New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Design of roadside barrier systems for MSE retaining walls

P.L. Anderson
The Reinforced Earth Company, North Reading, MA., USA

R.A. Gladstone
Association for Metallically Stabilized Earth, McLean, VA., USA

K. Truong
The Reinforced Earth Company, Vienna, VA., USA

ABSTRACT: There is confusion among civil engineers in the United States regarding the applicable design method and the appropriate impact load for sizing the moment slab of roadside barrier systems atop MSE retaining walls. The design method and impact load discussed herein have been used successfully for more than 15 years to size the barrier moment slab and to determine the magnitude of loads applied to the supporting MSE wall. The source of confusion by civil engineers is explained and the current research to eliminate this confusion is described.

1 INTRODUCTION

Concrete safety barriers have been constructed on MSE walls in the United States since the early 1980s. Wall-mounted barriers were developed in France and crash tested by Service D'Études Techniques Des Routes et Autoroutes (SETRA) and Terre Armée Internationale (TAI) in 1982 (TAI, 1982). Hundreds of kilometers of both cast-in-place and precast barriers are in service and performing successfully throughout the United States and around the world.

Safety barriers and their supporting MSE walls are designed by a pseudo-static design method developed more than 20 years ago. The resulting moment slab dimensions (typically ±350 mm thick × 1250 mm wide by 6 m long minimum) are reasonable and barrier performance has been excellent, with no reports of failures despite numerous impacts by both passenger vehicles and trucks. Figure 1 shows a typical precast concrete barrier and moment slab designed by the pseudo-static design method. This or similar barrier designs have been constructed atop thousands of MSE retaining walls from 1985 to 2000 and performance has been excellent.

Since 1994, The American Association of State Highway and Transportation Officials (AASHTO) specifications for the design of Mechanically Stabilized Earth (MSE) walls have included the pseudo-static barrier design method (AASHTO, 1994).

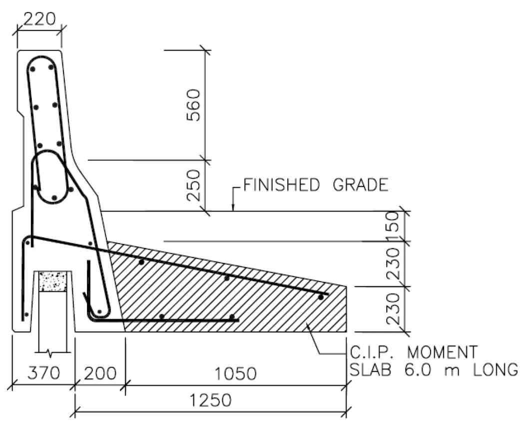

Figure 1. Typical barrier and moment slab 1985–2000.

Recently, AASHTO established new bridge railing and concrete barrier performance levels and higher dynamic impact loads, based on roadway type, speed, and percentage of truck traffic (AASHTO, 2002). Although the pseudo-static design method has not changed, engineers are attempting to design MSE barriers using the new dynamic loads. The result is unreasonable barrier designs having moment slabs with 2 to 3 times the mass required to withstand traditional pseudo-static design loading. Thus, the new AASHTO dynamic impact loads are significantly increasing barrier costs while providing no apparent benefit over the performance of long-proven designs.

2 DESIGN OF ROADSIDE BARRIER SYSTEMS

A roadside barrier system must be designed to contain and safely redirect a vehicle during an impact event. In addition, the barrier system must not transfer high impact forces to the precast concrete facing panels of the MSE wall below. Therefore, parapet shape, internal strength and overall mass stability must all be considered in barrier system design.

A variety of traffic barrier shapes with predictable deflection characteristics are in use throughout the United States. For overall mass stability against rotation and sliding, barrier systems atop MSE walls, whether cast-in-place or precast, are designed to resist the impact load by calculations using simple statics over a 6 m length of barrier and moment slab. Internal strength of the barrier is determined using appropriate reinforced concrete design procedures.

To preclude the transfer of high impact loads to the MSE wall panels below the barrier, a 20 mm gap is provided between the throat of the precast barrier and the back side of the facing panels. When casting a barrier in place, a 20 mm thick compressible foam material is placed on the back side of the facing panels prior to pouring the moment slab. Since there is no barrier-to-panel contact, due to the gap or the compressible material, the horizontal impact force is transferred to the reinforced soil by shear stresses that develop beneath the barrier slab. The influence depth of these shear forces is a function of the soil shear strength, the width of the barrier slab, and the stiffness of the reinforced soil structure. The stiffer the structure, the deeper the shear forces will distribute, thus reducing the concentration of these forces at the top of wall.

Due to the instantaneous nature of the impact loading, the apparent coefficient of friction between the soil and the reinforcements becomes virtually infinite as the load is applied. As seen from full scale crash testing, pullout of the reinforcements does not have time to occur before the impact loading ends. Therefore, only tensile stress in the MSE soil reinforcements needs to be checked, and pullout during impact may safely be ignored. Considering the minimum reinforcement density used in Reinforced Earth wall design (4 strips across a 3 m width of wall), the allowable tensile resistance of the top row is more than adequate to resist the AASHTO-specified pseudo-static 45 KN impact load. The excellent performance of hundreds of kilometers of both precast and cast-in-place traffic barrier atop Reinforced Earth structures having minimum reinforcing strip density (4), and in many cases minimum

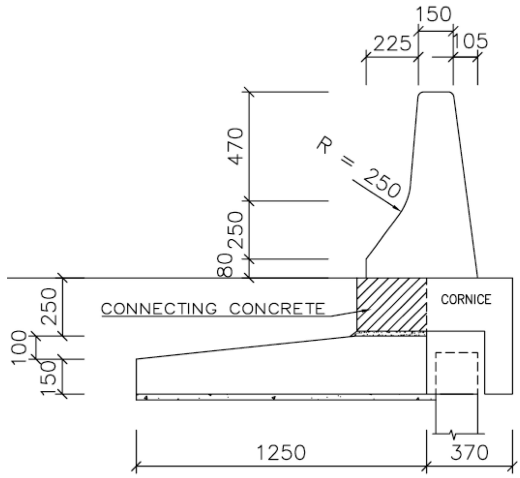

Figure 2. Crash tested barrier (TAI, 1982).

length (2.4 m), is testament to the appropriateness of this design method and pseudo static impact load.

3 FIELD TEST OF A ROADSIDE BARRIER ATOP A REINFORCED EARTH WALL

In 1982 SETRA and TAI jointly conducted crash tests on a roadside barrier system atop a Reinforced Earth wall.

The wall and barrier were constructed on the test site of the Organisme National de la Sécurité Routière in Bron, France. The tested barrier (Figure 2) was a so-called Jersey shape, 800 mm high from the roadway to the top of barrier, 150 mm thick at the top, and 480 mm thick at the roadway surface. Six 1500 mm long precast coping units (labeled “cornice” on Figure 2), connected by three 1250 mm wide junction slabs totaling 9000 mm in length, formed the base of the cast-in-place test barrier.

There was almost no concrete reinforcement in the Jersey barrier shape, with only 2 longitudinal 12 mm bars (Figure 3). The tension members connecting the 9000 mm long cast-in-place barrier sections to the junction slab would be considered extremely light by today’s standards, consisting of two 12 mm longitudinal bars and 8 mm stirrups at 250 mm on center.

The SETRA/TAI crash test vehicle was a Berliet PHN 8 bus. It weighed 12 metric tonnes and impacted the barrier at a speed of 71.2 km/hr and a 20° angle. During the event there were two distinct impacts, the first from the front of the bus and the second as the rear of the bus slid into the barrier. Sensors on the front and rear axles recorded the deceleration due to impact.

Damage to the precast barrier system was limited to the parapet itself. A 2200 mm-long V-shape area was

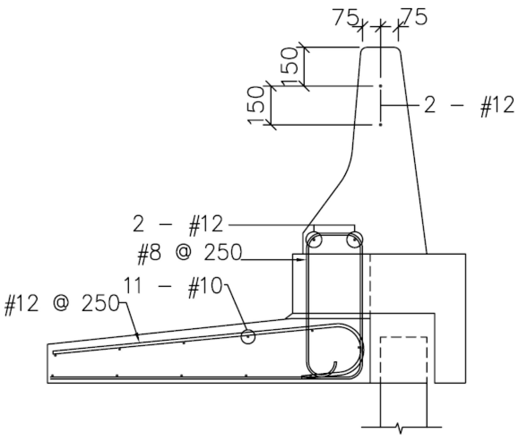

Figure 3. Concrete reinforcement in tested barrier.

ruptured, with the depth of rupture being 500 mm at the center of the V. Fragments of concrete from the rupture were contained on the roadway side of the barrier.

Dynamic displacement of the Reinforced Earth wall was limited to 4.9 mm during the event, with permanent deformation of 1.5 mm after rebound. There was no loss of adherence, and there was no failure of any of the 5 m long reinforcing strips in the top level, despite use of minimum strip density (four 40 × 5 mm strips per 3 m horizontally). The maximum force recorded on the most highly stressed reinforcing strip was 29 KN, less than the reinforcing strip long term allowable tension.

The SETRA/TAI crash test was instrumental in developing an understanding of the required dimensions of the roadside barrier system, including the width and length of the moment slab, and in development of a pseudo-static design method and appropriate impact load for roadside barriers mounted atop Reinforced Earth walls.

4 PSEUDO-STATIC DESIGN METHOD

The instantaneous nature and magnitude of the applied load cannot be modeled by static computations. Therefore, it is recommended to use the pseudo-static design method given in the 1994 AASHTO Interims. Using this method, the traffic barrier and junction slab system are designed for a (pseudo-static) 45 KN impact load applied at the top of barrier and distributed over a 6 m continuous junction slab length. The junction slab is joined to adjacent sections with either shear dowels or continuous reinforcement through the construction joints. Concrete design is by a strength design method, while overall stability of the barrier system is checked by calculations using simple statics.

The resulting barrier is proportioned and reinforced conservatively compared to the barrier that was crash tested by SETRA and TAI.

The minimum factors of safety for barrier/slab sliding and overturning should be 1.5 and 2.0, respectively, when using the pseudo-static 45 KN impact load applied to the top of the barrier. The full soil reinforcement length is considered effective in resisting pullout during the impact event. Since the impact load is distributed over a 6 m junction slab length, the full 6 m length of junction slab would need to move out as a unit for the barrier to move at all.

To check reinforcement tension, the 45 KN impact load is distributed over a 1.5 m length of wall. With the minimum reinforcing strip density, 4 strips per 3 m horizontally, the sum of the impact load plus the tensile load from soil retention results in a calculated total tensile load of 29 KN per strip. This total load must be less than the long-term allowable load for a reinforcing strip. Measurements of reinforcing strip tension during the TAI/SETRA crash tests were in excellent agreement with the pseudo-static design calculations and the top layer of reinforcing strips was loaded within allowable limits during the crash event. The calculated and measured 29 KN load is less than the 32 KN long term allowable tension for standard 50 × 4 mm reinforcing strips used in United States design practice.

5 DYNAMIC LOADS FOR YIELD LINE ANALYSIS OF RAILINGS

AASHTO recently established new bridge railing and concrete barrier performance levels, with associated dynamic impact loads, based on roadway type, speed, and percentage of truck traffic. The dynamic loads are presented in Table 1. These dynamic loads are for use in yield line analysis of metal bridge railings and for strength design of reinforced concrete parapets, but engineers have attempted to use them (notably the TL-4 loading condition) for dimensioning the moment slabs of barriers atop MSE walls. Considering the resulting confusion and unrealistic designs, it is instructive to compare the SETRA/TAI crash test to the TL-4 requirements.

AASHTO Test Level 4 is considered "…generally acceptable for the majority of applications on high-speed highways, freeways, expressways, and interstate highways with a mixture of trucks and heavy vehicles" (AASHTO, 2002). AASHTO defines a typical TL-4 test vehicle as a single unit van truck weighing 8.2 tonnes, traveling at 80 kph and impacting the barrier at 15°.

From Table 1, the expected transverse impact load is 240 KN. The SETRA/TAI crash test vehicle significantly exceeded those requirements, however. Multiplying the filtered rear axle deceleration (11.4 g) by one-half the weight of the vehicle (6 tonnes)

Table 1. AASHTO Table A13.2-1 Design Forces for Traffic Railings (AASHTO, 2002).

Parameter	Railing test levels					
Designations/ Design forces	TL-1	TL-2	TL-3	TL-4	TL-5	TL-6
F_t Transverse (KN)	60	120	240	240	550	780
F_l Longitudinal (KN)	20	40	80	80	183	260
F_v Vertical Down (KN)	20	20	20	80	355	355
L_t and L_L (mm)	1220	1220	1220	1070	2440	2440
L_v (mm)	5500	5500	5500	5500	12200	12200
H_e (min) (mm)	460	510	610	810	1070	1420
Rail Height (min) (mm)	685	685	685	810	1070	2290

the calculated dynamic force from the back of the bus impacting the barrier was 680 KN. This dynamic force was 2.83 times the recommended TL-4 value and even exceeded the TL-5 value by 23%. Yet the corresponding peak tensile force in the most highly stressed reinforcing strip indicated that the impact load reaching the soil reinforcements was only 45 KN over 1.5 m of wall, exactly as assumed in the pseudo-static design method. The 1250 mm wide moment slab and unreinforced parapet of the TAI-tested barrier proved adequate for the impact condition.

Civil engineers are attempting to use the dynamic loads specified in Table 1 in the pseudo-static design method. These loads were not intended for use in the pseudo-static design method for barriers atop MSE walls, however, and they were not added to the MSE section of the specifications. Indeed, the MSE specification is unchanged and continues to specify the pseudo-static impact load for barrier design. Since the pseudo-static design method has not been changed, MSE-mounted traffic barriers designed using TL-4 dynamic loads have unreasonable dimensions, such as moment slabs with 2 to 3 times the mass required by designs using the 45KN load. Figure 4 shows such a barrier; note the 2440 mm wide moment slab, fully 2.3 times the width of the in-service barrier in Figure 1 that was designed using the pseudo-static method and a 45 KN impact load.

The new AASHTO dynamic impact loads are significantly increasing barrier costs while providing no apparent benefit over the performance of proven designs.

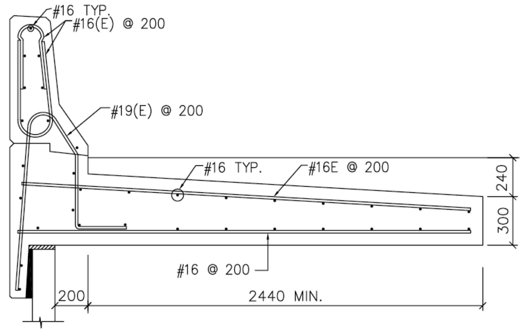

Figure 4. Moment slab sized using TL-4 dynamic loads.

6 RESEARCH CURRENTLY UNDER WAY

National Cooperative Highway Research Program (NCHRP) 22–20, *Design of Roadside Barrier Systems Placed on MSE Retaining Walls*, was begun in July 2004 to develop standardized procedures for economical design of roadside safety barrier systems placed on MSE retaining walls (NCHRP, 2004). Computer modeling and full scale crash testing are being used to develop these standardized design procedures. The results of this study, to be completed in 2008, should return barrier design to a more economical level, similar to that used successfully in the United States from 1985 to 2000.

REFERENCES

Terre Armée Internationale (TAI), Field Test of a GBA Safety Barrier erected on a Reinforced Earth wall, TAI Report No. R22, May 1982, not published.

American Association of State Highway and Transportation Officials (AASHTO), Standard Specifications for Highway Bridges; 15th Edition 1992, including 1994 Interim Specifications, Division I – Design, Section 5 Retaining Walls, Paragraph 5.8.9 Special Loading Conditions.

American Association of State Highway and Transportation Officials (AASHTO), LRFD Bridge Design Specifications; SI Units, Second Edition 1998, including 2002 Interim Specifications, Section 13 Railings.

National Cooperative Highway Research Program (NCHRP) Design of Roadside Barrier Systems placed on MSE Retaining Walls, July 2004, *www.trb.org/trbnet/project display.asp?projectid=693*