Reinforced Earth Applications in Australia and New Zealand

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SUMMARY Reinforced Earth was introduced to Australia and New Zealand relatively recently and has since been adopted for many projects.

Design procedures have been based on the work of Vidal and others at the LCPC and recognise the composite nature of the Reinforced Earth block. Basic design criteria are described.

Practical application has resulted from the inherent simplicity and flexibility of the Reinforced Earth system coupled with significant economies in many cases. The basic Reinforced Earth costs for some Australian projects are tabulated.

1 INTRODUCTION

Reinforced Earth was introduced to Australia in 1975 and New Zealand in 1979. Design procedures and systems used are based on those which have been developed by Vidal in conjunction with the Laboratoire Centrale des Ponts et Chaussées (LCPC) and others.

The extensive use of Reinforced Earth in many applications around the world have highlighted the advantages of Reinforced Earth over more traditional construction techniques

- simplicity (both technically and practically).
- flexibility (both in application and in ability to accept large movement).
- economy.

Instrumentation of both full scale structures and extensive model testing have confirmed the pioneering theories of Vidal and show Reinforced Earth as being what it is, viz, a composite material of (granular) earth and (linear, metallic) reinforcements which together form a monolithic yet flexible mass gravity structure.

2 REINFORCED EARTH THEORY

2.1 Vidal And The LCPC

Between 1958 and 1963, Henri Vidal conceived and developed the theory of Reinforced Earth and checked its validity with extensive model tests and prototype structures. In 1965 he introduced the technique as "a new material for public works" (1966) providing a simple, economic alternative to traditional construction techniques.

Basically, Vidal saw that the introduction of flexible, linear (metallic) elements into a cohesionless (granular) earth material produced a composite structure which behaved as a coherent gravity block.

The significant factors of this behaviour which he recognised were:

- the friction at the earth/reinforcement interface
- the secondary (structural) importance of the outside skin or facing.
- the flexibility of the structure and its components.

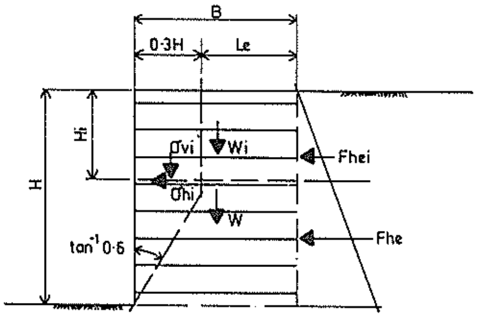
Methods of analysis and design were thus proposed on the basis of both elemental or unit properties and overall block stability (e.g. analysis of reinforced bodies cut by an assumed surface).

In 1969, Schlosser and Vidal showed that the composite behaviour resulted in an apparent cohesion which could be simply observed in triaxial tests on reinforced sand specimens (Long et al 1972). The effect of this apparent cohesion was to induce a curved (potential) failure surface, differing from the straight Coulomb line predicted by classical retaining wall theory. At working loads this curved failure surface is manifested as a curved locus of maximum tension, separating active and resistant zones within a Reinforced Earth block.

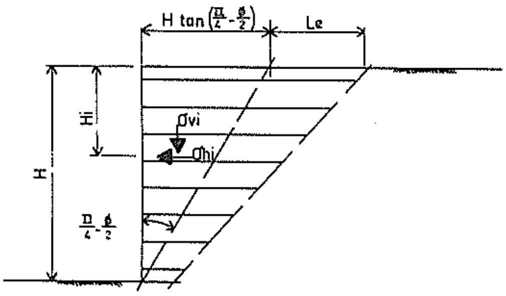
2.2 Recent Developments

As the use of Reinforced Earth became more widespread so has the research. The Vidal concept of a coherent gravity structure in which the earth and the reinforcement act compositely has been challenged by the hypothesis that Reinforced Earth (retaining) structures are analagous to tie-back or anchored walls. McKittrick (1978) suggested that proponents of this apparently neglected or basically misunderstood the basic mechanics of the material or the significant and substantial documentation that has existed for several years that should eliminate the tie-back or anchor approach as a conceivable failure mechanism. McKittrick cites field experience which strongly supports the coherent gravity structure theory - at Aguadilla, Puerto Rico and Roseburg, Oregon, U.S.A. where gross foundation failures under structures resulted in a demonstration of the coherence of the Reinforced Earth block.

The fundamental difference in the two approaches is reflected in the dimensions obtained - for the same earth pressure coefficients, K, Vidal's approach requires more reinforcements to resist higher stresses but results in a reduced maximum reinforcement length compared with that predicted by the anchor theory (Fig. 1)



a) COHERENT BLOCK



b) TIE - BACK WALL

Fig. 1 Design Hypotheses

Consider a coherent block structure of height, H and block width, B. At any level, Hi below the top of the wall the horizontal pressures range from $K.\gamma$. Hi near the top of the coherent block to 1.33 $K.\gamma$.Hi near the base (assuming the eccentricity of the base resultant = B/8) due to overturning effects. In the upper part of the block, the block width provided is then checked with respect to 0.3 H + Le.

In a tie back wall structure, at any level, Hi below the top of the wall the horizontal pressures are $K.\gamma$.Hi . The reinforcement length is then checked with the adherence length Le provided beyond the Coulomb failure line which at the top of the wall yields a total length H $\tan(\frac{\pi}{4} - \frac{\phi}{2})$+ Le.

Thus, the coherent gravity block may yield reinforcement tensions up to 1/3 greater than a tie back wall, whereas, if $\phi = 30^o$, the maximum reinforcement length required for adherence is 0.3 H + Le and 0.58 H+Le, respectively.

3 DESIGN

3.1 Static Design Procedures

Reinforced Earth design procedures in Australia are derived from those recommended by the LCPC (1974, 1979). External stability criteria are based on the concept of the monolithic yet flexible Reinforced Earth block and checked against suitable minimum factors of safety. In particular, the bearing capacity at the foundation takes into account the total block width (as reduced for eccentricity effects) and a factor of safety of 2 is adopted (instead of 3 for traditional structures) due to the flexibility of the structure.

Internally, for plain (smooth) reinforcement strip, the basic internal design procedures assumed that

a) at the limit, an active (K_a) state of stress existed within the Reinforced Earth block.

b) the horizontal pressure at each level resulted in a tension in each reinforcement strip dependant on its area of influence.

c) the friction factor (earth/reinforcement) was constant with depth.

d) the resistant zone within the Reinforced Earth block (to resist pullout) was not less than one half the block width.

The allowable tension in each reinforcement was based on 2/3 yield stress on the nett section (i.e. after deduction of a corrosion allowance) and checked with respect to its weakest point (usually reinforcement/facing connection).

Friction or bond failure in each level was checked with respect to the maximum tension in each reinforcement and its minimum resistant length or half block width (for a factor of safety greater than 1.0).

Empirical data at that stage suggested that to satisfy both external and internal stability as well as to achieve the observed composite behaviour, a rectangular block of width/height ratio greater than 0.8 was required.

Recent availability of more extensive data on the performance of both model and full scale structures, both at working stress levels and at failure have allowed some refinement of the design procedures. The introduction of a ribbed reinforcement strip has also resulted in a more efficient use of material but its behaviour is more complex (Schlosser and Elias, 1978).

Design procedures now take into account that

i) the state of stress within the Reinforced Earth block evolves from an at rest (K_o) condition at the surface to an active (K_a) condition at depths greater than 6 m.

ii) the friction factor (earth/reinforcement) for plain reinforcement (usually 0.4 for mild steel) is constant with depth whereas for ribbed reinforcement there exists an apparent friction factor (f*) greater than tan ϕ at depths less than 6 m.

iii) the line of maximum tension is defined by a line at a distance 0.3 x height of the structure behind the face and a line at $\tan^{-1}$ 0.6 from the toe (Fig. 2)

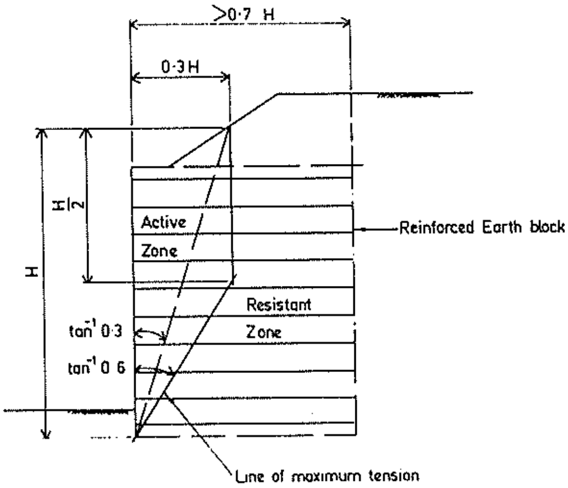


Fig. 2 Block Geometry

Friction is therefore checked with respect to the maximum tension line and resistant length available (i.e. reinforcement length - 0.3 x structure height) using a minimum factor of safety of 1.5.

Recent data has also suggested that a reduction in the minimum block width/height ratio to 0.7 is possible.

The evolution of these parameters and design criteria is described by Schlosser (1978, 1979) and they are incorporated in the comprehensive Guide, Specifications and Code of Practice for Reinforced Earth Structures issued by the LCPC and SETA in France (1979).

3.2 Aspects of Seismic Design

The introduction of Reinforced Earth to New Zealand has necessitated the adaption of the static design procedure to the dynamic conditions resulting from seismic design criteria.

Reinforced Earth structures, like other flexible earth structures, have the advantages of

a) a high degree of structural damping

b) an ability to accept large movement without loss of stability.

Richardson (1978) and others at UCLA have developed design procedures which are based on the response of a Reinforced Earth structure to dynamic loading and the effect of overall geometry, reinforcement distribution and damping. These procedures have been applied to the design of Reinforced Earth walls supporting the storage terminal for the Trans Alaska pipeline at Valdez which have a maximum height of 17 metres and are designed to withstand the following earthquake conditions:

- magnitude, 8.5 Richter
- ground acceleration, 0.6 g
- duration of strong motion, 50 seconds.

Basically, seismic design procedures involve the following considerations with respect to static design

i) the determination of an additional dynamic lateral earth pressure distribution based on the calculated stiffness and dynamic response of the structure. This generally results in an augmented reinforcement density in the upper region of the structure.

ii) the checking of tensile capacity of the reinforcement under static + dynamic loads and taking reinforcement to yield.

iii) the checking of capacity of the reinforcement for an adequate factor of safety under static loads only. Because of the cyclic nature of the dynamic loads, pull-out "failure" due to static + dynamic loads would only result in slight movement.

3.3 Durability

The corrosion of buried metals is a complex subject affected by many variables. Romanoff (1957) summarised the problem by stating that it was not possible to predict the rate or extent of corrosion from any single soil property, however, it was possible to qualitatively associate soil characteristics and properties (which are frequently interrelated) with the corrosion of particular metals.

Basically, in the presence of water, corrosion is fundamentally electrochemical. Long term studies by the National Bureau of Standards showed that, in well drained soils having a high resistivity, the corrosion rate of ferrous metals decreased after a few years from an initial high rate to an insignificant rate.

Analysis of NBS 10 year tests for relevant soil types (i.e. non organic soils with a resistivity greater than 2000 ohm.cm.) shows that 95% of increased corrosion rates for galvanised steels fall below 0.01mm/year (Boyd et al, 1978). Applying this figure to a corrosion allowance of 0.5mm/face leads to a conservative lower bound service life estimate of 80 years.

Darbin et al (1978) report on similar studies of long term corrosion and more recent research in France.

The corrosion allowance requirements for various service lives and environments adopted for the French code are summarised in Fig. 3

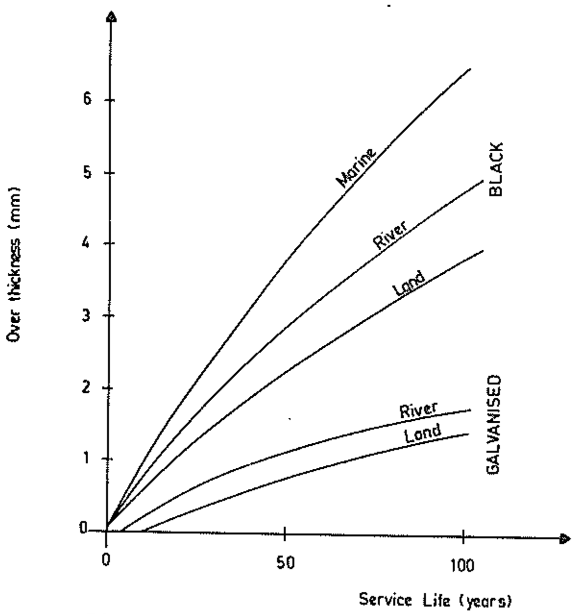


Fig. 3 Corrosion Allowances

4 AUSTRALIAN AND NEW ZEALAND PROJECTS

4.1 Applications

In Australia and New Zealand some 83 structures have been constructed or are under construction (at July, 1979). By far the major application is in the area of public road and highway retaining walls for grade separation or embankment support (TABLE I). The use of Reinforced Earth for bridge abutments, however, is a novel and spectacular example of the properties of the technique. It provides a simple, economic solution, particularly for overpass/underpass structures and has been adopted by many local and state authorities.

TABLE I

REINFORCED EARTH APPLICATIONS IN AUSTRALIA AND NEW ZEALAND.

Application	No. of Structures	Area	Proportion
		(m^2)	(%)
Retaining Walls			
- road (public)	51	22 763	77
- road (mining)	6	695	2
- rail	7	1 140	4
- marine	1	430	1
Bridge Abutments			
- public	14	3 731	13
- mining	2	495	2
Loading Stations			
- industrial	1	150	0.5
- mining	1	153	0.5
Total	83	29 557	100

The first marine wall has been constructed at Bluff in New Zealand while in Australia, the mining industry has adopted Reinforced Earth for road embankment support near dump bridges (Comalco, Weipa) and at rear dump stations (Kandos).

In Queensland, the Railways Department undertook the first structures which physically support railway tracks at the Lutwyche Road widening project in Brisbane.

4.2 Technical Characteristics

4.2.1 Reinforcement

Tie strip, reinforcement and connection strengths are based on AS.1250 for the structural grade reinforcement and precision bolts (strength grade 8.8) adopted. Properties of the reinforcement material used are shown in TABLE II.

TABLE II

REINFORCEMENT PROPERTIES

Property	Plain	Ribbed
Material	Zincform G300 mild steel sheet to AS. 1397	Hot rolled mild steel flats to AS 1204
Galvanising	Hot dipped 600 g/m^2	Hot dipped 600 g/m^2.
Sizes (mm)	80 x 3	40 x 5 60 x 5 (60x6)
Min. yield stress (MPa)	300	275
Min. ultimate strength (MPa)	370	410
Elongation	18%	20%
Friction Factor	0.4	tan ϕ (min.)
Allowable tension (kN)	26.4 (80x3)	24.0 (40x5) 42.5 (60x5)

In terms of wall face area, or Reinforced Earth block volume, the amount of reinforcement required is very small. For the structures described in this paper, reinforcement density varies from 20 to 60 kg/m^2 of wall face or 0.17 to 0.33% by weight, earth/reinforcement (0.04 to 0.08% by volume).

4.2.2 Select backfill

The physical, chemical and electrochemical characteristics specified for the select backfill in a Reinforced Earth block are summarised as follows:

a) Free from organic or other deleterious matter.

b) Grading limits
   - i) nothing over 350mm
   - ii) not more than 25% (by weight) larger than 150 μm
   - iii) not more than 15% (by weight) smaller than 75 μm

Where ribbed reinforcement is used, the lower grading limit may be extended to not more than 15% (by weight) smaller than 13.5 μm, providing that the angle of internal friction is not less than 25°.

c) Chemical limits
   - i) pH between 5 and 10
   - ii) not more than 200 ppm, Cl
   - iii) not more than 1000 ppm, SO_3

d) Electrochemical limit

Resistivity under saturated conditions not less than 3000 ohm.cm.

Very fine clayey materials are specifically excluded on the basis of reduced service life potential with respect to the buried reinforcement and variability of soil properties (friction, cohesion) at different moisture contents.
In addition, creep characteristics of reinforcement in very fine grained soils may lead to reduced long term stability.

Materials used in Australia and New Zealand have ranged from sands (reclaimed, dune), sandstone (ripped and crushed) and gravels (river, quarry or minesite overburden).

4.2.3 Facing

The two facing panel systems used have been the articulated precast concrete panel system, 1 500 mm x 1 500 mm by 180 or 220 mm thick or the flexible rolled steel panel system, 333 mm high, 3mm thick and up to 9 000 mm long.

Both systems provide the necessary flexibility required for the facing or skin of a Reinforced Earth block so that the composite block behaviour can develop. Both facing systems have the ability to accept differential settlements of at least 1% without distress.

4.3 Construction

Construction of Reinforced Earth structures is primarily an earthworks operation. Experience has shown that overall construction rates achieved are generally controlled by the rate of supply and placement of the backfill, not the erection of the Reinforced Earth components.

A basic team of four men (one foreman, three labourers) can erect precast concrete facing panels (and lay reinforcement) at an average rate of four panels/hour (72 m^2 per day). Peak rates of up to 46 panels (103.5 m^2) per day have been reported in New South Wales (Leece, 1978) and 40 panels (90 m^2) per day in South Australia (Boyd and Thomas, 1980).
The construction procedure is cyclic with placement of a facing panel course, backfilling to level of reinforcement, placement and connection of reinforcement and backfilling to base of next panel course following in succession to the top of the structure. All construction can be carried out from within the wall alignment and the structure is stable during all phases of the operation.

5 ECONOMICS

The simplicity and economy of Reinforced Earth construction is highlighted in TABLE III where the labour content and in-place cost of three forms of retaining wall constructed by the Department of Main Roads in New South Wales is compared (Leece, 1978).

TABLE III

RETAINING WALL COMPARISON

Technique	Labour Content	Cost
	(manhours/m^2)	(\$/m^2)
Reinforced Earth	4.1	121
Reinforced concrete (1)	11.5	300
Crib wall	13.3	200

Note (1) Includes skilled labour (e.g. carpenters, steel fixers, riggers and scaffolders).

The breakdown of costs reported by Leece (1979) on six New South Wales road retaining wall projects and Boyd and Thomas (1980) on two South Australian bridge abutment projects is shown in TABLE IV.

The use of Reinforced Earth has resulted in savings of up to 45% over alternative retaining wall systems. For single span, road and rail overpasses using Reinforced Earth abutments this has resulted in overall structure economies of between 10 and 25%.

6 CONCLUSION

Reinforced Earth design is based on normal, practical procedures which recognise the unique composite behaviour of the monolithic Reinforced Earth block.

Reinforced Earth has become accepted as a simple, economic and practical alternative to the more traditional construction techniques for many applications in Australia and New Zealand.

Construction costs reported highlight the economy of Reinforced Earth structures.

7 REFERENCES

VIDAL, H. (1966). "La Terre Armée (Un materian nouveau pour Travaux Publics)" Annales de L'Institute Technique du Batiment et des Travaux Publics.

SCHLOSSER, F. and VIDAL, H. (1969) "La Terre Armée" Bulletin de Liaison des Laboratoires Routiers - Pont et Chaussées.

LONG, N.T., GUEGAN, Y. and LEGEAY (1972) "Etude de la terre armée a l'appareil triaxial" Rapport de recherche No. 17., Laboratoire Centrale des Ponts et Chaussées, Paris.

McKITTRICK, D.P. (1978) "Reinforced Earth: Application of Theory and Research to Practice". *Proc. Symposium on Soil Reinforcing and Stabilising Techniques in Engineering Practice, Sydney.*

LCPC (1974) "*Dimensionnment des Ouvrages en Terre Armée - Murs et Culées de Ponts" Paris*.

LCPC/SETA (1979) "*Ouvrages en Terre Armée : Guide, Specifications et Regles de l'Art Final Draft, Paris*.

SCHLOSSER, F. and ELIAS, V. (1978) "Friction in Reinforced Earth" *Recherche Technique No. 11, la Terre Armée, Paris.*

SCHLOSSER, F. (1978) "History, Current and Future Developments of Reinforced Earth" *Proc. Symposium on Soil Reinforcing And Stabilising Techniques in Engineering Practice, Sydney.*

RICHARDSON, G.N. (1978) "Earthquake Resistant Reinforced Earth Walls" *ASCE, Symposium on Earth Reinforcement, Pittsburgh*

ROMANOFF, M. (1957) "Underground Corrosion" *Circular 579, National Bureau of Standards.*

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

DARBIN, M., JAILLOUX, J.M. and MONTVELLE, J. (1978) "Performance and Research on the Durability of Reinforced Earth Reinforcing Strips". *ASCE, Symposium on Earth Reinforcement, Pittsburgh.*

LEECE, R. (1978) "Reinforced Earth Construction at Bondi Junction Bypass". *Proc. Symposium on Soil Reinforcing and Stabilising Techniques in Engineering Practice, Sydney*.

BOYD, M.S. and THOMAS, A.I. (1980) "The Design and Construction of Reinforced Earth Bridge Abutments in South Australia" *Institution of Engineers, Australia, Annual Conference (in print)*.

LEECE, R. (1979) "Reinforced Earth Highway Retaining Walls in New South Wales". *Proc. Conference on Soil Reinforcement, Paris.*

TABLE IV

REINFORCED EARTH COSTS

Date	Project	Type	Max. Height	Area	Supply (1)	Erection (2)
			(m)	(m^2)	($\$/m^2$)	($\$/m^2$)
76	F5 Freeway, New South Wales	Retaining wall at abutment	6.0	450	75	43
76	Seven Hills, New South Wales	Retaining walls	8.25	1 000	88	19
77	North Parramatta, New South Wales	Retaining walls	8.25	2 300	82	19
77	Bondi Junction, New South Wales	Retaining walls	8.25	3 730	101	29
77	Epping Road, New South Wales	Retaining walls	10.50	3 310	95	24
77	Swanport Deviation, South Australia	Bridge abutments	6.00	400	104	19
78	Botany Road New South Wales	Retaining walls and abutments	7.50	3 350	98	32
78	Pt. Germein, South Australia	Bridge abutments	6.75	660	107	15

Note: (1) Includes supply of facing panels, reinforcement etc.
(2) Erection of facing panels, reinforcement etc. including labour and plant.
(3) Prices quoted are in Australian dollars.