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

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Reinforced earth structures in Australia

Ouvrages en terre armée en Australie

Depuis l'introduction de la terre armée en Australie en 1975, une vingtaine d'ouvrages ont été réalisés suivant le procédé VIDAL, et calculés selon les méthodes de dimensionnement développées par VIDAL et le LCPC.

L'article traite des spécifications australiennes, du calcul et de la construction, et présente les domaines de recherche en Australie.

1. Introduction to Australia

In 1975 the first reinforced earth structure designed in accordance with Vidal's theory (1966) was constructed for Parramatta Council at Smith Street, Parramatta, New South Wales. This structure, (4.5 m max. height, 150 m^2 face area) allowed the construction of a vertical retaining wall adjacent to an existing stormwater channel and new corrugated steel plate culvert due to the ability of the reinforced earth block to reduce the intensity of foundation pressure usually associated with traditional retaining structures.

The successful completion of this small, yet pioneering, structure in Australia demonstrated to local engineers and authorities the viability and practicality of the technique. Since then some 20 reinforced earth structures representing approximately 25000 m^2 of wall face are completed or are under construction for government authorities and private industry. (Table I)

2. Materials

2.1 Reinforcement

Initially reinforcement strip was cut from continuously hot dipped galvanised mild steel sheet, 3mm thick. Since 1977 a hot rolled ribbed reinforcement strip 5mm thick has been rolled in Australia to La Terre Armee specifications and has since been almost exclusively used in preference to the plain reinforcement due to greater economy of steel and increased service life potential. Properties and dimensions of reinforcement as generally available in Australia are shown in Table II.

2.2 Facing Panels

Both precast concrete and roll formed steel section panels are manufactured in Australia to La Terre Armee specifications. Precast concrete has been favoured for use in urban and highway structures due to its greater flexibility of application and variety of finish. Exposed aggregate, vertical ribbed and plain finishes have been adopted.

Steel facing panels have found application in remote, mining areas due to their portability and ease of handling.

2.3 Backfill

The criteria for selection of backfill in reinforced earth has followed the original recommendations of La Terre Armee for grading chemical and electrochemical limits (Fig. 1)

In Australia materials which have met this specification have ranged from sand and gravels to crushed sandstone and decomposed granite. The ability to find suitable material on, or near to, the construction site has been significant in overall structure economics.

In New South Wales, the Department of Main Roads found suitable indigenous material at the Bondi Junction Bypass (dune sand) and the Botany Road Railway Overpass (reclaimed marine sand) while at the North Parramatta Bypass and the Epping Road Overpass suitable material had to be imported. At the North Parramatta Bypass the blue shale available from adjacent road excavations was potentially suitable but required crushing before use and accordingly a decomposed dolerite gravel (Greystane's Gravel) was imported from Prospect quarry - this material had earlier been successfully used at the Seven Hills Road Railway Overpass by Blacktown Council. At Epping Road large stockpiles of local silty loam material did not meet the reinforced earth specification and consequently a crushed Hawkesbury sandstone was imported from Ryde quarries. This material is typical of the Sydney region and is proposed for use in other structures.

1. Free from organic or other deleterious materials.
2. Grading:
   a) For plain reinforcement:
      i) not sore than 15% by weight smaller than 75 microns.
      ii) not more than 25% by weight larger than 150mm.
      iii) no particle larger than 350mm.

   b) For ribbed reinforcement:
      i) not more than 15% by weight smaller than 15 microns. (provided that $\phi > 25^o$).
      ii) not more than 25% by weight larger than 150mm.
      iii) no particle larger than 350mm.
3. For land based sites requiring a service life up to 100 years:
   a) Electrochemical
      i) Resistivity under saturated conditions > 5000 ohm.cm.
   b) Chemical
      i) pH between 6 and 10
      ii) not more than 100 ppm Cl & SO_4 salts.

Fig. 1 Specification for Select Back-- Fill (Feb. 1978)

In South Australia, the Highways Department at Murray Bridge used an indigenous silty sand from a borrow pit adjacent to the Swanport Deviation site while at the Pt. Germein Railway Overpass site north of Adelaide, a red fine sandy material was obtained from a borrow pit some distance away but freely available.

Two bauxite mining areas, one at Weipa in North Queensland for Comalco and the other at Pinjarra in Western Australia for Alcoa have used a low grade bauxite or Ironstone material available generally as overburden from the surface mining operations.

3. Design

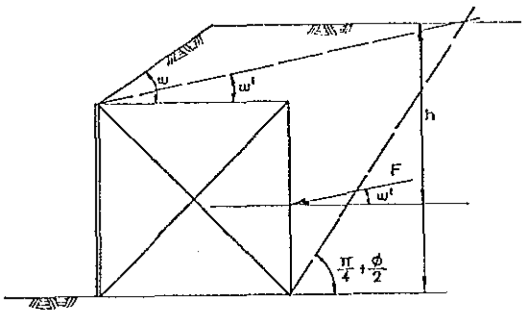
3.1 Internal & External Stability

Internal and external stability calculations are based on the methods proposed by Vidal, Schlosser, Long and others at the LCPC as reported elsewhere.

Generally, for roadworks the recommendations of the NAASRA (National Association of Australian State Road Authorities) Bridge Design specification are followed. In particular, a surcharge load equivalent to 1.2 metres of fill is usually applied plus any other relevent dead and live loads and the worst compatible combination is checked. Due to the flexibility of the reinforced earth block and its facing, the usual factors of safety as recommended by NAASRA for other, more rigid, structures have in some cases been reduced. In particular, bearing capacity is checked for a factor of safety of 2.0 and allowable differential settlement may be limited to 2% for metal facing panels and 1% for precast concrete facing panels.

For both internal and external lateral soil pressures the use of the Rankine active pressure is considered realistic given the character of the composite reinforced earth block, its flexibility and the deformation required for overall failure. The realisation of these active pressures under working conditions is of course not necessarily assured due to the effects of construction procedures, compactive effort applied, backfill properties and loading conditions and it has recently been shown by Schlosser that an "at rest" (Ko) pressure may be more realistic at shallow depths coupled with an augmented friction factor. The design method using active pressure coefficients is not considered unconservative if minimum friction factors are used and usual design factors for tensile capacity and the elongation of mild steel prior to failure are taken into account. In general, for failure it is felt that the earth must become "active" at the level considered.

External loading may be conveniently and realistically assessed using Rankine theory for most applications in earth embankments. Where non uniform sloping backfill surfaces are supported then some assumptions need to be made concerning the line of action of the Rankine active thrust due to the earth and the surcharge loads (if any). A useful technique for determining this angle of thrust (or average slope of backfill) for situations intermediate to the case of a uniform and horizontal sloping backfill of infinite extent has been developed and is described in Fig. 2. This permits a wider application of Rankine theory as suggested by the flexibility of the reinforced earth block and its relative similarity with the surrounding medium.



$$F = \frac{1}{2} K_a \gamma (h)^2$$

$$K_a = \cos \omega' \left[\frac{\cos \omega' - \sqrt{\cos^2 \omega' - \cos^2 \phi}}{\cos \omega + \sqrt{\cos^2 \omega' - \cos^2 \phi}}\right]$$

Fig. 2 Average Slope Construction for Rankine Analysis

Based on these developments and using Vidal's theory, the internal and external design can be conveniently handled by small desk top computers. Internal stability can then be checked, reinforcement type and size and distribution selected and design factors output to assess the relative effect of tensile or friction capacity at every reinforcement layer. The Tension Ratio output is the ratio of allowable design tension and actual calculated tension and has a minimum of 1.00 ; the Friction Ratio output is the ratio of actual reinforcement length to required adherence length determined on the basis of the overburden pressure at mid block and has a minimum of 2.00. In practice this compares with the check of adherence proposed by Schlosser which takes into account the observed active and resistant zones within the reinforced earth block and provides for a ratio of adherence length to resistant length of 1.5.

3.2 Capping/Crash Barriers

A significant area of application of reinforced earth in Australia is for grade separation structures and bridge approaches where a vertical wall is required close to a road alignment. The problem however, with such walls is the need for a crash barrier near the wall facing.

The design impact loads recommended by NAASRA are normally 45 kN at approx. 700 mm above road surface level. This force and point of impact may vary depending on the barrier geometry.

Initially the problem was solved using a bond beam fixed to the top course of facing panels which were, in turn, reinforced. The impact force was assumed to be distributed over up to four top course panels (6.0 m) by virtue of the flexural and torsional stiffness of the bond beam and the passive resistance of the panels against rotation. The density of upper layer earth reinforcement was then augmented.

Basic incompatability of such a system with the flexible facing system required for the reinforced earth could possibly promote long term serviceability problems and a barrier support system which was completely independant of the facing panels was developed. This required the provision of a distribution slab supported by the reinforced earth block which was itself stable under impact forces for sliding, overturning and bearing pressure. Some increased lateral pressure was distributed to the upper course facing panels through the fill resulting in increased upper layer reinforcement density however, standard panel types and configurations were applicable. The distribution slabs were made continuous over a sufficient length (up to 12 m) so that stability was ensured.

A typical detail of the independent type barrier support is shown in Fig. 3 as used at the Bondi Junction Bypass. Similar details have been provided at the Epping Road Overpass and the Belconnen Bus Station.

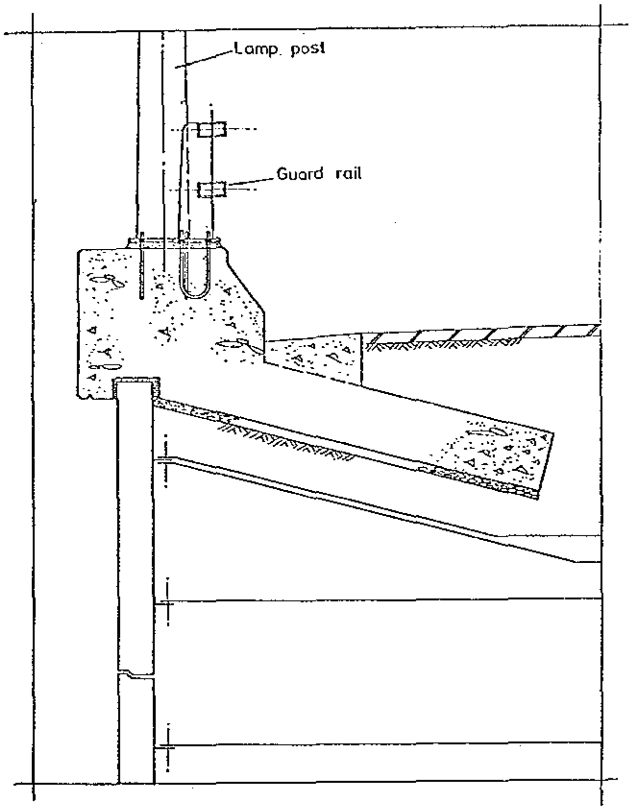


Fig. 3 Independant Barrier Support Bondi Junction Bypass

Where there is sufficient room to separate the barrier line and the wall line by more than 1.0 m then the problem is significantly reduced. Either a post-and-rail type flexible guardrail or a New Jersey type concrete profile may be successfully applied without directly affecting the reinforced earth block and facing. For example, at the Botany Road Railway Overpass, a concrete profiled barrier is supported effectively by the concrete pavement inside the footway. (Fig. 4)

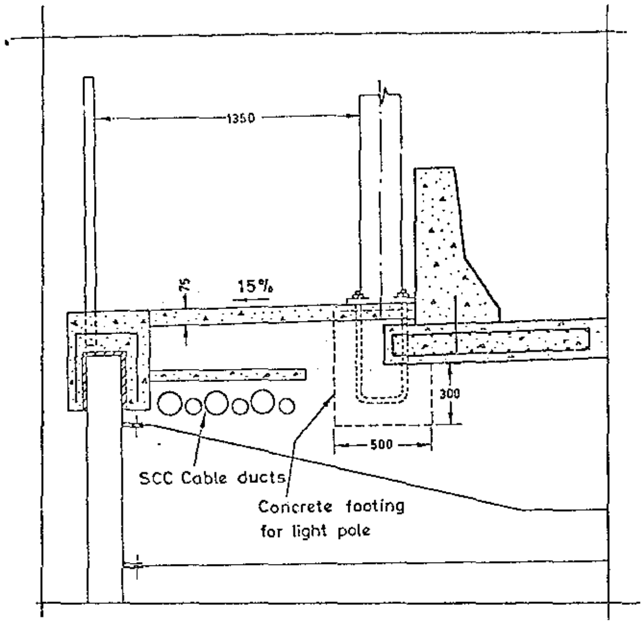


Fig. 4 Barrier & Capping Detail
Botany Road Railway Overpass

4. Construction

In Australia construction rates achieved on most of the projects have been low in comparison to those reported elsewhere due to several factors:

a) The use of government "day labour" teams

b) Site restrictions

c) Overall project staging.

At the major projects in New South Wales, the maximum rate is about 67 m^2 per day (30 panels) with an overall job average of 22 - 34 m^2 per day (10 - 15 panels). This is mainly due to external factors applicable to the employment of day labour teams. Leece (1978) reports a maximum rate of 103.5 m^2 (46 panels) at the Bondi Junction Bypass, however, their daily productivity potential was limited by site problems of service relocation, access, existing construction and the need to work towards, rather than away from, abutments. Once the panel erection teams became used to the system, productivity was governed by the fill supply rate. This rate was easily controlled whilst the fill was available on site, however, supply difficulties arose when the balance of material had to be hauled a distance of 26 km. The average rate of fill placement at Bondi was only 300 tonnes/day.

The total cost reported by Leece for the reinforced earth construction (excluding crash barrier) was A\$130/m^2 of which approximately 75% involved the design and supply of components. This compared favourably with mass concrete, reinforced concrete and crib walls which generally came to between A\$200 and A\$300/m^2 and did not include design costs. A significant factor in the reinforced earth economy is the labour content in construction, as shown in Table III, compared with traditional construction methods.

At the Swanport Deviation site near Murray Bridge, South Australia, the construction of reinforced earth bridge abutments to support a 13.5 m span underpass structure was reported by Tapp to result in overall economies in comparison to traditional bridge alternatives of at least 10% whilst offering the advantages of:

a) no specialised skills required for construction.

b) ability to carry heavy loads during construction.

c) ability to accommodate considerable differential settlement.

d) fast erection with light plant from behind the face (and hence minimal traffic obstruction).

The increased involvement of private contractors in the construction of reinforced earth in Australia should result in an increase in productivity and efficiency in many cases (particularly where site restrictions are minimal) and allow the full economic potential of the system to be demonstrated.

5. Research and Development

Initial theoretical studies were made in Australia by Hausmann and Lee (1976) on triaxial test specimens to determine the basic behaviour of various types and configurations of reinforced specimens. Hausmann has proposed two models to describe the observed behaviour - a Tau model and a Sigma model. Further programmes are planned to follow this work with model tests and full scale instrumentation of local projects.

Harrison and Gerard (1972) have reported on theoretical investigations into elastic layered systems to show the effect of thin high modulus, but flexible layers in a soft medium on the stress distribution and behaviour of loaded areas.

At the University of Sydney, Brown and

Poulos (1978) are investigating the stability and behaviour of reinforced embankments using an incremental finite element analysis which takes into account the sequential construction of reinforced earth structures and slip at the earth/reinforcement interface. The programme is aimed at the development of charts and procedures which will provide a rapid and accurate assessment of reinforced earth stability and behaviour in practical situations.

Walter (1978) has compared the behaviour of both ribbed and smooth reinforcement strip in controlled, laboratory pull-out tests which confirm the behaviour reported by Schlosser particularly highlighting the augmented friction properties of ribbed reinforcement at normal pressures below approx. 100 kPa.

Programmes for evaluation of reinforcement corrosion in projects around the Sydney region are also being set up with test specimens placed within structures for controlled withdrawal and analysis over the service life predicted for the structure.

References

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

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

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

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

Hausmann, M., Lee, I.K. (1976) "Strength Characteristics of Reinforced Soil" Uniciv Report No. R-162 University of New South Wales, Sydney

Harrison, W.J. Gerrard, C.M. (1972) "Elastic Theory Applied to Reinforced Earth" Jnl. of the Soil Mechanics & Foundation Division ASCE, Vol. 98, No. SM12

Brown, B.S., Poulos, H.G. (1978) "Finite Element Analysis of Reinforced Embankments" Symposium on Soil Reinforcing and Stabilising Techniques, Sydney

Walter, P.D. (1978) "Performance Comparison of Ribbed and Smooth Reinforcing Strips" Symposium on Soil Reinforcing and Stabilising Techniques, Sydney

TABLE I

AUSTRALIAN PROJECTS

PROJECT	STATE	WALL TYPE	MAX. HEIGHT(m)	AREA (m2)	CONSTRUCTING AUTHORITY	CONTRACTOR
Smith Street, Parramatta	NSW	Road Retaining Wall	4.5	150	Parramatta Council	Kingston Civil Engineers Pty. Ltd.
F5 Freeway Railway Overpass, Glenlee	NSW	Retaining wall at abutment	6.0	450	Department of Main Roads Outer Freeways	Day Labour
North Parramatta Bypass	NSW	Road retaining walls	8.25	2300	Department of Main Roads Parramatta Division	Day Labour
Sunnyholt Road, Blacktown	NSW	Retaining wall at abutment	7.5	50	Blacktown Municipal Council	Day Labour
Seven Hills Road, Railway Overpass	NSW	Road retaining walls	8.25	1800	Blacktown Municipal Council	Day Labour
Epping Road Overpass North Ryde	NSW	Road retaining walls	10.5	3310	Department of Main Roads Parramatta Div.	Day Labour
Swanport Deviation Murray Bridge	SA	Bridge abutment	6.0	400	Highways Department, South Australia	Day Labour
Bus Station, Belconnen	ACT	Road retaining walls	5.25	440	National Capital Development Commission	Civil & Civic Pty. Ltd.
Bottom Dump Bridge Lorim Point, Weipa	QLD	Road retaining walls	8.0	340	Comalco Limited	Mains Construction Pty. Ltd.
Bondi Junction Bypass	NSW	Road retaining walls	8.25	3730	Department of Main Roads Inner Freeways Division	Day Labour
Botany Road Railway Overpass	NSW	Road retaining walls and Bridge abutments	7.5	3350	Department of Main Roads Metropolitan Div.	Day Labour
Lutwyche Road Windsor	QLD	Rail embankment retaining walls	6.0	930	Queensland Railways	Hornibrooks (Northern Division) Pty. Ltd.
Del Park Road, Pinjarra	WA	Bridge abutment	10.7	495	Alcoa of Aust. Ltd.	Waroona Contracting Pty. Ltd.
Railway Overpass Pt. Germein	SA	Bridge abutment	6.75	666	Highways Department, South Australia	Day Labour
Tuggeranong Parkway Cotter Road Bridge	ACT	Bridge abutment	6.75	1065	National Capital Development Commission	Thiess Bros. Pty. Ltd.
South East Freeway Brisbane	QLD	Embankment retaining walls	6.4	620	Main Roads Department	Barclay Bros. Pty. Ltd.
A1 Load Station Andoom, Weipa	QLD	Embankment retaining walls	9.0	177	Comalco Limited	Mains Construction Pty. Ltd.
Brooklyn Road Railway Overbridge	NSW	Road retaining walls	9.6	1060	Hornsby Shire Council	White Industries Pty. Ltd.
Francis Road Railway Overpass Rooty Hill	NSW	False bridge abutment	7.5	710	Blacktown Municipal Council	Day Labour
Railway Overpass Doonside	NSW	Bridge abutment	12.75	2000	Blacktown Municipal Council	

TABLE II

REINFORCEMENT DESCRIPTION - PROPERTIES

Material	Zincform G300 Mild Steel to AS 1397	Hot rolled Mild steel flats to AS1204 Grade 250
Galvanising	Continuously hot dipped 640 g/m^2 (min.)	Hot dipped 600 g/m^2.
Surface	Plain	Ribbed
Sizes (mm)	(60 x 3) 80 x 3 (90 x 3) (120 x 3)	40 x 5 60 x 5 (60 x 6)
Min. Yield Stress (MPa)	300	275
Min. Ultimate Tensile Stress (MPa)	370	410
Min. Elongation (%)	18%	20%
Friction Factor	0.4	0.7 - 1.0
Connection at facing panel	1 No. 80 x 3 tie strip 2 No. M12 HT bolts (in single shear)	2 No. 60 x 4 tie strips 1 No. M12 HT bolt (in double shear)
Max. allowable tension for 1mm overthickness	80 x 3 26.4 kN	40 x 5 24.0 kN 60 x 5 42.5 kN

TABLE III

RETAINING WALL - CONSTRUCTION PERFORMANCE

(Ref. Leece, 1978)

Type of Retaining Wall	Labour Content in manhours/m^2
Reinforced Earth - without traffic barrier	4.1
Reinforced Earth - with traffic barrier*	4.7
Mass Concrete*	11.2
Reinforced Concrete*	11.5
Crib Wall	13.3

*Skilled labour - carpenters, steel fixers, riggers, scaffolders.