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# Reinforced earth bridge abutments

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ABSTRACT: Reinforced Earth abutments combine retaining and load bearing functions. A key factor in the observed behaviour of Reinforced Earth abutments is the compatibility of steel reinforcement and dense granular earth, which allows for the superposition of the effects of applied loads on to the well established retaining function behaviour at design stress levels. Design methods which have evolved from the experience of model tests, full scale instrumented structures and finite element analyses have allowed the confident application to bridge structures in a wide range of configurations and environments.

## 1 INTRODUCTION

Retaining walls may have both retaining and load bearing functions, however, many retaining wall systems have limited ability to support large loads. At the beginning, Henri Vidal recognised that the effect of increased load on a Reinforced Earth structure was to mobilise more effectively the internal resistance of the structure itself. The use of Reinforced Earth as a bridge abutment was seen, therefore, as a logical application of the technique and one which had many practical and technical benefits for bridge construction including simplicity, economy and flexibility.

Reinforced Earth is a composite material formed by the association of High Adherence steel reinforcement and compacted granular earth. The compatibility of these materials promotes an elastic behaviour at design stress levels which allows for the confident superposition of stress fields resulting from both retaining and load bearing functions.

Almost twenty years of development, using models, instrumented full sized structures and finite element analyses, has shown how the retaining and load bearing stresses are mobilised and how they may be confidently predicted in the design of bridge abutments over a wide range of configurations and loading conditions.

## 2 DEVELOPMENT

In 1970, at the Port of Dunkirk in France, a double sided wall, 15 m high, 550 m long and 18 m wide was constructed to support a travelling gantry crane applying loads of 280 and 380 kN/m, 0.8 m and 2.7 m respectively back from the face. This project was extensively instrumented and provided a unique opportunity to investigate the effect of concentrated loads on a Reinforced Earth structure.

The first major abutment structure was built at Thionville over the Moselle River in 1972 to support the 38 m end span of a continuous concrete bridge structure. Subsequently in 1973-74 the French Road Research Laboratory conducted an extensive series of tests on a highway bridge abutment to Lille to determine the evolution of tensile stresses in the reinforcement strips and of the state of stress within the soil. Further structures were monitored at Triel in 1975 and Angers in 1977.

The present design method is defined in the French Ministry of Transports' "Recommendations and Rules of the Art" (1979). The method, based on the data available at the time, is generally considered to be conservative.

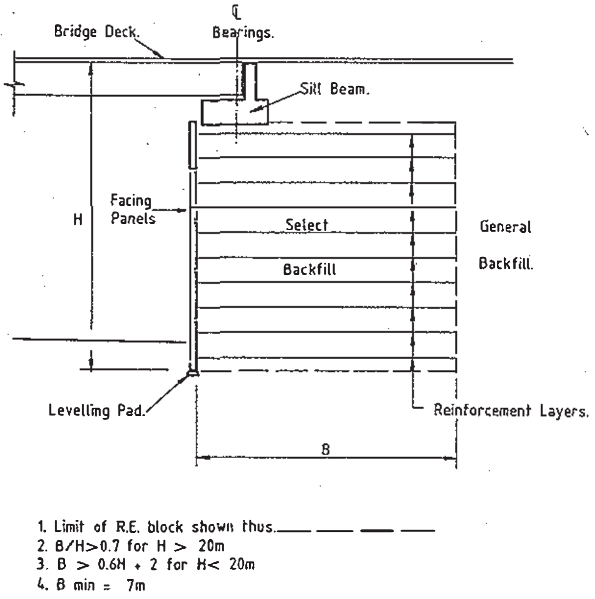
The evolution of Reinforced Earth technology has led to the conception of structures with trapezoidal and/or narrow sections (width/height < 0.7), at greater extremes of applied load and a wider range of geometry (skew, span etc.). Recent research has extended into the application of finite element analyses backed by the instrumentation of control structures to improve our understanding of the behaviour of abutments over a wider range of geometrical configurations. To this end, bridge abutments have been instrumented at Fremersdorf (Germany) in 1981 and Amersfoot (Netherlands) in 1984. Surcharged narrow and trapezoidal block sections have been tested at Milleville (USA) in 1983.

In 1982, TAI (Terre Armee Internationale) and CERMES (Centre d'Etude et de Recherches de Mecanique des Sols), undertook a research programme on three dimensional models with applied loading configurations. Despite their limitations (especially their ability to model friction behaviour and reinforcement characteristics) the models give valuable qualitive information on parameters relating to the behaviour and modes of failure in Reinforced Earth structures.

## 3 CONFIGURATIONS

The true Reinforced Earth abutment directly supports the bridge loads by way of a sill beam seated on the Reinforced Earth block immediately behind the facing panels (Fig. 1). Both horizontal and vertical bridge loads are transmitted directly to the Reinforced Earth block by the sill beam.

A Reinforced Earth structure may be applied to support an embankment either in front of, or behind, piles to form a "mixed" abutment (Fig. 2). On firm foundations, the piles may even be incorporated with the Reinforced Earth facing to form a "pier" abutment, to minimise the bridge span (Fig. 3). Mixed abutments allow the embankment to be separated from the bridge superstructure which may be useful where the bridge structure is sensitive to movements, however, the interaction of the embankment and the piles needs to be carefully evaluated. Pier abutments can only be considered, however, where there is no potential for post construction settlement as the flexibility of the facing is no longer available once construction is complete.



1. Limit of R.E. block shown thus.— — — —
2. B/H>0.7 for H > 20m
3. B > 0.6H + 2 for H< 20m
4. B min = 7m

Fig.1 Reinforced Earth abutment

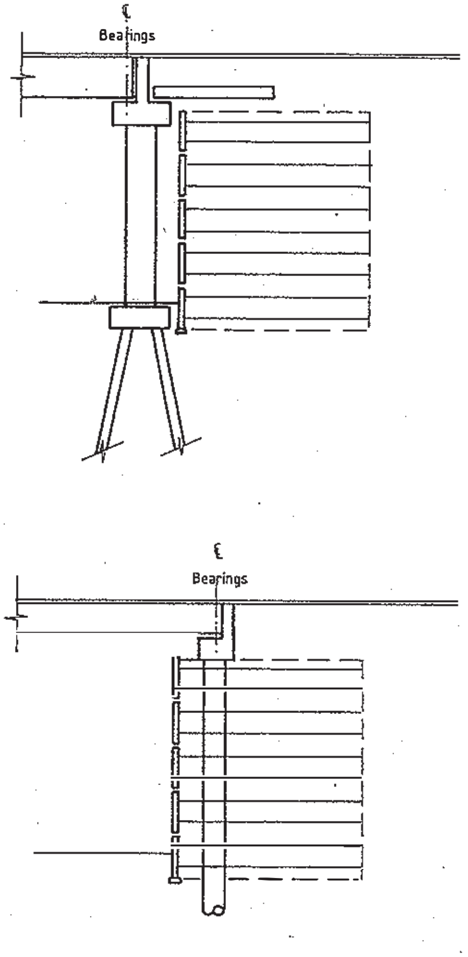


Fig.2 Mixed abutments

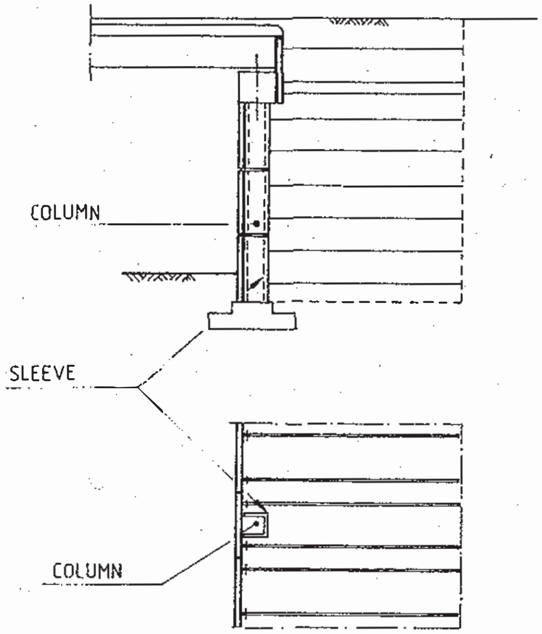


Fig.3 Pier abutment

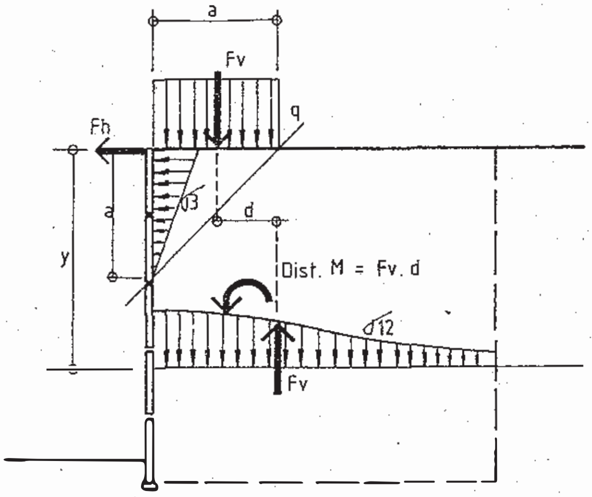


Fig.4 Load bearing stresses

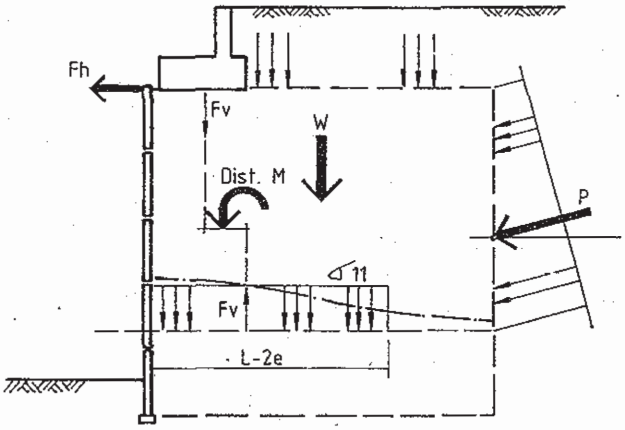


Fig. 5 Retaining stresses

## 4 DESIGN

The proportions of the sill beam are determined to satisfy local stability criteria for sliding, overturning and bearing. Factors of safety appropriate to bridge design standards are selected for sliding and overturning while for bearing, a limiting pressure of 200 kPa (150 kPa under sustained loading conditions) is recommended based on the need to limit differential movements and local stress concentrations immediately beneath the sill beam. These limits reflect the normal criteria for the selection and placement of the granular material used in the Reinforced Earth block.

As a load bearing wall, the stresses distributed from the applied loads need to be assessed for each layer. The vertical pressures (from the sill beam) is diffused following the Boussinesq analysis or, more simply, at 2:1 through the block. The horizontal force (applied by the sill beam) is distributed linearly over a depth at the face equal to the loaded width (Fig. 4).

As a retaining wall, the calculation of vertical stress at each layer needs to consider the overturning effects of embankment and overburden loads and surcharges as well as the overturning effects resulting from the diffusion of applied vertical loads through the Reinforced Earth block and applied horizontal loads from the sill beam (Fig. 5).

The tensile forces in the reinforcement are then calculated by superimposing all of the above effects, according to the formula:-

$$T = A\,(K\sigma_{11} + K\sigma_{12} + \sigma_3)$$

where:

A = tributary area for each reinforcement

K = earth pressure coefficient

$\sigma_{11}$ = vertical pressure (retaining)

$\sigma_{12}$ = vertical pressure (load bearing)

$\sigma_{3}$ = horizontal pressure (applied load)

Internally, a "potential failure line" is identified which equates to the locus of the points of maximum tension in each reinforcement layer.

The "potential failure line" defined by the retaining function is determined from the overall structure geometry and usually varies from a maximum of 0.3 H behind the face at the surface (where H is the functional height of the structure) to the face itself at the toe. This may be modified by the sill beam where its width exceeds the above limits.

The "potential failure line" defined by the load bearing function, passes through the centre of the load and approaches the facing at a depth defined by the "critical wedge" of the sill beam - that is, the Coulomb wedge defined by the rear of the sill beam. (Fig. 6)

For a structure to provide a satisfactory safety level, the tensile resistance of the reinforcement must be sufficient along each "potential failure line" as well as at the facing, while the friction resistance mobilised in the resistant zones must be sufficient for the tensile forces calculated at each "potential failure line".

The compatibility of dense granular earth and high modulus steel reinforcement is an important factor in the internal behaviour of load bearing Reinforced Earth structures. For typical reinforcement densities ranging from 2 to 4 strips/$m^2$, 60 mm X 5 mm in section, and steel modulus of 200 MPa, the effective reinforcement modulus is 100 to 200 kPa, which equates to the modulus of dense granular earth. Such compatibility is not able to be achieved with present generation polymer reinforcement materials such as geotextiles, geogrids or strips, whose effective modulus may be less than 1/10 that of steel. Furthermore, the time dependent behaviour of such materials will preclude it from application in bridge abutments.

## 5 APPLICATION

Reinforced Earth abutments have been designed to support bridge loads in excess of 1000 kN/m (width). Live load to dead

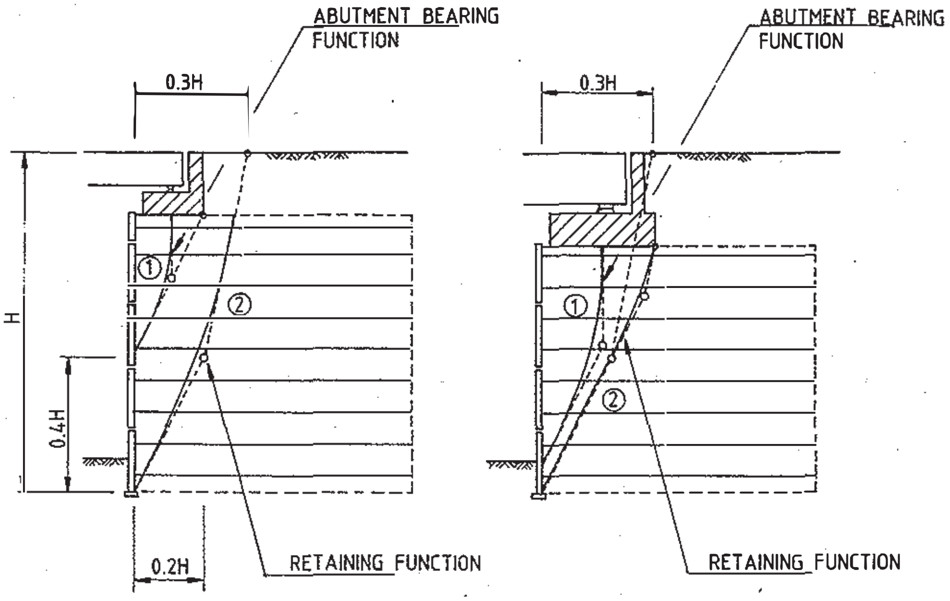


Fig.6 Potential failure lines

load ratios vary from less than 0.5 (highway structures) to more than 3 (mining structures). Abutment wall heights range from a few metres to over 20 m while bridge skew angles up to 75 degrees have been accommodated (square bridge skew angle equals zero).

The relative influence of the embankment (retaining) function and the abutment (load bearing) function depends on the magnitude of the applied loads and the size of the abutment. This will effect the internal and external design of the structure and its interaction with the foundation,both during and after construction. A primary advantage of the Reinforced Earth bridge abutment is its ability to be constructed on poor foundations. The Reinforced Earth block spreads the load more evenly on the foundation and its flexibility allows it to accommodate considerable settlements due to consolidation of the foundation. In some cases, pre-loading of the completed abutment can be applied to limit post construction settlements within acceptable structural and clearance tolerances.

In Spain, an abutment on the Bilbao - Behobie highway settled 1050 mm without distress. In Oregon, USA, a 55 m single span bridge was constructed on Reinforced Earth abutments founded on compressible soils to accommodate an anticipated 300 mm of settlement without loss of structural integrity. In Australia, an unusual bridge structure incorporating one Reinforced Earth abutment, 22 m high, was constructed by the Highways Department of South Australia over the Field River. Here the foundation was extremely variable including an ancient river bed and existing poorly compacted embankment material, however, the structure movements are within the limits required for the bridge and substantiated the use of the system to avoid the expensive foundation treatment required by conventional abutment structures.

The ability to design for dynamic loads is an important consideration for railway and mining bridge structures. In South Australia, a railway bridge of 42 m span over the River Torrens, is directly supported by 7.7 m high Reinforced Earth abutments where poor foundation and existing structures precluded the use of piles. In Queensland, Australia, a 16.3 m span steel bridge supported on 14.5 m high Reinforced Earth abutments is designed to support 300 tonne coal dump trucks unloading at the rate of 2000 tonnes per hour.

In many areas Reinforced Earth abutments are being designed to accommodate the extreme loading conditions required for urban and industrial bridge structures. The performance of these structures in a wide range of applications has confirmed the Reinforced Earth technology as a sound, appropriate and economic bridge abutment construction technique. Worldwide, over 1000 bridge structures incorporate Reinforced Earth abutments.

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