

MSE WALLS WITH INDEPENDENT FULL-HEIGHT FACING PANELS

Naser Abu-Hejleh¹, George Hearn², Michael McMullen³, and Jorge G. Zornberg⁴

Abstract: MSE walls with independent full-height facing panels (MSE/IFF walls) combine self-stable reinforced fill, full-height facing panels not attached to fill reinforcements, facing anchors that accommodate panel movement during construction, and a trench with flow fill and bracing for the temporary support of facing panels during construction. Colorado DOT built an MSE/IFF wall in 1996 along I-25 with two tiers of reinforcement lengths (8 ft long in the lower zone and 20 ft long in the upper zone). This wall system offers rapid and reduced construction work, an appearance similar to monolithic walls, and slender and lightweight facing panels since they carry only limited lateral pressure from fill. Since this MSE wall system is the first of its kind, it was considered experimental and a comprehensive instrumentation and monitoring program was performed. The objective of this research is to establish a workable and predefined MSE/IFF wall system and to refine design and construction methods used for the I-25 MSE/IFF walls. This paper reports the features, design, materials, construction, instrumentation, and measured performance of the I-25 MSE/IFF wall. Wall performance and design are assessed in terms of measured movements of facing panels and measured loads in fill reinforcements and facing anchors. The wall system performed as intended in the design. During construction, the wall facing was allowed to move outward sufficiently to mobilize tensile strains in the reinforcements and keep lateral earth pressure on facing panels low. After eight years, the I-25 wall shows no signs of distress or alignment problems.

INTRODUCTION

MSE walls offer advantages including low cost, simple and rapid construction, good seismic performance, and the ability to tolerate large total and differential settlements without distress. Block facings and stacked panel facings are attractive, but some projects need full-height facing panels to create monolithic fronts not broken by horizontal joints. Lateral stresses acting on full-height facing panels in conventional MSE walls can be minimized if the facing is independent of soil reinforcement and is allowed to move with the objective of keeping low earth pressures against the facing panels. This is the concept of MSE/IFF walls, first explored in research sponsored by the Colorado Department of Transportation (CDOT) (Hearn and Meyers 1994, Hearn et al. 1995). Independent facing panels carry only limited lateral pressure from fill, and are slender, lightweight, and relatively easy to handle during construction.

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In 1996, CDOT built a MSE/IFF wall for a two-lane ramp connecting northbound Interstate 25 to Interstate 70 in Denver, Colorado (Figure 1). The wall is 1400 ft long and ranges in height from 5.7 ft to 18.8 ft. The MSE/IFF wall is an extension of an existing cantilever reinforced concrete retaining wall. The MSE/IFF system was selected to match the monolithic appearance of existing walls. The I-25 wall combines a self-stable, welded wire fabric (WWF) reinforced soil mass with full-height, independent prestressed concrete facing panels. WWF reinforcement layers are shorter in the lower zone of the wall to reduce excavation work and costs, and longer in the upper zone of the wall. Excavation was a concern at this site because subsoils may have been contaminated. Facing anchors are designed to secure the facing panels but accommodate displacements to minimize lateral pressure on facing panels. Traffic on I-25 was not disrupted during construction. The design for this structure was performed by the second author, who supervised the construction of the wall.

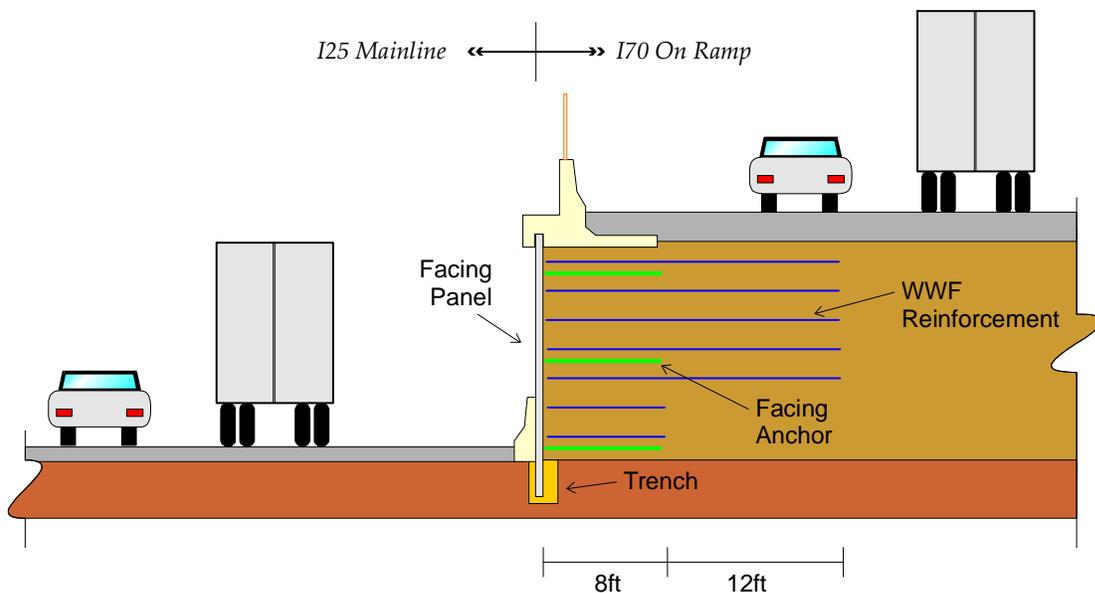


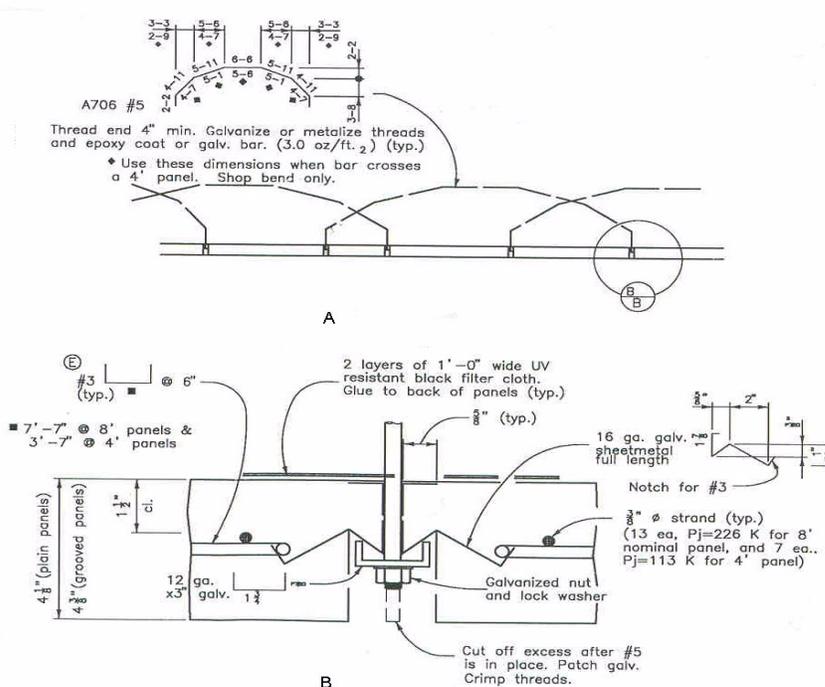
Figure 1 – Section of the I-25 IFF/MSE Wall

The I-25 wall was the first MSE/IFF wall in Colorado to carry highway traffic. Since there are no AASHTO or FHWA or CDOT standards for design and construction of this structure, the wall was experimental. A comprehensive instrumentation and monitoring program was added to the project as a part of a research study. The main objective was to validate the MSE/IFF wall system and to identify modifications and additions to the design and construction of the MSE/IFF wall system that would improve performance and save resources. Wall performance is assessed in terms of measured movements of facing panels and measured loads in fill reinforcements and facing anchors. Detailed information on the I-25 wall, its materials, construction, monitoring program, collected performance data and analysis, design assessment, and recommendations for future MSE/IFF applications are presented by Abu -Hejleh et al. (2001).

MATERIALS AND COMPONENTS OF THE I-25 MSE/IFF WALL

The fill of the I-25 MSE/IFF wall meets specifications for CDOT granular and high quality class-1 backfill material. The gradation requirements for Class-1 backfill with particles smaller than 2 inches are 30-100 % passing sieve #4, 10-60 % passing sieve # 50, and 5-20 % passing sieve # 200. The liquid limit should be less than 35 % and the plasticity index smaller than 6 %. This soil often classifies as SW-SM per ASTM 2487, and as A-1-B (0) per AASHTO M 145. The backfill should be compacted to 95 % of the maximum density measured in accordance with AASHTO T-180 Method A. While the material properties of the placed backfill material are not reported, Class-1 backfill have a minimum unit weight, γ , of 125 pcf, and an internal friction angle of 34° . These soil parameters should lead to conservative design.

Fill reinforcements are galvanized steel welded wire fabric furnished as 12x12-W2.9xW2.9. Steel wires have a minimum tensile yield stress of 60 ksi. The WWF is manufactured in sheets that are 8 ft wide and 20 ft long. These sheets are placed in the backfill using a vertical spacing of 1 ft and an embedment length of 8 feet in the lower portion of the wall (up to 8 ft above the ground level) and a length of 20 feet in the upper portion of the wall (Figure 1).



Anchors for facing panels are No. 5 epoxy coated rebars of 60 ksi steel. Each anchor is bent to form a seven-sided arch that approximates one half of an ellipse (Figure 2a). Embedment of anchors is 8 ft, and typical vertical spacing is 5.33 ft with the lowest anchor placed at the ground surface. For attachment to facing panels, the threaded ends of facing anchors engage steel plates that bear on armored edges of panels (Figure 2b). Bearing plates distribute anchor forces to both adjacent panels. Because of the bearing plates, adjacent panels remain aligned. The alignment is controlled during construction by adjusting the nuts at the ends of anchors (Figure 2b).

Figure 2 - Anchors for Panels: (a) Pattern of overlapping anchors, (b) Anchor Attachment to IFF Panel.

that bear on armored edges of panels (Figure 2b). Bearing plates distribute anchor forces to both adjacent panels. Because of the bearing plates, adjacent panels remain aligned. The alignment is controlled during construction by adjusting the nuts at the ends of anchors (Figure 2b).

The facing includes prestressed reinforced concrete panels with dimensions of 4 ft x 8 ft. The single 4 ft wide panels are typically alternated with four 8 ft wide panels. The 4 ft wide panels are 4-1/8 inches thick and have a smooth finish. The 8 ft wide panels are 4-3/8 inches thick and have a grooved finish. Concrete for panels has a compressive strength of 4000 psi at transfer and 6000 psi after 28 days. Mild reinforcing steel for panels are grade 60 epoxy-coated bars. Prestressing steel is 5/8 inch six-wire strand in 250 ksi steel. Panels are placed using an inward batter (toward the fill) in anticipation of outward movement that may occur during construction. The top and bottom setbacks from the wall layout line are illustrated in Figure 3.

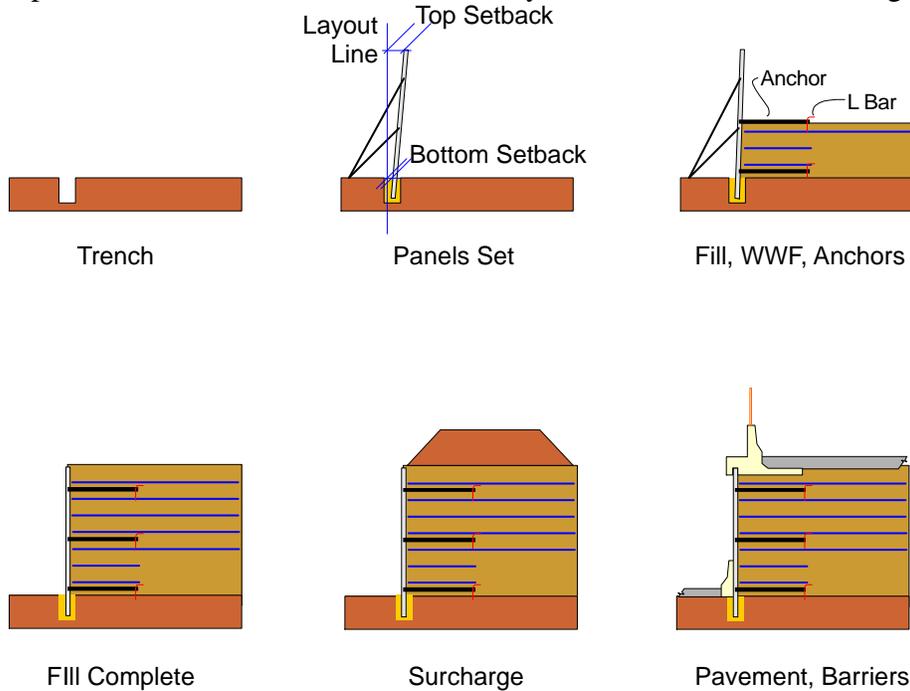


Figure 3: MSE/IFF Wall Construction

DESIGN OF THE I-25 MSE/IFF WALL

This wall system was developed to economize the construction and meet geometric constraints. The I-25 MSE/IFF differs from conventional MSE walls in the following aspects:

1. The facing is not attached to the reinforcements and can rotate as a rigid body with minimal resistance around the base. The facing anchors can slip and protect facing panels against greater lateral pressure. These features are employed to mobilize large tensile resistance in the soil reinforcements, thus keeping lateral earth pressure against the facing panels low.
2. Reinforcement lengths are not uniform with height.

The objective of this research is to establish a workable and predefined MSE/IFF wall system for certain applications/conditions and refine any design method suggested as

a starting point for MSE/IFF walls. Additional research work is needed to refine the design methods for MSE/IFF walls for various loading conditions.

The FHWA guidelines for MSE walls with inextensible reinforcements were selected by CDOT as the initial basis for design. CDOT design calculations confirmed the adequacy of the internal stability of the WWF reinforcements. In spite of the difficulties in calculating the lateral earth pressures against a flexible facing, such pressures are believed to be very low, based on published literature and findings of CDOT studies (Abu-Hejleh et al. 2001). According to McGown et al. (1998), if the lateral boundary of the MSE wall is allowed to yield sufficiently, large tensile stresses will develop in the reinforcements to balance the lateral earth pressure, leading to a negligible earth pressure against the facing. This provides the lower limit case for earth pressure on the facing of flexible MSE wall systems. Small localized stresses may develop near the facing because each soil layer between the reinforcement layers tends to act independently, causing the wall to be subjected to active earth pressure over the vertical spacing between reinforcement layers. For reinforcements with a vertical spacing of 1 ft, a backfill with unit weight of 125 pcf, and a coefficient of active earth pressure of 0.28, this lateral earth pressure ranges from 0 at the top of reinforcement layer to 35 psf at bottom of reinforcement layer. For the I-25 wall, an earth pressure of 30 psf against wall facing was adopted for design of the facing panels and anchors. CDOT design calculations verified the internal stability of the facing anchors and structural capacity of the facing panels. The overall design approach was to be demonstrated by monitored sections of wall.

Guidance on the bottom and top setbacks for facing panels was needed. Initial setbacks were recommended based on the judgment of the design engineer. Accordingly, a six-panel portion of wall was constructed initially as a trial for construction operations and control. The trial revealed excessive panel movements. As a result, changes to the initial design details were made. This included increased setbacks at the top of the panel (twice the initial values, see Table 1) and decreased maximum spacing of the # 5 face anchors rebar (from 8 ft to 5.33 ft). These corrective measures led to less than 1/2" misalignment plumb upon completion.

Table 1. Depths of Embedment and Setbacks for IFF Facing Panels

Facing Height above Ground-Level (feet)	4	10	12	20
A. Employed for I-25 MSE/IFF Wall				
Panels Embedment depth (feet)	2	2	2	2.8
Panels Bottom Setback (inch)	0.12	0.24	0.24	0.36
Panels Top Setback (inch)	0.96	2.16	2.4	4.8
B. Recommended for Future MSE/IFF Applications				
Embedment (feet)	2	2	2	2.8
Expected Panel's Settlement (inch)	0.5	0.9	1.1	1.6
Panel Bottom Setback (inch)	0.2	0.4	0.5	1.0
Panel Top Setback (inch)	0.6	2.4	3.2	7.9

CONSTRUCTION OF MSE/IFF WALLS

The steps followed during construction of MSE/IFF walls, as employed in the I-25 wall, are (see Figure 3):

- Position facing panels in a shallow trench supported by flowfill with required top and bottom setbacks using temporary weak bracing at the front. The flowfill is a lean concrete mix usually made of cement (50 lb/CY), sand (~3500 lb/CY) and water (325 lb/CY). The trench and bracing support panels during construction. All panels are erected before the fill and reinforcements are placed. The panels define the front of the wall and provide a forming surface for fill. Values for setbacks and depth of trench as employed in the I-25 wall and recommended in future application are presented in Table 1.
- Place high quality granular backfill, WWF, and facing anchors behind the facing panel. The backfill should meet the material and construction requirements for CDOT Class-1 backfill. Lightly compact the 3 ft behind the facing with one pass of a hand-operated vibrating plate and keep heavy equipment beyond 2 ft from the panels. Control of compaction and monitoring of panel tilt. Fill movement is necessary for mobilization of tensile resistance of reinforcements, but excessive movement can result in poorly aligned panels.
- Place WWF as close as possible to the facing. Bend the WWF tails at facing as needed to get the first cross wire within 2 inches of the facing. This was done for the I-25/IFF wall to reduce the wall outward movements experienced in the trial portion. It is recommended in future applications that WWF at the front of the wall be bent behind the facing to form an L-shape or to wrap the reinforcements.
- Snug the facing anchor rebars by pulling the rebars and driving a # 4 L bar into the ground at each of the back ends of the anchor loop. When one lift has been placed on the face anchor rebars, tighten the nuts finger tight plus two full turns on both this layer of anchor bars and lower layers.
- Monitor movement of panels as backfilling progresses. If the top of panel deform excessively, add supplemental layers of wire mesh and move the heavy compaction equipment further from the face of the wall. Check the plumb of the panel just before the last lift of backfill is compacted. Adjust the panel so that it achieves a near-vertical alignment (top setbacks between 0.5 inch to 1 inch) when fill is complete.
- Once fill is complete and all panel anchors are installed, remove temporary braces. It was reported that most of the braces in the I-25 wall were loose during construction and even removed before fill placement reached the top of the wall. This is expected as the weakly braced system is not needed after the 2nd layer of face anchor is placed. The trench remains in place but is no longer needed for panel support. Panel alignment can be adjusted, if needed, by loosening nuts to panel anchors. Place 3ft of loose fill over the finished top grade for a period of at least 60 hours to minimize long-term movements. Finally, surcharge fill is removed and construction of pavement and barriers can proceed.

MONITORING OF THE I-25 WALL

Two sections of the wall (labeled 3116 and 3119) were instrumented and monitored during construction. The width of each section is 56 feet (8 panels). The total height of the panel facing was 17.7 ft at Station 3116 (15.2 ft above ground level). The total height of the panel facing at Station 3119 was 15.3 ft (13.1 ft above ground level). Instrumentation included survey targets on front of facing panels, inclinometers placed at the back of panels, and strain gages (Figure 4). For face anchors, Geokon Model 4911A vibrating wire strain gages were pre-mounted on sections of #5 reinforcing bars (sister bars) and spliced into anchors with threaded couplers close to the facing panels. For WWF reinforcements, Geokon Model 4100 strain gages were mounted on individual WWF wires at selected points. Data collected in Sections 3116 and 3119 include movements of facing panels and tensile strains in WWF and facing anchors. Thermistors were installed near the strain gages to monitor temperatures. The wall was monitored during the three-month construction period.

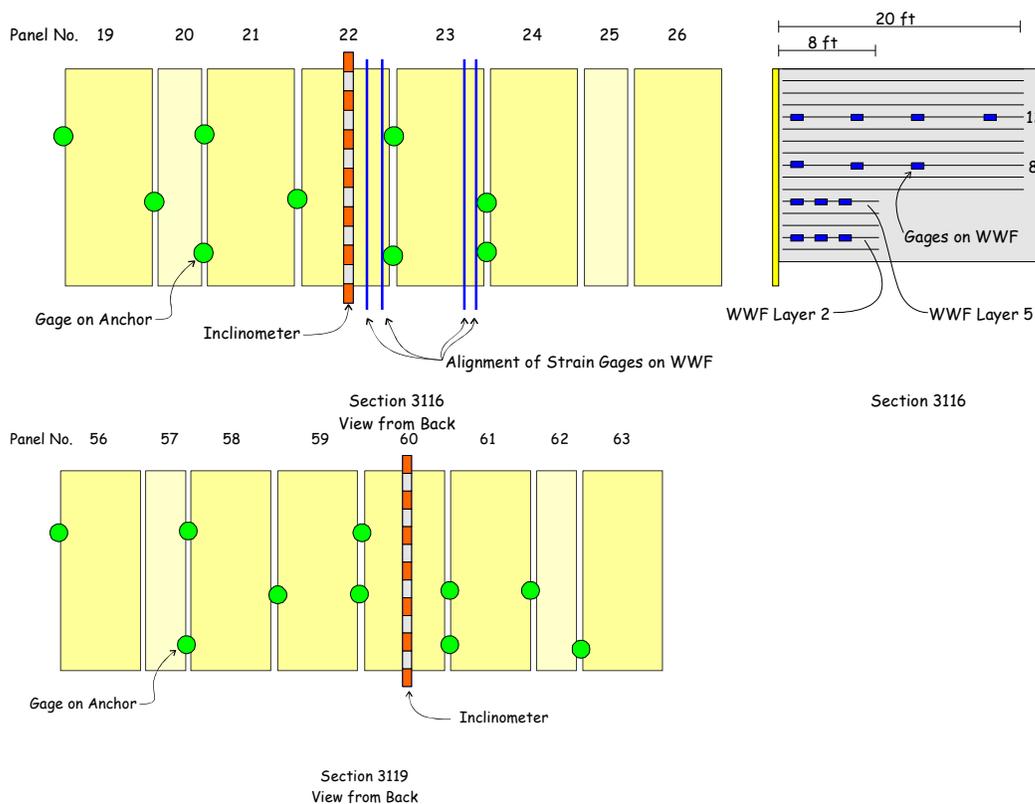


Figure 4 - Instrumentation for I-25/I-70 Wall (adapted from Blanks, 1996)

PANEL MOVEMENTS IN THE I-25 WALL

Displacement of the facing, settlements from surveying, and facing tilt from inclinometers were initially reported by Christina and Wu (1999). Panel displacement and tilt and the corresponding change in backfill height are summarized in Table 2. In the last column of Table 2, displacements are normalized with respect to backfill height. The results in Table 2 show larger facing outward displacements and tilt at

Station 3116 than at Station 3119. The data indicate that wall facing experienced an average vertical settlement of 0.07” due to the placement of 1 ft of backfill. The average measured facing tilt (inch/feet) due to the application of 1 ft of backfill is 0.015 inch/feet. Measured vertical profiles of the facing outward displacements along Stations 3116 and 3119 from surveying data (Table 2) were plotted and then extrapolated to estimate the facing outward displacements at the base and top of the wall facing. It was found that the rotation point of the facing panels is close to the base of the panel for Station 3119 and slightly below the base for Station 3116.

Based on the measured settlement and tilt values due to placement of 1 ft of backfill in the I-25 MSE/IFF wall (presented before), expected vertical settlement and required bottom and top setbacks for panels with different heights above ground level are provided in Table 1. Use of movement data of the I-25/IFF wall to estimate the movements in future walls should consider that: 1) facing settlement and tilt are related linearly to the height of backfill, 2) the facing panel rotates as a rigid body around its base, 3) the equivalent backfill height of the roadway structure and traffic placed on top of the wall is 3 ft, and 4) the field conditions at future sites are similar to those at the I-25 site.

Table 2. Measured Movements of Facing Panels

A. Vertical Settlement of Facing				
Station	Date	Settlement (inch)	Change in Backfill Height (feet)	Average Settlement (inch) per 1ft of Applied Backfill
3116	From 6/18 to 8/5	0.66	13.2	0.05
3119	From 7/1/ to 8/16	1.2	16.1	0.07
B. Outward Displacements of the Wall Facing				
1. Station 3116, Reference Date is 6/18, Change in Backfill Height is 13.2 ft				
From	Location (feet)	Displacement (inch)	Facing Tilt (inch/feet)	Average Facing Tilt Rate ((inch/feet)/feet)
Surveying	H=1	1.02		
	H=4	1.74		
	H=7	2.52		
			0.25	0.019
Inclinometer			0.17	0.013
2. Station 3119, Reference Date is 7/1, Change in Backfill Height is 16.1 ft				
Surveying	H=1	0.78		
	H=4	1.56		
	H=7	2.28		
			0.25	0.016
3. Station 3119, Reference Date is 7/14, Change in Backfill Height is 9.6 ft				
Inclinometer			0.11	0.012

PERFORMANCE OF THE REINFORCED SOIL MASS

Overview of the Design of the Reinforced Soil Mass

The design of the reinforced soil mass followed FHWA guidelines used for conventional MSE walls with inextensible reinforcements (Elias et al. 2001). The design requires that the maximum WWF axial forces at any level be less than the allowable WWF tensile force, and less than the WWF pullout resistance (with adequate margin of safety). The allowable WWF tensile load is 835 pounds per wire (48% of the WWF yield strength). The design procedure is demonstrated for the instrumented WWF layers of Section 3116 when the fill height was 15.2 ft. The design tensile force in WWF layers is calculated as (Elias et al. 2001):

$$T_{max} = K_a S_v K \gamma z \quad \text{Eq 1}$$

where K_a is the coefficient of active earth pressure (estimated as 0.28), S_v is the reinforcement vertical spacing (1 ft), and z is the depth of fill above the reinforcement layer. K is a multiplier for WWF equal to 2.5 at the top of Section 3116 and decreasing linearly to 1.2 at 20 feet depth and below. Note that this multiplier, K , is 1 for geosynthetic reinforcements. Higher values for K , especially near to the surface, are recommended based on measured field data. This is attributed to the influence of compaction and high stiffness of the WWF reinforcements (Abu-Hejleh et al. 2001).

To ensure adequate pullout resistance and global stability in the design of MSE walls, Elias et al. (2001) recommends a length of reinforcements equal to 70% of the wall height. The WWF reinforcement lengths of the I-25 wall are not uniform with height. A shorter length of reinforcement was used towards the base to reduce excavation. The selected reinforcement lengths, 8 ft and 20 ft, correspond to the dimensions of a WWF sheet. The pullout resistance of the instrumented WWF reinforcement layers, P_r (pound/ft), can be estimated (Elias et al. 2001) as:

$$P_r = 2 F^* \gamma z L_e \quad \text{Eq. 2}$$

where F^* is the friction-bearing factor and L_e is the effective length. Elias et al. (2001) recommend laboratory or field tests to determine F^* . Default F^* values for WWF reinforcements can be estimated as $20t/S_t$ at top of the wall, decreasing linearly to $10t/S_t$ at depth of 20 feet and below, where t is the thickness of the bearing transverse steel wire (0.192 inch) and S_t is the spacing between transverse wires (12 inches). Location of the maximum tensile force line is needed to estimate the reinforcement embedment length in the resistance zone.

Measured Data and Performance Assessment

Data from WWF strain gages are employed to assess the performance of the reinforced soil mass. Strain gages were placed in WWF of Station 3116 at four

elevations. Gages in WWF (instrumented layers 1 to 4) were placed at elevations of 1, 4, 7, and 11 ft above ground level. Strain data were collected during construction until the backfill height above ground level was 15.2 feet. No data were collected after that. Measured strains in the WWF are converted to tensile forces. The measured values and location of maximum tensile force along each WWF layer are presented in Table 3 and Figure 5. Table 3 also lists the design tensile forces from Eq 1, and Figure 5 also presents the location of the maximum tensile force line as proposed by Elias et al. (2001) for MSE walls with inextensible reinforcements. The measured L_e for layer 4 was 8.5 ft less than 15.4 ft expected in the design. Calculated values for the WWF pullout resistance from Eq. 2 using estimated and measured values for the resistive length of reinforcement, L_e , are also shown in Table 3.

Table 3. WWF Tensile Forces and Pullout Resistance

WWF Layer #	Estimated WWF Tensile Force (lb/ft)	Measured WWF Tensile Force (lb/ft)	Pullout resistance using assumed maximum tension line (lb/ft)	Pullout resistance using measured maximum tension line (lb/ft)
1	784	396	5422	4763
2	695	262	3612	4192
3	565	418	8240	6519
4	327	923	4643	2556

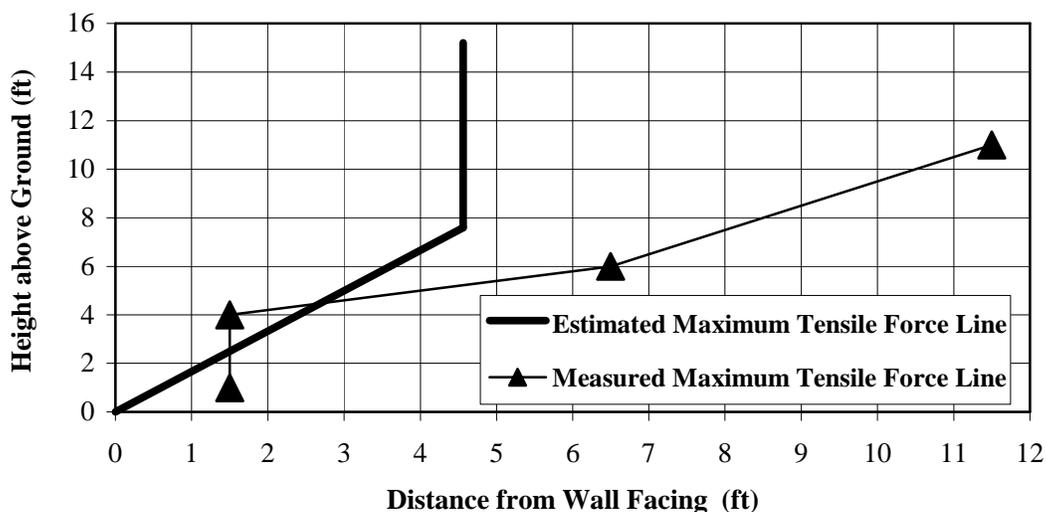


Figure 5. Measured and Predicted Location of the Maximum Tensile Force Line

Measured WWF tensile forces were generally below forces estimated in the design, below the allowable WWF tensile force (825 lbs), and below the pullout capacity of WWF reinforcements. However, the maximum tensile force in WWF layer 4 (923 lbs) was above the allowable WWF tensile force, but less than the WWF yield force of 1740 pounds. Also, the design estimated pullout resistance for WWF layer 4 is

larger than the estimated pullout resistance with the measured maximum tension line, but significantly larger than the measured WWF tensile forces. The results also show tensile forces and size for the potential failure surface in the upper zone of the wall are larger than expected in the design. The triangular distribution of reinforcement loads with height, as is the case for conventional MSE walls, seems not to apply for MSE/IFF walls, as the highest reinforcement loads were measured at the top of the wall. These findings are consistent with the large deformations of walls noticed during construction of the upper zone of the wall. This behavior is attributed to:

- 1) The full-height facing panel is effectively pinned at the bottom and offers little resistance to movement, leading to rotation of the facing. This leads to larger displacements and strains at higher locations of the wall with development of larger tensile forces in the WWF.
- 2) The higher concentration of soil reinforcements in the upper zone of the wall, which led to a stiffer portion of the structure in this zone.

PERFORMANCE OF FACING PANELS AND ANCHORS

Strain data from facing anchors are used to assess the design of the face anchors and facing panels. Gages at both stations were placed on anchors at three different levels: Lowest, intermediate, and highest elevations, respectively (Figure 4 for Station 3116). Strain data were collected manually up to a backfill height of 16.1 feet for Station 3116 (0.9 ft above top of facing panel) and 12 ft at Station 3119 (1.1 ft below top of facing panel). The strains measured in anchors were converted to tensile forces. The measured anchor forces are shown in Table 4.

The lateral earth pressure against the facing was estimated using the anchor forces measured at end of backfill placement. A tributary panel area was defined for each anchor, and lateral earth pressure was estimated as the uniform pressure acting on the tributary area, which is in equilibrium with the anchor force. The uniform pressure in Section 3119 was 60 psf from H=0 to 2.5 ft, 40 psf from H=2.5 to 7 ft, and 18 psf from H=7 to 12 ft, with an overall average of 35 psf. The uniform pressure in Section 3116 was 20 psf in the lower layer of face anchor, 48 psf in the middle layer, and 14 psf in the upper layer of face anchors, with an overall average of 28 psf. The overall average lateral earth pressure estimated from all anchor strain gages was 32 psf, which compares well with the design earth pressure of 30 psf. The development of movements in the facing panels led to very low lateral earth pressures against the facing.

Facing Anchors

Anchor strength is limited by pullout capacity. Yielding in tension is not a control for the #5 steel reinforcing bars used for the I-25 wall. Pullout capacity of face anchors, P_a , is estimated as

$$P_a = C_s L_e \gamma z \tan \phi \quad \text{Eq. 3}$$

where C_s is bar perimeter (0.164 ft for # 5 rebar), and L_e is the effective length of the anchor that resists pullout. The effective length excludes a portion of the anchor length near the facing panel where fill vertical pressures are low. L_e is estimated at 14.2 ft when facing anchors do not cross 4 ft panel and at 12.5 ft when it does (Figure 2a). Eq. 3 is similar to that used in AASHTO for pullout of steel reinforcing strips. It is based on sliding friction, as opposed to a capacity based on soil bearing that is used for geogrid reinforcements. Pullout of facing anchors must, ultimately, involve a combination of sliding and bearing. Initial movement of anchors is primarily by sliding with some compatible bending in loops.

The pullout capacity for the anchors is listed in Table 4, along with the measured anchor forces. For anchors near the bottom of panels, the measured forces are below the predicted pullout capacities. For anchors at the middle to top of panels, the measured forces are similar to the pullout capacity, and exceed that capacity in several anchors. These anchors may have slipped during construction. This is the desired response of anchors and it acts to prevent higher lateral earth pressures against the wall facing. If there were continuing panel movement, anchor forces would increase as bearing resistance is mobilized.

Table 4. Pullout Capacity for Facing Anchors

Gage #	Measured Anchor Force (lbs)	Estimated Pullout Capacity (lbs)	Gage #	Measured Anchor Force (lbs)	Estimated Pullout Capacity (lbs)
Station 3116			Station 3119		
Top Tier					
10300	779	875	10311	901	525
10301	531	990	10312	640	594
10316	650	990	10317	322	594
Middle Tier					
10303	2159	1980	10298	1361	1230
10305	1740	1750	10299	1037	1390
10310	1881	1980	10302	1405	1390
			10304	1480	1390
Bottom Tier					
10307	504	2970	10306	795	2100
10313	342	2630	10318	1384	2380
10314	480	2970	10308	885	2100

Facing Panels

The facing panels are designed for distinct load cases during construction and in service. During construction, the facing panels must resist wind loading. The trench for panels was designed to support panels for 8 psf wind load. Bracing for panels provided additional support against wind. Calculated trench depths as a function of panel height are listed in Table 1. For a 20-ft tall facing panel, the moment at the trench due to 8 psf wind loading is 1600 ft.lb/ft. The controlling moment capacity of

panels for vertical bending is 4300 ft-pound/ft, larger the wind induced moment. In service, the facing panels and anchors for panels must resist lateral earth pressure and smaller wind suction. Vertical and transverse moments for panels in service are estimated from measured anchor forces and estimated corresponding lateral earth pressures. The maximum moments for vertical bending due to earth pressure occur near ground level with tension at the back surface of panels. The estimated moments are 104 ft.lb/ft at Station 3116 and 188 ft.lb/ft at Station 3119. These are below the panel moment capacity of 7800 ft.lb/ft, and also below the trench moment resistance (924 ft.lb/ft in Station 3116 and 687 ft.lb/ft in Station 3119). The maximum transverse bending occurs in the vertical centerline of the panels. The estimated maximum transverse moment along an 8 ft wide panel is 348 ft.lb/ft in Station 3116 (middle level) and 480 ft.lb/ft in Station 3119 (lower level). These are below the panel moment capacity in transverse bending of 2000 ft.lb/ft.

CONCLUSIONS AND RECOMMENDATIONS

In 1996, the Colorado Department of Transportation (CDOT) completed the construction of a mechanically stabilized earth (MSE) wall with independent full-height facing (IFF) in Denver, Colorado. This paper reports the features, design, materials, construction, instrumentation, and measured performance of the MSE/IFF wall. The wall system performed as intended in the design. After eight years, the I-25 wall continues in service with no signs of distress or misalignment. The facing of the wall was allowed to move during construction, which maintained low lateral earth pressures against the facing panels. The average estimated lateral pressure is 32 psf. The triangular distribution of reinforcement loads with height, which is conventional for MSE walls, does not apply for the MSE/IFF walls as the highest reinforcement loads were measured at the top of the wall. This is because the facing system is flexible and rotates around its base.

CDOT is now developing standard worksheets for the design and construction of MSE/IFF walls. The proposed MSE/IFF wall system is adequate for all MSE walls with field and loading conditions similar to those in the I-25 wall (e.g., high quality backfill and for a wall height less than 20 ft). Construction should be as described in the construction recommendations with depth of embedment and setbacks as listed in Table 1. Until additional experience in construction of IFF walls is gained, panel movements and anchor forces should be monitored. The specification for WWF will be changed to wires having a cross-sectional area of 0.029 in² and welded in grid pattern of 6"x6" squares (referred to 6x6 w 2.9 x w2.9 welded wire fabric) with a vertical spacing of 1 ft. The facing anchors will be changed to galvanized #4 steel bars placed at 4 ft maximum vertical spacing. The proposed CDOT standard for MSE/IFF walls is fixed in terms of material properties and layout to ensure the internal stability of walls, and adequate strength of all components. However, designers still need to perform the calculations for the internal stability analysis and the external and global stability analyses as described in FHWA guidelines for MSE walls. Additional research and test walls are needed to refine the design methods for MSE/IFF walls.

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