C.R. Coll. Int. Renforcement des Sols. Paris 1979.

VERGE G.C.

W.P. Brown and Partners Pty. Ltd, Australia

Reinforced earth applications for bridge abutments in Australia

Les culées de pont en terre armée en Australie

La terre armée trouve de plus en plus d'applications dans les culées et les murs de soutènement de ponts en Australie. Cet article passe en revue les plus récentes utilisations de ce matériau depuis les vraies culées où les surcharges du tablier sont transmises par l'intermédiaire d'une semelle de répartition jusqu'aux murs de soutènement résistants soit aux efforts horizontaux du pont soit à la poussée du remblai de la rampe d'accès ; la charge verticale étant supportée par des pieux.
Les principes de dimensionnement et les détails des différents dispositifs sont analysés. Des exemples d'ouvrages sont utilisés pour illustrer les influences importantes des caractéristiques des fondations et des exigences de construction.

1. Introduction

The reinforced earth bridge abutment originally developed in France and Spain has found favour with bridge designers as an economical and technically satisfactory alternative solution to the traditional concrete wall or box abutment. The development and early applications of reinforced earth retaining walls in Australia have been reported extensively Boyd et al (1978), Verge et al (1977) and Leece (1978). Since the first reinforced earth bridge abutment was completed at Swanport, South Australia, bridge designers have gained confidence in the practical application of this new technique and the number of such structures being designed and built is increasing.

The acceptance of this novel form of construction comes from the practical advantages and economy of reinforced earth, the simple and rapid form of construction using unskilled labour, the technical advantage of eliminating differential settlement between the bridge deck and the approach embankment and thus obviating the need for a relieving approach slab. Additionally, in those cases where weak compressible foundation soils occur the replacement of conventional deep piles or piers by reinforced earth results in substantial cost savings.

The satisfactory long term performance of the reinforced earth abutment is a necessary condition for continued acceptance by bridge designers. The safety of the bridge depends upon the integrity of the reinforcement and its resistance to corrosion in the soil backfill. Research is continuing on this and other fundamental aspects of reinforced earth, however, the test results and performance of structures built to date provide a reasonable confirmation of the sound judgement of those bridge designers who have accepted these abutments as a satisfactory alternative to traditional structures.

2. Design Principles and Practice

The principles of design of reinforced earth abutments are simple and based on the analysis of internal and external stability as developed by Vidal, Schlosser and others at the Laboratoire Central des Ponts et Chaussees and reported extensively in the rapidly developing technical literature related to reinforced earth. A reinforced earth mass acting as a bridge abutment (Fig. 1) is similar to a retaining wall subjected to the additional concentrated surcharge loads from the bridge deck. The ability of a reinforced earth mass to transmit concentrated loads has been demonstrated by field measurements and by the large number of structures successfully completed.

Several combinations of loading on the bridge deck and the approach are considered to determine the most adverse compatible combination for each part of the abutment. The stability of the sill beam is analysed first to ensure that the proportions are satisfactory under the action of the bridge loads, earth pressure and embankment design surcharge. These loads are usually in accordance with the bridge design specification of the National Association of State Road Authorities. The standard vehicle loading comprises a series of 44 tonne trucks or equivalent lane loads and an embankment surcharge equivalent to 1.2 m of fill.

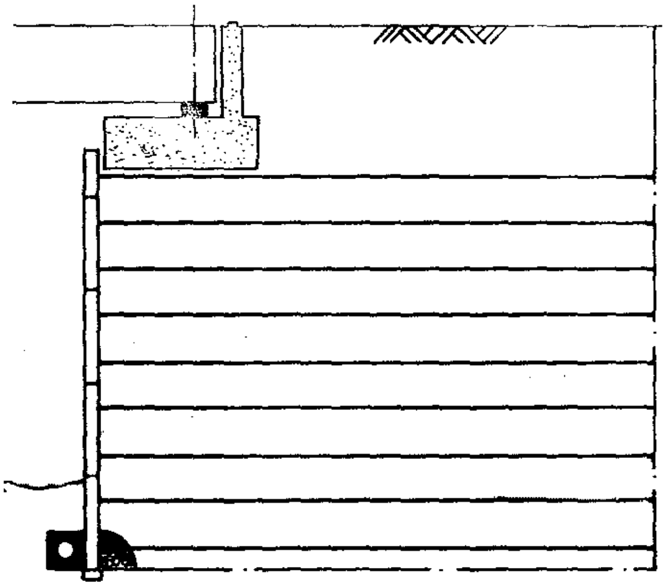

Fig. 1 Reinforced Earth Abutment

In practice the sill beam proportions are chosen to limit the equivalent base pressure within the range 150 to 200 kPa and to reduce the eccentricity of the resultant force at the base of the sill.

Analysis of the reinforced earth mass below the sill beam follows the usual practice of checking reinforcement tension, adherence and facing pressure at each level. This process is simplified by adopting proportions for the reinforced earth mass according to the following guidelines:

$H < 12$ m	$L = H$ m
$H > 12$ m	$L = 0.8\,H$ m

where H is the total height of the structure and L is the length of the reinforcement.

The distribution of vertical load at the base of the sill beam (Fig. 2) is assumed usually to follow a line at 1 on 2 vertically commencing at the back edge of the equivalent loaded width (using the Meyerhof effective width for the eccentric loading). The horizontal load is distributed to the reinforced earth mass by a wedge with rear face inclined at (π / 4 + ϕ / 2) and following a triangular distribution over the depth of this wedge with the maximum value at the top.

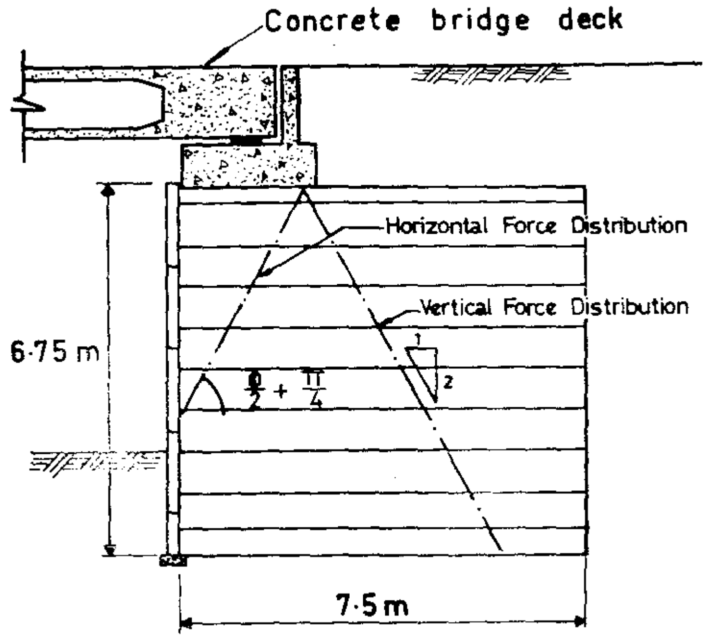

Fig. 2 Distribution of Bridge Forces within the Abutment

The repetitive nature of these calculations leads naturally to the development of computer programs for the complete design of the abutment. Such a program has been written to compute the external stability and pressures for the sil beam and the overall reinforced earth block for each load combination. Reinforcement density is selected at each level and the tension and adherence safety factors output along with the average reinforcement density for assessing the efficiency of the design and estimating the cost of the wall. The pressure distribution on the wall is plotted at each level and compared with the capacity of the reinforcement as provided.

3. Layout and Detailing of Structures

During recent years there has been a trend towards the standardisation of bridges especially in short and medium spans. Standard precast concrete beams and slab units and standard designs using steel universal beams have assisted this move towards simplification and reduction in total design effort for bridge decks. However, the bridge substructures - abutments, piers and foundations have tended to be custom designed and detailed to suit the particular requirements of each project. The standard components of reinforced earth facing panels and reinforcement provides one useful method of introducing some standardisation of the design of abutments.

The facing panels are important because of their effect on the appearance of the completed structure. As the scope and diversity of structures built in reinforced earth has increased so has the development of a variety of special panels cast from the 1.5 m x 1.5 m master mould. Special panels are cast to accomodate stepping and sloping walls, short ends, corners with a range of angular deviation and capping units.

A variety of concrete surface finishes, textures and colours are produced also to match different job requirements. Curved walls can be built conveniently by deviating adjacent panels at each joint without the need for special corner units.

The arrangement and detailing of each project depends upon the constraints and requirements at the particular site. In general, the simplest arrangement and frequently the most economical is the open type abutment with walls generally parallel to the lower access way and separate from the small bridge wing walls incorporated at the ends of the sill beam. Frequently the walls are curved or tapered in plan and sloped down to produce an open effect and to reduce the quantity of retained fill in the embankment. This arrangement has the practical advantages of permitting generous tolerances in set out and erection and minimum requirement for special panels and co-ordination between the abutment facing and the bridge superstructure. It permits also severe skew spans to be built with little difficulty and complication.

Where space is limited or side access is required a closed or box abutment with substantial side walls generally parallel to the overbridge may be needed. If the space is strictly limited the reinforced earth walls may be constrained to the alignment of the bridge parapet and the detailing at the junction becomes critical. The tolerance between the prefabricated wall components and the insitu concrete bridge deck and wing walls requires careful co-ordination and often special units are required. For skew spans these problems are increased and the detailing at the acute corners requires special care. Of course these problems exist for conventional skewed structures, however, the simplicity and convenience of the prefabricated facing may not be realized if complicated details are adopted.

4. Completed Projects

4.1 Reinforced Earth Abutments

At the Swanport deviation near Murray Bridge, South Australia, the reinforced earth abutments support a 13.5 m single span concrete bridge carrying the highway over a local raod. The foundation conditions at this site posed no special problems. The soil profile consists of a surface layer of sandy clay (SC) overlying layers of medium - low plasticity clay (CL) and high plasticity clay (CH) and weathered sandstone. Tests indicated that shallow spread footings would be adequate for conventional piers and abutments and using an allowable bearing pressure of 450 kPa differential settlements were expected to be less than 5 mm. There were no drainage problems at this site and no ground water was encountered during the field investigation.

The calculated design pressures for the worst combination of loading on the bridge deck and approaches are 135 kPa under the sill beam and 255 kPa at the base of the reinforced earth block. As expected, these values are quite low for this relatively small bridge and well within the capacity of the foundations.

An economical conventional solution for the bridge would be three spans with piers and spill through abutments or a single span and wall abutments. A cost comparison by the Highways department showed a direct saving of at least 10% for the reinforced earth solution at this site. In addition to this direct cost saving, other advantages were realized during the construction of the bridge. The prefabricated facing panels and reinforcement enabled rapid erection of the walls by unskilled labour; the placing of fill in the approach embankments proceeded at the same time as the wall erection; construction was carried out with light plant working behind the wall thus providing a minimum obstruction to traffic along the road.

Another bridge abutment at Botany, Sydney, (Fig. 2) is designed to support a concrete deck carrying six lanes of highway traffic and spanning 32 m over a railway line which is being widened and upgraded to serve a port development. Foundation conditions at this site consist of loose sands overlying dense sands at a depth of about 12-14 m with a layer of silt or sandy silt at about 18-20 m depth below natural surface.

During the preliminary design two types of abutment were considered and detailed cost estimates prepared for each. A conventional reinforced concrete retaining wall supported on steel piles driven into the dense sand was estimated to cost at least twice as much as the reinforced earth abutment and shallow sill beam. The total cost of the reinforced earth abutment and prestressed slab bridge deck showed a saving of about 40% compared with the conventional scheme.

Reinforced earth is a very economical solution at this site because of two additional factors: the loose sands require deep foundations for the conventional structure and the reclaimed sand adjacent to the bridge provided for construction to be carried out in two stages thus permitting a minor diversion of traffic along the existing road and later over the first completed section of the bridge. The prefabricated components of the wall facing enabled this detail to be accomplished easily by adding a short return wall at the junction of the two stages.

The calculated design pressure at the base of the reinforced earth block is 320 kPa. Under this surcharge loading the loose sands are expected to settle approximately 100mm most of which should occur during the construction of the embankment and prior to the casting of the sill beam. The settlement caused by the superimposed load from the bridge deck and any long term effects is not expected to be significant. In any event the smooth transition from the bridge to the embankment is an advantage for the reinforced earth abutment compared with the conventional piled abutment with practically no settlement and its approach embankment which would be expected to settle almost as much as the reinforced earth abutment.

The Botany site is close to the sea and the reclaimed sand filling might be expected to contain a significant proportion of chloride. However, tests showed only traces of chloride and sulphate in the sand stockpiles apparently because of the leaching due to exposure to the weather. Test results for soil resistivity 9 000 ohm cm and pH of 6 were satisfactory also. The long term durability and corrosion resistance of galvanised steel reinforcement is a vital consideration for the designer of a bridge abutment. Extensive research on the corrosion of metals buried in soils was begun in 1910 by the U.S. National Bureau of Standard and continued until 1955. The results of these tests as reported by Romanoff (1967) showed that in well drained soils having high resistivity such as sandy and silty loams, the rate of corrosion decreased after a few years to an insignificant rate. Darbin et al (1978) in a comprehensive review of the NBS data appropriate to reinforced earth environments derived charts relating average loss of thickness of metal to predicted service life. For the standard 5 mm thick galvanised reinforcement and 1 mm corrosion allowance as currently adopted a service life in excess of 100 years is predicted. As a safeguard against the adverse effects of an abnormal rate of corrosion, test speciments are placed in the structure; these samples will be pulled out and examined at intervals to ensure that the safety of the brige is assured during its design life.

The possibility of unauthorised excavation and damage to the reinforcement by mechanical excavators should be foreseen also. Road authorities have developed standard signs for placing on the walls as a warning against such abuse either by digging at the top of the wall or too close and too deep at the bottom of the wall. If an excavation is required in the future this can be provided for. At Botany such an excavation will be required at a nearby culvert which passes under the reinforced earth walls and is bridged by concrete planks and side abutments. The future widening and deepening of the culvert will require difficult excavation in the water bearing sands, so cut off walls are provided at the abutments and carried down below the level of the future excavation. Similarly, excavations for future oil pipelines and watermains are provided for by carrying the concrete facing panels down somewhat deeper than normal, thus reducing the possibility of undermining the wall and leaching of sand fill from behind the panels.

Difficult foundation conditions at another railway overpass at Doonside in Sydney required a detailed analysis of the stability of the reinforced earth abutments to ensure the safety and integrity of the walls during construction. This site is located on an alluvial flat adjacent to a creek; the surface is a plastic boggy clay, clayey sand abut 5 m thick overlies the shale bedrock. The railway embankment is about 3 m above the general level of the flat and the road approach embankments are 13-14 m high.

Reinforced earth abutments were chosen to support the concrete deck because of the cost saving compared with deep foundations and the relatively low overburden pressure of the abutment comparable with that caused by the approach embankments. The bridge designers preferred a box abutment with wing walls returned parallel to the roadway and the approach fill battered at 1 on 2 and spilling against the outside face of the return walls. At the abutment face the embedment of the panels, usually about1 m below the general level of the flat, was increased due to the railway embankment. The overall effect of this embedment and filling against the outside face of the wall, is to improve the stability of the abutment and to increase the factor of safety against an overall shear failure in the foundations.

Tests on the soil indicated that the embankment should be built over a period of 6 months and the load applied slowly so that the pore pressures will be dissipated as the soil consolidates. The effective strength parameters of the soil for the drained condition would then apply. Because of the importance of this dissipation of pore pressure to the stability of the structure, the pore pressures in the consolidating layers will be monitored during construction. Simple standpipe type piezometers will be used to measure the increase in pore water pressure and to regulate the rate of construction.

Concrete facing panels are generally used for bridge abutments in urban areas because of favourable cost, ease of application and flexibility of layout and surface finish and generally acceptable appearance. The steel facing panels have been used on some projects especially those in remote areas such as mining developments where lower freight costs, lower weight and ease of handling manually are favourable.

Steel facing panels were used for the abutments supporting a two span overbridge carrying Del Park Road over a bauxite haul road at ALCOA's mine at Pinjarra, Western Australia. This layout was chosen in preference to a conventional four span structure with spill through side spans. The abutment walls run parallel to the haul road centreline and wing walls are returned parallel to the Del Park Road embankment with the bottom of the facing stepped up as the embankment fill spills around the outside walls. Foundation conditions at this site posed no particular problems as the soil comprises a compact gravelly clay over weathered granite. Backfill was a low grade bauxite readily available as overburden from the surface mine and meeting the standard specification for grading and chemical properties.

4.2 Reinforced Earth Walls at Abutments

Where the bridge superstructure can tolerate only small differential settlements and the foundation conditions are not sufficiently uniform to permit a reasonable prediction of the expected settlement the reinforced earth abutment may not be a satisfactory solution. In this case the vertical load of the bridge deck may be supported by piles or piers and a reinforced earth abutment wall used to support the embankment.

Such an arrangement was adopted for the bridge over Darling Mills Creek on the North Parramatta By-Pass arterial road. (Fig. 3) The foundation conditions at this site are variable with sandstone rock close to the surface at one side of each abutment but dipping steeply with varying depths up to 8 m of loose sands and sandy clay overlying bedrock at the other side of the abutment. The bridge layout comprises a central span of 15 m and two side spans of 12 m with an overall width of 42 m to accomodate the through traffic lanes and the on and off ramps. It seemed difficult to accomodate the expected differential settlements along each abutment wall and between the piers and abutment so steel piles were used to carry the loads to rock and reinforced earth walls to retain the embankment and provide the required waterway for the expected maximum flood. This layout was more economical than the conventional arrangement with reinforced concrete wall abutments founded on piles or a bridge with longer side spans and spill through abutments.

abutments with counterforts founded on pile supports. A reinforced earth alternative was accepted by the Authority because it showed substantial cost savings. In the detail design a compromise arrangement was agreed whereby the superstructure spans and details were not altered but the abutment comprised columns on piles in front of a reinforced earth wall which was designed to resist the embankment pressure and the horizontal force from the bridge deck. The horizontal force is transmitted to the reinforced earth mass via a combined concrete thrust block and relieving slab.

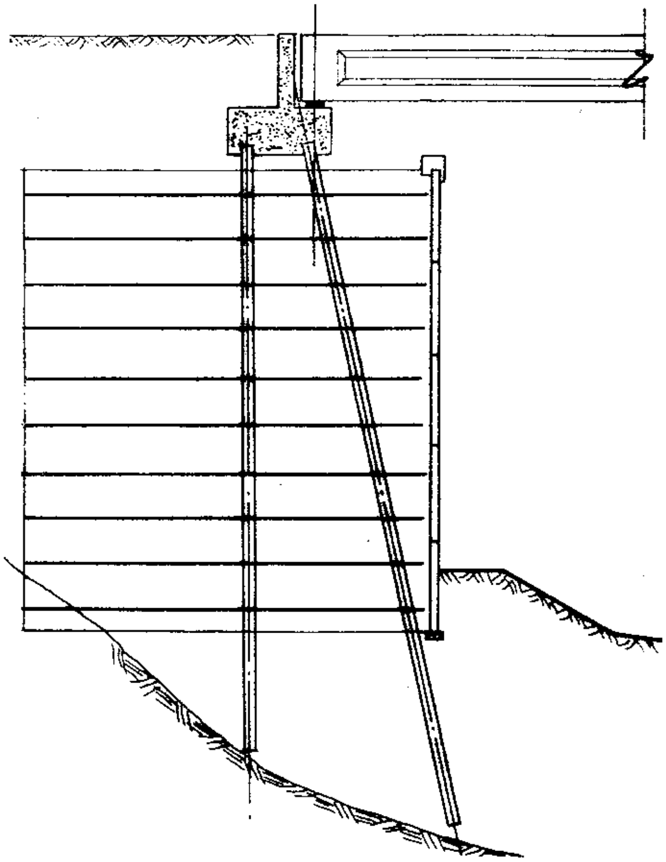

Fig. 3 Bridge on Parramatta By Pass

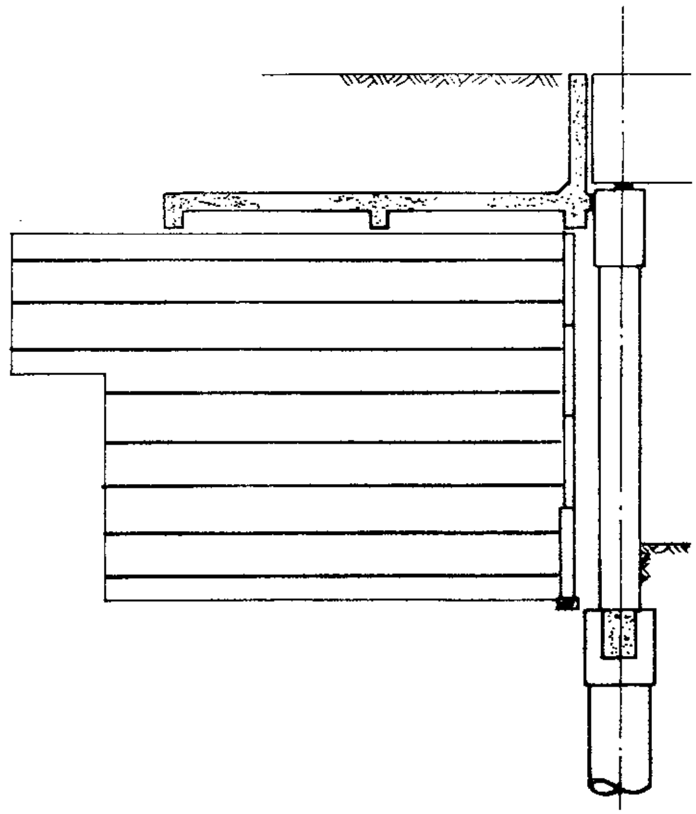

Fig. 4 Francis Road Overpass, Blacktown

Construction of the walls and embankment was completed before work started on the bridge. To avoid any interference between the piles and the reinforcement the piles were spaced at 3 m to suit the horizontal module of the reinforcement and the location marked on the back of the wall panels as the work progressed. The Greystanes gravel backfill was compacted readily to a dense well graded mass, through which the vertical steel H piles were driven. The front row of raking piles were close to the wall facing near the toe however, so to eliminate excessive pressures and possible damage to the facing panels these piles were predrilled.

Another project at Francis Road railway overpass, Blacktown, required a different solution. In this case the bridge plans had been completed using wall

To reduce differential settlements between the bridge and approaches the construction of the embankment is planned to start early so that most of the settlement will have occurred before the bridge deck is completed. In addition, the relieving slab is hinged to the adjacent headstock.

A three span railway overbridge at Unanderra, N.S.W., founded on various soft and stiff clay layers overlying basalt is designed with piers and abutment columns founded on piles. Reinforced earth walls behind the abutment columns are detailed to provide a simple layout of open walls curved in plan at the ends. At the top of the wall the headstock is extended to provide a capping separated from the wall by a compressible filler and bridging the gap between the embankment and the deck.

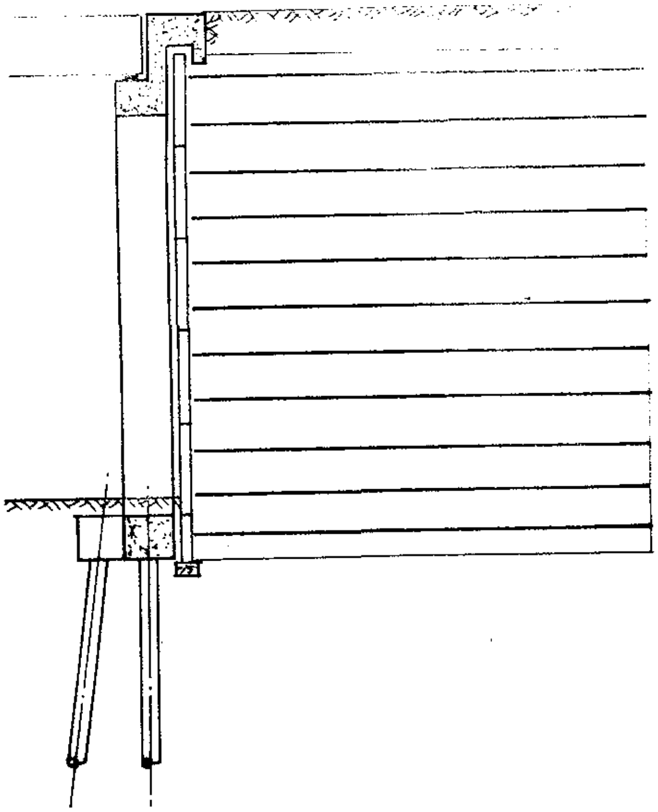

Fig. 5 Railway Overpass, Unanderra

Reinforced earth walls are being used for industrial applications such as loading ramps at mines and bulk materials handling projects. The trucks and loaders at these sites impose large forces on the walls which are similar in principle to the bridge abutments previously discussed. These industrial applications of reinforced earth are expected to increase in the future.

5. Conclusion

The projects described in this paper illustrate the variety of applications of reinforced earth to bridge abutments. Because the foundation and traffic conditions at each site vary the possibility of standard solutions is limited. However, the pre-fabricated components of facing panels and reinforcement provide some scope for standarisation and reduction in time for detailing of projects. To achieve economical use of standard components and rapid construction in the field, the arrangement and detailing of the reinforced earth and the bridge deck should be planned carefully and co-ordinated with the responsible authority thus ensuring that overall economies are realised.

References

BOYD, M.S., VERGE, G.C., REID, J.B. (1978) "The Practical Application of Reinforced Earth Theory" Symposium on Soil Reinforcing and Stabilising Techniques, Sydney

DARBIN, M., JAILLOUX, JJ., MONTUELLE, J., (1978) Performance and research on the durability of reinforcing strips. Symposium on Earth Reinforcement. Pittsburg ASCE National Convention - April 1978

Dimensionnement des ouvrages en terre armée.
murs et culées de ponts
Ministere de L'équipement
Laboratoire Central des Ponts et Chaussées
Ecole Nationale Des Ponts et Chaussées

LEECE, R.B., (1978) "Reinforced Earth Construction at Bondi Junction By-Pass" Symposium on Soil Reinforcing and Stabilising Techniques, Sydney.

SCHLOSSER, F., (1978) "History, Current and Future Developments of Reinforced Earth" Sumposium on Soil Reinforcing and Stabilising Techniques, Sydney.

TAPP, W., (1978) "Reinforced Earth Walls" Highway, South Australia. Highways Department of South Australia.

VERGE, G.C., REID, J.B., (1976) Reinforced Earth Retaining Walls in Highways Australia Road Research, Vol. 6, No. 3.

VIDAL, H., (1968) "La Terre Armée" (Un materiau nouveau pour travaux publics)" Annales de L'Institute Technique du Batiment et des Travaux Publics.

ROMANOFF, M., (1967) "Results of NBS Corrosion Investigations in Disturbed and Undisturbed Soils" Technical Bulletin No. 86, Eng. Exp. Stn. West Virginia University.