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Earthwork for Retaining Structures and Abutments

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Structural elements are often incorporated in earth embankments to retain or reinforce the soil mass. This chapter outlines the general design concepts and construction considerations for conventional earth-retaining structures and abutments as well as those with reinforced or mechanically stabilized backfills. Because such structures are often critical features of the highway system, details of design and construction that, if overlooked, may compromise their safety or reduce their life expectancy deserve careful attention.

CONVENTIONAL EARTH-RETAINING WALLS AND ABUTMENTS

Design Concepts

Conventional earth-retaining structures may be classified into two broad categories: rigid and flexible. Rigid retaining structures are commonly constructed of concrete or masonry. Rigid retaining structures used in highways include gravity, semi-gravity, cantilever, counterfort, and buttressed walls. All have occasionally been used for bridge abutments, some more commonly than others. Flexible retaining structures may be unbraced, as in the case of interlocking sheet piling, gabion walls, and crib walls. Alternatively, they may be braced or anchored, as in sheet pile walls, bulkheads, or tieback walls. Flexible walls are not commonly used for abutments. See *Foundation Engineering* (Peck et al. 1974) and *Design Manual 7.2* (U. S. Navy 1982) for information about the design of conventional retaining walls.

A properly designed conventional retaining structure must satisfy the following requirements:

1. The structural components of the wall or abutment must be capable of resisting the lateral earth pressures as well as any other loadings such as surcharges and hydraulic forces acting on it.
2. The wall or abutment must be safe against overturning and sliding at the base.
3. The foundation soil must have sufficient bearing capacity to avoid bearing failure due to both horizontal and vertical loads.
4. The wall and the soil mass it supports must be safe against an overall slip failure.
5. The structure must be able to tolerate the total and differential settlements caused by compression of the foundation soil.

All factors relating to the stability of a retaining structure are affected by the magnitude and distribution of the lateral earth pressures acting on the wall. In the design of rigid retaining walls with cohesionless backfills, it is standard practice to assume that the minimum or "active" earth pressure state exists because wall movements of less than 0.5 percent of the wall height are sufficient to mobilize the active earth pressures. On the other hand, movements less than this will result in greater earth pressures than assumed in design. Construction engineers need to remember this in case conditions occur during construction that effectively reduce or prevent wall movement. Examples of these conditions include the use of temporary bracing during backfilling and the discovery that the foundation of the wall is partially or entirely on bedrock instead of soil, as assumed in design. Abutments, on the other hand, are often designed assuming at-rest or greater earth pressures, especially if they are an integral part of the bridge.

The magnitude of the lateral earth pressures acting on the wall depends on the backfill, soil type, and placement density, as well as the compaction operations. Clean, free-draining granular soils should be used whenever possible. Backfills containing clay, silt, or organic matter are susceptible to swelling, shrinkage, creep, and frost action, all of which may cause excessively large earth pressures and detrimental settlements. For example, shrinkage cracks in clay may become filled with water and create undesirably large pressures against the wall. Particular care should be taken to prevent the use of swelling clays as backfill (see Chapter 9, section on Compaction Problems with Swelling Clays). Silt is also sensitive to moisture changes. Increase in moisture may cause a collapse of the soil structure and result in significant settlements. To reduce detrimental settlements behind abutments supported on piles, some states use free-draining select granular material as backfill.

Partial or total submergence of a backfill results in an undesirable increase in the active thrust acting on the wall. Seepage pressures are one of the most common causes of retaining wall failures. Reduction of water pressures can be enhanced by the use of free-draining backfill and by providing effective drainage of the backfill. Unexpected surcharge loadings, including traffic and temporary construction loads, can also be very detrimental to the wall. Although it is ordinarily desirable to achieve good compaction of the backfill, heavy compaction equipment operating near the wall can induce lateral stresses on the wall much greater than the active earth pressures assumed in the design.

Construction Considerations

Walls are normally constructed by first erecting the wall and then backfilling behind it.

Excavations

To provide room for wall construction, it is common to over-excavate the soil back of the wall. Whenever an open excavation is needed, a safe slope or temporary shoring is required for the excavation. The maximum safe inclination of the slope depends largely on the shear strength of the soil, but the Occupational Safety and Health Administration (OSHA) requires that all trenches exceeding 5 ft in depth be properly shored.

If a retaining structure is constructed near a stream or river, the excavation may be below the groundwater level and special precautions are needed to protect the construction. Temporary flooding may leave soft muck in the bottom of the excavation that must be stabilized or removed before backfilling.

Control of Water During Construction

Surface water can cause erosion and deterioration of a slope, or even induce a slope failure. It can also reduce the capability of the soil to support structures or construction equipment. As discussed in Chapter 5, section on Surface Water, surface runoff should be directed away from the site during construction. In addition, surface runoff from adjacent areas should be prevented from encroaching on the site. The simplest way to control surface water is to excavate a trench or construct a dike or curb around the perimeter of the site and dispose of the water by gravity or by pumping from sumps.

Retaining walls are sometimes constructed below the groundwater table, and dewatering may be required to provide a working platform (see Chapter 5, section on Subsurface Water). Although there are many methods available for this purpose (well points, horizontal drains, and the like), the simplest technique is to construct perimeter trenches and connect them to sumps. This method is most effective when the excavation is in cohesive material and the groundwater is not too high. The trench should be installed as far from the location of the wall base as practical to prevent disturbance due to groundwater seepage. In certain cases, impermeable barriers to reduce or eliminate the inflow of groundwater into the work site may be more effective than dewatering. Usually the selection of the method is left to the contractor.

Backfilling

Backfilling is generally the most important single aspect in the construction of walls. This is especially true when the space for compaction equipment is restricted. Inadequate compaction may cause excessive settlements or even failure of the structure. This is especially important when the abutment supports a spread footing foundation for a bridge (Cheney and Chassie 1982; Wahls 1983).

If possible, the backfill materials should be compacted at their optimum water content (Chapter 3). Backfill should be compacted in layers or lifts, which should slope away from the wall. The lift thickness depends on the compaction equipment and the backfill material, but typical lift thicknesses are 6 to 8 in. Thicker lifts may be used for coarser granular soils. When hand-held compactors are used, the loose lift thickness should be about 4 in. The recommendations of Chapter 4, particularly the sections on Compaction, Compaction in Confined Areas, and Structure Backfill, should be followed.

Constant supervision is necessary to obtain the proper lift thickness, especially in areas of limited working space. If the fill material is dumped in a pile and spread by hand, considerably thicker lifts than specified may result, leaving pockets of poorly compacted backfill behind the wall.

The specification for the gradation and density of the backfill should be adhered to strictly. Do not permit the contractor to substitute materials for the backfill without the prior approval of the engineer in charge. If clean granular backfill is specified, do not allow materials to be placed with clay or silt fines, organic materials, or any other material that does not meet the specifications.

The use of frozen materials in backfills is generally recognized as bad practice (see Chapter 4, section on Cold Weather Construction and Chapter 8, section on Frost Action in Embankment Design and Construction). Frozen backfill may look quite satisfactory when placed, but it can be extremely troublesome and totally unstable after it thaws. Care is needed during backfilling to prevent damage to any geotextile or geocomposite drains installed on the back of the wall or, in the case of anchored sheet pile walls, to tie rods. The soil in front of the toe and anchorage must also be adequately compacted.

Drainage

Conventional walls built above the groundwater table are normally designed with the assumption that no significant water pressures exist behind the wall. To ensure that this is the case, through-the-wall weep holes or a collector-drainage system, or both, are commonly provided and will be shown on the plans. Today a combination of granular drain materials and geotextiles, or a geocomposite drain, are commonly used (Christopher and Holtz 1985).

During installation, contamination of the drainage materials and system must be avoided. The drain outlet pipe, which connects to the drain, must also be carefully installed. Because proper drainage is very important to the long-term performance of the wall, all aspects of the drainage system construction should be carefully inspected.

To reduce percolation of surface water into the backfill, the site should be graded to direct runoff away from the back slope. Sometimes interceptor drains on the back slope are used (see Chapter 5, section on Surface Water). Periodic maintenance is also necessary to minimize runoff infiltration.

Scour

If a retaining wall is located adjacent to a stream or river, it is susceptible to scour during floods. Consequently, the erosion protection system is very important and must be constructed strictly according to the plans.

WALLS WITH REINFORCED BACKFILLS

Design Concepts

It is becoming increasingly common to use some type of tensile reinforcement in backfills behind retaining walls in order to reduce the earth pressures acting on the wall face. A variety of reinforcing materials such as steel strips, sheets of geotextiles or geogrids, welded wire mats, metal grids or bars, and various anchor systems have all been successfully used for this purpose. Although soils are relatively strong in compression and shear, they are very weak in tension. By incorporating a material of high tensile strength in the soil, the composite soil mass will exhibit greater strength and be able to tolerate larger movements without distress. The mechanisms of reinforcement for the different types of materials have been summarized by Mitchell and Villet (1987) in NCHRP Report 290. The reinforced retaining structure must satisfy both external and internal stability requirements. For external stability, all the requirements described in the section on Design Concepts for conventional retaining walls must be met. Internal stability must satisfy two criteria: (a) the tensile reinforcement must not break, and (b) there must be sufficient friction or bonding between the soil and reinforcement so that it does not pull out from the backfill. Many of the reinforcing systems commonly used today are proprietary, and designs and contract specifications are often prepared by the individual material suppliers or contractors.

The inclusion of tensile reinforcement in permanent highway structures requires that the reinforcement be sufficiently durable throughout its design life. Examples of problems include creep and chemical degradation of geosynthetics and the corrosion of metals.

Construction Considerations

Earthwork construction control for reinforced structures is essentially the same as that required for conventional retaining structures, but with a few additional details that require special attention. Several of the proprietary firms have published quality control procedures and manuals (for example, Reinforced Earth Co., 1987). The contractor should obtain a copy from the company or the design engineer and follow the recommendations as closely as possible. Field substitutions of backfill materials or changes in construction sequence, procedures, or details should *only* be permitted with the express consent of both the responsible geotechnical or preconstruction design engineer and the proprietary system material supplier.

Site Preparation

Before placement of the reinforcement, the ground should be graded to provide a smooth, fairly level surface. The surface should be clear of vegetation, large rocks, stumps, and the like; depressions should be filled; soft spots should be excavated and replaced with backfill material; and the site should be proof rolled (see Chapters 4 and 6).

With reinforcing systems utilizing precast concrete facing panels, a small strip footing is commonly employed as a foundation under the facing panels.

Handling of Reinforcement Materials

Specific material-handling instructions for proprietary reinforcement materials are generally provided by the individual material suppliers. Geosynthetics, especially geotextiles, should be protected from sunlight and extreme temperatures. Concrete facing panels should be handled carefully to prevent cracking and chipping. Damaged or improperly handled reinforcing materials should be rejected.

Placement of Reinforcement Material

After the reinforcement is in place, it should be examined carefully. Any damaged or torn materials should be removed or repaired as detailed in the specifications. In no case should construction equipment be allowed to operate directly on any reinforcement before fill is placed. In the case of geosynthetic reinforcement, it should be unrolled transverse to the alignment of the embankment or wall, and wrinkles and folds should be eliminated. Procedures for seams and overlaps detailed in the plans and specifications should be adhered to strictly.

Fill Placement and Compaction

Special attention should be given to ensuring good compaction of the backfill, especially near the face of the wall. Otherwise detrimental settlements behind the face may cause a downward drag on the reinforcement, which might induce excessive tensile stresses, particularly near the face where reinforcements are attached to concrete panels (see Chapter 4, sections on Compaction in Confined Areas and Structure Backfill).

At the end of each day's backfilling operation, the last lift of fill should be sloped away from the wall facing to direct any possible runoff away from the face.

Alignment of Facing Panels

Alignment of the structure is usually established by initial layout of the foundation wall section and strip footing, if required. In addition, some type of external bracing, formwork, or scaffolding, usually erected in front of the wall face, is often used to maintain the alignment of especially the first lift. For all reinforced structures, particularly for those that do not use precast concrete facing panels, care should be taken not to allow heavy construction equipment to operate too close to the face. Otherwise undesirable bulging of the face may result.

REFERENCES

ABBREVIATION

FHWA Federal Highway Administration

Cheney, R. S., and R. G. Chassie. 1982. *Soils and Foundations Workshop Manual.* FHWA, U. S. Department of Transportation, 338 pp.
Christopher, B. R., and R. D. Holtz. 1985. *Geotextile Engineering Manual.* Report FHWA-TS-86/203. FHWA, U. S. Department of Transportation, 1024 pp.
Mitchell, J. K., and W. C. B. Villet. 1987. *NCHRP Report 290: Reinforcement of Earth Slopes and Embankments.* TRB, National Research Council, Washington, D. C., 323 pp.
Peck, R. B., W. E. Hanson, and T. H. Thornburn. 1974. *Foundation Engineering,* 2nd ed. Wiley, New York, N. Y., 514 pp.
Reinforced Earth Company. 1987. *Quality Control Manual.* Arlington, Va., 8 pp.
U. S. Navy. 1982. Foundations and Earth Structures. *Design Manual 7.2.* Naval Facilities Engineering Command, Alexandria, Va.
Wahls, H. E. 1983. *NCHRP Synthesis of Highway Practice 107: Shallow Foundations for Highway Structures.* TRB, National Research Council, Washington, D. C., 38 pp.