# Reinforced Earth Wall - A Sustainable Alternative to a Piled Vehicular Abutment Ramp

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### Abstract

A vehicular ramp was proposed to replace the existing elevated road (which has been planned for future demolition) connecting to existing podium deck of the Building for vehicular circulation.In the original design, socket H-piles with pile cap and reinforced concrete wall would be constructed as the abutment for supporting the replacement ramp in form of steel girders. In order to minimize the construction time and to fit in the tight construction schedule, a Reinforced Earth Wall was proposed as an alternative. This Reinforced Earth Wall was designed as a true abutment with no piling required and the steel girder was supported by a reinforced concrete seating which was located directly on the backfill of the Reinforced Earth Wall. This vehicular ramp was designed as a permanent structure and would be used as a new access to replace the existing elevated road until the commencement of the next phase of development. It would be much easier to demolish in comparison with the original design of socket H-piles and reinforced concrete wall, and significantly reduce the construction wastage.

**Keywords:** Reinforced earth wall, Design optimisation, Abutment ramp

## 1 Introduction

Reinforced Earth is a composite material formed by the association of granular earth and flexible reinforcement. The friction which is developed between the earth and the reinforcement strips mobilizes and binds all particles within the Reinforced Earth block into a monolithic, yet flexible mass gravity structure capable of retaining and supporting large applied loads on top.

With over 50 years of research and development, this technology has been refined and is widely used all over the world. These include roads and slope retaining walls, bridge abutments and railway embankment; hydraulic structures such as sea walls, river walls, flood protection structures and dams; industrial structures including material processing and storage facilities; containment dikes for crude oil and liquefied natural gas storage; protective bund walls against fire and explosion in military application, to mitigate against natural terrain landslide and boulder fall hazards.

This project is going to demonstrate the use of Reinforced Earth Wall as a “true abutment” (Figure 1). A “true abutment” is a Reinforced Earth retaining wall with a bridge abutment footing bearing directly on top of the reinforced soil volume. The footing is directly supported by the Reinforced Earth structure below without the need of piles or columns. The design considers the heavy concentrated vertical and horizontal loading imposed by the bridge superstructure and traffic loading together with horizontal earth pressure acting behind the abutment footing.

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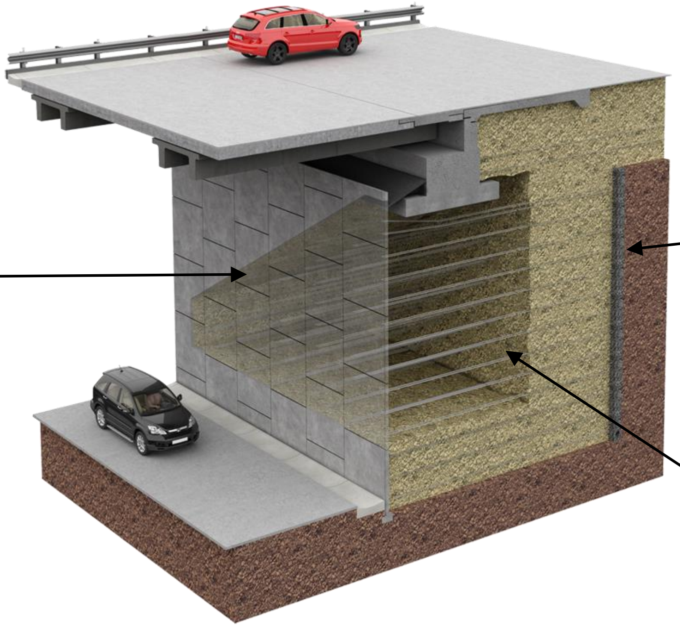


**Figure 1**: True abutment

## 2 Principle of Reinforced Earth

A Reinforced Earth structures has three essential components, which are defined as:

### 2.1 Selected Backfill Material

Selected backfill materials which extends from facing to the end of the reinforced strips is commonly called the "reinforced volume". The selected fill material must be cohesionless, granular material and contains not more than 10% particles smaller than 63mm. This is to ensure that the material has little plasticity and is relatively free draining so that a sufficient and predictable friction is achieved under saturated or dry conditions.

### 2.2 Reinforcing Strips

Reinforcing strips are fastened only to the facing. The dimension of the strips will depend on the external loading and height of structure. These material strips are hot-dip galvanized (to protect against the corrosion) with ribbed surfaces (to increase the friction with the backfill).

### 2.3 Facing

The facing which acts essentially as a skin to protect the exposed surface of the Reinforced Earth block. The facing system adopted must be flexible and may not restrict the movement of the block itself. A precast concrete facing system is commonly used to provide an easy and rapid erection procedure and a very pleasing appearance.

## 3 Ground Profile and Design Parameter

Based on the ground investigation information, the general ground profile in the area comprises of a reclaimed fill layer at the surface, followed by marine deposit, alluvium and decomposed quartz monzonite. The summary of soil stratum is shown in Table 1.

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**Table 1.** Soil stratum

| Stratum | Thickness (m) | Typical SPT 'N' Value |
|---|---|---|
| Fill (FILL) | 4.5 - 8 | 9 - >35 |
| Marine Deposits (MD) | 2.5 – 10 | 3 - >30 |
| Alluvium (ALL) | 0.5 – 5.5 | 9 - >45 |
| Completely Decomposed Quartz Monzonite (CDM) | 10.19 – 31.13 | 20 - >200 |

The shear strength parameters for different soils are determined according to the results of laboratory tests (Triaxial compression test, determination of bulk & dry density test and unconfined uniaxial compressive strength test) carried out for the soil samples retrieved during ground investigation works. The effective friction angles are obtained from the s'-t' plot for different soil types. The design parameters are summarised in Table 2 as shown below.

**Table 2.** Design parameter

| Soil Type | Bulk Density (kN/m$^3$) | Effective Friction Angle Ø (˚) | Effective Cohesion c' (kPa) |
|---|---|---|---|
| FILL | 19 | 33 | 0 |
| MD (SAND) | 19 | 30 | 0 |
| ALL (SAND) | 19 | 33 | 0 |
| CDM | 19 | 35 | 5 |
| SELECTED FILL | 19 | 36 | 0 |

## 4 External Design and Internal Design

The vehicular ramp is a plate girder bridge with 109m span supported by two steel truss towers and an abutment. The original design of abutment is a Reinforced Concrete (R.C.) retaining wall supported by socketed H-pile with 1.5m combined pile cap (Figure 2). The design has been revised to Reinforced Earth True abutment with a L-shape R.C. seating as an alternative (Figure 3).

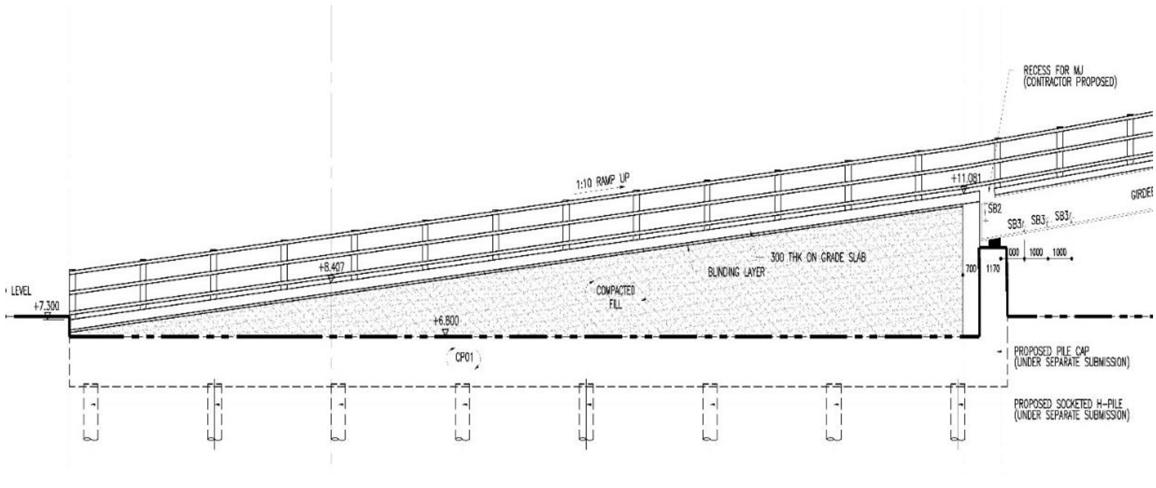


**Figure 2:** Original Design

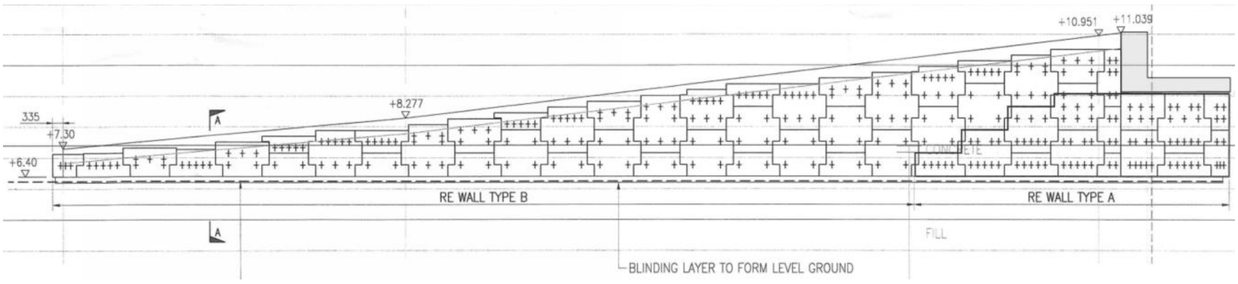


**Figure 3**: Reinforced Earth Wall Design

## 4.1 External Design

For the external stability, the load from the vehicular ramp to soil need to be checked. Adequate frictional resistance between the L-shape R.C. seating and Reinforced Earth retaining wall should be provided to resist the sliding force from the ramp above while dead weight of the R.C. seating should provide adequate moment resistance to resist overturning moment. Apart, bearing of Reinforced Earth retaining wall to be considered to ensure the load from the R.C. seating will not fail the foundation.

Load path of gravity load is as below: Vertical load from vehicular ramp will be transferred to R.C. seating through bearings and then to Reinforced Earth (R.E.) retaining wall which is directly on grade. Horizontal load from bearings will be transferred to R.C. seating and then to R.E. retaining wall by frictional resistance.

## 4.2 Internal Design

The stability of reinforced fill relies upon the mechanism of load transfer between the selected fill material and the reinforcing element. When a load is applied to the reinforced fill feature, tensile strains can develop within the reinforced fill. The internal stability of a reinforced fill structure relates to the tensile and pullout failure of reinforcing elements. Both failure modes may lead to large movements or possible collapse of the structure. Tensile failure occurs when the tensile forces in the reinforcing elements become larger than the tensile strength, so that they elongate excessively or break. The pullout failure occurs when the tensile forces become larger than the force required pulling the reinforcing elements out of the soil mass. The internal design is based upon the principles in Geoguide 6 published by Geotechnical Engineering Office. In common with other codes for the design of civil engineering structures, this code of practice adopts limit state principles. These principles involve the application of partial material and load factors for various structure types; design lives and load combinations to ensure sufficient safety margins.

The internal stability design is used to determine the amount of soil reinforcement required to maintain the structural integrity of the reinforced soil mass. The following modes of instability should be considered in the design.

(a) Rupture of reinforcement

(b) Pullout of reinforcement

(c) Failure of connections

(d) Rupture of facing panels

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The design life of the structure is used to determine the thickness of reinforcing strip which will be lost due to corrosion. This is referred to as the sacrificial thickness and is used to calculate the strength of the reinforcing elements at the end of the design life.

## 5 Comparison of Original Piling Design Vs Reinforced Earth Retaining Wall Design

The benefit of using the Reinforced Earth retaining wall by comparing with the R.C. retaining wall is not only the cost saving, but also the environment friendliness. Table 3 illustrated the material used in the two systems.

**Table 3.** Comparison of Material Used

| Scheme | Element | No. of pile (nos.) | Concrete ($m^3$) | Structural Steel / Rebar / Strip (ton) |
|---|---|---|---|---|
| Piling Scheme | Foundation | 24 | - | 245 |
| | Cap | - | 535 | 130 |
| | Wall | - | 100 | 6 |
| **Total** | | **24** | **635** | **381** |

| Scheme | Element | No. of pile (nos.) | Concrete ($m^3$) | Structural Steel / Rebar / Strip (ton) |
|---|---|---|---|---|
| Reinforced Earth Wall Scheme | Panel | - | 33 | 2 |
| | Levelling Pad | - | 6 | 0 |
| | L-shape RC wall | - | 35 | 4 |
| **Total** | | | **74** | **6** |

The table above reveals that the consumption of concrete, structural steel, and reinforcement / steel strip of Reinforced Earth retaining wall with L-shape R.C. seating is far below than the original piling and pile cap with R.C. retaining wall scheme. Carbon footprint could be reduced by this proposal. By eliminating the piling, construction waste can further be reduced and clean underground could be allowed for future development in case.

## 6 Construction Sequence

The construction of the Reinforced Earth retaining wall can be done by one team of 5 workers with the backhoe and vibratory roller. The construction sequence of the Reinforced Earth retaining wall is straightforward and as shown below.

### 6.1 Excavation

Excavate to the level and alignment as stated in the drawings, except during excavations in rock and in areas of fill formed of rock fill material, formations shall be compacted to obtain a relative compaction of at least 98% to a depth of 200mm below the formation by main contractor. (Figure 4a)

**Figure 4a**: Formation level

### 6.2 Leveling Pad

Pour concrete leveling pad (Figure 4b). The leveling pad should be of concrete grade 20/20, cured for 12 hours. The concrete finish must be smooth and flat. The size of the leveling pad is 350mm width with 200mm thick.

**Figure 4b:** Leveling Pad

### 6.3 Installation of first layer of panel and laying the filter material

The alignment of the first layer of first layer of panel (Figure 4c) should be checked. Use the timber to fix the position of the panel to make sure the alignment is maintained and place the filter material.

**Figure 4c**: First layer of panel

### 6.4 Placing the selected backfill and compaction

Place approved selected fill material (Figure 4d) up to the bottom row of panels tie strips and each layer is around 300mm thick and compact by vibratory roller.

**Figure 4d:** Placing selected backfill

### 6.5 Placing of Reinforcement

Place reinforcing strips on the compacted backfill (Figure 4e). Position strip end into the tie strip gap and match the holes. Push a bolt through the holes from below, put a washer on top and thread on a nut (Figure 4f). Tighten the nut with a socket wrench to complete the connection.

**Figure 4e**: Placing reinforcing strip

**Figure 4f**: Thread on a nut

### 6.6 Erection of the Pre-Cast L-Shape Wall

When the selected backfill is laid to the bottom level of the precast L-shape seating, it is placed on the Reinforced Earth retaining wall (Figure 4g).

**Figure 4g:** Erection of the precast L-shaped R.C. seating

By repeating the construction sequence of section 5.3 to 5.5, the construction of Reinforced Earth Wall is completed (Figure 4h and Figure 4j).

**Figure 4h:** Completion of Reinforced Earth wall

**Figure 4j**: Completion of Reinforced Earth wall with L-shape R.C. seating with steel girder ramp erected

## 7 Other True Abutment Project Reference

The first Reinforced Earth True Abutment Wall was built more than 50 years ago (Figure 5) and more than 1,000 Reinforced Earth True Abutment Wall were completed to date. Suncor Steepbank River Bridge (Figure 6 and 7) is a heavily loaded true abutment in Canada. The wall height is around 15m with 20m long reinforcing strip. The loading is more than 1300ton. Another example of the Reinforced Earth True Abutment with wire mesh facing is shown in Figure 8. A TerraTrel wire mesh facing Reinforced Earth True Abutment can provide a cost effective solution when the facing appearance is not a critical requirement. It can also be used as a permanent structure or temporary structure as

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requested by the client. Another application of the TerraTrel wire mesh facing is for two-stage construction (Figure 9, 10 & 11) which enables the Reinforced Earth retaining wall to allow traffic during construction. Concrete panel facing is used in one side and the wire mesh facing is used in the middle to support the ramp. After stage 1 is completed and the traffic is transferred to the new ramp, the stage 2 can start to complete the other half of the ramp.

**Figure 5:** 1969 Strasbourg, France

**Figure 6:** Suncor Steepbank River Bridge

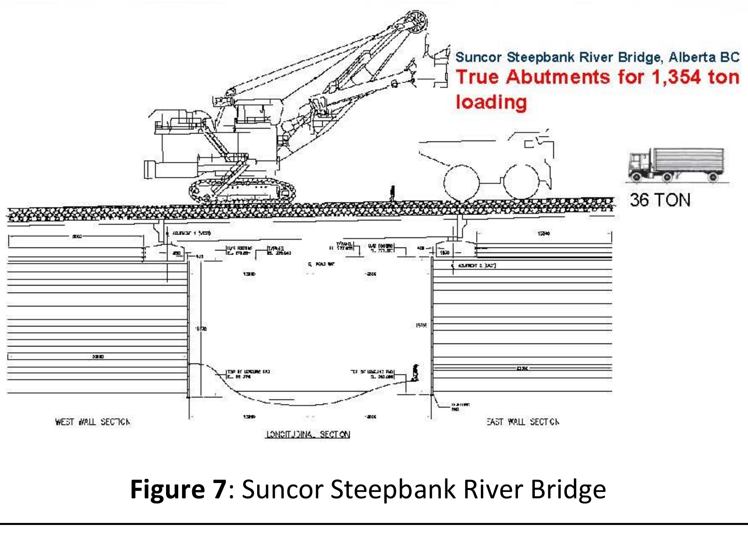


**Figure 7**: Suncor Steepbank River Bridge

**Figure 8:** TerraTrel Reinforced Earth True Abutment

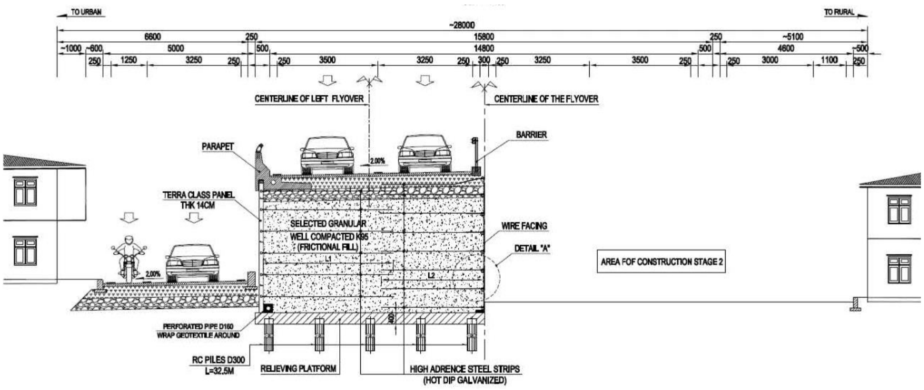


**Figure 9:** Section of stage 1 of a two-stage construction of Reinforced Earth

**Figure 10**: Two-stage construction of Reinforced Earth

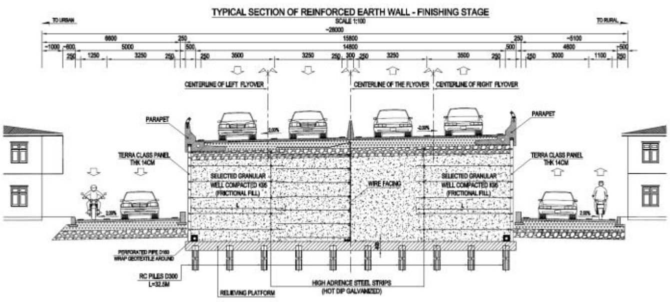


**Figure 11:** Section of stage 2 of a two-stage construction of Reinforced Earth

## 8 Conclusion

Reinforced Earth structures provide great strength and flexibility. The precast concrete facing system adopted provides an attractive appearance and a simple and rapid construction procedure. The procedure is repetitive and mainly consists of panel erection, filter and selected fill backfilling, and reinforcing strips laying. Moreover, the ecological advantages of Reinforced Earth retaining wall are undeniable. The use of the technique results in saving materials and energy, reducing nuisance associated with the construction of a structure such as air pollution and traffic congestion and also reducing disturbances to the foundation soil. In this project, the use of Reinforced Earth retaining wall for the construction of true abutment offer numerous technical and economical advantages including savings made on the foundation works, on the cost of materials, on the skillfulness of the labour and also on the total duration of works.

## References

[1] GEO, CEDD, 2002, Geoguide 6 Guide to Reinforced Fill Structure and slope design