift hang-up may require special study. Many of the major and costly engineering shortcomings over the years have been due to lack of proper consideration for hydraulics. A hydraulic study should be conducted for those stream crossing where the primary problem is to pass floods of unusual magnitude and frequency. Crossings controlled by high grade lines or those over well-defined or diked channels often require little if any hydraulic study. A nutshell sketch of a hydraulic study where the problem is the determination of an adequate sized structure to pass estimated flood flows would include:

1. A hydrologic analysis of stream flow data to establish the magnitude of the design flood.
2. An evaluation of existing structures over the same river or stream.
3. Identification and location of dwelling and other high-cost development.
4. Documentation of past flood heights complete with location and dates.
5. Hydraulic-sizing of the culvert or bridge so that watersurface elevations during flood flows are kept at acceptable levels.

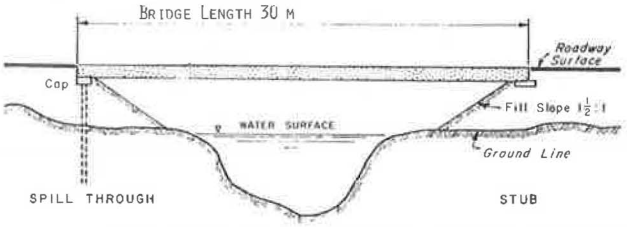
If funds are not available to build a structure which will carry the anticipated flood flow, there are other possibilities. A low level bridge can be built which will be overtopped during the higher flows. When designing this type of structure special attention should be given to the elevation of the structure, streamlining of the section, and type of anchorages. Since drift is supposed to pass over the top of low level bridges, it is advisable to omit the railing. Another possibility is to build the approach road low to serve as an overflow or build a portion of the fill with a sand core that will wash out when flooding becomes critical.

Design Considerations

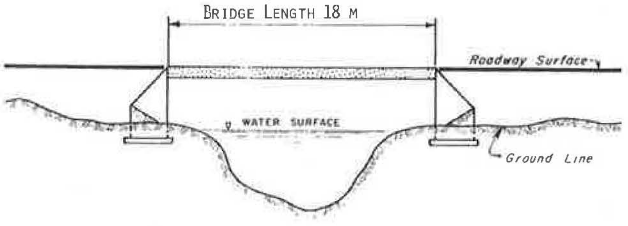
Once the decision has been made to use a bridge with a certain waterway opening, the engineer has numerous choices. The bridge type may depend on how the construction is to be performed. If the construction is to be done with in-house personnel, the bridge crew may be skilled and have equipment for only one type of construction. The responses to the questionnaire indicated that most bridge crews were experienced with timber construction; several used their own forces primarily on short-span concrete construction, and a few specialized in steel construction. When the construction is let to contract the above limitations do not apply and all logical bridge types should be considered. Span lengths and beam spacing need careful study during detail design. As a general rule, maximum economy is obtained by using the minimum number of beams without requiring excessive deck thickness.

Fortunate are the counties that can afford an engineer on their staff who is knowledgeable about bridges. Even though he may not have time to do much design work, he would be available to make studies of needs and programs, deal with problems regarding maintenance and repairs, evaluate foundation conditions and determine the most suitable and economical bridge types. For example there are many choices available in the type of abutment or end support for a bridge. The use of spill-through, half spill-through, or retaining type abutment may significantly affect the cost. The abutment selected will influence the bridge length which in turn may dictate the most logical superstructure type. (Figure 3.) The spill-through type abutment is generally most economical unless, for example, it requires the use of two spans instead of a single span. When pile bents are used the end bent piling can also serve to retain the fill by the addition of timber, steel or concrete planking bearing against the piles. The cheapest way to support a bridge end is to pour a concrete footing, or lay a sill on the ground or on a compacted embankment. The abutment is completed by the addition of a solid diaphragm between the beams or a back wall above the footing or sill. If the bridge is in a remote area where concrete is not readily available and the ground will not support a sill, the weight of the bridge can be spread over a greater bearing area by supporting the sill on gabions, filled binwalls, or reinforced earth. When the structure is not too long, the abutment should be monolithic with, or firmly secured to, the superstructure. This avoids the extra cost and maintenance involved with expansion devices. Monolithic abutment construction has been used successfully on many bridges up to 100 m (328 ft.) long. When retaining-type concrete abutments are used, the walls and wings can be precast to reduce construction time in the field. (Figure 4.) If poured-in-place concrete is used and the wings are not too long they can be cantilevered from the abutment wall. These are just a few items to be considered in the design to get the most economical construction.

Figure 3. Showing the effect abutment type has on bridge length.

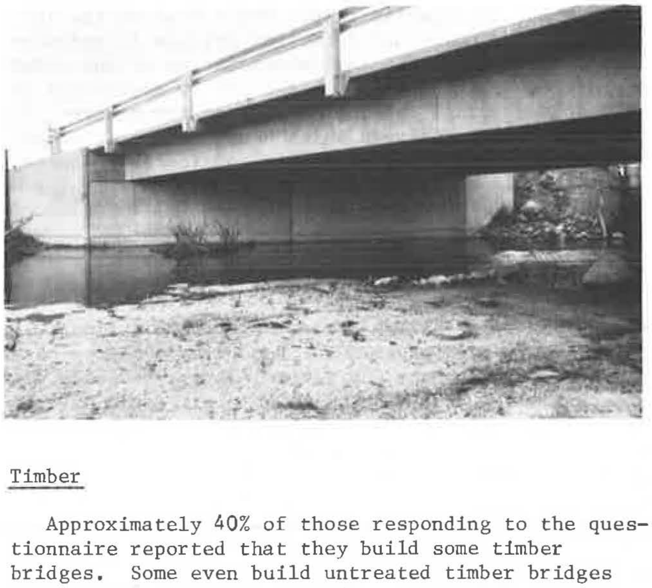


SPILL-THROUGH or STUB TYPE ABUTMENT



RETAINING TYPE or CLOSED ABUTMENT

Figure 4. Bridge on county road in Washington with precast abutment and wingwalls.

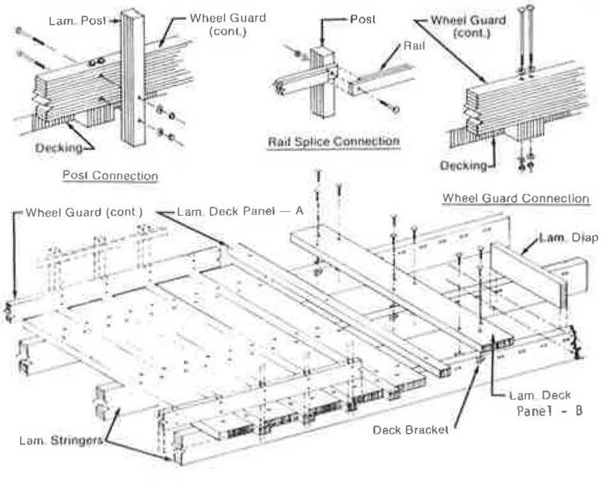


Timber

Approximately 40% of those responding to the questionnaire reported that they build some timber bridges. Some even build untreated timber bridges on extremely low-volume roads. Others use treated timber only for sills, bents, stringers, and headers and untreated timber for the decking and rails. In general untreated timber is unsuitable for bridge construction except for temporary structures or for foundation piling remaining permanently below the water table. Treated timber can and generally does give a long service life varying from 25 to 50 years. A few treated timber bridges have lasted only 10 to 15 years which is obviously unsatisfactory. Such a short life must be due to careless erection or to the manner of construction whereby the effectiveness of treating is lost by drilling, cutting, and nailing during construction. The principal factors contributing to the life of treated timber are environment or location, exposure to the elements, type of treatment, and the care and manner in which the fabrication and erection are performed. Pressure treatment with oil borne preservatives is recommended for best results.

In recent years there have been many improvements in the fabrication and erection of timber bridges which have made them both more competitive and more long lasting. Modular systems have been developed which consist of completely prefabricated members and require no cutting, drilling, or nailing after treatment. All connections are made by bolts through predrilled holes. The girders, felloe guard, and rail posts are all glu-lam members. Deck panels are also glu-lam in widths of 0.6, 0.9, and 1.2 m (2, 3, and 4 ft.). Structures such as these have been built in the Northwest with spans up to 36.6 m (120 ft.) carrying loadings heavier than HS20. (Figure 5.)

Figure 5. Panelized timber bridge system. Assembly diagram.



A new concept in timber now being developed by Forest Products Laboratory is a process referred to as "Press-Lam". The system involves rotary cutting of logs into plies up to 1.2 cm thick. The veneers are glued together with all laminations placed vertically to form a continuous sheet of wood which can then be ripped and cross-cut to the desired dimensions for stringers, deck panels, etc. The process involves less waste of material and scatters the defects better which produces higher structural quality from any given grade of log. To date, one small bridge in West Virginia has been constructed using press-lam members. The members were actually fabricated in the Forest Products Laboratory since the necessary manufacturing equipment is not currently available in industry.

Some advantages of timber, or the conditions under which timber seems especially appropriate, include the following:

1. Timber is plentiful in many areas and is a resource that replaces itself and is more conserving of energy than concrete and steel.

2. When used as friction piling, timber will generally be most economical, i.e., will furnish the highest bearing-to-cost ratio. When soil conditions are right it is possible to use high bearing values. On one recent Interstate project in Nevada, timber piles were designed for 64 t (70 tons). A word of caution here, however, many treated timber piles have been damaged during handling and by over-driving so that the effectiveness of treatment is lost and the service life greatly reduced.

3. When existing abutments and piers are to be reused, they may be able to support a superstructure dead load of timber but not concrete. Several old trusses have been replaced with glu-lam girders using existing abutments and piers.

4. Glu-lam panels used for decking apparently are not affected by salts and therefore under some circumstances may be more durable than concrete decks.

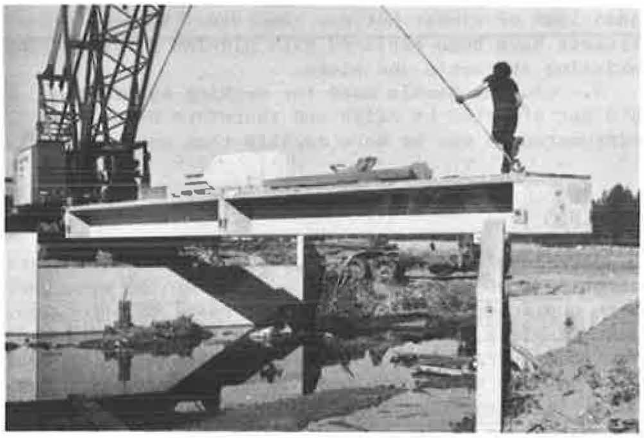
Concrete

Cast-in-place concrete, for superstructure members of bridges on low-volume roads, has for the most part been replaced with precast, prestressed construction. Cast-in-place concrete, nevertheless, has certain advantages. Bridges with curves and flares can be built more readily with cast-in-place concrete. Also, for multiple spans, cast-in-place concrete lends itself to continuous design which contributes to smoother riding qualities. In general, however, the cast-in-place bridge has become too expensive due to the on-site labor for falsework, forms, placing resteel, and pouring and finishing concrete. Another disadvantage of the cast-in-place bridge is the extra time required for construction and the additional inspection. The fact that precast work requires less on-site field inspection should not be carried too far. We have seen some precast, prestressed structures which apparently got little or no inspection and the result was poorly placed foundation, poor welded connections and improperly grouted keyways.

For the low-cost, short-to-medium span range, 6 to 40 m (20 to 130 ft.), prestressed concrete is by far the most commonly used bridge material on new construction in the Northwest. In our survey of several Northwest prestress plants, we found that a large number of different forms and sections are being used. The standard bridge sections that were developed by AASHTO and PCI are well known and have been used extensively throughout the country. These standard sections were selected in the hope that they could be used for most precast, prestressed concrete contruction in all of the states. Their goal was only partially successful. Many prestress plants developed their own sections and have successfully promoted their use. Their objective has been to develop cheaper members and a total bridge system that requires the minimum material and field labor. Fortunately, these are not patented, so that any plant can get the forms and compete for the business. The most significant revision in these non-standard sections, and the one which is saving money on many jobs, is the precasting of an integral deck slab along with the beams (Figure 6.) With the standard AASHTO - PCI precast sections, the integral slab is obtained only with the use of slab or box sections. With non-standard sections, integral decks are obtained with many different shapes. Some of the most common non-standard shapes with integral decks being used in the Northwest are shown in Figures 7, 8, and 9.

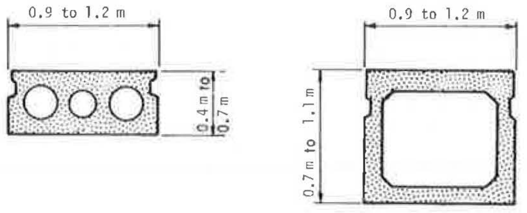
The use of integral decks on prestress tee beams was pioneered by Concrete Technology in Tacoma, Washington in the early 1950's. A few of these structures are now 25 years old and are giving good service. As their general use spread, other prestress plants followed suit and went on to develop other bridge sections such as the double-tees, channels, and rib deck. The double tees and channels are more stable than single tees during handling and placing and consequently are being selected by some contractors.

Figure 6. Prestressed single tee with integral deck being placed. The end and intermediate diaphragms on this 15 m (50 ft.) span are also integral with the beam. The material stacked on top of the beam includes rail posts and rail members.



On the other hand, they require heavier handling equipment. The four-stem rib deck section shown in Figure 7, has been very popular for several years in areas where they have been produced. About a year ago a prestress plant in Yakima, Washington introduced a larger rib deck section with three stems (not shown). It varies in depth from 0.5 m (18 in.) to 0.6 m (24 in.) and in width from 1.2 m (4 ft.) to 1.8 m (6 ft.). Their economic span ranges from 12 m to 18 m (40 to 60 ft.). The efficient rib deck shape requires less material and is lighter to handle than solid or voided slabs. When bid as an alternate it is being selected by contractors in preference to slab units. The survey showed that only a few bridges were being constructed with the box beam section shown in Figure 7. This is as it should be because the box shape is inherently less efficient than the tees and channels.

Figure 7. Miscellaneous prestressed shapes.



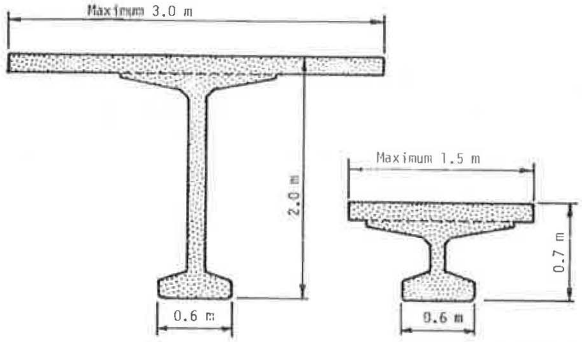
SPAN RANGE 9M TO 20M
VOIDED SLAB

SPAN RANGE UP TO 32M
BOX BEAM

SPAN RANGE UP TO 6M
THIN VOIDED SLAB

SPAN RANGE 10M TO 14M
RIB DECK

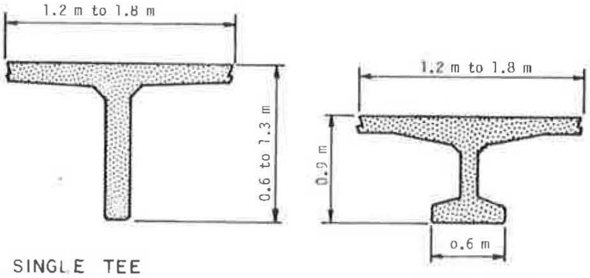
Figure 8. Prestressed single and bulb tee with integral deck.



MAXIMUM SIZE

MINIMUM SIZE

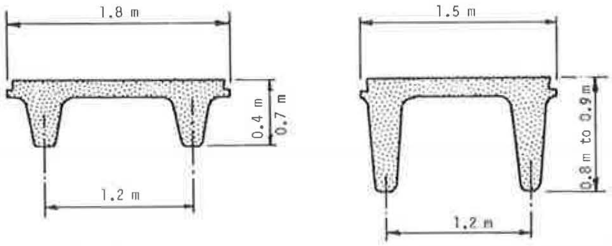
DECK BULB TEE
SPANS FROM 15M TO 55M



SINGLE TEE
ECONOMICAL RANGES
12-18 m & 27-38 m

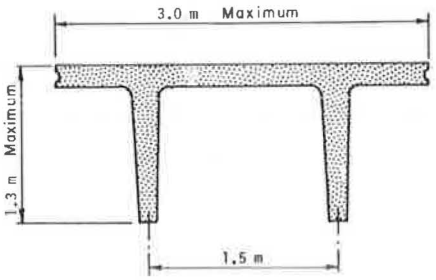
BULB TEE
ECONOMICAL RANGE 18-26 m

Figure 9. Prestressed double tees and channels.

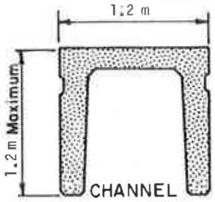


SPAN RANGE 8 m to 18 m

SPAN RANGE 15 m to 24 m



SPAN RANGE 12 m to 24 m



CHANNEL
SPAN RANGE
UP TO 30 m

Some counties are getting maximum economy by using sections without any overtopping or extra wearing surface. When this is done it is important that the beams end up with the same camber. One plant obtains closer camber control by applying partial prestressing initially and then following-up with appropriate post-tensioning a couple of weeks later. Another company has devised a system of jacking beams up or down after erection and then tying them together by welding tie bars to insert plates on adjacent precast diaphragms. Many counties prefer to place a bituminous wearing surface over the deck, and when this is done the matter of unequal camber is not so critical.

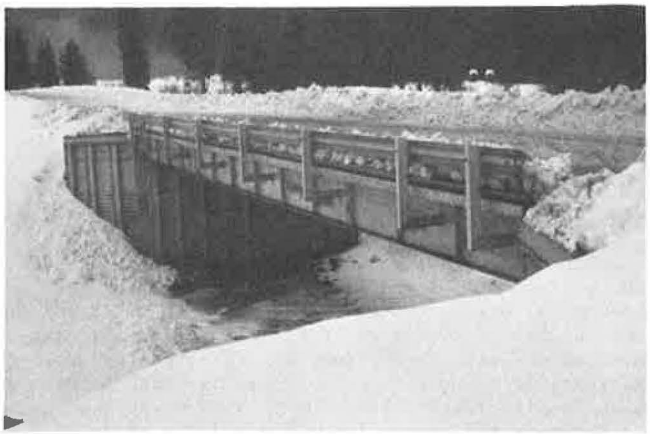
Some other developments in the precast, prestress business include tilting flange forms on tee beams which allows roadway crown to be built into the precast member. Also, some prestress plants are now renting precast slabs and beams to contractors for use on detours and other temporary structures.

Steel

Steel bridges are also being built on low-volume roads; however, relatively few have been constructed in the Northwest in the past few years due to their higher cost. A few counties in the Northwest have been using their own forces to build all-steel bridges - mainly over irrigation canals with spans of 5 to 7 m (16 to 24 ft.). These are supported on wide-flange sills resting on the ground or on steel pile bents. Steel bridge plank is used for the end bulkhead and extended out as necessary to serve as wing walls. The deck consists of steel plank welded or bolted to the wide-flange stringers and overlaid with a bituminous wearing surface.

Until recently several counties in the Northwest were constructing a prefabricated steel "package" consisting of welded beams, decking, wheelguards, railing, and bracing. They came in span lengths of 6 to 24 m (20 to 80 ft.). Over 200 of these were built in the past several years. Average construction time of a single span bridge, including pile driving, was reported to be 12 days. One of these steel structures in Idaho is shown in Figure 10.

Figure 10. Steel "package" bridge with 24 m (80 ft.) span in Latah County, Idaho.

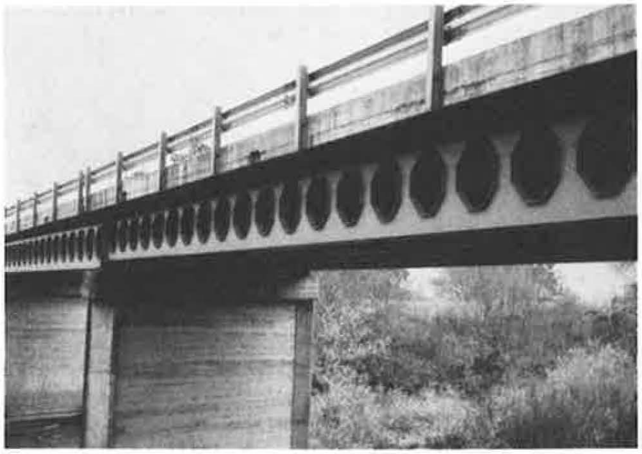


Douglas County in Oregon has had an ambitious and unusual steel bridge replacement program for many years. For their longer girder spans, from 18 to 24 m (60 to 80 ft.), they fabricated castellated beams (Figure 11). Over the years they have built up expertise in welding and steel fabrication within their own bridge crews. They report that economical steel structures are being obtained by careful planning and scheduling of steel fabrication to take advantage of any otherwise slack periods.

Some well-known details of steel construction that result in economies, but are overlooked by some designers and fabricators, include:

1. Keep details as simple as possible.
2. Use automatic welding wherever possible.
3. Place stiffeners on one side only or stagger them, or omit them by using rolled beams or by thickening the webs of welded girders. This suggestion is intended only for moderate span lengths up to 40 m (130 ft.).
4. Use elastomeric bearing pads or, on spans up to about 20 m (65 ft.), use the cheaper milled fiber/rubber bearing pads.
5. Use weathering steel if available, particularly in wet climates, to avoid cost of frequent painting.

Figure 11. Bridge in Douglas County, Oregon with castellated steel beams.



Contracting Methods

Many agencies are using their own forces to build smaller bridges. Since they must have bridge crews to do maintenance work, the crews can be used to advantage on new construction during otherwise slack times. Competitive bidding in these cases is used only for purchase of materials. Substantial savings can be had if bids are taken on carload lots, or on a large number of bridge components at one time. Some counties we surveyed preplan and budget their funds so they can contract for a year's supply of prestressed units at one time. As their designs are finalized, they retain the privilege of revising the number of various lengths and specifying the skew angle, if any, that is desired. This permits the prestress plant to schedule their work more advantageously and therefore bid lower than they would on smaller quantities. As a variation of the above a few counties contract for the furnishing and erection of prestress units and use their own forces for the substructure work and for shear key grouting and rail installation.

When construction is fully contracted the conventional method is to take bids on a single design. This will yield the most economical structure providing the designer has made the best selection. When a number of small bridges are to be constructed in one area, significant savings can be realized by letting several bridges in one contract.

Some agencies take bids on alternate designs from time to time. While this requires more engineering, it helps establish better comparative costs. One county surveyed has on two occasions taken alternate bids on a prestressed beam design versus long-span culverts. In both instances the successful contractor bid low on the culvert. Some other bidders did not see it that way. In any event the bids were close.

Some counties are using the "design and construct" type contract which is sometimes referred to as the "open competitive" contract. This conforms approximately to what industry calls the "turnkey" system and is similar to the European design competition contracts. The county engineer determines the structural and hydraulic requirements and specifies the gradeline, clearance requirements, roadway width and general design criteria. Caution must be used with this type of contracting as it places the burden on the agency engineer to evaluate the bid proposals to determine whether they are in compliance with the plans and specifications and will provide the desired end product. The principal advantage to this open competition contract is that it encourages maximum innovation and economy by the engineer, supplier, and contractor working as a team.

Geometrics

The main geometric consideration for bridges on low-volume roads is the bridge width. The widths reported by questionnaire respondents varied all the way from 6 to 13 m (20 to 44 ft.) for two-lane bridges. The 6 m (20 ft.) width is not considered satisfactory except when it is located on a road serving only a few families and there is little prospect of the traffic increasing in the future. In farming areas the width may have to be a minimum of 7 m (24 ft.) to accommodate farm machines. The upper limit of 13 m (44 ft.) width would include full shoulders and obviously would not be on a low-volume road. The most common widths reported on new construction were 8 to 10 m (26 to 32 ft.). A few counties reported they were building 4 to 5 m (12 to 16 ft.) single-lane bridges on extremely low-volume roads.

It is desirable to leave the bridge width flexible until the design stage is reached. Often it is possible to add some width at little extra cost. For example, if an 8 m (26 ft.) minimum width is desired and this width would require 5 beams for a particular span length, it may be that 5 beams would also be adequate for a 9 m (30 ft.) width. If so, the extra width could be obtained for relatively little cost. On the other hand, if the wider roadway required an extra beam, the additional cost would be substantial. Several comparative cost studies have been made of various bridge widths. In general the extra width can be obtained for much less cost per square foot than the overall bridge cost, since many bridge costs including overhead, mobilization, and railing, remain the same regardless of width.

Most counties follow state standards which are similar to those in AASHTO publication "Geometric Design Guide for Local Roads and Streets." Our office made a study of bridge widths and came-up with suggestions for new construction. These are shown in Table 1.

Table 1. Suggested bridge width guide.

	Traffic Volume (Current ADT)			
Speed km/h	Over 750	250 to 750	50 to 250	Under 50
>80	12	11	10	9
50 to 80	11	10	9	8
<50	10	9	8	7

Miscellaneous

1. Curbs are expensive and most often unnecessary. The decks on bridges with open rails keep cleaner of snow and debris when no curbs are used.
2. Railings on low-volume bridges may logically be less substantial than those on high-volume roads. Most of the counties responding to the questionnaire were using steel beam rails with posts spaced at 1.9 m (6 ft. 3 in.) centers. Other rails included timber, steel tubes with posts spaced at 2.4 to 3.7 m (8 to 12 ft.) and a few were using the "New Jersey" safety rail. The concrete safety rail with its heavweight (dead load) is hardly necessary or suitable for low cost bridges on low-volume roads. While many of the rails being used were substandard by AASHTO criteria, they may well be satisfactory for low-volume roads depending on traffic volume, highway alignment and bridge widths.
3. Simple details and realistic specifications that can be met using economical and preferably local materials should be used. As an example, elastomeric neoprene bearing pads or the cheaper milled fiber/rubber pads can be used in lieu of more expensive metal assemblies.
4. Several studies have been made over the years to establish the extra cost to design for HS20 instead of HS15. The difference in cost is nominal, varying from 2% or less for most bridges up to a maximum of about 4%. With this small difference it is advisable to use HS20 for all except the very low-volume roads.
5. Foundation designs should be conservative particularly for bridges crossing bad streams. A little extra expense on the foundation may save the structure when the next flood comes.
6. Concrete piles should be cast with a "jet" hole in the center in case jetting is required to drive them.
7. For the larger structures, the possibility of using drilled shafts in lieu of the more conventional substructure with pile or spread footings should be investigated.

Conclusions and Recommendations

With today's rising prices and declining revenues, the engineer has a challenge to arrive at the most economical bridge system. It appears that, regardless of material used or bridge type selected, maximum economy will be obtained by prefabricating as many bridge components as possible in order to reduce on-site labor costs.

The principal economies suggested are intended to be within acceptable geometric, design, and safety standards. It was considered inappropriate to suggest building in structures as weak links on low-volume roads and thereby furthering substandard design on a system that is in need of substantial upgrading.

Some specific recommendations to keep in mind when planning and designing structures on low-volume roads include the following:

1. Develop a long-range structure replacement program based on findings of a continuing bridge inspection program.
2. Make adequate preliminary studies.
3. Preferably have a bridge engineer on your staff; otherwise seek the services of a consultant or another qualified engineer.
4. Evaluate contract procedures and use one that gives you the best opportunity to save money.
5. Ensure that specifications and special provisions are complete to avoid costly construction claims.
6. Consider replacing bridges with culverts when conditions are right, and particularly when commonly used sizes will handle the runoff.
7. Use spill-through abutments as they generally will be most economical.
8. Use bridge types requiring minimum on-site labor.
9. For bridge lengths of 25 m (85 ft.) or under, consider the use of single spans. They present the minimum obstruction to the waterway and may also be most economical.
10. For long structures over flood plains, consider using span lengths of 15 to 30 m (50 to 100 ft.) as they often will be more economical than shorter spans depending upon bridge height and type of intermediate bents or piers.

Considering the current price situation in the Northwest the most economical bridge type on low-volume roads is precast, prestressed concrete with integrally cast decks. Average cost of these structures in the Northwest (Alaska excluded) ranges from $22 to $28 per square foot. Most counties that construct bridges by both in-house personnel and contract report that they get lower prices using the in-house method since the bridge crew can work on new construction when they are not otherwise occupied with maintenance work. On the other hand, several counties that previously used their own forces on new construction now report that all such work is done by contract.

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