Bridge Construction Details

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THERE is a wide variation in the complexity of bridge construction details that satisfactorily perform identical functions. These details have a profound effect on the cost of short span bridges and should be afforded more attention than is usually given to them.

One study has shown a range in cost from \$0.22/lb to \$0.16/lb for the same structure with different framing and details. This has more significance than the 38 percent spread in these prices. Assuming the material cost to be \$0.08/lb and deducting this cost from the total, the amount required for fabrication and erection (the remaining portion of the cost) is \$0.08/lb for one and \$0.14/lb for the other. This is a 75 percent variation in the cost of fabrication and erection due to differences in the design of the framing and details.

To achieve the minimum cost, bridge details should be examined in the light of their intended functions. The least sophisticated device that will satisfy the need will generally be the least costly. For all details used in the construction of bridges, the AASHO and AREA specifications provide a latitude of choice, with restrictions imposed by individual states or railroads due to geographical differences and special preferences. However, it is not uncommon to disregard this latitude of choice and select standard details, instead of applying objective consideration to the specific need for the detail. This can be costly.

AISC has studied a large number of details contained in the standards submitted by 32 state highway departments. A selection was made of typical details which appeared to have the greatest potential for economy. Cost estimates for these details were prepared by several fabricators, and cost comparisons were made. One result of the study was to emphasize the wide variation in the cost of details required to perform the same function under the same or similar conditions. This variation exceeded 450 percent in some cases.

The authors believe that careful attention to the design of bridge details, based on objective analysis rather than precedent, can significantly reduce the cost of steel bridges. The suggestions in this paper are based on observations and experience, and on the results of the AISC cost study described above. When details are compared, they are identified in the order of economy, with Detail 1 indicating the lowest cost in each group. Specific costs and relative cost factors are not given because they vary extensively in different regions.

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EXPANSION DETAILS

Expansion bearings, rocker bearings, sliding bearings, elastomeric bearing pads, and expansion joints are provided in most bridge structures to accommodate changes in length. Temperature variation is usually isolated as the major cause of these changes. The abutments and piers are considered to be fixed in position, and bearings are provided which allow the superstructure to expand and contract over these supports in conjunction with the roadway expansion devices.

Fixed Bearings—Light, Intermediate—Figure 1 shows four typical fixed bridge bearings for light to intermediate reactions. The elastomeric or neoprene bearing pad, shown as Detail 1, is the least expensive of the four. Detail 4 is approximately four times as expensive as Detail 1. The costs for Details 2 and 3 are about equal, a little more than double the cost of the neoprene pad.

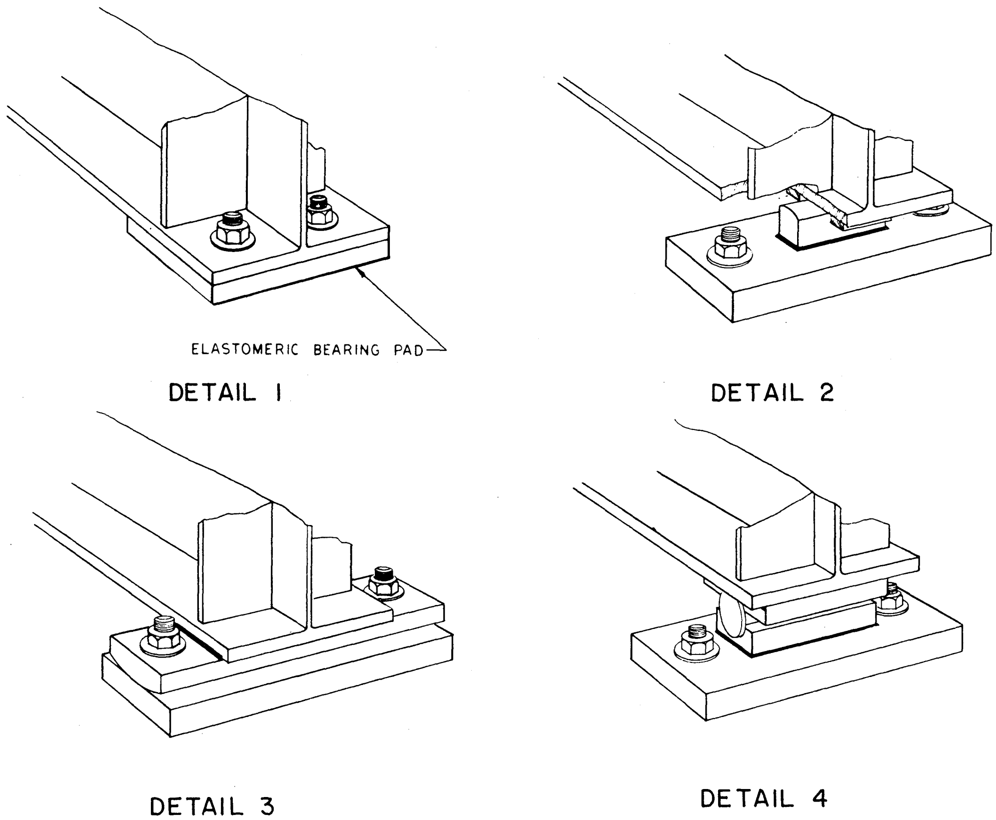

Fig. 1. Fixed bearings—light and intermediate

Fixed Bearings—Heavy—Five typical fixed bearings used frequently for heavy reactions are shown in Fig. 2 and numbered in the order of economy. As might be expected, the simplest (Detail 1) costs the least. This device is as effective in performing its intended function as any of the more expensive details and, in fact, the more refined designs will require additional maintenance.

In Detail 2, the web plate is fitted into a machined recess in the sole plate under the girder. The flat sole plate in Detail 1 (key not shown) serves the same purpose at less expense.

When machined surfaces are required, the designer should avoid calling for unnecessary machining operations. For example, engineers often require that machine tool marks be parallel to the direction of movement. This requirement for the sliding contact surfaces in Details 2, 3 and 5 in Fig. 2 would increase the cost with very little benefit. In the case of Details 1 and 4, this requirement would not improve the performance of the rolling surfaces at all.

The most expensive type (Detail 5) would certainly not be needed in most cases, as the vast majority of structures do not require tie-down bearings. It is used much more extensively than it should be in spite of the fact that it costs approximately 3½ times as much as the simpler but usually adequate Detail 1.

Expansion Bearings—Light, Intermediate—Figure 3 shows expansion bearings for light and intermediate duty. The simplest device does not depend upon sliding between the component parts, requires the least maintenance, and has by far the lowest cost. This is the elastomeric pad, Detail 1. Detail 3 has two variations: one uses a self-lubricating bronze plate and the other, which is now being called for more frequently, uses a steel plate with bonded Teflon surfaces.*

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* *Teflon is the du Pont trade name for the fluorocarbon resin tetrafluoroethylene (TFE). A booklet entitled "Bearing Pads of Teflon" is available on request from E. I. du Pont de Nemours, Wilmington, Del. This publication lists 25 bridges in 13 states that have used Teflon bearings.*

Combination Teflon-neoprene bearing pads, similar to the elastomeric pad in Detail 1 of Fig. 3, have been suggested. The Teflon would provide low friction sliding surfaces and the neoprene would accommodate the girder's end rotation and insure against high localized bearing pressures between the Teflon surfaces.

Of interest on this subject of Teflon bearings is a paper presented at the 1966 AASHO Meeting in Wichita, Kans., by V. W. Smith, Jr., Assistant State Maintenance Engineer for the Georgia State Highway Department, entitled "Teflon Bridge Bearings." This was printed by the Georgia Highway Department Engineers' Association in Bulletin No. 18—Spring, 1967.

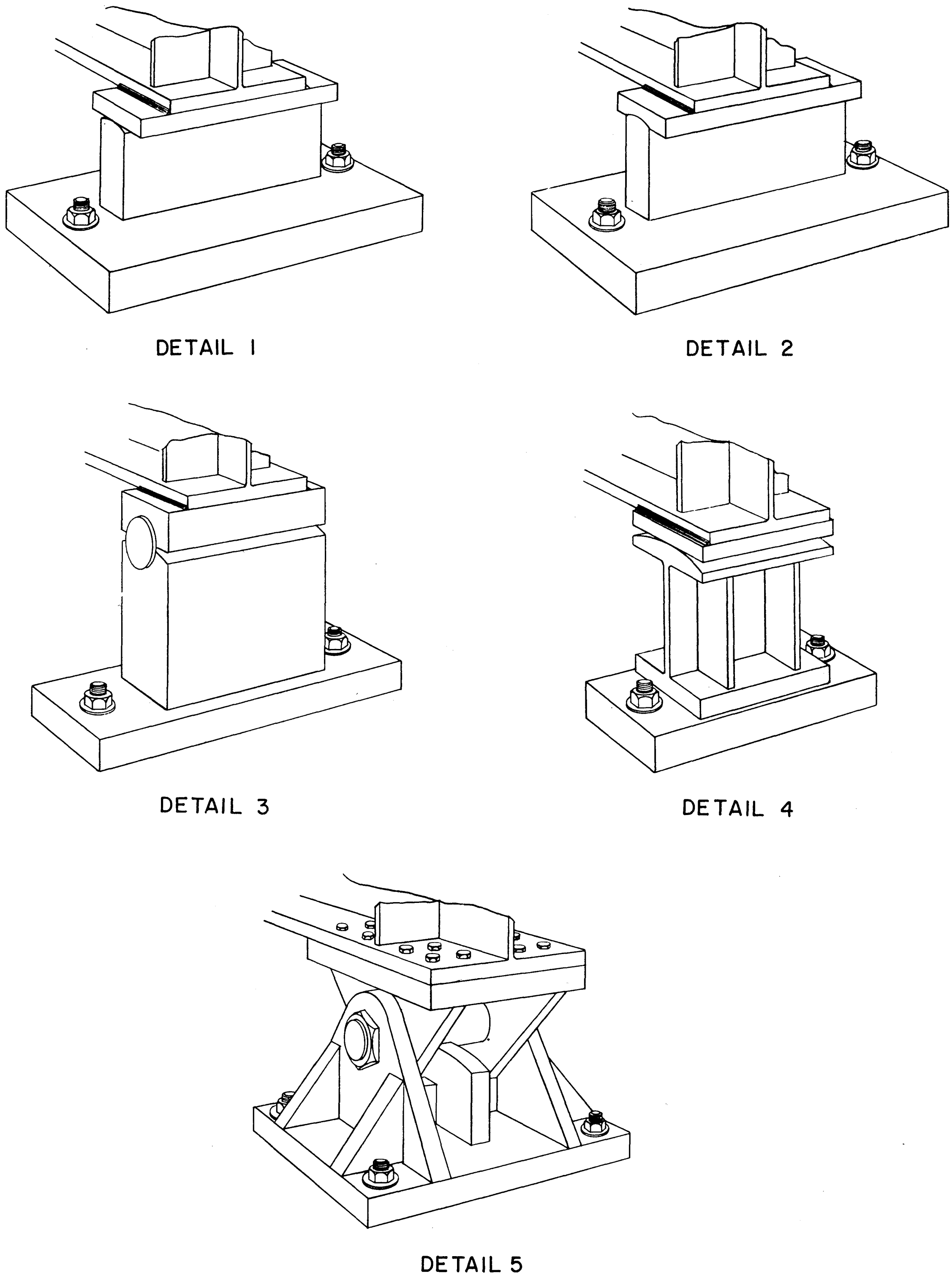


Fig. 2. Fixed bearings—heavy

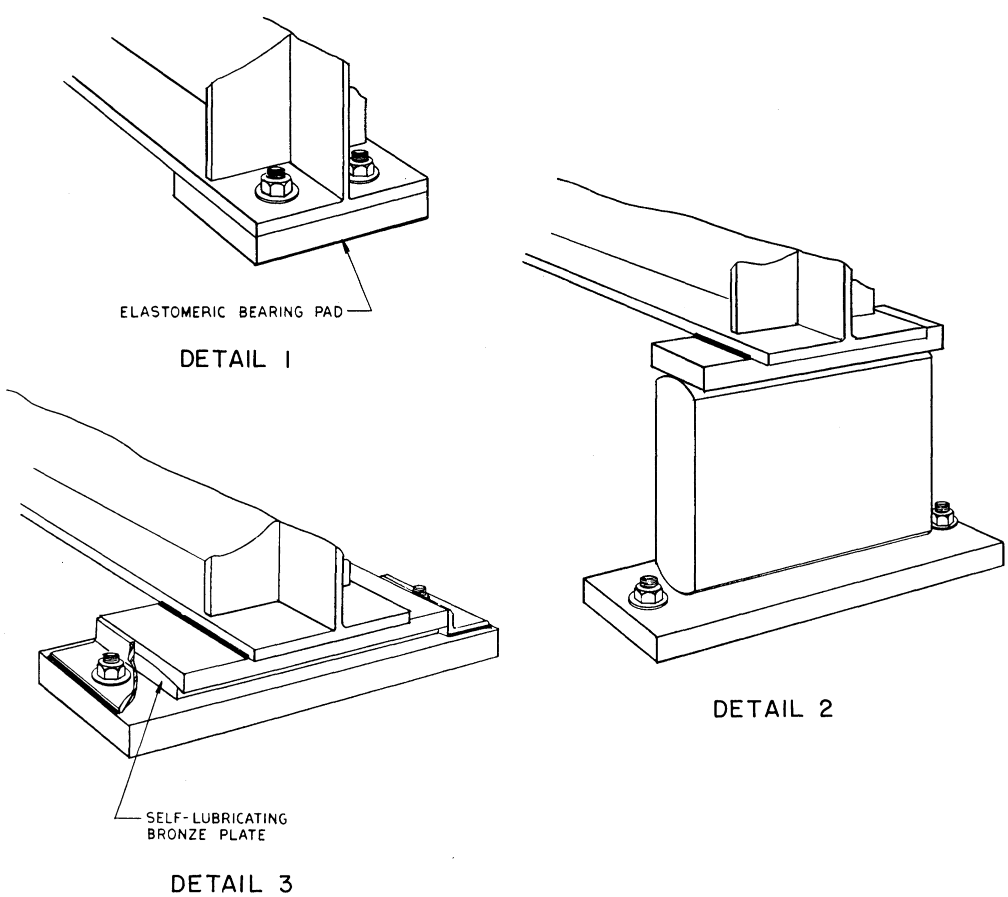


Fig. 3. Expansion bearings—light and intermediate

Expansion Bearings—Heavy—A group of typical standard expansion bearings for heavy reactions is shown in Fig. 4. The relative ranking, by cost, is in the order shown, but there is very little cost difference between Details 1 and 2. The lowest relative cost, again, is provided by the simplest devices. Detail 1 has the advantage of providing for the expansion displacement by rolling between the two surfaces instead of sliding; therefore, there will be less maintenance required.

As noted in the discussion of heavy fixed bearings, the designer should avoid stipulating machining requirements that increase costs but have little or no effect on the performance of the device. For example, requiring machine tool marks to be parallel to the direction of movement is not warranted for any of the bearings illustrated in Fig. 4.

Elastomeric Bearing Pads—Although elastomeric bearing pads are by far the lowest in cost of any of the bearing details in the AISC study, they are not yet being used to the extent that AASHO specifications permit and economy justifies. One reason for this phenomenon seems to be a lack of confidence in their quality and performance on the part of the individuals who have had no experience with elastomeric bearings.

Actually, those who have studied the performance of elastomeric bearing pads in service have reported good performance whenever proper material was supplied.*

* *This was a conclusion in the report on a nationwide survey, "Problems of Bridge Supporting and Expansion Devices and an Experimental Comparison of the Dynamic Behavior of Rigid and Elastomeric Bearings." by J. H. Emanuel, Assistant Professor of Civil Engineering, and C. E. Ekberg, Jr., Professor and Head, Department of Civil Engineering, Iowa State University, Ames, Iowa.*

This conclusion is confirmed by R. L. Pare in an article entitled "Neoprene Elastomer Bearings—Ten Years Experience" in Civil Engineering, November, 1967, which states in part:

"Although there have been a number of reported failures of elastomer bearings, there has been no reported failure in which the material supplied did in fact meet AASHO specifications. It is almost impossible to overestimate the importance of testing for conformance to specification. . . . In summary, neoprene bearings have performed extremely well over the past ten years, and all installations built during this period appear to be continuing their load-carrying function with little or no deterioration. Elastomer bearings can be designed for any degree of vertical or horizontal restraint desired. The flexibility of design and material is unique in the opportunity afforded the designer in controlling the load distribution to the substructure."

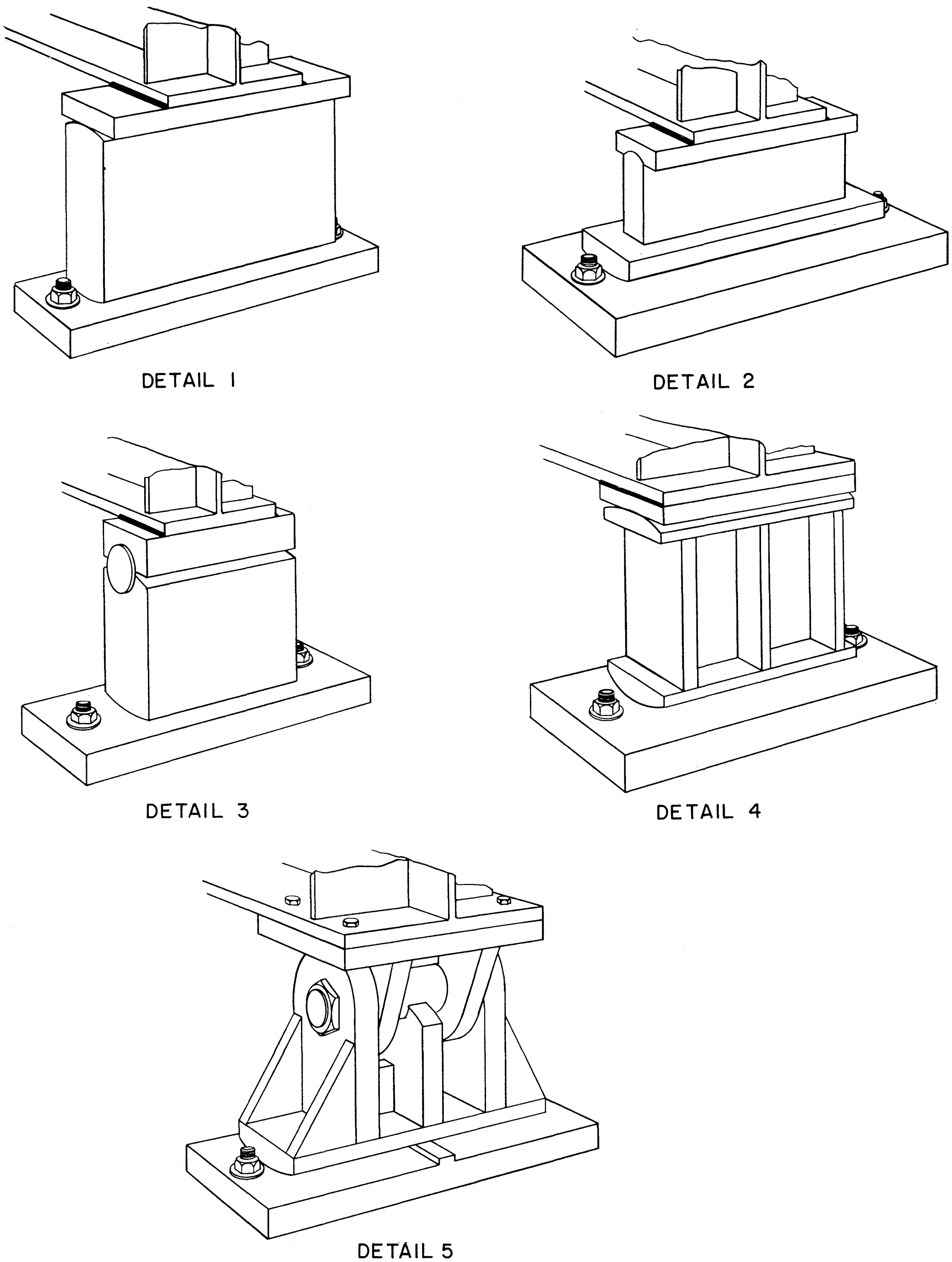


Fig. 4. Expansion bearings—heavy

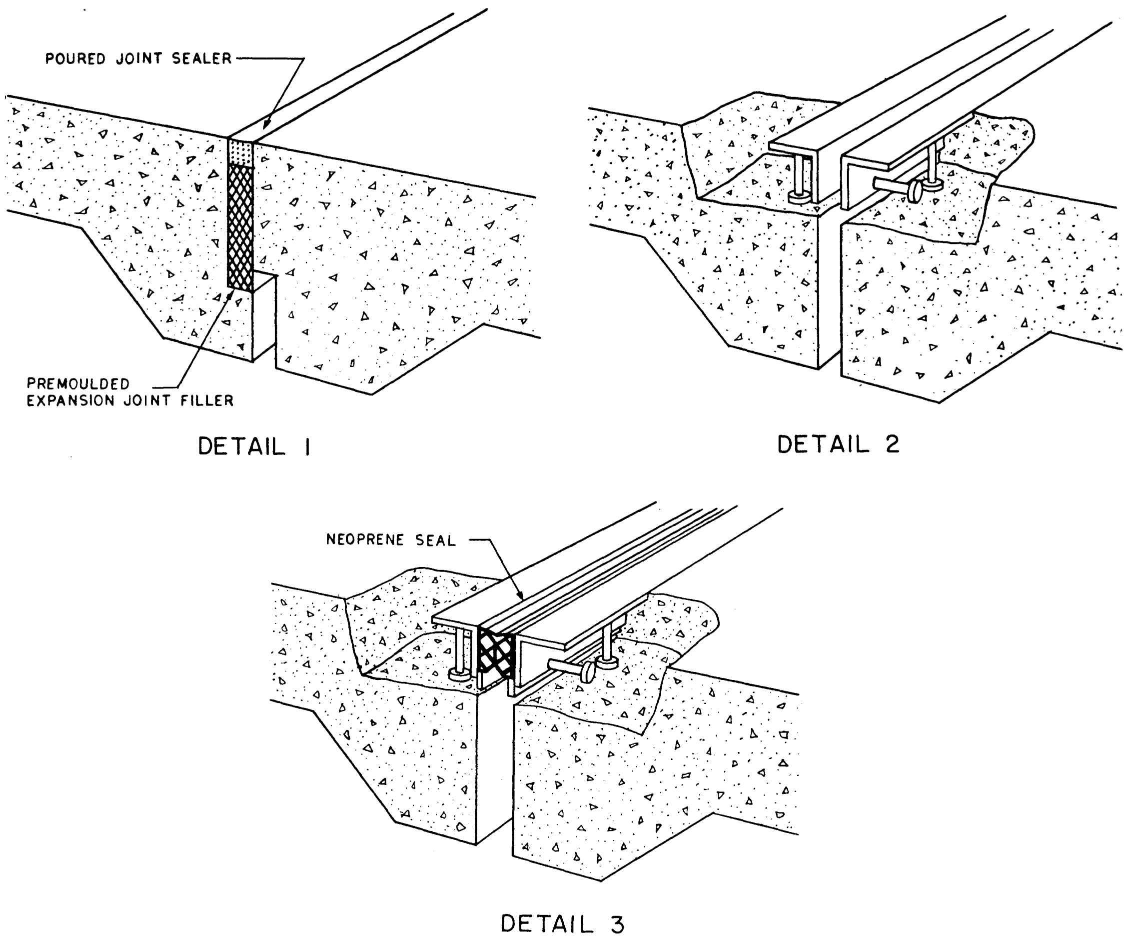


Fig. 5. Simple roadway expansion joints

The authors strongly recommend increased use of elastomeric bearings in steel bridge construction, where suitable. This recommendation is based on the significant savings that can be realized with these devices, and on their proven performance.

Simple Expansion Joints—The second half of the team that provides for a bridge superstructure's movement is the roadway expansion device. Open expansion joints are certainly the simplest and least costly and should be used wherever possible. However, watertight joints are generally desirable or even essential, although watertightness of joints is difficult to achieve and is expensive. A wide range of costs is observed when roadway joint details are compared.

The AISC cost study of roadway expansion joints, as would be expected, showed the lowest relative cost to be that for Detail 1 in Fig. 5. This device is unarmored and makes use of a premolded filler, topped with a poured-in-place sealer. There are applications where this detail is adequate and there is no reason for not using it when armored edges are not required.

The armored joint is, of course, the most durable and should be used wherever traffic is too heavy for the less expensive unarmored joint. Details 2 and 3 in Fig. 5 are typical armored joints; Detail 2 is open and Detail 3 is sealed. The cost spread between the unarmored sealed joint and the armored joint using a preformed compression seal is in the order of 700 percent. Of course, these expansion devices are not designed to meet the same conditions.

Sliding Plate Expansion Joints—Costing approximately twice as much as simple armored sealed joints (Detail 3 in Fig. 5) is the family of sliding plate joints shown in Fig. 6. These joints do not provide watertight seals. They require maintenance to clear out trapped foreign material and to repair damage resulting from impact. The spread in cost between Details 1 and 3 is approximately 20 percent.

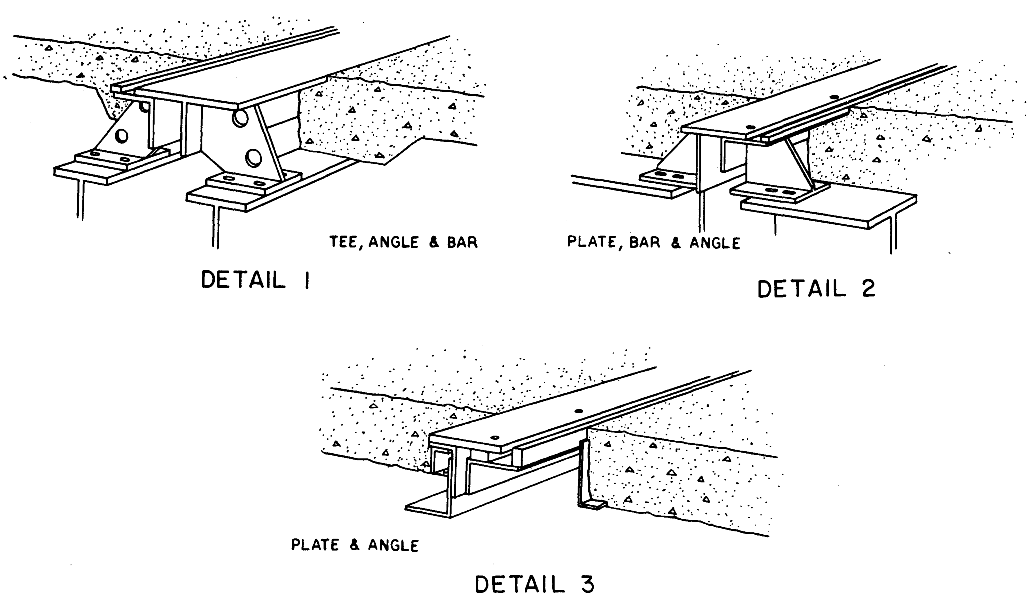


Fig. 6. Sliding roadway expansion joints

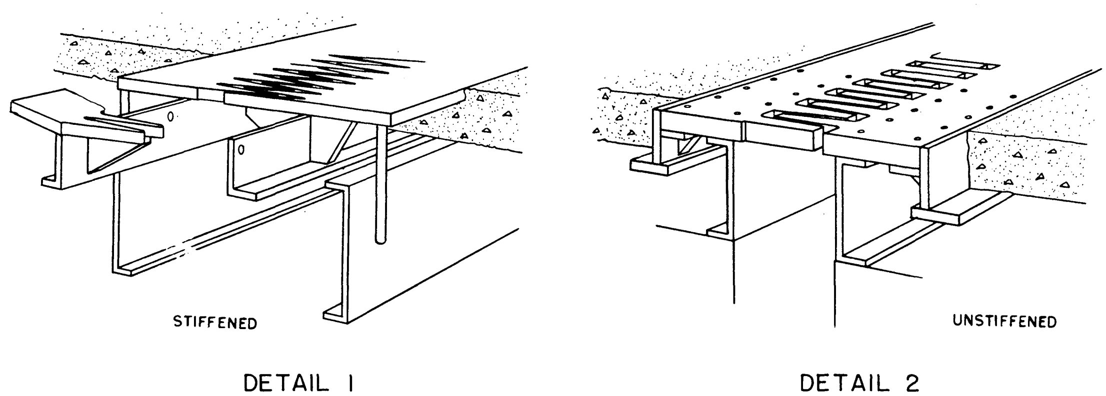


Fig. 7. Finger plate expansion joints

Finger Expansion Joints—Finger joints are by far the most expensive roadway expansion devices in common use. Their cost is 5 to 6 times that of the simple sliding plate joints in Fig. 6 and 10 to 12 times as expensive as the simple sealed joint in Fig. 5. They should be used only where large movements must be accommodated.

Figure 7 shows two typical finger type expansion joints. Detail 1 is a stiffened type and Detail 2 is unstiffened. There is not a wide spread in cost between these details. The smaller number of pieces and generally simpler layout of Detail 2 might seem to be more economical despite the heavier material required. Note, however, that countersunk bolts are required through the top plates, resulting in more expensive fabrication. For Detail 2, welding would be even more expensive than bolting. This is because the minimum size welds required for the 2-in. thick finger plates would be ½-in. multiple-pass fillet welds. The thinner plates of Detail 1, on the other hand, can be welded with relatively small single-pass welds.

When a finger joint *is* required, careful attention should be given to the design details. For example, it may not be obvious that flame cutting a single plate to fabricate the two parts of a finger joint may, if the cut is not in the center of the plate, result in fingers that do not mesh. The reason for this is that one side may be upset more than the other from the cutting heat. When steel is heated, as in flame cutting, the heated region tries to expand in length, but is restrained by the surrounding cold metal, so that upsetting takes place. That is, the heated steel, since it cannot increase in length, accommodates to the elevated temperature by increasing in thickness. Upon cooling, the steel shrinks to less than its original length. If the cut is not made along the center of the plate, the amount of upset will be unequal on each side of the cut, and the amount of shrinkage will be greater in the narrower piece because expansion is restricted by the fingers. In a long joint, this difference in length would cause the fingers not to mesh, resulting in the need for costly adjustments.

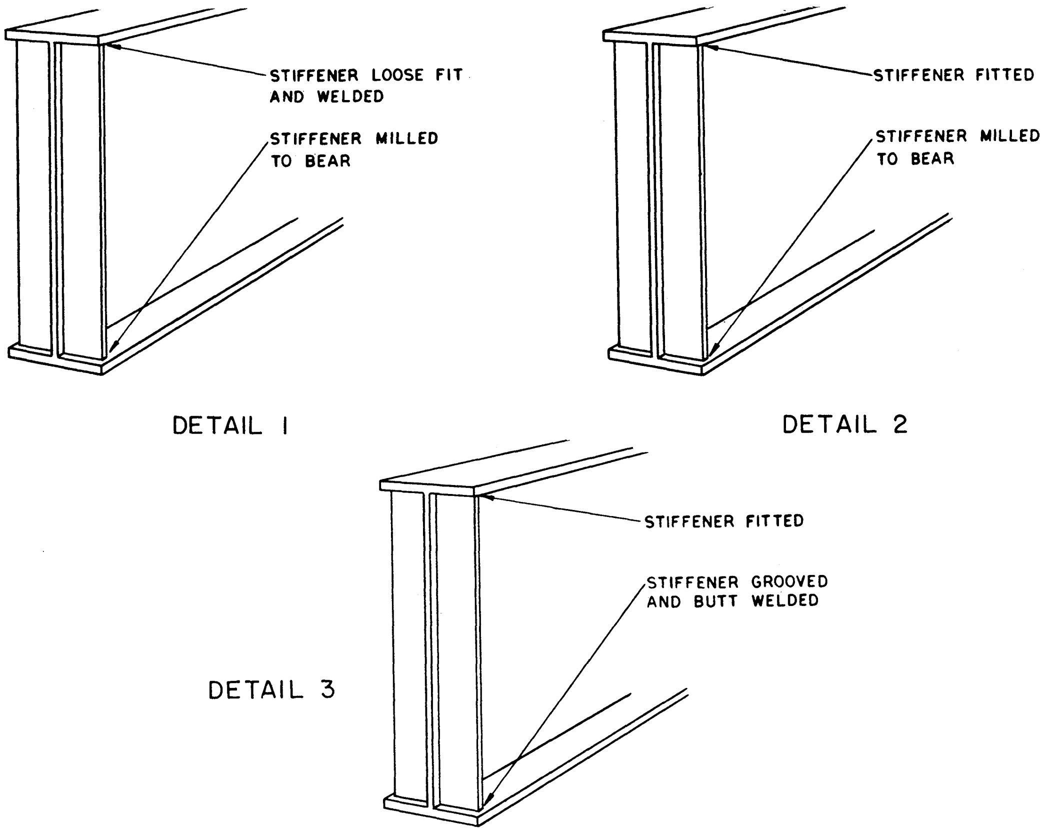


Fig. 8. End bearing stiffeners

Need for Expansion Devices—Before leaving the topics of bearings and roadway expansion devices, the question of whether such devices are necessary or even desirable for short span structures should be asked. Large numbers of short span bridges have been in service for many years without expansion devices, or with devices that were frozen or jammed by crowding of the abutments. Most of these structures have continued to perform their intended function without difficulty. Several of the northernmost states have noted this fact, and have begun to build bridges to increasing lengths using flexible abutments with the beams or girders rigidly connected to the abutments. The State Bridge Engineer of North Dakota has reported that approximately 150 bridges, both steel and concrete, have been built up to 300 ft in length without expansion devices, and have been functioning in a manner superior to structures with such devices. Maintenance costs have been reduced and the expense of rockers and roadway devices has been virtually eliminated from the initial costs of the bridges. Other examples, using similar schemes (one 500 ft in length) have been reported. A bridge for U. S. Highway 50 over the Floyd River in Kansas has been in service since 1934 without expansion devices. In the face of such evidence, it must be concluded that the criteria for accommodating expansion and contraction have been excessive for the majority of short span bridges.

STIFFENERS

End Bearing Stiffeners—Requirements that end bearing stiffeners be both fitted and welded to the flanges of the girder are redundant and costly. If the stiffener is to be welded, it is not necessary to fit it to the flange. The gap that would otherwise exist provides a natural detail for a partial or full penetration weld. AASHO requires that stiffeners be *either* fitted *or* penetration welded, not both. Detail 1 in Fig. 8, with the stiffener fitted at the top flange and milled to bear at the bottom, was found to be the lowest in cost of the three bearing stiffener details shown.

Intermediate Vertical Stiffeners—The use of vertical stiffeners on one side of the girder web only (or staggered on opposite sides) will result in much lower costs than smaller stiffeners back-to-back on opposite sides. There will be less material and, more important, there will be only half the amount of welding. Detail 1 in Fig. 9, using stiffeners on one side of the plate girder cut back at the tension flange and welded to the compression flange, has the least relative cost. A further refinement to this detail might be to eliminate the welding to the top compression flange where this flange is inhibited from any twisting movement by a composite deck. This would improve the fatigue performance also.

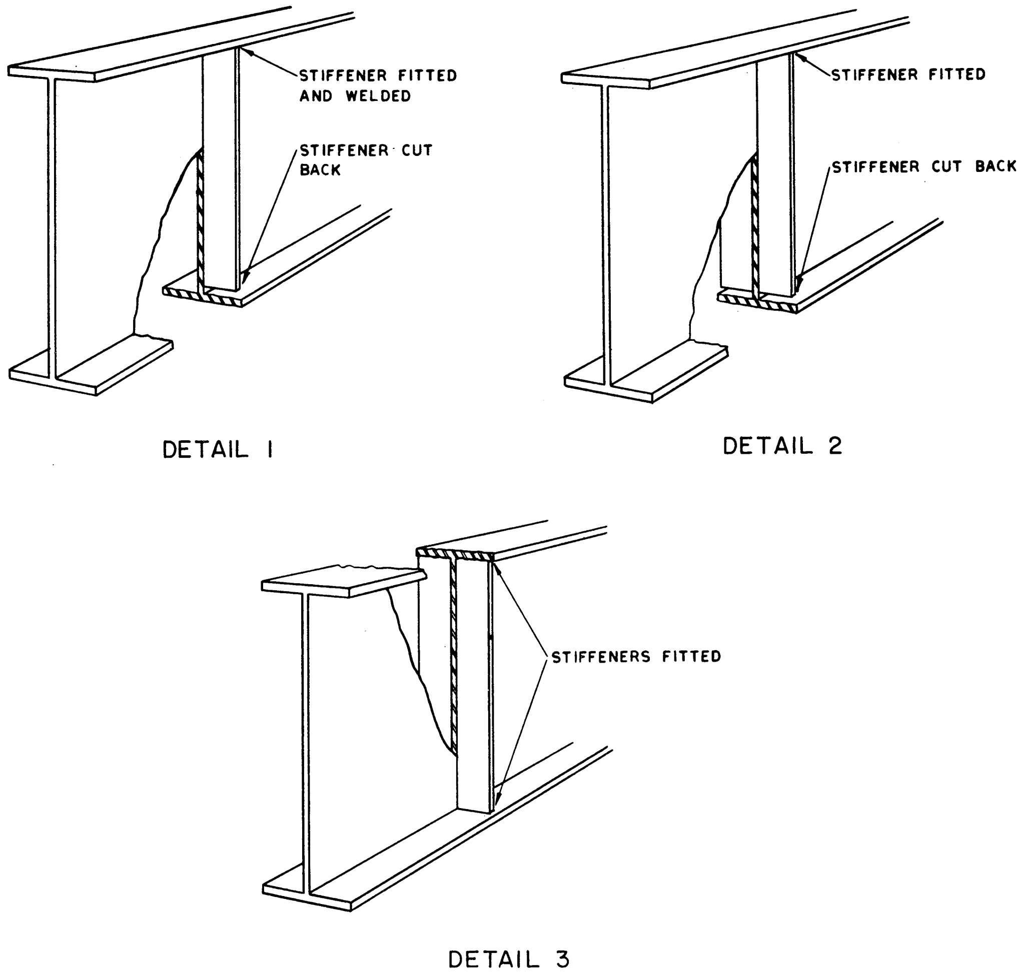


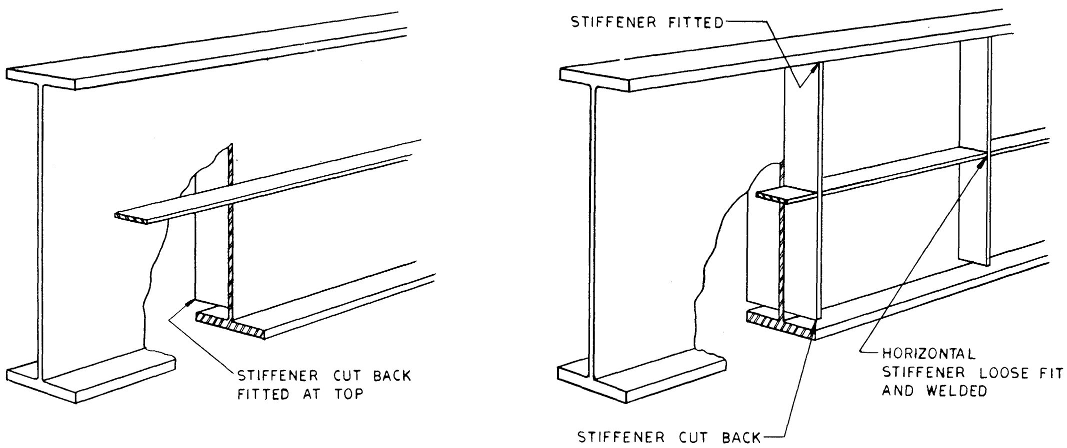
Fig. 9. Intermediate stiffeners

Cutting the stiffener short of the tension flange provides a twofold benefit. First, fabrication costs are reduced, since it is much easier to fit to one flange only than to fit between two flanges. Second, the service is improved, since a narrow crack which must be sealed by paint to prevent capillary attraction from pulling water into the joint is avoided. With the stiffener cut back, there will be no capillary attraction and plenty of room for maintenance cleaning and painting.

Avoid bolting stiffeners to the girder web unless dictated by special conditions. The largest part of fabrication cost is material handling. Therefore, a good rule to follow wherever possible, is to put the holes in the detail material and not the main material. It is more economical to carry small stiffeners to punches or drills and then weld them to the webs of girders than to carry the whole girder to the machinery.

Design intermediate stiffeners so that they also serve as diaphragm connections. Coordinating the stiffener locations with the required diaphragm spacing so that the stiffeners can perform this dual function will lead to significant cost savings.

Longitudinal Stiffeners—A longitudinal stiffener on the fascia girder of a bridge may improve its aesthetics. It carries the view horizontally, minimizing minor out-of-plane variations of the web plate. The structural value of longitudinal stiffeners is questionable; however, except for limiting web-buckling movements (oil-canning) beyond the working stress range. The ultimate strength of the plate girder web is not improved with these stiffeners except as they may be considered to increase the compression area when located on the compression side of the neutral axis. Interrupting longitudinal stiffeners with transverse stiffeners is very expensive. The relative cost of Detail 2 in Fig. 10 is approximately 50 percent higher than Detail 1 and not one bit more effective.



DETAIL 1

DETAIL 2

Fig. 10. Longitudinal stiffeners

DIAPHRAGMS

Except for curved girder bridges, where they resist torsion, intermediate diaphragms provide lateral stability and alignment during erection and end diaphragms serve as supports for the end of the concrete floor slab and transmit all lateral forces to the bearings. Some credit is usually allowed for lateral distribution of live load when the beams are closely spaced or when full depth cross frame diaphragms are designed. However, a recent study by Prof. C. R. Bramer of North Carolina State University at Raleigh* seems to indicate that diaphragms contribute only negligibly to the lateral distribution of load. On the basis of information available to date, it must be concluded that the only real function of diaphragms is to provide stability and alignment during erection.

* *Professor Bramer tested a full scale, simple span, two-lane bridge with an overall length of 60 ft and a span of 59 ft-4 in., having five 24WF100 stringers 6 ft-6 in. o.c. The bridge, with a non composite slab, was designed for an H-10 loading at working-stress or an H-15 loading at 150 percent of working stress—a stress level well below the yield point of A36 steel. A 50 percent increase in allowable stress was used to provide a more flexible bridge. Four diaphragms, 9[13.4, 10WF25, 14WF34 and 16WF61, each with moment resistant end connections, were provided so that the diaphragms would make their maximum contribution to lateral load distribution. The diaphragms were not welded in place (to permit changing of sizes and locations). Instead, the diaphragms were connected to the stringers by means of welded end plates and $^{7}/_{8}$-in. dia. high strength bolts. In the first series of observations, an unbonded 4-in. bridge slab was cast on the stringers. This was later replaced, for a second series of observations, by a $5^{1}/_{2}$-in. reinforced slab made composite with the stringers by using $^{3}/_{4}$-in. dia. 4-in. shear studs. The structure was loaded with different patterns and magnitudes of concentrated load for the various diaphragm sizes and locations and also without the diaphragms or slab. The results of this study are expected to be published soon.*

Figure 11 shows five end diaphragms that are in common use. The one with the least cost is the poured concrete diaphragm (Detail 1). This can be formed and poured with the slab. In ascending order of cost are the cross-frame comprised of loose angles that are welded in the field (Detail 2), the field-bolted bent plate (Detail 3), the field-welded channel (Detail 4), and finally the WF beam (Detail 5).

The relative cost values for intermediate diaphragms, Fig. 12, show that the field-welded individual angles (Detail 1) are the least expensive, followed by the field-welded channel (Detail 2), the field-bolted bent plate (Detail 3), and finally, the field-bolted plate and angle diaphragm (Detail 4).

Diaphragms can be arranged to perform dual functions, with additional opportunities for economy. If the diaphragm is designed as a beam and moved up flush with the tops of the girders, the concrete slab may be designed as a two-way reinforced slab, providing increased slab stiffness or permitting a reduction in slab thickness, or wider stringer spacing and, consequently, fewer stringers.

When diaphragms frame into a girder web, the diaphragm connection should be welded to the web. As noted previously in the discussion of intermediate vertical stiffeners, stiffeners should be utilized as diaphragm connections whenever possible.

Although not shown in Fig. 12, one rather expensive detail uses diaphragms bolted through the web on opposite sides of the girder. This detail would require punching or drilling of the main material (always costly), and during erection the diaphragms would need to be suspended on both sides of the girder while bolts were placed through the diaphragm angles and the web. This error increases both shop and erection costs.

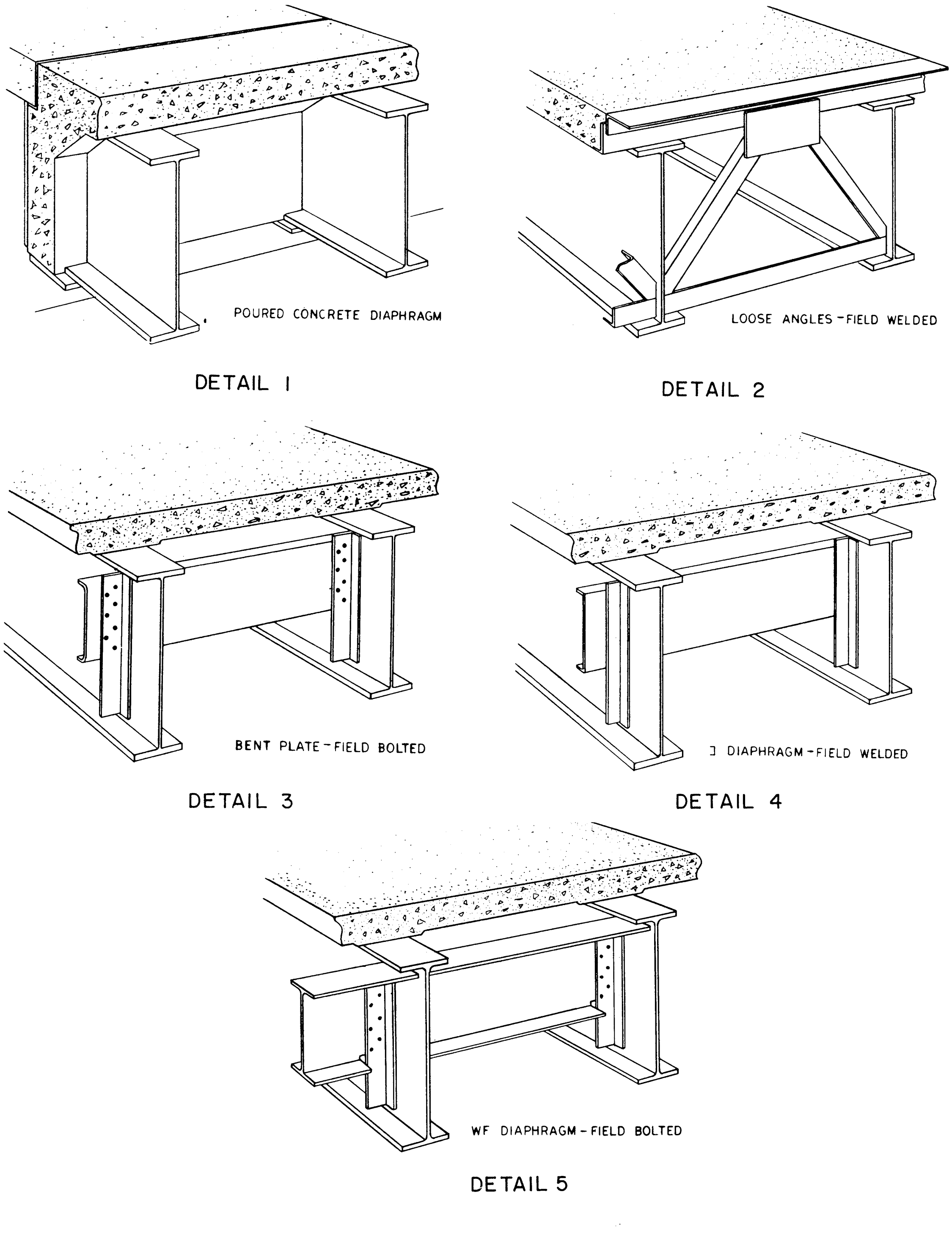


Fig. 11. End cross frames

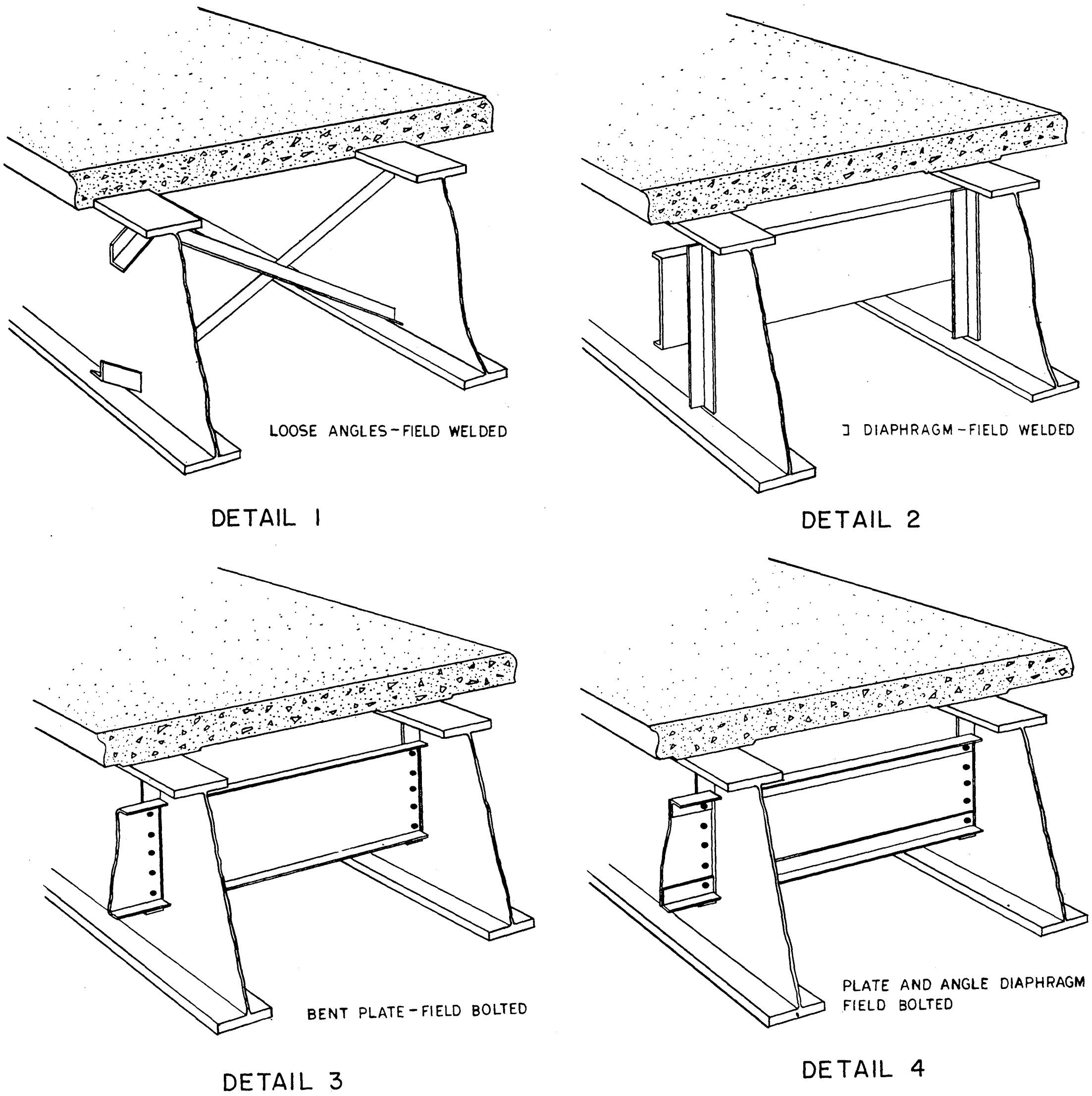


Fig. 12. Interior cross frames

SPLICES

It is illogical to design a full moment and shear splice in a girder and then restrict its location to the area of dead load and uniform live load inflection. If the fabricator is given a wider latitude of choice for locating the splice, economies will be reflected in the bid price.

Field welding today warrants the full confidence of the designer. Welded splices are safe and economical. Figure 13 illustrates a typical welded splice in a plate girder. The girder sections were aligned and held in place for welding by angles that were bolted to the webs. Their positions are indicated by the unpainted rectangular areas adjacent to the weld. The angles on the cantilevered members were turned to make seats for the angles of the suspended member. This provided a direct bearing support for easy longitudinal adjustment. The angles were removed after the welding was partially completed and reused for other girder splices. Bolt holes in the web were then plug welded and ground flush.

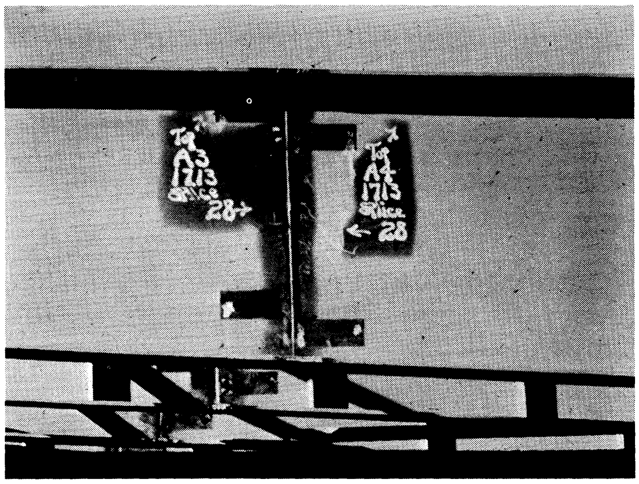


Fig. 13. Welded splice

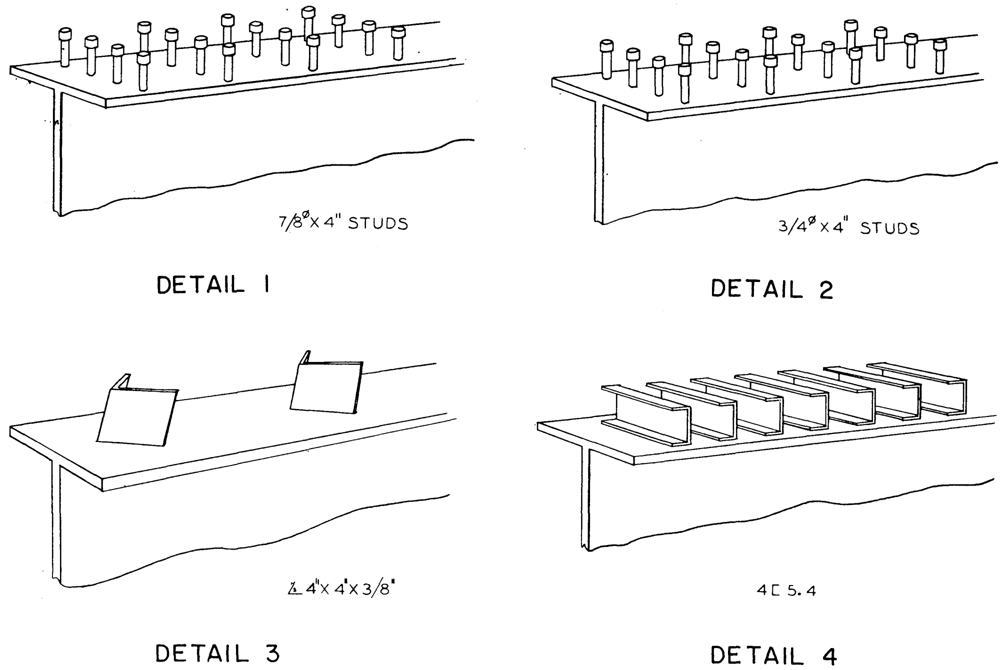


Fig. 14. Shear connectors

SHEAR CONNECTORS

Current studies on composite shear connectors conclude that they should be equally spaced and not spaced in conformance with the static shear diagram as is now the practice. This is because in resisting the horizontal shear due to the moving live load they are all subjected to the same fatigue range of stress. The detail utilizing $\frac{7}{8}$-in. dia. x 4-in. studs (Detail 1) in Fig. 14 is the least expensive of the four details shown. The detail with more closely spaced $\frac{3}{4}$-in. studs (Detail 2) is the next most economical. Uniform spacing of studs will, in the future, show lower actual costs than the varied spacing presently used. The vertical angle connectors shown in Detail 3 are preferred by some individuals because of the ease of getting a good field connection under adverse conditions. However, under fatigue loading the flexible studs have been shown to perform better than hard type connectors such as angles. The automatic equipment used for installing studs eliminates much of possibility of human error.

CONCLUSIONS

The cost of bridge details can have a significant effect on the total cost of a steel bridge. Bridge engineers are urged to pay careful attention to the details they indicate on design drawings, and to eliminate unnecessary refinements in function or fabrication. The following suggestions and comments are based on the authors' personal observations and experience as well as the result of an AISC study of the relative cost of standard bridge details used by 32 state highway departments.

1. The simplest detail will usually function best and cost the least.
2. Elastomeric bearings should be used far more extensively. Their performance in service has been proven satisfactory, and they are the most economical type of bearing for light and intermediate reactions.
3. Reexamine the need for expansion devices. Recent evidence indicates that the flexibility of stub abutments on piles provides sufficient accommodation for temperature expansion in most steel bridges.
4. Diaphragms are not effective in distributing live loads but are useful for alignment and stability during erection, except for curved girders where they resist torsion. This suggests that they are often overdesigned.
5. Avoid locating intermediate stiffeners on opposite sides of the girder web at the same location. They should be located on one side only, or staggered on opposite sides. They should be cut back from the tension flange. Whenever possible, utilize intermediate stiffeners as diaphragm connections to the girder web.
6. Put holes in the detail material, not in the main material, whenever possible. Unnecessary material handling can make fabrication costs soar.
7. Let the fabricator help achieve economies. Give him latitude in the choice and location of full moment and shear splices. Scrutinize his requests for changes during preparation and approval of shop drawings—his ideas may be useful in reducing fabrication costs for future designs.
8. Examine all details on the basis of cost and function, rather than precedent, and objectively compare alternative details. Precedent can be the most costly item in a modern bridge design.