Specialty construction on urban highways

by

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Signatures have been redacted for privacy

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ABSTRACT

30 to 50 billion dollars are being expended each year, in USA, on urban highway re-construction and maintenance. These projects usually involve many years of construction and span tens' of miles. During these reconstruction periods, commuters face traffic delays and congestion. Construction teams also have to work on a space and time budget. For the above mentioned reasons, it is beneficial to minimize all the costs of construction (economic, spatial and time period). To accommodate these requirements, it is vital to have good estimates before construction begins.

To make use of local resources thereby maximizing efficiency, highway reconstruction is split into many individual projects. The estimates of these projects greatly affect the overall estimate of urban highway reconstruction. Bridge construction and grade and pave jobs form the bulk portion of the individual projects.

Large amounts of time and money are invested in foundation systems and retaining structures, which happen to be the essential components in the above mentioned projects, if involved. Urban highways pass through various (including weak) soils, and varying levels of elevation. A good foundation system is needed when the highway passes through areas with poor ground properties. A retaining structure is needed when a highway differs considerably in elevation from the surrounding landmass.

There are various types of ground improvement techniques and retaining structures. This thesis attempts to bring to light the differences in terms of cost and time between the various techniques. It also discusses the pros and cons of using these techniques in an urban environment.

The urban highway reconstruction project in the state of Iowa (I-235, Des Moines) has been chosen as a case study to distinguish the differences in techniques used for ground improvement and retaining structures. Study has been conducted on stone columns, rammed aggregate piers, mechanically stabilized earth structures, soil nail wall and cast in place cantilever retaining wall.

A literature review is presented to provide a history and summary of previous research performed on such specialty earth work construction. Next, a detailed description of the construction process, engineering properties, productivity rate, schedule and cost for rammed aggregate pier, stone columns, mechanically stabilized earth structures, soil nail wall, and cast in place cantilever retaining wall are presented. The last section will include the differential advantages among construction activities mentioned above. Appendices are provided at the end of the document for references on the data collected.

INTRODUCTION

Project location and description

The urban highway reconstruction project, I-235 (Figure 1) in Des Moines, Iowa, USA has been chosen as a case study project for this research. The reconstruction of this project is a budgeted $426 million project managed by the Iowa Department of Transportation (Iowa DOT). As one of the most expensive road projects in the Iowa DOT's history, it began in 2002 and is scheduled to be completed in 2007.

The I-235 project is located in Des Moines, Iowa and has been divided into ten sections for organizational purposes. The first four sections, Sections 1-4, are located west of downtown Des Moines, and will be widened from the current configuration, essentially a four-lane roadway, to a six-lane configuration. The entire six-lanes will then be resurfaced with hot-mix asphalt. The last three sections, Sections 8-10, located north of downtown Des Moines, will be upgraded in a similar manner. The middle three sections, Sections 5-7, located in downtown Des Moines, will be totally reconstructed and paved with Portland cement concrete. 71 bridges and 21 interchanges on this 14-mile corridor need to be rebuilt. The reconstruction of I-235 is a comprehensive multifaceted project with multiple contractors, multiple jobs, and cost-valued tasks.

The general construction timeline for the reconstruction is as follows:

2002 ~ 2004: Utility Relocation, Bridge Widening and Replacements, Median Paving, Temporary Paving, Interchange Reconstruction.

2005 ~ 2007: Mainline Paving.

Many specialty construction techniques such as soil nail wall, mechanically stabilized earth structure, rammed aggregate piers, stone columns, noise walls, tie back walls and cast-in-place retaining walls are being executed through out the corridor.

Starting in August 1999, Iowa State University researchers began working with the Iowa DOT to develop better methods to schedule highway renewal projects and using I-235 as a case study site. Considerable effort has been invested in developing a computer-based conceptual schedule, calculating production rates, and loading resources.

This researcher will present the observations and analysis for the above mentioned specialty construction techniques made on basis of numerous field visits made to the test site. Because of the varied contractors and construction types, I-235 has proven to be a valuable test site. The data obtained is based on the observations made at different projects by different contractors.

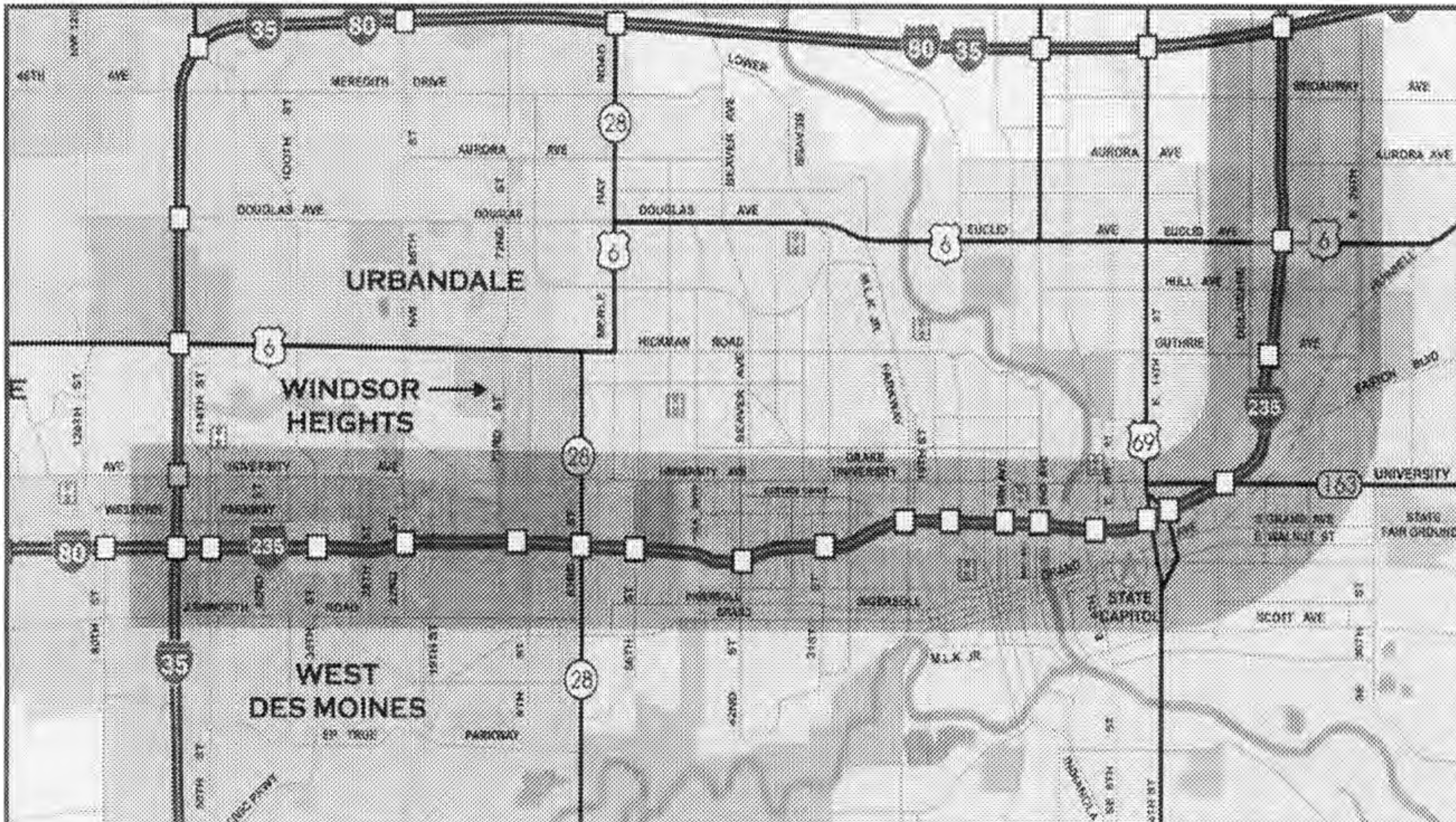

Figure 1. I-235 corridor in Des Moines, Iowa

Problem statement

Large amounts of time and money are being invested in constructing foundation systems and earth retention systems during the process of re-constructing urban highways. It is essential to employ a better system which is economical in the use of resources and yet is effective for a given condition.

To select a system which is effective in the given conditions, it is important to answer the following questions:

- What is the time required for the completion?
- What is the cost for undertaking a project of this nature?
- What are the other alternatives?
- What are the space limitations for using a selected system?

Objectives

In order to answer these questions, this researcher developed a comparison matrix to determine and satisfy the levels of detail needed. This thesis will focus on comparing available and currently used alternatives for similar conditions. Cost, time and other important considerations have been addressed through this thesis. The construction processes, advantages and disadvantages of each system have also been enumerated.

LITERATURE REVIEW

The literature review intends to bring to light the previous research done on various specialty construction processes. Firstly, a brief history on the research conducted on stone columns and rammed aggregate pier is presented. And a discussion on the research done on mechanically stabilized earth retaining wall and soil nail retaining wall will be presented following the latter. Enough literature was not found on cast-in-place cantilever retaining wall, which could explain the research done on time and cost needs for its construction. Hence, it was not discussed in this literature review.

History of research done on Rammed aggregate piers and Stone columns

Extensive research was performed to identify properties and determine feasibility of Stone columns and Rammed aggregate piers (Geopiers®) in various soil conditions. Few researchers have also compared the above mentioned foundation systems. Stone columns are relatively old and the most popular type of aggregate piers until Geopiers® were developed by Dr. Natheneil S Fox and Lawton Evert C in 1983. They were first commercialized in 1988.

Stone columns

Stone columns (Figure 1) can reduce of settlements by up to 50% as compared to the original soil condition (Brignoli et al, 1994) and can improve the density of loose to medium dense gravelly silty sand sufficient to support footing loads of 290 KN/m2 (6056.65 psf) with no greater than 5.1 cm of settlement (Allen et al, 1990). These findings have been further reinforced by case studies presented by Hayden et al, 1990; Stewart et al, 1994; and Buggy et al, 1994. The stone columns create maximum stress concentrations near the treated area and reduce stresses beyond the treated area (Kundu et al, 1994) resulting in lower settlements compared to the original soil conditions. Settlement of treated earth occurs during first few months and is minimal after that time period (Snethen et al, 1990).The stone columns have also proven to be less costly than steel piles or over-excavation.

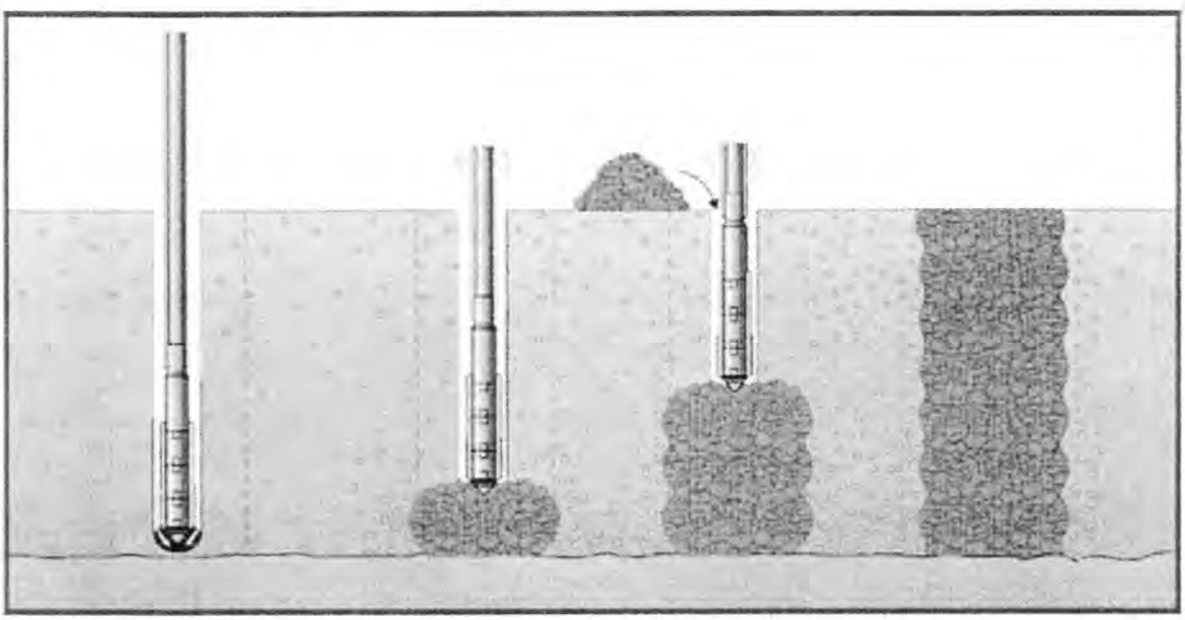

Figure 2. Wet, top feed construction method for Stone Columns
(From http://www.haywardbaker.com)

Rammed aggregate pier

The rammed aggregate pier (Figure 2) case studies presented by Lawton et al, 1994 have demonstrated considerable decrease in settlements, in comparison to the original soil settlements. It is evident from the findings of the case studies presented by the above mentioned authors that the settlements in the soil have decreased up to 60% – 75%. The Geopiers® cost less than steel piles (Wissman et al, 1999); they 25 % less than caissons socketed into rock or minipiles (Moser et al, 1999). An other paper presented by Wissmann et al, 2000, establishes that settlements in the footing were less than 4 cm and the project cost was reduced by $187,000 by using Geopiers® instead of 23m long steel pipe piles for a six-story parking garage. Most of the other projects executed by the researchers have also proven that the use of Geopiers® decreases the settlement to a considerable amount in comparison to the original ground condition and also cost less than piles and other foundation systems such as minipiles, cassions and over excavation. Geopiers® can be effectively used in soil conditions such as peat, highly organic soils and very soft soil zones (Fox et al, 2001). Settlement of the treated earth is complete in three to four weeks, a sufficiently short time to avoid construction delays (Gaul, 2001).

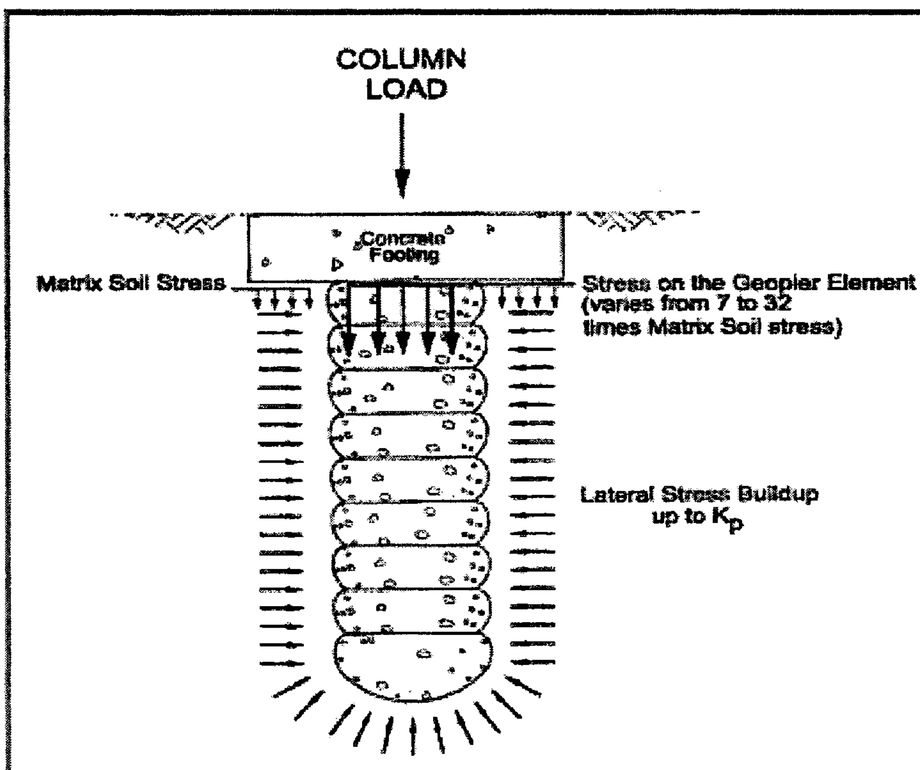

Figure 3. Rammed aggregate pier

(From http://www.geopierglobal.com)

Comparison of Rammed aggregate piers and Stone columns

Dr. Natheneil S Fox and Lawton Evert C, in U.S. Patent No. 5,249,892, stated that stone columns could improve the load bearing capability of the ground but fail to laterally prestress or compact the surrounding soil to a significant degree. By contrast, Geopiers® laterally prestress and compact the surrounding soil to a higher degree than stone column enabling a better load bearing capability. As a result, fewer rammed aggregate piers will be needed for a stipulated superimposed load in comparison to stone columns. This results in reduction in cost and a possible increase in safety. They also stated that stone column construction requires a specialized piece of equipment, called a Vibroflot, and more specialized crew members to monitor the compaction and numerous calibration units.

A project done by Gaul, 2001 highlighted that:

1. The stress concentration ratio in rammed aggregate piers was greater than stone columns. Increase in stress concentration ratio increases the load bearing capacity of the column. Thus rammed aggregate piers carry more load than stone columns,
2. Stresses on the rammed aggregate pier matrix soils increase with time while stresses on the stone column matrix soils and stresses on un-reinforced soils decrease with time or remain constant,
3. Rammed aggregate piers elements and the soft adjacent matrix soils settled nearly identical amounts, where as, stone columns and the surrounding soils were acting independently of each other,
4. Geopiers® inhibit settlement because; the lateral stresses acts in both radial and tangential directions. By contrast, the lateral stress development adjacent to the

stone column was not constant at all points. Because of which this, resistance to settlement may be less than that for Geopiers®, and

5. Rammed aggregate piers are about 10 to 15 times stiffer than stone columns.

The information obtained from CTRE project 00-60 report: "Highway Applications for Rammed Aggregate Piers in Iowa Soils" and the Website of Geopier® Foundation Company has been grouped and presented in the following table (Table 1). It highlights the important technical differences between stone columns and rammed aggregate piers.

Table 1. Comparison of Stone Columns and Geopiers® (Rammed aggregate piers)

Characteristic	Stone columns	Geopiers® (Rammed aggregate piers)
Construction		
Formation of cavity	Vibroflot	Drilling
Backfill	Crushed stone	Crushed stone
Backfill lift thickness	2 to 4 ft. (Barksdale and Bachus 1983, p. 20)	1 ft. (Fox and Cowell 1998)
Depth of installation possible	Up to ~ 100 ft.	Up to ~ 30 ft.
Column diameter	2 to 5 ft. (Barksdale and Bachus 1983, p. 13)	2 to 3 ft. (Fox and Cowell 1998)
Typical L/D Ratio (Length/Diameter)	5 to 30 (Geopier® Foundation Company)	2 to 4 (Geopier® Foundation Company)
Typical Spacing (on-centers)	4 times diameter (Geopier® Foundation Company)	1.5 to 2 times diameter (Geopier® Foundation Company)
Lift Thickness during Construction	5 to 10 feet (Geopier® Foundation Company)	8 to 12 inches (Geopier® Foundation Company)
Backfill densification	Vibroflot	Impact ramming with beveled tamper
Site condition after construction	Jetting, if used, causes water ponding at ground surface (Barksdale and Bachus 1983); ground heave (Observation)	Spoils from drilling must be removed (Observation)
Densification of clean sand to large radial distances	Effective	Not effective
Measured Design Parameter Values		
Aggregate friction angle	40 to 45 degrees (Barksdale and Bachus 1983, p. 158)	48 to 52 degrees (Fox and Cowell 1998; White 2002)
Response of matrix soil to construction	Complete remolding of soil during installation – formation of smear zone (Barksdale and Bachus 1983, p. 19); lateral earth pressure approximately represented by K_o conditions (Gaul 2001; White et al, 2002a)	Increase in lateral earth pressure to approximate K_p conditions (Lawton and Merry 2000; White et al, 2000; Gaul 2001; White et al, 2002; Handy et al, 2002)
Average SPT N-value in column	11 (Gaul 2001; White et al, 2002)	17 (Gaul,2001; White et al, 2002)
Stress concentration ratio	2 to 5 (Barksdale and Bachus 1983, p. 143)	4 to 45 (Lawton and Fox 1994; Lawton and Merry 2000; Hoevelkamp 2002)
Modulus of elasticity	600 ksf to 1,200 ksf	3,000 to 4,000 ksf (Wissmann et al, 2001)

Table 1 (Continued)

Characteristic	**Stone columns**	**Geopiers® (Rammed aggregate piers)**
Measured Design Parameter Values (Contd...)		
Typical unit cell loading	40 to 100 kips (Barksdale and Bachus 1983, p. 3)	30 to 150 kips for foundation support (Fox and Cowell 1998); as high as 200 kips for floor slab applications (Minks et al, 2001); as high as 800 kips for stability applications (Hall et al, 2002)
Ratio of applied stress required to initiate bulging (Geopiers®: stone column)	~ 4:1 (Gaul 2001)	
Ratio of Geopiers® rammed aggregate pier stiffness to stone column stiffness	~ 2 to 15 (Gaul 2001; White et al, 2002)	
Generalized Behavior		
Design stress during load test	100% to 150% of stone column design stress (Barksdale and Bachus 1983, p. 23)	150% of pier design stress (Fox and Cowell 1998)
Typical load transfer mechanism	End-bearing (Barksdale and Bachus 1983, p. 27)	Floating (Lawton and Fox 1994; Lawton et al, 1994; Fox and Cowell 1998; Lawton and Merry 2000; Wissmann et al, 2000; Wissmann et al, 2002)
Typical mode of deformation	Bulging (Barksdale and Bachus 1983, p. 27)	Bulging or tip stress (Wissmann et al, 2001c)
Effect of adjacent elements on propensity for bulging	More elements provides less propensity for bulging (Barksdale and Bachus 1983, p. 29)	More elements provides less propensity for bulging (Hoevelkamp 2002)
Effect of group on punching bearing capacity	Data Not Available	Bearing capacity of group ≥sum of bearing capacities of individual piers (Hoevelkamp 2002)
Typical Parameters for Design		
Density	100 to 200 pcf (Geopier® Foundation Company)	140 to 150 pcf (Geopier® Foundation Company)
Void Ratio	0.4 to 0.7 (Geopier® Foundation Company)	0.07 to 0.23 (Geopier® Foundation Company)
Typical Allowable Footing Bearing Pressure for Foundation Design	500 to 3000 psf	5000 to 7000 psf

Table 1 (Continued)

Characteristic	Stone columns	Geopiers® (Rammed aggregate piers)
Design Approaches		
Method of calculation of bulging stress	Cavity expansion theory (Hughes and Withers 1974; Mitchell 1981; Barksdale and Bachus 1983)	Cavity expansion theory considering rammed aggregate pier construction process (Hughes and Withers 1974; Mitchell 1981; Wissmann 2000)
Method of computing time rate of settlement using radial drainage	Combined vertical and radial flow using principle of stress concentration; account for smearing (Barksdale and Bachus 1983, pp. 69-74; Han and Ye 2001)	Combined vertical and radial flow using principal of stress concentration; no smearing (Han and Ye 2001; Wissmann et al, 2002; FitzPatrick and Wissmann 2002)
Method of computing settlement magnitude	Chart solution based on unit cell equilibrium method (Barksdale and Bachus 1983, pp. 42-46)	Upper zone/lower zone model – upper zone model incorporates unit cell equilibrium method (Lawton and Fox 1994; Lawton et al, 1994; Fox and Cowell 1998; Wissmann et al, 2000; Hoevelkamp 2002; Wissmann et al, 2002)
Method of computing bearing capacity of a group of elements	Terzaghi linear "lower bound" triangular block method (Barksdale and Bachus 1983)	Terzaghi linear "lower bound" triangular block method with shape correction factor (Barksdale and Bachus 1983; Wissmann et al, 2002)
Method of calculating increase in global stability	Weighted average of shear strength values including concept of stress concentration (Mitchell 1981, pp. 37-38; Barksdale and Bachus 1983, pp. 76-83)	Weighted average of shear strength values including concept of stress concentration (Mitchell 1981, pp. 37-38; Barksdale and Bachus 1983; FitzPatrick and Wissmann 2002)
Primary Use		
	Support for Extremely Flexible Structures (embankments, tanks, wood frame buildings) (Geopier® Foundation Company)	Support for Rigid, Semi-Rigid, AND Flexible Structures (All types of buildings, embankments, etc.) (Geopier® Foundation Company)

As part of this thesis, additional rows containing information on cost, schedule, and construction equipment required and crew sizes will be added to the above table. The finished table includes all technical, cost and schedule information necessary for comparing the two types of foundation systems.

History of research performed on Soil Nail Wall, Mechanically Stabilized Earth and Cast-in-Place Wall

Considerable research has been presented on the designing, construction, inspection and maintenance aspects of retaining structures such as soil nail wall, mechanically stabilized earth structure, etc., This literature review presents some considerations for wall selections as presented by researchers, and the limitations and advantages of few retaining structures.

Following items are considered when selecting earth retention systems (Hess et al, 1995; Cheney, 1990; Schnabel, 1990 and Munfakh, 1990)

1. Cut / fill application,
2. Soil Properties,
3. Ground water table,
4. Construction considerations such as schedule, availability of material, site accessibility, equipment availability, and labor considerations,
5. Estimated cost,
6. Tolerance to settlement and foundation conditions,
7. Availability of right of way,
8. Need for temporary excavation support system,
9. Average wall height and size of wall area,
10. Expected deflection,
11. Durability and maintenance,
12. Maintenance of traffic during construction,
13. Aesthetics,
14. Environmental concerns,

15. Politics, and
16. Tradition.

Information required at the time of wall selection is as follows:

1. Soil borings with strata identified,
2. Water table location,
3. Soil lab test reports, and
4. Horizontal and vertical alignment.

Highway Innovative Technology Evaluation Center (HITEC) in the papers 'Evaluation of The Iso Grid© Retaining Wall System' and 'Evaluating of SSL MSE PLUSTM Retaining Wall System' in Technical Evaluation Report (May, August 1999) provided typical wall designs, material details and an installation manual. It also highlighted the following limitations of Mechanically Stabilized Earth Walls (Figure 3):

1. MSE walls cannot be used where stray electrical currents are present,
2. Utilities cannot be placed within the select fill volume,
3. MSE walls cannot be used in regimes exposed to acidic run-off or industrial pollution characterized by low pH and high concentrations of chlorides and sulphates. Acidic runoff may corrode the straps and spoil the geo-textile filter fabric resulting in failure of the wall, and
4. MSE walls cannot be used in flood plain areas above potential scour depth. Running water can undercut the soil, thus weakening the friction between the straps and granular backfill which results in the failure of the system.

The advantages of MSE walls are as listed below:

1. wall system construction is relatively rapid and does not require specialized labor or equipment,
2. limited foundation preparation is required,
3. wall system is flexible and can accommodate relatively large total and differential settlements without distress,
4. reinforcement is light and easy to handle,
5. concrete facing panels permit greater flexibility in the choice of facing and architectural finishes, and
6. Since wall system is flexible, it is well - suited for applications in regions of high seismicity.

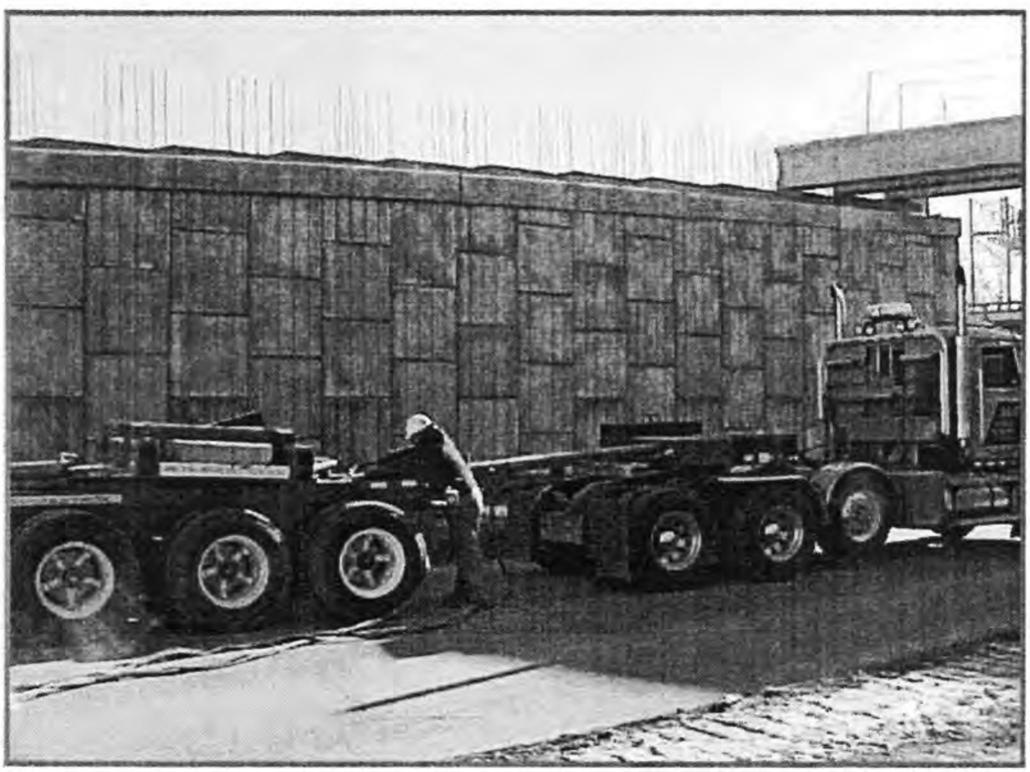

Figure 4. Mechanically stabilized earth retaining wall on I-235

The following is the summation of the limitations and advantages of the soil nail wall (Figure 4), presented in the French National Research Project on Soil Nailing: Clouterre (C. Plummelle et al, 1990) and the construction manual of Chance® Company:

Limitations:

1. Use limited to soils that are above the water table or that are drained. A high water table can corrode the nails and result in the failure of the system,
2. Use can be difficult or delicate in certain soil conditions – cohesionless sands, caving sands, soils containing pockets of water, soil containing high quantity of clay where the moisture content might increase after construction, and frost susceptible soils,
3. Soil nailing in very low shear strength soil may require a very high soil nail density, and thus be uneconomical,
4. Horizontal displacements may be greater than those associated with tieback construction, and therefore, may limit use adjacent to critical structures, and
5. Reinforcements may interfere with existing or future utilities.

Advantages:

1. Rapid Construction,
2. Soil Nailing is readily adaptable to otherwise difficult sites as long as no prior excavation work is needed. In particular, it allows structures to be built on slopes where access is difficult. Walls can also be built in segments, and if necessary, on a curve or with benches,
3. Competitive cost, and

4. The capacity of a screw anchor can be inferred by calculation after finding the torque required to install the anchor. This provides immediate feedback to determine if design requirements are being met in the field, and eliminates expensive and time-consuming load tests.

Soil Nailing technique is generally not recommended for organic and some clayey soils. This restriction is primarily empirical – based, and little data exists on deformations or stress induced in the nails or soil mass when the method is applied in these soil types. Oral et al, 1998 demonstrated that construction of soil nail walls in clayey soils is possible, at least for short-term excavation support.

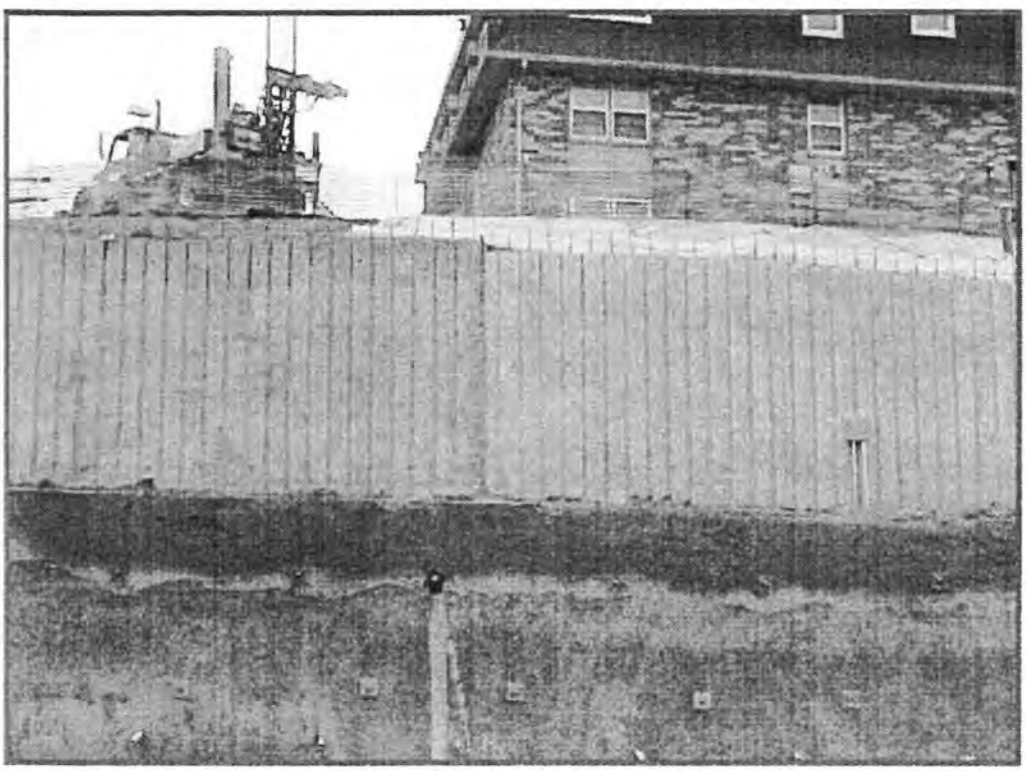

Figure 5. Soil Nail retaining wall on 1-235

1. JOBSITE VISITS

Introduction

Field visits to jobsites are very important to create a schedule and update the current schedules. They are also a very valuable source in finding out the productivity of the projects which are in progress. The productivity from these projects can be taken as a scale to predict the duration required by other projects and any other urban projects which might come up in the Iowa state.

Meetings attended

As a part of noting the changes in the start dates, potential discussions held on each project, meeting the contractors and to express any ideas and concerns, we attend numerous meeting like:

1. Wednesday's Iowa DOT – Contractor meetings, where they talk about all the contracts and the potential activities and concerns from each project. Attending this meeting provides us with valuable information and also allows us to express our views and concerns,
2. Thursday's Constuctability meeting: This gives us a heads-up on the staging and also the schedule which we may look at. While attending these meetings, we gain insight and work in conjunction with Iowa DOT in developing a staging which is efficient and has fewer conflicts with the schedules and the traffic, and
3. Pre-Con Meetings: The pre-con meetings provide the action plan and the tentative start and finish dates. They also might highlight the potential conflicts which have to be resolved during the construction process.

Jobsite visits

There are three most important points in jobsite visits:

1. Preliminary planning,
2. Visit, and
3. Using the data.

The most important aspect of jobsite visits is to note the progress, collect necessary data, and use the data for furthering the tasks of the project. Preliminary planning is important to understand the progress of the project, till date, and plan the visit accordingly. And during the visit, all the necessary data has to be acquired.

Preliminary planning: Detailed schedule

From the available plans, production rates and the meeting minutes from the numerous meetings attended, a detailed schedule for each project is established.

The detailed schedule highlights the critical activities and the milestones of the project. The detailed schedule is used to keep track of progress of the project. The detailed schedule is discussed with the contractor so that a better and efficient way to construct the project can be achieved.

Preliminary Planning: Field data collection forms

There are three kinds of field data collection forms used to collect and report the data. These forms have been designed to acquire data depending on the frequency of visits.

1. Field data collection form (Daily) : Figure 6
2. Field data collection form (Weekly) : Figure 7
3. Field data collection form (Official) : Figure 8

Field Data Collection Form (Field copy, Daily)

Project:
Date:
Time and duration of stay:
Observations:

Crew size:

Equipment:

Figure 6. Picture showing field data collection form (Daily Copy)

After the filed visit is completed, observations of the visit, crew size and equipment used will be noted. Any specific comments will also be taken as a note.

Field Data Collection Form (Field copy, Weekly)

Project:
Activity:
Date:
Time and duration of stay:
Expectations about the job with respect to last weeks observations:

Expectations about the job with respect to the schedule:

Observations:

Crew size:

Equipment:

Any specific note:

Figure 7. Picture showing field data collection form (Weekly Copy)

Prior to the field visit expectations about the progress with respect to last week's observance and updated schedule will have to be filled out. This enables proper analysis of the job and better anticipation of what has to be observed on the field and any new activity on the field can be picked up very fast. After the filed visit is completed, observations of the day, crew size and equipment used will be noted. Any specific comments will also be taken as a note.

Field Data Collection Form (Official Copy)

Name: ____________________ Date : ____________

Time and Duration of stay: ____________

Weather Conditions: ______________________________

Project: (   ) ______________________________

Activity 1: ______________________________

Location With Respect to the Plans: ______________________________
(E.g.: Station Points, activity ID)

Crew Size: ______________________________

Equipment: ______________________________

____

Observations: ______________________________

____

Work Progress with respect to last week: ______________________________

____

Work Progress with respect to the schedule: ______________________________

____

Any Specific observations: ______________________________

Note:
1) Please attach a copy of the plan of the job under consideration
2) Please attach a copy of the UPDATED* schedule with this form.
*3) UPDATED: Remarks and notes made on the field on the latest schedule available.
4) Please add sheets if you have more than one activity

____________________ ____________________

(AREA OF SPECIALIZATION) (SIGNATURE)

Figure 8. Picture showing field data collection form (Official Copy)

After a field visit, data is transferred from the field copy to an official copy which will be filed and stored for future reference. This form is more of a formal way of presenting the document and field observation to the group and who ever is concerned. It documents the duration of stay, weather conditions, person who visited the field, his observations and all the relevant data about the project.

Tasks that must be accomplished during field visits

The main tasks which have to be accomplished during a field visit are:

1. Discuss progress with project superintendent,
2. Discuss progress with DOT Inspectors,
3. Observe progress directly,
4. Compare actual progress with the schedule,
5. Take photographs (Figure 9), and
6. Fill out the field data forms.

Sufficient time has to be spent looking at each activity with the aid of plans and the available schedule. Field data forms have to be filled after going through the project progress and comparing it with the available schedule. Progress of the work and the number of working days charged from the date of previous visit and other queries can be discussed with the DOT inspector at the job site. Discuss progress with project superintendent gives an insight about the target dates and possible completion of activities and the project.

Sufficient (10 or more) photographs have to be taken, which enable, easy communication with the team who have not been to the field. The photographs have also to be documented for further reference. Photographs are a valuable source of visualization of the project. Good photographs highlight the work and the people at work. Equipment and other important activities have to be captured.

Figure 9. Picture showing a photograph taken on field

Using the data

Detailed schedules of each project will be updated every week with the help of the data collected from the field. The updated schedule (Figure 10) helps observers identify the most critical activities and monitor them every time. The delays in the project and the possible delay of the project can be noted. A potential delay can be identified at an early stage and can be rectified before a loss.

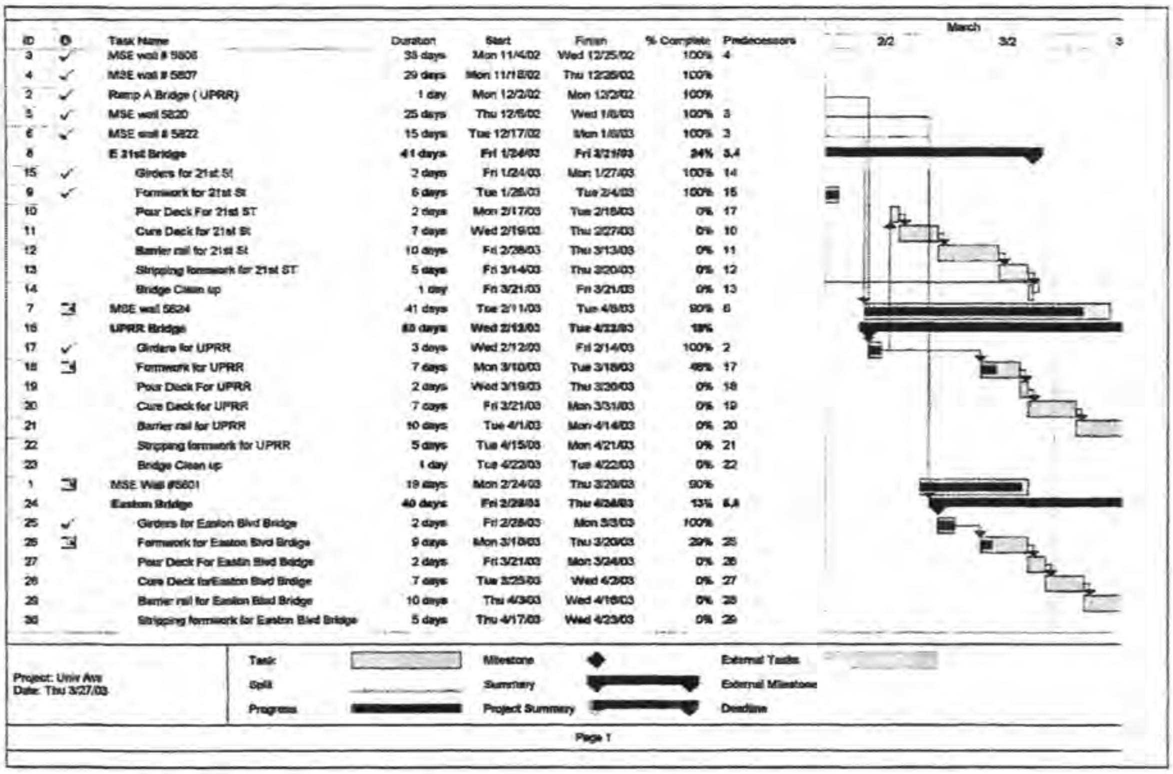

Figure 10. Picture showing the updated schedule after field visit

Productivity analysis

The data collected from the field is analyzed and productivity rates for different activities are established. As an example, the data collected on the duration for setting-up MSE wall panels at different projects has been shown in table 2. An analysis for determining the productivity rate for setting-up the MSE wall panels follows the table. Similarly productivity and cost estimates can be developed for all the activities based on the data collected from the field.

Table 2. Example of productivity rate analysis

Wall #	5801	5808	5807	5820	5822	5824
Sq m	540	398.2	363.2	740.3	135	1149
Duration	30	8	20	33	27	70

Approximately 100 Sq m of MSE wall can be setup in 5 days.

Or 25 panels with dimensions of 5'X5' can be setup in a day.

Average Crew: 4

Equipment: 1 Crane.

2. RAMMED AGGREGATE PIERS

Rammed aggregate piers also known as Geopier®, is a foundation support system for soft soils and can be used as an alternative to deep piles, caissons, over-excavation and replacement filling. A Geopier® element is a dense aggregate pier constructed in a pre-excavated cavity.

Principle

Geopier® is a short aggregate pier having a typical length/diameter ratio of 2 to 6. These are constructed in a pre excavated shaft by dynamic compaction of well graded aggregate in various lifts. This dynamic compaction Increases the lateral earth pressure and stress concentration ratios in the surrounding soils. Good aggregate interlock in the pier results in higher friction angle, thus increasing the load carrying capacity of both Geopier® and the resulting soil matrix.

Geopiers® are also called floating foundations, as the load from the superstructure is transmitted to the adjoining soils and the stresses at tip of the pier are minimal. Since the Geopier® and soil matrix act as a single unit; settlements are reduced to a great extent. Apart from reducing the settlements to a considerable amount, they act also as drains.

Components of Rammed aggregate Pier (Figure 11)

Original Ground

This is the original ground surface which is weak and can not support the load of the foundation and the superstructure at the site.

Foundation

The foundation is a reinforced or a non-reinforced concrete pad used to provide stability, level and consistent surface to the superstructure.

Superstructure

This is the designed load which has to be carried by the Geopier®. The superstructure can be a foundation for a building, retaining walls, etc.

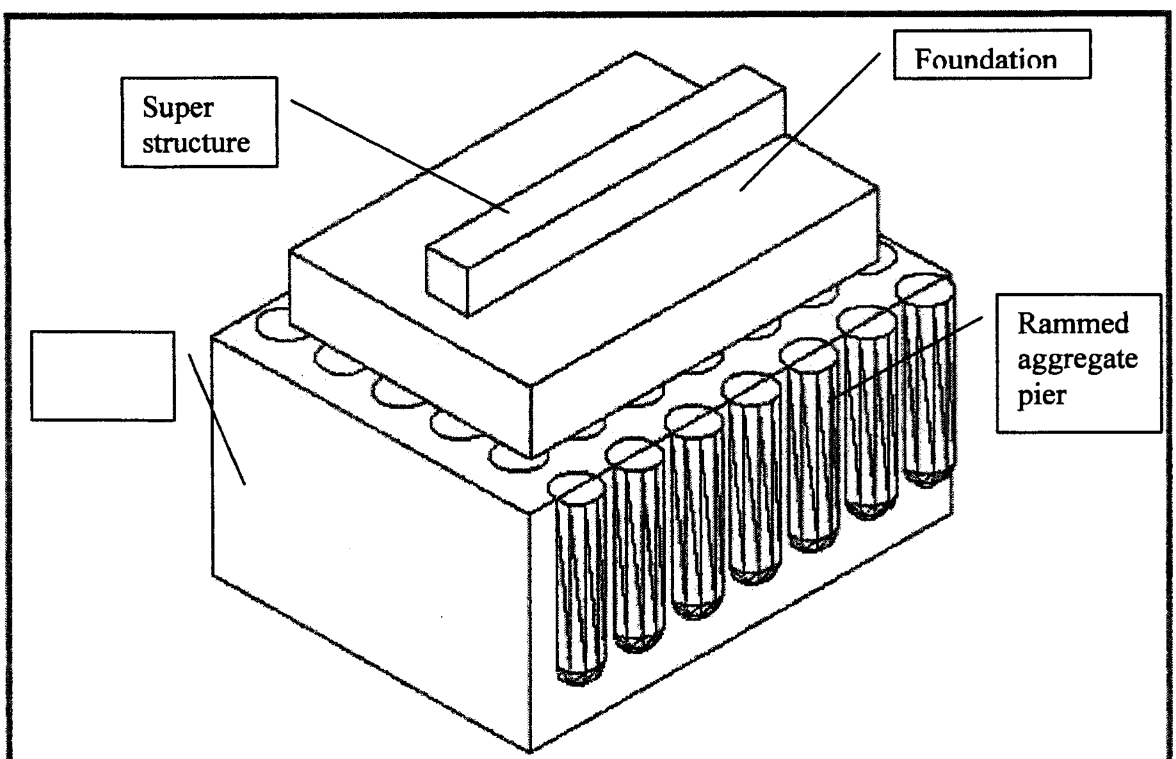

Figure 11. Picture showing the components of Rammed aggregate pier

Geopier®

This is a short aggregate pier made of clean base course stone. The Geopier® stiffens the surrounding soil, thus providing enough strength to uphold the loads on the soil created by the foundation and the superstructure.

Construction Process

Geopier® is constructed by building successive layers of densely compacted aggregate in a drilled or excavated shaft. Nominal twelve inch thick layers of uniformly graded aggregate are placed in the excavation and impacted with hydraulic rams at pressures which compact the aggregate layer and densifies the surrounding soil layer, resulting in improved load resistance for the combined pier-soil system. At grade level, footings or caps are cast on one or more piers to support the structure.

Steps

1. Drill a cavity in the existing ground with an auger drill (Figure 12-1).
2. Dump a small volume of clean stone (open graded) at the bottom of the excavated shaft (Figure 12-2).
3. Using a tamper that imparts impact ramming energy pre-stresses and pre-strains the soil to create a bulb at the bottom of the hole (Figure 12-3).
4. Well-graded highway base course stone is placed in the shaft in one-foot lift thickness and is compacted as in step 3 (Figure 12-4).
5. Step 4 is repeated until the shaft is filled.

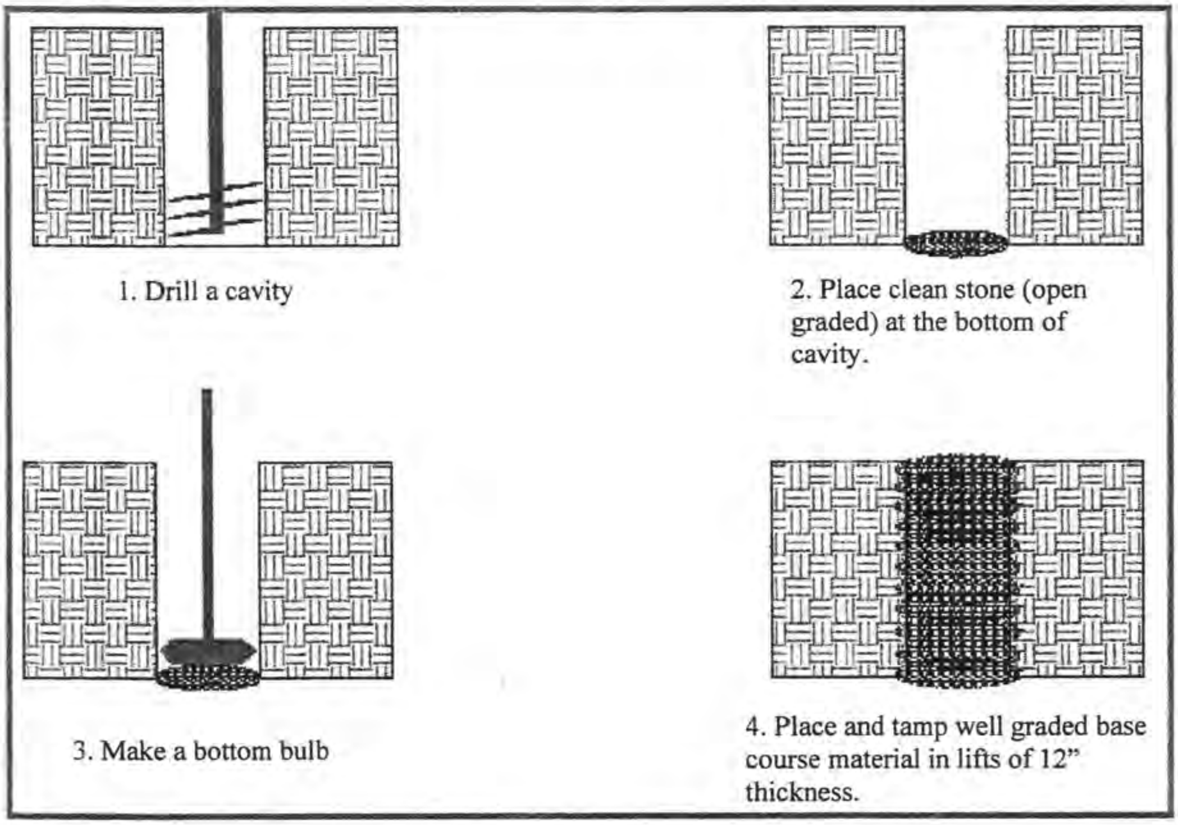

Figure 12. Picture showing the construction process of Rammed aggregate pier

Advantages

1. Compared to Stone columns Geopier® are less expensive and quicker to install.
2. Often there is less Settlement with Geopier® compared to shallow Foundations.
3. Provides an alternative to over excavation and replacement of soil.
4. Compared to Stone Columns Geopier® elements resist much greater amounts of foundation stresses due to higher stiffness.
5. Geopier® elements can resist uplift forces caused by earthquakes or wind when a steel anchor cage is added.

Disadvantages

1. They cannot be installed in caving soils or sands with a high ground water table.
2. They rely on the lateral support of the adjacent soils, which if weak (e.g. peat), may result in the failure of Geopier®.

Applications

The Geopier® is applicable in any situation where a significant increase in stiffness and/or shearing strength of a soil mass will improve engineering performance. This includes:

1. Spread footings -- Increase in bearing capacity and reduction of settlement
2. Floor slabs / mats -- Improve sub-grade uniformity and reduce settlements
3. Slopes -- Increase in factor of safety for stability
4. Excavations -- Increase in temporary support

Construction of Geopier® on 35th Street in West Des Moines

Geopier® (Figure 13) system was constructed to build a cast in place retaining wall on top of it at south side of 35th street Bridge over I-235. The productivity data is shown in the table 3.

Table 3. Productivity analysis of Rammed aggregate piers

Equipment	Crew	Production Rate
1. Auger Drill (Figure 14) 2. Skid loader (Figure 15) 3. Tamper (Figure 16)	3 People	1 Rammed aggregate pier (5 meters Deep) takes 15 min.

Figure 13. Picture showing the completed Rammed aggregate pier

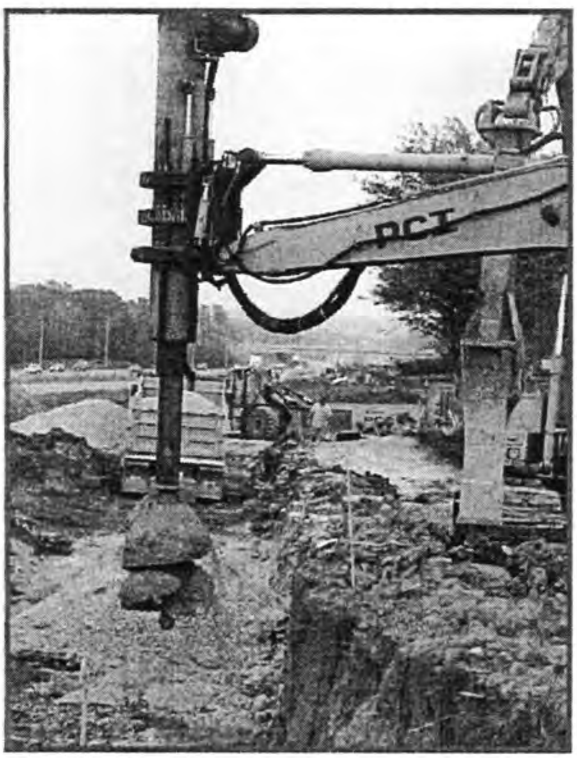

Figure 14. Picture showing the Auger Drill

Figure 15. Picture showing a Skid Loader with a special Bucket

Figure 16. Picture showing a Tamper

Problems Encountered and Solutions

Water / wet soil on the construction site

Because of rain and poor drainage facility, the site became unsuitable for construction of Geopier® because of loose soil which might collapse after excavating the shaft.

Solution: Initially the work was being done at the south end of the proposed work place. But the material and the equipment had to be relocated to the north end of the proposed area of the project. Figure 17 shows a schematic representation of the work sequence.

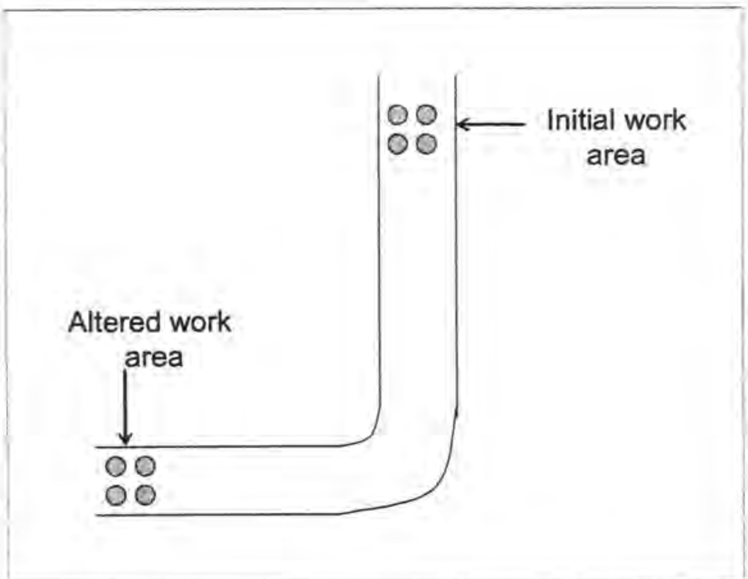

Figure 17. Picture showing work sequence at 35th St West Des Moines on I-235

Narrow working space

The construction site is located right next to the parking area of an apartment complex. That parking area could not be utilized for construction. The other side of the construction site is steep slope. Therefore, the only space available for construction was about 10 feet wide. This narrow working space limited the movement of equipment and conveyance of material, thus slowing down the construction procedure.

Gas pipeline

There was a gas pipe line in the middle of the work place, which could not be removed. So the work had to be carefully executed which reduced the speed and efficiency of the crew.

Cost Estimate of Rammed Aggregate Pier

A conceptual cost estimate of rammed aggregate piers has been shown in Table 4 and table 5. The calculations are based on a real site project, for which, a cost estimate was available. The original estimate has been used to crosscheck the conceptual estimate.

The following estimate has been developed for 175 piers which have an average depth of 5 meters.

The values have been rounded off to the nearest whole digit.

Table 4. Initial data available for calculating the cost of Rammed aggregate pier

No. of piers	175 + 1 test pier
Total duration of work:	9 Days (8hr working days)
Quantity of rock	1320 ton
Total Working Hours (Man hours)	9x8 x 3 (Crew) = 216 hours (Say 230 hours)
Cost of aggregate	$ 10/ ton
Skid loader	$ 50/ hr
Drill Rig	$ 100 / hr
Tamper	$ 100 /hr
Cost of operator	$40 / hr

Table 5. Calculation for obtaining the cost of Rammed aggregate pier

	Quantity	Unit	Cost/Unit	Total Cost
Aggregate	1320	ton	$10	13,000
Equipment	80	hr	$50	4,000
Equipment	80	hr	$100	8,000
Equipment	80	hr	$100	8,000
Labour (Crew size = 3)	230	hr	$40	9,000
Construction Cost				42,500
Margin (20% of total Cost)	LS	LS	LS	11,500
Design (20% of total Cost)	LS	LS	LS	11,500
Final Cost				65,500

Additional Cost has to be added for:

1) Mobilization

2) Construction Survey

3) Verification /Testing

The percentage involved in margin takes into account all the company overheads, profits, liability, insurance and any other extra charges required to maintain the project.

Calculation for Aggregate:

Volume of Aggregate per pier:

$\prod \times r^2 \times h = 3.14 \times 1.5^2 \times 17$

= 120 Cuft

Density of limestone = 125lb/Cuft

Wt of stone = 120 x 125 Lbs
= 15000 lbs
= 7.5 Tons

Therefore

Volume for 176 piers:

176 x 7.5 = 1320 Tons.

Add an additional 30% to account for wastage.

To validate the results obtained, the above estimate was discussed with a real time estimator from PCI (Mr. Doug Clark).

3. STONE COLUMNS

Stone column (vibro-replacement) is a process of improving the load bearing capacity of weak soils by reinforcing them with dense compacted aggregate material. This is a deep foundation system which can be used as an alternative to steel piles, dynamic compaction, vibro compaction, deep soil mixing and over-excavation and replacement methods.

Principle

The stone columns (Figure 18) are built by displacing the earth laterally and filling the space by compacted well graded aggregate. The stone columns thus formed have high load bearing capacity and high angle of internal friction, which results in reduction of settlements in the adjoining soils. The loads from the top of the stone columns are transferred to the stiff layer underneath. Apart from transmitting the loads to a stable layer, stone columns act also as drains.

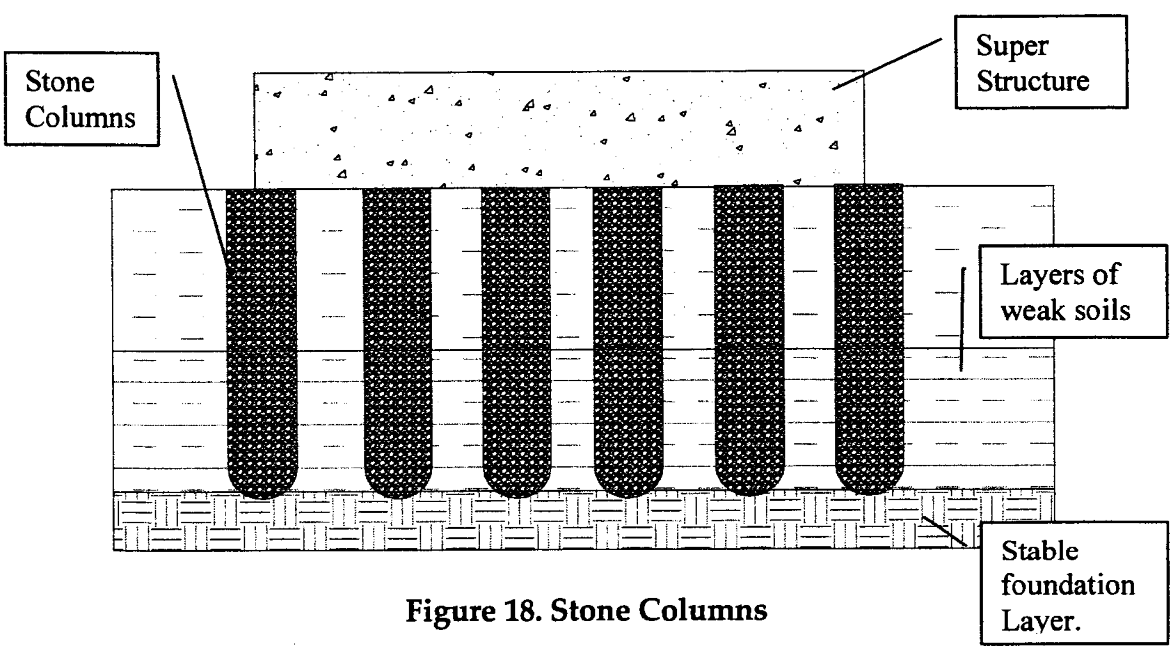

Figure 18. Stone Columns

Components of Stone Column

Stable Foundation Layer:

This is a layer which has more stability and can take more loads than the top layers of earth can. The load from the foundation and superstructure are transmitted to this layer by stone columns.

Weak soil layers:

These are the layers of weak soils that can not support the superimposed loads.

Stone Columns:

These are long vertical shaft columns filled with well graded aggregate. They transfer the load to a stable foundation layer and also make the adjacent soils stiffer. The stresses induced in the soils increases the load bearing capacity of the soil matrix.

Super structure:

This is the designed load which has to be carried by the stone columns. The superstructure can be a foundation for a building, retaining walls, etc.

Construction Process

Stone columns are constructed by displacing the earth laterally, by a special vibratory probe called Vibroflot. There are two processes of constructing stone columns. They are:

1. Vibro-replacement.
2. VIbro- displacement.

In Vibro-replacement process water under high pressure is used to open a hole for the vibroflot to penetrate the top soil surface. And in Vibro-displacement process air under high pressure is used to open a hole for the probe to penetrate. Weight of the follower tubes and the vibration of the probe aid in advancing the probe further into the soil.

Steps (Figure 19)

1. With the aid of water or air under high pressure, the vibroflot penetrates to the designed depth under its own weight.
2. Once the desired depth is achieved, a small quantity of well graded material is placed at the bottom of the shaft, through a special provision in the vibroflot (Figure 21). This method of placing the aggregate through the vibroflot (Figure 20) is sometimes referred as bottom feed.
3. By moving the vibrator in small steps up and down and by the horizontal forces of the vibrator, the back fill material is compacted and forced into the surrounding soil. The density of the placed aggregate is determined by the ammeter readings obtained.
4. Aggregate is placed and compacted in layers of 1 to 4 feet. Steps 2 and 3 are repeated till the shaft is filled up to the level of original earth.

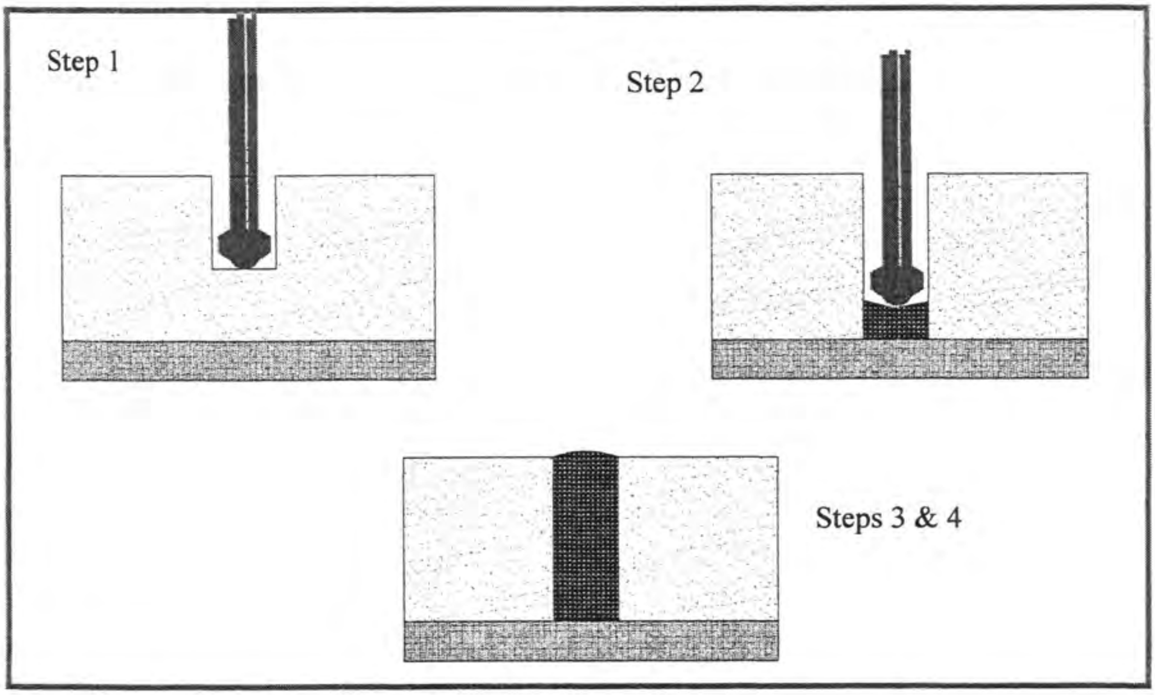

Figure 19. Stone Column - Construction process

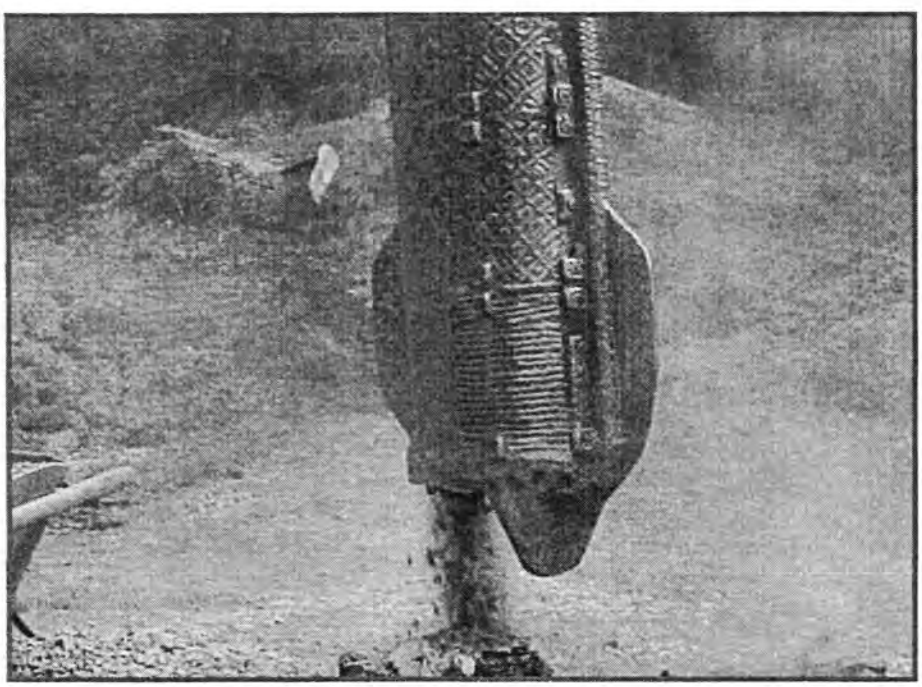

Figure 20. Tip of the vibroflot with the tube releasing aggregate

Figure 21. Picture showing the Vibroflot tip and the tube for feeding the aggregate

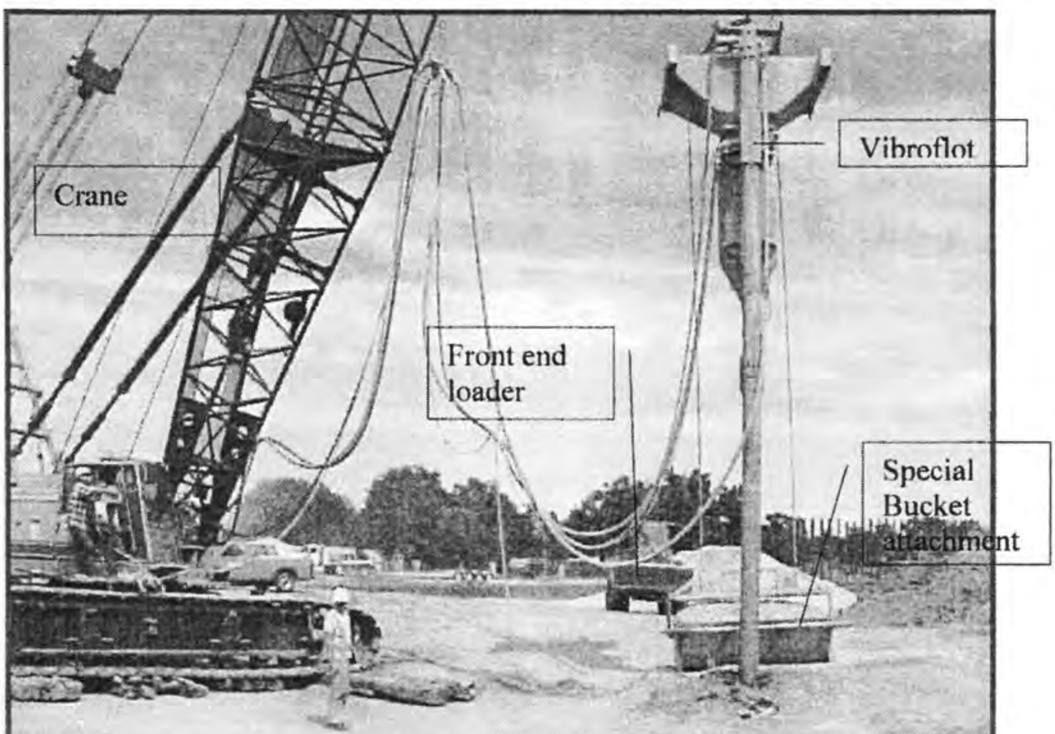

Figure 22. Picture showing the equipment for constructing Stone Columns

Table 6 describes the productivity rate, crew size and equipment needed for the construction of Stone Columns.

Table 6. Productivity analysis of Stone Columns

Equipment (Figure 22)	Crew	Production Rate
1. Vibroflot 2. Crane 3. Front end loader 4. Hydraulic pump for operating the Vibroflot.	4 People	1 Stone column (10 meters Deep) – 30 mins.

Advantages

1. They cost less than steel piles or over excavation.
2. They are quicker to install than steel piles and over excavation methods.
3. They act as vertical drains.
4. They can be placed in caving soils. Where as Geopier® are difficult to place in caving soils.
5. Construction is possible in rain, thus facilitating the progress of construction in wet weather.

Disadvantages

1. Settlement of soils is more compared to Geopier®.
2. Settlement of soils takes place at a slower pace compared to Geopier®.
3. They have less load carrying capacity than Geopier®.
4. Large ponds of water are created at the site, if wet process is used, making the site unusable until the water is drained out.

Possible Obstructions to construction

Obstructions to construction of stone columns can be:

1. The vibratory probe can be misdirected or meet refusal during penetration on in-situ debris that has a maximum particle dimension of 15-20 cm.
2. Pre-drilling is usually required through dense or hard soil zones to provide probe access to other layers requiring treatment. Pre-drilling costs are typically compensated by increased rate of stone column production.

Cost Estimate of Stone Column

A conceptual cost estimate for Stone Columns has been shown in Table 7. The calculations are based on a real site project, for which, a cost estimate was available. The original estimate has been used to crosscheck the conceptual estimate.

The following estimate has been developed for 454 Stone Columns which have an average depth of 12 meters and the total depth of Stone Columns placed is 5509 meters. The values have been rounded off to the nearest whole digit.

Table 7. Calculation for obtaining the cost of Stone Columns

Item	*QTY*	*Unit*	*Unit Cost*	*Total Cost*	*Notes*
No of Columns	454	Each			
Quantity of Rock	8900	tons	$10	$89,000	
Duration of work	40	days			8hr working days
Crew size	4				
Total man hours	1280	hrs	$40	$51,000	4*8*40
Equipment	4	Each			
Equipment Hours	1280	hrs	$100	$128,000	4*8*40
		Construction Cost		$268,000	
		Designing Cost (20%)		$54,000	
		Magin (20%)		$54,000	
BASE Cost of Project				$376,000	
		Mobilization		$15,000	
		Construction Survey		$7,500	
		Verification Testing		$45,000	
Bid Price				$443,500	

Additional Days have been added for Mobilization

Equipment Used

1. Front end Loader (A bulldozer with front attachment)
2. Crane
3. Vibroflot
4. Hydraulic pump for operating the Vibroflot

The percentage involved in margin takes into account all the company overheads, profits, liability, insurance and any other extra charges required to maintain the project.

Calculation for aggregate

$V = \prod \times r^2 \times h$

$= 3.14 \times (.455)^2 \times 5509$

= 3583 Cum

Density of limestone = 125 lb/Cuft

= 2.25 Tons/Cum

Qty of Rock = 2.25 • 3583 Tons

= 8062 Tons

Add 10% wastage

= 8062 x 1.1 Tons

= 8870 Tons

≈ 8900 Tons

4. COMPARISON BETWEEN FOUNDATION SYSTEMS

A revised comparison which includes information on required crew size, schedule, cost, construction equipment and material needed for the selection of the most favorable foundation system for a given condition has been provided in table 8.

This table includes all technical, cost and schedule information necessary for comparing the two types of foundation systems.

Comparison has been made between the foundation systems on per unit basis. Cost and schedule information has been provided, for placing each unit of the desired foundation system.

Table 8. Revised comparison of Stone Columns and Geopiers® (Rammed aggregate piers)

Characteristic	Stone columns	Geopiers® (Rammed aggregate piers)
Construction		
Formation of cavity	Vibroflot	Drilling
Backfill	Crushed stone	Crushed stone
Backfill lift thickness	2 to 4 ft. (Barksdale and Bachus 1983, p. 20)	1 ft. (Fox and Cowell 1998)
Depth of installation possible	Up to ~ 100 ft.	Up to ~ 30 ft.
Column diameter	2 to 5 ft. (Barksdale and Bachus 1983, p. 13)	2 to 3 ft. (Fox and Cowell 1998)
Typical L/D Ratio (Length/Diameter)	5 to 30 (Geopier® Foundation Co.)	2 to 4 (Geopier® Foundation Co.)
Typical Spacing (on-centers)	4 times diameter (Geopier® Foundation Co.)	1.5 to 2 times diameter (Geopier® Foundation Co.)
Lift Thickness during Construction	5 to 10 feet (Geopier® Foundation Co.)	8 to 12 inches (Geopier® Foundation Co.)
Backfill densification	Vibroflot	Impact ramming with beveled tamper
Site condition after construction	Jetting, if used, causes water ponding at ground surface (Barksdale and Bachus 1983); ground heave (Observation)	Spoils from drilling must be removed (Observation)
Densification of clean sand to large radial distances	Effective	Not effective
Construction Cost, materials and equipment		
Crew	*4*	*3*
Duration	*30 minutes per 10 meters*	*15 minutes per 5 meters*
Cost†	*$600 Each (Average depth: 12m)*	*$250Each (Average depth: 5m)*
	$50 - $ 100 per meter	*$50 - $100 per meter*
Equipment Used	*Front end loader*	*Drill Rig*
	Crane	*Skid loader*
	Vibroflot	*Tamper*
	Hydraulic pump	
Material Used	*1.5" Clean Stone*	*1" – 1.5" Clean Stone*

Table 8 (Continued)

Characteristic	**Stone columns**	**Geopiers® (Rammed aggregate piers)**
Measured Design Parameter Values		
Aggregate friction angle	40 to 45 degrees (Barksdale and Bachus 1983, p. 158)	48 to 52 degrees (Fox and Cowell 1998; White 2002)
Average SPT N-value in column	11 (Gaul 2001; White et al, 2002)	17 (Gaul 2001; White et al, 2002)
Response of matrix soil to construction	Complete remolding of soil during installation – formation of smear zone (Barksdale and Bachus 1983, p. 19); lateral earth pressure approximately represented by Ko conditions (Gaul 2001; White et al, 2002a)	Increase in lateral earth pressure to approximate Kp conditions (Lawton and Merry 2000; White et al, 2000; Gaul 2001; White et al, 2002; Handy et al, 2002)
Stress concentration ratio	2 to 5 (Barksdale and Bachus 1983, p. 143)	4 to 45 (Lawton and Fox 1994; Lawton and Merry 2000; Hoevelkamp 2002)
Modulus of elasticity	600 ksf to 1,200 ksf	3,000 to 4,000 ksf (Wissmann et al, 2001)
Typical unit cell loading	40 to 100 kips (Barksdale and Bachus 1983, p. 3)	30 to 150 kips for foundation support (Fox and Cowell 1998); as high as 200 kips for floor slab applications (Minks et al, 2001); as high as 800 kips for stability applications (Hall et al, 2002)
Ratio of applied stress required to initiate bulging (Geopiers®: stone column)	~ 4:1 (Gaul 2001)	
Ratio of Geopiers® rammed aggregate pier stiffness to stone column stiffness	~ 2 to 15 (Gaul 2001; White et al, 2002)	
Generalized Behavior		
Design stress during load test	100% to 150% of stone column design stress (Barksdale and Bachus 1983, p. 23)	150% of pier design stress (Fox and Cowell 1998)
Typical load transfer mechanism	End-bearing (Barksdale and Bachus 1983, p. 27)	Floating (Lawton and Fox 1994; Lawton et al, 1994; Fox and Cowell 1998; Lawton and Merry 2000; Wissmann et al, 2000; Wissmann et al, 2002)
Typical mode of deformation	Bulging (Barksdale and Bachus 1983, p. 27)	Bulging or tip stress (Wissmann et al, 2001c)
Effect of adjacent elements on propensity for bulging	More elements provides less propensity for bulging (Barksdale and Bachus 1983, p. 29)	More elements provides less propensity for bulging (Hoevelkamp 2002)

Table 8 (Continued)

Characteristic	**Stone columns**	**Geopiers® (Rammed aggregate piers)**
Generalized Behavior (Contd...)		
Effect of group on punching bearing capacity	Data Not Available	Bearing capacity of group ≥sum of bearing capacities of individual piers (Hoevelkamp 2002)
Typical Parameters for Design		
Density	100 to 200 pcf (Geopier® Foundation Co.)	140 to 150 pcf (Geopier® Foundation Co.)
Void Ratio	0.4 to 0.7 (Geopier® Foundation Co.)	0.07 to 0.23 (Geopier® Foundation Co.)
Typical Allowable Footing Bearing Pressure for Foundation Design	500 to 3000 psf	5000 to 7000 psf
Design Approaches		
Method of calculation of bulging stress	Cavity expansion theory (Hughes and Withers 1974; Mitchell 1981; Barksdale and Bachus 1983)	Cavity expansion theory considering rammed aggregate pier construction process (Hughes and Withers 1974; Mitchell 1981; Wissmann 2000)
Method of computing time rate of settlement using radial drainage	Combined vertical and radial flow using principle of stress concentration; account for smearing (Barksdale and Bachus 1983, pp. 69-74; Han and Ye 2001)	Combined vertical and radial flow using principal of stress concentration; no smearing (Han and Ye 2001; Wissmann et al, 2002; FitzPatrick and Wissmann 2002)
Method of computing settlement magnitude	Chart solution based on unit cell equilibrium method (Barksdale and Bachus 1983, pp. 42-46)	Upper zone/lower zone model – upper zone model incorporates unit cell equilibrium method (Lawton and Fox 1994; Lawton et al, 1994; Fox and Cowell 1998; Wissmann et al, 2000; Hoevelkamp 2002; Wissmann et al, 2002)
Method of computing bearing capacity of a group of elements	Terzaghi linear "lower bound" triangular block method (Barksdale and Bachus 1983)	Terzaghi linear "lower bound" triangular block method with shape correction factor (Barksdale and Bachus 1983; Wissmann et al, 2002)
Method of calculating increase in global stability	Weighted average of shear strength values including concept of stress concentration (Mitchell 1981, pp. 37-38; Barksdale and Bachus 1983, pp. 76-83)	Weighted average of shear strength values including concept of stress concentration (Mitchell 1981, pp. 37-38; Barksdale and Bachus 1983; FitzPatrick and Wissmann 2002)

Table 8 (Continued)

Characteristic	**Stone columns**	**Geopiers® (Rammed aggregate piers)**
Primary Use		
	Support for Extremely Flexible Structures (embankments, tanks, wood frame buildings) (Geopier® Foundation Co.)	Support for Rigid, Semi-Rigid, AND Flexible Structures (All types of buildings, embankments, etc.) (Geopier® Foundation Co.)

Note:

† Only the base construction cost has been indicated. Additional cost has to be accounted for mobilization, verification testing, construction survey, design, and margin for the contractors.

5. MECHANICALLY STABILIZED EARTH WALL

A segmental, pre-cast facing mechanically stabilized earth wall employs metallic (strip or bar mat) or geo-synthetic (geo-grid or geo-textile) reinforcement that is connected to a pre-cast concrete or prefabricated metal facing panel to create a reinforced soil mass.

Principle

The reinforcement is placed in horizontal layers between successive layers of granular soil backfill. Each layer of backfill consists of one or more compacted lifts. A free draining, non-plastic backfill soil is required to ensure adequate performance of the wall system. For walls reinforced with metallic strips, load is transferred from the backfill soil to the strip reinforcement by shear along the interface. For walls with ribbed strips, bar mats, or grid reinforcement, load is similarly transferred but an additional component of strength is obtained through the passive resistance on the transverse members of the reinforcement. Metallic galvanized reinforcement and high modulus geo-synthetic reinforcement, which are relatively inextensible, require less deformation to mobilize shear strength as compared to geo-textiles and lower modulus geo-grids. Facing panels are typically square, rectangular, or hexagonal in shape and are up to 4.5 m^2 in area.

Components of MSE Wall

The following are the components of MSE wall and their functions (Figure 23):

Original Ground

This is the existing ground surface at the site.

Foundation

The Foundation is a non-reinforced concrete pad used to provide a level, consistent surface at the proper grade to place the panels.

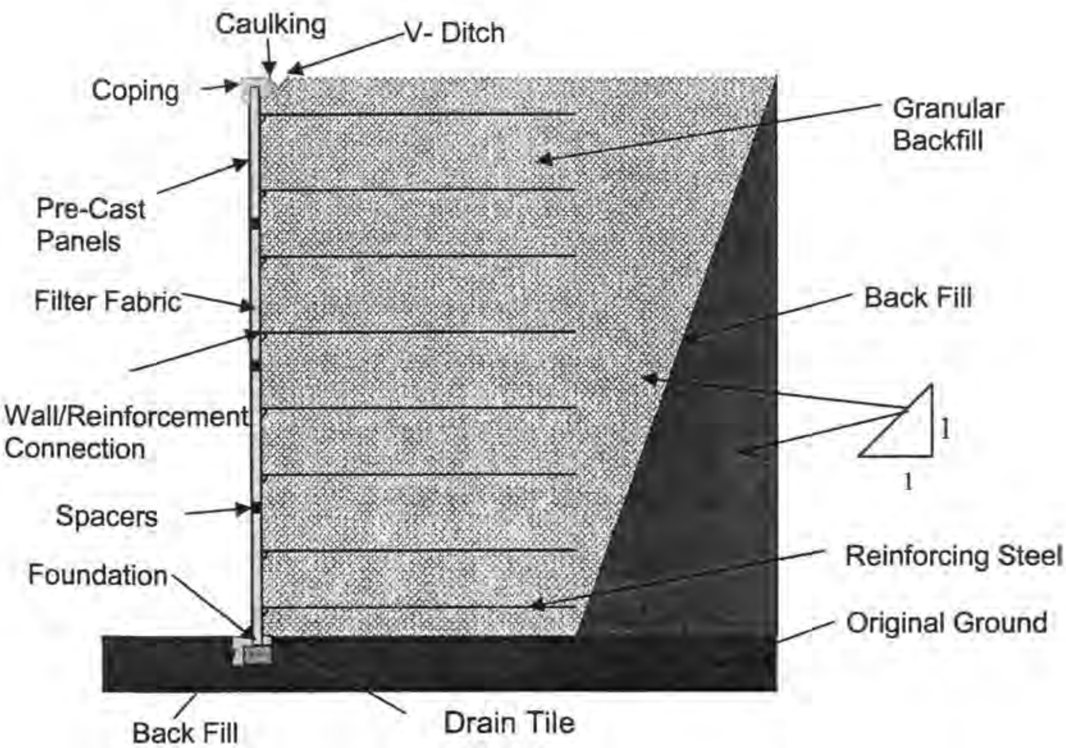

Figure 23. Picture showing the components of Mechanically Stabilized Earth (MSE) Retaining wall

Wall Facing Panel

Wall Facing panels or panels are used to hold the soil in position at the face of the wall. The panels are typically concrete but they can be metal, wood block, mesh or other material.

Soil Reinforcement

Soil reinforcement holds the wall facing panels in position and provides reinforcement for the soil. The soil reinforcement can be strips, grids, or mesh. The reinforcement can be made of steel, an inextensible material or polymers, an extensible material. A minimum reinforcement length of 0.7 H or more is recommended.

Spacers

Wall panel spacers are typically ribbed elastomeric or polymeric pads. They are inserted between panels to help provide the proper spacing. Proper spacing keeps the panels from having point contact and spalling the concrete.

Select Backfill

Select backfill is the fill that meets the gradation, corrosion, unit weight, internal friction angle and any other requirements of the specifications.

Filter Fabric

A geo-textile filter fabric is used to cover the joint between panels. It is placed on the backside of the panels. This keeps the soil from being eroded through the joints and allows any excess water to flow out.

Wall/Reinforcement Connection

This is where the connection is made between the wall facing panel and the soil reinforcing.

Coping

The coping is used to tie in the top of the wall panels and to provide a pleasing finish to the wall top. It can be cast-in-place or prefabricated segments.

V-Ditch

The V-ditch is Made of Concrete and is used to prevent the Seepage of Water. This also collects water and transfers it to the drain.

Backfill

Back fill is the backfill that is allowed in normal embankment construction.

Construction Process

The construction sequence is typically as follows:

1. The site is cleaned and made Suitable for construction (Figure 24).
2. Excavation for foundation (Figure 25).
3. The foundation is placed. The concrete is allowed to cure a minimum of 12 hours before any panels are placed (Figure 26).
4. The first row of panels is placed on the Foundation and braced (Figure 27).
5. An adhesive is used to hold the filter fabric across all of the panel joints. The adhesive should be applied on the panel next to the joints then the filter fabric is placed over the joint.
6. The select backfill is then placed and compacted to the level of the first row of connections. A drain tile is placed at the bottom of the MSE wall panel, near the top of the footing to allow free drainage of water to a storm sewer (Figure 28).
7. The first row of connections/wall reinforcement is placed and a six inch select Backfill is placed and compacted over the reinforcement. Backfill is placed with a slope of 1:1 as the wall rises up. Theoretically the interface between random backfill and granular backfill could be vertical. However, a 1:1 slope

works better because it prevents random backfill from falling into granular backfill and contaminating it (Figure 29).

8. Wall connections are placed and the select backfill is placed in 6″ layers untill the top of the panel (Figure 30).
9. Then another row of wall panels is placed with the proper batter. Place fill in 6″ lifts to reinforcement and connect and tighten the reinforcement. Ensure that the filter fabric does not wrinkle as more granular fill is placed against the wall elements (Figure 31).
10. Repeat step 9 until the top of the wall is reached. As soon as practical the front of the wall should be backfilled. This should occur prior to reaching the top of the wall (Figure 32).
11. The coping is then placed on the top of the wall (Figure 33).
12. The V-ditch is then placed beside the Coping. The Wall is finished when the V-ditch is finally completely (Figure 34). A fabric is placed between coping and V-Ditch to reduce the friction between them.
13. The wall is cleaned and the work is finished.

[redacted]

Figure 24. Picture showing step 1 of the construction process of MSE wall

Figure 25. Picture showing step 2 of the construction process of MSE wall

Figure 26. Picture showing step 3 of the construction process of MSE wall

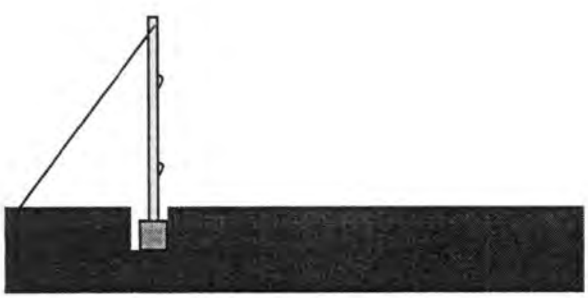

Figure 27. Picture showing step 4 of the construction process of MSE wall

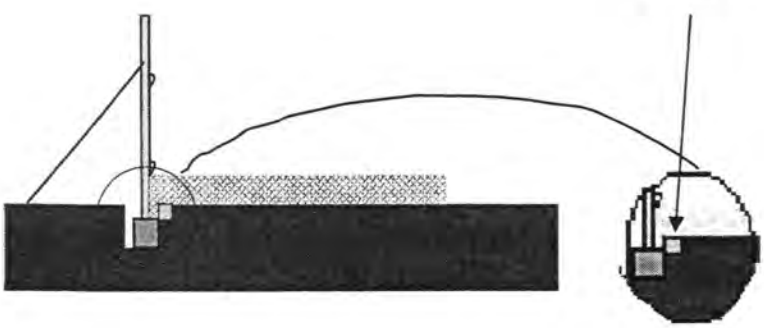

Figure 28. Picture showing step 6 of the construction process of MSE wall

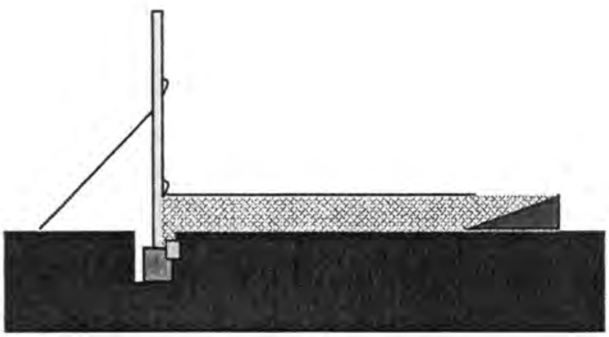

Figure 29. Picture showing step 7 of the construction process of MSE wall

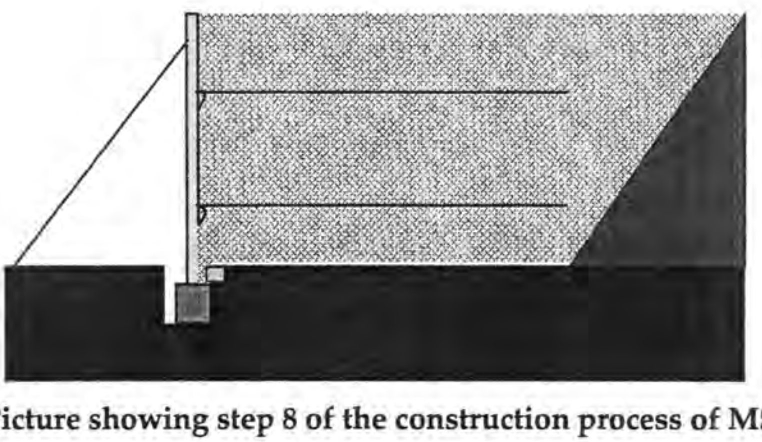

Figure 30. Picture showing step 8 of the construction process of MSE wall

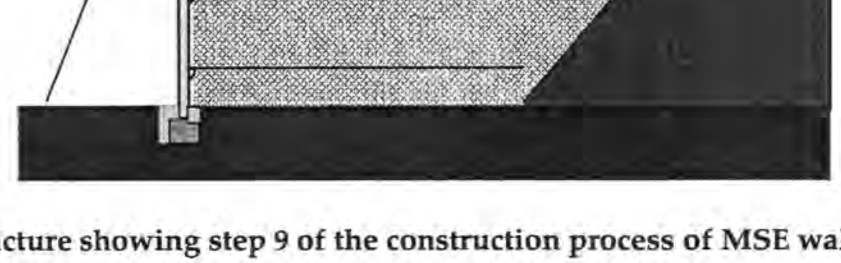

Figure 31. Picture showing step 9 of the construction process of MSE wall

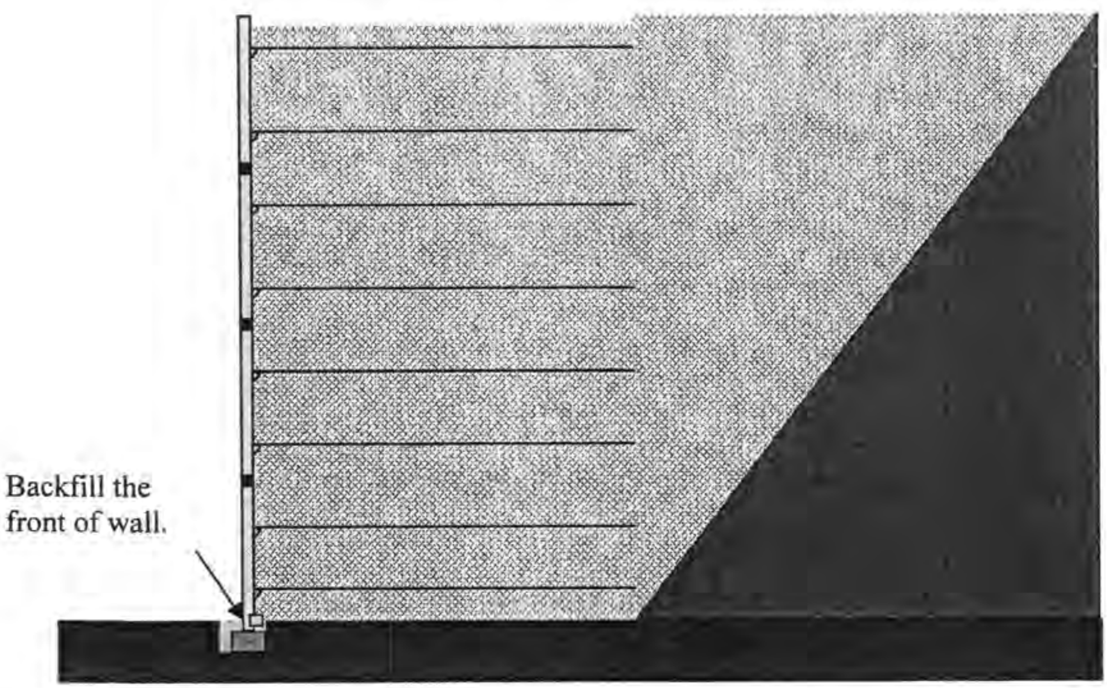

Figure 32. Picture showing step 10 of the construction process of MSE wall

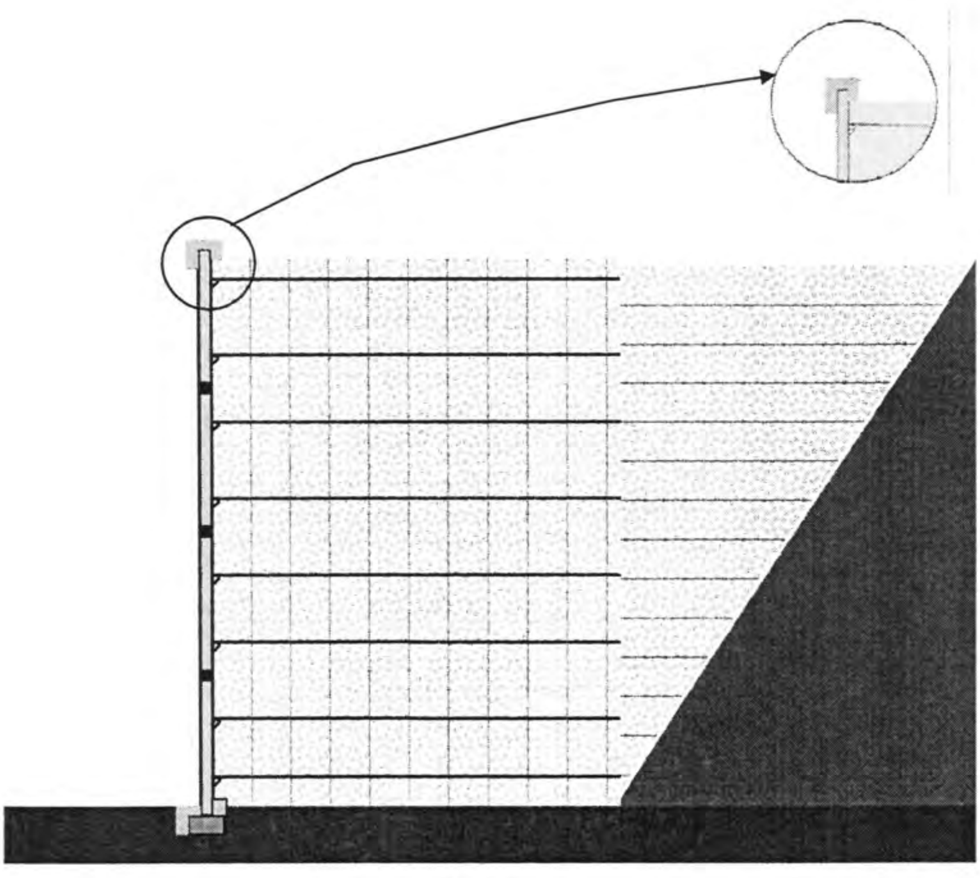

Figure 33. Picture showing step 11 of the construction process of MSE wall

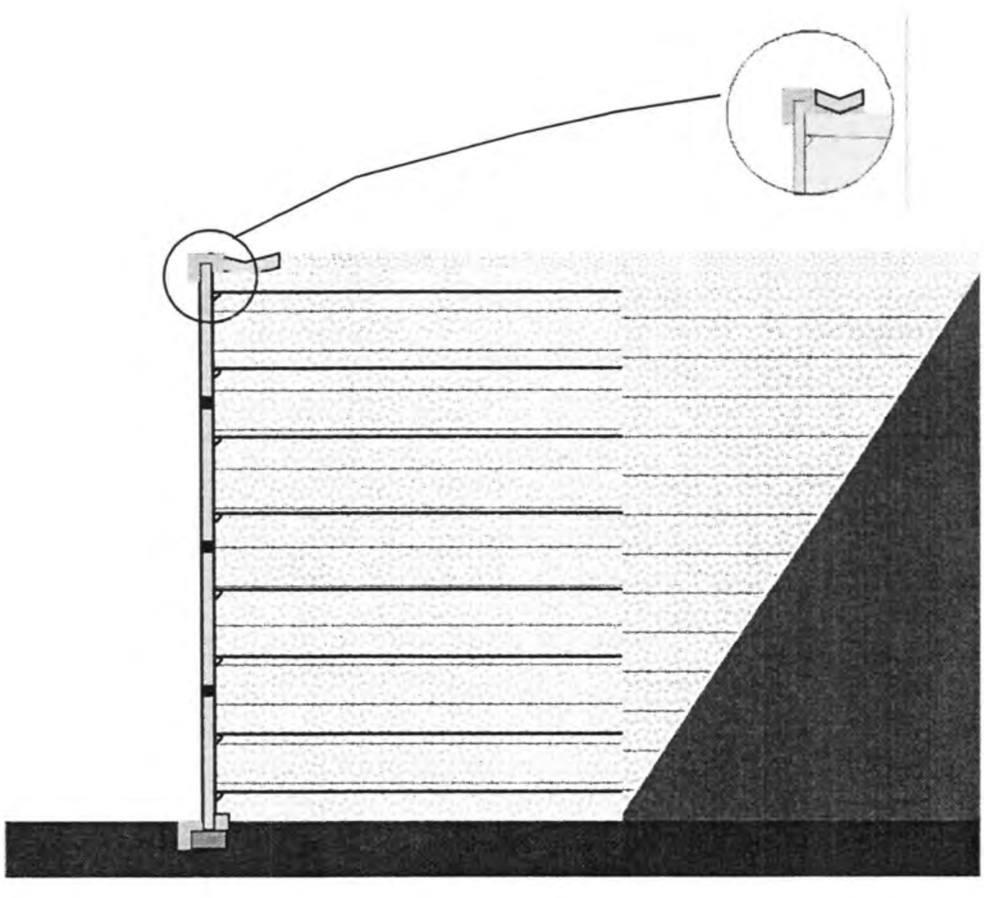

Figure 34. Picture showing step 12 of the construction process of MSE wall

Advantages

1. Wall system construction is relatively rapid and does not require specialized labor or equipment,
2. Limited foundation preparation is required,
3. Wall system is flexible and can accommodate relatively large total and differential settlements without distress,
4. Reinforcement is light and easy to handle,
5. Concrete facing panels permit greater flexibility in the choice of facing and architectural finishes, and
6. Since wall system is flexible, it is well - suited for applications in regions of high seismicity.

Disadvantages

1. Wall system requires relatively large base width,
2. Use of metallic reinforcement requires that backfill meet minimum electrochemical requirements for corrosion protection,
3. Allowable load for geo-synthetic reinforcement must be reduced to account for creep, durability, and construction damage, and
4. Wall system may not be appropriate for applications:
   a. Where it may be necessary to gain future access to underground utilities;
   b. At locations subject to scour; or
   c. Involving significant horizontal curvature.

Pictures 35- 42 represent photographs from the field, which depict different stages and components of MSE wall. These photographs have been taken at different projects on I-235.

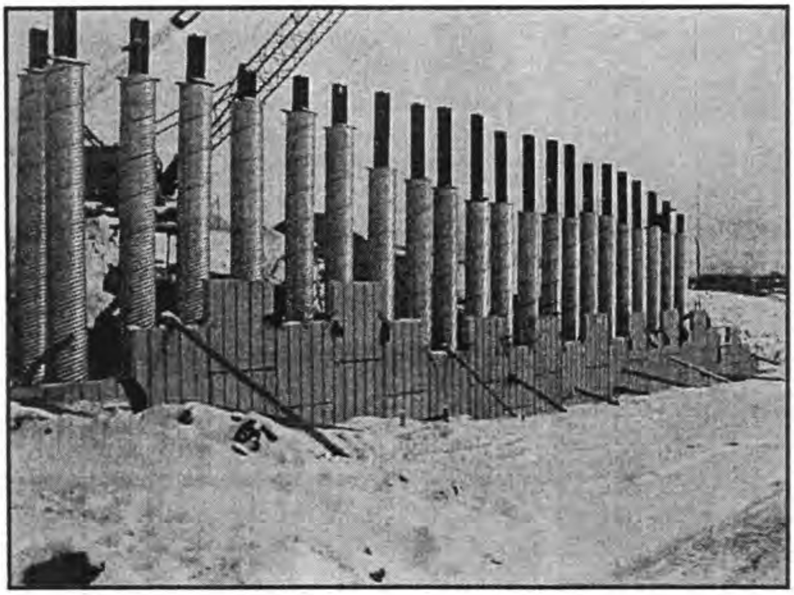

Figure 35. Picture showing MSE wall at 3rd St Bridge (South of I-235)

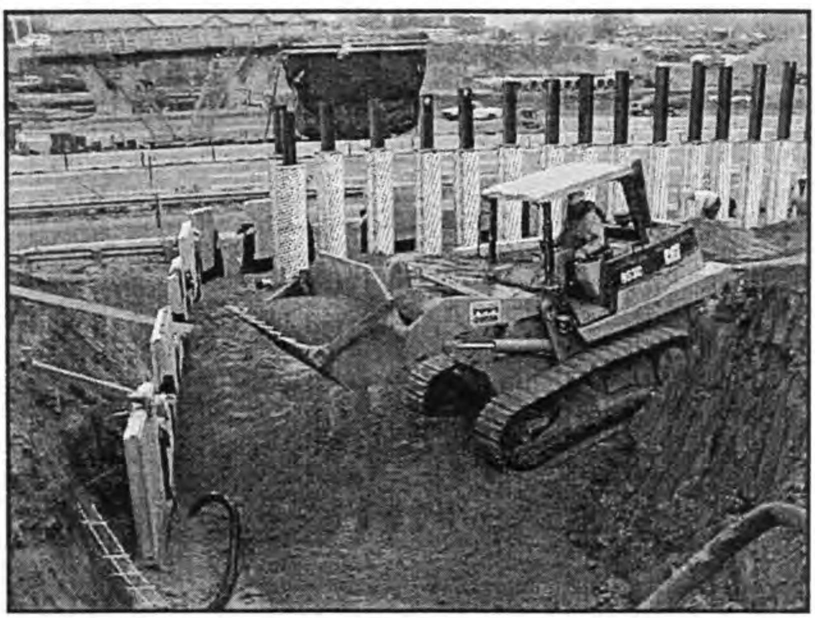

Figure 36. Picture showing MSE wall at 3rd St Bridge (North of I-235)

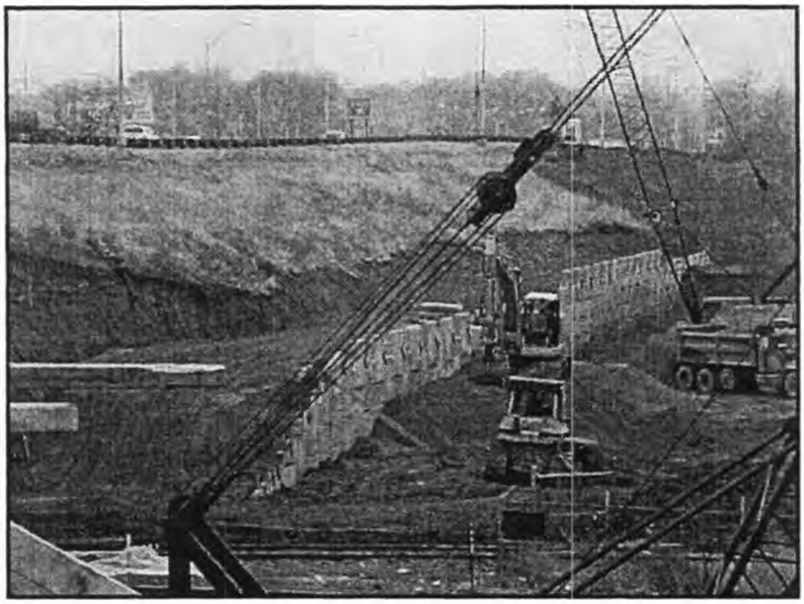

Figure 37. Picture showing MSE Wall #5801 at U.P.R.R in University Avenue Project (I-235)

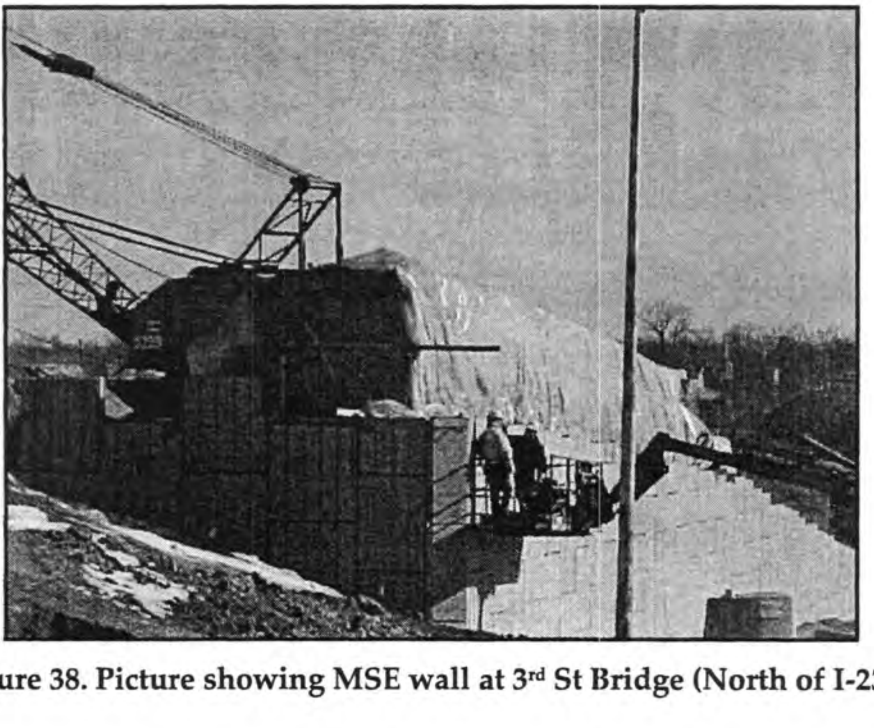

Figure 38. Picture showing MSE wall at 3rd St Bridge (North of I-235)

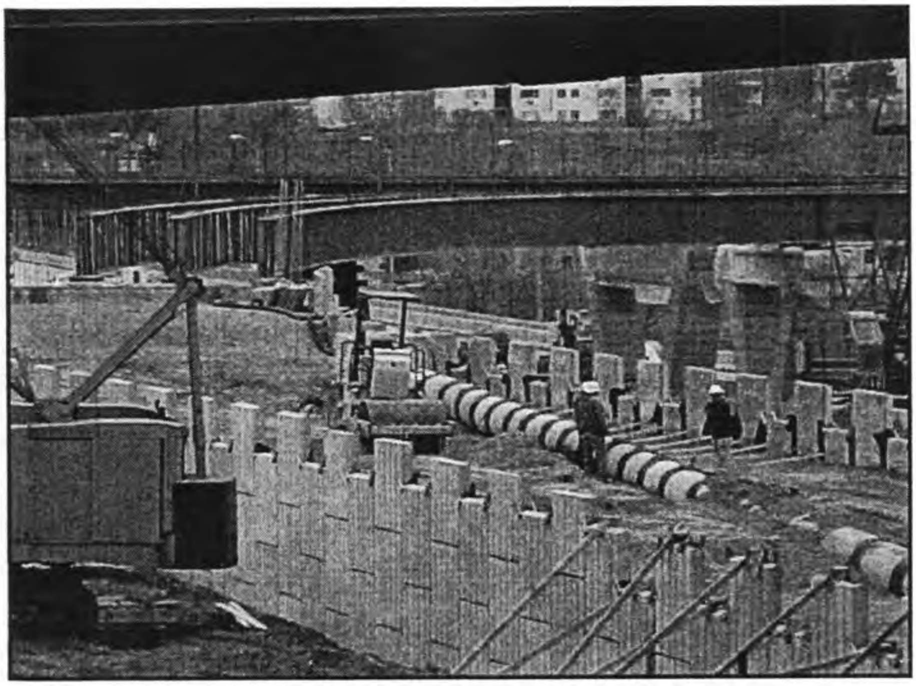

Figure 39. Picture showing MSE Wall at 2nd St Ave. Bridge

Figure 40. Picture showing filter fabric for MSE wall at Easton Blvd

Figure 41. Picture showing formwork for Coping on MSE wall at Easton Blvd

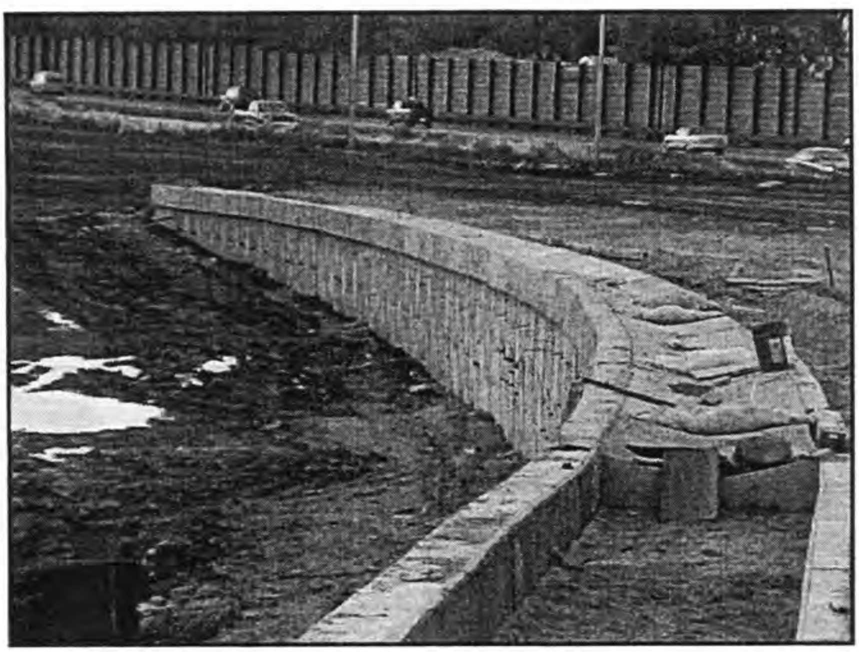

Figure 42. Picture showing V-Ditch on MSE wall at Easton Blvd

Productivity Analysis

The productivity analysis is based on observations of MSE walls constructed by three different contractors. Also a Schedule Template (Figure 43) has been developed for an assumed MSE wall with a height of 10 M and a length of 40 M.

Approximately 100 Sq m of MSE wall can be setup in 5 days.

Or 25 panels with dimensions of 5'X5' can be setup in a day.

Average Crew: 3

Equipment: 1 Crane.

Granular Backfill:

Approximately 300 CuM can be placed in a day.

Equipment: 1 Front end loader or Bulldozer; 1 compactor

Crew: 2

Coping:

Approximately 50 Lm of Coping can be formed in a Day and placed the following day.

Average Crew: 5

Equipment: 1 Crane and a Concrete Bucket

V-Ditch:

Approximately 60 Lm of V-Ditch can be formed and placed in a Day.

Average Crew: 5

Equipment: 1 Crane and a Bucket

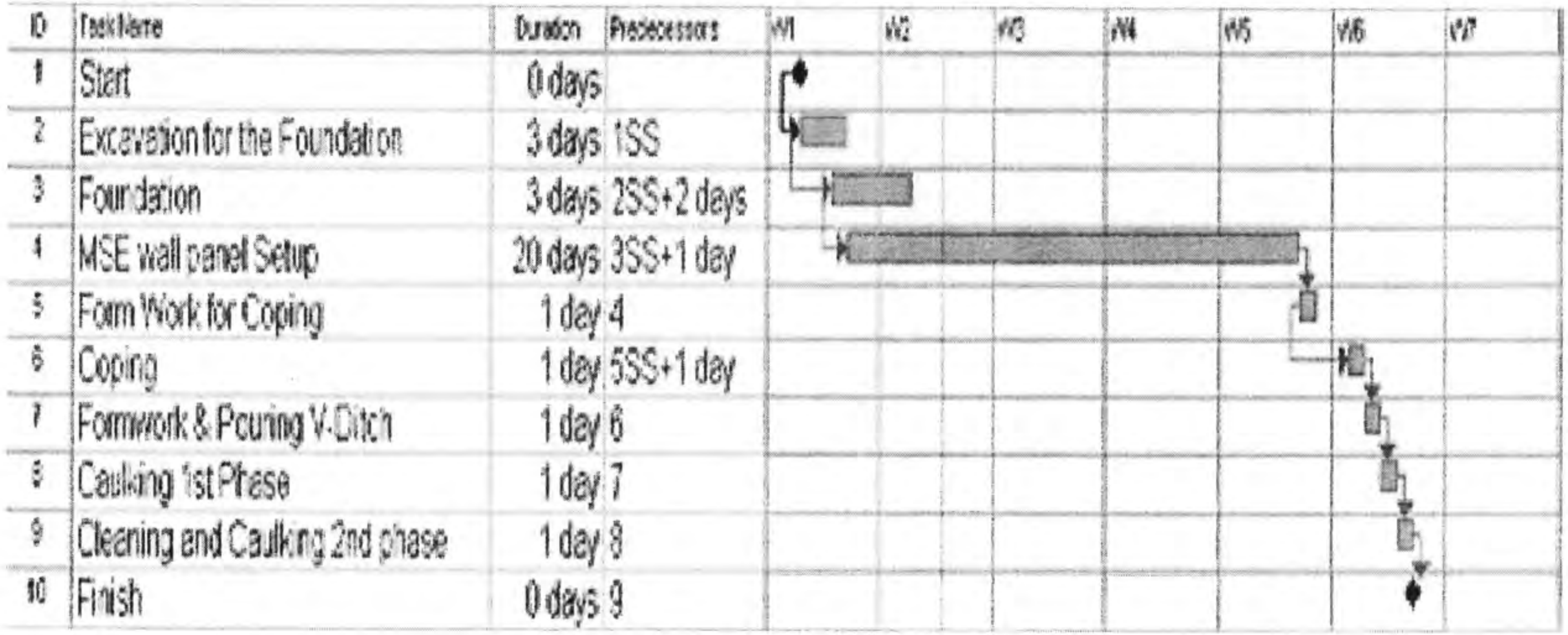

Figure 43. Schedule template for a MSE wall

MSE wall Estimate

A conceptual cost estimate for MSE wall has been shown in Tables 9 - 14. The calculations are based on a real site project, for which, a cost estimate was available. The original estimate has been used to crosscheck the conceptual estimate.

The following estimate has been developed for 502.94 Sq m of MSE wall with an average height of 4.75 meters and a length of 106 meters.

The values have been rounded off to the nearest whole digit.

Table 9. Initial data available for obtaining the cost of MSE retaining wall

Item	QTY	Unit	Unit Cost	Total Cost	Notes
Wall Panels	502.94	Sq m	$140	$70,500	Includes Straps
Granular Backfill	4670.00	Tons	$11	$51,500	Includes Hauling
Excavation	197.00	CuM	$6	$1,000	Includes Euip and Labour
Forms		M	$2		
Concrete		CuM	$86		

Table 10. Calculation to estimate the cost for MSE wall panels

Duration	25	Days	(8 hr working periods)
Crew	3		
Cost per labour hr	$20		
Cost for labour	$12,000		(25*3*8*20)
Equipment			
Crane	1		
Cost per hr	$50		
Cost for equipment	$10,000		(25*1*8*50)
Cost for material	$70,500		
Total cost for panel Setup	$92,500		

Table 11. Calculation to estimate the cost for Granular backfill for MSE wall

Duration	25 Days	(8 hr working periods)
Crew	2	
Cost per labour hr	$20	
Cost for labour	$8,000	(25*2*8*20)
Equipment		
Compactor	1	
Bulldozer with front end attachment	1	
Cost per hr	$50	
Cost for equipment	$20,000	(25*2*8*50)
Material		
Cost for material	$51,500	
add 25 % for waste	$13,000	
Total cost for placing Granular backfill	$92,500	

Table 12. Calculation to estimate the cost of Level pad for MSE wall

Quantity of Concrete	4.95	CuM	(.305*.153*106)
15% waste Factor	0.74	CuM	
Total Quantity of Concrete	5.69	CuM	
Cost for material	$500.00		(5.69* $86)
Forms	106.00	M	
Cost for forms	$200.00		(2*106)
Duration	2.00	Days	(8 hr working periods)
Crew	5.00		
Cost per labour hr	$20.00		
Cost for labour	$1,500.00		(2*5*8*20)
Equipment			
Crane	1.00		
Cost per hr	$50.00		
Cost for Crane	$800.00		(2*1*8*50)
Total cost for placing Level Pad	$3,000.00		

Table 13. Calculation to estimate the cost for Coping of MSE wall

Material			
Quantity of Concrete	19.72	CuM	(.305*.610*106)
15% waste Factor	2.96	CuM	
Total Quantity of Concrete	22.68	CuM	
Reinforcement	$2,000.00		($20*106M)
Cost for material	$4,000.00		
Forms	106.00	M	
Cost for forms	$200.00		(2*106)
Duration	4.00	Days	(8 hr working periods)
Crew	5.00		
Cost per labour hr	$20.00		
Cost for labour	$3,500.00		(4*5*8*20)
Equipment			
Crane	1.00		
Cost per hr	$50.00		
Cost for Crane	$1,600.00		(4*1*8*50)
Cost of Equipment	$1,600.00		
Total Cost of placing Coping	$9,300.00		

Table 14. Total cost for Mechanically Stabilized Earth retaining wall construction

Excavation	$1,000
Level Pad	$3,000
Panels	$92,500
Granular Backfill	$92,500
Coping	$9,300
Sub-drain	$3,500
Construction Cost	$201,800
Margin (25%)	$50,200
Final Bid Price	$252,000

The percentage involved in margin takes into account all the company overheads, profits, liability, insurance and any other extra charges required to maintain the project.

6. SOIL NAIL WALL

A soil nail wall is a gravity composite soil structure in which an excavated slope or vertical cut is internally reinforced through placement of closely spaced linear reinforcing elements (Steel bars).

Principle

Soil nailing is a technique to reinforce and strengthen the ground by installing closely spaced steel bars, called as "nails". The reinforced ground becomes the primary structural element of the wall which can retain the ground behind it, and shotcrete supports the excavation's face between the soil nails. This is generally a top-down process. The soil nails significantly increase the apparent cohesion of the soil through their ability to carry tensile loads. The fundamental concept of soil nailing consists of reinforcing the ground by steel "nails" (bars) which create an in-situ coherent gravity structure which increases the overall shear strength of the in-situ soil and restrains displacements. The basic design consists of transferring the resisting tensile forces generated in the steel bars to the ground through the friction mobilized at the interfaces.

The shotcrete facing of the soil-nailed wall is not a major structural load carrying element, but rather ensures local stability of the soil between reinforcing layers and protects the ground from surface erosion and weathering effects. It creates a bond with the soil and fills in voids which may develop due to sloughing of soil at the wall face. The cast-in-place concrete facing is used to satisfy aesthetic and durability design criteria and to accommodate adequate facing drainage.

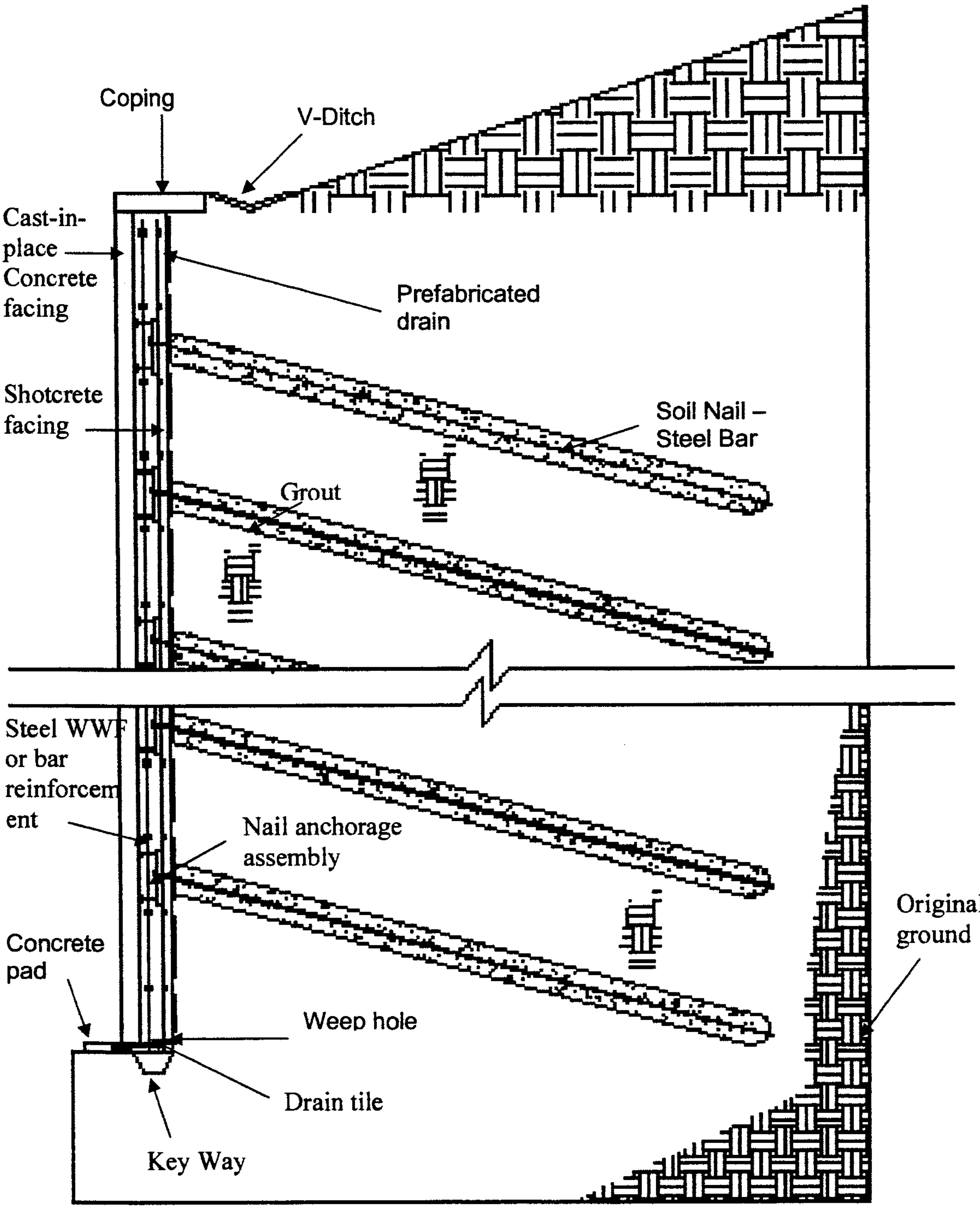

Figure 44. Picture showing Soil Nail wall components

Components of Soil Nail Wall

The following are the various components of Soil nail wall (Figure 44) and their functions:

Original Ground

This is the existing ground surface at the site.

Steel Bar

Also referred as Soil Nail, this bar is the structural element which reinforces the ground to act as a single structural element for the Soil Nail Wall. The Soil Nails are generally 0.7 to 1.2 times the height of the wall.

Grout

The cement grout acts as a corrosion protector and creates a cohesive bond between the ground and the Nail.

Prefabricated Drain

A geo-textile filter fabric placed in between the nails, runs vertically and horizontally, and is connected to the weep hole to facilitate the drainage of seeping water.

Steel Mesh

It is either a welded wire frame mesh or bar reinforcement used as reinforcement for the shotcrete facing.

Nail Anchorage Assembly

A steel plate is used to tie steel bar to the concrete facing and the earth so that all the nails act as a coherent system.

Shotcrete Facing

The shotcrete placed by pumping concrete through a pressure nozzle temporarily protects the wall from collapsing and ensures local stability of the soil. It creates a bond with the soil and fills in voids which may develop due to sloughing of soil at the wall face.

Concrete Pad

It is used as a leveling surface for the concrete facing.

Weep Hole

These are used to collect water from the filter fabrics and divert them to the drain tile.

Drain Tile

Collects water and transfers it to the storm sewer.

Concrete Facing

It is a cast in place wall used to satisfy aesthetic and durability design criteria and to accommodate adequate facing drainage.

Coping

The coping is used to tie in the top of the wall panels and to provide a pleasing finish to the wall top. It can be cast-in-place or prefabricated segments.

V-Ditch

The V-ditch is Made of Concrete and is used to prevent the Seepage of Water. This also collects water and transfers it to the drain.

Construction Process

1. A bench is cut to a depth of 4-6 feet (Figures 45 & 46).
2. Holes are drilled to the specified depth with a track-mounted drill rig, in accordance to the plans (Figures 47 & 48).
3. Cement grout is pumped into the holes (Figure 49).
4. Nails (Steel Bars) are then placed in these holes (Figure 50 & 52).
5. A filter fabric is placed between the nails (horizontally and vertically) to allow for the seepage of water (Figures 51 & 54).
6. A reinforcing mat (steel bars or a welded wire frame mesh) is placed against the excavated and nailed surface (Figure 53 & 54).
7. Shotcrete is applied to the reinforced surface (Figures 55 & 56).
8. Nail anchorage assembly is then placed to the nail before the shotcrete curves (Figure 57).
9. Steps 1 through 8 are repeated in top-down fashion till the complete wall is finished (Figure 60).
10. After the entire wall is finished to the desired height, weep holes, drain tile and the concrete pad are placed at the bottom of the wall.
11. A cast in place wall is placed against the shotcrete surface (Figure 58).
12. Coping and V-ditch are placed at the top of the wall after the cast in place facing has been finished (Figure 59). A fabric is placed between coping and V-Ditch to reduce the friction between them.

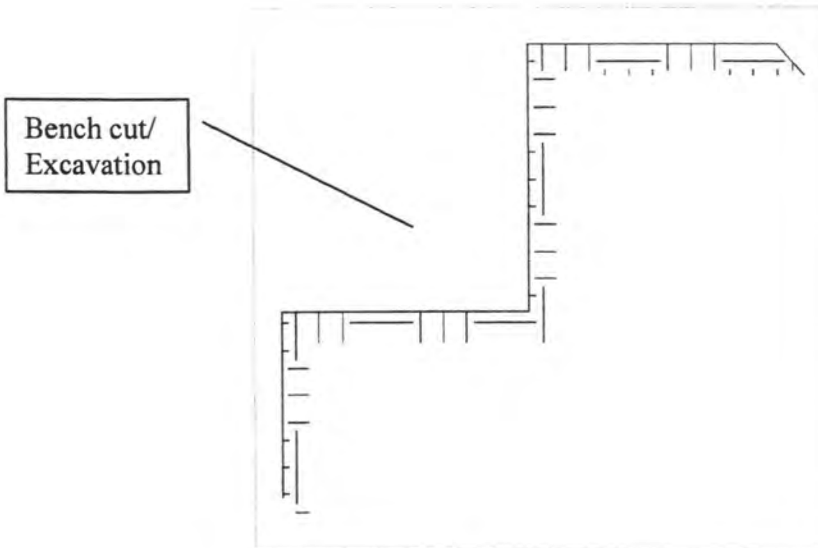

Figure 45. Picture showing step 1 of the construction process of Soil Nail wall

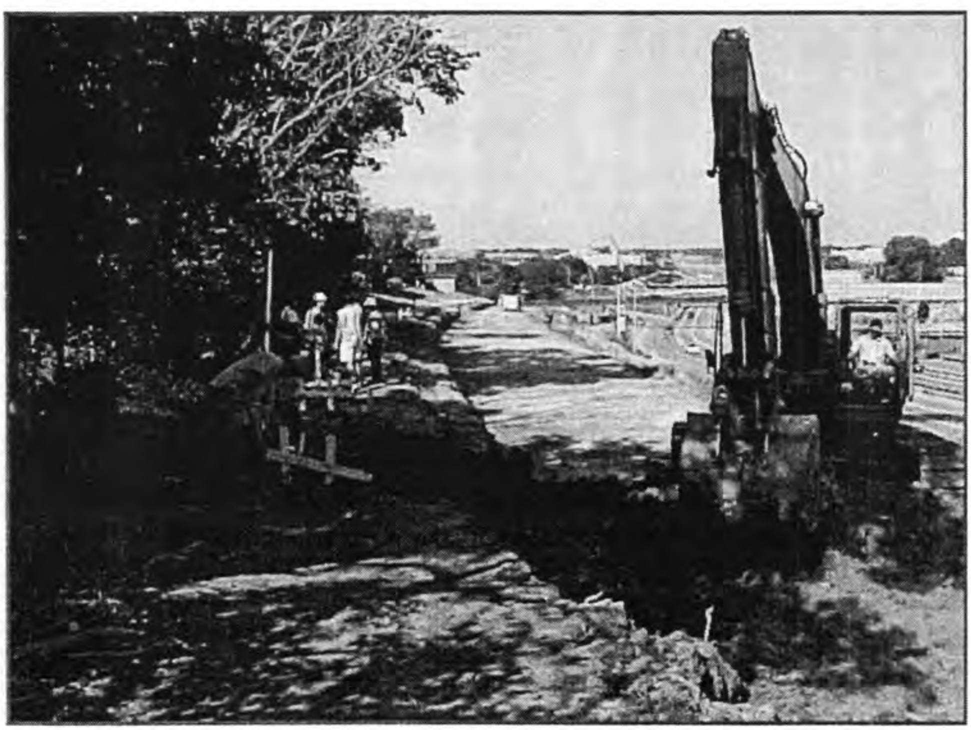

Figure 46. Photograph showing step 1 of construction process

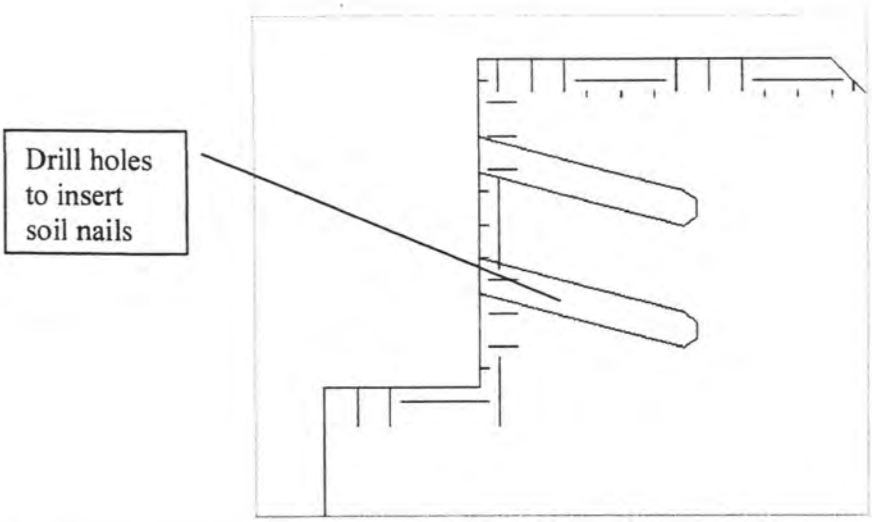

Figure 47. Picture showing step 2 of the construction process of Soil Nail wall

Figure 48. Photograph showing step 2 of construction process

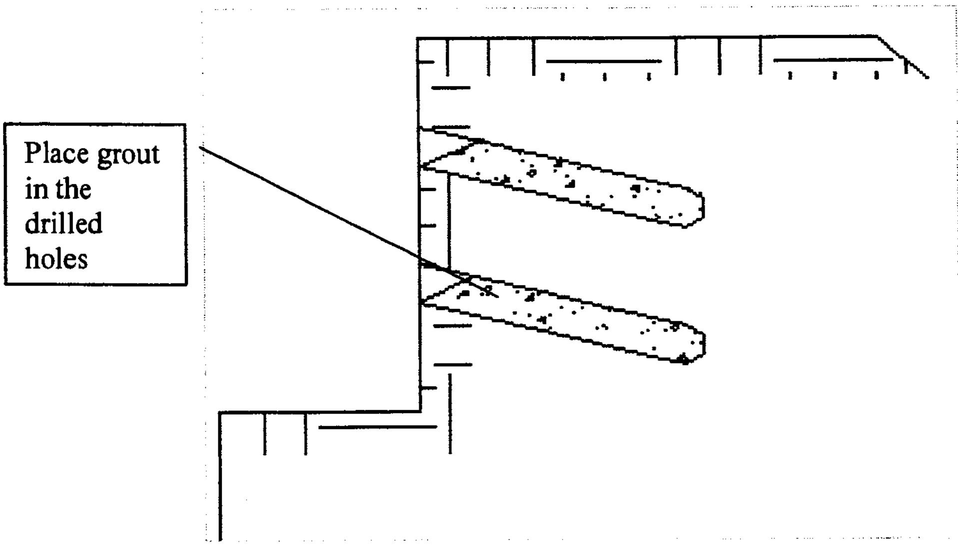

Figure 49. Picture showing step 3 of the construction process of Soil Nail wall

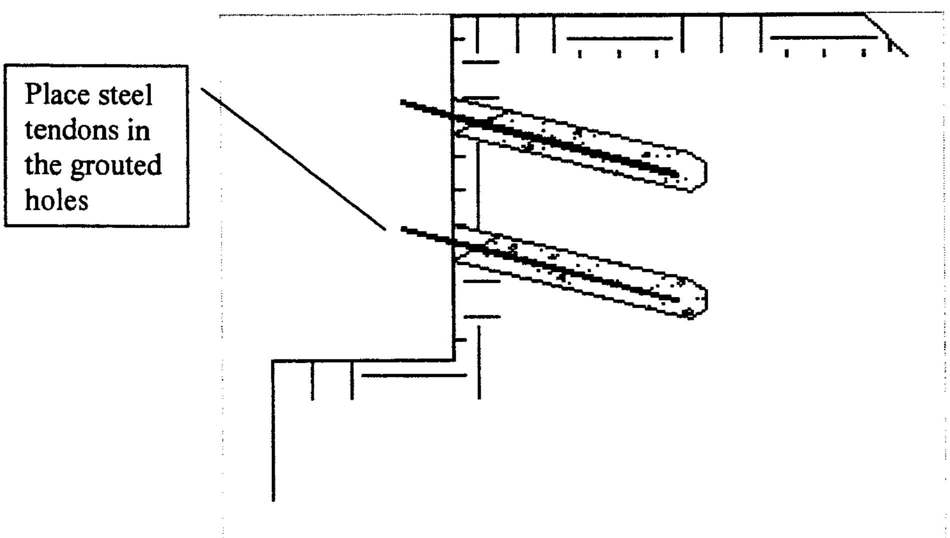

Figure 50. Picture showing step 4 of the construction process of Soil Nail wall

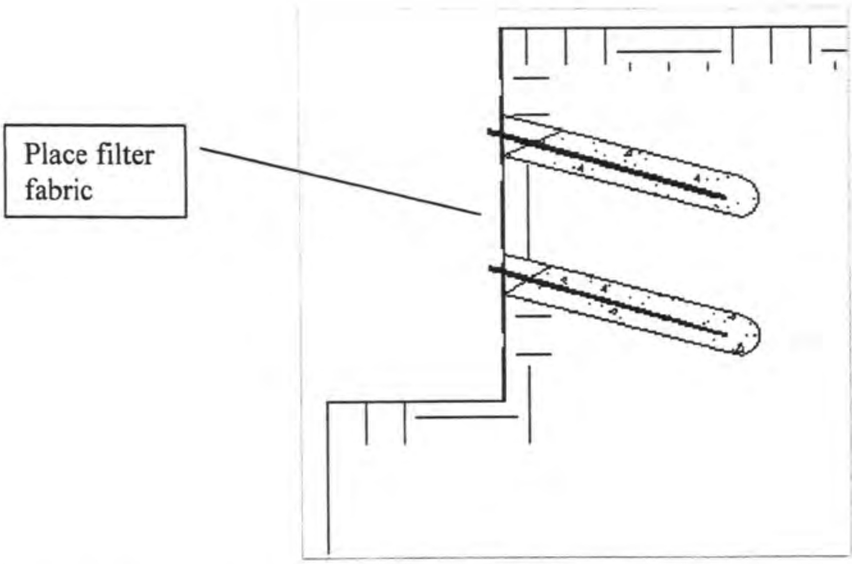

Figure 51. Picture showing step 5 of the construction process of Soil Nail wall

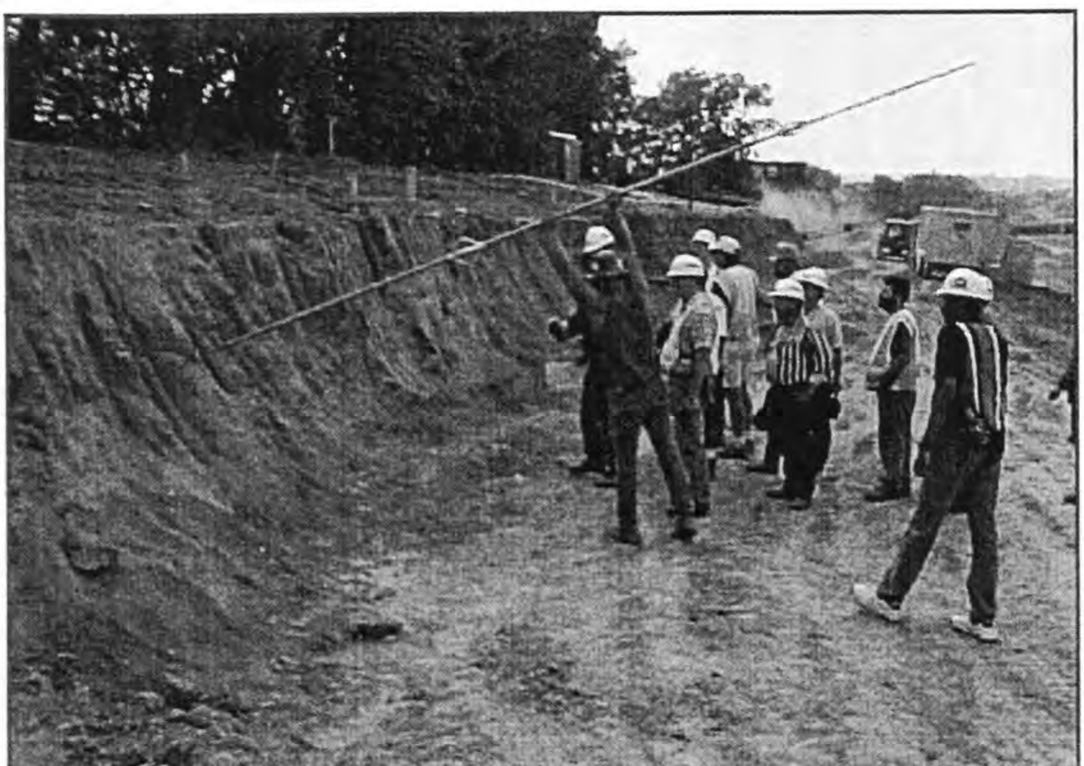

Figure 52. Picture showing steel tendon being placed in the drilled and grouted hole

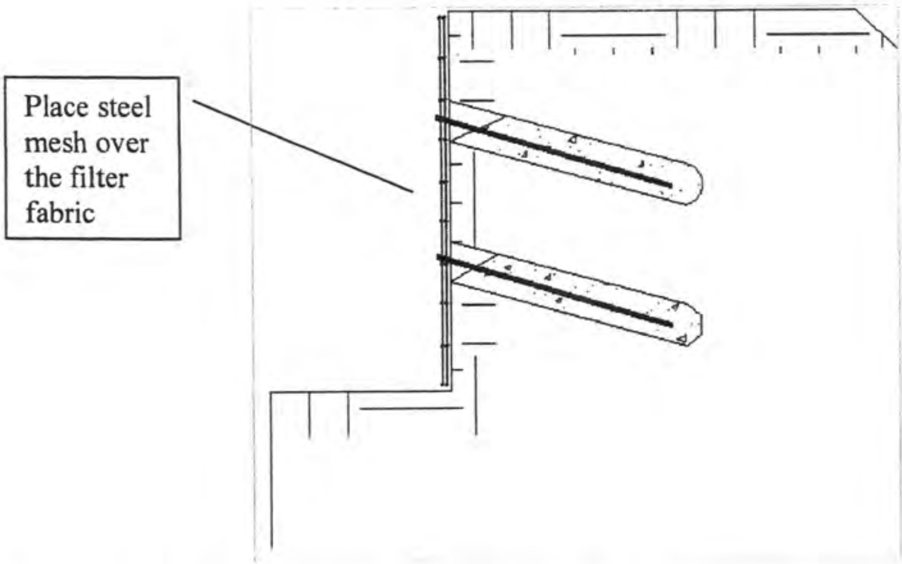

Figure 53. Picture showing step 6 of the construction process of Soil Nail wall

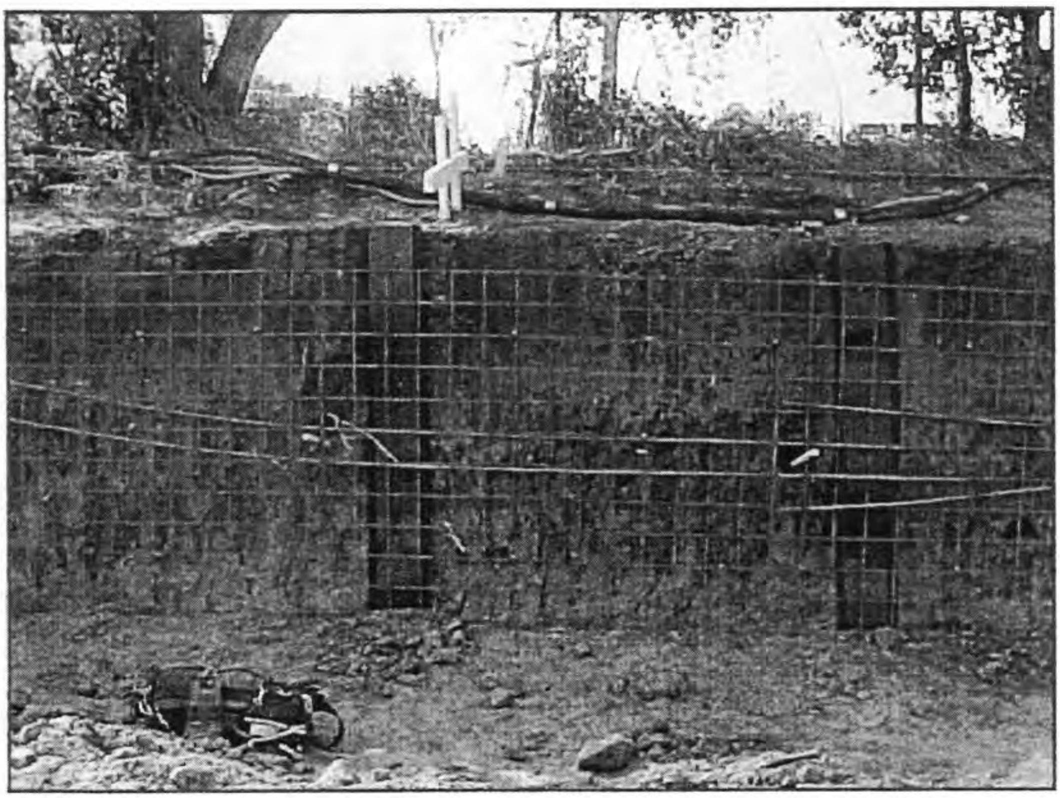

Figure 54. Picture showing steps 5 & 6

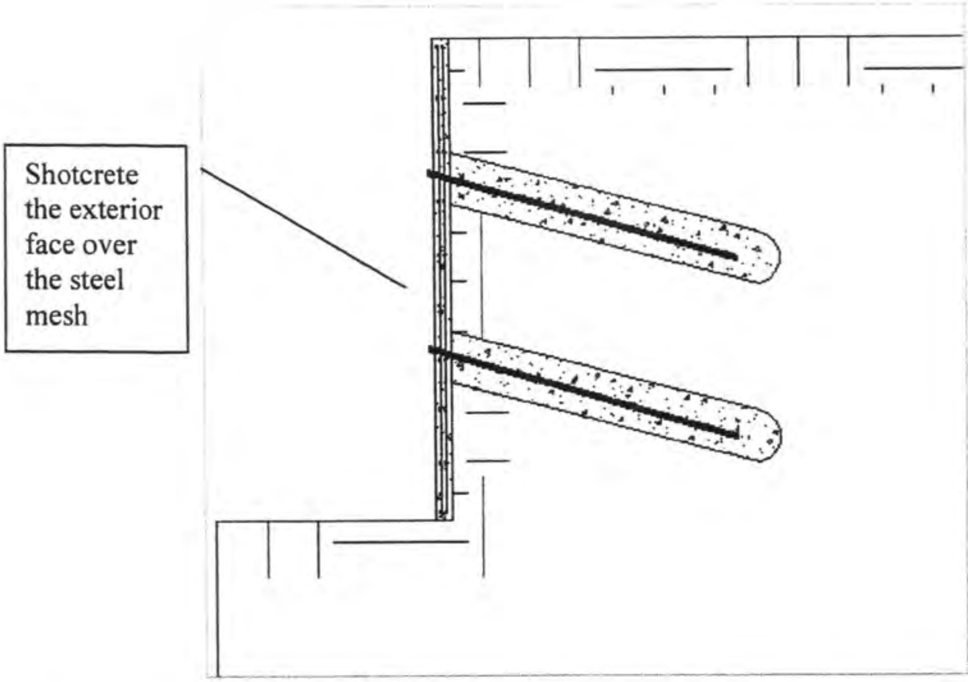

Figure 55. Picture showing step 7 of the construction process of Soil Nail wall

Figure 56. Picture showing a laborer placing Shotcrete

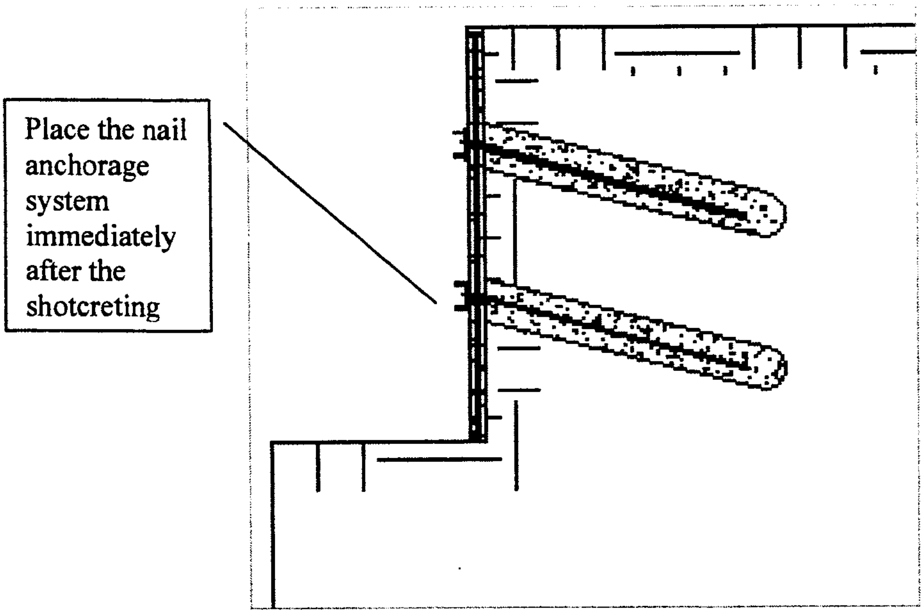

Figure 57. Picture showing step 8 of the construction process of Soil Nail wall

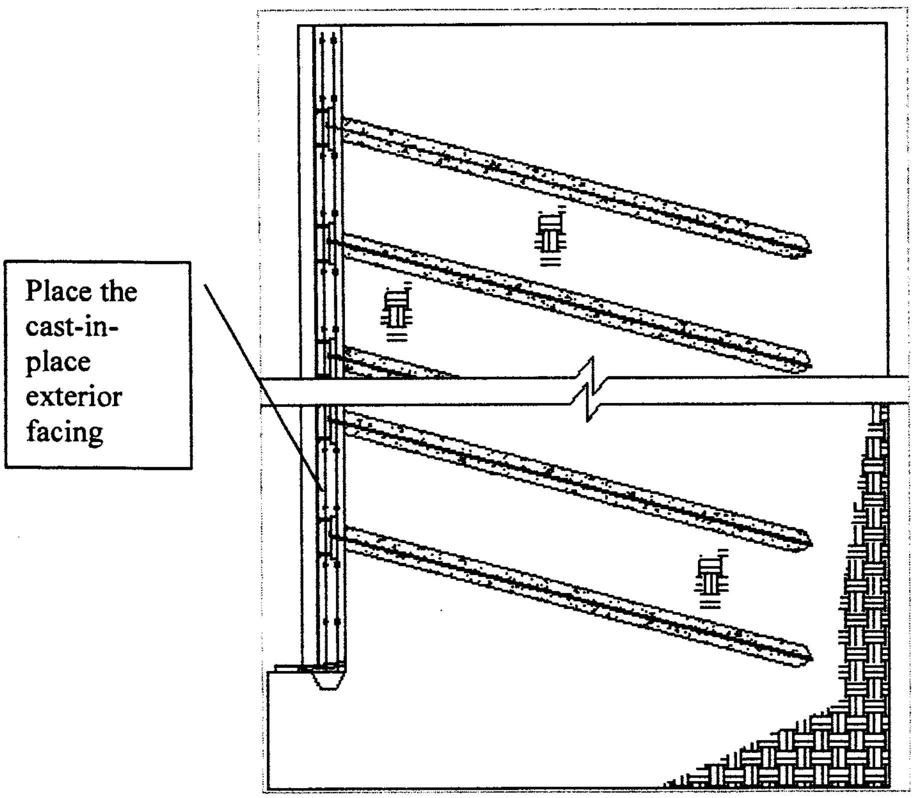

Figure 58. Picture showing step 11 of the construction process of Soil Nail wall

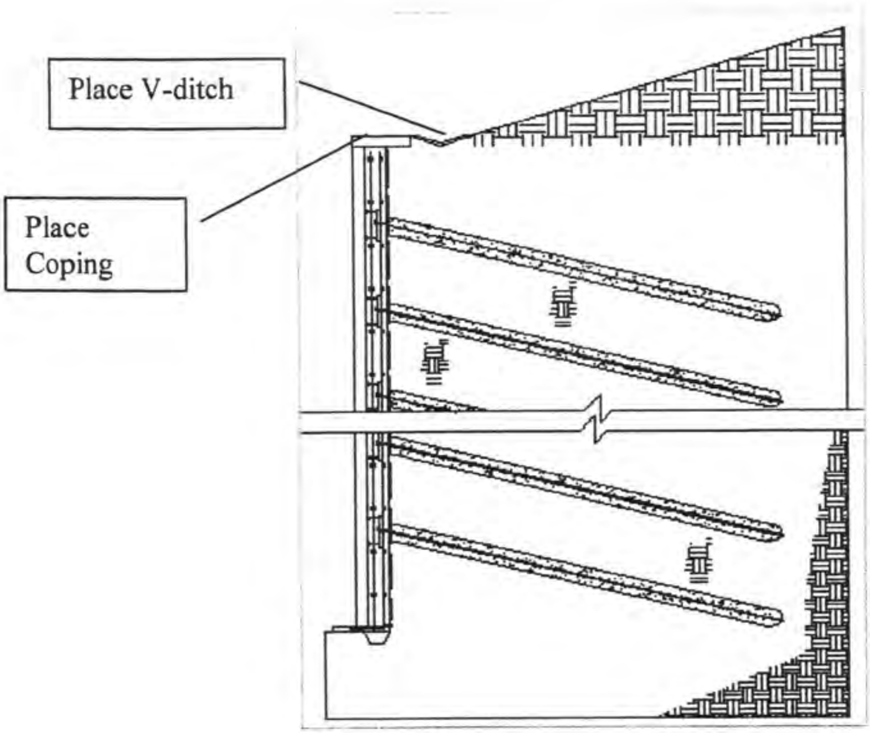

Figure 59. Picture showing step 12 of the construction process of Soil Nail wall

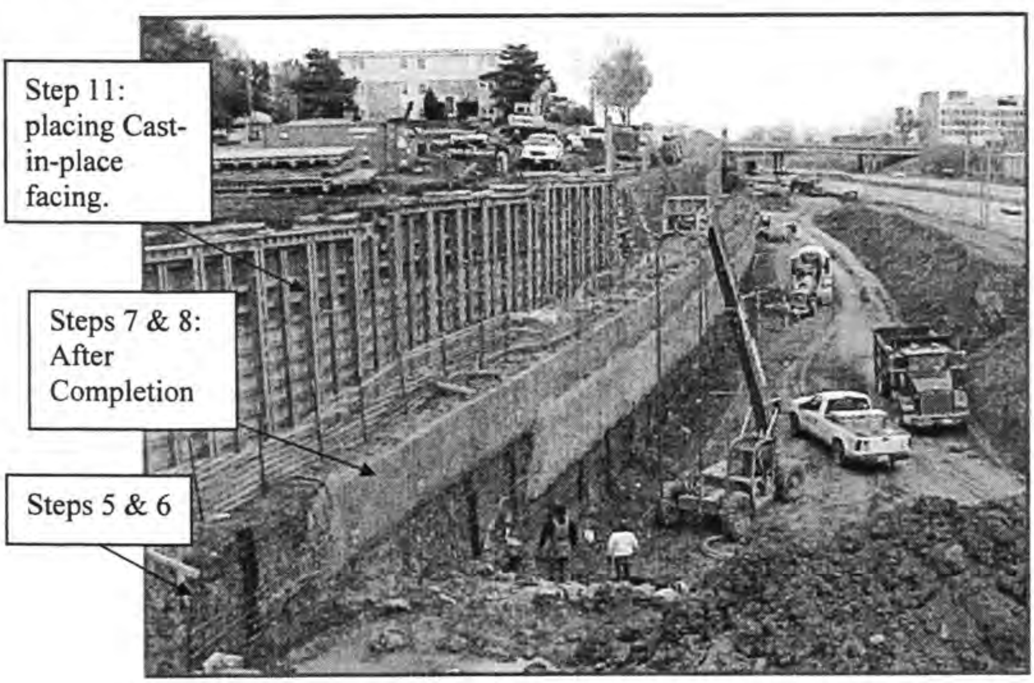

Figure 60. Picture showing steps 5, 6, 7, 8 and 11

Productivity Analysis

Approximately 135 Sq m of Soil Nail Wall can be built in a day. (Additional time has to be allotted for excavation)

Average Crew: 8

Equipment: 1 track-mounted Drill rig; 1 high lift (Fork Lift); Shotcrete equipment, 1 scraper.

Additional time has to be allotted for Earth work; and this requires an excavator.

Facing:

Approximately, 150 Sq m of wall can be formed in a day and then placed on the following day. That is an average of 75 Sq m per day.

Average Crew: 5

Equipment: 1 Crane and a Concrete Bucket

Coping:

Approximately 50 Lm of Coping can be formed in a day and placed the following day.

Average Crew: 5

Equipment: 1 Crane and a Concrete Bucket

V-Ditch:

Approximately 60 Lm of V-Ditch can be formed and placed in a day.

Average Crew: 5

Equipment: 1 Crane and a Bucket

Advantages

1. Soil Nailing is readily adaptable to otherwise difficult sites as long as no prior excavation work is needed. In particular, it allows structures to be built on slopes where access is difficult. Walls can also be built in segments, and if necessary, on a curve or with benches.
2. Modifications can be made to the wall during the construction process (e.g., nail locations can be moved to miss obstructions)
3. It accommodates the common constraints of operating in urban environments (e.g., need for minimum noise, small overhead clearance, less requirement for right of way, etc.).
4. It costs less and can be constructed faster than tieback walls.

Disadvantages

1. Use limited to soils that are above the water table or that are drained. A high water table can corrode the nails and result in the failure of the system.
2. Use can be difficult or delicate in certain soil conditions including cohesionless sands, caving sands, soils containing pockets of water, soil containing high quantity of clay where the moisture content might increase after construction, and frost susceptible soils.
3. Soil nailing in very low shear strength soil may require a very high soil nail density, and thus be uneconomical.
4. Horizontal displacements may be greater than those associated with tieback construction, and therefore, may limit use adjacent to critical structures.
5. Reinforcements may interfere with existing or future utilities.

Soil Nail Wall Estimate

A conceptual cost estimate for 3750 Sq m of Soil Nail wall has been shown in Tables 15 - 19. The Soil Nail Wall is assumed to have a maximum height of 5 meters and a length of 750 meters.

Table 15. Calculation to estimate the cost of Shotcrete face of Soil nail wall

	Quantity	Units	Unit Cost	Total Cost	Remarks
Material					
Concrete	450	m^3	$150	$67,500	750*5*.2
Steel Tendons				$112,500	$30/Sq m
Steel Mesh				$75,000	$20/Sq m
Prefabricated Drain				$19,000	$5/Sq m
Nail Anchorage Assembly				$37,500	$10/ Sq m
Drain Tile	LS	LS	LS	$10,000	
Cost of Material				$321,500	
Equipment					
Excavator	224	hrs	$75	$16,800	28days*8hrs
Scraper	224	hrs	$75	$16,800	28days*8hrs
Drill rig	224	hrs	$75	$16,800	28days*8hrs
Fork Lift	224	hrs	$50	$11,200	28days*8hrs
Shotcrete Pump	224	hrs	$50	$11,200	28days*8hrs
Cost of Equipment				$72,800	
Crew	1792	hrs	$30	$53,800	28days*8hrs*8 people
Cost for shotcrete face				$448,000	

Table 16. Calculation to estimate the cost of cast-in-place face of Soil nail wall

	Quantity	Units	Unit Cost	Total Cost	Remarks
Material					
Concrete	1125	CuM	$86	$96,700	750*5*.3
Forms	3750	Sq m	$10	$37,500	
Cost for material				$134,200	
Equipment					
Crane	400	hrs	$50	$20,000	50days*8hrs
Cost for Equipment				$20,000	
Crew	2000	hrs	$30	$60,000	50days*8hrs*5people
Cost of Cast-in-place facing				$214,200	

Table 17. Calculation to estimate the cost of Coping for Soil nail wall

	Quantity	Units	Unit Cost	Total Cost	Remarks
Material					
Concrete	140	CuM			(.305*.610*750)
15%waste factor	21	CuM			
Concrete Quantity	160	CuM	$86	$13,800	
Reinforcement				$15,000	$20/M
Forms	3750	Sq m	$2	$7,500	
Cost for material				$36,300	
Equipment					
Crane	240	hrs	$50	$12,000	30days*8hrs
Cost for Equipment				$12,000	
Crew	1200	hrs	$30	$36,000	30days*8hrs*5people
Cost of Coping				$84,300	

Table 18. Calculation to estimate the cost of V-ditch for Soil nail wall

	Quantity	Units	Unit Cost	Total Cost	Remarks
Material					
Concrete	229	CuM			(.305*1*750)
15%waste factor	34	CuM			
Concrete Quantity	263	CuM	$86	$22,600	
Forms	3750	Sq m	$2	$7,500	
Cost for material				$30,100	
Equipment					
Crane	104	hrs	$50	$5,200	13days*8hrs
Cost for Equipment				$5,200	
Crew	520	hrs	$30	$15,600	13days*8hrs*5people
Cost of V-Ditch				$50,900	

Table 19. Total cost for 3750 Sq m of Soil Nail retaining wall construction

Shotcrete Face	$448,000
Cast-in-place Face	$214,200
Coping	$84,300
V-Ditch	$50,900
Total Construction Cost	$746,500
Design 20% of Construction Cost	$150,000
Margin 25% of Construction Cost	$190,000
Total Cost	$1,086,500

The percentage involved in margin takes into account all the company overheads, profits, liability, insurance and any other extra charges required to maintain the project.

7. CAST-IN-PLACE CANTILEVER RETAINING WALL

A cast-in-place cantilever-gravity earth retaining structure holds the earth by counter-acting the forces exerted by the soil with its own weight.

Principle

The retained earth and any surcharge on the retained earth exert an active thrust on the retaining wall. These forces act to push the wall outward and cause overturning. The outward motion of the wall is resisted by sliding resistance along the base of wall and the passive resistance of the soil lying above the toe of wall. While the weight of the wall and the reinforcement in the wall resist the over-turning and bending caused by the active earth pressure. The shear key below the toe helps in increasing the resistance to sliding. The face of the retaining wall can be designed and built to accomplish the required aesthetic look.

Components of cast-in-place Cantilever retaining wall

The following are the components of cast-in-pace cantilever retaining wall (Figure 61) and their functions:

Original Ground:

This is the existing ground surface at the site.

Backfill:

The portion of the earth, which is replaced after the construction of retaining wall.

Reinforcement:

The steel reinforcement in the retaining wall counter-acts the bending forces created by the active earth pressure. And also restrains shrinkage and problems caused by temperature stresses.

Shear Key:

Shear key increases the resistance of the retaining wall against overturning.

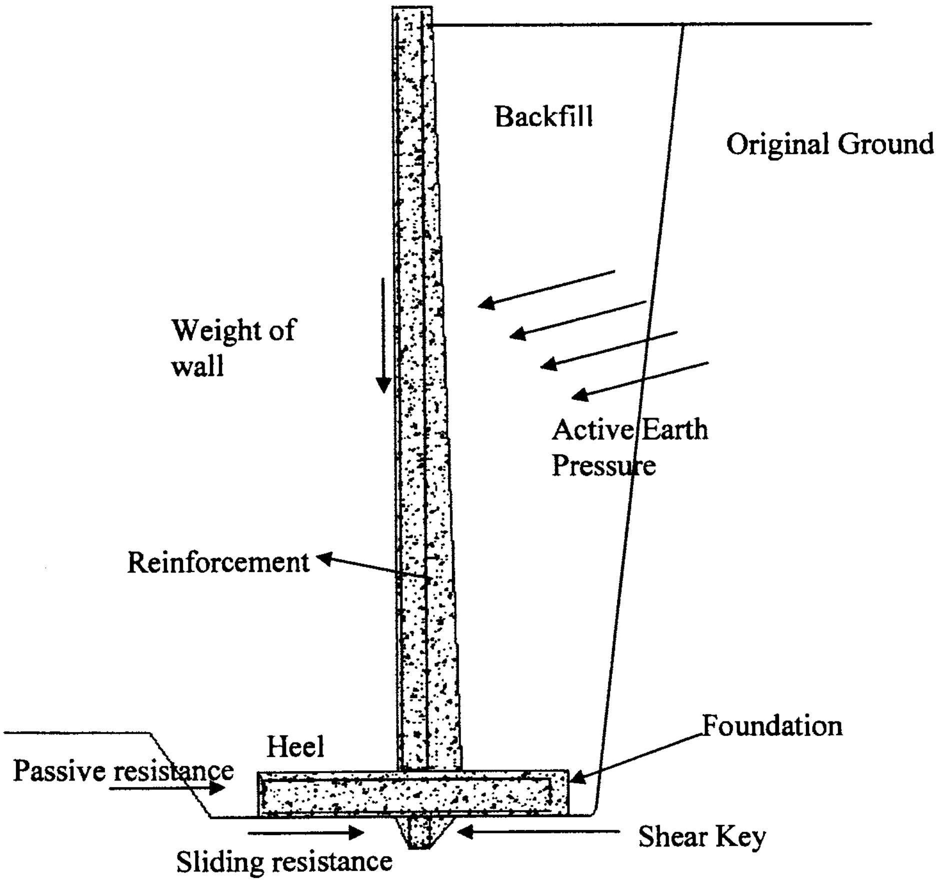

Figure 61. Picture showing the components of cast-in-place Cantilever retaining wall

Construction Process

1. Excavate for Foundation (Figure 62).
2. Form and place steel for foundation (Figure 63, 64 & 65).
3. Place concrete for shear key and foundation (Figure 66 & 67).
4. Erect reinforcing steel for the retaining wall (Figure 68 & 69).
5. Place concrete for retaining wall (Figure 70).

Figure 62. Picture showing step 1 of the construction process of cast-in-place Cantilever retaining wall

Figure 63. Picture showing step 2 of the construction process of cast-in-place Cantilever retaining wall

Figure 64. Picture showing step 3 of the construction process of cast-in-place Cantilever retaining wall

Figure 65. Picture showing the reinforcement and form work for footing of Cantilever retaining wall

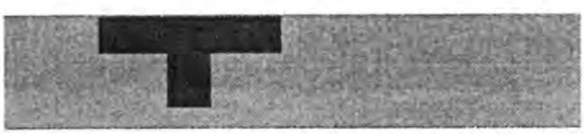

Figure 66. Picture showing step 4 of the construction process of cast-in-place Cantilever retaining wall

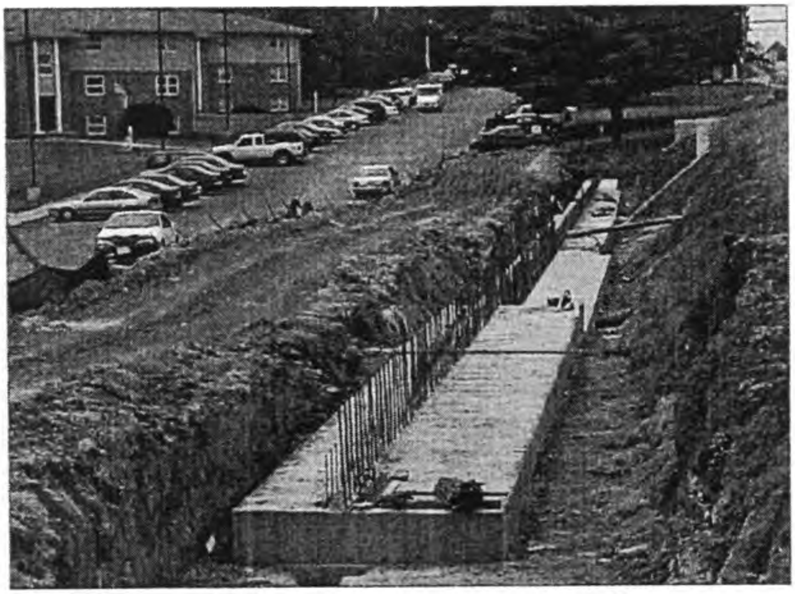

Figure 67. Picture showing the footing of cantilever retaining wall

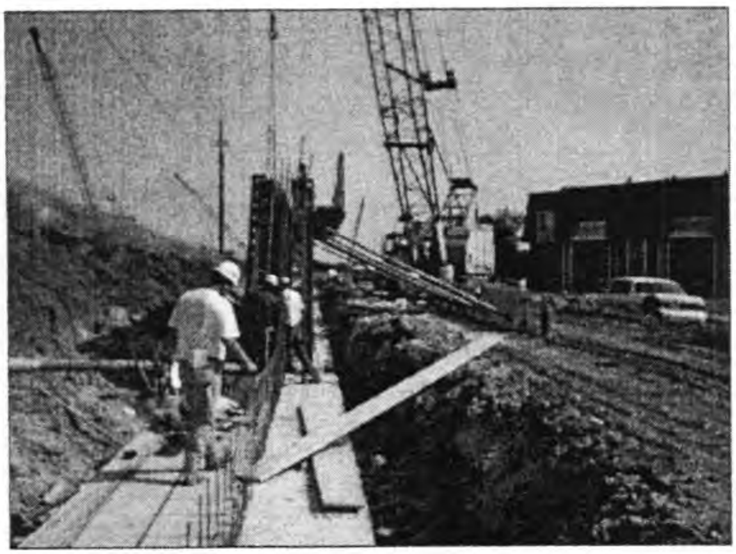

Figure 68. Picture illustrating the setting for form work for cantilever retaining wall

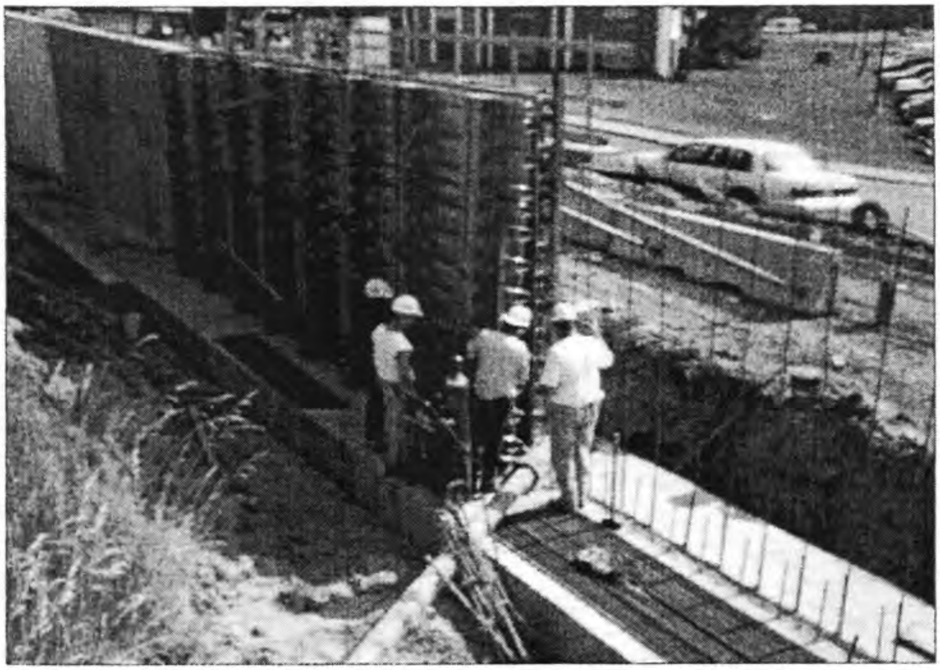

Figure 69. Picture showing the construction of cantilever retaining wall

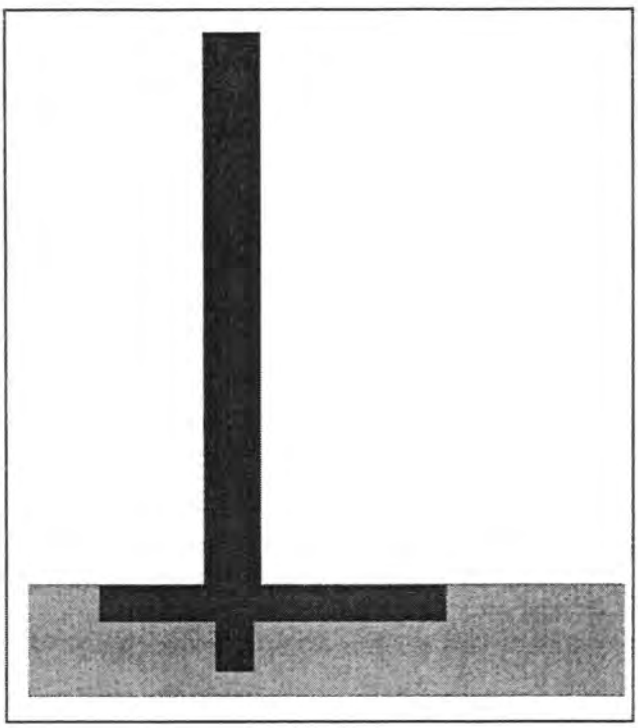

Figure 70. Figure showing a retaining wall

Advantages

1. Can be used in both cut and fill applications.
2. Can be built with less experienced crew compared to Soil Nail wall.
3. Traditional cantilever retaining walls are an efficient and economical method of earth retention in areas where severe excavation or right-of-way restrictions prevent the use of earth retaining methods such as mechanically stabilized earth and other similar Reinforced Earth systems.
4. Can be constructed in areas with high ground water table.

Disadvantages

1. It is not ideal for construction in irregular terrain.
2. As compared to Soil Nail wall, Cast-in-place wall requires more construction space and is not ideal in such situations.

Productivity analysis

Approximately 25 Lm of Shear Key and footing can be formed in a single day and placed the following day.

Average Crew: 4

Approximately 40 m^3 (9 X 5.5 X 0.8) of retaining wall can be formed in a single day and placed the following day.

Average Crew: 4

Equipment: 1 Crane.

Cast-in-place Retaining wall Estimate

Excavation Class 20:

Total Volume: 1445 m^3.

Productivity: 700 m^3/ day.

Total number of working days: 48 Days.

Cost:

Crew = 1

= 1*2*25*8

= 400

Equipment = I Front end loader (Excavator)

= 1*2*50*8

= 800

Total Cost = $ 1200.00

Granular Backfill:

Total Volume: 3474 m^3.

Productivity: 300m^3/ day.

Total number of working days: 12 Days.

Cost:

Crew = 2

= 2*12*8*25

= 4800

Equipment:

1 bulldozer with front end attachment

1 Compactor

= 2*12*8*50

= 9600

Material:

$12 / m^3

= 3474*12

≈ 41700

Total Cost =$ 56100.00

Retaining Wall:

Material:

Structural Concrete: 542.9 m^3

Cost= $86/m^3.

≈ $46700.00

Reinforcing Steel: 23257 kg

Cost = $1.1/kg

≈ $25600.00

Reinforcing Steel, Epoxy Coated = 8977 kg

Cost = $1.2/kg

≈ $10800.00

Forms: 200 m.

Total Duration for Construction:

Shear Key + Footing: 18 days.

Wall: 39days.

Total: 57 Days.

Cost:

Crew: 4

= 4*8*57*25

=$45600.00

Equipment

1 Crane

= (1*8*57*50)

=$22800.00

Forms

Footing: $5/lm

= 200*5

=$1000.00

Efco Lite forms: $10/m²

= 20*700

=$14000.00

Total Cost: $166500.00

Total Cost of the entire project:

= 1200.00+56100.00+166500.00

=$223800.00

Total Cost including margin of 20%: $268500.00

The percentage involved in margin takes into account all the company overheads, profits, liability, insurance and any other extra charges required to maintain the project.

8. COMPARISON BETWEEN EARTH RETENTION SYSTEMS

A comparison which includes information on required crew size, schedule, cost, construction equipment and material needed for the selection of the most favorable earth retaining system for given conditions has been provided in table 20.

Comparison has been made between the earth retaining structures on per unit basis. Cost and schedule information has been provided, for placing each unit of the desired earth retention system.

The range in cost has been determined by observing the minimum and maximum price of many projects which involved similar construction components.

Table 20. Comparison between Soil nail wall, Mechanically stabilized earth structure and Cantilever retaining wall

	Mechanically Stabilized earth	Soil Nail wall	Cantilever Retaining wall
CUT / FILL APPLICATION	Both	Cut	Both
GROUND WATER TABLE	Can not be constructed at places with high water table	Water has to be drained out before construction at places with high ground water	CAN BE CONSTRUCTED WITH ANY GROUND WATER TABLE LEVEL
AVAILABILITY OF RIGHT OF WAY	Needs excessive right of way	Needs Negligible right of way	CAN BE WORKED AROUND RIGHT OF WAY CONSTARINTS
NEED FOR TEMPORARY EXCAVATION SUPPORT SYSTEM	Needs a 1:1 cut in original ground to be constructed	No	YES
MAINTENANCE OF TRAFFIC DURING CONSTRUCTION	Can not be maintained	Can be maintained	CAN BE MAINATINED
AESTHETICS	Desired Aesthetics can be achieved	Desired Aesthetics can be achieved	DESIRED AESTHETICS CAN BE ACHEIVED

Table 20 (Continued)

	Mechanically Stabilized earth	**Soil Nail wall**	**Cantilever Retaining wall**
DURABILITY	Good	Good	GOOD
MAINTENANCE	Not costly	Not costly	NOT COSTLY
AVERAGE WALL HEIGHT	Desirable up to 15 meters	Desirable up to a max of 10 meters per each segment	CAN BE USED FOR WALLS 20 METERS OR MORE.
TOLERANCE TO SETTLEMENT AND FOUNDATION CONDITIONS	NEEDS A STABLE FOUNDATION	Good Tolerances	NEEDS A STABLE FOUNDATION
DEFLECTION	NEGLILGIBLE	Deflects over a period of time and then remains constant	NEGLIGIBLE
SOIL PROPERTIES	Any	Can not be constructed in Specific Soils.	ANY

Table 20 (Continued)

	Mechanically Stabilized earth	**Soil Nail wall**	**Cantilever Retaining wall**
DURATION	Approximately: 30 m^2/ Day	Approximately: 100 m^2/ Day	APPROXIMATELY: 30 M^2/ DAY
COST‡	\$250 - \$ 450 Per m^2	\$200 - \$ 500 Per m^2	\$200 - \$ 300 PER M^2
EQUIPMENT	EXCAVATOR, CRANE, BULLDOZER, & COMPACTOR.	Excavator, Scraper, Track mounted drill rig, High lift & Crane.	EXCAVATOR, CRANE, BULLDOZER AND COMPACTOR.
CREW	5	8	5
TOPOGRAHY	Not suitable to stepped construction or Sloped construction	Suitable for stepped and Sloped construction.	NOT SUITABLE TO STEPPED CONSTUCTION OR SLOPED CONSTRUCTION.

NOTE:

‡ Only the base construction cost has been indicated. Additional cost has to be accounted for mobilization, verification testing, construction survey, design, and margin for the contractors.

9. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

During an urban highway reconstruction project, large amounts of time and money are invested in foundation systems and retaining structures, which happen to be the essential components of bridge, and grade and pave projects, if involved. It is vital to select a foundation system and a retaining structure which reduces cost and time apart from meeting the design considerations for a given situation.

The researcher spent considerable time gathering appropriate data to assess the productivity rates, cost and schedule for such specialty construction. The information gathered and assessed has been presented in tables 8 and 20 of this thesis report. These tables provide essential data required for comparing the systems and help the decision maker to choose an appropriate construction system.

It is essential to understand that the lesser cost and time required for completion of a specialty construction project are not the sole deciding factors. Apart from design considerations, environmental issues, location of project and availability of right of way should also be considered before making a decision. Understanding the equipment needed to accomplish a project is also important because of the space constraints resulting from urban traffic congestions.

Recommendations for further study

1. A study performed on the systems discussed in this thesis, in a rural environment can help a better understanding of the effects with respect to cost and schedule in urban environment. Comparison between urban and rural projects is vital to understanding cost and schedule over-runs.

2. A comparison of projects by different contractors from different cities would lead to a better data. Also, if two projects of the same magnitude consisting of different systems are compared, then the data obtained will have more credibility in deciding the most suitable system.

3. Also, important is the knowledge on expedition costs and multiple crew compatibility. A study has to be performed on construction projects with multiple crews and projects with short duration. Data obtained from these projects helps in understanding the expedition costs and the feasibility of using multiple crews to expedite the project and accomplish the project completion in less than required time.

APPENDIX A – RAMMED AGGREGATE PIER DATA COLLECTED FROM FIELD

The following observation does not record non-working days:

Day	TIME (Min)	DEPTH (Meters)	Crew	Equipment
1	140	380	3	Drill Rig, Skid Loader, Tamper
2	Change of Work place			
3	Verification Testing			
4	200	595	3	
5	230	684	3	
6	210	636	3	
7	225	680	3	
			3	
Total	1005	2975	3	

APPENDIX B – STONE COLUMN DATA COLLECTED FROM FIELD

The following observation does not record non-working days:

Day	TIME (Min)	DEPTH (Meters)	Crew	Equipment
1	406	100	4	Crane, Front End loader, Vibroflot, Power generation Unit.
2	384	153	4	
3	416	128	4	
4	396	148	4	
5	489	160	4	
6	530	132	4	
7	504	129	4	
8	519	184	4	
9	521	145	4	
10	155	48	4	
11	333	136	4	
12	483	190	4	
13	498	185	4	
14	499	187	4	
15	359	135	4	
16	501	184	4	
17	533	181	4	
18	419	116	4	
19	489	127	4	
20	552	210	4	
21	505	210	4	
22	511	183	4	
23	473	168	4	
24	509	195	4	
25	111	35	4	
26	362	89	4	
27	293	69	4	

APPENDIX C – MECHANICALLY STABILIZED EARTH COLLECTED FROM FIELD

The Following observations have been recorded from different projects done by different contractors. The observations recorded included non-working days also.

Wall #	5801	5808	5807	5820	5822	5824
Sq m	540	398.2	363.2	740.3	135	1149
Duration	30	8	20	33	27	70

APPENDIX D – SOIL NAIL WALL DATA COLLECTED FROM FIELD

Soil Nail wall:

Day	Sq m	Crew	Equipment
1	91.82	8	Excavator, Scraper, Track mounted drill rig, High-lift
2	114.78	8	
3	105.6	8	
4	151.51	8	
5	137.74	8	
6	128.55	8	
7	146.92	8	

Cast-in-place facing:

Day	Sq m	Crew	Equipment
1	150	5	Crane
2		5	
3	150	5	
4		5	
5	150	5	
6		5	
7	150	5	
8		5	
9	150	5	
10		5	

APPENDIX E – CANTILEVER RETAINING WALL DATA COLLECTED FROM FIELD

Footing: 18 days

Days	Meters	Crew	Equipment
1	16.49	4	Crane
2	27.00	4	
3		4	
4	27.00	4	
5		4	
6	27.00	4	
7		4	
8	27.00	4	
9		4	
10	27.00	4	
11		4	
12	15.01	4	
13		4	
14	11.99	4	
15	26.62	4	
16		4	
17	21.47	4	
18		4	

Retaining Wall:

Days	Meters	Crew	Equipment
1		4	Crane
2	9	4	
3		4	
4	7.5	4	
5		4	
6	9	4	
7		4	
8	9	4	
9		4	
10	9	4	
11		4	
12	9	4	
13		4	
14	9	4	
15		4	
16	9	4	
17		4	
18	9	4	
19		4	
20	9	4	
21		4	
22	9	4	
23		4	
24	9	4	
25		4	
26	9	4	
27		4	
28	6	4	
29		4	
30	11.93	4	
31	9	4	

32		4	
33		4	
34	9	4	
35		4	
36	8.62	4	
37		4	
38		4	
39	21.47	4	

APPENDIX F- GLOSSARY OF TERMS

1. Aggregate friction angle (Ø): The angle that the total stress failure envelope makes with the normal stress axis (Das M. B., (1990), Principles of Geotechnical Engineering, 2nd Edition, p 311).
2. SPT N-value: Blow count value from standard penetration test.
3. Stress concentration ratio: Is the ratio of the stiffness in a column (such as a column or rammed aggregate pier) to the stiffness in soil matrix.
4. Modulus of elasticity: It is defined as axial deviator stress to axial strain in a triaxial compression test (psi) (Aggregate Hand Book, 1996, p 3-17).
5. Tip stress: Stress developed at the bottom of the Rammed aggregate.
6. Floating: Rammed aggregate pier foundations are termed as floating foundations, because of its load transfer from it tip occurs in compressible layer. Where as, stone column transfers its load to a stiff layer which is termed as end bearing.

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