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Special uses of reinforced earth in the United States

Utilisation spéciale de la terre armée aux U.S.A.

L'utilisation de la Terre Armee comme materiel de construction dans les Etats Unis a connu un essor considerable depuis sa premiere utilisation comme remblai retenue dans le domaine routier.

A la suite, on decrit les projets dans lesquels des dalles de fondation, des bassins de sedimentation, des digues de retention et des ouvrages a la mer en Terre Armee, chacun repondant a des exigences de dimensionnement variees et peu usuelles furent mises en oeuvre.

Dans chacun des cas, la heureuse realisation de ces ouvrages a permis des economies considerables.

Introduction

In the United States during the last 10 years, a number of innovative special uses and applications for Reinforced Earth structures have been developed, tested and applied.

Of particular interest are those designed and built as foundation slabs and foundation reinforcements; as sedimentation basins and ponds; as containment dikes for liquefied natural gas (LNG) and crude oil; as marine walls constructed in tidal waters and capable of withstanding significant cyclical hydraulic pressures; and as retaining walls of unusual configurations.

These special uses have achieved, much the same as Reinforced Earth structures in more traditional transportation and highway applications, project economies on the order of thousands of dollars each and have demonstrated the same speed of construction.

This paper will outline several of the most significant applications of these special use Reinforced Earth structures.

Foundation Slabs

Reinforced Earth slabs were first used in the United States in conjunction with the construction of a portion of relocated Route 202 near Philadelphia, Pennsylvania. The new highway alignment through this location crossed a dolomitic area which contained numerous and widespread sinkholes that had caused a collapse along the existing Route 202 nearby. The initially conceived solution to bridge this irregular sinkhole area consisted of a two-way reinforced concrete slab to support the roadway. The slab design, 3 feet (.9m) thick, 150 feet (45.8m) wide and 1,100 feet (335.5m) long would span a 50 foot (15.3m) diameter design cavity without significant deflection. In addition, a grouting program was proposed to fill the voids in the dolomitic strata and stabilize the deteriorating subsurface condition.

The alternate Reinforced Earth solution consisted of alternating layers of steel strips and crushed stone backfill constructed to form a flexible membrane slab capable of spanning the design cavity. (Figure 1) As constructed, the Reinforced Earth slab obtains its strength to resist deflections by its placement under a minimum of 15 feet (4.6m) of overburden and by the construction of peripheral Reinforced Earth side walls which would develop additional passive resistance under design conditions.

In the slab, reinforcing strips were spaced 5-inches (127mm) on centers, both transversely and longitudinal, and bolted to the walls as necessary to achieve the required slab width. In all, two transverse and two longitudinal layers of steel were placed with a 12-inch (305mm) layer of granular backfill between each strip layer. The gradation and thickness of the lower backfill layer was so selected to guarantee its performance as an inverted filter to prevent loss of fill between the edges of strips if a sinkhole collapse should occur. This design, using flexible slab membrane analogy, provided that maximum deflections, under design conditions, would be limited to a few inches.

The Reinforced Earth slab proved to be 25% less costly than the reinforced concrete slab.According to the owners, a savings of $500,000 and an unexpected reduction in construction time of almost 60% were realized.

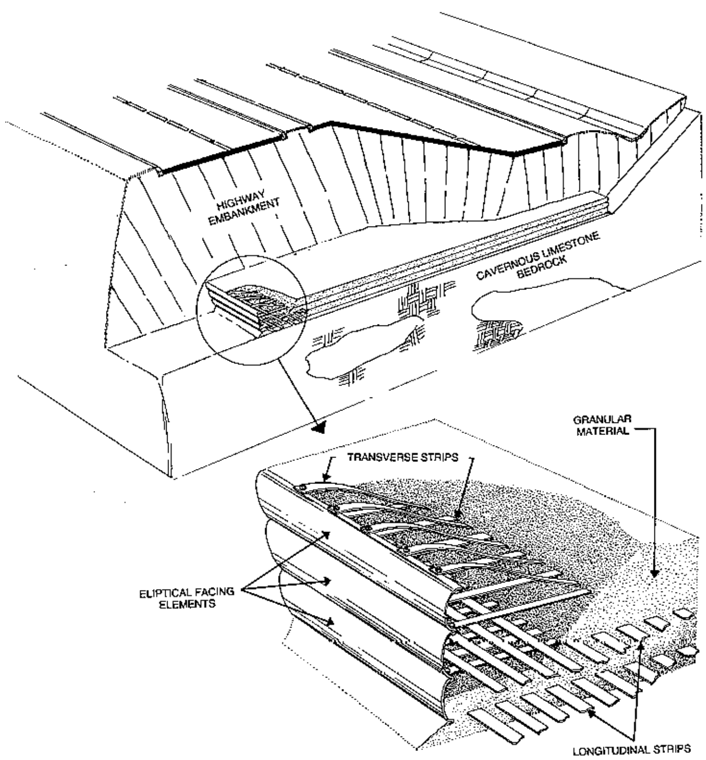

Fig.1: Pennsylvania Route 202 Slab

A similar project was constructed a year later in Mercer County, West Virginia. There, the Reinforced Earth slab was used in lieu of an alternate solution which would have required excavation through approximately 60 feet (18.4m) of overburden to reach and choke the neck of existing and well-developed sinkholes (Figure 2).

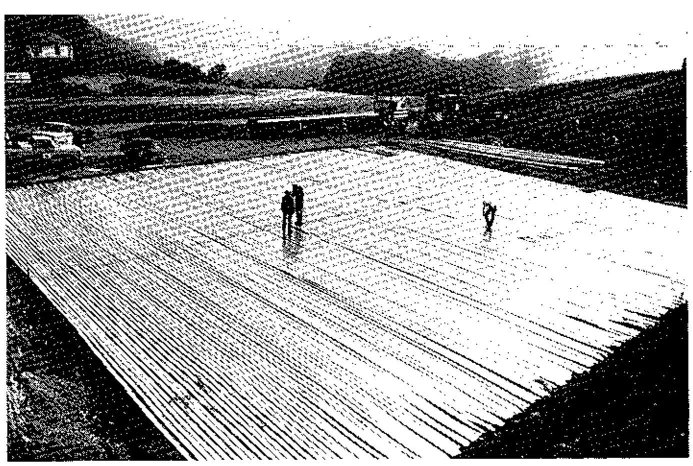

Fig. 2: Mercer County Slab

Reinforced Earth slab technology has also been successfully used for the improvement of bearing capacities under Reinforced Earth retaining walls constructed over compressible soils of marginal bearing capacity.

In Tennessee, in connection with the construction of a slide repair on Route 73, a Reinforced Earth wall was conventionally designed and constructed over a Reinforced Earth zone. This foundation reinforcement, which extended from the sloping and irregular rock surface to a convenient and level foundation elevation, reduced the required height of wall and the length of the reinforcing strips. This solution substantially avoided the excavation of an unstable backslope (Figure 3) insuring project success.

An essentially similar technique was used to provide a uniform foundation area for another slide correction structure constructed on Heart O'Hills Road in Washington state.

In each of these foundation reinforcement applications, either longitudinal or transverse rows of reinforcing strips at relatively wide spacings were sufficient to provide the required foundation strengthening and, more important, uniform bearing conditions.

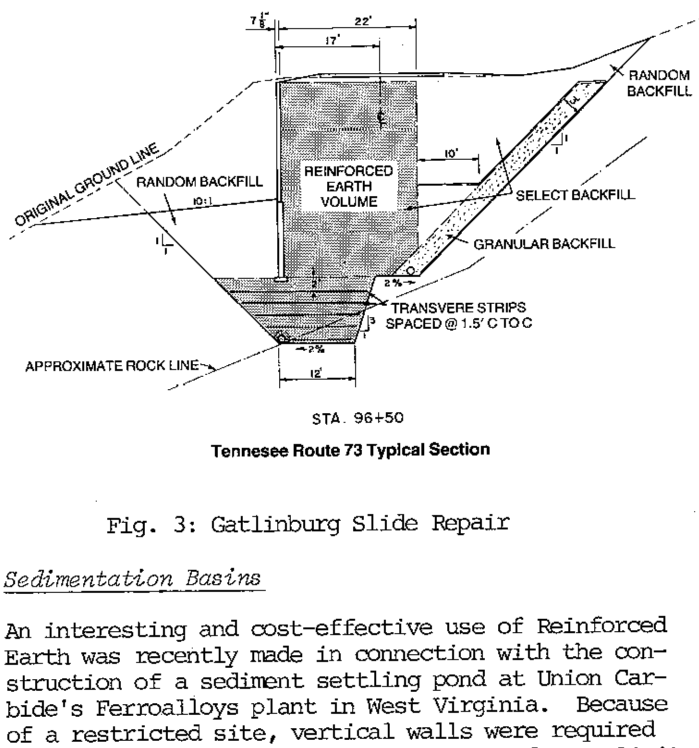

Fig. 3: Gatlinburg Slide Repair

Sedimentation Basins

An interesting and cost-effective use of Reinforced Earth was recently made in connection with the construction of a sediment settling pond at Union Carbide's Ferroalloys plant in West Virginia. Because of a restricted site, vertical walls were required on the interior sides of the basin in order to limit the overall size of the pond (Figure 4). Water tightness of the basin was provided by placing an impervious Hypalon® membrane over the walls and bottom. To insure that potentially rough concrete panel edges would not tear the liner, the pre-cast concrete panels were first covered with polystyrene boards. Intake pipes and a discharge structure were conveniently located.

Reinforced Earth walls, in combination with impervious liners as demonstrated in this initial project, should prove to be an attractive engineering solution to settling ponds for a variety of industrial uses.

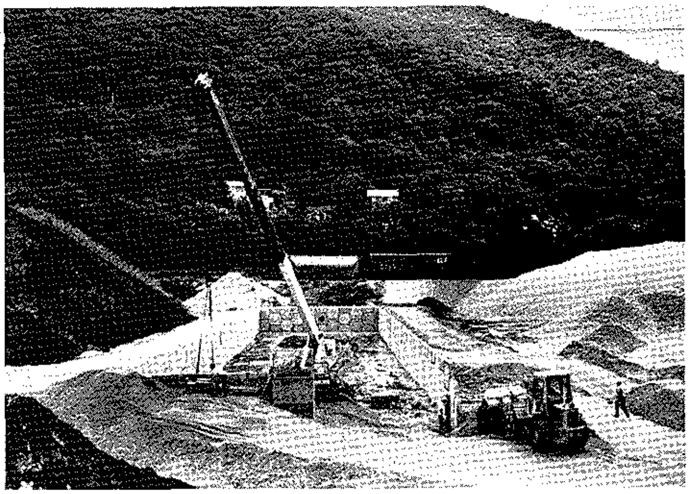

Fig. 4: Union Carbide Sedimentation Basin

Containment Dikes

Containment of hazardous liquids in tank storage areas has been traditionally achieved by low earthen dikes. This containment concept results in shallow ponds with large surface areas which increase the difficulties associated with control under accident conditions and require large land areas for tank farm layouts.

At the Columbia LNG Corporation's Cove Point LNG Receiving Terminal in Maryland along the Chesapeake Bay, design requirements dictated the use of relatively high dikes to restrict the impoundment surface area around each tank. The lack of available land area further limited the choices available to the designers.

To satisfy these requirements, the site designers examined composite dikes of either soil cement, metal bins, tied sheetpiles or Reinforced Earth structures constructed on earthen embankments. Reinforced Earth was selected as the most economical solution which fully responded to the technical requirements (Figure 5).

Now, the secondary containment system at the Cove Point Terminal employs a series of 15-foot (4.5m) high Reinforced Earth structures built on top of 10-foot (3m) high earth embankments to achieve the total height considered necessary in light of vapor dispersion considerations (Figure 6). The dikes are either doubled-faced or single-faced with an earthen 2:1 backslope, depending on general plant layout requirements.

In addition to earth and fluid pressure design considerations, the structures were design to withstand thermal excursions imposed by an instantaneous primary containment vessel failure, impoundment of liquefied gas to within one foot of the dike top, and associated sudden chilldown and ignition of the impounded liquid.

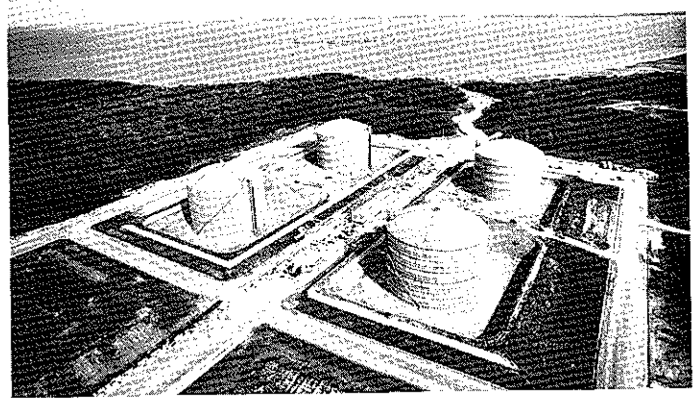

Fig. 5: Cove Point LNG Receiving Terminal

Prior to structure design, a thorough field investigation was conducted to assess the integrity of the individual structural elements. In case of an accident, the most significant stresses felt by the precast concrete facing elements and by the aluminum alloy reinforcing strips would result from chilldown by the impounded open pool of LNG which would produce a temperature drop to -260°F and/or from ignition of the impounded LNG which would produce subsequent temperature rise to +2000°F.

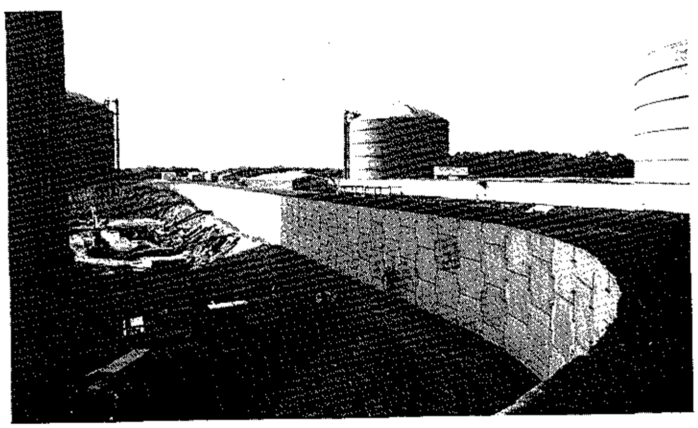

Fig. 6: Cove Point Secondary Containment Dike

The results of the field tests clearly demonstrated that no structural loss of integrity under these conditions should be anticipated. In fact, the only damage noted in the test was minor spalling of the concrete face elements.

Aluminum magnesium reinforcing strips were utilized for both the single-and double-faced walls at this site because of the relatively acid nature of the available granular backfills and near-surface ground water regime.

At the Valdez crude oil terminal of the Trans-Alaska Pipeline in Alaska, a Reinforced Earth containment dike system was constructed along the eastern end of the large East Tank Farm (Figure 7). Again, severe space restrictions precluded the use of earthen dikes. The inside earth slope of the dike was surfaced with an asphaltic concrete lining to insure imperviousness under design accident conditions.

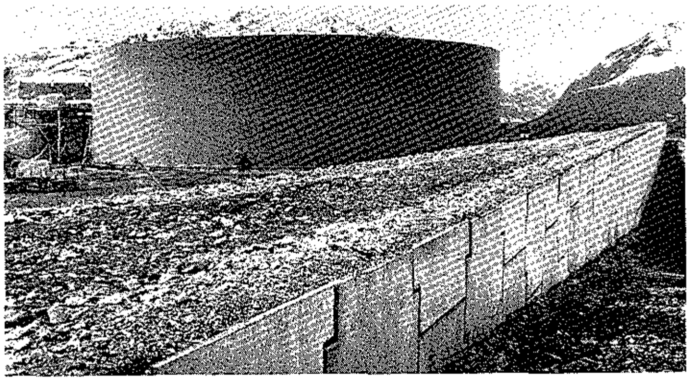

Fig. 7: Valdez Containment Dike

Marine Structures

A number of marine structures have been completed in the United States, each involving the solution of unusual design or construction problems.

For the riverport facility at Owensboro, Kentucky, a 33 foot (10m) high by 690-foot (210m) long Reinforced Earth retaining wall was required to provide the grade separation necessary to insure the facility's full use during flood stages of the Ohio River. During periods of normal river flow, cargo is off-loaded by a crane operating on a lower roadway in front of the wall.

Design parameters required that the wall be capable of supporting loads imposed by railway operations on tracks placed within 10 feet (3m) of the wall face and of withstanding the differential hydralic heads imposed by rapidly receding river levels.

To facilitate drawdown in the backfill and to reduce differential hydralic heads, a three-foot-thick crushed rock filter blanket was placed directly behind the facing panels and a filter cloth was glued over all joints on the backside of the panels to prevent potential migration of fines.

The founding elevation of the wall was established above the normal river level and construction generally proceeded "in the dry". However, when construction had reached an approximate height of 16.4 feet (5m) the structure was unexpectedly topped by a flood. This flood provided an early and unplanned test of the wall's ability to withstand rapid drawdown conditions. No structural damaged resulted.

In the fall of 1978, the structure experienced a more severe flood which crested 11.5 feet (3.5m) from the top of the wall and again, no structural damage resulted (Figure 8).

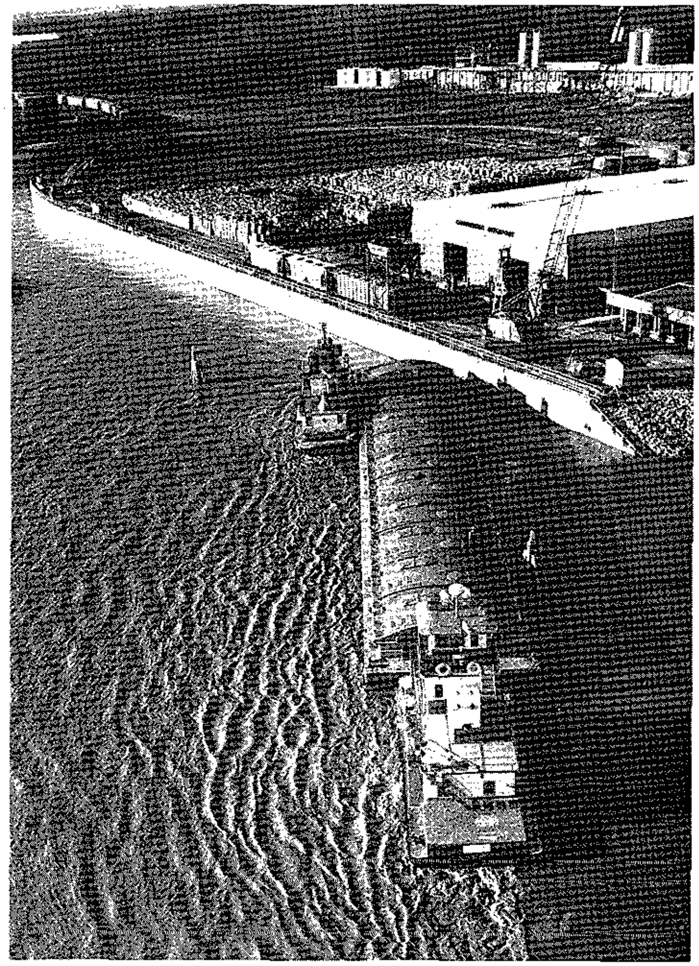

Fig. 8: Owensboro Riverport During Flood

A somewhat similar design problem was solved in connection with the construction of a seawall to support a shore road at Petersburg, Alaska. There, Reinforced Earth was an economical alternative to a cast-in-place concrete wall.

The required founding elevation was below mean tide levels. This necessitated construction "in the wet" during daily high tides (Figure 9). Erection of panels and placement of backfill and reinforcing strips normally occurred during daily low tide periods. After the level of construction had exceeded normal high tides, erection was able to proceed totally in the dry.

In addition to differential hydralic forces generated by daily title fluctuations, the completed structure will also be subjected to storm tide levels. To reduce drawdown-induced differential heads, the backfill used consisted of extremely permeable crushed rock , rather than the combination of crushed rock blanket and typical backfill such as was used at Owensboro.

Unusual Retaining Wall Configurations

Until the design and construction of the curved, tiered walls along Interstate 70 at Vail Pass, Colorado, Reinforced Earth walls utilized a cruciform panel geometry. Architectural effects were achieved by texturing the panel surface and/or adding color to the concrete mix.

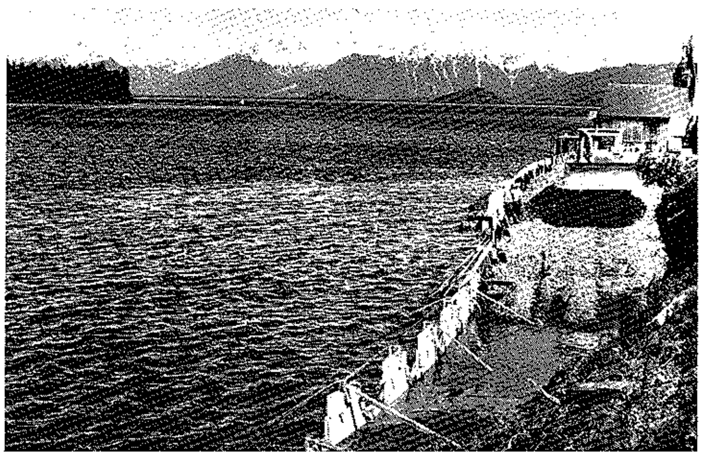

Fig. 9: Petersburg Retaining Wall Under Construction

At several previous sites, a two-tiered system of relatively high vertical walls was used to retain side hill fills. For the Vail Pass projects, however, architectural requirements and environmental constraints dictated the use of low, multi-tiered retaining walls which would permit subsequent plantings within the horizontal shelf to mitigate the visual impacts (Figure 10). A curved panel configuration was chosen by the designers for aesthetic reasons. The largest of the curved panel retaining walls at Vail Pass is 56 feet (17.07m) and incorporates seven tiers of 8 feet (2.44m) effective height each. Total tier height is 10 feet (3.05m); however, 2 feet (0.61m) of embedment per tier is incorporated. Since each tier is stepped back 6 feet (1.83m), the retaining wall has an effective slope of 3/4:1.

The design concept utilized considered the aggregate tiers as a unified mass capable of withstanding the conventionally-developed horizontal earth pressures. Each tier, in addition, was designed as an individual structure capable of supporting surcharges imposed by tiers constructed above.

Construction of these curved panel, tiered walls proceeded conventionally. At each new tier level, an unreinforced concrete leveling pad was constructed.

As demonstrated at Vail Pass, this tier configuration can be less costly than vertical structures of equivalent heights.

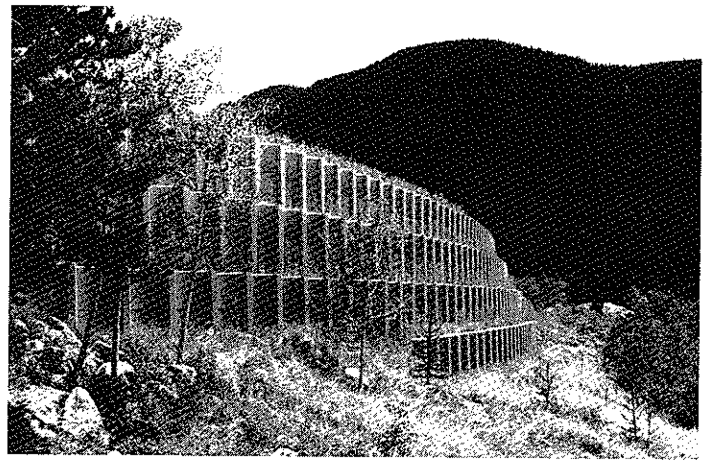

Fig. 10: Vail Pass Tiered Retaining Walls

Conclusion

The concept of Reinforced Earth as a new construction material as originally conceived by Henri Vidal[1] has proved to be extremely adaptable to a wide range of structural requirements. Progress in design and engineering as well as construction technology has broadened the domain of utilization as demonstrated by these project applications.

Bibliography

[1] Vidal, H. "The Principal of Reinforced Earth", Highway Research Records, Washington, D. C. No. 282, 1969.