TOWARDS A RESILIENT DESIGN: L-SHAPED BARRIER-IMPACT LOAD MODELLING ON REINFORCED SOIL WALL STRUCTURES

P. Wanis[1] and T. Fitzpatrick[2]

[1]Senior Design Engineer, [2]Design Engineer, The Reinforced Earth Company, Australia

ABSTRACT

It has always been a challenge to model the effect of crash barrier loadings on Reinforced Soil Wall (R.S.W.) structures due to the complexity of their design and the manner in which the load is transferred through each soil reinforcement layer of the R.S.W. structure. Current design practices in Australia rely heavily on the designers experience and the individual knowledge the impact crash barrier loadings have on the R.S.W. structure. Each designer has an individual approach to the same problem. Relevant codes do not adequately cover this issue and leave it up to the designer"s experience. This paper outlines and discusses a design beyond the current codes and how codes and standards can be enhanced. There is a clear necessity to provide a systematic, well proven and tested approach to the manner in which the loading on the R.S.W. structure from the crash barrier is interpreted, modelled and analysed.

1 INTRODUCTION

An R.S.W. structure is a soil block formed by the association of earth and soil reinforcement. Flexible, linear soil reinforcing elements are placed in a granular earth fill. Frictional forces between the soil and the soil reinforcing elements provide a cohesive strength to the earth fill forming a composite material, „Reinforced Earth®". The most common case of an R.S.W. structure is where it supports the access embankment for an overpass. Therefore, the top of the R.S.W. structure must allow for the effects of traffic surcharge and impact. In general, the road surface consists of asphalt pavement which provides far less structural resistance for the incorporation of crash barriers than a concrete pavement. For the purpose of crash barrier design, the crash barrier has to be assumed to take the full impact load without any support from the asphalt pavement.

In the case of L-shaped barriers, the footing is intended to provide stability for the barrier to resist impact loads and to reduce the influence of these impact loads on the R.S.W. structure by distributing the load over a wide area (Briaud et al 2012). The resistance is generated by the inertia force required to lift the slab. The impact load then generates additional stresses in the R.S.W. structure soil reinforcement in addition to the static loads due to gravity. The dynamic design loads are specified using both a pressure distribution approach and a line load approach.

Australian Standards currently do not provide any clear guidelines in relation to the effect crash barrier loadings have on R.S.W. structures. As a result there are no design analysis programs currently available that adequately examine the impact loads and their net effect on the R.S.W. structure. The accurate design of R.S.W. structures with an incorporated crash barrier system requires a good understanding of the relevant failure modes and the magnitude and distribution of impact loads transferred from the crash barrier system onto the R.S.W. structure. The manner in which the design has been approached can often be dictated by information provided by the external designers. This information may be unrealistic however; it can control the design where it is not possible to provide a clear alternative which can be adequately backed up by the relevant codes.
This paper aims to:

i) Provide information on how codes and standards can be enhanced.

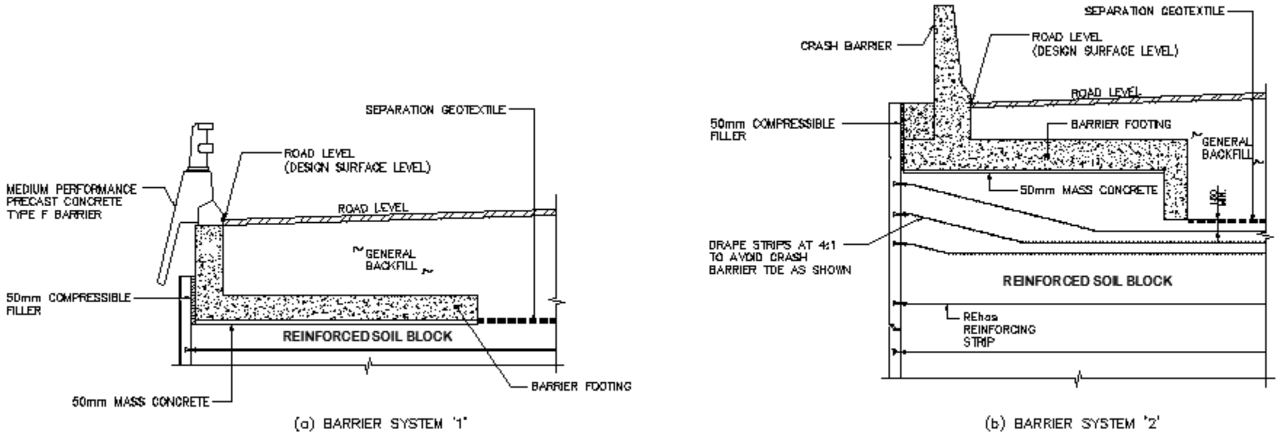
ii) Recommend a new design approach for the accurate interpretation and modelling of crash barrier loading on R.S.W. structures based on current Australian Standards and other relevant international standards.

2 THEORY

2.1 LOADS

2.1.1 Permanent Loads

The soil above the crash barrier footing and the concrete crash barrier self-weight has to be considered in the analysis. The magnitude and line of action must also be calculated. Therefore, the geometry of the crash barrier and depth of soil plays a significant role in the analysis of the system. As shown in Figure 1, there are several different crash barriers systems that are already in place and have been built for various projects. Table 1 shows the value of the permanent loads (working) and point of action behind the wall facing.



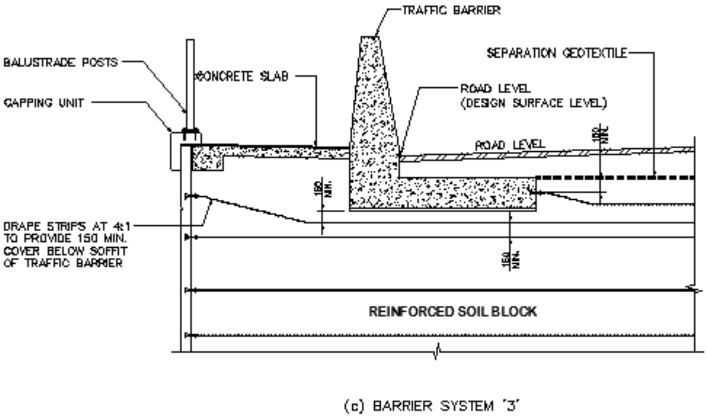


Figure 1: Different Crash Barrier Geometries

Table 1: Permenant Loads – Working

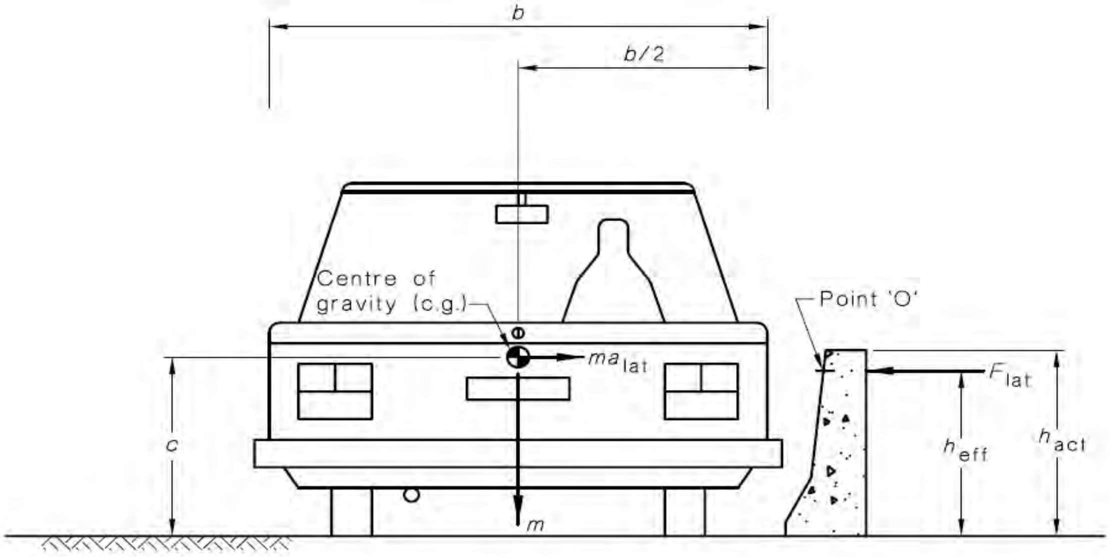
Barrier System	Weight $_{\text{Soil}}$ (kN/m)	Weight $_{\text{Concrete}}$ (kN/m)	Weight $_{\text{Total}}$ (kN/m)	Distance between Weight $_{\text{Total}}$ line of action & wall facing (m)
1	72	45	117	1.88
2	32	61	93	1.95
3	12	48	60	3.10

2.1.2 Live Loads

The vehicle vertical load must be considered in the design. Many guidelines are available for the value of the vertical load to be incorporated in the design based on Australian Standards and technical specifications as follows:

1- Australian Standards AS5100; Bridge Design Code, Part 2: Design loads, road traffic vary between W80 wheel load, A160 axle load, M1600 moving traffic load, S1600 stationary traffic load and heavy platform load. The majority of these loads are equivalent to 20 – 25 kPa.

2- Australian Standards AS/NZS 3845; Road Safety Barrier Systems, Clause 3.5 suggests using the mass of the vehicle in the analysis as shown in Figure 2.



where

F_{lat} = effective lateral force applied to the road safety barrier

h_{act} = height of the road safety barrier system above ground, in metres

Figure 2: Suggested vertical load to be used in the analysis as per AS/NZS 3845.

3- The information on owner product specifications (mainly for heavy vehicles and dump trucks) is available for the public. These specifications include information regarding: total vehicle weight, load distribution over the front and rear axle, vehicle dimensions and pay load. Table 2 shows the load distribution details for a CAT 797B Mining Truck (Gross Vehicle Weight 624T). By using this information designers can model the live loads to be considered in the analysis accurately and as per site conditions.

Table 2: CAT 797B Mining Truck Weight Distributions Details

Weight Distributions - Approximate	
Front Axle - Empty	43.5%
Rear Axle - Empty	56.5%
Front Axle - Loaded	33.3%
Rear Axle - Loaded	66.7%

2.1.3 Collision Loads

Similar to the vertical live load, many guidelines are available in Australian Standards and technical specifications for different levels of vehicular collision loads. They vary depending upon the crash barrier performance level as follows:

1- Australian Standards AS5100; Bridge Design Code, Part 2: Design loads Clause 11.2.2 “Traffic barrier design loads” and Appendix A. The classification is based on the crash barrier performance level as per Table 3, the direction and notations for these loads are shown in Figure 3.

Table 3: Traffic Barrier Design Loads as per AS5100.

Barrier performance level	Ultimate transverse outward load (F_T) **(kN)**	Ultimate longitudinal or transverse inward load (F_L) **(kN)**	Vehicle contact length for transverse loads (L_T) and longitudinal loads (L_L) **(m)**	Ultimate vertical downward load (F_V) **(kN)**	Vehicle contact length for vertical loads (L_V) **(m)**	Minimum effective height(H_E) **(mm)**
Low	125	40	1.1	20	5.5	500
Regular	250	80	1.1	80	5.5	800
Medium	500	170	2.4	350	12	1100
Test level 6 (36 T articulated tanker)	750	250	2.4	350	12	1400
Greater than Test Level 6 (44 T articulated van)	1000	330	2.5	450	15	1400

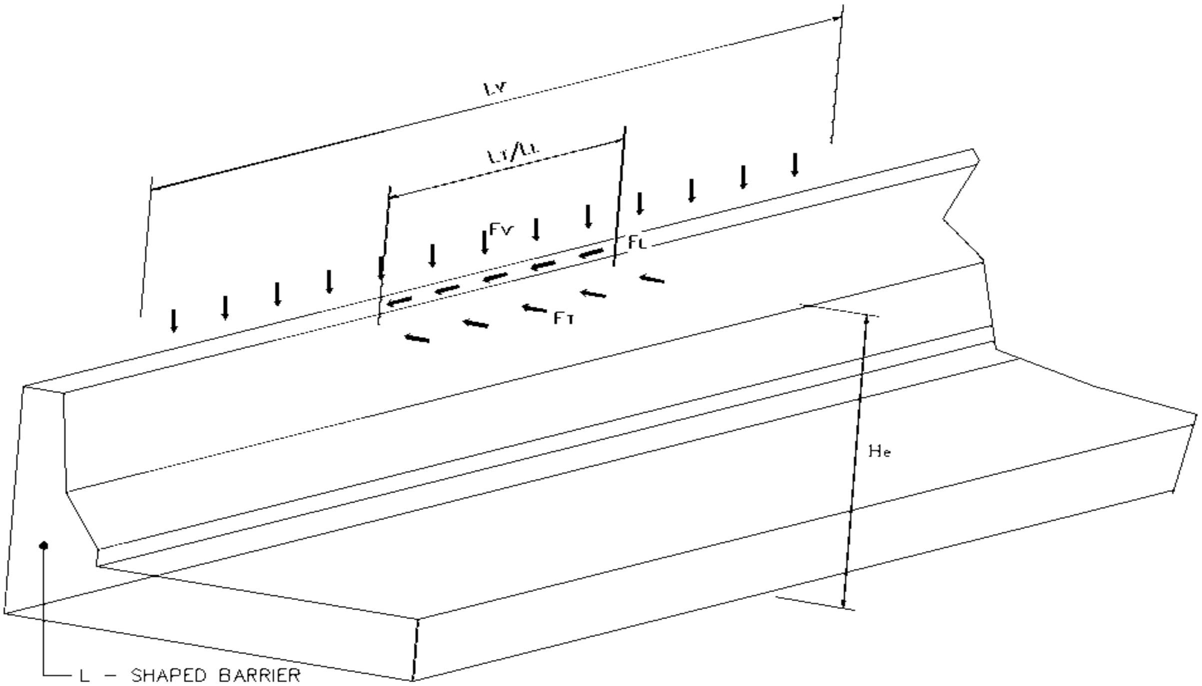


Figure 3: Crash Barrier Load Directions and Distributed Length as per AS5100.

2- Australian Standards AS/NZS 3845; Road Safety Barrier Systems, Appendix C Tables C1 and C2 summarize the design loads and distributed length based on type of vehicle and category of test level. Table 4 shows a summary of this information.

Table 4: Traffic Barrier Design Loads as per AS3845.

Corresponding AS5100 barrier performance level	Type of vehicle	Longitudinal length (L_T) **(mm)**	Category	Design Load **(kN)**	Minimum height above road surface **(mm)**
Low	Pick up or small vehicle	1200	Test Level 2	100	535
			Test Level 3	100	535
Regular	Van or truck with single rear axle	1070	Test Level 4	300	820
Medium	Truck with rear tandem axles	2400	Test Level 5 <	700	1500

2.2 LOAD CASES

Australian Standards AS4678; Earth-Retaining Structures, Appendix J gives some guidelines for the load combinations that have to be checked for the R.S.W. structure design. The load factors that should be used in the design for R.S.W. stability are as per Table 5.

Table 5: Load Factors as per AS4678.

Dead load	0.80 (min.)	1.25 (max.)
Live load	0.00 (min.)	1.50 (max.)

The combinations of these load factors that should be used in the design are shown in Table 6.

Table 6: Static Load Combination as per AS4678.

Load Case	1 (static)	2 (static)	3 (static)
Weight of the R.S.W. Structure	0.80	1.25	1.00
Earth Pressure from Backfill	1.25	1.25	1.00
Live Load on R.S.W. Structure	0.00	1.50	0.00
Live Load behind R.S.W. Structure	1.50	1.50	0.00

There is no reference in Australian Standards AS4678; Earth-Retaining Structures on how to incorporate the collision loads, so guidelines from Australian Standards AS5100; Bridge Design Code, Part 2: Design Loads can be used. According to AS5100.2 Clause 22.2(c), the Permanent effect + Ultimate collision load case has to be considered. The permanent effect load factor can be obtained from Table 5.2 of the same standards which refers to a load factor of 1.2 or 0.85 to be considered for the dead load factor, depending upon whether it reduces or increases safety. However, for the ultimate collision load factor AS5100.2 Clause 11.2.2, states that a load factor of 1.0 is to be used. Therefore Table 6 can be modified to include the collision load cases as per Table 7.

Table 7: Static Load Combination as per AS4678 and Collision Load Combination as per AS5100.

Load Case	1 (static)	2 (static)	3 (static)	4 (collision)	5 (collision)
Weight of the R.S.W. Structure	0.80	1.25	1.00	0.85	1.20
Earth Pressure from Backfill	1.25	1.25	1.00	1.25	1.25
Live Load on R.S.W. Structure	0.00	1.50	0.00	0.00	1.50
Live Load behind R.S.W. Structure	1.50	1.50	0.00	1.50	1.50
Collision Load	0.00	0.00	0.00	1.00	1.00

2.3 MAXIMUM SOIL PRESSURE

In order to properly examine the effect of the collision load combination on the R.S.W. structure, the maximum soil pressure at the soffit of the crash barrier footing due to collision load has to be calculated. The collision load will be transferred to the soffit of the crash barrier footing as an equivalent vertical pressure and horizontal load.

2.3.1 Vertical Pressure Calculation

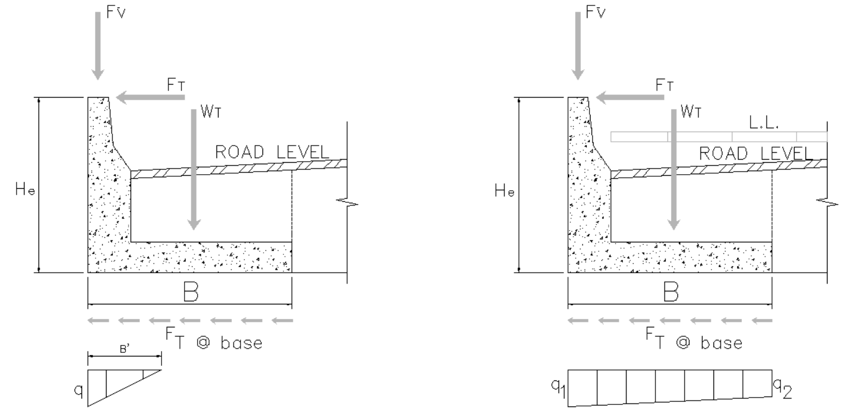
For R.S.W. structure design purposes, by considering 1.0m section of the crash barrier, depending upon the load case, the maximum soil pressure diagram will be one of the following:

2.3.1.1 Triangular soil pressure (generally Load Case 4 in Table 7)

An equation for the maximum soil pressure q and the effective footing length B‟ can be obtained from Figure 4 (load case 4) where it is obvious that the base area is not fully effective by the amount B-B‟. The area of the pressure distribution must be equal to the total vertical load ($\Sigma F_Y = 0.0$) and acts at B‟/3 from the toe through the triangle centroid. Also the summation of the moment of all forces is equal to zero at any point ($\Sigma M = 0.0$). Therefore q and B‟ can be easily determined based on these two equations.

2.3.1.2 Trapezoidal soil pressure (generally Load Case 5 in Table 7)

An equation for the maximum soil pressure q1 and q2 can be obtained from Figure 4 (load case 5) where it is obvious that the total base area is fully effective. The area of the pressure distribution must be equal to the total vertical load ($\Sigma F_Y = 0.0$) and acts at its centroid. Also the summation of the moment of all forces is equal to zero at any point ($\Sigma M = 0.0$). Therefore q1 and q2 can be easily determined based on these two equations.



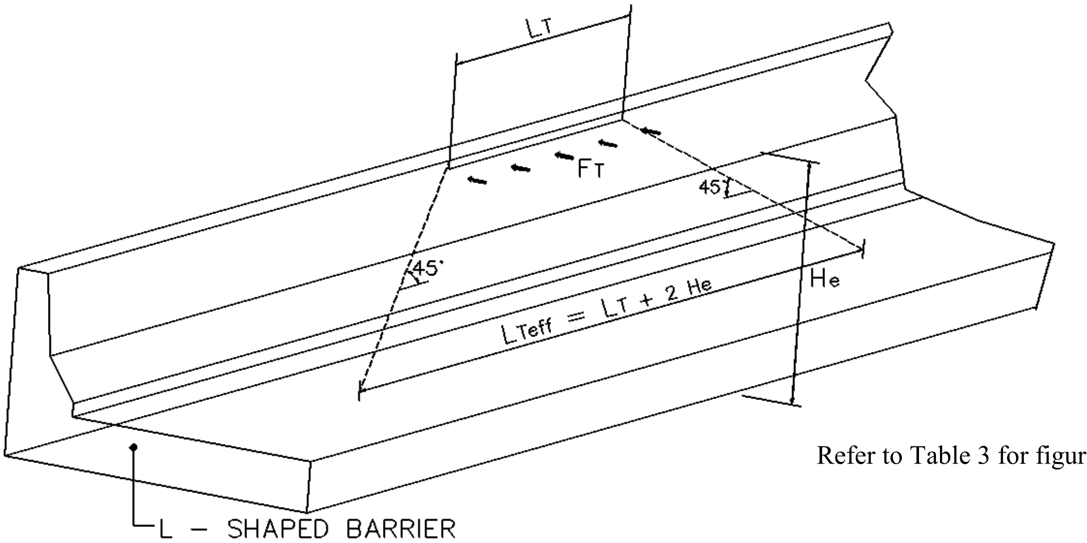
(a) LOAD CASE 4

(b) LOAD CASE 5

Figure 4: Maximum Soil Pressure at Soffit of Crash Barrier Footing for Load Case 4 and Load Case 5.

2.3.2 Horizontal Load Calculation ($F_{T\ @\ base}$)

The analysis can be undertaken by assuming the distribution of the transverse load at 45° to the horizontal from the point of application of the load to the soffit of the crash barrier as shown in Figure 5. End effects such as expansion joints should be considered to determine the effective distribution length. Referring to Figure 5, $F_{T\ @\ base} = F_T / L_{Teff}$



Refer to Table 3 for figure notations

Figure 5: Collision Transverse Load Distribution.

3 CURRENT PRACTICES

In Australia, the code that governs the design of R.S.W. structures is the Australian Standards AS4678; Earth-Retaining Structures. AS4678 offers limited guidelines for the crash barrier load effect on the R.S.W. structure in Appendix J Clause J10.1 (b) which states: “In some cases, the retaining structure may support other amenities such as sound barriers or New Jersey kerbs that may attract loadings, e.g. wind loads or traffic impact loads. The effect of such loads should be checked for the global and internal stability of the retaining structure.”

Additionally, there are no guidelines for the load cases to be considered with such a special loading. Also from experience, the authors have seen many approaches for the distribution of the crash barrier load through to the soffit of the crash barrier footing. Australian Standards AS5100; Bridge Design Code defines the distribution width at the top of the crash barrier however, the manner in which the load is transferred to the soffit of the crash barrier is not clear and is left open for interpretation.

There are varying methods and methodologies taken to examine the net impact on the R.S.W. structures by designers. This has resulted in the implementation of overly conservative designs to account for the uncertainty regarding the manner in which the loads are transferred and transmitted through the R.S.W. structure. More importantly, there is a risk that the effects of load transfer onto the R.S.W. structure are being underestimated by inexperienced designers and therefore the full effect of collision impact on the R.S.W. structure are being inadequately designed for.

4 DESIGN APPROACHES

As Australian Standards do not adequately provide guidelines for the effects for crash barrier loading on R.S.W. structures, designers have turned to both the USA and UK Standards to examine their methodologies. Both have examined the crash barrier effects in more detail, particularly the USA where the crash barrier impact on the R.S.W. structure is outlined in AASHTO LRFD. However, neither approach has been implemented in their entirety for the approach proposed in this paper.

4.1 AASHTO LRFD

AASHTO LRFD Bridge Design Specification (SI) examines the design of three main components:

1. Barrier-moment slab system
2. R.S.W. structure reinforcement
3. R.S.W. facing panel

The barrier-moment slab design examines two failure modes in addition to structural failure; sliding and overturning. For sliding, the barriers factored resistance is examined, it must be greater than the factored static load applied over the length of the slab ($F^* > ØR$). In regards overturning, the factored moment resistance must be greater than that of the factored moment applied ($M^* > ØM_R$). The moment applied is the factored equivalent static load times the relevant lever arm.

AASHTO LRFD also outlines the design approach for the effect of the crash barrier on the R.S.W. structure in Clause 11.10.10.2. It specifies the concentrated horizontal load that the upper layers of soil reinforcement have to resist. The soil reinforcement‟s resistance has to be examined at both pull-out and tensile failure. AASHTO LRFD sets out the relevant factors to be considered as part of the design as well as the relevant load cases. Interestingly the force distribution for pull-out calculations is greater than that used for tensile calculations because the entire base slab must move laterally to initiate a pull-out failure due to the relatively large deformation required according to AASHTO LRFD.

4.2 BRITISH STANDARDS

British Standards base its design on two main effects:

1. Local Effects: examines the area in the vicinity of the collision.
2. Global Effects: examines the structure as a whole.

Both effects examine sliding, toppling and rupture of the base slab. However, it is only the Global Design that examines the effect on the R.S.W. structure. The design examines both the Ultimate and Serviceability Limit State Design to ensure that the design requirements from a structural and useability perspective are met.

For loads due to vehicle collisions, BSI British Standards BS 8006-1:2010 Annex E requires the following collision loads to be applied uniformly over a 3m length at the top of the traffic face of a high level of containment parapet:

1. A horizontal transverse load of 500kN
2. A horizontal longitudinal load of 100kN
3. A vertical load of 175kN

The code also recommends that any load effects be distributed both vertically and horizontally through any up-stand plinth. The load is distributed at a 1:1 ratio through the structure. Also clear guidelines are given for the live load and load combinations to be considered in the design.

5 RECOMMENDED APPROACH

Having reviewed the current practices and approaches, The Reinforced Earth Company commenced researching a new design analysis approach that would take into account the current Australian Standards as well as other international codes where aspects were not adequately covered under the Australian codes. This new approach had to take into account the varying range of crash barrier performance levels and geometries. It also had to place emphasis on examining the effect of loading and its distribution at each soil reinforcement layer. The program was required to be flexible to easily cater for geometry, soil reinforcement and loading changes. However, the main purpose of implementing a new design analysis approach was to introduce a clear and systematic method of design, backed up with the relevant codes that could be easily reviewed by clients and external designers (relevant stakeholders). The following steps summarise the design steps taken in this approach.

5.1 STEP 1: CALCULATE THE DESIGN ACTION EFFECT ON TOP OF THE R.S.W. STRUCTURE

This can be calculated using force equilibrium equations as discussed in Section 2.3.1 of this paper. It is recommended to use Meyerhof pressure distribution where the pressure beneath the soffit of the crash barrier footing is assumed to be uniform over an effective width as shown in Figure 6 and given by $B_{ref} = B\text{-}2e$. Two load cases (L.C. 4 & L.C. 5) should be considered in calculating the **vertical** Meyerhof pressure as per Table 7.

Calculation of the **horizontal** shear load based on barrier performance level following the guidelines as per Australian Standards AS5100 Bridge Design Code and the approach discussed in Section 2.3.2 of this paper.

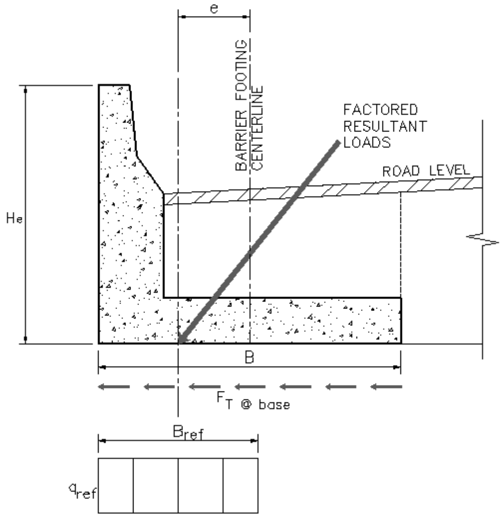
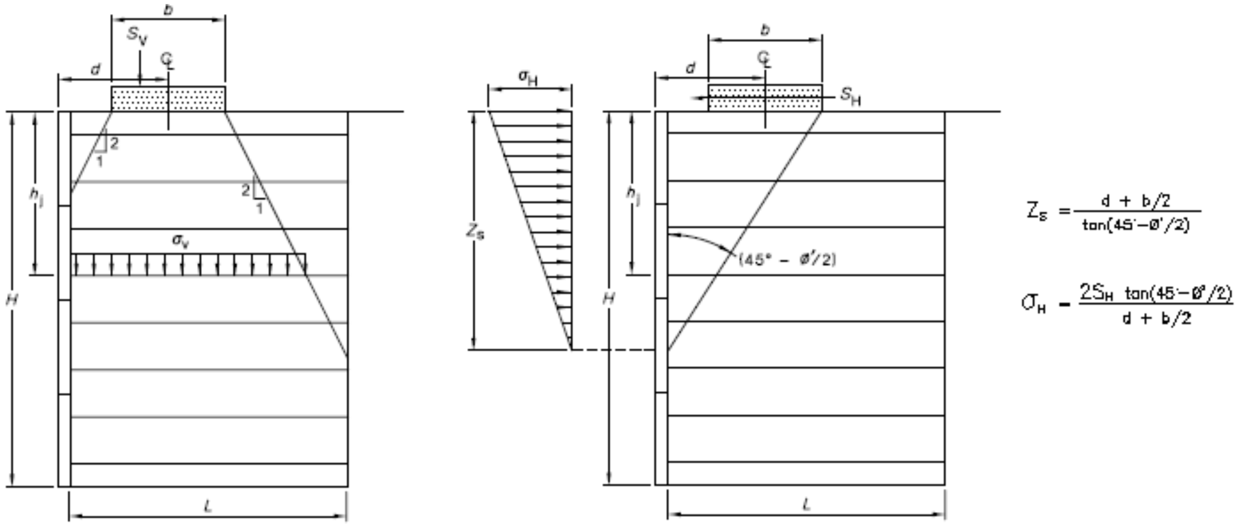


Figure 6: Meyerhof Pressure Distribution.

5.2 STEP 2: DISTRIBUTION OF THE DESIGN ACTIONS ON EACH SOIL REINFORCEMENT LAYER

This includes the calculation of the vertical pressure at each layer due to the vertical Meyerhof soil pressure. Also the calculation of the horizontal pressure due to the horizontal shear load at barrier soffit footing level. Both can be done using the guidelines from Australian Standards AS4678 Earth-retaining Structures Clause J10.4 and Figure J8.



(a) Vertical Strip load Dispersion (b) Horizontal Shear load Dispersion

Figure 7: Dispersal of vertical strip load and horizontal shear load through reinforced fill as per AS4678 Figure J8.

5.3 STEP 3: DESIGN

a) Examine the internal design of the R.S.W. structure at each soil reinforcement layer, taking into account the additional horizontal and vertical pressures for each load case. The design should ensure that the soil reinforcement does not pull-out or rupture. Accordingly, the soil reinforcement‟s resistance has to be examined for both pull-out and tensile failure. In examining the pull-out capacity of the soil reinforcement, its full length is considered to be effective in resisting pull-out due to the impact load (following AASHTO LRFD Bridge Design Specifications Clause 11.10.10.2; Australian Standards do not currently examine this). The soil reinforcement frequency and length should be amended to achieve optimum design as required. The location of each soil reinforcement layer relative to the loaded area will have a significant effect on the load distribution across each layer.

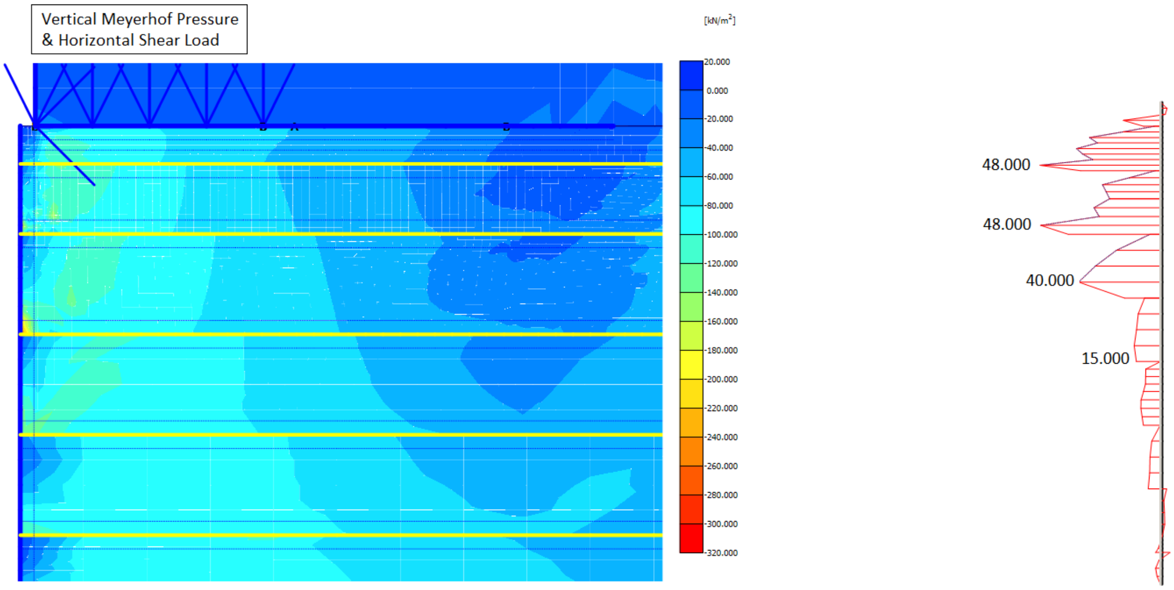
b) Examine circular and linear slip failures with a stability analysis program by modelling the barrier footing and applying the vertical Meyerhof pressure and the horizontal shear load on top on the R.S.W. structure.

c) Check the wall facing capacity, taking into account the additional horizontal and vertical pressures for each load case. The wall facing should have sufficient structural capacity to resist the maximum design pressure.

6 APPROACH VERIFICATION

Having researched and developed the above design approach, it was required to fully verify its results before this design approach was fully implemented. An analysis was carried out using PLAXIS 2D version 8.2, a finite element computer program. This allowed the modelling of the combined R.S.W. structure, foundations and crash barrier loading. The crash barrier loading was modelled as per Section 5.1 above, the Meyerhof pressure was assumed to act at barrier soffit footing level combined with the horizontal load.

A selected output from PLAXIS 2D analysis is shown in Figure 8 which clearly demonstrates the manner in which the stresses are transferred from the crash barrier footing through to the R.S.W. structure along the wall facing. These stresses are then transferred to the soil reinforcement which act to resist the additional stresses. The results from this analysis are consistent with the stress distribution assumed in the recommended design approach.



(b) Effective Mean Stress (kPa)

(a) Approximate Shear Stress @ Facing (kPa)

Figure 8: PLAXIS 2D version 8.2 analysis results.

7 CONCLUSIONS AND RECOMMENDATIONS

A step by step systematic design approach has been developed that incorporates force equilibrium with all available guidelines from the Australian Standards. This approach has been verified using a finite element analysis program. The net effective pressure resulting from all forces acting on top of the crash barrier is examined for its effect on external and internal stability on the R.S.W. structure taking into account the most critical load cases.

Having examined Australian and other international standards, it is essential that the Australian Standards are enhanced to provide a clear design approach for the R.S.W. structure design under collision loading that specify the following:

1. The load cases to be considered and the manner in which this loading is transferred from the top of the crash barrier through to the soffit.
2. The full length of the soil reinforcement should be considered effective in resisting pull-out due to the impact load.
3. A consistent traffic barrier design loading specification (transverse load, vehicle contact length and effective height) across all Australian Standards.

It is essential that the stress distribution of the collision load in the three dimensions through the R.S.W. structure is fully understood. Currently, to the author‟s knowledge, the only research being carried out in this area has been completed by the Texas Transport Institute in conjunction with The Reinforced Earth Company USA. With such little research and full scale testing being carried out, it is an area that needs much further development of knowledge and understanding and for that to be translated into applicable design standards.

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