BART Warm Springs Extension: First MSE Walls in the US Constructed Over a Seismic Fault

The Fremont station, south of the city of Oakland, CA, has long been the southernmost point on San Francisco's BART transit system. An extension of this line was begun in 2011 to add 5.4 miles of mixed surface and subway line, ending in the Warm Springs District near the southern border of the City of Fremont in Alameda County. The first contract (Fremont Central Park Subway Construction Contract) ran through and beneath Fremont Central Park and beneath Lake Elizabeth and a Union Pacific Railroad freight track. The second contract, a design-build contract dubbed LTSS (Line, Track, Station and Systems), is now under construction by Warm Springs Constructors, a joint venture of Kiewit Corporation and Mass. Electric Construction Company (Kiewit-MEC). The LTSS contract is unique in that it includes the first two Reinforced Earth® Mechanically Stabilized Earth (MSE) "true" abutments for public infrastructure in California and also the first MSE structure in the United States to sit directly over a seismic fault.

Mechanically Stabilized Earth is a composite construction material comprising a facing system, soil reinforcements and a specified backfill soil. The design-build contractor selected The Reinforced Earth Company to supply the required MSE structures, meaning the facing is square 5 ft. x 5 ft. precast concrete panels, the galvanized steel ribbed soil reinforcements are 50 mm wide x 4 mm thick, and the backfill is granular and free-draining (as specified by the AASHTO Bridge Construction Specifications (American Association of State Highway and Transportations Officials, Table 1). As is typical of MSE companies using steel reinforcements, the complete internal stability design of the Reinforced Earth structures was performed by The Reinforced Earth Company, including design of the panels, the reinforcing strips, and all connections, joint materials and accessory items. The company provided the internal stability design calculations and a professional engineer's certification of its design. Engineering of the project site, including global stability of the site, bearing capacity of the foundation soils, and a settlement analysis, was performed by the project designer and the geotechnical engineer, HNTB Corporation and Parikh Consultants, Inc., respectively, both members of the Kiewit-MEC design-build team.

Table 1. MSE BACKFILL	
Gradation Requirements*	
Sieve Size	Percent Passing
4"	100
No. 40	0-60
No. 200	0-15
Assumed & Minimum Design Parameters	
$\phi = 34°$, $c = 0$ psf, $\gamma = 120$ pcf	

*AASHTO Construction Specifications

There are two types of MSE abutments – true and mixed. In a true abutment the bridge seat is supported directly on the reinforced soil of the MSE structure (Figure 1), while a mixed abutment uses piles to carry the abutment load through the reinforced soil to the in situ foundation (Figure 2). Both abutment types are used extensively throughout the United States, but the Walnut Avenue bridge is the first in California public infrastructure to use Reinforced Earth true abutments. A driving force behind this design choice was the Hayward Fault, which passes directly under the south bridge abutment.

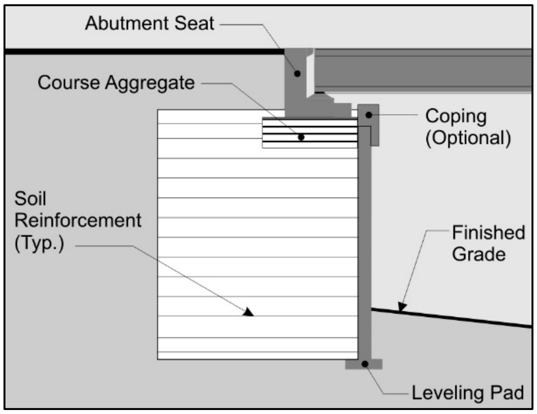

Fig. 1. True MSE Abutment (no piles)

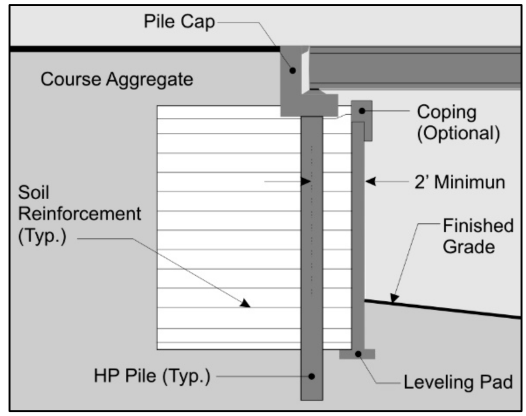

Fig. 2. Mixed MSE Abutment

MSE walls and mixed abutments are common in California and typically, per Caltrans specifications, there are no special design requirements to accommodate seismic loads. This approach is based on research in the early 1970s by the late Prof. Kenneth Lee of UCLA, and on the more recently documented excellent performance of both in-service and under-construction MSE structures during the Loma Prieta (1989) and Northridge (1994) earthquakes. In a Reinforced Earth or other steel-reinforced MSE wall, seismic excitation may shake the whole structure but it does not rearrange the panels, reinforcements or backfill, meaning structural stability is maintained.

Using a mixed MSE abutment at the Walnut Avenue south abutment would have been problematic. With the abutment sitting directly over the Hayward Fault, piles would be like anchors, carrying the relative movements of the two adjacent tectonic plates directly up to the bridge seat and likely tearing apart the abutment. Therefore, the choice at Walnut Avenue was clear – true MSE abutments were needed.

Two long MSE retaining walls support the BART embankment as it approaches Walnut Avenue from the north; these walls are continuous with the MSE true abutment through the use of special corner panels. On the south side, a short wingwall on the east also folds back and parallels the track, while the west wingwall simply extends along the line of the abutment face and tapers down to grade. This is the abutment which sits atop the Hayward Fault, where it is subjected to two risks – seismic-fault creep and a dynamic force during an earthquake. Seismic fault creep is the constant but extremely slow slippage that occurs on some active faults, even without an earthquake. Along the Hayward Fault, the creep rate is only a few millimeters annually, as seen in Figure 3. By comparison, an earthquake rupture along this fault could produce *seismic* differential movements at ground level (bottom of wall) of more than 6 in.

Fig. 3. ±15 years of curb displacement due to seismic-fault creep, Hayward Fault, Fremont, CA (photo courtesy of Wikipedia, in the public domain)

vertically and more than 24 in. horizontally.

The HNTB/Parikh design team wanted to minimize the effect of fault creep (and differential movement during fault rupture) on the Reinforced Earth wall supporting the south abutment. To accomplish this, they designed a slip plane to be constructed directly beneath the MSE structure (panels + reinforcements + backfill). The initial slip plane design consisted of composite layers of sand, geotextile, PVC geomembrane and drain rock. The concept was that shearing forces and movements due to seismic-fault creep would be absorbed in this relatively flexible layer, protecting the MSE wall and the abutment above. On further consideration, however, the slip plane concept evolved into a load transfer concrete slab topped by a sand layer (Figure 4), also extending under the full MSE abutment structure.

Fig. 4. Placing sand layer atop concrete load distribution slab constructed across Hayward Fault and beneath south abutment.

Construction of the walls and abutments began in February of 2014 and was completed in April. The internal design was unique due to the high inertial forces in general and, at the abutments, due to the additional seismic/lateral loading from the inertia of the bridge which would be transferred to the reinforced soil through the abutment footing. These loading conditions, combined with the foundation conditions, required reinforcing strip densities roughly 4 times greater than those in "normal" walls of similar height, and reinforcing strip lengths nearly 3 times as long as in a non-seismically-designed structure. The strip installation was performed by the conscientious Kiewit crew, taking great care to adjust the layout pattern (Figure 5) to avoid excessive overlapping.

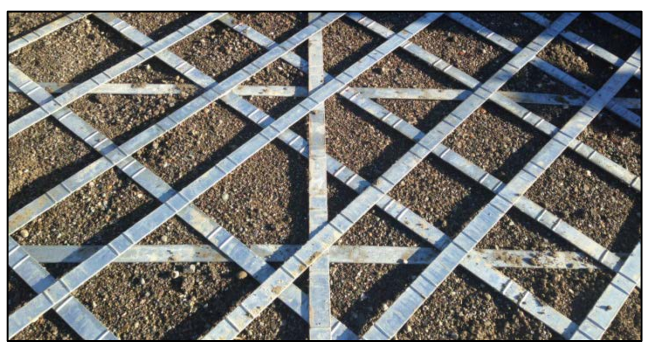

Fig. 5 Unusually high strip densities, angled and overlapped in corners.

In most MSE construction with AASHTO-specified backfill, facing panels are battered inward (toward the fill) to accommodate the outward movement caused by backfill placement and compaction (also performed according to AASHTO specifications). This process causes the panels to end up vertical. On this project, however, due to the extremely high density and length of reinforcing strips and the well-graded quality of the backfill, less than typical batter was required.

Mechanically Stabilized Earth walls and abutments have long been used throughout California, the United States and the world to support embankments and bridge abutments on highways, railroads and transit systems, and for other heavily loaded structures in civil, industrial, mining and waterfront applications. The inherent ability of steel-reinforced MSE structures to tolerate seismic loads and vibrations with little or no damage has enhanced the construction economy and operational safety of projects in places as diverse as Turkey, Japan, Australia and the United States. When the BART Warm Springs Extension enters revenue service in late 2015, the Walnut Avenue Reinforced Earth walls and true abutments will provide those same benefits to the people of the San Francisco region.