To: **Mark Dalton, Project Manager**

Through: **Larry Kyle, P.E.**

From: **Denny Grigg, P.E.**
Jim Sheahan, P.E.

Date: **June 3, 2003**

Subject: **Soil Nail Walls Assessment, Mileposts 49 to 50.5**
Kenai River Wall Alternative, Sterling Highway SDEIS, Mileposts 45 to 60

BACKGROUND

The feasibility of the Soil Nail Wall concept for use in the Kenai River Walls (KR-W) Alternative of the Sterling Highway Supplemental Environmental Impact Statement (SDEIS) was assessed through extensive review and research. The KR-W Alternative generally follows the existing corridor, with alignment adjustments to flatten curves and improve sight distances. Because of the topography in the area of the KR-W alignment, wall systems are proposed between Milepost (MP) 49 and MP 50.5 to stabilize and protect cut sections required for flattening the curves. The three major walls reviewed are within a 1.1-mile reach of the KR-W alignment, between Stations 1669+ and 1728+.

The January 2001 *Preliminary Geotechnical Memo* (PGM), prepared for the project by R&M Consultants, Inc., provides a preliminary assessment of geotechnical conditions along the project corridor. No field explorations have been conducted specifically for development of the Seward Highway SDEIS, particularly for the KR-W Alternative. The PGM does reference four test holes (TH-1 through TH-4) drilled by the Alaska Department of Transportation and Public Facilities (ADOT&PF) on top of the bluff along the existing roadway between MP 49 and MP 50.5, in support of the *Reconnaissance Geology Report* (ADOT&PF, August 1983). Discussions with R&M's project manager indicated that the boring locations were not necessarily indicative of the geotechnical conditions at the walls being considered. At the time of this assessment, R&M had preliminary batters of 1H:10V on the walls, but had considered 1H:4V, which would require significant additional excavation.

The proposed project is located in an area of high seismicity. The old Kenai River Bridge collapsed in the 1964 Good Friday Earthquake, apparently due to liquefaction of underlying soils. Although the need to consider seismic events was not specifically mentioned in the PGM, the American Association of State Highway and Transportation Officials (AASHTO) gives an acceleration (A) coefficient of $A \approx 0.58g$ for the area, based on a 90 percent probability of not being exceeded in 50 years (Figure 1–5, Map of Horizontal Acceleration, Division 1A, Seismic Design, *AASHTO Standard Specifications for Bridges,* 1996).

SYNOPSIS OF FINDINGS AND RECOMMENDATIONS

The HDR team that assessed the Soil Nail Walls concept for the KR-W Alternative concluded that there is no precedent for a wall system of this type and magnitude, particularly for use with the heights proposed. The highest known wall is less than 100 feet. The team does not consider the Soil Nail Wall concept to be technically well suited and cost-effective for the site.

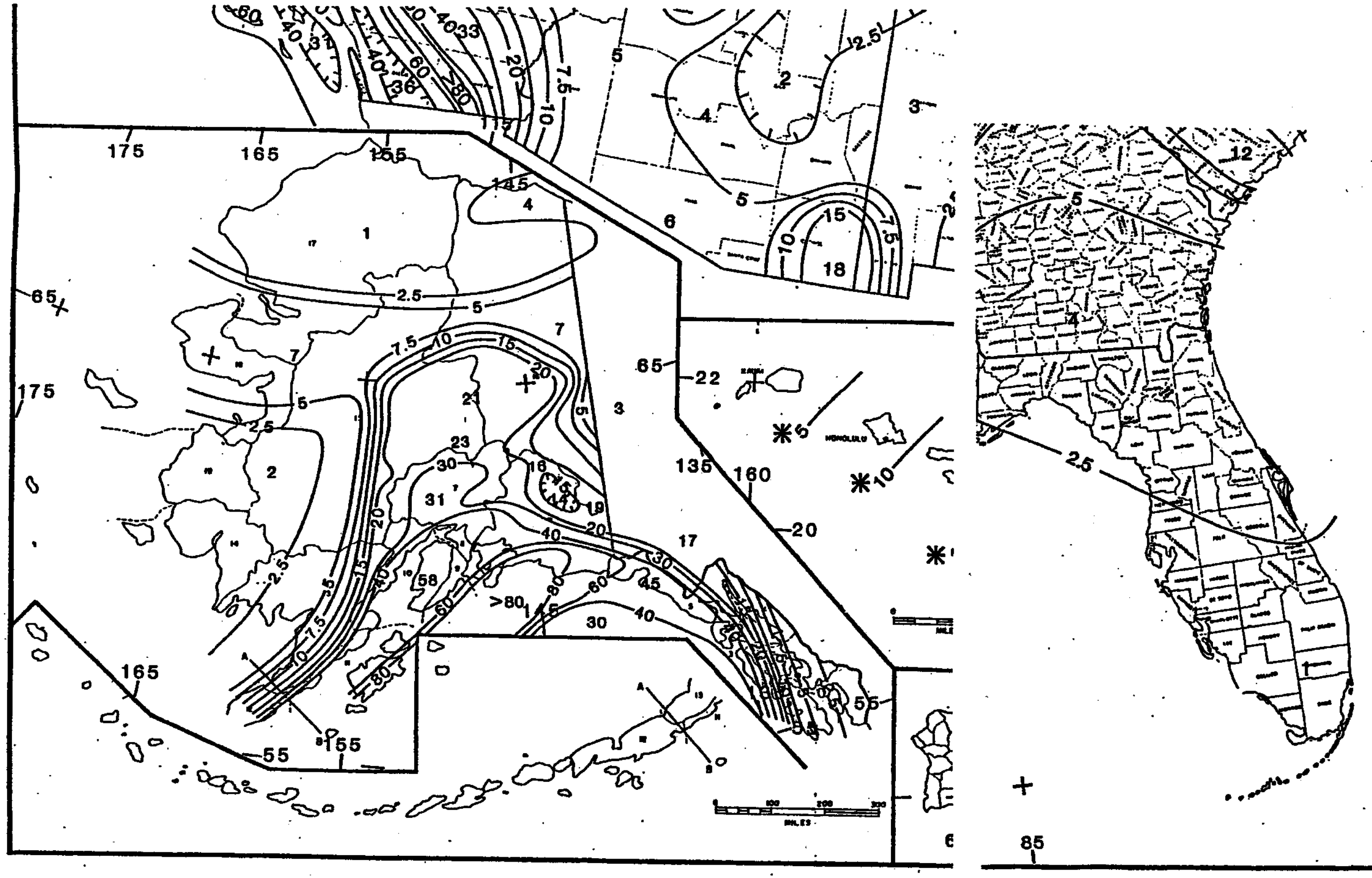

FIGURE 1-5

Map of Horizontal Acceleration, A (expressed as percent of gravity) in Rock with 90 Percent Probability of Not Being Exceeded in 50 Years. Variability in Attenuation of Log_e Ground Motion (σ_A = .62) and Log_{10} Fault Rupture Length (σ_L = .52) are Included in the Calculation.

✱ Hawaii and Puerto Rico are derived from Commentary Section 1.4.1, Figure C1-4.

Prepared by the U.S. Geological Survey for the 1988 edition of NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings

The HDR team recommends that this type of wall should not be considered for use in the KR-W alignment, particularly not for wall heights tentatively presented. This recommendation is based on the following significant issues:

- Proposed wall heights (165 feet, 132 feet, and 135 feet [west to east]) are 1½ to 2 times higher than any Soil Nail Wall built to date.
- Cuts may be as tall as 200 feet and would present considerable geotechnical risk.
- The excavation of 1.5 million cubic yards (cy) has not been addressed.
- Considering costs of inflation, Alaska price impacts, and uncertainties for soil conditions and heights above any soil nail wall currently designed or built, the wall costs are estimated as much as $154.00 per sf for a cost of $63.6 mill. This does not include the cost of excavation mentioned above.
- The in situ soil properties are unknown.
- The global stability of the bluffs and the stability of high Soil Nail Walls on the bluffs are unknown.
- Constructability and safety are concerns because of the closeness of existing traffic on the road, which is the only road to the Kenai Peninsula.
- The proximity of the proposed walls to the Kenai River and the potential for a catastrophic failure of exposed slopes resulting in material entering the river during construction.

The HDR team noted that any wall solution for the KR-W alignment is expected to be very expensive and possibly beyond the current industry standards for retaining walls. The use of a tied back wall is considered the most applicable, given the information available, and is therefore used as the basis of the current conceptual cost estimates. An appropriate geotechnical exploration, sampling, and testing program will be necessary to validate the use of any wall type in this location.

DISCUSSION

Assessment Team Members

Members of the HDR team who conducted the Soil Nail Wall assessment were Jim Sheahan, P.E.; Eric Keen, P.E., S.E.; Duane Hippe, P.E.; Denny Grigg, P.E.; Steve Aisaka, P.E.; and Larry Kyle P.E, S.E.

The Walls, the Site, and Findings of the PGM

As noted above, three major walls are being considered in a 1.1-mile roadway segment of the KR-W alignment (MP 49 to MP 50.5). The combined area of the three walls is estimated at 410,000 sf.

The most prominent features of the Soil Nail Walls are their proposed heights of 165 feet, 132 feet, and 135 feet, from west to east, at their respective wall apexes above the proposed grade for the roadway profile. Team research indicates that all three heights are at least 1½ to 2 times higher than any permanent Soil Nail Wall used to date.

The PGM, which reports preliminary findings, notes that the cut or cuts at the site may be as tall as 200 feet and would present considerable geotechnical risk. The PGM also identifies the following potential issues:

- Because the greatest risk results from the height of the cut, it may be necessary to use means to lower the height.

- If significant groundwater is encountered, the mitigation costs to prevent slumps and deep-seated failures may make the deep cut impractical.
- If underlying till is predominately silts and clays, rather than sand and gravel, the potential for erosion and slope instability would increase. Also, the excavation would generate significantly less usable roadway fill material, and special waste areas may be required.

Excavation

The PGM does not address the issues of excavating 1.5 million cy of excess material, assessing what portion of the materials may be suitable for roadway fill material, and the manner and cost of disposing of excavated materials that may not be suitable for site use. Further, the process of excavation and hauling the material off-site would substantially impair use of the existing roadway during construction. The uncertainties resulting from the undefined amount and composition of bluff excavation for the KR-W Alternative present drawbacks not only in developing wall concepts and cost, but also in assessing earthwork and the corresponding construction sequencing.

Summary of Soil Nail Walls Reconnaissance

Members of the HDR team contacted numerous agency and industry resources in assessing applications, size, height, and cost of Soil Nail Walls. The following resources were consulted:

1. Table 1–1, Cost Data for Soil Nail Walls on U.S. Transportation Projects, from the 1999 Federal Highway Administration (FHWA) *Demonstration Project 103: Design & Construction Monitoring of Soil Nail Walls*, Project Summary Report, FHWA-IF-99-026, was reviewed. The report is available as an attachment at http://www.fhwa.dot.gov////bridge/if99026.pdf. The cost data in Table 1–1 are somewhat dated, covering Soil Nail Walls constructed from 1987 to 1995. Maximum wall height in Table 1–1 was 40 feet, and general costs ranged from $28 per sf to $37 per sf for permanent Soil Nail Walls used for roadway cut. The report also provided the following information (values have been converted from metric to English units and represent 1990s data):
    a. The highest vertical Soil Nail Wall is 72 feet.
    b. The highest battered (73 degree face angle) Soil Nail Wall is almost 98 feet.
    c. Lengths of Soil Nail Walls are typically 70 percent to 100 percent of the wall heights.

    Table 1–1 lists 41 Soil Nail Walls, including 7 from Washington, 5 from Oregon, and 9 from California. In Washington and Oregon, the combined 12 Soil Nail Walls had an average height of 23 feet, at a numerical average cost of $42.50 per sf. Adding the 9 walls from California, the averages for the 21 walls were 24 feet high and $40 per sf. Note that these numbers are, on average, 10 years old; not from Alaska; and not representative of walls taller than 100 feet.

2. Professional and industry contacts consisted of the following:
    a. Nicholson – Pittsburgh, Pennsylvania: This firm has not used Soil Nail Walls higher than 50 feet. The contact suggested that impacts of seepage during construction of Soil Nail Walls might be a concern.
    b. Schnabel – Glen Allen, Virginia: The representative of this firm commented that 50 feet is a typical height and 70 feet is the highest Soil Nail Wall it has

provided. The highest Soil Nail Wall this contact had heard of is about 100 feet, in Seattle.

c. Goettle – Cincinnati, Ohio (a large specialty geotechnical-foundation contractor that probably has not done as much soil nailing as others): The representative contacted said that 50 to 60 feet would probably be comfortable heights, but that he "wouldn't touch it" at 170 feet because of unknowns and potential impacts from a failure. Although a geotechnical analysis would provide important information, the company still would expect to have concerns.
d. Shannon & Wilson – Anchorage, Alaska: The person interviewed believed that a 180-foot wall would be too high. A primary concern was the type the material to be retained.
e. Jolly Miller – Seattle, Washington: The representative of this firm described a 100-foot wall that Jolly Miller is providing in Provo Canyon, Utah. The material is essentially bad rock that has been rock bolted before. The firm believes it could do a 180-foot wall, as long as a geotechnical engineer designed it. Costs would be $20 per sf just for materials.
f. Golder Associates – Redmond, Washington: This contact said the high walls Jolly Miller has done in Utah were in fractured rock, which is much different than what is along the Kenai. The Golder representative pointed out that the Bellevue Technology Tower (Washington) is the highest Soil Nail Wall constructed to date.
g. DBM – Seattle, Washington: This company completed a temporary Soil Nail Wall for the Bellevue Technology Tower in Washington that was 95 feet at its maximum height. The wall was designed to last 1½ years, and the nails were not very long. The contact described a “gut feeling” that a 180-foot shoring wall should not be soil nailed. Also noted was that the work DBM has seen in Alaska does not lend itself to soil nailing because some good “standup” time is needed for the soil while the nails are installed and the shotcrete facing is applied. If a soil boring was available, DBM could take a look and give a more specific opinion. Another topic discussed was cost. The contact noted that if feasible, the use of soil nails typically is less expensive than a soldier pile system.

The feedback indicated that the walls under consideration are unusually high. There was a general consensus that a tied back type anchored wall system is probably more appropriate for the heights being considered, based on the need to use fewer anchors and the lengths of nails and anchors required. The Soil Nail Wall in rock, used by Jolly Miller, is different because of global conditions controlling stability factors in the slope; the project involved building continuity and jointing of a rock mass as opposed to retaining soils of various types and strengths. Groundwater conditions on the KR-W Alternative could also be very different from those encountered in Utah.

The professional respondents emphasized the importance of geotechnical exploration, materials, slope and global stability, groundwater and seepage, and sound design practices. The conversations showed that Soil Nail Walls at the KR-W Alternative would be a state-of the-art application of the technology if they could (1) be made to work and (2) be used cost-effectively.

Other Wall Systems

The HDR team gathered the following information about other wall systems:

- Reinforced concrete cantilever walls – Economics generally limit maximum heights to 18 to 20 feet.
- Reinforced concrete counterfort walls – Often used when reinforced concrete cantilever walls cease to be economical, these walls are suitable for applications with heights up to about 30 feet.
- Non-gravity cantilever walls – This system relies solely on “pole action” to retain embankments and resist overturning. A frequent solution for depressed roadway facilities with tight right-of-way and utility constraints, the non-gravity cantilever walls result in heights that are typically in the mid-20-foot range, which is probably close to the practicable limit.
- Prefabricated modular walls – Although suitable for higher walls, ADOT&PF typically uses these walls for maximum heights of 18 to 20 feet.
- Mechanically stabilized embankments – This type of wall was used for heights up to about 70 feet on the San Joaquin Hills Transportation Corridor in Orange County, California.
- Tieback walls – Tieback (anchored) walls have been constructed with varying heights and lengths throughout the United States and in Europe. Most tieback walls are probably less than 50 feet high. The largest U.S. application that members of the HDR team are aware of is on Ohio SR7, along the Ohio River. This wall, with a height of about 140 feet and total area exceeding that of any other tieback wall in the United States, retains a jointed rock cut. The anchors are taken into the rock, and the facing is primarily cast-in-place concrete.

This comparison of available wall applications indicates that for any system other than tieback walls to be feasible, the KR-W Alternative must be adjusted to reduce the required wall heights. This results in increasing the amount of excavated material that has to be disposed.

CONCLUSIONS AND FINDINGS

HDR does not recommend consideration of the Soil Nail Wall concept at this time, as presented, for the reasons cited below:

1. **Precedent –** There is no precedent for a wall system of this type and magnitude, particularly of this height, having been designed or constructed.

2. **In situ soil properties –** The Soil Nail Wall concept and the site materials assessment for the KR-W Alternative require substantially more design level information, primarily geotechnical, to ascertain Soil Nail Wall feasibility, particularly related to cost. Conducting an appropriate geotechnical exploration, sampling, and testing program that is broad enough for concept verification and definition, and identification of the resulting design engineering requirements, are essential to validating the wall concept for use on the KR-W Alternative.

3. **Seismicity –** The high seismic coefficient for horizontal acceleration in the area ($A \approx 0.58g$) increases concerns about the seismic stability of a major high wall system. The performance of these prominent bluffs along the roadway during the Good Friday Earthquake in 1964 does not ensure the performance of a major wall system during a seismic event.

4. **Global stability –** The following concerns are noted:

   a. The effort to evaluate whether acceptable global stability is realistically available or attainable with soil nailing, including the extent of soil nailing that might be required, is unclear.

   b. The availability of similar assessments about the stability of the work area or bench in front of the wall, once the progressive cut excavation "daylights" on the outboard side (see Note 5, immediately below), also is unknown.

5. **Constructability and safety –** The location for construction of the tallest Soil Nail Walls is not directly over existing traffic, because of the combined geometry of the site and proposed roadway. However, the stability of the slope surface (based on observed slope materials) during wall construction, specifically at the wall limits for each progressive level of construction, is not known. At each level, the excavated cut in front of the wall transitions to a day lighted ledge or bench at the outer limit of the wall (at that level). Although a concern at all elevations of wall construction, the slope stability is perceived as a greater hazard at lower elevations, where the wall construction is closer to existing traffic. This day lighted bench in front of the wall may have limited strength and stability, unless reinforced. If stability becomes insufficient, prevention of the resulting safety hazard would increase wall costs.

6. **Cost –** Two elements are essential to establishing estimated costs for the Soil Nail Wall concept at the KR-W Alternative site:

   a. Appropriate conceptual and preliminary engineering assessments and analyses should be performed to validate feasibility of the Soil Nail Wall concept. If that is not possible with the data available, the deficiencies should be listed and a cost estimate should be prepared to obtain needed design-level engineering information. Adequate, validating analyses should be performed to establish a reasonable representation of the conceptual walls, suitable for industry review and assessment, including costs. Throughout this effort, the merits and deficiencies of the concept should be continually assessed. The design life of the "solution" should be 50 years.

   b. Complete-in-place wall costs should be verified on a broader basis. Consultation with industry experts may provide additional insight into the practicality, including constructability, cost, serviceability, and maintenance, of the proposed concept. It is anticipated that the industry responses would include emphasis on elements crucial to a solid, durable end product.

   Lacking more specific design information, cost estimate ranges are based on existing data and engineering judgment only. Unit prices for walls of average 24 feet in height are approximately $40.00 per sf in 1993 dollars. Inflated to 2003 dollars this price becomes $55.00 per sf, based on ENR CCI for Seattle. Adjustment for Alaska conditions typically adds approximately 40%, to a price of $77.00 per sf. And allowing for the unknown of the impact of the soil conditions, and heights exceeding any current soil nail wall heights could add a factor of 1.5-2 times, or as much as $154.00 per sf. At this estimated unit cost, the total cost for a soil nail wall installation at this sight would be $63.6 mill.

7. **Maintenance –** The requirements of periodic inspection and maintenance, as well as occasional repair efforts, should be considered.

Attachment 1

RETAINING WALLS, SOIL NAIL WALLS, AND STABILITY

The 1996 16th edition American Association of State Highway and Transportation Officials (AASHTO) Standard *Specifications for Highway Bridges*, revised through 2000, and the 1998 2nd edition AASHTO *LRFD Bridge Design Specifications*, revised to date, both provide design specifications for structural retaining wall systems briefly described below. The only AASHTO document addressing Soil Nail Walls is the 1990 AASHTO Task Force 27 Report – *In Situ Soil Improvement Techniques*, which has a subsection containing a design-build construction specification for permanent soil nailed structures. The Federal Highway Administration (FHWA) has been the leader in introducing Soil Nail Walls into American transportation construction practice, highlighted by Demonstration Project 103 initiated in 1992, which resulted in FHWA manuals for Soil Nail Wall design and construction in 1996.

Retaining Walls

The following are general classifications for retaining walls in the AASHTO bridge specifications:

- Gravity – includes massive concrete, mortared masonry, prefabricated modular, and mechanically stabilized embankment (MSE) walls
- Semi-gravity – includes reinforced concrete cantilever and counterfort walls
- Non-gravity cantilever – includes driven piles and cast-in-place drilled shafts with planking/lagging systems to retain embankment
- Anchored – includes soldier pile tieback and flexible anchor walls

Attached Figures 5.2A, 5.2B, and 5.2C[1] provide depictions of various retaining wall types.

All retaining walls are structural elements or systems. Gravity walls, except for modular and MSE, are typically rigid; all other retaining wall systems are flexible, in varying degrees. Retaining walls must have their own *internal stability*—massive concrete, mortared masonry, reinforced or prestressed concrete, structural steel, or MSE reinforced soil mass. The internal stability is essentially the structural integrity of the wall (system) and provides redistribution of applied loads and forces.

All retaining wall systems are subject to settlement, lateral displacement, deflection, and rotation. Retaining walls must meet *external stability* requirements, complying with specific factors of safety pertaining to ultimate soil-bearing pressures, sliding, and overturning. These factors of safety are discipline-established to generally ensure the serviceability of any retaining wall, by limiting its settlement, lateral movement, deflection, and rotation. Serviceability is driven by (1) acceptable displacements, which define external stability and, in turn, drive retaining wall proportioning; and (2) the structural requirements (internal stability) for the wall system.

All retaining walls are typically constructed from the bottom up, with the exception of non-gravity cantilever walls, which may also be constructed from the top down, and soldier pile tieback or anchored walls, which are often completed with two or more levels of anchors from the top down.

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[1] AASHTO *Standard Specifications for Highway Bridges*

- Retaining walls constructed from the bottom up are typically over excavated to facilitate wall construction and temporary slope stability requirements during wall construction. Backfill then is placed behind the wall. Backfilling of MSE is integral to MSE construction. Backfilling of prefabricated modular gravity walls generally continues as crib or bin wall height increases. Most other walls constructed from the bottom up are backfilled after completion, particularly if structural strengths essential to internal wall stability must be attained. Retaining walls constructed from the bottom up are ideally suited for retaining fills; they are less feasible in cuts or where construction room is limited.

- Non-gravity cantilever walls constructed from the top down and soldier pile tieback and flexible anchor walls are ideally suited for cuts and areas where construction areas are limited. Where tiebacks and anchors extend beyond right-of-way limits, permanent easements are typically required.

Soil Nail Walls

The primary design concepts for Soil Nail Walls differ considerably from design concepts for retaining walls. The Soil Nail Wall has two primary functions:

- The stability of the facing and the *stability and structural integrity of the localized soil zone* behind the facing are functions of the pattern and spacing, length, and size (diameter) of the nails. The nails are not tensioned after installation, and the facing exerts minimal pressure on the cut soil face. The facing simply protects the soil face from the elements and resulting erosion; the nails reinforce the soil mass from the cut face back. As the Soil Nail Wall construction advances from the top down, any increasing global stability requirements initiate tensile stresses in the soil nails.

- The support and *global stability* of the overall wall and soil mass relies on the in situ resistance between the active and resistant zones in the soil mass, and is supplemented by the penetration of the soil nails beyond the soil mass active and resistant zones interface. As depicted in the attached Figure 2.4[2], Conceptual Soil Nail Behavior, if the active zone is delineated by a horizontal distance of 0.30 to 0.35 H (H being height of wall, at any point), the total length required for the soil nails is typically a minimum of 0.6H to 0.8H (H being total wall height, in this case). This total length provides sufficient embedment in the resistant zone to develop the required nail tension at the active/resistance zone interface, as progressive construction from the top down initiates and increases nail tension. The slope and global stability of the active zone earth mass behind the soil nail facing must be designed with appropriate factors of safety for construction and service conditions.

Global Stability for Retaining Walls

Global stability for retaining walls is similar to that for Soil Nail Walls, except that the former is generally independent of the retaining wall's internal and external stability configurations. If the estimated factors of safety for global stability are inadequate, the overall embankment geometry would need to be reconfigured. In addition, the resulting forces would need to be determined, external stability of the retaining wall would need to be verified, and a new global stability analysis would need to be performed.

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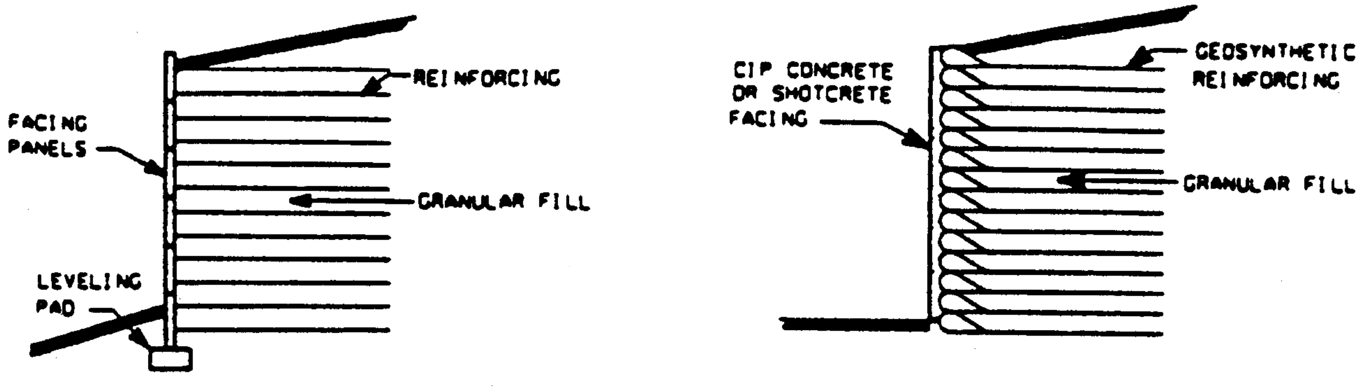
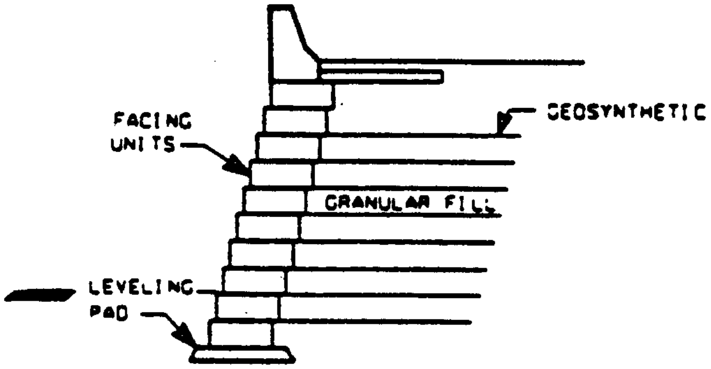
[2] From *The Manual for Design and Construction Monitoring of Soil Nail Walls,* FHWA-SA-96-096R, developed from Demonstration Project 103.



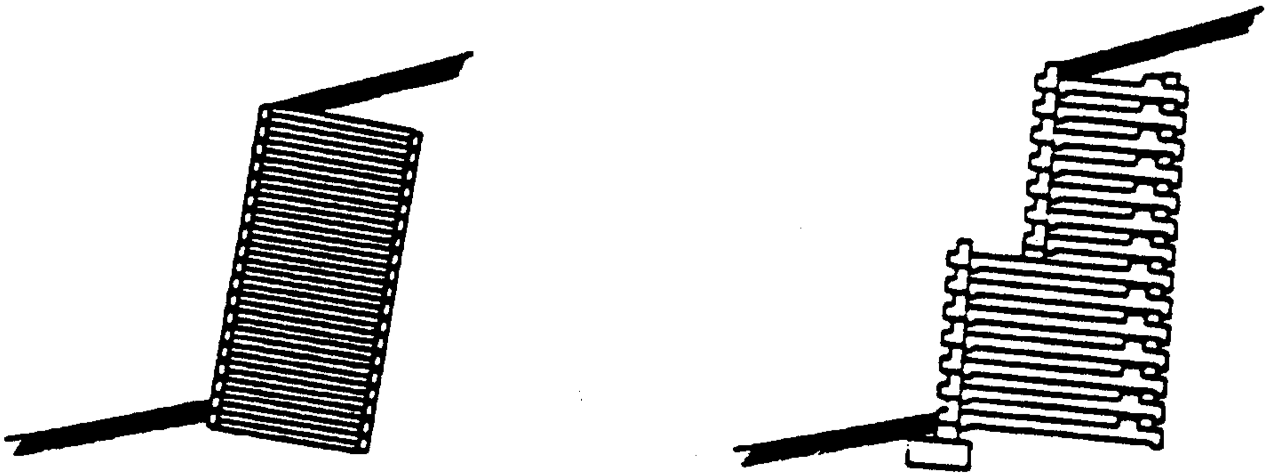
MSE WALL WITH MODULAR PRECAST CONCRETE FACING PANELS

MSE WALL WITH GEOSYNTHETIC REINFORCEMENT AND CIP CONCRETE OR SHOTCRETE FACING



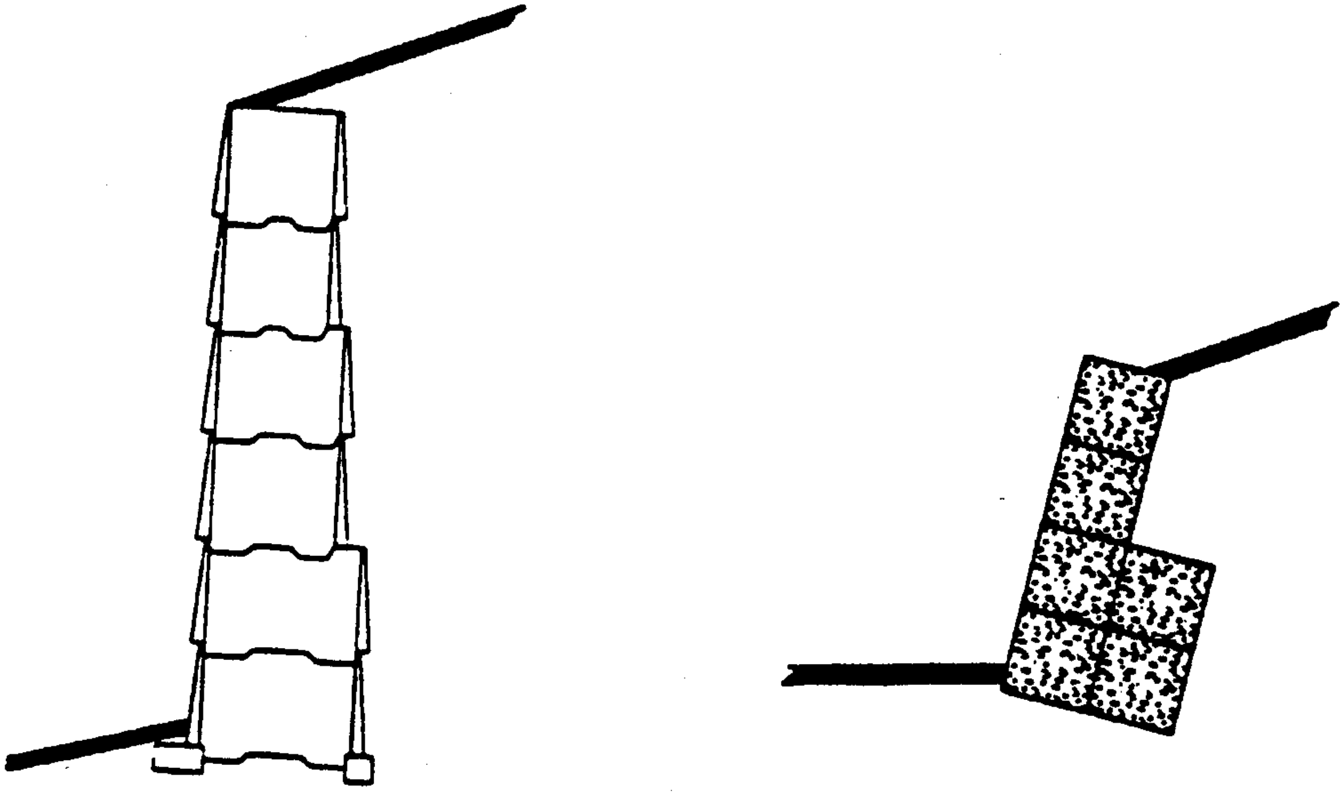
MSE WALL WITH SEGMENTAL CONCRETE BLOCK FACING

FIGURE 5.2A **Typical Mechanically Stabilized Earth Gravity Walls**



METAL BIN WALL

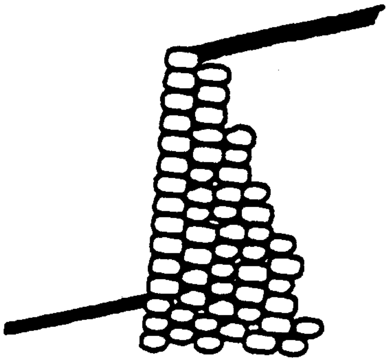
PRECAST CONCRETE CRIB WALL



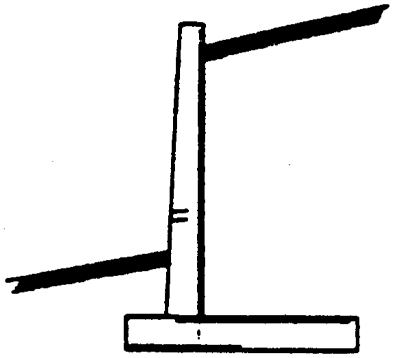
PRECAST CONCRETE BIN WALL

GABION WALL

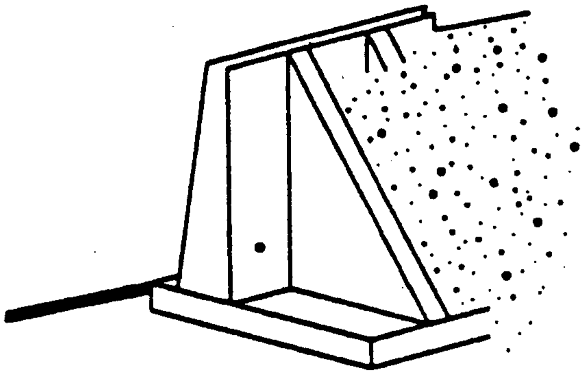
FIGURE 5.2B **Typical Prefabricated Modular Gravity Walls**



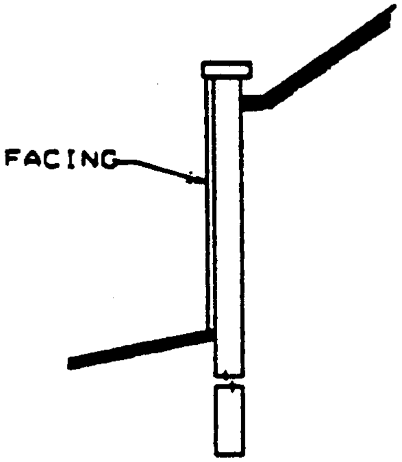
Mortar Rubble Masonry
Rigid Gravity Wall



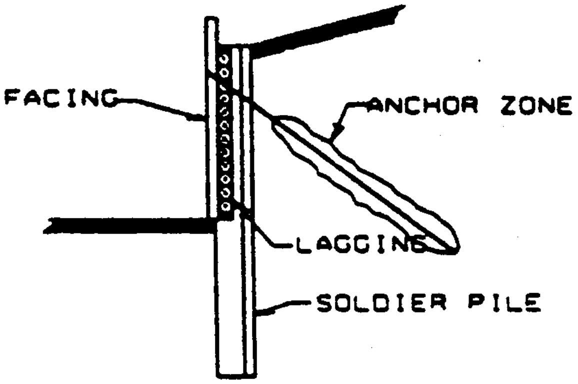
Reinforced Concrete Cantilever
Semi-Gravity Wall



Reinforced Concrete Counterfort
Semi-Gravity Wall



Slurry or Cylinder Pile
Non-gravity Cantilever Wall



Soldier Pile Tieback Wall

FIGURE 5.2C Typical Rigid Gravity, Semi-Gravity Cantilever, Non-gravity Cantilever, and Anchored Walls

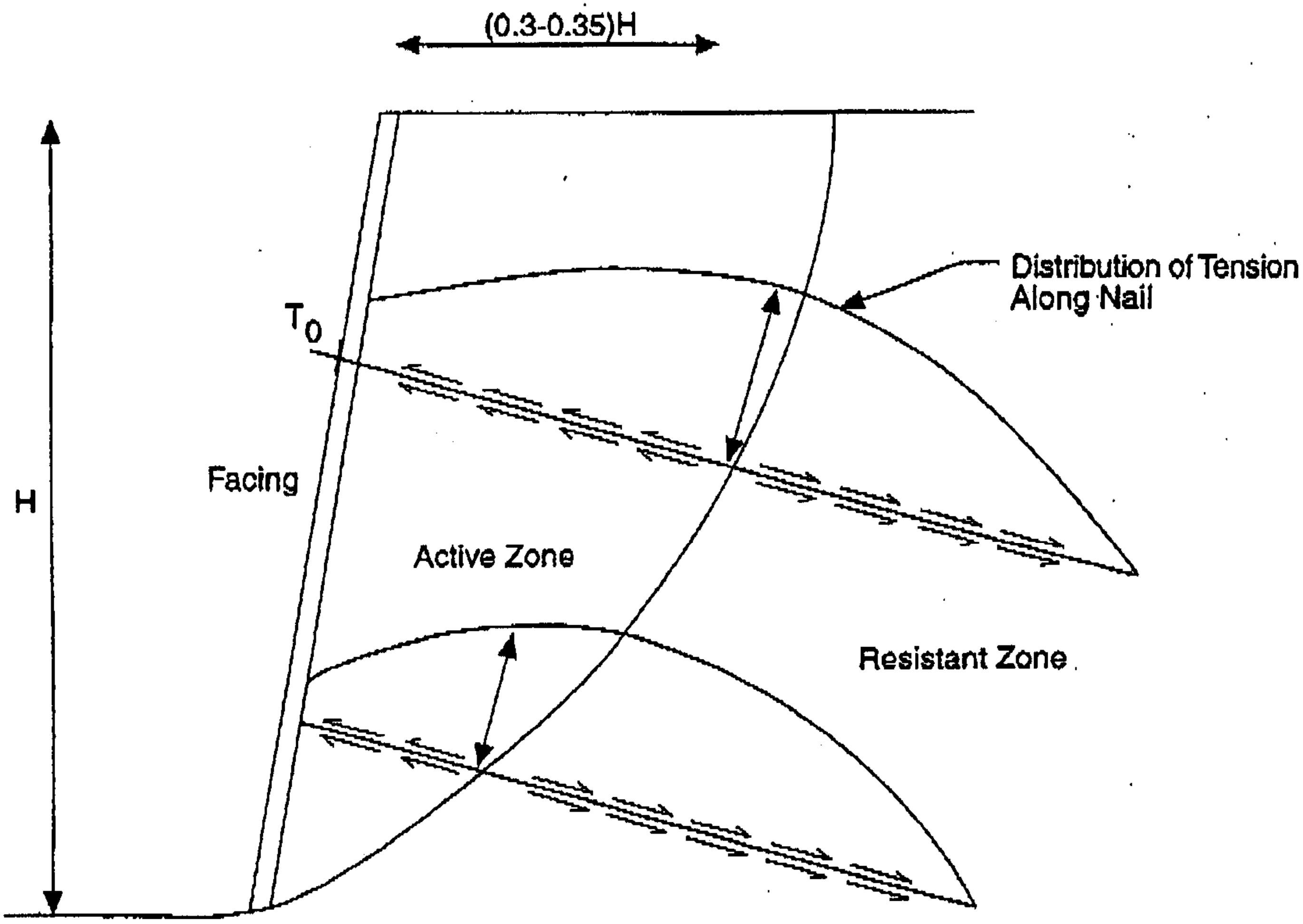


Figure 2.4 Conceptual Soil Nail Behavior