New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-45775-0

SeaTac third runway: Design and performance of MSE tall wall

J.E. Sankey
The Reinforced Earth Company, Vienna, Virginia, USA

M.J. Bailey & B. Chen
HartCrowser, Inc., Seattle, Washington, USA

ABSTRACT: Expansion of the SeaTac International Airport in the State of Washington (USA) included construction of a third runway, which required installation of a series of single face and multi-tiered Mechanically Stabilized Earth (MSE) wall structures. The tallest of the MSE walls consisted of a four-tier structure with a total exposed height of approximately 43 meters (45 meters with wall base embedment). This paper discusses the investigation, design, construction and performance of the West Wall, one of the tallest MSE walls built in the world.

1 INTRODUCTION AND BACKGROUND

1.1 *Location, project purpose and subsurface conditions*

In 1999, HartCrowser, Inc. started subsurface investigations for the addition of a third runway as part of expansion to the Seattle Tacoma (SeaTac) International Airport. The airport is a major international hub located in the northwest part of the United States between the cities of Seattle and Tacoma, Washington. Major embankment construction (13,000,000 m^3) was necessary to accommodate the added runway on the western part of the airport; however, the presence of a stream and wetlands confined the expansion to the steeply sloping topography that bounded the area.

As a result of the space limitations posed by the site, consideration was given to the construction of a series of single face and multi-tiered retaining walls along the runway right-of-way alignment. The topographic features required consideration of exposed wall heights approaching 43 meters. The tallest such wall location was designated as the West Wall.

The area of the West Wall was the subject of a detailed geotechnical investigation. The results of the investigation identified the presence of fill and recent alluvium overlying recessional outwash, glacial till and advance outwash. The basal layer addressed in the investigation consisted of very dense silty sand with gravel (glacial till) and very stiff to hard silt and clay. In summary, the physical features of the area were influenced by subsurface conditions containing peat, liquefiable sands and the potential for excess pore pressures in silt and clay soils. Subgrade improvement was considered to address these issues.

1.2 *Selection of MSE wall system*

The significant height of the retaining walls for the project left few viable options from engineering and economic standpoints. The design team made a preliminary evaluation of more than sixty retaining walls and slope geometric relationships before selecting steel-reinforced Mechanically Stabilized Earth (MSE) walls for the three main retaining walls. It is notable that a comparison of wall technologies provided by FHWA (1995) indicates that steel-reinforced MSE walls are a stand alone selection for heights exceeding 20 meters. On this basis, a qualifications-based selection process by the Port of Seattle (Owner) and HNTB (Architect/Engineer) found that Reinforced Earth ®technology had a reliable international track record with regard to retaining walls exceeding 30 meters in height. The technology for tall Reinforced Earth walls typically consists of cruciform facing panels connected to discrete steel reinforcing strips in a select granular fill matrix. The design of the panels and the material components that make up the Reinforced Earth volume needed to be based on a combination of internal, external and compound stability evaluations.

2 DESIGN BASIS FOR WEST WALL

2.1 *Wall geometry*

The West Wall was designed using four terraces to break up the sight lines of the structure. Space limitations for the wall limited offsets to a little more than 2 meters between terrace levels. The ratio of the minor offsets in the tiers compared to the overall

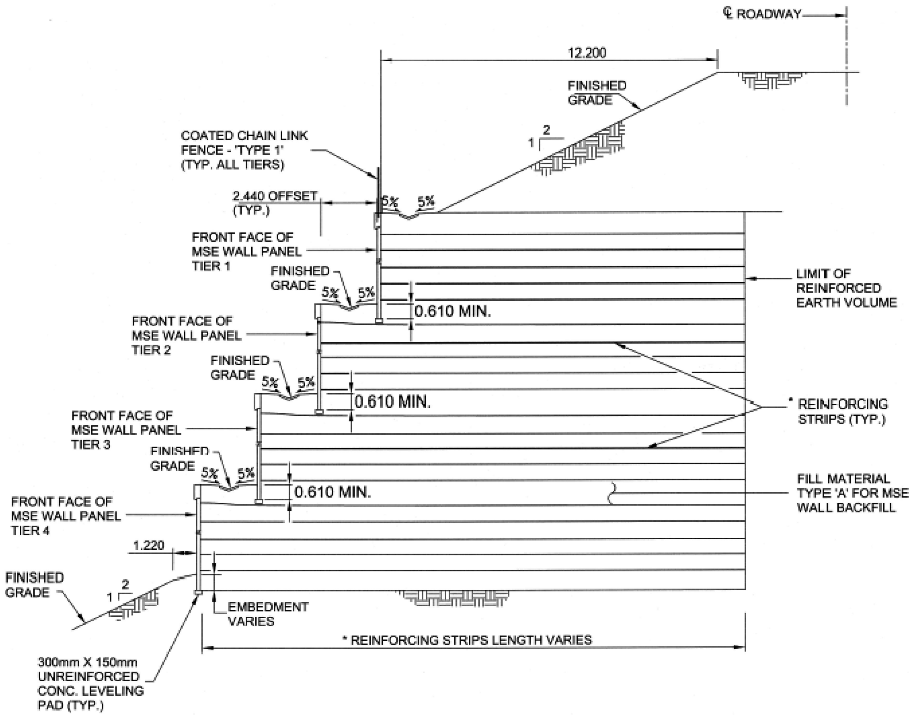

Figure 1. West wall typical section.

wall height dictated that the lines of maximum tension within the Reinforced Earth volume be evaluated as a single structure (FHWA 1997). In other words, the limited offsets provided no reduction in the influence of the upper tiers on the lower tiers of the wall. A typical section of the West Wall is shown on Figure 1.

2.2 *MSE wall stability*

Borrow source requirements for the select granular fill in the Reinforced Earth volume were identified early in the design process. Specific fill sources were selected and pre-qualified on the basis of shear strength and other tests during the construction bidprocess. The design parameters for the select fill were established at 37° for the friction angle and 22 kN/m^3 for the unit weight. The random fill behind the Reinforced Earth volume had design parameters selected at 34° for the friction angle and 21 kN/m^3 for the unit weight.

Lengths for the reinforcing strips were evaluated on a terrace-by-terrace basis and maintained at a minimum of at least 70% of the overlying wall height. The longest reinforcing strips of approximately 30 meters were therefore located at the tallest wall section with exposed height of 43 meters. Evaluations were made for pullout, tensile capacity, sliding and overturning in both static and seismic conditions. It is noted that the lower tier of the wall was embedded up to 4 meters below the finished grade. Upper terraces had the base panels embedded approximately 1 meter into the next lower terrace, which allowed reinforcing strips to be installed without interference between strip levels.

The significant loads imposed by the overall height of the West Wall required increasing the design reinforcing strip thickness, as well as the thickness of the lower precast panels themselves. In the case of the 50 mm wide reinforcing strips, the thickness was increased from the 4 mm standard normally used in the United States to a modified 6 mm thickness. While precast panels in the upper terraces could be maintained at the standard 140 mm thickness, the lower panels were increased to 178 mm thickness.

The nominal plan dimensions of the cruciform panels were maintained at 1.5 m by 1.5 m. However, even with the increased strip thickness considerations, it was necessary to use a large number of strips in the lower terrace panels. The number of reinforcing strips in the upper terrace was maintained at a nominal density of 4 per panel; while in the lower level the density varied from 12 to 21 reinforcing strips per standard-sized panel (some larger special panels at the base had up to 28 strips – Figure 2).

As a final design consideration, the number and thickness of elastomeric bearing pads separating the

Figure 2. Tie strips ready to receive reinforcing strips in lower tier panels.

precast panels at the horizontal joints needed to be adjusted by terrace level. Upper terraces could use two pads per panel with a nominal thickness of 19 mm each, while the lowest terrace needed four evenly spaced pads per panel at a nominal thickness of 25 mm each. The selection of the number and thickness of bearing pads was critical in maintaining the structural integrity of the panels and corresponding joints, as well as the overall wall appearance when architectural treatment was added to the fascia casting.

2.3 *Settlement and global stability*

The bearing pressures imposed by the West Wall varied with the height and number of wall terraces. The maximum bearing pressure was considered at 1.1 MPa. Settlements of as much as 500 mm were originally estimated without any ground or wall improvement measures due to the presence of compressible and liquefiable bearing soils. The Probabilistic Seismic Hazard Analysis for the wall gave a basis for peak ground horizontal acceleration of 0.36 g for a 475-year event and 0.47 g for a 975-year event.

Following a test of subgrade improvement using stone columns (Chen and Bailey 2004), design measures were made to remove and replace the subgrade soils of concern. In addition, slip joints were added to the wall to better accommodate differential settlements at critical elevation changes in the wall. The additional design measures resulted in a reduction in total settlement to approximately 150 mm, with a maximum differential settlement of about 1/100 to 1/200.

Global stability analyses were conducted using the computer program SLOPE/W (Geo-Slope 1998). Both external and composite failure planes were evaluated using the limit equilibrium based methods available in the program including Janbu, Bishop Spencer and Morgenstern-Price Methods. Other computer programs were used for additional evaluation (e.g., Newmark analysis) of the global stability under seismic conditions. Reinforcing strip lengths, thickness and/or depth of embedment were modified in some cases to meet stability requirements, based on analyses of different sections for the three main walls.

2.4 *Numerical analyses*

Critical sections of the West Wall were selected for numerical analysis using the FLAC computer program (Itasca 2000). The purpose of the FLAC analyses was to provide additional information to the design team on anticipated wall performance to supplement AASHTO design analyses (1996 thru 2000). Results of the FLAC analyses were not intended to replace design analyses accomplished in accordance with AASHTO code.

Information was developed for input to the FLAC analyses including wall geometry, soil analyses, concrete facing properties and steel reinforcing strip properties. A dynamic time history for seismic shaking was developed based on a site-specific design response analysis. The FLAC analyses verified that predicted stresses in the reinforcing strips would be maintained close to the performance criteria allowed by AASHTO (0.55 times yield). Furthermore, predicted wall settlements and horizontal displacements were deemed acceptable for both steady state (normal) and seismic conditions. Horizontal displacements at the tallest wall section under static loading were analyzed to be less than 90 mm; subsequent monitoring showed end-of-construction displacements ranged up to 150 mm.

3 CONSTRUCTION AND MONITORING

3.1 *Performance*

Construction of the West Wall started in October 2004 along with the four other Reinforced Earth walls designed for the runway extension. Installation was performed by TTI Constructors, a joint venture of Seattle, Washington firms Fiorito Construction, Scarsella Construction and Tri-State Construction. Work on the West Wall was completed in September 2005, though progress was split with the other walls and main embankment being constructed during the same period.

The select granular backfill considered in design development was tested and confirmed during its use throughout construction of the walls. The West Wall itself covered a face area of approximately 12,100 m^2, with a length along the top tier measuring approximately 450 m and a length along the bottom tier measuring approximately 190 m. Considerable demands were placed not only in the delivery of select backfill (approximately 1,500 trucks per day delivering 110 million kilograms of fill during peak construction), but

Figure 3. Reinforcing strip placement.

Figure 4. Architectural treatment.

also on the panel and reinforcement components delivered to the site. Reinforcing strips were manufactured and galvanized at longer lengths of approximately 12 meters to minimize splicing needs (Figure 3). Over 250 form liners were manufactured to accommodate the architectural appearance of the panels, many used only once per panel (Figure 4). Material delivery was expedited to meet project and weather-related deadlines.

3.2 *Monitoring*

An extensive instrumentation and monitoring system was provided during construction of the West Wall. Instrumentation included survey points on selected panel faces, strain gages attached along the length of selected reinforcing strips, piezometers and inclinometers. Monitoring of the instrumentation was conducted during wall construction to confirm tolerances

Figure 5. View of completed four tier Reinforced Earth wall.

established during design. In addition to the instrumentation, bearing pads at selected joints were also measured for compression. As a final measure, durability samples were installed in the West Wall select fill volume to monitor the integrity of the reinforcing strips over the 100 year design life of the structure.

Results of the monitoring during construction generally confirmed the design tolerances set for the West Wall. The survey points on the panel faces measured up to 150 mm of lateral deflection and a maximum of 178 mm of settlement. The inclinometers showed somewhat less deformation of the overall wall volume at a lateral movement ranging between 10 to 74 mm. The strain gages generally showed deformation and calculated stresses at less than predicted FLAC values. Piezometers showed normal seasonal fluctuations of up to 2.1 m in the shallow unconfined aquifer, with no discernable head gain due to the consolidation of the underlying very stiff to hard sediments. Finally, the bearing pad compression varied from 12% to 53%, which is well within tolerable horizontal joint maintenance.

4 CONCLUSION

The West Wall for the SeaTac Airport represents the tallest MSE structure built in the United States and one of the tallest walls in the world. Modifications made to the basic components of the Reinforced Earth system proved that ever increasing wall heights may be considered for MSE technology using steel reinforcements. With the use of increasing wall heights comes the need to incorporate both the standard codes used in typical MSE wall design along with numerical modeling tools for detailed evaluations. Instrumentation and monitoring during construction may be compared to the design evaluations for verification of stability. The excellent quality of the select fill and well planned delivery and placement of the wall components, in strict compliance with the project specifications, is necessary to achieve a reliable and aesthetically pleasing MSE wall.

REFERENCES

AASHTO. 1996–2000. Standard Specifications for Highway Bridges – Retaining Walls. 16th Edition, 1996, with periodic addenda through 2000. American Association of State Highway and Transportation Officials.

Chen, B.S. and Bailey, M.J. 2004. Lessons Learned From A Stone Column Test Program in Glacial Deposits. In *GeoSupport 2004*, edited by J.P. Turner and P.W. Mayne, Geotechnical Special Publication No. 124, published by the GeoInstitute, ASCE and ADSC, pp. 508–519.

FHWA Report No. SA-96-071. 1997. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines.

FHWA HI-95-038. 1995. Cost Comparison for Retaining Walls.

Geo-Slope. 1998. Slope/W software for stability analysis, Version 4. Geo-Slope International Ltd. Calgary, Alberta.

Itasca. 2000. FLAC software for deformation analysis, Version 4.0. Itasca Consulting Group, Sudbury, Ontario.

Sankey, J.E. and Soliman, A. 2004. Tall Wall Mechanically Stabilized Earth Applications. *Proceedings of Geo-Trans 2004, ASCE, pp. 2149–2158.*