Chapter 3
Special Design Considerations for Paved Trapezoidal Channels

3-1. Introduction

a. Background. Corps practice, prior to the 1960's, was to employ concrete pavement with expansion and contraction joints for paved trapezoidal channels. Typically, the channel pavements contained light reinforcement. Many types of joints and a wide variety of joint spacings were used. The experience with these channels shows that substantial joint maintenance is required. Routine cleaning and replacement of the joint sealing compounds and expansion joint materials is needed. Pavement blowups result from improperly constructed joints and an infiltration of incompressible materials into the joints. Some of these jointed pavements have also developed uncontrolled cracks away from the joints that require repair. Many states were eliminating transverse joints and constructing continuously reinforced concrete highway pavements during the 1950's. By the 1960's, continuously reinforced concrete pavement was no longer considered experimental, and the Corps began to use this type pavement for trapezoidal channels.

b. Pavement type. When concrete paving is used for trapezoidal channels in soil, it should be continuously reinforced concrete pavement (CRCP). CRCP is concrete pavement with continuous longitudinal and transverse reinforcement achieved by lapping the reinforcing bars. There are no control joints, and the continuous reinforcement is used to control cracks which form in the pavement due to volume changes in the concrete and foundation friction. Construction joints must be provided in CRCP at ends of construction pavements. Slab continuity is provided by continuing the reinforcing steel through the construction joints. Special measures are required when the continuity of the CRCP is terminated or interrupted with fixed structures or other pavements. The procedures provided in this chapter for the design of CRCP have been developed from observed performances of Corps flood control channels and the research of the design criteria used for continuously reinforced highway paving.

3-2. Constructibility of Paving Slabs on Sloped Sides of Channels

The characteristics of the in situ materials and the level of the water table are considered in determining the slopes of channel sides. Small trapezoidal channels with depths of 3 m (10 ft) or less may be constructed with side slopes of 1 vertical on 1.5 horizontal. Slopes between 1 vertical on 3 horizontal and 1 vertical on 2 horizontal are commonly used for the sides of larger channels. Vibrating screeds are commonly used in constructing paving slabs on sloped sides within this range of steepness. Cylinder finishing machines are available for finishing paving slabs with slopes up to 1 vertical on 3 horizontal in steepness. Control units should be mounted at the top or bottom of sloped sides to provide the capability of finishing upgrade to eliminate slump in the finished slab. Machines are available for trimming and slipforming the entire cross section of channels with bottom widths up to about 3.5 m (12 ft) in one pass. Paving construction procedures should provide for the curing protection of completed paving.

3-3. Drainage Provisions

Drainage systems for channels formed in soil should be placed beneath paving slabs on bottoms of channels to relieve excessive hydrostatic pressures. The drainage system beneath the side slope paving typically does not need to extend higher than one-half the channel depth due to natural drawdown of the water table near the channel. The drainage system may need to extend higher than one-half of the slope height if the normal ground water is nearer the ground surface or a shallow perched ground water condition is encountered. Closed and open drainage systems have been used in past designs. Based on previous discussion in paragraph 2-4*a*, closed drainage systems should be used for large channels and where long-term performance of the drainage system is critical to channel life. Open drainage systems are sometimes sufficient for smaller channels and short channel sections, such as sections under bridges. The open drainage system can serve as an additional measure of protection for sections of channel where excessive hydrostatic pressures are not expected to develop. The design of channel paving slabs should reflect possible increased hydrostatic pressures resulting from some loss of drainage system effectiveness during the life of the project as discussed in paragraph 2-4*e*.

a. Open drainage systems. Open drainage systems consist of collector drains which drain through weep holes in the sloped sides of the paving. The collector drains should be encased with a graded filter material to prevent the blockage of drains or the removal of foundation materials. The weep holes are commonly spaced not more than 3 m (10 ft) apart horizontally.

b. Closed drainage systems. Closed drainage systems consist of drainage blankets, collector drains, collector manholes, and outlet drains as shown in Plate 1. Refer to Appendix C for a typical analysis of a drainage system for a paved trapezoidal channel.

(1) Drainage blankets. A drainage blanket must retain the foundation soils, allow relatively free movement of water, and have sufficient discharge capacity to convey all ground water seepage which enters the blanket to the collector pipes. Therefore, the drainage blanket must satisfy the requirements for both a drain and a filter. An open-graded granular material with a relatively narrow range in particle sizes has a higher permeability and discharge capacity than a well-graded granular material. However, a well-graded granular material is generally required to meet filter criteria. A two-layer drainage blanket will often be required to satisfy both the drainage and filter requirements. Estimated quantities of seepage which will enter the drainage blanket should be determined by seepage analyses. EM 1110-2-2502, EM 1110-2-1901, and Cedegren (1987) provide guidance on design of the drainage blanket. The blanket should have a minimum thickness of 150 mm (6 in.) for a single layer system, and each layer for a multilayer system should have a minimum thickness of 150 mm (6 in.).

(2) Collector drains. Collector drains should be 150-mm (6 in.) minimum diameter polyvinyl chloride pipe with perforations in the bottom half of the pipe's circumference. Drains should be located at the bottom of the sloped sides, inverts of channels, and at intermediate locations, if required, to prevent development of excessive hydrostatic heads in the drainage blanket. Drains should be placed on top of the drainage blankets and should be encased with a coarse filter gravel. The coarse filter gravel should be covered with a material such as kraft paper to prevent clogging during placement of the concrete paving. Guidance on sizing the drain pipe is presented in TM 5-820-2 and Cedegren (1987). Guidance on sizing the perforations is presented in EM 1110-2- 2502, TM 5-818-5, and Cedegren (1987).

(3) Collector manholes. Collector manholes should be of precast or cast-in-place concrete and should be provided with secured, watertight manhole covers for cleanout access. Manholes should be provided with adapters or blind flanges for connecting outlet and collector drains. The size and spacing of manholes should be determined by a seepage analysis.

(4) Outlet drains. Outlet drains from collector manholes should be a minimum of 150 mm (6 in.) in diameter. The outlet drains should be provided with check valves to prevent the backflow of water from channels into the drainage system. However, it may be more practical to attach the check valves to the collector drains on the inside of the manholes where channels are subjected to heavy sediment.

(5) Maintenance considerations. The design should provide for access to the drainage system to allow future maintenance and rehabilitation. Manholes should be sized and constructed to provide access to collector pipes for flushing, jetting, etc. Provisions should be made for cleanouts at locations where collector drains and laterals intersect, at intermediate points between widely spaced manholes, and at other locations as required to provide access to all segments of a drainage system for maintenance and rehabilitation.

c. Pressure relief systems. Pressure relief systems should be developed for areas where perched ground water is encountered during construction.

d. Monitoring. The most positive method of monitoring performance of the drainage system is to install piezometers in the drainage blanket to directly measure hydrostatic pressures acting against the channel paving. Piezometers are sometimes installed to monitor the effectiveness of the drainage system. When piezometers are not installed, the drainage system should be monitored for discharge during drawdown periods. The drainage system should be evaluated during the inspections discussed in paragraph 3-12*a*.

3-4. Continuously Reinforced Concrete Paving

a. Concrete.

(1) Concrete strength. Concrete should have a minimum compressive strength of 25 MPa (3,000 psi). Channel paving is not normally designed for heavy vehicular loading as highway paving; therefore, the compressive strength is specified instead of flexural strength. Control of the concrete strength is important to the design since shrinkage increases as concrete strengths are increased. Concrete with nominal compressive strengths higher than 25 MPa (3,000 psi) will require greater percentages of reinforcement than those given in Tables 3-1 and 3-2. Therefore, CECW-ED approval should be obtained when the nominal concrete strength for continuously reinforced concrete channel paving exceeds 3,000 psi.

(2) Concrete thickness. Based on past experience, the minimum thicknesses of main channel paving

Table 3-1
Minimum Percentage of Reinforcing Steel

For Continuously Reinforced Concrete Paving of Invert and Side Slopes of Trapezoidal Channels

Longitudinal Reinforcing Steel

f'_c <25 MPa 3,000 psi - reinforcement = 0.40%

f'_c > 25 MPa 3,000 psi - reinforcement percentage as required by Equations D-1 and D-3 of Appendix D.

Transverse Reinforcing Steel

Widths* < 12 m (40 ft) = 0.15%

Widths > 12 m (40 ft) - Same as longitudinal reinforcement

* The total channel width should not be used, but instead, the width of the slab sections which extends between changes in slope or along the slope should be used.

Table 3-2
Longitudinal Reinforcing Steel

Design Reinforcing Steel Percentage Based on Average Seasonal Temperature Differential

(Equation D-2 of Appendix D, using $f'_c \leq$ 25 MPa 3,000 psi $f_t \leq$ 2 MPa 230 psi and f_y = 500 MPa 60,000 psi)

Delta T, °C (°F)	67 (120)	78 (140)	89 (160)
Steel Percentage	0.43	0.48	0.53

supported on soil foundations should be 200 to 250 mm (8 to 10 in.) for invert paving and 150 to 200 mm (6 to 8 in.) for slope paving, respectively. Thicknesses of pilot channel paving should be 250 mm (10 in.) or greater when flows carry scouring materials. The bottom slab and side slope paving thickness may be decreased to 150 mm (6 in.) for small side channels with the bottom slab less than 4.5 m (15 ft) wide and channel depths less than 3 m (10 ft). Paving of rock is usually not required; however, when required, the paving thickness should not be less than 13 mm (5 in). The designer should verify that the pavement is adequately designed for equipment loads which may occur during construction, maintenance, and operation of the channel.

b. Reinforcement. Reinforcing steel should comply with paragraph 2-3*a*. Typically, a single layer of reinforcement should be used. The longitudinal steel should be located at or slightly above the center of the slab. The spacing of longitudinal bars should not exceed two times the paving thickness, and the spacing of transverse bars should not exceed three times the paving thickness.

(1) Minimum cover. Reinforcement should be placed in such a manner that the steel will have a minimum cover of 75 mm (3 in.). The thickness of paving subjected to high-velocity flows or heavy sand scouring should be increased to provide a 100-mm (4-in.) cover on the reinforcement.

(2) Percentage of reinforcing steel. Reinforcing steel for CRCP slabs on soil foundations should comply with Table 3-1 or Table 3-2, whichever governs. The minimum percentage of reinforcing steel is given in Table 3-1, and the design percentage of longitudinal reinforcing based on the seasonal temperature differential is given in Table 3-2. Both longitudinal and transverse reinforcing steel in paving slabs on rock foundations should be in accordance with the longitudinal steel requirements of Table 3-1.

(3) Splices in reinforcement. Splices in reinforcement should conform to American Concrete Institute (ACI) Building Code Requirements for Reinforced Concrete 318 (ACI 1989). Splices should be designed to develop the full-yield strength of the bar. Fifty percent of the splices should be staggered, and the minimum stagger distance should be 1 m (3 ft).

(4) Bar size. Typically, bar sizes #10, #15, or #20 (#4, #5 or #6), are used for reinforcing CRCP. The bar size should be limited to a #6 to satisfy bond requirements and control crack widths. Reinforcing may be placed in two layers when a single layer would result in bar spacings that inhibit concrete placement.

c. Pavement subject to vehicular traffic. Channel pavement designed in accordance with paragraph 3-4*a*. and 3-4*b* is adequate for light vehicular traffic. Pavement that will be subjected to heavy vehicular traffic, such as loaded dump trucks, should also be designed in accordance with TM 5-809-12. The modulus of subgrade reaction k, used in designing for the wheel loads, is dependent on the drainage blanket material and the in situ foundation material below the pavement slab and these values should be selected by the geotechnical engineer.

3-5. Construction Joints

Construction joints should be placed in continuously reinforced paving to provide longitudinal joints between adjacent lanes of paving, where concrete pours are terminated at the end of the day or when delays in concrete placement would otherwise result in the formation of cold joints. The length of time for cold joint development depends on the severity of temperature, humidity, and other factors. Contract specifications should specify the maximum delay time permitted prior to the requirement for formed construction joints. Concrete should be placed alternately in lanes of channel with multiple lanes. Small channels may be constructed without longitudinal joints. Reinforcing steel should be continuous through all construction joints. In addition, the amount of longitudinal reinforcement through transverse joints should be increased 50 percent to accommodate stresses as the pavement gains strength near the joint. This is accomplished by the addition of a 2-m (6-ft) long bar, of the same size as the longitudinal bars, placed between every other longitudinal bar.

3-6. Expansion Joints

Expansion joints should be provided in continuously reinforced paving at channel intersections and where paving abuts other structures such as box culverts, bridge piers, and bridge abutments. A 25-mm (1-in.) expansion joint is acceptable for concrete linings on soft ground when end anchorage is provided. When end anchorage is not provided, a 75-mm (3-in.) expansion joint should be provided for continuous paving on soft ground. Expansion joints in paving on rock will probably not function because of the interlock and bond between the concrete and paving. However, a 12-mm (1/2-in.) expansion joint should be provided in paving on rock where thinner paving sections abut thicker sections or structures. Expansion joints should be provided with a waterstop, smooth dowels, sponge rubber filler, and sealant. Expansion joint details for continuous concrete paving are shown in Plate 1.

3-7. End Anchorage

There is not sufficient friction between the concrete pavement and the drainage blanket material or soft ground to prevent substantial movements at the ends of continuously reinforced concrete pavements due to temperature effects. End anchorage is typically used to minimize movement and damage at the ends of paving or where the continuity of paving is interrupted by other structures. An acceptable anchorage system consists of three structurally reinforced concrete anchorage lugs which are keyed into the foundation material. The lugs are usually 40 mm (15 in.) thick by 1 m (3 ft) deep, cast with dowels for anchoring the paving and spaced transversely at 3-m (10-ft) centers, beginning about 1.5 m (5 ft) from the end of paving. Lug depth may vary depending on soil and frost conditions. Anchor lugs should not be used in soils having poor resistance characteristics. Two layers of reinforcement should be provided in the pavement in the area of the lugs to develop the lug bending. Typical end anchorage details are shown in Plate 1.

3-8. Cutoff Walls

a. Scour protection at ends of concrete paving. Cutoff walls should be provided at the ends of the main channel and side channel paving to prevent undermining or the transporting of foundation materials from beneath the paving. Reinforced concrete cutoff walls should be provided when their use is suited to the foundation materials. Sheetpile cutoff walls should be provided in pervious materials. Cutoff walls should be keyed into undisturbed foundation materials and should extend up the side slopes to the standard project flood elevation. The unpaved reaches of the channels immediately upstream of cutoff walls in side channels, immediately downstream of cutoff walls in side channels, and immediately downstream of cutoff walls in main channels should be protected by riprap as required.

b. Cutoffs at top edges of paving. Cutoffs should be provided along the top edges of the channel paving. The depth of approximately 0.5 m (1.5 ft) is usually sufficient to prevent water from entering beneath the slab foundation due to minor amounts of scour or ground settlements. A typical detail of the cutoff at the top edge of paving is shown in Plate 1.

3-9. Intersecting Channels

a. Configuration. The design configuration of channel intersections should be coordinated with hydraulic engineers. Channel intersections and interruptions such as access ramps should have smooth curves, tangent to the main channel when possible to minimize the interruption of smooth channel flow. Abrupt changes in the normal channel cross section can cause standing waves which overtop the paving or impinge on bridges crossing the channel.

b. Intersection of side channel and main channel paving. Paving damage occurs when long lengths of intersecting side channel paving are made monolithic with the main channel paving. This damage occurs because of the “jacking” action during high temperatures. Therefore, an expansion joint should be placed in the intersecting side channel paving no more than 15 m (50 ft) from the intersection. When the intersecting side channel paving is more than 45 m (150 ft) long, the side channel subdrainage system should not connect with the main channel subdrainage system.

c. Drop structures. Where the invert of the main channel is below the invert of the intersecting side channel, a drop structure may be necessary. A concrete or sheetpiling cutoff wall should be provided at drop structures to block transmission of pressure from the higher to the lower channel paving.

d. Partially paved main channel. When channel side paving does not extend up to the standard project design flood elevation, provisions should be made at channel intersections to prevent undermining and scour which could cause failure and to prevent the occurrence of inflows which would increase the hydrostatic pressures beneath the paving. Channel side paving should be extended up to the standard project flood elevation or top of bank, whichever is less, for a distance of 15 to 30 m (50 to 100 ft) upstream and downstream of intersections. Consideration should also be given to increasing the depth of the cutoff at the top edge of the sides.

3-10. Deficiencies in Past Designs of Paved Trapezoidal Channels

a. Jointed paving of partially lined channels. Significant changes in channel water levels, combined with the formation of water paths to and under paving, have permitted inflows greater than drainage systems were able to relieve. These heavy inflows resulted in excessive uplift pressures which have caused failures in jointed paving of partially lined channels. The excessive uplift pressures caused separations at the joints in the channel bottom paving and subsequent movement of the separated paving sections by flowing water. Paving on the sloped sides of channels usually failed after the failure of bottom paving. Paragraph 3-9*b* discusses solutions to alleviate this deficiency.

b. Intersecting channels. Excessive expansion or elongation of paving due to high seasonal temperatures has caused “jacking” in paving at channel intersections. “Jacking” action causes the paving to lift off the supporting foundation and places its underside in compression. This compressive force causes localized cracking, popouts, and spalling. Expansion joints, similar to the details shown in Plate 2, should be provided at intersecting channel pavements to prevent damage. Reference is also made to paragraph 3-9*b*.

c. Penetrations. In past designs stress concentrations have caused failures in continuous paving when the continuously reinforced paving was interrupted by large penetrations for drainage culverts or pipes. Reinforced concrete frames, structurally integral with the continuous paving, should be provided as a stiffening system around penetrations or openings greater than 0.6 m (2 ft) to prevent failure of the channel paving. Thrust stiffening members should be provided in the longitudinal direction with thickened members at each end to collect and distribute the loads into the paving slab. A typical detail of the stiffening system is shown on Plate 2. When the channel paving is penetrated by structures with an outside dimension greater than 1.2 m (4 ft) the paving should be separated from the drainage structure with expansion joints which extend completely across the channel paving. A typical detail for treatment at large penetrations is shown in Plate 2.

3-11. Drainage Layer Construction

Major considerations during drain placement include:

a. Prevention of contamination by surface runoff, construction traffic, etc.

b. Prevention of segregation.

c. Proper compaction.

d. Proper layer thickness

e. Monitoring of gradations.

EM 1110-2-1901, EM 1110-2-1911, and EM 1110-2-2300 provide guidance for the construction of drainage layers.

3-12. Maintenance Considerations

A drainage system will be most effective when initially constructed and will deteriorate thereafter. Even with design precautions, deterioration of the system will occur. The system cannot be designed to prevent contamination throughout the life of a project without proper maintenance. Contamination of the drainage system can occur as a result of malfunctioning check valves, migration of foundation soils into the drainage blanket, growth of algae or bacteria, etc. Therefore, regular and routine maintenance is necessary for a drainage system.

a. Inspection and maintenance. The frequency of project inspections is discussed in paragraph 2-7. The inspection should check for proper operation of check valves, sediment in manholes, obvious differential movements between joints, leakage through joints, discharge of sands from collector pipes, etc. Routine maintenance should include removal of sediment from manholes and collector drains. Repair of check valves, etc., should be performed as deficiencies are noted, and all deficiencies critical to performance of the project should be corrected with urgency. Additional guidance for inspection and maintenance of drainage systems is presented in EM 1110-2-1901.

b. Rehabilitation. The majority of rehabilitation of drainage systems is in connection with contamination of the collector pipes and drainage blankets by the backflow of silt-laden channel water. Rehabilitation can also be required because of incrustation, growth of algae or bacteria, migration of fines in foundation soils into the drainage blanket, etc. Pumping, jetting, flushing, and treatment with certain chemicals or detergents can be used in rehabilitation. Guidance for the rehabilitation of drainage systems is presented in EM 1110-2-1901.

3-13. Repair of Damaged Paving

Several concrete paving failures have occurred in the past which required the removal and replacement of the failed sections. In some cases, the repairs were made without evaluating the cause of damage which allowed future failures to occur. Therefore, when repair measures are necessary the cause of the failure should be determined and all provisions should be taken to prevent any recurrence of the damage. When such repairs are made the reinforcing steel along the edge of removed paving section should be preserved and lapped with the new reinforcement in the repair section. The area of the longitudinal reinforcing steel in small repaired areas is often doubled. This is done because the edges of the existing channel paving around the break-out move due to temperature changes, and the concrete in the repaired area shrinks during curing. High-early strength concrete is sometimes used to shorten the curing time of the repair concrete. For repairs requiring long periods of construction, sheetpile cutoffs should be installed beneath the existing paving at upstream and downstream limits of repaired area. These cutoffs are provided to prevent further damage to the paving should flood flows occur which are larger than those which can be controlled by the construction cofferdam and the bypass system.