# New Folded-Plate Bridge Culvert System

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A new precast concrete bridge/culvert system is described. The system is particularly suitable for a roadway crossing over a waterway, where the span is relatively short (20 to 60 ft), and the clearance between the high water level and roadway surface is greater than 6 ft. The system can be built quickly by most contractors, making it an attractive alternative for replacement of many of the nation's deficient secondary road bridges and culverts. It consists of precast concrete folded-plate elements supported on ledges of end walls, which are in turn supported on drilled piers. Variations of this basic system are possible to suit other span ranges and crossing geometries. The system is extremely efficient as its components use available space to increase structural cross section depth and to reduce dead loads that would otherwise be heavy. Other benefits are offered by this new system, including short construction time, economy, and ease of construction. The new system is compared with an existing system; a cost analysis demonstrates potential savings as high as 20 percent over the traditional system. Plans are under way to construct a full-scale functional prototype in eastern Nebraska.

The annual reports to Congress on "Highway Bridge Replacement and Rehabilitation Program," by the FHWA have repeatedly voiced concern about the state of the nation's bridge infrastructure. The Ninth Annual Report included data about 577,710 highway bridges in the National Bridge Inventory (NBI). The FHWA indicated in their report that as of June 30, 1988, 23.5 percent of those bridges were classified as structurally deficient and 17.7 percent as functionally obsolete. There is need for economical systems to rebuild the rapidly deteriorating bridges. Where spans are relatively short and vertical clearances allow, culverts are often used as economical alternates to bridges. Among the most commonly used culvert systems are low-profile corrugated metal culverts, precast concrete box culverts and arches, and cast-in-place (CIP) concrete box culverts. However, a new and promising concept of an economical and efficient bridge/culvert system is currently being developed at the University of Nebraska. The final design of the new system will be completed in the near future, followed by the construction of a full-scale functional prototype structure. Several projects have been identified as possible test sites in the eastern Nebraska region.

The new concept uses precast folded-plate elements as the primary load-carrying components. Folded plates are thin and efficient structural members that used to be popular in the 1960s for building roofs. The large structural depth of folded plates allows them to span long distances at lower material cost compared to other structural systems. Popularity of reinforced-concrete folded plates for building roof framing has diminished in recent years because of the high cost of CIP concrete formwork, the distinctive appearance of folded plates (which is not anymore fashionable to some), and because of possible snow load buildup. None of these problems are valid for the proposed usage of folded plates. Precasting significantly reduces formwork cost and improves quality. Appearance is not a problem as the folded plates are covered with soil. Finally, a folded-plate system, as will be shown later, carries a significantly smaller total soil load than an alternate CIP reinforced-concrete box.

Several other advantages are offered by the proposed system over the currently used culverts or bridges for the same crossing characteristics.

1. A folded-plate system would require a shorter overpass span than the corresponding bridge (or narrower width than the corresponding culvert barrel length).
2. When a waterway is being crossed, the new system does not require any waterway channel alterations or waterway rerouting during construction.
3. Keeping the waterway unchanged would provide the least interruption to wildlife habitat.
4. In comparison with CIP construction, the construction of the proposed system is much quicker, resulting in less traffic disruption and public inconvenience.

The proposed system is described here for roadway-waterway crossings with the following characteristics.

1. Width of the highest water surface of 20 to 60 ft.
2. Width of bridge, that is width of roadway including shoulders, up to 50 ft.
3. Clearance of 6 to 10 ft between the highest water level and surface of roadway.

These characteristics apply to a large number of crossings on low-volume roads and secondary highways. Where intermediate supports are allowed, use of the proposed system can be extended to include a variety of applications and dimensions beyond these limits.

A brief description of the present competing bridge/culvert systems is presented accompanied by a comparison with the proposed system. A detailed description of the proposed system along with conceptual plans and sections are given. Functional and economical comparisons are made between a preliminarily designed folded-plate bridge and a recently constructed box culvert in Sarpy County, Nebraska. It is shown that along with several advantages, construction cost savings as high as 20 percent could be achieved by using the proposed system instead of the existing box culvert. And finally, several design aspects of the proposed bridge system are considered.

## PRESENT SYSTEMS

There are several bridge/culvert systems available on the market; each lends itself to certain sites with different character-

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istics. For the purpose of comparison, available competitive systems are briefly discussed below. Only those systems that can be used for sites with the characteristics mentioned will be discussed.

### Single or Multiple Tubular Culverts

One or more pipes are generally used across the roadway to allow water flow under the roadway. The number of pipes and their diameters depend on the volume of water flow expected in the waterway channel. A large volume of fill is usually required for this type of construction. These systems generally require modification of the geometry of the waterway channel, and they are suitable for sites with low volume of flow.

### CIP or Precast Concrete Culverts and Bridges

Concrete box and arch culverts are rather popular. CIP construction costs may be relatively high because of the high cost of forming. On the other hand, precast concrete box culverts are relatively small in size and limited by the availability of precasters and heavy equipment contractors. Conventional CIP and precast/prestressed concrete bridges are usually used for wide crossing sites and for highway overpasses. They are most economical for relatively low vertical clearances that do not allow for soil cover under the roadway.

### Low-Profile Corrugated Metal Culverts

Steel as well as aluminum culverts are available. Typically, the culvert is assembled by bolting a number of transverse corrugated plates together to form the box section. The box can be assembled in place or preassembled on site, then lifted into place. During erection and backfilling, the assembled box is flexible and sensitive to distortion. Transverse stiffeners are sometimes used to preserve the shape of the box during erection and backfilling. Strict backfilling sequence is necessary for proper installation of this type of structure. These culverts have relatively short service life (as short as 20 years). They require rerouting of the waterway during construction and a relatively large volume of fill and site work.

### Prestressed Concrete Patented Systems

Two patented culvert systems are available: Con/Span and Hy-Span culverts. Although these culvert systems are different in shape from each other, they are similar in nature and material. Both systems are composed of three-sided precast concrete segments (inverted U shape) joined together in the direction of the waterway to form a single-cell culvert. Multiple cells can be formed by putting units next to each other. Both of those systems are designed to bear on spread footings or bottom slabs. The construction of such structures offers no savings over traditional boxes in the volumes of excavation and backfill, rerouting of the waterway during construction, or interruption of the natural channel and wildlife habitat.

## DESCRIPTION OF THE PROPOSED SYSTEM

The proposed folded-plate bridge/culvert system is composed of four major components. The components from the ground up are the foundation, the end walls, the wing walls, and the folded plates (Figures 1 and 2).

### Foundation

The foundation of this bridge system consists of four CIP concrete drilled piers or precast concrete driven pile groups. (Only four piers or pile groups are required, as will be explained later.) Other types of foundation are possible depending on the span of the bridge/culvert, the topographical character-

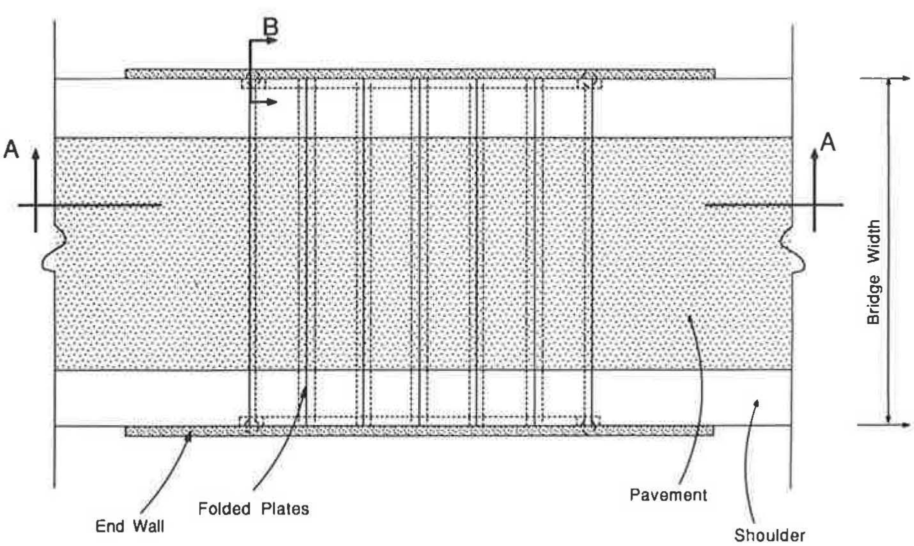


**FIGURE 1 Folded-plate bridge plan view.**

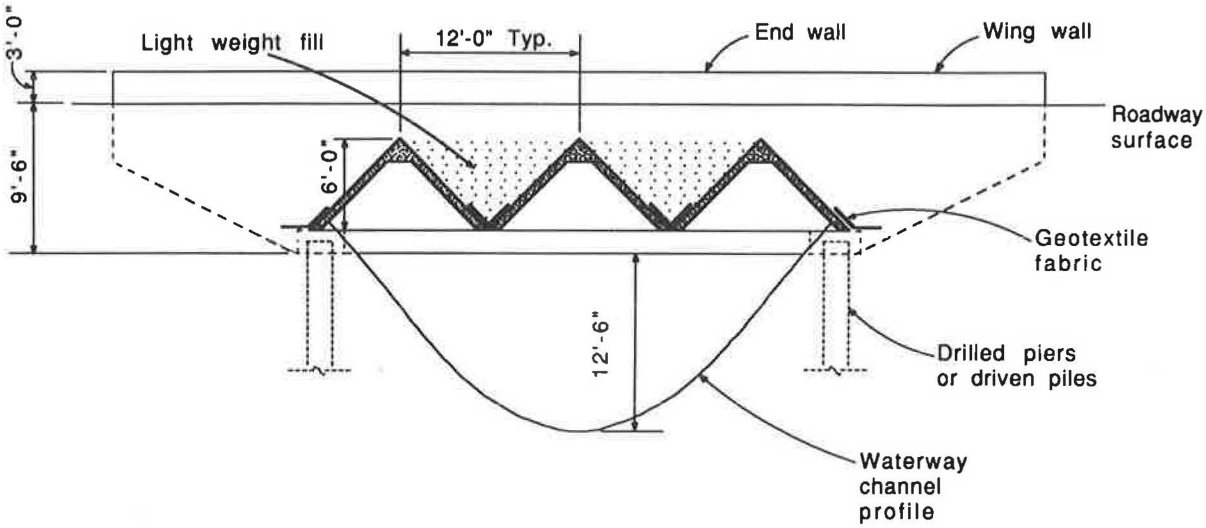


**FIGURE 2 Folded-plate bridge, Section A-A.**

istics of the site, the design loads, and the subsoil conditions. Drilled piers are particularly attractive for the proposed system because they occupy small space and can be installed, by a relatively large number of contractors, without disturbing the natural profile of the channel.

### End Walls

The end walls serve three primary functions: first, each end wall spans across the waterway between two piers or pile caps and supports one end of the folded-plate units. Second, they retain the road embankment. Third, they can be made high enough to work as a traffic barrier.

### Wing Walls

The wing walls in the proposed system are continuations of the end walls that cantilever on either side of each end wall. They retain the road embankment within the distance required to achieve smooth grade transitions.

### Folded Plates

The folded-plate units span between the end walls, across the roadway, to transfer dead and live loads to the end walls (Figure 1). In addition, they stabilize the end walls in the out-of-plane direction because the end walls as well as the wing walls are subject to lateral earth pressure. Ninety-degree folds are assumed in the preliminary design and are the most economical for forming purpose; other configurations are possible depending on the crossing dimensions and loading. The advantages of using reinforced-concrete folded plates as the main structural members as well as the advantages of the entire system compared to a CIP box culvert system are discussed in the next section.

## COMPARISON WITH AN EXISTING SYSTEM

In order to best demonstrate the efficiency and advantages of the proposed system, a comparison between an existing CIP reinforced-concrete twin-box culvert built in Sarpy County, Nebraska, and a preliminarily designed folded-plate alternative for the same site is presented. The construction of the box culvert was completed in April of 1988. Plan view and cross sections of the box culvert are shown in Figures 3 and 4, respectively.

Six bids were submitted for the construction of the box culvert. The bids ranged from $105,920 to $191,980 with an average of $142,170. It was felt that, for comparison purposes, the average bid price most accurately represents the actual box-culvert construction cost. The cost estimate of the proposed folded-plate bridge was carried out conservatively by local precast concrete suppliers and contractors to closely represent its actual construction cost. The estimated total construction cost was $109,800, which is 20 percent less than the average bids for the box culvert. The primary reasons behind the lower construction cost of the new system versus that of the box culvert in comparison are discussed in the following paragraphs.

### Less Volume of Excavation and Backfilling

In order to construct the box culvert, the contractor had to excavate to a level slightly lower than the bed of the waterway channel, and the excavation had to extend a few feet outside the design dimensions of the culvert on four sides. After completely curing the CIP concrete culvert, a large volume of fill had to be hauled in, placed, and compacted on all sides and on top of the culvert to build the roadway embankment above and to smooth the grades around it. Considerably less volume of excavation and backfilling is required for the construction of the proposed bridge system. Only a small amount of fill needs to be placed above the folded-plate units to build the roadway embankment. Also, because of the geometry of the

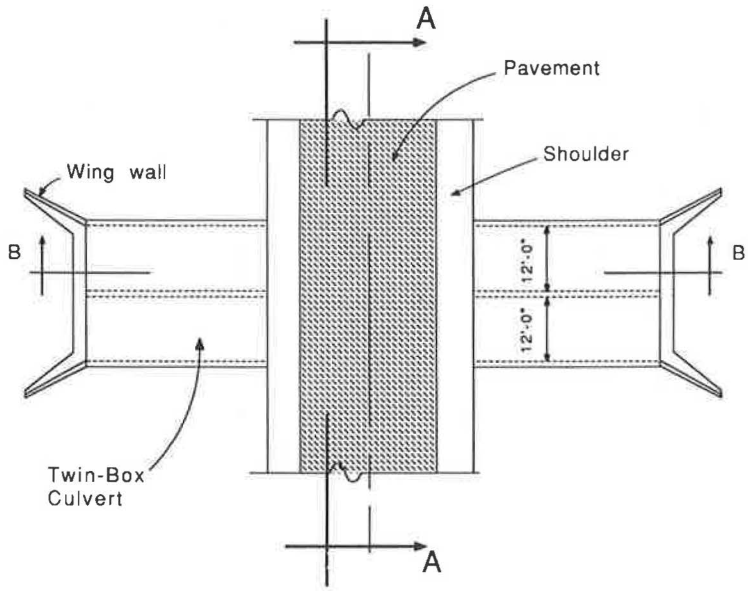


**FIGURE 3 Twin-box culvert plan view.**

folded plates themselves, less fill is required to bring the roadway embankment to the final pavement elevation (Figure 2).

### Less Site Work

Because of the nature of the proposed bridge system and its geometry, little site work is required for its construction. This is mainly because of the function of the end walls as retaining elements, which eliminates the need for gradually sloping the road embankment on both sides of the road. Unlike the construction of the culvert, which requires a great deal of grading to smooth the surfaces of the new fill, the proposed system has a level, well-defined fill geometry that requires only minimal grading work.

### Less Materials

In order to accommodate the slopes of the roadway embankment, the box culvert had to be 100 ft long. The folded-plate bridge, on the other hand, is only about 38 ft wide. This is mainly because of the fact that the length of culvert is parallel to the waterway, whereas the width of the folded-plate bridge is parallel to the waterway. The total concrete volume needed for the CIP concrete culvert was approximately 350 $yd^3$, and the total concrete volume needed for the CIP and precast concrete members in the proposed bridge system was conservatively estimated to be 100 $yd^3$. The box culvert needed 250 percent more concrete than the proposed bridge did for the same crossing.

### Shorter Construction Time

Most of the folded-plate bridge members can be precast concrete members including the pile foundations. This means shorter construction time and less susceptible-to-weather construction process than that of the CIP concrete box culvert. Shorter construction time means more economical construction, shorter traffic disruption time, and less public inconvenience.

### No Interference With the Natural Waterway Channel

When used for sites with characteristics similar to those mentioned previously, construction of the proposed bridge system causes no interference with the natural profile of the waterway channel. This is true because the foundations of the proposed system are the only portions extending below the water surface and they occur outside the perimeter of the running water. Hence, unlike the CIP box culvert, the new system does not require an extensive hydraulic study or rerouting of the waterway, nor does it cause interference with the wildlife habitat.

### Less Overall Cost

Less volume of excavation and backfilling, less site work, less materials, and shorter construction time add up to less construction cost. That was reflected clearly in the difference between the construction cost of the box culvert in comparison and that of the proposed folded-plate system. As much as 20 percent cost saving can be accomplished by using the proposed system versus the CIP concrete box culvert.

## DESIGN CONSIDERATIONS OF THE PROPOSED SYSTEM

Because the detailed analysis and design of the proposed bridge system are still in the early stages, little technical information and mainly the concept of the proposed system are provided.

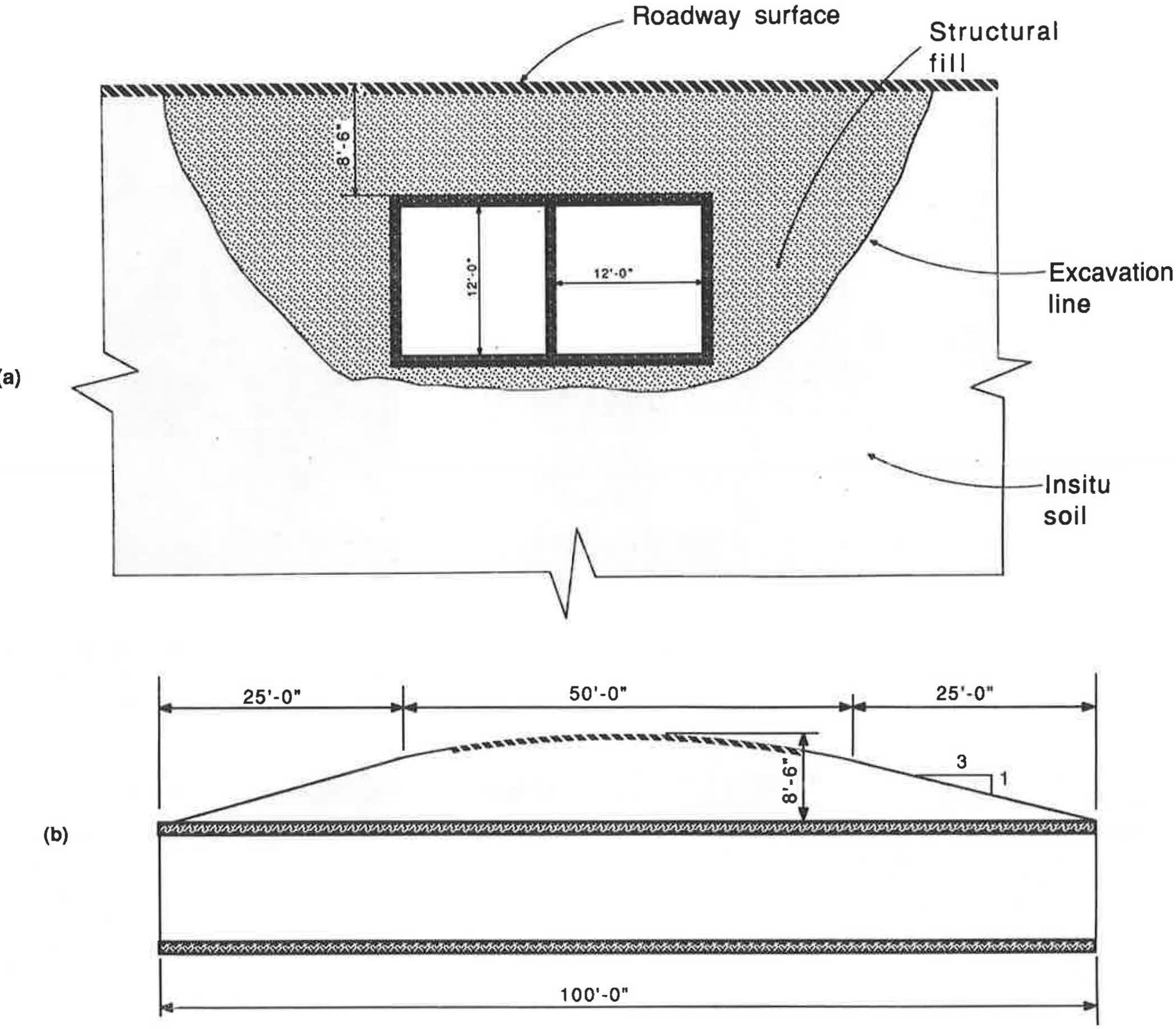


**FIGURE 4 Twin-box culvert, (a) Section A-A, (b) Section B-B.**

The two major components of the bridge system, the end walls and the folded-plate units, will be considered precast concrete members hereafter. CIP concrete construction of these two components will preclude the purposes behind developing this system—namely, economy, short construction time, and minimum interference with the waterway channel. So far, the structural design of the proposed bridge/culvert system is still in its preliminary stages. The more extensive study of the structural design and detailing will take place in the near future. However, a few of the most important design considerations are discussed in the following paragraphs.

### Design of Folded Plates

The folded plates span between the end walls to support their own weight, the weight of road embankment and pavement, and the design live loads caused by traffic. At the same time, the folded plates have to support the end walls in the out-of-plane direction as the end walls are subject to lateral earth pressure from the fill and road embankment. Design live loads will depend on the classification of the overpass as specified by the *AASHTO Standard Specifications for Highway Bridge*. The distribution of soil pressure resulting from the road embankment and design live loads, however, is difficult to predict. The unusual geometry of the top surface of the folded plates results in a complex soil-structure interaction. The problem is further complicated by the material nonlinearities of soil and concrete, as well as the additional nonlinearity caused by cracking of concrete. Boundary nonlinearities also exist at the interface between the soil and structure. In order to model these effects as accurately as possible, a special-purpose finite element program is required. One such program, Culvert Analysis and Design (CANDE) will be used in the analysis phase of this investigation. CANDE is capable of accounting for all of the nonlinearities, and outputs such information as the soil pressure and internal forces (shear and bending moment) at the nodal points of the folded plates.

One of the interesting design concerns is how to connect the adjacent folded-plate units to each other and how to connect them to the end walls. The connections shall transfer the loads from the folded plates to the end walls, and vice versa, with the least local stress concentrations.

The precast folded-plate units can be either conventional or prestressed concrete members. The need for prestressing will be determined by the thickness of the embankment, design live loads, and the span of the plates.

### Design of End Walls

The main function of end walls is to support the folded plates and to transfer the loads to the foundations. But they also retain the road embankment, and if desired, they can be made deep enough to project above the road embankment to work as a traffic barrier or guard. For that reason, the folded plates will have to support the end walls in the out-of-plane direction. Therefore, a connection cable of transferring forces in the out-of-plane direction has to be designed between the folded plates and the end walls (Figure 5). When the bridge span is short, erection of the end walls is simple as they are short and relatively light. For relatively long-span bridges, however, the end walls become too heavy, and erecting them becomes a challenge that will have to be investigated in the final design stages. For roadway widths greater than those specified above, more than one folded-plate span can be used across the roadway. In these instances, intermediate walls as well as intermediate foundations have to be used (Figure 6).

The effect of temperature changes will be investigated and accounted for when designing the end walls. The connections of end wall to foundation will require special attention because they have to transfer the largest, and most important, forces in the system (Figures 5 and 6).

### Foundation Design

The most appropriate foundation for this system is CIP-drilled piers. They can carry a considerably large axial load in most soil conditions, they have relatively small areas, and they can be easily installed by most contractors. Friction piers, bearing piers, or friction-bearing-combination piers can be used depending on the foundation loads and the subsoil conditions. Driven-pile foundation is another candidate for the folded-plate bridge. Only four pile groups with CIP concrete pile caps are required. However, type, cross-sectional area, and length of piles will depend on the foundation loads and subsoils conditions. Regardless of the type of foundations used, they have to be designed and detailed to support vertical dead and live loads, lateral wind or seismic loads, and loads caused by temperature changes.

## SUMMARY AND CONCLUSION

Economical systems are needed to rebuild the rapidly deteriorating bridges and culverts in the country. A few bridge and culvert systems are presently available on the market for waterway crossings with spans up to 60 ft and vertical clearances greater than 6 ft. A new promising bridge/culvert system is being developed at the University of Nebraska for sites with

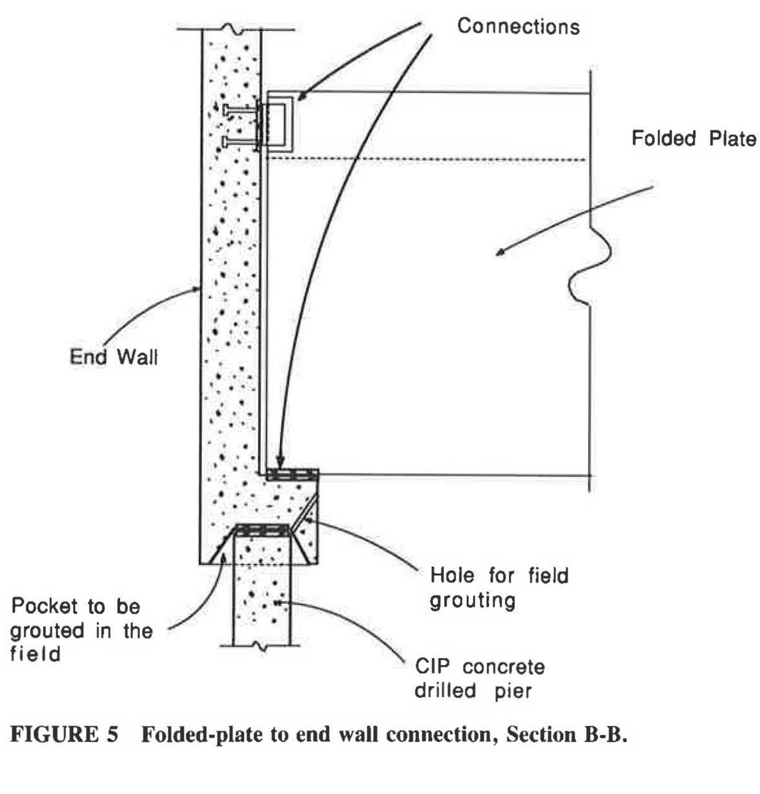


**FIGURE 5 Folded-plate to end wall connection, Section B-B.**

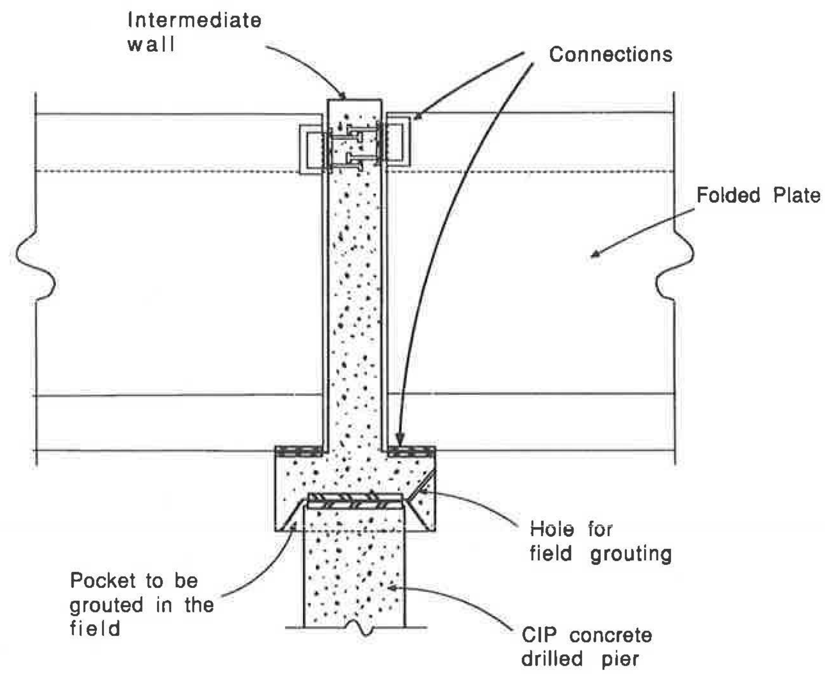


**FIGURE 6 Typical folded-plate to intermediate wall connection.**

these characteristics. The new system concept makes use of precast-concrete folded plates as the main structural elements of the bridge. In order to demonstrate the potential for cost savings, a construction cost estimate based on preliminary design of a folded-plate bridge was compared with the construction cost of an existing culvert system. The comparison indicated that the proposed system has obvious potential time saving and approximately 20 percent cost savings over the box culvert. In addition, the proposed bridge system permits no interference with the natural waterway profile. Although the system is being limited to certain dimensions and applications at this stage of its development, it can be further adapted for use in roadway overpasses and for long and wide bridges where intermediate supports are allowed. Research is underway at the University of Nebraska to further develop this new concept both from design and constructibility points of view.