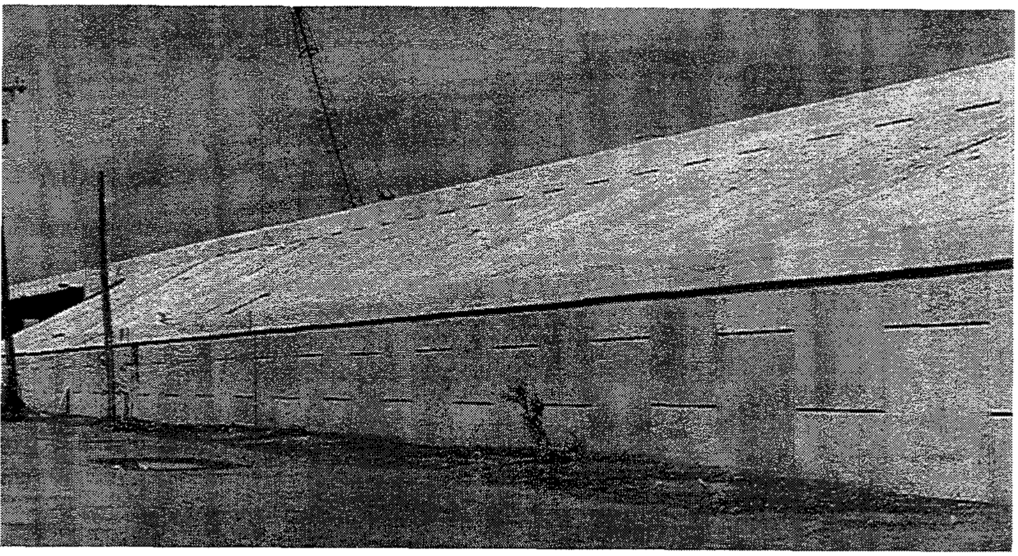
STRENGTHENED EARTH WALL



Final Report
November 1997

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16. ABSTRACT

The Oklahoma Department of Transportation (ODOT) recently completed a project that included a Strengthened Earth Wall. The Mechanically Stabilized Earth (MSE) wall was constructed by Muskogee Bridge Company as a part of project IM-NHIY-44-2(349)231 on I-44 in Tulsa.

The main objective of the Strengthened Earth Wall project was to evaluate the constructability of the structure as compared to other MSE walls currently used in Oklahoma. A strong secondary consideration was cost analysis.

The wall was constructed in a timely fashion and no problems with performance are anticipated. Some advantages included; speed of construction, larger panels, and thicker backfill lifts.

It is recommended that Strengthened Earth Wall be included in ODOT specifications and its use allowed where competitive bidding makes the cost comparable with other MSE structures.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac	acres	0.4047	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7645	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N
lbf/in^2	poundforce per sq inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
		AREA		
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce	lbf/in^2

STRENGTHENED EARTH WALL

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EXECUTIVE SUMMARY

In order to constantly evaluate new retaining wall systems, it is necessary to demonstrate their feasibility under Oklahoma Department of Transportation (ODOT) conditions. The evaluation of new designs, materials, and construction procedures provides the opportunity to build a more cost effective wall. The new designs should also take into consideration the limited space available with urban construction.

Strengthened Earth Wall (SEW) is the trade name of a mechanically stabilized earth (MSE) system developed by Gifford-Hill & Company. The touted features include thicker layers, larger panels, and faster construction. The major feature of the earth stabilizing element is a galvanized welded wire mesh.

ODOT recently completed a project including a Strengthened Earth Wall installed by Muskogee Bridge Company of Muskogee, Oklahoma. After some initial changes in placement due to the in-situ soil conditions, construction went relatively well. There have been no reported problems since the project's completion, one year ago.

The cost was somewhat high [$430/m^2$ ($40/ft^2$)] because of the experimental nature of the MSE wall and the sole source acquisition. According to Gifford-Hill & Company's Larry Shaw, Vice President and General Manager - Special Products Region, the average cost for their Strengthened Earth Wall would be comparable to that of other MSE walls currently used in Oklahoma.

INTRODUCTION

The MSE wall was constructed by Muskogee Bridge Company as a part of project IM-NHIY-44-2(349)231. The wall is located on I-44 right-of-way in Tulsa, OK between 31st Street and Memorial Avenue. (Figure 1.)

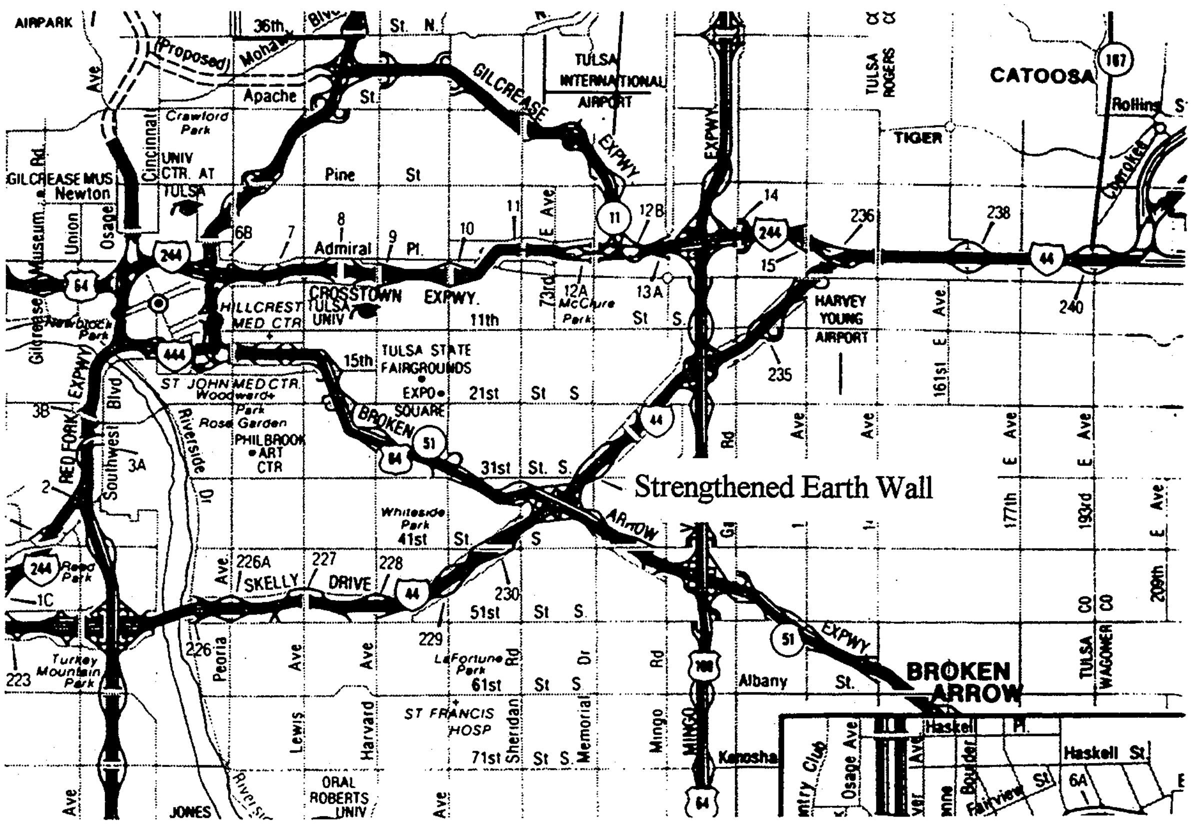

Figure 1. Project location map.

The Strengthened Earth Wall consists of a series of precast concrete panels. The total length of the wall is 143 m (469 ft). The main section of the wall (119 m [329 ft]) is of uniform height. The ends are tapered to match slopes.

CONSTRUCTION

Materials

Four primary sizes of panels were used; types A (1.8 × 2.1 m [6 × 7 ft]) fitted to panels on all sides, B (same dimensions as A but flat on the bottom), C (0.9 × 2.1 m [3 × 7 ft]) flat on the bottom, and E (same dimensions as C but flat on the top). The panels at each end of the wall were fabricated to match the slopes. The wall was designed to be built on a 300 × 150 mm (12 × 6 in) unreinforced concrete leveling pad. The fill was constructed with a drainable granular material and galvanized wire mesh. (Figure 2.) Joints were covered with a non-woven filter fabric and a High Density Polyethylene underdrain pipe was installed. All panels were cast in class 'A' concrete.

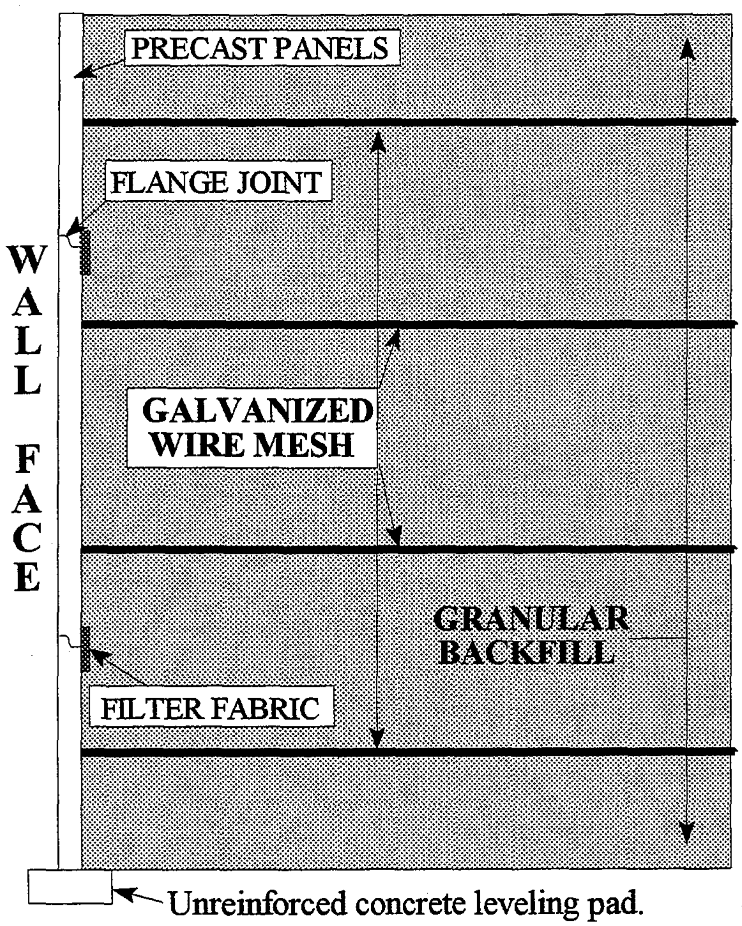

Figure 2. Cross section detail.

Procedure

The plans stated that it was the responsibility of the owner to determine if the maximum applied bearing pressure at the foundation level, shown by the calculations, was allowable for that location. As a result of poor bearing pressure, the SEW was relocated horizontally from 20 m (65 ft) right to 30 m (100 ft) right and vertically from elevation 208.258 m (683.26 ft) to 204.216 m (670.00 ft).

The Strengthened Earth Wall panels were prefabricated by Gifford-Hill & Company at the Grand Prairie, Texas plant and delivered to the site by flat bed truck. The panels were separated by 100 × 100 mm (4 × 4 in) wood blocks. The number of panels per load varied due to the different sizes. The panels were 350 mm (7 in) thick and varied in height and length. The largest panels weighed about 1600 kg (3500 lbs). The panels were flanged and aligned vertically with 2 × 46 cm (0.75 × 18 in) fiberglass dowels. (Figure 3.) The panels were supported by galvanized wire mesh with the specially designed interlocking system detailed

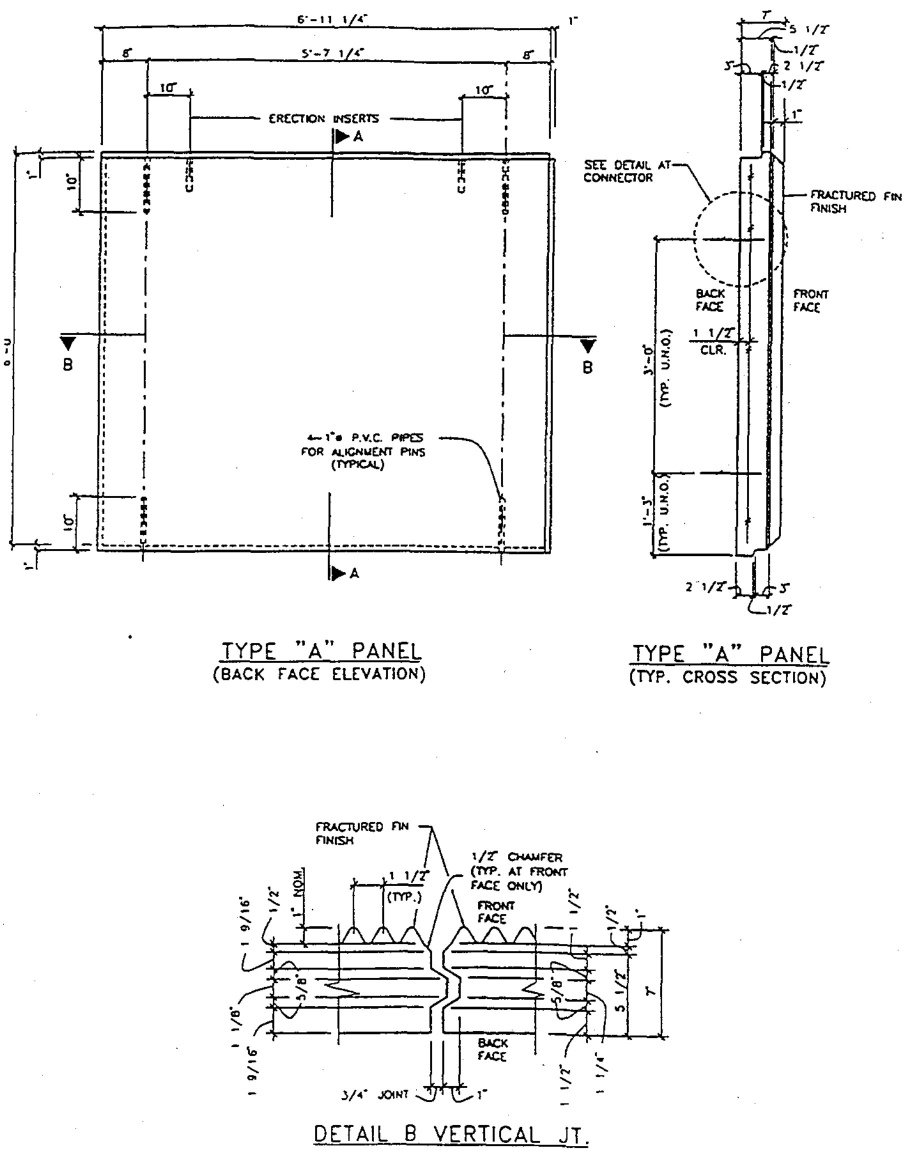

Figure 3. Back face elevation of typical panel.

in Figure 4. Where CIP inlets obstructed the connection of the mesh to the panels, the inlets were anchored to the panels and the mesh was connected to the back side of the inlets. (Figure 5.)

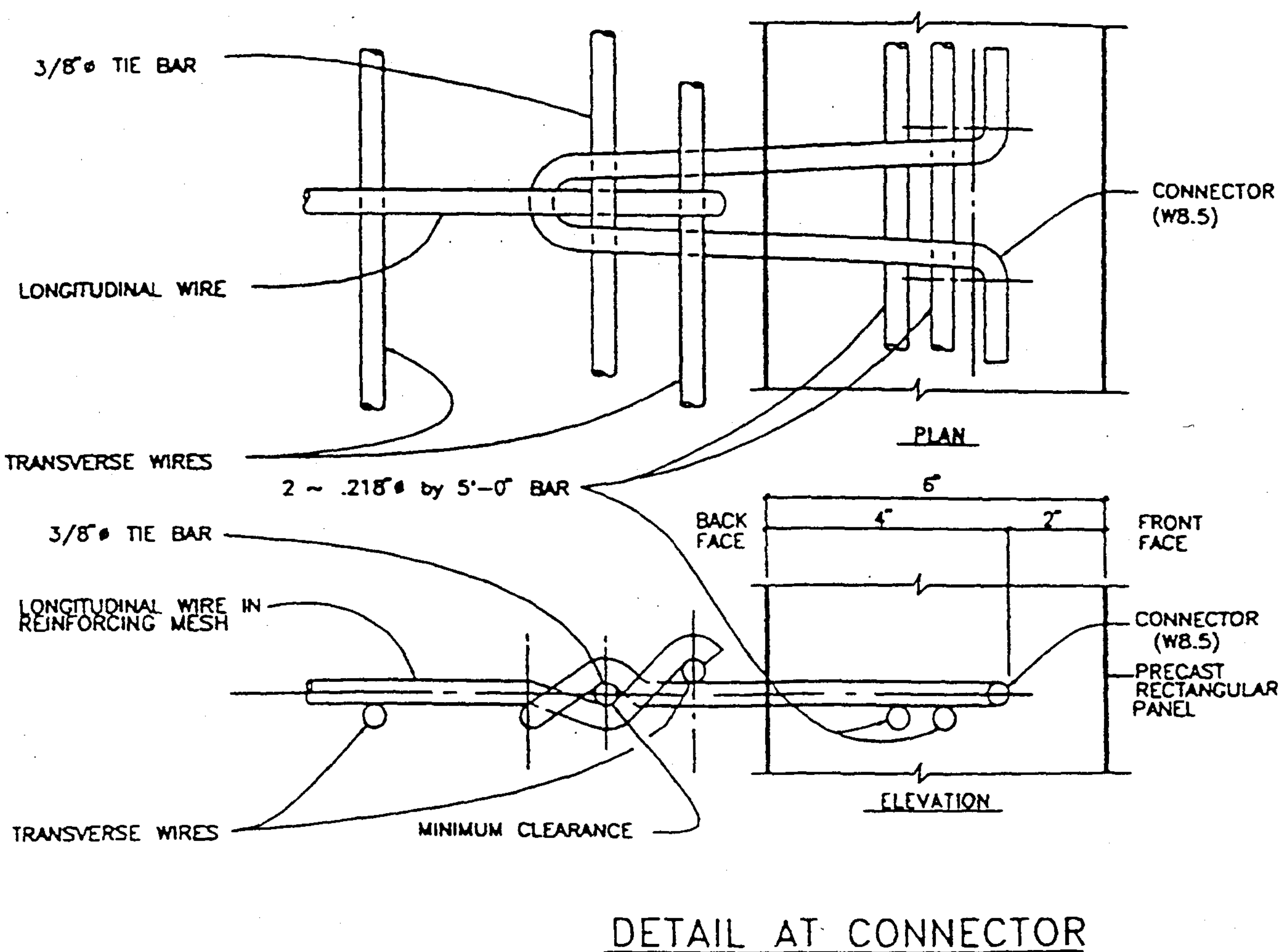

Figure 4. Wire mesh connectors.

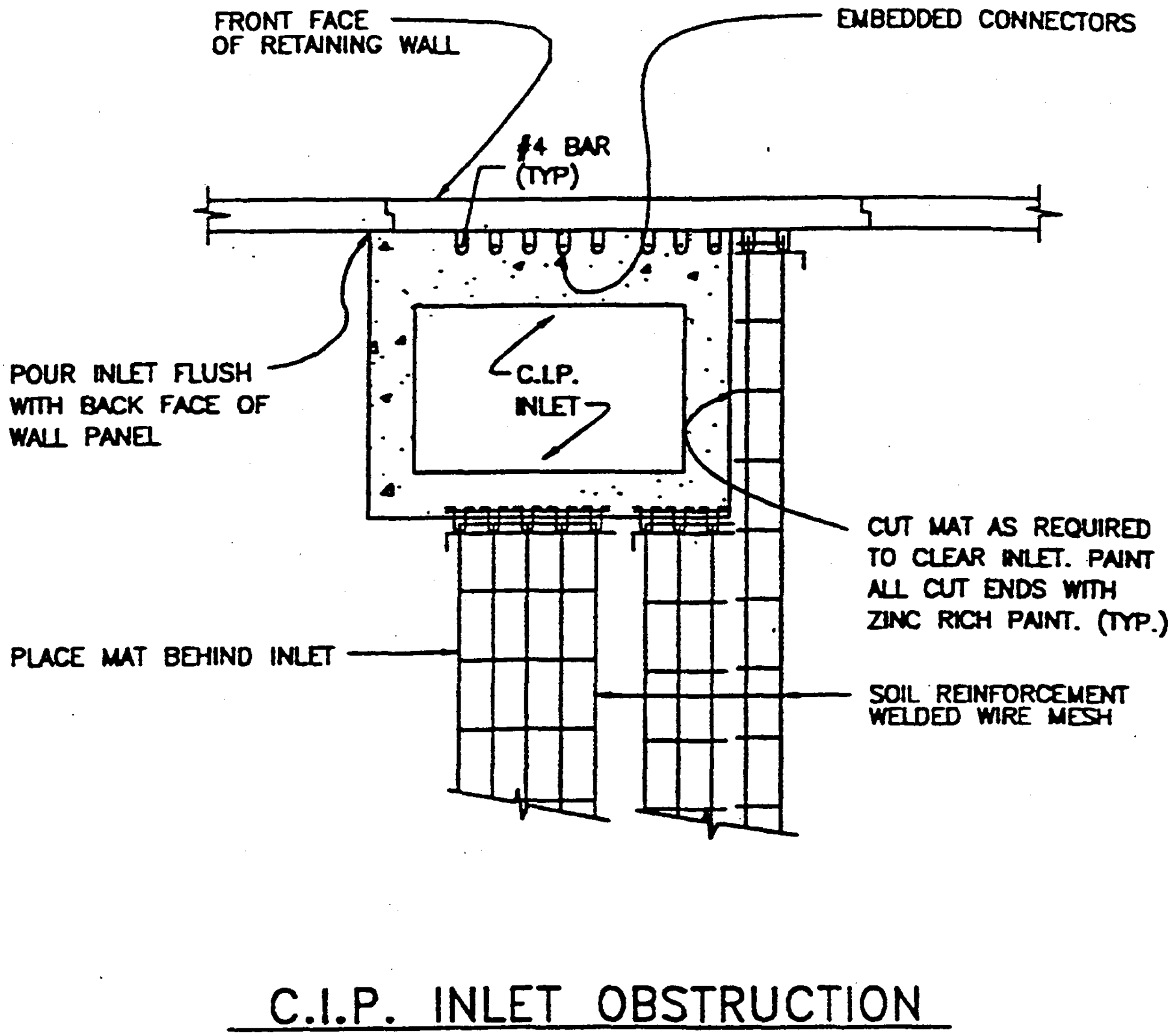

Figure 5. Mesh connection at CIP inlet.

The wall on this project was designed to be 4 m (13 ft) tall in the main section. A JCB Loadall, with two steel lifting cables attached, was used to unload and erect the panels. Each cable was attached using a ring clutch and "Burke Spread Anchor" lift device. (Figure 6.) The panels were stacked on the ground near the erection location, spaced between layers by wooden blocks.

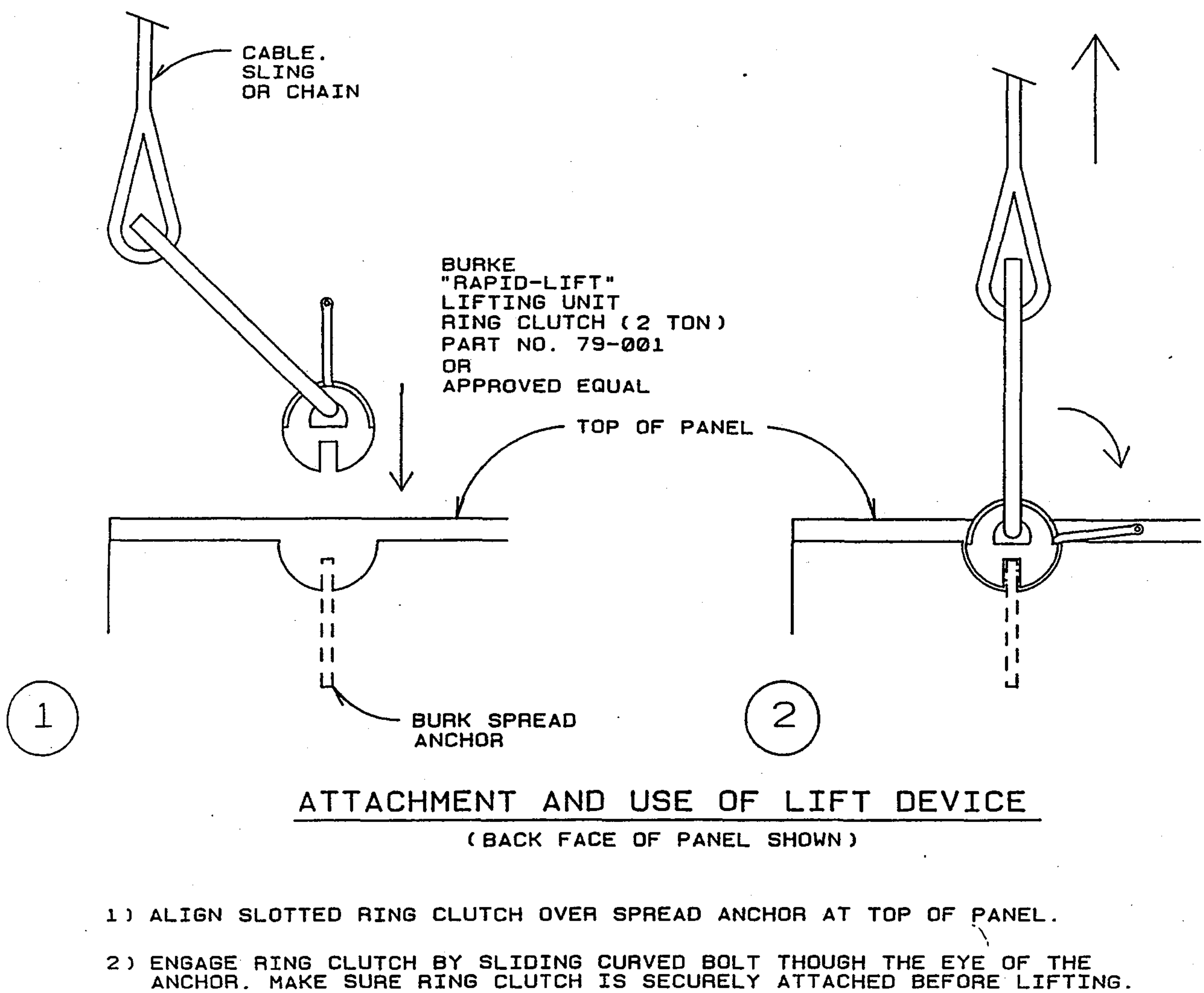

Figure 6. Cable attachment system.

On this project, erection of the panels was to be completed in four lifts. Before erecting any panels the leveling pad was surveyed and laid out (according to construction procedures provided by Gifford-Hill & Company) in order to identify low spots where shimming might be necessary to establish proper grade. The first lift was the most critical for the erection of this wall. The Loadall carried the panels as close to their position as possible where the contractor's employees guided them into place. (Figure 7.) Each panel on the first lift was placed on an initial 10 mm/m (⅛ in/ft) batter and leveled with shims. (After completion of the wall and compaction of the granular backfill, the batter averaged 0 mm/m [0 in/ft]).

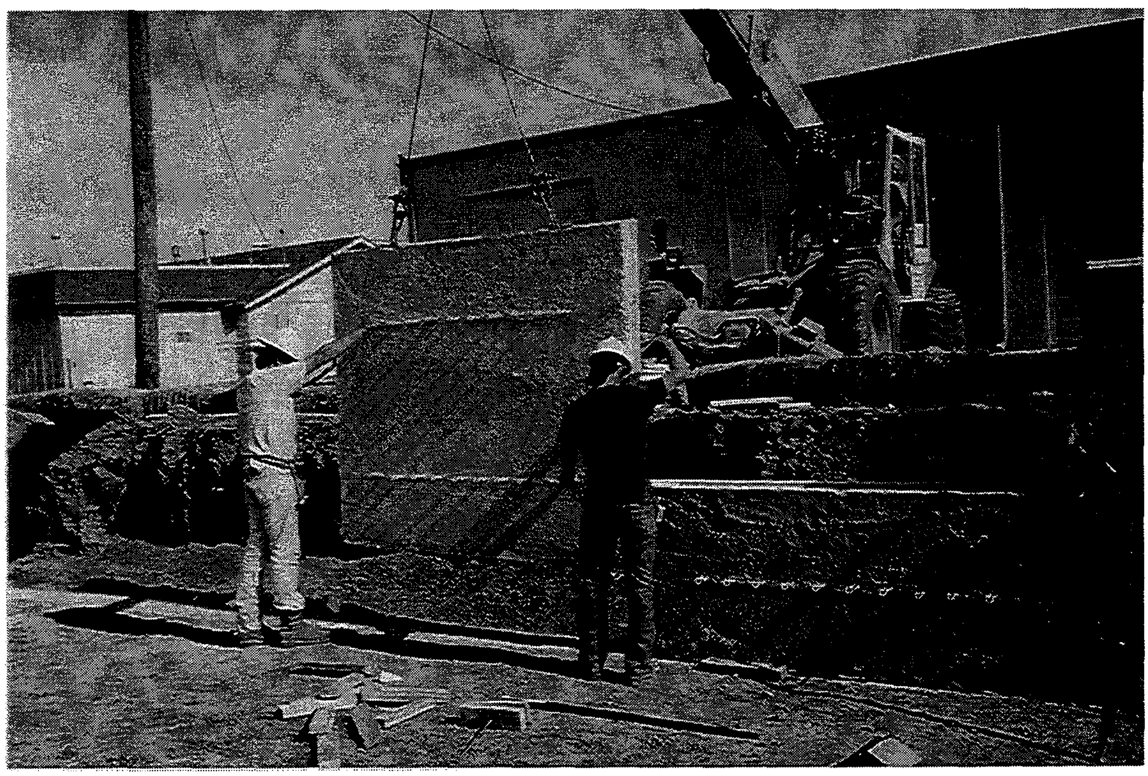

Figure 7. Setting first lift of panels.

The erection of the first lift began with the slope panels and continued with alternating 'B' and 'C' panels. Batter boards were placed on the 'B' panels for stabilization. Clamps and hardwood wedges

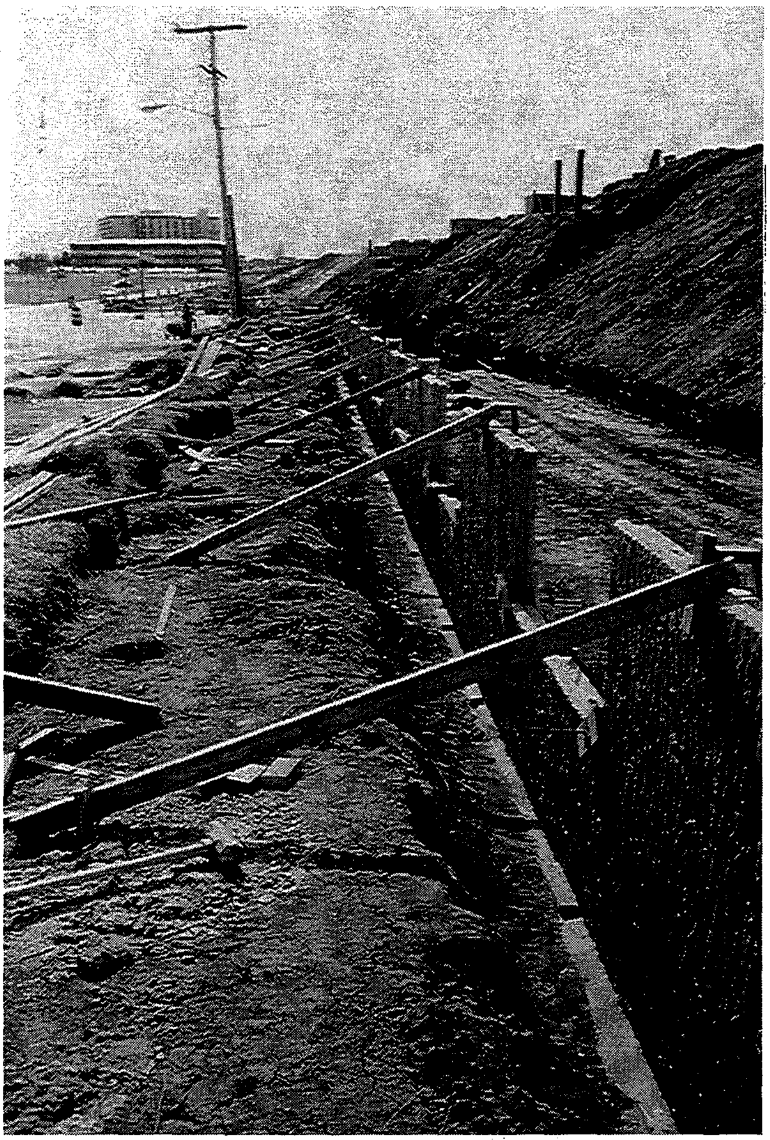

Figure 8. 'C' Panels with batter boards and wood clamps.

After completion of the first lift, a non-woven filter cloth was placed along all joints and 200 mm (8 in) perforated high density polyethylene pipe with pipe underdrain cover material installed over the leveling pad.

Backfilling began by unloading ten-wheel dump trucks and placing the select granular backfill (Table 1, Appendix.) in 200 mm (8 in) lifts. Compaction was achieved by flooding the fill with water. Density was recorded by the ODOT Materials Division, Soils & Foundations Branch, with a nuclear density gauge. (Table 2, Appendix.)

The fill was placed until a height of 460 mm (18 in) above the leveling pad was reached. At this point, the contractor placed the first row of galvanized wire mesh as shown in Figure 9. Backfilling continued until the height of the 'C' panels was reached. The contractor then began the second lift consisting of 'A' panels resting on top of the 'C' panels. Clamps were used to hold the 'A' panels in place. Alignment pins were used between the 'C' and 'A' panels to achieve vertical alignment.

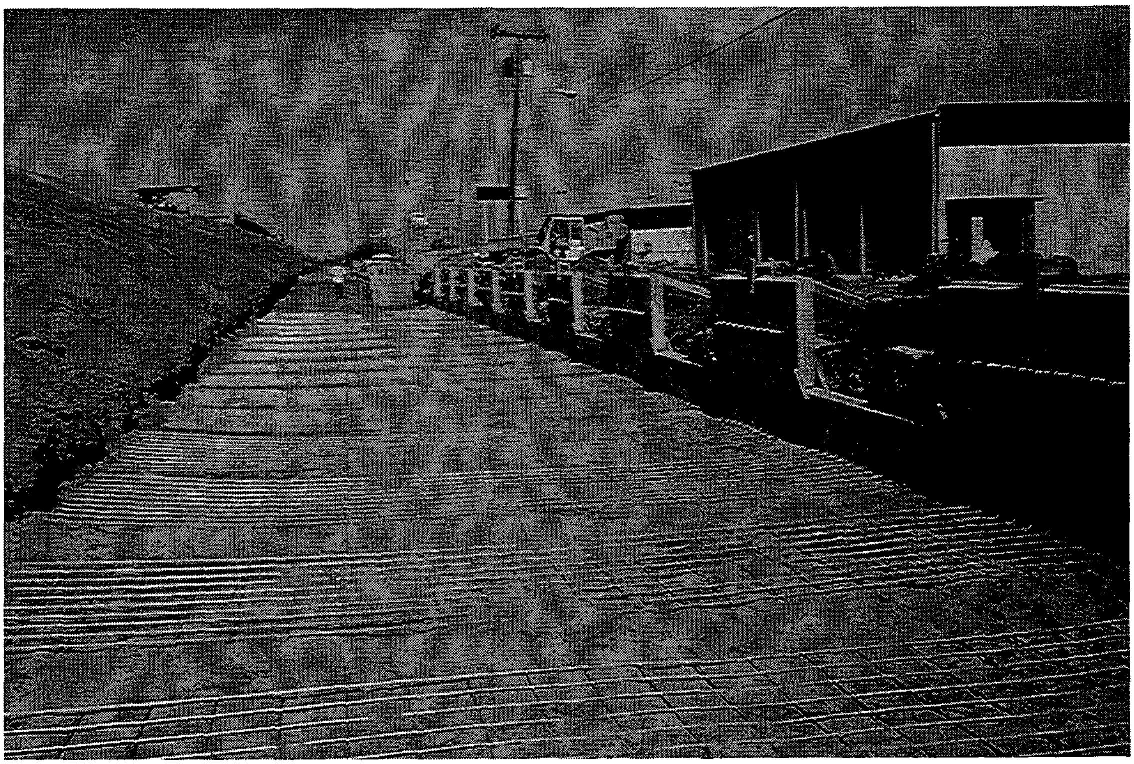

Figure 9. Wire mesh over backfill.

Backfilling recommenced, the second row of wire mesh was installed, and backfilling continued to the height of the 'B' panels. The third lift of panels was erected in similar fashion with the 'A' panels resting atop the 'B' panels. Backfilling continued to the level of the third row of reinforcing mesh and, after installation of the mesh, proceeded to the top of the second lift of 'A' panels. Finally, the 'E' panels were erected and the fourth row of wire mesh was completed.

Chronology

The first lift of panels (67 pieces) was erected on March 11-12, 1996.

The second lift (32 pieces) was erected on March 14-15, 1996.

The third lift (31 pieces) was erected on March 20-21, 1996.

No unusual problems were encountered to this point. One problem occurred in the fourth lift, however; panel S16-4 was cast in the wrong dimensions. ODOT field personnel and the contractor agreed to have the manufacturer fabricate the correct size and the fourth lift (29 pieces) was erected on April 1-2, 1996.

Finally, the leveling pad was poured for coping on April 1-2, 1996 and the coping was placed on April 3-4, 1996. (Figure 10.)

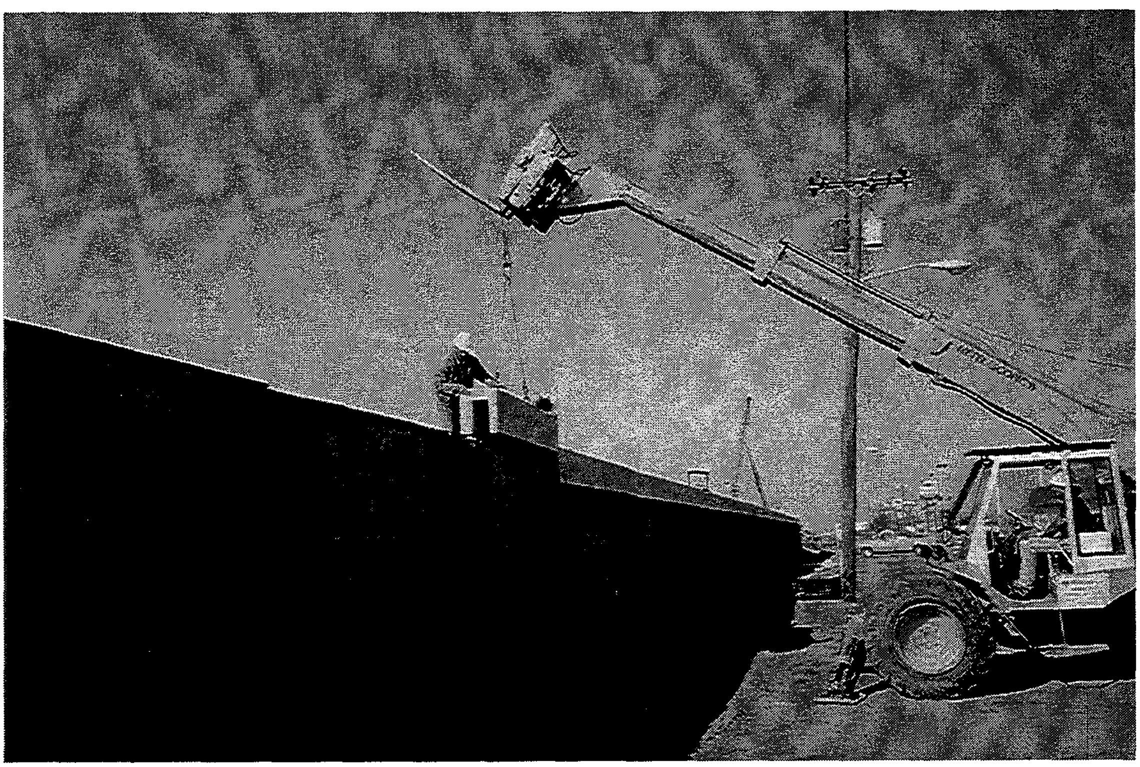

Figure 10. Placing coping.

The total amount of time for the erection of panels, backfilling, placing wire mesh grids, and placing the coping was approximately 17 days. The overall procedure of constructing the Strengthened Earth Wall moved rapidly without any major problems. Photos appear in Figure 11 below.

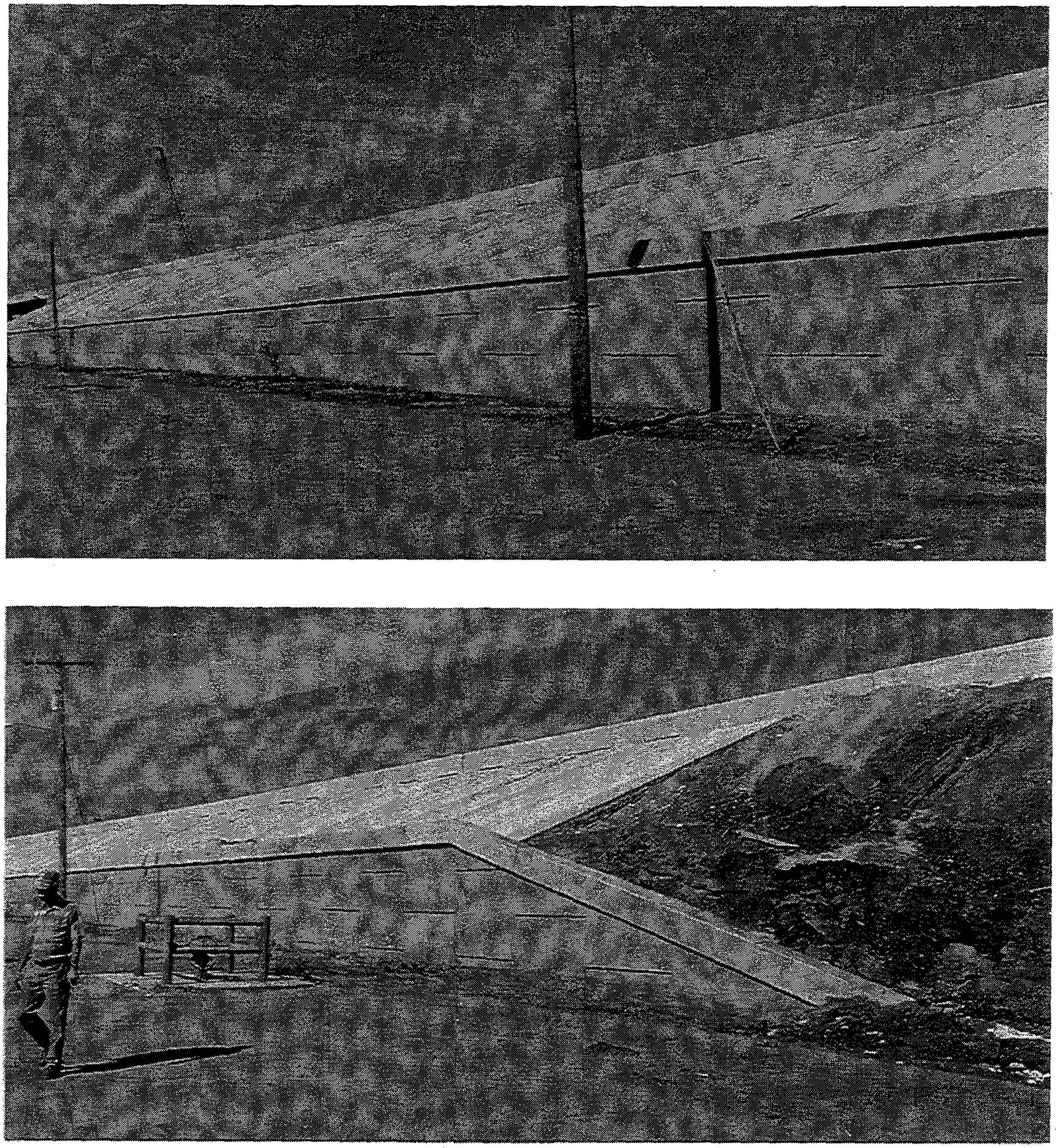

Figure 11. Completed Strengthened Earth Wall.

ANALYSIS

On May 15, 1997 Curt Hayes, Research Project Branch Manager, made the following observations in a letter to the project file.

"On Monday, May 12, 1997, a reconnaissance survey was made of the above wall [SEW] located at I-44 and Memorial in Tulsa. At this time, no cracks or misaligned panels were noted." "The wall appears to be performing satisfactorily."

Subsequent observations from ODOT personnel in the Roadway Design Division concurred with Mr. Hayes' findings and the Department does not anticipate any problems with performance of the SEW in the future.

COST INFORMATION

The total cost of the SEW to ODOT was $430/m² ($40/ft²). This is considerably higher than the cost of comparable MSE walls previously constructed in Oklahoma. However, the experimental nature of the project and the sole source acquisition of the product greatly inflated the cost. According to Gifford-Hill & Company's Larry Shaw, Vice President and General Manager - Special Products Region, the average cost for their Strengthened Earth Wall would be comparable to that of other MSE walls currently used in Oklahoma.

CONCLUSIONS

The main objective of the Strengthened Earth Wall project was to evaluate the constructability of the structure as compared to other MSE walls currently used in Oklahoma. A strong secondary consideration was cost analysis. The original work plan identified the following six aspects of construction and performance as the basis of the final evaluation.

1) Panel erection
2) Wall integrity (tilting, etc.)
3) Settlement
4) Lateral movement
5) Backfill procedures
6) Drainage

Panel Erection

The panels for the SEW were larger than those usually used in Oklahoma. While this called for the use of larger lifting machinery, it also sped up the construction process considerably. The availability of various sizes of panels allowed the design process to be more site specific; the wall could be configured for the existing conditions. Fewer panels means fewer joints and, therefore, less maintenance.

Wall Integrity

One year after construction the wall showed no signs of leaning, bulging, cracking, or any other distress related to wall integrity. It is the opinion of ODOT personnel from Construction, Design, and Research that the wall integrity will remain sound for an acceptable period of time.

Settlement

It is important to know the foundation conditions at the construction site. It is the responsibility of the owner to determine the bearing pressure at the foundation level. Had this wall been built at the original location, settlement would have become a major problem. However, because the location was checked and found unsuitable, the wall was constructed on an acceptable foundation and no settlement problems have occurred nor are any expected in the future.

Lateral Movement

The one year visual evaluation found no signs of lateral movement other than that expected and allowed for with the original batter. There was some slight lateral undulation in the coping but this was determined to have occurred during installation and not as the result of movement.

Backfill Procedures

The method of backfilling by increments as construction progressed and compacting by flooding each lift was successful and efficient. It is important to remember that the material specifications must meet drainage needs. The gradation of the granular backfill for this project was purposely shifted toward the coarse end of the specification. (Average gradation appears in Table 1, Appendix.)

Drainage

No drainage related problems were discovered during the evaluation period. The granular backfill appears to be draining well and no erosion problems have been detected.

RECOMMENDATIONS

It is recommended that the use of the Strengthened Earth Wall be permitted as an option where competitive bidding makes the cost commensurate with the needs of ODOT. Current specifications for MSE walls should be reviewed and, where necessary, revised to include SEW construction.

The SEW constructed for this project should be visually inspected at one year intervals for a period of five years in order to monitor long term performance and maintenance; results of each visit to be documented in a letter to the project file.

APPENDIX

Specification Tables

Table 1. Average gradation on granular backfill material.

SIEVE	%PASSING REQUIRED	%PASSING FOUND
3"	100	100
1"	90-100	100
40	0-60	28
200	0-15	0.34
PROPERTIES	**REQUIRED**	**FOUND**
LL	NA	NP
PI	6 max	NP
Aggregate Durability Index*	30 min	54

* Tested by ODOT Soils & Foundations Branch in Oklahoma City, Ok.

Table 2. Average densities on granular backfill.

GRID	AVERAGE %COMPACTION (REQUIRED = 95.0)	AVERAGE %MOISTURE (OPTIMUM = 4.0)
1	97.3	3.6
2	98.4	6
3	96.9	2.5
4	97.3	2.9