CHAPTER 7

INSTALLATION & CONSTRUCTION PROCEDURES

INTRODUCTION

This chapter presents information of fundamental importance regarding installation and construction procedures including base preparation, unloading and assembly, and placement and compaction of the backfill. The emphasis is on corrugated steel pipe in embankment installations such as highway culverts. For pipe in trench installation such as storm sewers, reference should be made to the CSPI publication, "Modern Sewer Design" for a thorough presentation. For additional information, reference may also be made to ASTM recommended practices under ASTM designations A 796 / A 796 M, A 798 / A 798 M, and A 807 / A 807 M.

A well situated, properly bedded, accurately assembled, and carefully backfilled galvanized steel drainage structure will function properly and efficiently over its design life. Although smaller structures may demand less care in installation than larger ones, reasonable precautions in handling, base preparation, assembly and backfilling are required for all structures.

Corrugated steel structures, because of their strength, light weight and resistance to fracture, can be installed quickly, easily and with the least expensive equipment. The flexible steel shell is designed to distribute external loads to the backfill around it. Such flexibility permits unequaled tolerance to settlement and dimensional changes that would sometimes cause failure in rigid structures. This clear advantage of corrugated steel structures is further strengthened when they are installed on a well prepared foundation, and surrounded by a well compacted backfill of stable material. Reasonable care during installation is required. Just as with drainage structures of concrete or other materials, careless installation of corrugated steel structures can undo the work of the designer.

In Chapter 6, minimum cover requirements were presented for corrugated steel pipe under highway and railway loadings. These requirements are based on years of practical experience, as well as fundamental design criteria. However, it must be emphasized that such minimum covers may not be adequate during the construction phase, because of the higher live loads that may be incurred. Therefore, when construction equipment, which produces wheel loads or gross loads greater than those for which the pipe has been designed, is to be driven over or close to the structure, it is the responsibility of the contractor to provide any additional cover needed to avoid damage to the pipe.

BASE PREPARATION

Pressure developed by the weight of the backfill and live loads is transmitted both to the side fill and the strata underlying the pipe. The supporting soil beneath the pipe, generally referred to as the foundation, must provide both longitudinal and lateral support.

The portion of the foundation in contact with the bottom of the structure is referred to as the bedding. Depending upon the size and type of structure, the bedding may either be flat or shaped.

Soft Foundation

Evaluation of the construction site may require subsurface exploration to detect undesirable foundation material, such as soft material (muck) or rock ledges. Zones of soft material give uneven support and can cause the pipe to shift and settle non-uniformly after the embankment is constructed. Thus material of poor or non-uniform bearing capacity should be removed and replaced with suitable compacted fill to provide a continuous foundation that uniformly supports the imposed pressures. The bedding may then be prepared as for normal foundations. Figure 7.1 illustrates the treatment of soft foundations.

It is important that poor foundation material be removed, for a distance on either side of the pipe, and replaced with compressed backfill. Otherwise, that material will settle under the load of the backfill alone and actually increase the load on the pipe. This is referred to as “negative soil loading.

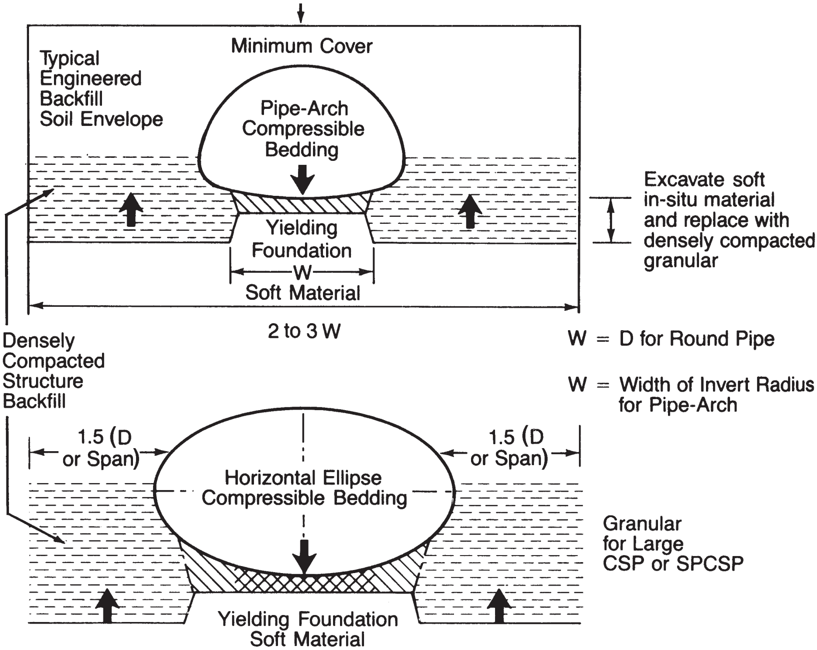


Figure 7.1 Yielding foundation treatment may be specified for larger pipe structures, and/or large invert radii. By selective excavation, it is possible to set up relative (not actual) motion (as indicated by arrows), thereby improving soil-structure interaction.

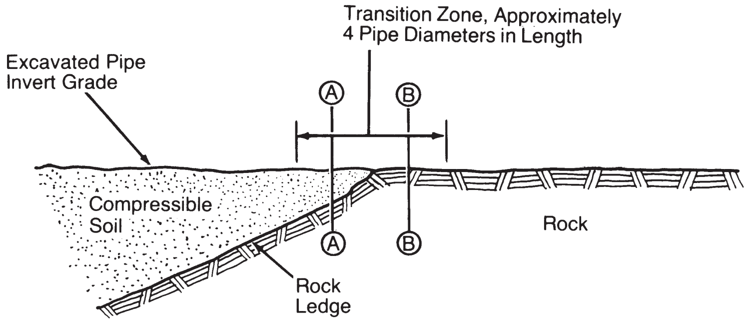
Rock Foundations

If rock ledges are encountered in the foundation, they may serve as hard points that tend to concentrate the loads on the pipe. Such load concentrations are undesirable

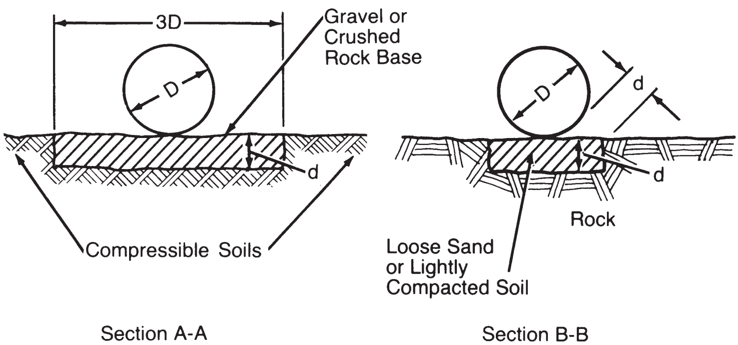
Backfill placement and compaction.

Stormwater detention tank installation in the City of Toronto.

since they can lead to distortion of the structure. Thus large rocks or ledges must be removed and replaced with suitable compacted fill before preparing the pipe bedding. Furthermore, when the pipe foundation makes a transition from rock to compressible soil, special care must be taken to provide for reasonably uniform longitudinal support. Figure 7.2 illustrates the treatment for rock foundations and transition zones.



Transitions of pipe foundations from compressible soils to rock. Excavate rock and compressible soil in transition section to provide reasonably uniform longitudinal pipe support and minimum differential settlement.



d = 4% of Fill Over Pipe; 200 mm Minimum

NOTE:
Section B-B is applicable to all continuous rock foundations.

Figure 7.2 Rock foundations and transition zones.

Normal Bedding

With flat bedding, which is usually standard for factory-made round pipe, the pipe is placed directly on the fine-graded upper portion of the foundation. Soil must then be compacted under the haunches of the structure in the first stages of backfill.

The bedding concept for pipe-arch structures also relates to large diameter and underpass shapes. For these structures, the bedding should be shaped to the approximate contour of the bottom portion of the structure. Alternatively, the bedding can be shaped to a slight V-shape. Shaping the bedding affords a more uniform support for the relatively flat structures. The shaped portion need not extend across the entire bottom, but must be wide enough to permit the efficient compaction of the backfill under the remaining haunches of the structure.

Figure 7.3 illustrates shaped bedding for a pipe-arch. Note that the soil beside and below the corners of a pipe-arch must be of excellent quality, highly compacted, and thick enough to spread and accommodate the high reaction pressures that can develop at that location.

Whether the bedding is flat or shaped, the upper 50 to 100 mm layer should be relatively loose material so that the corrugations can seat in the bedding. The material in contact with the pipe should not contain gravel larger than 75 mm, frozen lumps, chunks of highly plastic clay, organic matter, or deleterious material.

Camber

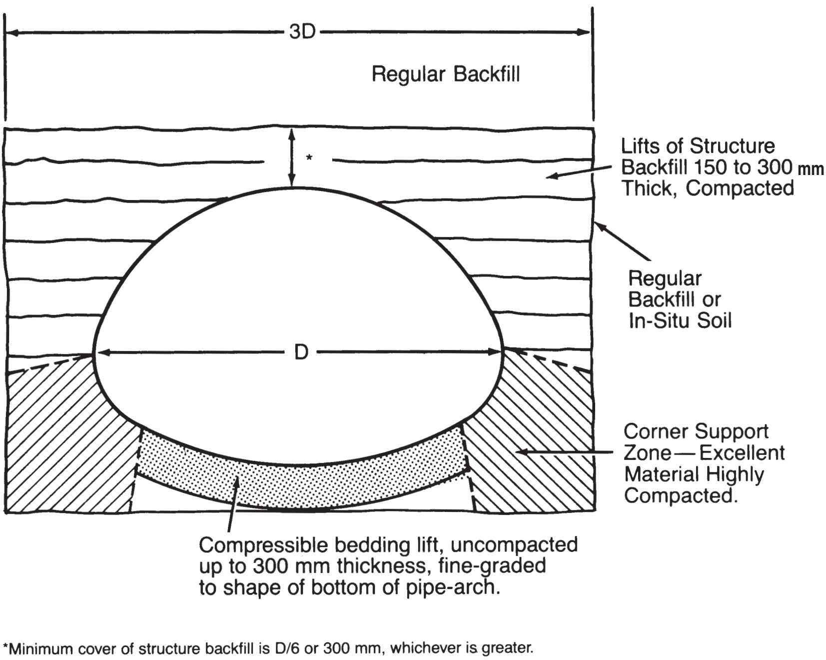


Figure 7.3a Typical backfill envelope for pipe-arch or long span structures.

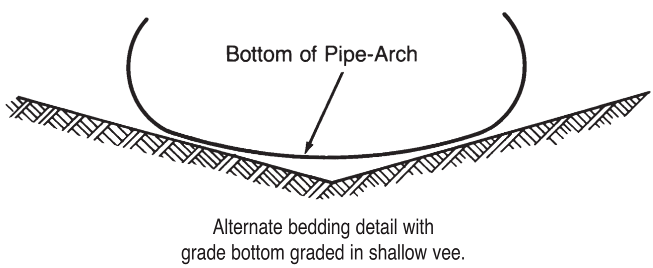


Figure 7.3b Typical vee-shaped bedding for pipe-arches and large diameter structures.

Camber in the grade under high fills, or on a foundation that may settle, should be considered in base preparation. Camber is simply an increase in the foundation or bedding elevation at the center of a culvert above a straight line connecting its ends (the intended grade or slope of the pipe). The objective is to shape and/or elevate the grade to assure a proper flow line after settlement takes place. This forethought will prevent a sag in the middle of the culvert that might pocket water, or reduce capacity because of sedimentation. Generally, enough camber can be obtained by placing the base for the upstream half of the pipe on an almost flat grade, and the downstream half on a steeper than normal grade. The greater load at the center of the embankment, and the corresponding settlement, will result in the desired positive slope after full consolidation. Soils engineering techniques are available to predict the amount of camber required for unusual conditions. It is possible to obtain a camber equal to one-half of one percent of the length of the culvert without special fittings. For structures under high fills, the ordinates of this curve should be determined by a soils engineer. Figure 7.4 illustrates camber for a pipe under a high fill.

INSTALLATION OF CORRUGATED STEEL PIPE

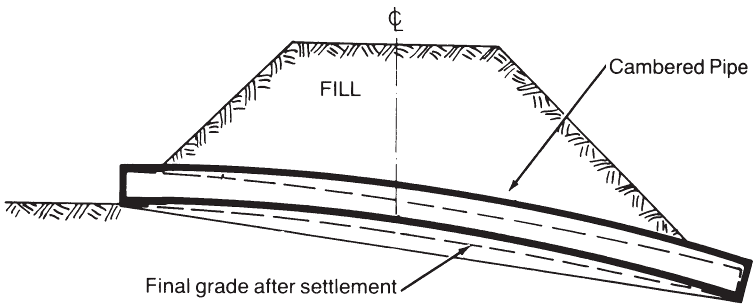


Figure 7.4 Camber allows for settlement of a culvert under high fill. Diameters 3000 mm and smaller are easier to camber, as are the lighter wall thicknesses.

AND PIPE-ARCH

Unloading and Handling

Although corrugated steel drainage structures will withstand rough handling without deformation, they should be handled with reasonable care. Pipe should never be dumped directly from a truck bed while unloading, but should be lifted or rolled to protect the galvanized surface. Polymer laminated pipe should be secured and lifted only, using fabric slings. Dragging the structures at any time may damage the coatings and jeopardize durability. Also, avoid striking rocks or hard objects when lowering pipe into trenches.

If the pipe has been ordered with lifting lugs, utilize them by using wire rope slings equipped with hooks. This simplifies installation, but rough handling should still be avoided. Since corrugated steel structures are relatively light in weight, they can be handled with simple, light equipment. If necessary, a small crew can lower pipe into trenches by means of rope slings.

Lifting CSP into place.

Assembly

The usual methods of joining two or more lengths of pipe or pipe-arch is by means of steel connection bands. The bands engage the ends of each pipe section, and are placed to overlap equally amounts of each pipe providing an integral and continuous structure.

For many years, joints for corrugated steel pipe were specified with full details and dimensions, based on traditional devices. Little thought was given to the functional requirements for joints on individual projects.

However in the early 1980s, rational structural requirements were developed for field joints in corrugated steel pipe. Extensive research towards realistic performance requirements, in terms of moment, shear, tension and degree of tightness, was conducted by California Transportation (CALTRANS).

From this, rational mechanical and structural performance requirements were developed by the Bridge Design Code Committee of the American Association of State Highway and Transportation Officials (AASHTO). These performance requirements are published in Division II, Section 26.4.2, of the current edition of the AASHTO Bridge Specifications.

CSP stream diversion fittings.

The AASHTO Specifications provide an excellent description of joint types. Joint properties include shear strength, moment strength, tensile strength, joint overlap, soil tightness and watertightness. Their recommended minimum requirements depend on whether the pipe is being installed in erodible or non-erodible soil.

The basic corrugated coupler systems in general use in Canada, as shown in Chapter 2, were tested by CALTRANS and were formed to meet all of the performance requirements. It should be emphasized that most corrugated steel pipe installations will only require a standard joint.

One-piece bands are used on smaller sizes of pipe. Two or three-piece bands are used on larger diameter pipe and when installation conditions are difficult. Rod and lug bands are used on levees, aerial sewers and similar installations where improved water-tightness is essential. Bands utilizing gaskets are commonly used in restricted leakage applications. Specially fabricated connectors can be supplied for use in jacking and for special or unusual conditions.

Bands are put into position at the end of one section of pipe with the band open to receive the next section. The second section is brought against or to within about 25 mm of the first section. After checking to see that connecting parts of both band and pipe section match, and that the interior of bands and exterior of pipe are clean, bolts are inserted and tightened.

Lifting spiral rib pipe into place.

To speed the coupling operation, especially for large diameter structures, a chain or cable-cinching tool will help tighten the band. Special clamping tools are available that fit over coupling band connectors and quickly draw the band together. Such devices permit faster hand tightening of the bolts, so that a wrench is required only for final tightening.

On large diameter structures, merely tightening the bolts will not assure a tight joint because of the friction between the band and the pipe ends. In such installations, tap the band with a mallet to cause it to move relative to the pipe as the band is tightened.

The wrench used to tighten coupling bands may be a box end wrench, but for greater speed a speed or ratchet wrench equipped with a deep socket is recommended.

Coated Pipe

On coated pipe, the surface between coupler and pipe may need lubrication with vegetable oil or a soap solution. This will allow the band to slip around the pipe more easily and to draw into place more firmly, particularly in cold weather. Lubricating and tapping the band so it can seat will assure a strong joint.

Where damage to the coating exposes the metal, repair by patching with a suitable material before the structure is backfilled.

Paved Invert Pipe

Pipe with bituminous pavement must be installed with the smooth, thick pavement in the bottom.

To simplify such placement and to speed handling, paved invert pipe lengths may be ordered with metal tabs or lugs fastened to the pipe exterior exactly opposite the location of the pavement. Slings, with hooks inserted in the lugs, automatically locate the paved invert in the bottom of the structure.

INSTALLATION OF STRUCTURAL PLATE (SPCSP) AND DEEP CORRUGATED STRUCTURAL PLATE STRUCTURES

Unloading and Handling

Plates for structural plate structures are shipped nested in bundles, complete with all plates, bolts and nuts necessary for erection. Included with the shipment are detailed erection instructions showing the order of assembly and the position of each plate. Bolts are colour coded for length identification. Bolts for every SPCSP structure are provided in two lengths. The longer length is required when three or four thicknesses of plate overlap.

Bundles are sized so that cranes, forklifts, or other construction equipment already on the job are all that is needed for unloading. Normal care in handling is required to keep the plates clean and free from damage by rough treatment.

Pre-sorting the plates as they are unloaded, on the basis of their radius and location in the structure, is important. All plates are clearly identified so that they can be easily sorted.

Lifting pre-assembled side plates into place.

Assembly of horizontal ellipse structural plate.

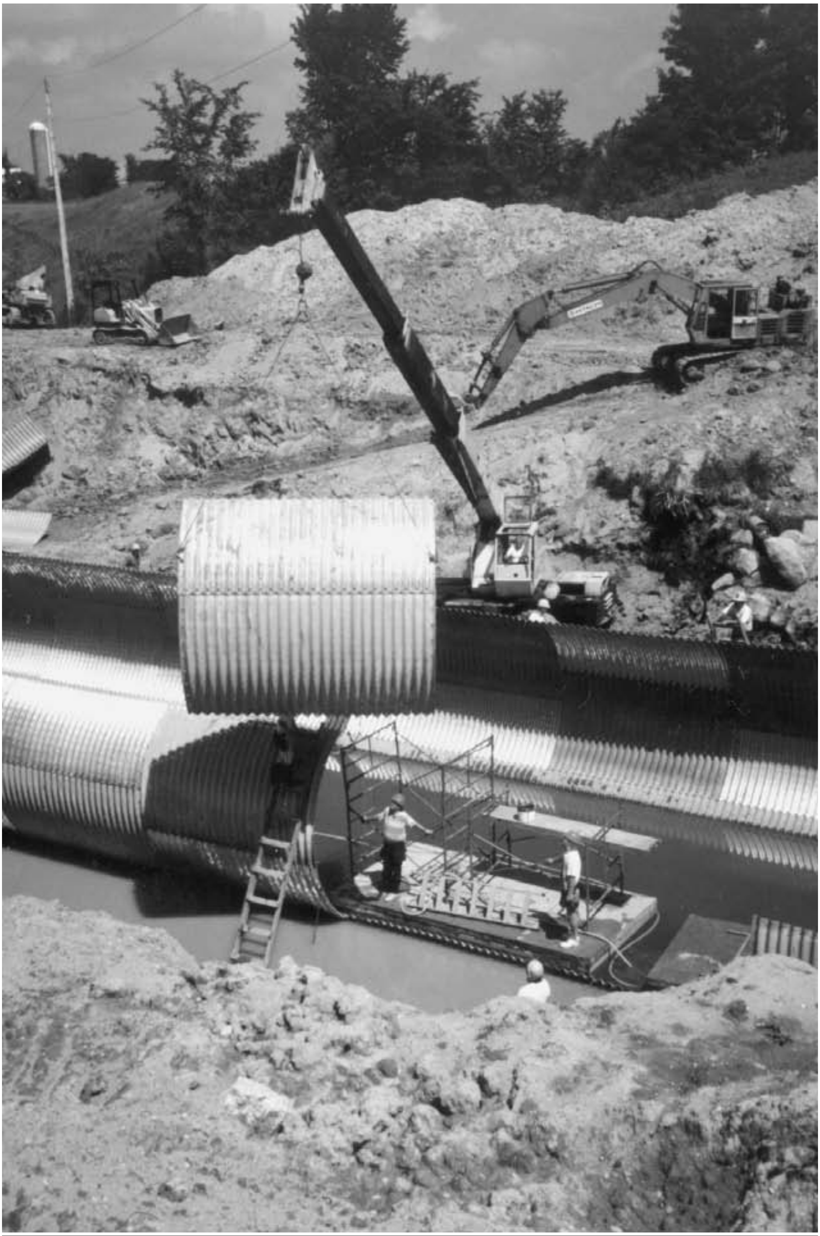


Plate assembly done from a raft.

Assembly Methods

A variety of assembly techniques are available, to suit site conditions, and/or size or shape of the structure. Maintaining the design shape must be a key objective during plate assembly.

There are four basic methods by which structural plate structures can be assembled:

1) *Plate-by-Plate Assembly* - The majority of SPCSP structures are assembled directly on the prepared bedding in a single plate-by-plate erection sequence, commencing with the invert, then the sides, and finally, the top. This method is suitable for any size of SPCSP structure.

   Initially, structures should be assembled with as few bolts as possible. The curved surface of the nut is always placed against the plate. Three or four untightened bolts near the center of each plate, along longitudinal and circumferential seams, are sufficient. This procedure gives maximum flexibility until all plates are fitted into place.

   After part of the structure has been assembled into shape by partial bolting, the remaining bolts can be inserted and hand tightened. Always work from the center of a seam toward the plate corner. Alignment of bolt holes is easiest when bolts are loose.

   After all the bolts are in place, tighten the nuts progressively and uniformly, starting at one end of the structure. The operation should be repeated to be sure all bolts are tight.

   If the plates are well aligned, the torque applied with a power wrench need not be excessive. A good fit of the plates is preferable to the use of high torque. Bolts should not be overtightened. The bolts should be torqued to a minimum of 200 N.m and a maximum of 340 N.m.

   It is important that the initial torquing be done properly. In many structures, nuts may be on the outside, and retorquing would not be possible after backfill.

   In some applications, such as for pedestrian and animal underpasses, it is specified that all bolt heads should be on the inside of the structure, for safety and visual uniformity. If a paved or gravelled invert is to be placed, it may be allowable to have the bolt ends protruding into the area to be covered.

   After backfilling, the structure relaxes and the actual in-service bolt torque will decrease slightly. Depending on plate and structure movements, some bolts may tighten, and some may loosen or vary over time. The degree of change in torque values is a function of metal thickness, plate match, and change of structure shape during backfilling. This is normal and not a cause for concern, should checks be made at a later stage.

2) *Component Sub-Assembly* - This is the pre-assembly of components of a ring, away from the bedding. The components are usually comprised of the bottom plates, the side plates and the crown plates. This method is suitable for most soil-steel bridge installations. Component sub-assembly is often more efficient than the plate-by-plate method. Its main advantage is that it permits simultaneous progress at two different locations at the structure site. The foundation preparation and bedding operation can be carried out at the same time as the sub-assembly operation.

   A step-by-step erection sequence using this technique is illustrated in the sketches in Figure 7.5. Two different types of mobile crane equipment are shown to indicate that either one would be satisfactory.

   Placing the invert components on prepared shaped bedding poses a problem with bolt insertion and torquing for large radius inverts (i.e. pipe-arch or horizontal ellipse in particular). Bolts can be preplaced by the use of spring clips. Other methods, such as the use of magnets or access trenches, may be used.

Experienced assemblers often place and tighten the bolts prior to bottom plate placement, as long as this does not affect the placement of side and top plates.

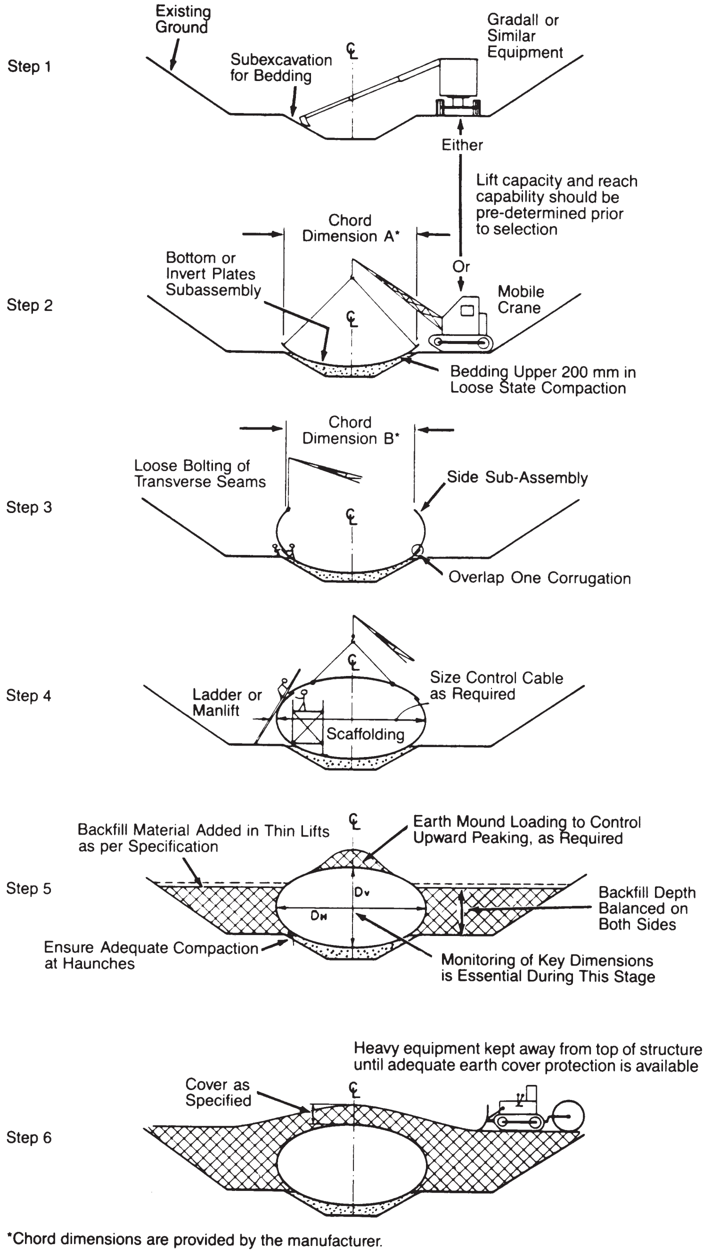


Figure 7.5 Typical component sub-assembly erection sequence for soil-steel structures: Step 1 - excavation for bedding; Step 2 - bedding and bottom sub-assembly (lift capacity and reach capability should be determined prior to equipment selection); Step 3 - erection of side sub-assembly; Step 4 - closure with top sub-assembly; Step 5 - back-filling and deformation control; Step 6 - completion of engineered backfill.

During component assembly of larger SPCSP structures, it is important to maintain curvature against the flattening due to torquing and self weight of the plate sections. The invert component should be sized to the proper radius and chord length, (Figure 7.5, Step 2) before the side assemblies are started. This can be controlled by horizontal sizing cables. As the side components are bolted in place, these cables should be moved to the springline. Similarly, the sides should be held to the design shape, to effect top closure (Figure 7.5, Step 3). When design shape is maintained during erection, the top sub-assembly should literally drop into place.

The sizing cables should be left in place until all the bolts are torqued and the cables slacken as a result of backfilling. It is important that design shape and size be maintained throughout the backfill operation, with allowances for normal movement arising from backfill pressures. On large soil-steel structures, all struts or supports, if used, should be removed when the backfill reaches the 2 and 10 o'clock positions.

The bolts in plate assembly components are all fully tightened prior to placement. This means that loose-bolting until the full ring is completed, is not possible. Therefore, it becomes much more important that exact design shape be maintained during erection, and that the component bolting be carefully aligned before torquing.

Shape checks should be carried out during and after erection to be certain that the erected shape is within design tolerances. If not, the necessary corrections must be carried out as before or backfill proceeds.

Additional bolt tightening may be required on large structures. Corner bolts control position, and the balance of the nuts are torqued to mid-range (approx. 270 N.m). Once the structure is completed, and correct alignment of plates is assured, another pass may be made to fully torque to not more than 340 N.m, before the next ring assembly is completed.

Cabling for shape control of horizontal ellipse long-span.

3) *Pre-Assembly of Rings* - In this method, circumferential rings of round structures are assembled off-site. These rings, or cans, are then transported to the assembly site for connection along their circumferential seams. A special technique is used to lap the end corrugations of one ring with those of its adjoining ring, to provide continuity in the assembly.

4) *Complete Pre-Assembly* - Pre-assembly of the complete structure can be done either at the factory or at the jobsite. The factory pre-assembled method is used for relatively small span installations; this application being limited by shipping size. The field pre-assembly method is selected for structures to be lifted intact or to be skidded onto a prepared foundation and bedding. Pre-assembly techniques are essential for installation under submerged bedding conditions.

Special Considerations For Structural Plate Arches

Structural plate arch shapes differ from other plate structures, since the edges of the arch are erected on an abutment, or footing. The arch footings are usually constructed of poured-in-place concrete, but may also be timber sills or steel plates. The use of piling is not recommended, as this will introduce an unyielding foundation. If the entire soil-steel arch structure is allowed to settle with the foundation, this will relieve load on the arch, and encourage positive soil arching and interaction.

The unbalanced steel channel on which the bottom plates rest must be located accurately to line, grade and span, as per the design drawings, to ensure proper and easy plate assembly. Care must be taken to insure that the pre-punched holes in the two opposing channels are in accurate alignment. The installer must remember to cast the unbalanced channel at the correct angle or slope to accommodate the bottom plates. Improper placement of base channels can create serious problems in arch construction.

The layout for channel installation should be shown on the fabricator's plate assembly drawings. If accurate structure overall length is important, as it may be in pre-locating concrete headwalls, the designer should remember that the actual overall length is the net length plus 100 mm, due to the lips at the end of the end plates. Pre-locating headwalls is not recommended practice, due to the flexible nature of these structures and due to manufacturing tolerances.

Scaffolding or temporary support of the early rings is usually necessary with the arch shape, as the initial plates are not self-supporting. Component pre-assembly is often advantageous.

Special Considerations For Structural Plate Pipe-Arches

During the assembly of multiple radius structures such as pipe-arches, care must be taken to ensure proper assembly and plate laps. Where different radius plates meet at a longitudinal seam, it may take extra effort to fully seat the corrugations and obtain the tangent plate lap required. A properly shaped bedding is especially important to assembly.

Pipe-arches are currently fabricated in two forms. Some have multiple radius corner plates that include both corner and top radius elements. Others use separate corner and top plates with a longitudinal seam at this juncture. The plate lap arrangement differs with this type of fabrication. The manufacturer's assembly instructions should be followed to avoid improper plate laps.

Asphalt Coating - Shop or Field

Where structural plates require a protective coating in addition to galvanizing, there are suitable materials available for applying to the components, to the assembled structure in the field, or on pre-assembled structures in the plant. Plates must be clean and dry. The coating can be an asphalt mastic containing mineral fillers and stabilizers sprayed on under high pressure to a minimum thickness of 1270 µm. (AASHTO M-243 / ASTM A849).

Seam Sealants

Improved watertightness of SPCSP structures is possible with modern seam sealants. Standard SPCSP structures, because of the bolted construction, are not intended to be watertight.

On occasion, where a degree of watertightness is required, it is practical to insert a seam sealant tape within the bolted seams. The seam sealant normally specified is wide enough to cover all rows of holes in plate laps, and of the proper thickness and consistency to effectively fill all voids in plate laps.

The procedure for installing sealant is as follows. The tape is rolled over all seams and worked into the corrugations. The tape should not be stretched. Any paper backing must be removed prior to placing the lapping plates. At all points where three plates intersect, an additional thickness of tape should be placed for a short distance, to fill the void caused by the transverse seam overlap. A hot spud or a sharp tool dipped in machine oil is used to punch through the tape, to provide a hole for inserting the bolts. At least two tightenings of the bolts are usually necessary to achieve the required torque.

Sub-Drainage

The use of CSP sub-drainage, to insure positive groundwater control in the structural backfill, is recommended practice for all medium and large span underground structures. Care must be exercised to ensure the sub-drains do not act as culverts, or cross drains, with the potential for piping or other loss of backfill. The use of geotexile filter fabrics, as a pipe wrapping for sub-drains, should be considered.

Backfilling stormwater detention system.

PLACEMENT AND COMPACTION OF BACKFILL

Selection of Structural Backfill

For the roadway conduit to support the pavement or track above it adequately and uniformly, a stable composite structure is vital. Stability in a soil-steel structure interaction system requires not only adequate design of the structure barrel, but also a well-engineered backfill. Performance of the flexible conduit in retaining its shape and structural integrity depends greatly on the selection, placement and compaction of the envelope of earth surrounding the structure which distributes its pressures to the abutting soil masses.

Requirements for selecting and placing backfill material around or near the conduit are similar, in some respects, to those for a roadway embankment. However, a difference in requirements arises because the conduit may generate more lateral pressure than would the earth within the embankment if no structure existed. Therefore, the soil adjacent to the conduit must be compacted densely.

The structure backfill is usually considered to extend one diameter on either side of the structure, and from the invert to an elevation over the pipe of 300 mm or one sixth the diameter, whichever is greater. Trench construction requires less in width, as long as the trench wall is competent. Foundation and bedding may also be included in the structure, or engineered backfill.

Soil Design for CSP

All highway and railroad engineering departments have adequately detailed specifications for selecting and placing material in embankments. These specifications provide for wide variations in terrain and for available local materials, and so they can generally apply to backfill material around conduits for normal installations. If abnormal conditions exist at a specific site or if unusual performance is expected of a conduit and embankment, a soils engineer should be consulted for designing the backfill.

Backfill material should preferably be granular to provide good structural performance. Bank, pit run gravel, or coarse sands are usually quite satisfactory. Cohesive-type material may be used if careful attention is given to its compaction at optimum moisture content. If used, geotechnical advice is recommended. Very fine granular material may infiltrate into the structure and should be avoided when a high ground water table is anticipated. A coarse granular filter layer, or a plastic cover, may be placed between fine soil and the pipe. If infiltration is desirable, to lower the ground water table, geotextiles may be used to provide the necessary filtration function.

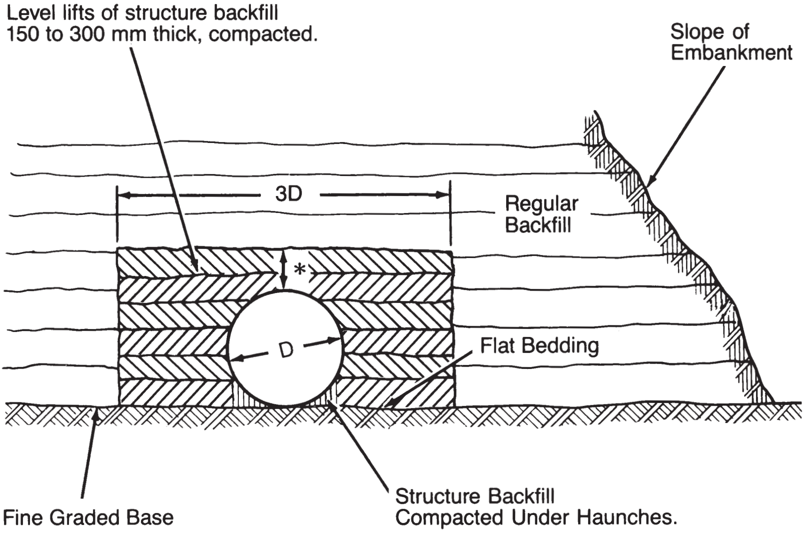
Soil Design for Soil-Steel Structures

Granular-type soils should be used as structural backfill (the soil envelope next to the metal structure). The order of preference of acceptable structure backfill materials is as follows:

1) Well-graded sand and gravel; sharp, rough, or angular if possible.
2) Uniform sand or gravel.
3) Mixed soils (not recommended for large structures).
4) Approved stabilized soil.

The structure backfill material should conform to one of the soil classifications from AASHTO Specification M-145. For heights of cover less than 3400 mm, A-1, A-3, A-2-4 and A-2-5 are recommended. For heights of cover of 3400 mm or more, A-1 and A-3 are suggested.

The extent of the structure backfill zone is a function of the pressures involved and the quality of the foundation soils, the trench wall or embankment soil, and the fill over the structure. Figure 7.6 shows a typical backfill envelope.



* Minimum cover of structure backfill is D/6 or 300 mm, whichever is greater.

Figure 7.6 Typical backfill envelope for round pipe installed on flat bedding, in an embankment condition.

Compaction Density

Experience and research have shown the critical density of backfill to be below 85% Standard Proctor Density. Backfill must be compacted to a greater density than critical to assure good performance. Backfill for all structures should be compacted to a specified Standard Proctor Density of 95% minimum.

Compaction Equipment

1. Hand Equipment

For compaction under the haunches of a structure, a pole or 50 x 100 mm (2 by 4) timber is generally needed to work in the smaller areas. Hand tampers for compacting horizontal layers should weigh not less than 9 kg and have a tamping face not larger than 150 x 150 mm. Ordinary sidewalk tampers are generally too light.

2. Mechanical Compactors

Most types of power tampers are satisfactory and can be used in all but the most confined areas. However, they must be used carefully and completely over the entire area of each layer to obtain the desired compaction. Care should be exercised to avoid striking the structure with power tamping tools.

3. Rollers

Where space permits, sheepsfoot, rubber-tired and other types of tamping rollers can be used to compact backfill around the structure. If rollers are used, fill adjacent to the structure should be tamped with hand-held power equipment. Be sure to keep the rollers from hitting the structure. Generally, smooth rollers are not satisfactory for compacting fills.

4. Vibrating Compactors

Vibrating equipment is excellent for compaction of granular backfills, but generally is unsatisfactory for clay or other plastic soils.

Placing Backfill Around Structure

Fill material under haunches and around the structure should be placed in layers 150 to 300 mm thick to permit thorough compaction. The fill is placed on both sides of the structure at the same time, or alternating from one side of the structure to the other side, to keep it close to the same elevation on both sides of the structure at all times. Figures 7.3 and 7.7 show how pipe-arch and round pipe structures should be backfilled. Pipe-arches require that the backfill at the corners (sides) be of the best material, and be especially well compacted.

Compaction can be done with hand or mechanical equipment, tamping rollers, or vibrating compactors, depending upon field conditions. More important than the method is that it be done carefully to ensure a uniformly compacted backfill.

Mechanical soil compaction of layers is preferred. However, when acceptable end results can be achieved with water consolidation, such as by jetting, it may be used. When water methods are used, care must be taken to prevent structure flotation or material freezing. It should be used only on free draining backfill material.

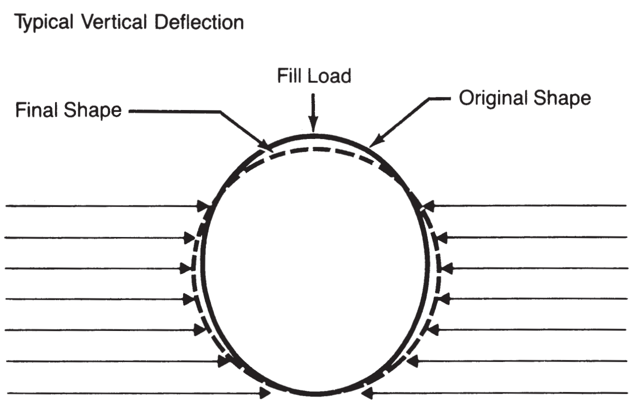


Figure 7.7 Corrugated steel pipe functions structurally as a flexible ring which is supported by and interacts with the compacted surrounding soil. The soil constructed around the pipe is thus an integral part of the structural system. Therefore it is important to insure that the soil structure or backfill is made up of acceptable material and that it is well-constructed.

Lifting spiral rib pipe into place.

Steps in Backfill Operation

Backfilling and compacting under the haunches are important steps in the backfill sequence. The material under the haunches must be in firm and intimate contact with the entire bottom surface of the structure. The area under the pipe haunches are more difficult to fill and compact and may not receive adequate attention. Care must be taken to assure that voids and soft spots do not occur under the haunches. Manual placing and compaction must be used to build up the backfill in this area.

Windrow backfill material on each side of the structure and place under haunches by shovel. Compact firmly by hand with 50 x 100 mm (2 by 4) tampers, or suitable power compactors (Figures 7.8 and 7.9).

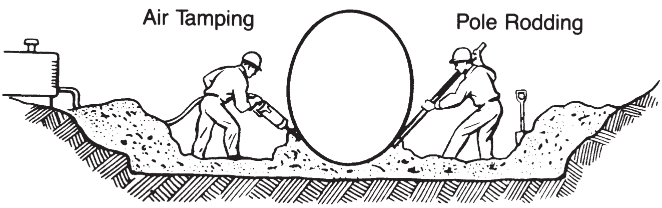


Figure 7.8 Backfill under the haunches should be placed and compacted by the most economical methods available, consistent with providing uniform compaction without soft spots.

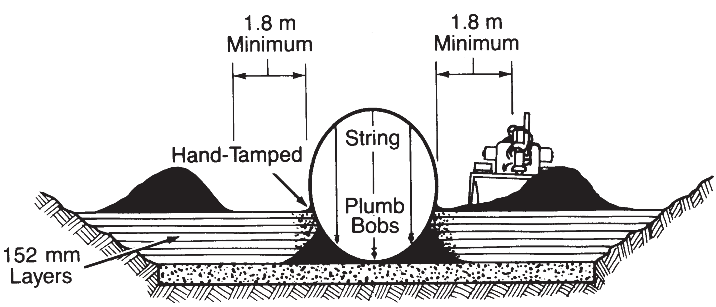


Figure 7.9 Backfilling with plumb bob monitoring.

Continue placing backfill equally on each side, in uncompacted layers from 150 to 300 mm in depth, depending on the type of material and compaction equipment or methods used. Each layer must be compacted to the specified density before adding the next. Generally, no more than a one layer difference in elevation on each side should be allowed. These compacted layers must extend at least one-half to one diameter on each side of the structure or to the side of the trench or natural ground line.

Backfill in the corrugation valleys and the area immediately next to the pipe should be compacted by hand-operated methods. Heavy compaction equipment may approach as close as 1000 mm. Any change in dimension or plumb of the structure warns that heavy machines must work further away.

Structural backfill material should be compactible soil or granular fill material. Structural backfill may be excavated native material, when suitable. Select materials (not larger than 75 mm), with excellent structural characteristics, are preferred. Desired end results can be obtained with such material with a minimum of effort over a wide range of moisture contents, lift thicknesses, and compaction equipment.

To ensure that no pockets of uncompacted backfill are left next to the structure and to minimize the impact of the material placement and compaction methods on the structure, it is necessary to follow a simple rule; all equipment runs parallel to the length of the pipe (Figure 7.10) until such time as the elevation of the backfill reaches a point that is at 3/4 of the rise of the structure.

Figure 7.11 illustrates poor practices. The possibility of uncompacted fill, or voids next to the structure are bound to arise with equipment operating at right angles to the structure. Mounding and dumping of backfill material against the structure will also impact the installation.

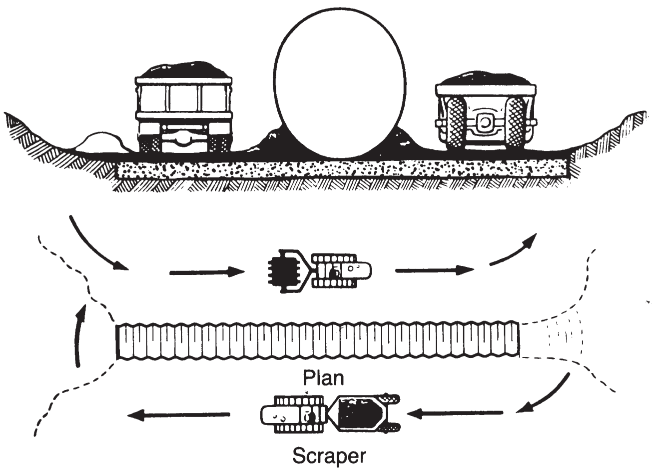


Figure 7.10 Good backfilling practice.

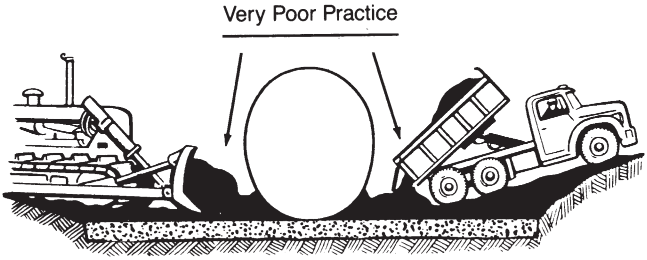


Figure 7.11 Poor backfilling practice.

Adding water to bring backfill to optimum moisture content

Backfill compaction adjacent to long span structural plate.

A balanced sequence of backfilling on either side is recommended:

- dump trucks or scrapers windrow granular backfill one-half to one span away (depending on size of structure and site) on either side;
- graders or dozers spread in shallow lifts for compaction;
- pedestrian-type compactors are used for close work, while heavier self-propelled vibratory drum compactors are used away from the structure and for the rest of the soil envelope once minimum cover is achieved;
- supervision of material placement and compaction methods and inspection of pipe shape provide invaluable feedback;
- hand work, or very light equipment, is used over the top of the structure until minimum cover is achieved.

In order to provide proper drainage of the backfill above the springline, it is desirable to grade or slope the fill slightly toward the ends of the structure (with no headwalls). This also facilitates fill over the crown, or locking-in the structure. Conversely, if headwalls have been built prior to backfilling, work should proceed from the ends towards the middle (Figure 7.12).

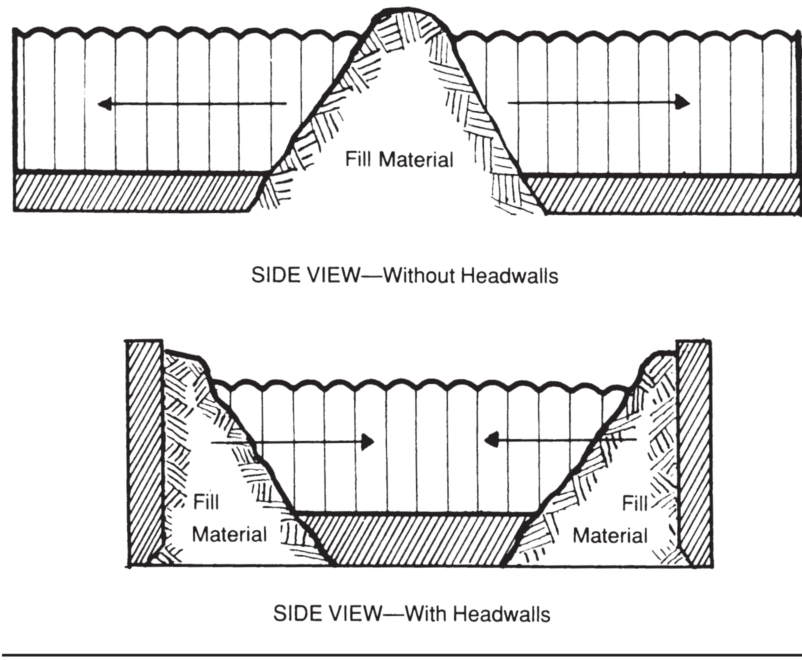


Figure 7.12 Recommended backfilling direction depending on presence of end walls.

The headwall first approach, although not recommended, may be useful where it is desirable to divert the stream through the structure and/or to give cut and fill access from both sides at an early stage. Care must be exercised to provide for surface runoff, to prevent ponding or saturation of the backfill from rainfall or snowmelt.

Backfill compaction over long span proceeds in a direction perpendicular to the length of the structure.

Shape Control

Shape control refers to controlling the symmetry of the structure during backfill, by control of the backfill operation.

Two movements may occur during backfill - "peaking", caused by the pressure of the compacting sidefills, and "rolling", caused by unbalanced fill or greater compaction on one side (Figure 7.13).

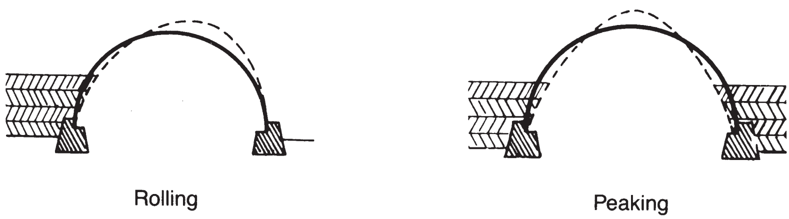


Figure 7.13 Rolling and peaking.

As a general rule, deflection in any direction, measuring greater than 2% from original shape, should not be allowed during the backfill operation.

The plumb-bob method of deflection monitoring (Figure 7.9) is convenient and effective. Suspend plumb-bobs, prior to backfilling, from the shoulder (2 and 10 o'clock) positions so that the points of the bobs are a specific distance from a marked point on the invert.

Peaking action can be detected when the points of the bobs move upwards. Corrective action is to keep equipment further away from the structure and/or to be cautious above compaction effort. It is unlikely that peaking will become severe, except for structures with long radius sides (i.e. vertical ellipses, medium and high profile arches, and pear-shapes).

Rolling action can be detected when the bobs move laterally. It is corrected by filling or compacting on the side towards which the bob has moved. For example, a roll to the right will be corrected by placing a higher fill on the right.

Careful monitoring of the plumb-bobs and prompt remedial steps prevent peaking or rolling action from distorting the structure.

If distortion greater than the recommended occurs, backfill should be removed and replaced. The steel structure will usually return to erected shape, unless distortion has been excessive.

Shop-cut bevel and skew ends act as cantilever retaining walls, and may not be able to resist the lateral pressures caused by heavy equipment and vigorous compaction. Temporary horizontal bracing should installed across beveled or skewed ends before backfill commences, if heavy equipment is to be used close to the cut ends. Alternatively, heavy equipment should be kept away from the cut ends of the pipe.

Vertical Deflection

The sides of a flexible structure will naturally push outward, compacting the side fills and mobilizing their passive resistance. As the sides go outward, the top moves downward (Figure 7.7).

This downward vertical deflection is normal. With reasonable backfill practice, any flexible underground structure can be expected to deflect vertically. With excellent practice, the deflection is usually less than 2% of the rise dimension.

If the sidefills are placed loose and/or not compacted, the sides of a flexible structure will move outward to a point where the allowable vertical deflection will be exceeded and pipe failure may occur by buckling. For smaller diameter round pipes, experience has shown that complete vertical (snap-through) buckling failure may occur at about 20% vertical deflection.

Positive soil arching usually occurs over flexible structures with depths of cover greater than the pipe diameter. If the column of fill over the pipe settles slightly more than the sidefills, some of the weight of this column is effectively transferred to the sidefills through shear. In the process, a positive soil arch is mobilized, which reduces the effective load on the structure. Once again, correct installation and backfilling are required for this to occur.

Minimum Cover

When the fill on both sides approaches the top of the structure, the same techniques of spreading shallow layers and compacting thoroughly must be continued as the fill covers the pipe. For the initial layers over the pipe, light compaction equipment, working across the pipe, is recommended.

Minimum cover for structures with spans of less than 3 m is span divided by 6 for highways and span divided by 4 for railways. The absolute minimum cover is 300 mm. Minimum cover for structures greater than 3 m span is outlined in Chapter 6.

After minimum cover requirements of the design have been met, and the structure is locked-into-place, further filling to grade may continue using procedures applicable to regular embankment construction.

Construction Loads

Depth-of-cover tables are based on extensive research, as well as experience and fundamental design principles. However, it must be emphasized that the listed minimums may not be adequate during the construction phase because of higher live loads from construction equipment. When construction equipment with heavy wheel loads, greater than those for which the pipe was designed, is to be driven over or close to the structure, it is the responsibility of the installer to provide the additional cover needed to prevent pipe damage.

Construction load on pipe.

Special Considerations for Pipe-Arches

Pipe-arches require special attention to the backfill material and compaction around the corners. A large amount of the vertical load over the pipe is transmitted into the soil at the corners. Therefore, just as with the foundation, the backfill adjacent to pipe-arch corners must provide at least 200 kPa of bearing resistance. In the case of high fills or deep trenches, a special design may be required for corner backfill zones. Round pipe is recommended in these conditions, rather than the pipe-arch shape.

Special Considerations for Arches

Structural plate arches require extra care during backfilling. Since arches are restrained at the footings, they are more susceptible to the peaking and rolling reactions described earlier (Figure 7.13). Half-circle, and medium or high profile arches, are particularly susceptible.

The ideal backfilling method would be to cover the structure with uniformly thick layers of material conforming to the shape of the arch. Unfortunately, this method is impractical. Arches are backfilled in the same manner as regular pipe, but extra attention is paid to the plumb-bobs to detect any rolling or peaking action. Loading loose earth on top of the crown (top-loading) can be used to reduce the peaking motion.

Cohesive Backfill

Clay soils are not recommended for use as structural backfill, as good compaction is difficult to obtain due to the very narrow optimum range for moisture content vs. density.

Backfilling high-profile highway underpass.

It is difficult to maintain allowable moisture content throughout the backfill operation as a result of snow and rain. Most native clays are above the allowable moisture content and require that either a drying operation be arranged or time is allowed for each lift to air-dry before the next lift is added. Generally, shallower lifts are required for acceptable end results.

If clay soils are used, much closer inspection and field testing must be exercised to assure good results.

Cohesive material should only be used for small pipes; not for larger structures. If cohesive backfill material is to be used, geotechnical advice is recommended.

Hydraulic Backfill

Cement slurries, or other materials that set up without compaction, may be practical for unusual field conditions. Limited trench widths, or relining of existing structures, may warrant the use of self-setting cementitious slurries or grout.

Care must be taken to ensure that all voids are filled, and that the material used will provide the compressive strength required. As with water consolidation techniques, measures should be taken to prevent flotation. Expert advice is recommended.

Submerged Bedding

In rare cases, the installation of corrugated steel pipe may have to be done "in-the-wet". Preferably, the bedding and backfill operation should be conducted entirely in the dry. For sites where it is not possible or practical to divert the stream, it is common practice to pre-assemble and lift, roll, or skid CSP or SPCSP into place.

Since such conditions make it very difficult to ensure good base preparation and proper backfill, the designer should consider first quality granular backfill materials. Expert advice is recommended.

Backfill Summary

In summary, the key points in the backfilling operation are:

1) Use good backfill material.
2) Ensure good backfill and adequate compaction under haunches.
3) Maintain adequate width of backfill.
4) Place material in thin, uniform, layers.
5) Balance fill on either side of the structure as fill progresses.
6) Compact each layer before adding the next layer.
7) Monitor design shape and modify backfill procedures if required.
8) Do not allow heavy equipment over the structure, without adequate protection, until minimum depth of cover is achieved.

PROTECTION OF STRUCTURE DURING CONSTRUCTION

It is important to protect drainage structures during construction because maximum strength does not develop until the fill consolidates. To avoid imposing concentrated loads far in excess of those the structure would normally carry, heavy construction equipment should not cross the structure prematurely. Also, heavy vehicles moving too close to the wall of the structure can create a concentrated load with harmful results.

For the finished structure, the minimum cover required is shown in Chapter 6 fill height tables. Construction loads may require additional cover, again as discussed in Chapter 6.

Box culverts are particularly sensitive to heavy construction wheel loads as well as cover levels. Consult the manufacturer for limits on construction loads and covers.

MULTIPLE STRUCTURE INSTALLATION

When two or more steel drainage structures are installed in parallel lines, the space between them must be adequate to allow proper backfill placement, particularly in the haunch and compaction area. The minimum spacing requirement depends upon the shape and size of the structure as well as the type of backfill material. The design methods in Chapter 6 (Figure 6.2 and page 228) provide recommended minimum spacings for structures.

The minimum spacings provide adequate space to place and compact the backfill. These minimum spacings can be reduced when crushed rock or other flowable backfill materials which naturally flow into the haunch, and require little compaction, are used. When controlled low strength material (CLSM) is used as backfill, the spacing restriction is reduced to that necessary to place the grout between the structures. Regardless of the materials, backfilling between and outside the structures cannot be done independently. Rather, backfilling must proceed on all sides of the structures simultaneously in order to maintain a balanced load.

The room required for the compaction equipment also should be considered in determining spacing between the structures. For example, with structural plate structures it may be desirable to utilize sheepsfoot rollers or mobile equipment for compaction between the structures. The space between structures should allow efficient operation of tamping equipment.

Stormwater detention system installation.

CONSTRUCTION SUPERVISION AND CONTROL

As in all construction activity, the owner should assign a knowledgeable member of the team to supervise the work in progress, and an inspector to ensure the installation is being performed to specification or accepted practice.

Standard small CSP culverts (150 to 1600 mm) should be checked at the foundation, bedding, haunches, springline and minimum cover stages. Generally, construction records need not be kept for CSP in this size range.

Larger CSP (1800 to 3000 mm) and SPCSP should have inspection at all stages of assembly and installation. Documentation of approval by the authorized inspector should be provided for each stage of construction. *Stage inspection* means that the contractor is required to have work inspected at specific points of progress, and to secure authorization to proceed to the next stage, in writing. A typical stage inspection form is shown in Figure 7.14.

SOIL-STEEL BRIDGE STRUCTURE
CONSTRUCTION CONTROL FORM

Owner ______________________ Location ______________________

Supervising Engineer and/or Auth./Rep. ______________________

Contract Firms and Supervising Personnel ______________________

____

Design Engineer ______________________

Geotechnical Assessment ______________________

Stage Inspection	Dates of Inspection	Action-Date and Time of Stage Approval	Authorization to Next Stage
1. Foundation			
2. Bedding			
3. Erection			
4. Backfill-Haunches			
5. Backfill to Spring Line			
6. Backfill to Crown			
7. Backfill to Min. Cover			

Note:

It is suggested that the above form be attached to the certificate of final inspection, and that "as-constructed" drawings be based on cross-section and deflection surveys at least six months after reaching profile grade. (Note: This is a typical control document only.)

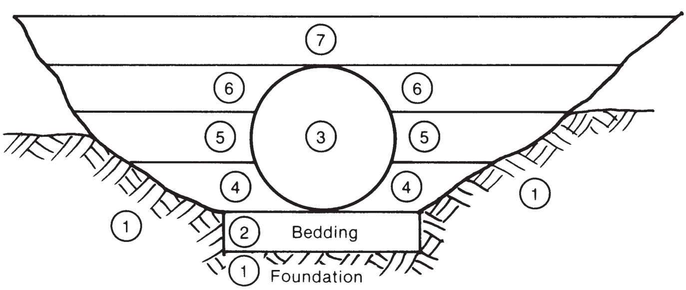


Figure 7.14 Typical inspector's document for construction control of large corrugated steel pipe structures.

Soil-steel structures with spans greater than 3 m should have continuous, and knowledgeable, on-site inspection personnel, authorized to accept or reject procedures or equipment. These engineered structures should be accorded the same degree of inspection and control as is given conventional bridge construction, which is recognized universally as a specialized discipline in engineering and contracting.

END TREATMENT

In many cases, the ends of corrugated steel pipe that project through the embankment can be simply specified as square ends; that is, not beveled or skewed. The square end is lowest in cost and readily adaptable to road widening projects. For larger structures, the slope can often be warped around the ends to avoid severe skews or bevels on the pipe end. When desired for hydraulic considerations, flared end sections can be furnished for shop fabricated pipe. Such end sections can be bolted directly to the pipe.

When specified, ends of corrugated steel structures can be cut (beveled or skewed) to match the embankment slope. However, as indicated in Chapter 6, cutting the ends destroys the ability of the end portion of the structure to resist ring compression forces. Thus, ends with severe cuts must be reinforced, particularly on larger structures. For more complete information see Chapter 6.

The maximum angle permissible for unreinforced skew cut ends is dependent on the pipe's span (or for multiple runs, their combined span) as well as the fill slope. Greater spans or steeper fill slopes limit the degree of skew that can be used without being reinforced with concrete headwalls or ring beams.

For longer span structures and multiple structures, this limit needs to be viewed in regard to maintaining a reasonable balance of soil pressures from side to side, perpendicular to the structure centerlines.

Cut ends are usually attached to the headwalls or ring beams with 19 mm diameter anchor bolts spaced at about 450 mm. (See Chapter 2)

During backfill and construction of headwalls, pipe ends may require temporary bracing to prevent excessive distortion.

The embankment slope around the pipe ends can be protected against erosion by the use of a headwall, a slope pavement, stone riprap, or bags filled with dry sand-cement mixture. Steel sheeting, welded wire, Bin-type retaining wall or gabion headwalls may also provide an efficient, economical solution.

End treatment of large structure.

LINING TO EXTEND LIFE

Need for Lining

Tunnels, conduits and culverts of various materials eventually may begin to deteriorate and lose strength. The decision to rehabilitate or replace the structure is usually based on available methods, safety and economics. Also, because of changing conditions, some older structures must be strengthened to accommodate present and future loads greater than those for which they were originally designed. This discussion covers some of the economical methods used to rehabilitate and strengthen these structures.

Masonry and concrete arches begin to deteriorate over the years. Freeze-thaw is a major source of deterioration, causing mortar to come out of joints, loosening the stone or brick. Excessive settlement will cause concrete to crack. Road salts will cause spalling of concrete. Heavier than anticipated loads further lead to foundation settlement and concrete cracking. The consequence of these deleterious actions is the need for the structure to be strengthened or replaced. Rehabilitation, in many cases, is the most economical method and can be accomplished with least effort.

Lining with a structural steel plate or steel liner plate arch takes little space, and conserves a maximum amount of the original waterway capacity. These steel arches can be supported on new concrete side walls or on original bench walls where feasible. Small arches, 2000 mm or less in span, can be lined with corrugated steel sections.

Thousands of masonry arches have been relined with satisfactory results.

Pressure Grouting

Pressure grouting the space between the old and new structures prevents further collapse of the old structure and avoids concentrated pressures on the new lining. Fifty millimeter grout couplings welded into the liner plates can be furnished at proper intervals for convenience in grouting. A mixture of 1 part cement to 3 parts sand, plus an additive for lubrication, has been found satisfactory. Modern grouting materials, with advantageous properties, are also available.

Grouting should be done carefully. Inspect frequently to see that voids are being thoroughly filled. In fact, due to shrinkage of the grout after set up, the top row of grout holes should be check-grouted after grout placement is completed to be sure that voids due to shrinkage have been filled. Care is required to avoid buckling the liner by using too high a pressure.

Other Shapes of Structures

The same relining method can be applied to full round, elliptical, or other structural shapes that have begun to show signs of deterioration or collapse. New corrugated steel pipe, structural plate or liner plate can be threaded inside an old structure to give it new life for long, trouble-free service.

Frequently, due to excessive deflection or joint settlement, the diameter of the new lining will be much smaller in order to have clearance for threading. In such cases it is sometimes necessary to jack or tunnel a supplementary opening alongside the existing structure to restore the lost end area. See Chapter 11, Tunnel Liner Plates. However, sometimes changes in runoff conditions mean that a smaller opening is acceptable. In such cases, a reduction in waterway area may not be a design issue. The required end area should be investigated before the engineer defines requirements.

Rehabilitation through relining can also be applied to storm or sanitary sewers beginning to show signs of weakening. Methods of liner installation for sewers will vary with sewer size and liner type, but the basic principles here are the same as those used in threading or lining any relatively short culvert open at both ends.

BACKFILL OF LONG SPAN STRUCTURES

Long spans are available in spans up to 23 m. Plate erection may differ from the recommendations for standard structures with added attention given to maintaining structural shape during installation. Proper backfilling and compacting are essential to structural integrity and should comply with instructions given under backfilling.

Foundation

Long span structures are relatively light in weight and often have significant rise dimensions. Typically, they exert lower bearing pressures on the foundation than the structural backfill materials beside the structure. Foundation bearing strength requirements generally relate to the need to support the sidefill without excessive settlement. If any relative settlement occurs, it is preferable that the structure settle relative to the side fill to avoid developing increased loads as a result of negative soil arching.

Where a shape with a bottom is used, plates have relatively larger radii and exert limited pressure on the foundation. It is often only necessary to provide a uniform, stable foundation beneath the structure to support erection activities.

For arch structures, footing designs must recognize the desired relative settlement conditions. The need for excessively large footings or pile supports is indicative of poor soil conditions and therefore, inadequate support beneath the sidefill.

Bedding

Bedding for long span structures with invert plates exceeding 3.7 m in radius requires pre-shaping for a minimum width of 3 m or half the top radius of the structure, whichever is less. This pre-shaping may be simply a V-shape, fine graded in the soil.

Backfill

While basic backfill requirements for long-span structural-plate structures are similar to those for smaller structures, their size is such that excellent control of soil placement and compaction must be maintained to fully mobilize soil-structure interaction. A large portion of their full strength is not realized until backfill (sidefill and overfill) is in place.

Of particular importance is control of structure shape. Equipment and construction procedures used should ensure that excessive structure distortion will not occur. Structure shape should be checked regularly during backfilling to verify acceptability of the construction methods used. The magnitude of allowable shape changes will be specified by the manufacturer.

The manufacturer should provide a qualified construction inspector to aid the engineer during all structure backfilling. The inspector should advise the engineer on the acceptability of all backfill materials and methods, and undertake monitoring of the shape.

Structural backfill material should be placed in horizontal uniform layers not exceeding 200 mm thickness after compaction and should be placed uniformly on

Backfill proceeds parallel to structure.

both sides of the structure. Each layer should be compacted to a density not less than 95% per (Standard Proctor Density). The structure backfill should be constructed to the minimum lines and grades shown on the plans. Permissible exceptions to the structural backfill density requirement are: the area under the invert; the 300 to 450 mm width of soil immediately adjacent to the large radius side plates of high profile arches and inverted pear shapes; and the first horizontal lift of overfill carried ahead of and under construction equipment initially crossing the structure.

Construction of large arch.

BOX CULVERTS

Box culverts are treated differently than soil steel structures. They are very stiff compared to long spans and this makes the placement and compaction of backfill materials easier. Box culverts require an engineered backfill zone that extends 1 m on each side of the outside of the box and up to the minimum cover. The granular backfill material in the engineered backfill zone should be placed uniformly on both sides of the box culvert, in layers not exceeding 200 mm in depth and compacted to a minimum of 95% Standard Proctor Density (ASTM D698). The difference in the levels of backfill on the two sides, at any transverse section, shall not exceed 400 mm.

Heavy vibratory compaction equipment should not be allowed within 1 m of the structure wall or close enough to cause distortion. At no time should the backfill material be dumped next to the structure wall so as to change the shape or the alignment of the structure.

The box culvert must be checked periodically during the backfilling procedure to ensure the shape is consistent with the manufacturer's tolerances. Place and compact the backfill over the top of the structure (once the side fill elevation is above 3/4 of the rise) using light equipment in a direction perpendicular to the longitudinal axis of the structure. No equipment should be allowed over the structure that would exceed the design live load.

It is always recommended that the manufacturer's representative or delegated person be present during erection and backfilling of the box culvert. Compaction testing during construction is the responsibility of the contractor.

A non-woven geotextile should be placed at the ends of reinforcing ribs to prevent backfill from entering the cavity between the barrel and the reinforcing rib (See Figure 7.15).

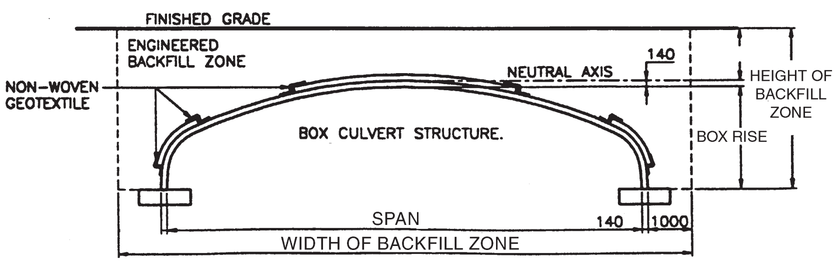


Figure 7.15 Backfill envelope.

STORM WATER DETENTION AND RETENTION STRUCTURES

When there are a series of closely spaced multiple lines connected into a header or manifold pipe, greater care must be exercised in placing the backfill, particularly under the haunches. Fine granular material or CLSM is often preferred.

SUMMARY

Proper installation of any drainage structure will result in longer and more efficient service. This installation and construction chapter is intended to call attention to both good practice and to warn against possible pitfalls. The principles apply to most conditions. It is not a specification but an aid to your own experience.

The following items should be checked to insure proper installation:

1) Check alignment and grade in relation to streambed.
2) Make sure the length of the structure is correct.
3) Excavate to correct width, line and grade.
4) Provide a uniform, stable foundation.
5) Unload and handle structures carefully.
6) Assemble the structure properly.
7) Use a suitable backfill material.
8) Construct bedding appropriate for the size of structure.
9) Place and compact backfill as recommended.
10) Protect structures from heavy, concentrated loads during construction.
11) Use backfill subdrains with properly graded fill.

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