FANWALL NOISE BARRIER WALL.

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CONSTRUCTION REPORT

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16. ABSTRACT

The Oklahoma Department of Transportation (ODOT) has completed a 295.97 foot long section of FANWALL Noise Barrier Wall. The experimental FANWALL was part of Project IR-240-1(338)000.

FANWALL is a proprietary product produced by Reinforced Earth, Inc. FANWALL Noise Barrier Walls are erected from precast, reinforced, concrete panels. On IR-240-1(338)000, the panels were cast at Reinforced Earth's Waco, Texas plant and shipped to the project site by truck.

The major advantage of FANWALL over Cast in Place Noise Barrier was expected to be lower overall cost. Although the purchase price per square foot is higher for FANWALL than the contract price per square foot for Cast in Place Wall, it was thought that lower labor costs for erecting the wall would bring the overall price of FANWALL below that of the the Cast in Place type. On Project IR-240-1(338), the expected labor reduction did not materialize, due to problems in fitting the panels together.

Difficulties in fitting the panels were corrected. However, this was not done before the labor required (man-hours) had increased to the point where it was approximately equal to that for the same length of Cast in Place Wall.

The completed Fanwall section will be monitored for settlement, lateral movement, and tilting.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

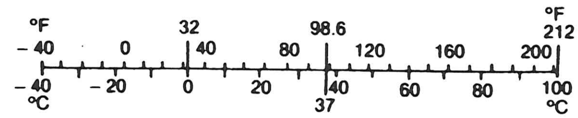
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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Introduction.

The Oklahoma Department of Transportation (ODOT) has recently completed construction of an experimental section of FANWALL Noise Barrier Wall. The FANWALL section covered a 295.97 foot length of curve. 4,825 square feet of FANWALL (44 sections) was constructed under Project IR-240-1(338)000. This project also included 76,700 square feet of Cast in Place Noise Barrier Wall.

The contractor on Project IR-240-1(338)000 was Lippert Construction, Inc., of Oklahoma City. The IR-240-1(338)000 site is located in southwest Oklahoma City. The FANWALL section was built on Right-of-Way, along an entrance ramp from northbound I-44 to eastbound I-240 (Figure 1.).

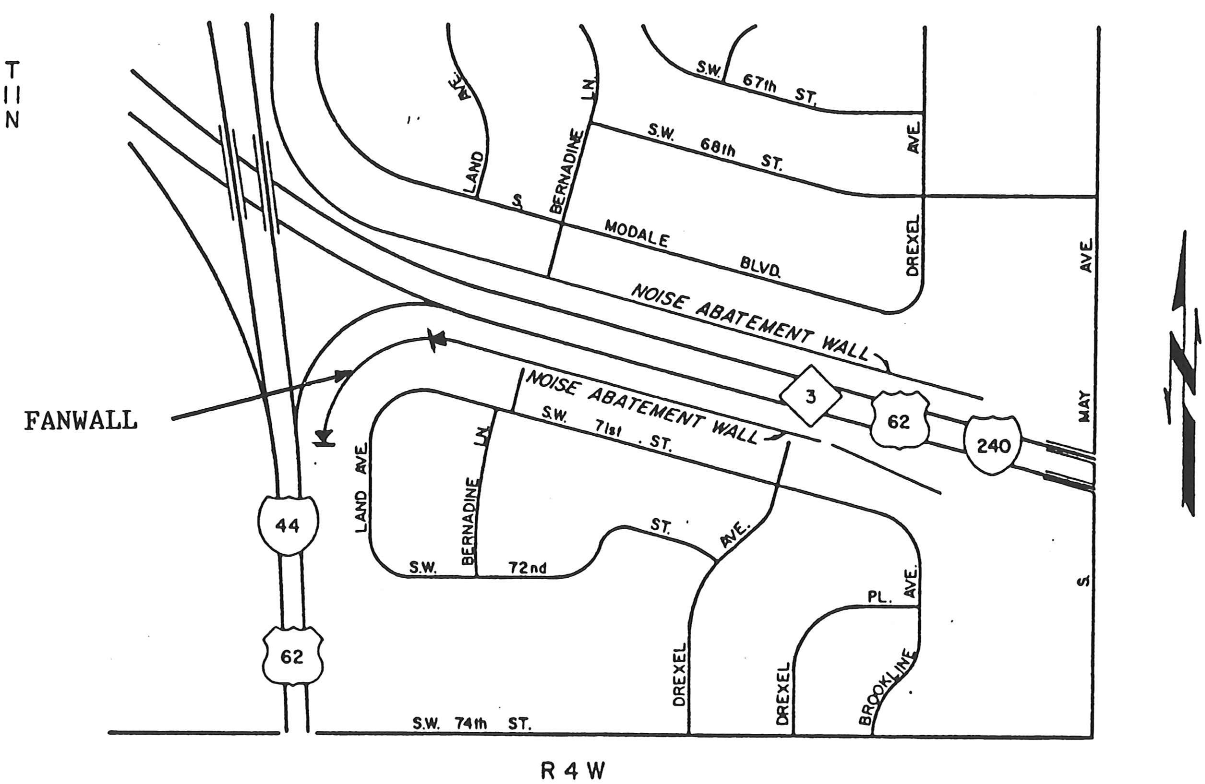


Figure 1. FANWALL Location.

FANWALL System

The FANWALL Noise Barrier System consists of a series of precast concrete panels. Panel dimensions are: Eight feet high by fifteen feet long by eight inches thick. The panels are reinforced with number 4 reinforcing bars on 18-inch centers, in both the horizontal and vertical directions (Figure 2). On this project, two types of FANWALL panels, "tops" and "bottoms", were used. Individual panels are designated by number for reference purposes (Figure 3). Each numbered section consists of a "top" (T), and a "bottom" (B). Tops and bottoms are connected to each other by a keyway joint. Vertical joints are ball and socket type (Figure 4).

Panels are tied together horizontally by "FANWALL Panel Connector Assemblies" These consist of 3/8 inch diameter, 7 X 19, 302 stainless steel wire rope (aircraft cable) with capscrews and washers on each end (Figures 6 and 7). The connector assembly cables pass through the panel in two (2) channels, on the socket end, and one channel on the ball end of the panel (Figure 4). The channels are formed by 3/4 inch diameter PVC pipe, placed through the panel before casting. Adjacent FANWALL panels are connected by two (2) cables, located on each end of the panel (Figure 3). Connected panels form a wall with the shape shown in Figure 8.

FANWALL is designed to be supported by a gravel base. Due to soil conditions in the Project IR-240-1(338)000 area, a three foot wide by one foot thick unreinforced concrete levelling pad (Figure 8). was substituted for the gravel base. According to information in the manufacturer's shop drawings, there should have been 1 to 2 inches of gravel on top of the footing when the panels were put into place. No gravel was placed on the footing.

The FANWALL Panels were cast at the manufacturer's Waco, Texas plant and delivered to the IR-240-1(338)000 site by truck.

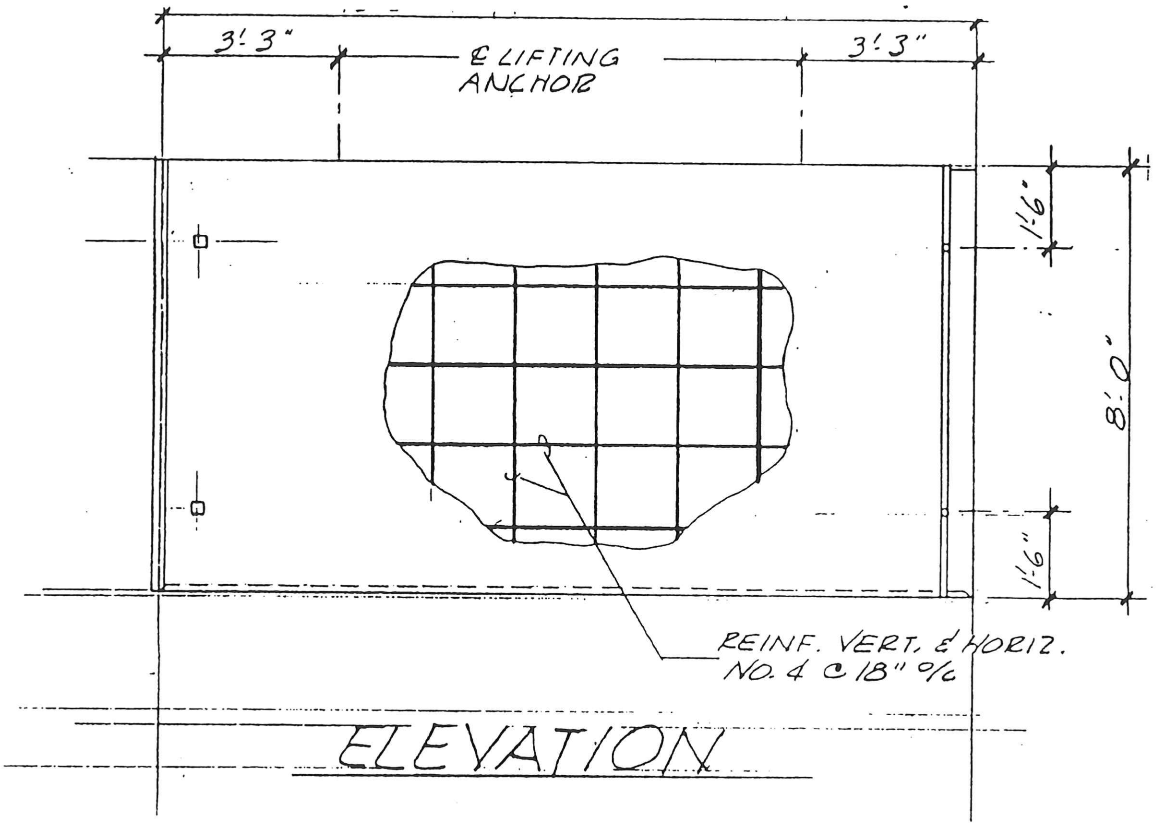


Figure 2. FANWALL Panel Reinforcement.

East ◄———————► **West**

1T	2T	3T	4T	5T	6T	7T	8T	9T	10T	11T	12T	13T	14T	15T	16T	17T	18T	19T	20T	21T	22T
1B	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B	12B	13B	14B	15B	16B	17B	18B	19B	20B	21B	22B

Figure 3. FANWALL Panel Numbers.

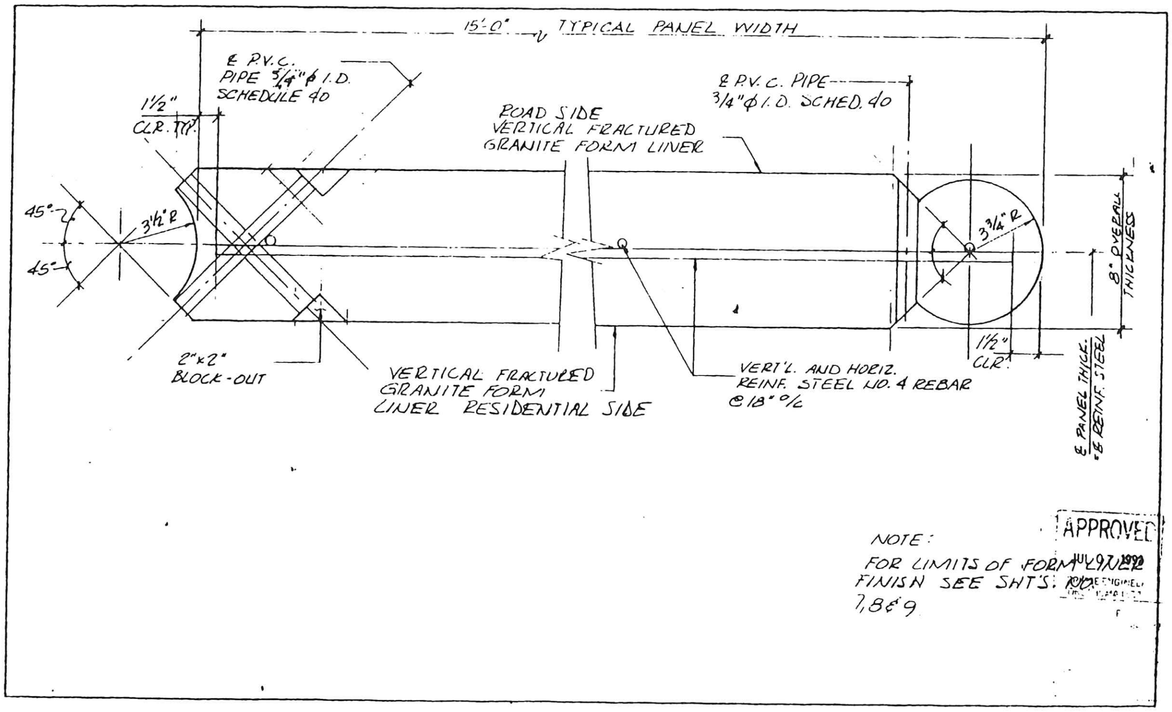


Figure 4. Ball and Socket Joints, FANWALL Panels.

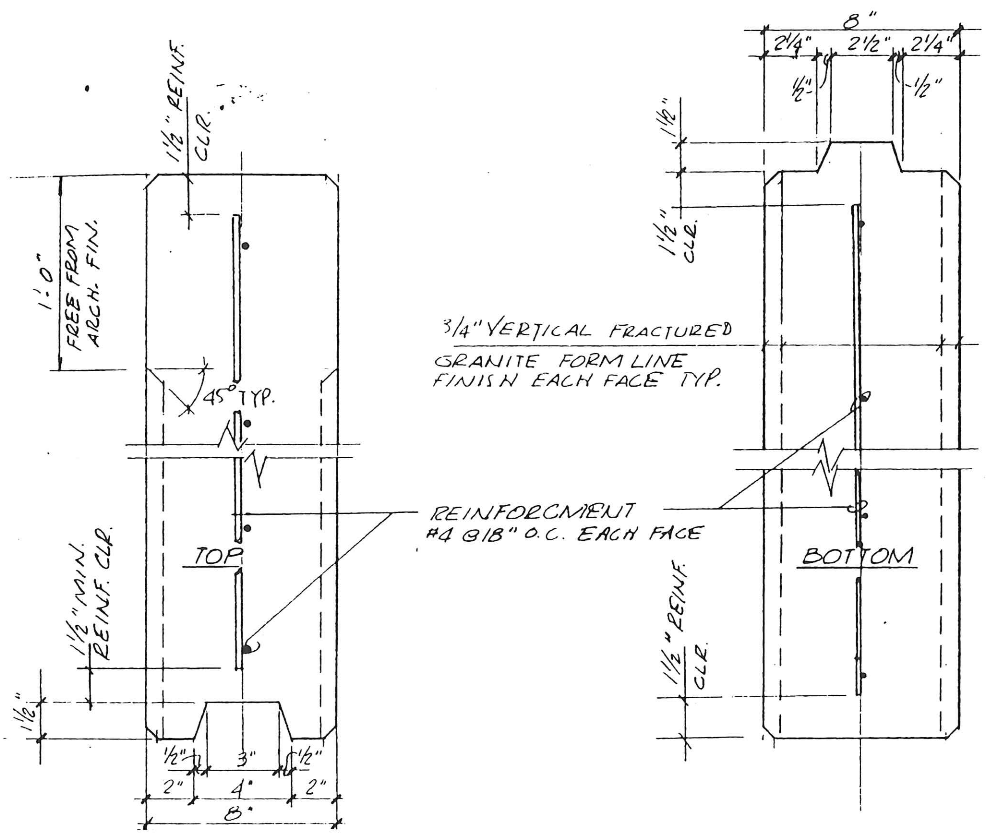


Figure 5. Keyway Joint for FANWALL Top and Bottom Panel Connection.

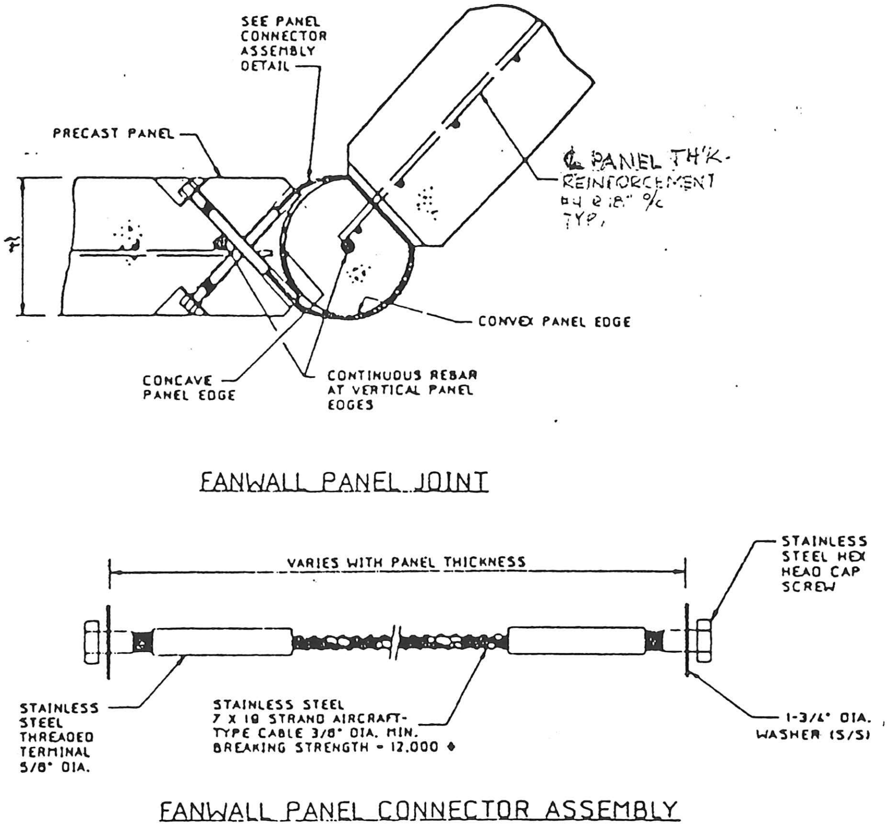
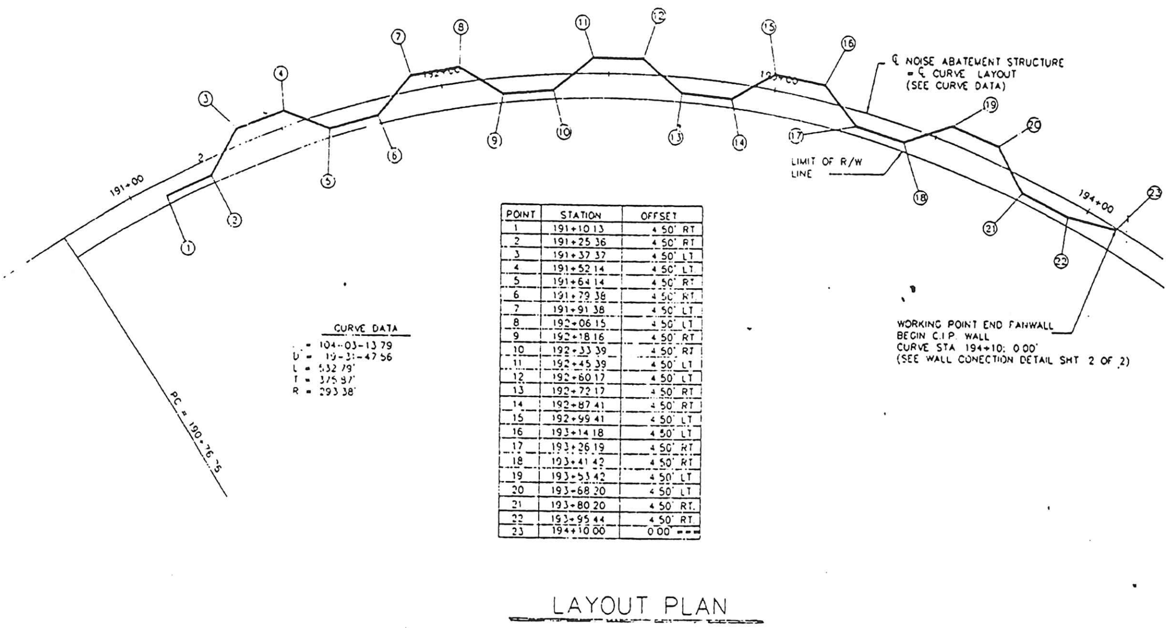


Figure 6. FANWALL Panel Joint and Connector Assembly.

Figure 7. FANWALL Panel Connector Assembly.



POINT	STATION	OFFSET
1	191+10.13	4.50' RT
2	191+25.36	4.50' RT
3	191+37.37	4.50' LT
4	191+52.14	4.50' LT
5	191+64.14	4.50' RT
6	191+79.38	4.50' RT
7	191+91.38	4.50' LT
8	192+06.15	4.50' LT
9	192+18.16	4.50' RT
10	192+33.39	4.50' RT
11	192+45.39	4.50' LT
12	192+60.17	4.50' LT
13	192+72.17	4.50' RT
14	192+87.41	4.50' RT
15	192+99.41	4.50' LT
16	193+14.18	4.50' LT
17	193+26.19	4.50' RT
18	193+41.42	4.50' RT
19	193+53.42	4.50' LT
20	193+68.20	4.50' LT
21	193+80.20	4.50' RT.
22	193+95.44	4.50' RT.
23	194+10.00	0.00' ---

Figure 7. FANWALL Shape (Plan View).

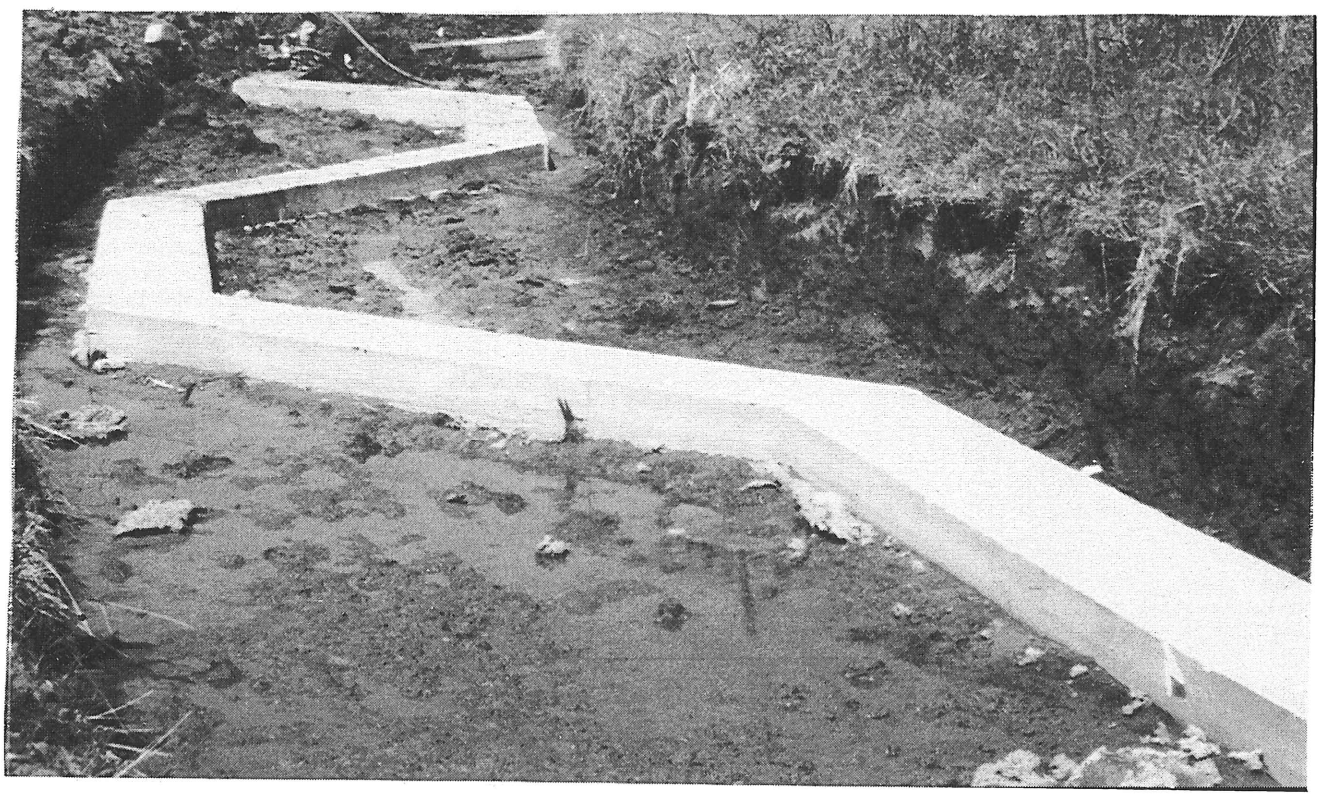


Figure 8. Unreinforced Concrete Levelling Pad.

FANWALL Construction, Project IR-240-1(338)000

The FANWALL panels were produced by Reinforced Earth's Waco, Texas plant, and shipped to the IR-240-1(338)000 site by truck. The panels were hauled on standard flatbed trucks with 4 X 6 wood supports under them. Each truck hauled three panels, so the panels did not have to be stacked while in transit. When the panels arrived at the IR-240-1(338)000 site, they were unloaded by a crane using two nylon lifting straps (Figure 10). The panels were then stacked on the ground, as near as possible to the FANWALL footing, supported by 4 X 6 wood supports.

FANWALL panels are eight feet high, fifteen feet long, and eight inches thick. Panels weigh roughly six tons (12,000 lbs.) each. The FANWALL Noise Barrier Wall on this project was designed to be sixteen feet (two panels) high, measured from the levelling pad to the top of the wall, before any backfilling around the base is done. Panels were erected by crane. The crane lifts panels by attaching a cable to each of two "Burke Erection Anchors" (Figures 11 and 14). The cables are attached using a ring clutch (Figures 11 - 14).

The crane places the panels as close as possible to where they will be positioned in the FANWALL. The contractor's employees then guide them into place with crowbars, while the crane supports their weight (Figure 15). When a proper fit between panels is achieved, the crane lowers the panels into position in the FANWALL. They are then attached to adjacent panels by FANWALL Connector Assemblies. The cap screws on the Connector Assemblies are tightened with hand operated wrenches. Connector Assemblies are supposed to be tightened to 75 foot pounds torque. Several were tightened more than this, resulting in breaks in the panel where the channel for the Connector Assembly is located near the edge of the socket (Figure 16). There were some small breaks on corners where crowbars were used to guide the panels into place. Also, several spalls, approximately 1/2 inch deep, developed near the edges of the panels where contractors employees used crowbars or other tools to guide them (Figure 16). All of these types of breakage appeared to be relatively minor, and all were repaired by patching. It is possible that breaks along the connector assembly could affect the strength of the cable connection over a longer period of time.

The first two panels (one top and one bottom), were attached to the cast in place wall (Figure 17). The contractor knew this connection would be made before the section of Cast in Place Wall involved was formed. Because of this, the contractor was able to place the PVC pipes which formed the channels for the Connector Assemblies at the same time the cast in Place Wall was formed. If FANWALL was connected to an existing wall on a future project it would be necessary to drill holes for this type of connection.

The first 16 panels (Numbers 1T and 1B through 8T and 8B) went up without any unusual problems. Time required to erect this portion of FANWALL was approximately two hours per panel. This was more construction time than ODOT construction personnel or the contractor had expected. At this point, erecting FANWALL still required less construction time than would have been required to build the same length of Cast in Place Wall.

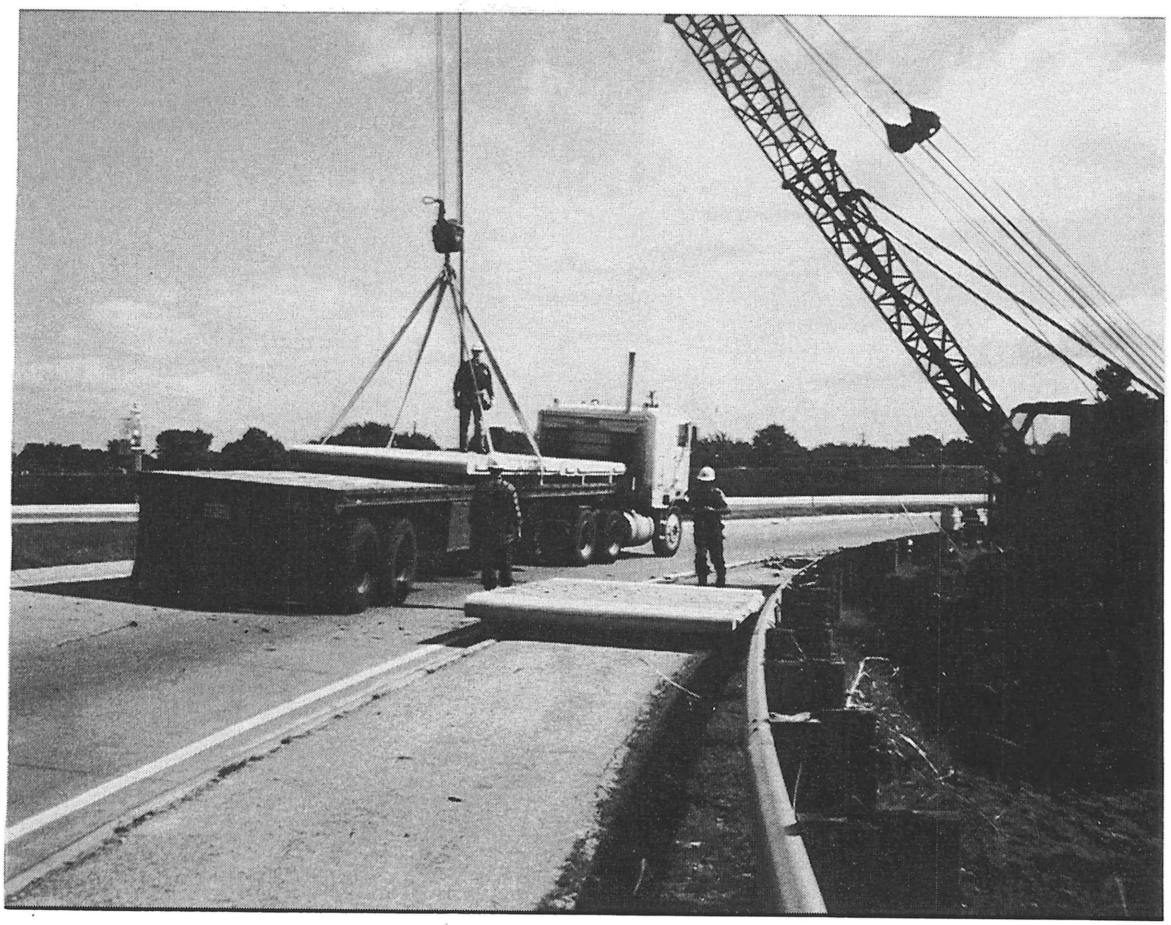


Figure 10. Unloading FANWALL Panel with Lifting Straps.

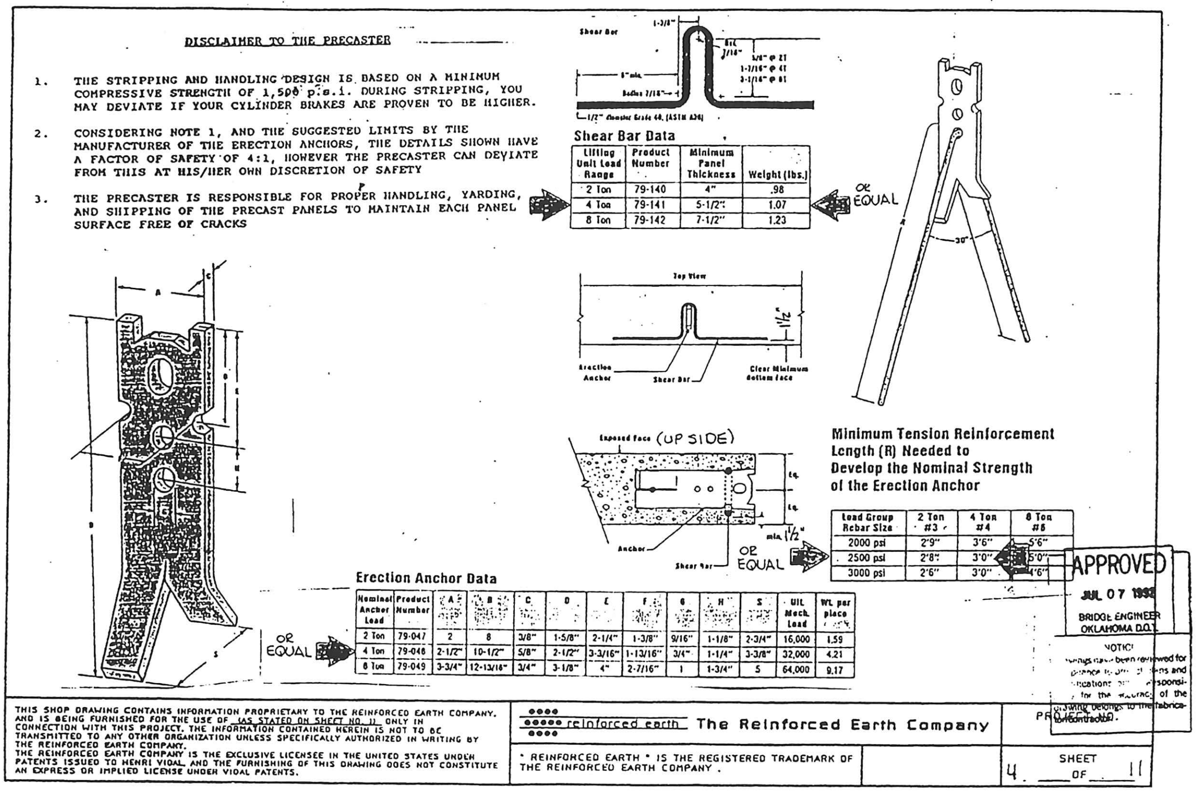


Figure 11. Burke Erection Anchors.

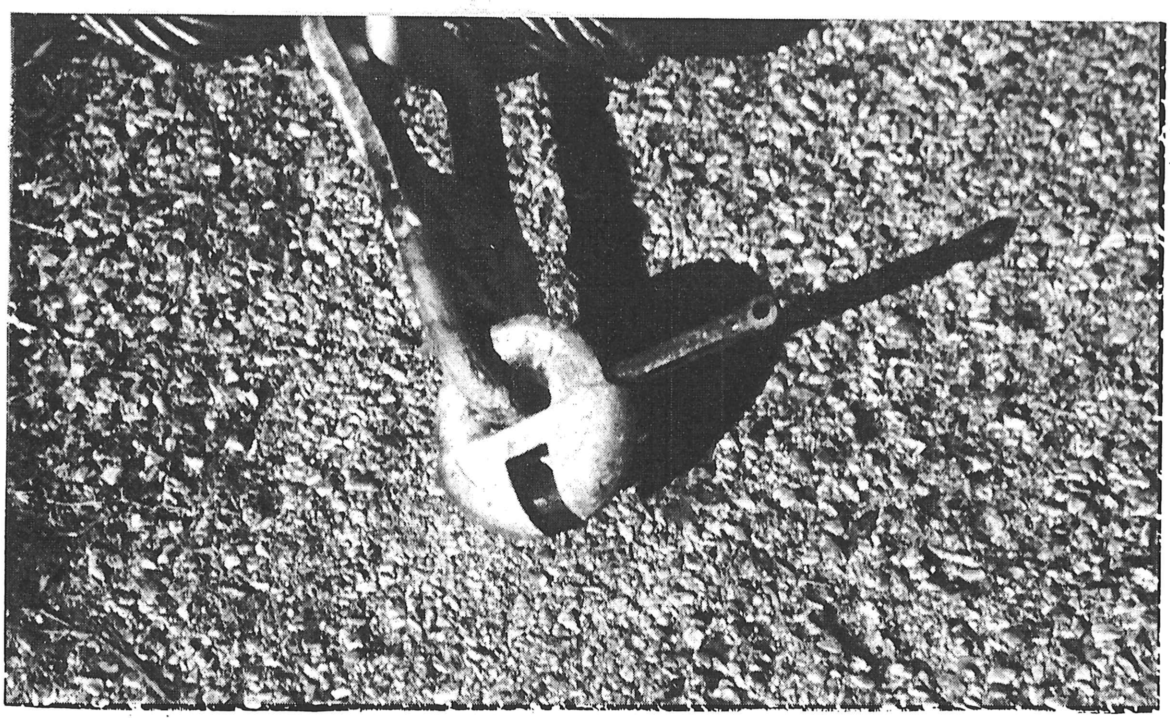


Figure 12. Ring Clutch.

Engaging, Releasing and Maintaining Ring Clutch

To engage the ring clutch to the anchor, first pull the bolt handle upward so that the mouth of the ring clutch is open. Then lower the ring clutch into the recess, sliding the mouth of the ring clutch over the head of the anchor. By pushing the bolt handle downward, toward the concrete, the curved end of the bolt will pass through the eye of the anchor, completing the union. The unit is now ready for handling.

Note: Before applying load, check that the ring clutch, hooks, cables, and so forth are free to move and are not wedged or kinked.

To disengage the ring clutch from the anchor, simply pull the bolt handle upward. The ring clutch can now be withdrawn from the anchor.

Ring clutches should be inspected every six months. Bolts showing normal wear may be replaced by removing the blocking pin located at the top of the clutch.

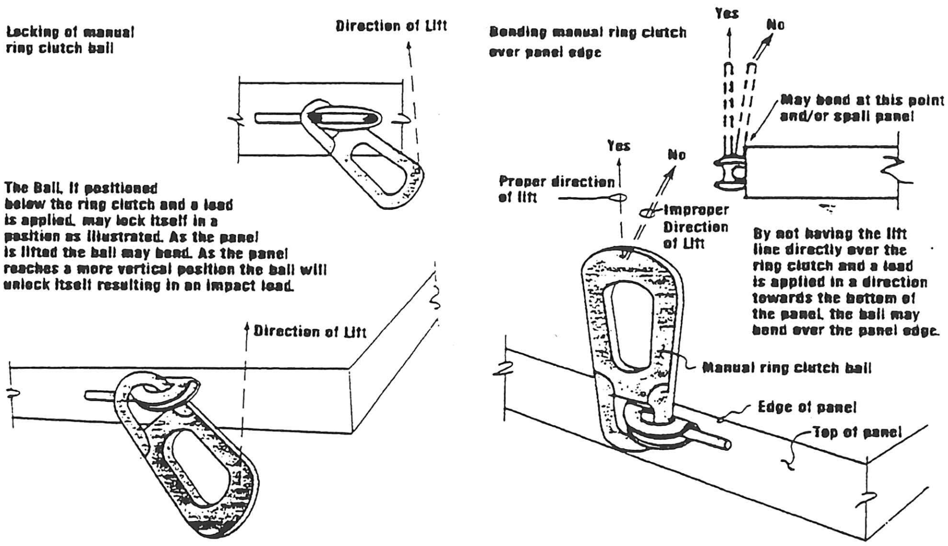


Figure 13. Ring Clutch Information.

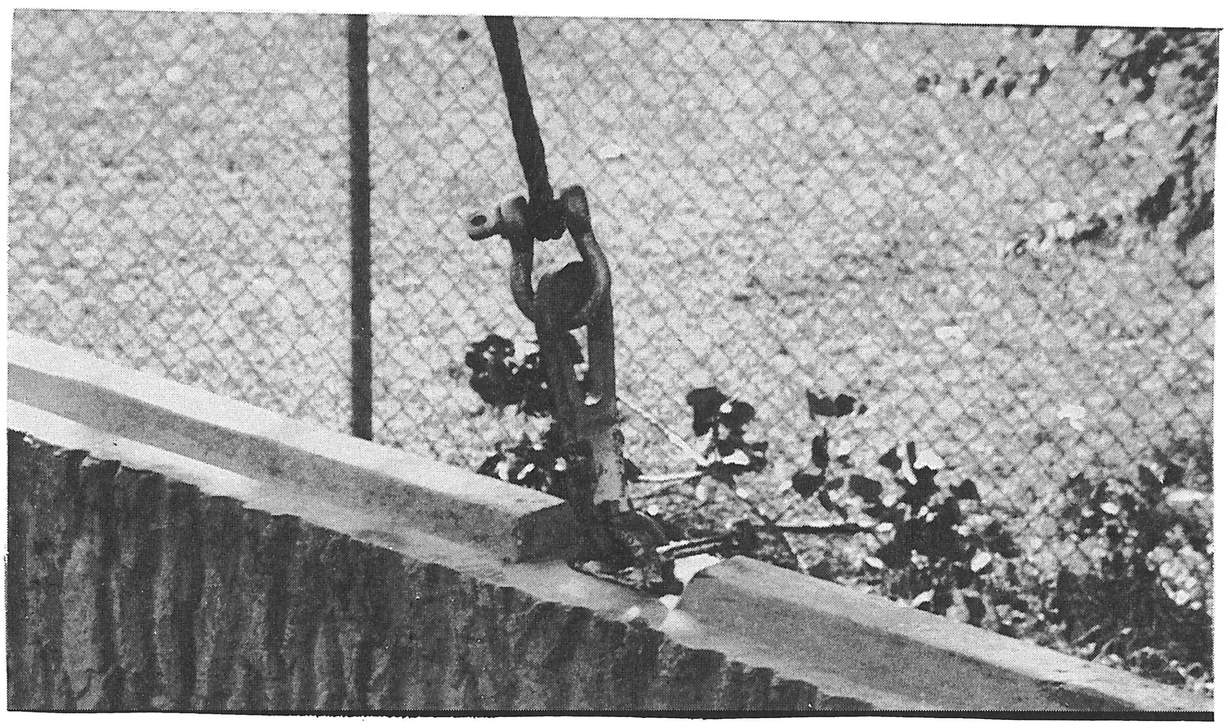


Figure 14. Ring Clutch hooked to Burke Erection Anchor.

Figure 15. Guiding FANWALL Panels into Place.

Figure 16. Spall Along Edge of Panel and Break Along Connector Assembly Channel.

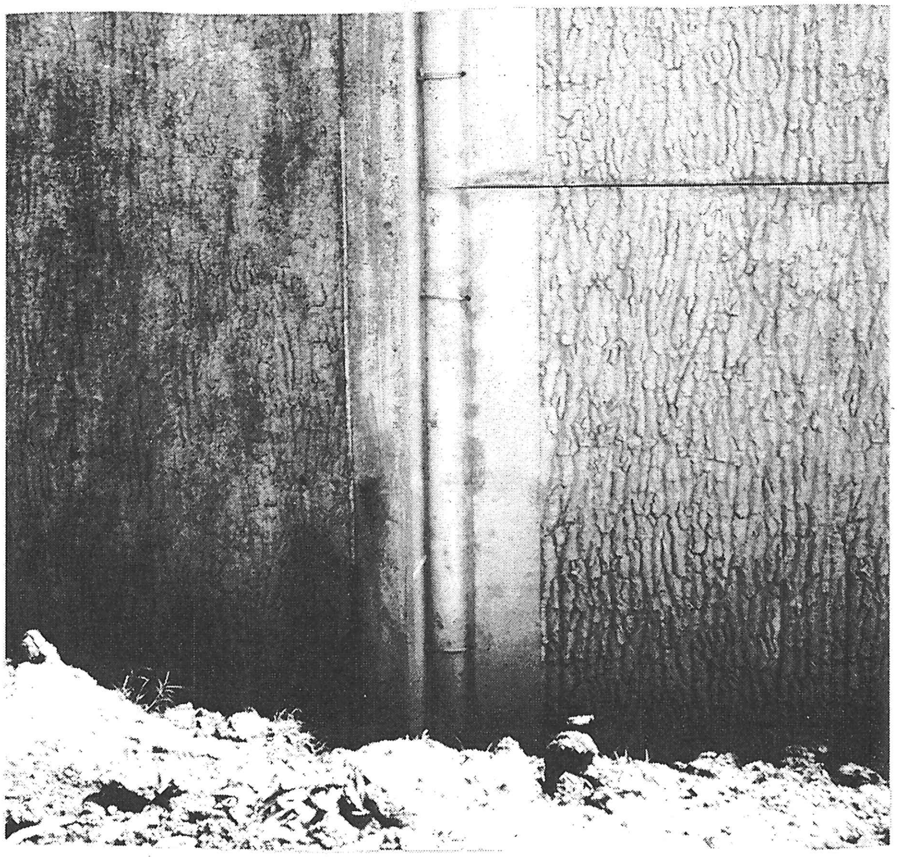


Figure 17. FANWALL to Cast in Place Wall Connection.

The panels were delivered nine at a time (three trucks carrying three panels each). Construction of the FANWALL was scheduled for days when panels were delivered. The right-of-way in the FANWALL area consisted mainly of the foreslope and backslope of a ditch, and there was only a limited amount of space to store the panels until they were put up. The panels can be stacked, but this must be done carefully, with supports between panels located directly over any supports below them. Panels located toward the bottom of the stack will crack if supports aren't aligned (Figure 18.). Erecting a few FANWALL panels, then working on other parts of the project until the next shipment arrived, may have slowed construction slightly. However, this was not a large factor, since the same crew worked on Cast In Place Wall construction, done on the same site, when FANWALL work wasn't scheduled.

The first nine panels were erected on August 25, without any unusual problems. Nine more panels were delivered and five more were put up on August 28, also without unusual problems. At this point, ODOT field personnel and contractor's employees felt that FANWALL was easier and faster to construct than Cast In Place Wall. Up to this point, it was generally agreed that the expected lower labor cost for FANWALL construction was likely to offset the higher purchase price.

On August 29, the contractor had scheduled a day of FANWALL construction. The first panels to be set were two top panels (Numbers 16T and 17T). The FANWALL crew was not able to fit the keyway system between the top and bottom panels, and the ball and socket system connecting adjacent panels, and still produce a plumb, well-fitting wall. The FANWALL crew spent the day taking down panels, and replacing the same panels. They were still not able to produce a plumb wall, and get well-fitting connections. At approximately 3:00 PM, the contractor decided to stop FANWALL work until a meeting could be arranged with the manufacturer, the contractor, and various ODOT personnel.

The meeting was held on August 31. The manufacturer's representative had determined that the problems in fitting the panels were caused by inaccuracy in casting the bottom panels. The manufacturer had cast the panels for this project using two forms (one for "tops", and one for "bottoms"). The Form used for casting "bottoms" had developed a slight twist which had not been noticed. The twist in the form was believed to have been caused by casting the panels in an upright position. It is difficult to support the form in this position, and the weight of the concrete caused the form to shift, twisting the form. It was not possible to cast the panels with the forms in a horizontal position, because the architechtural finish on the panels (Figure 15.) made it impossible to strip the forms unless they were upright. There were variations in panel dimensions, some of which exceeded the 1/4 inch limit. The representative felt that this could also be improved if casting could be done in a horizontal position, as it normally is. For casting to be done in a horizontal position, the design would have to be changed, so that only one side of the FANWALL had the architechtural finish.

To make it possible to fit the panels together, and complete the FANWALL with acceptable fits between panels, it was decided that the manufacturer would sandblast the ball and socket joints. This was intended to increase the clearance by approximately 1/4 inch between the ball and socket connections. The panels with modified (sandblasted) joints were to be alternated with unmodified panels, which had been delivered before the fitting problems were discovered.

On September 3, nine modified panels were delivered to the IR-240-1(338)000 site. The contractor resumed the FANWALL construction operation, and eleven panels were erected with no unusual problems. This included six sandblasted panels and five which were not modified. On September 10 and 11, nine panels were delivered each day, and the FANWALL Section was completed. No unusual problems came up on any of the days after the modifications were made.

In addition to alternating sandblasted and unmodified panels, the FANWALL crew began measuring all panels before using them. They would then select the next panel to be put up according to dimensions. If the last panel had a slightly long dimension, they would use a panel with a short dimension adjacent to it. This appeared to have at least as much of an effect on fit as using the sandblasted panels. On all of the sandblasted joints, only part of the joint was sandblasted, rather than the entire surface (Figure 19.). This could not have had much effect on fit unless the part of the joint that was not sandblasted somehow broke away during construction (no breakage of this kind was observed).

Nine panels were put up on September 10, and the last six panels were put up September 11, completing the FANWALL Section.

Table 1. Number of FANWALL Panels Erected.

Date	Panels Erected.
8-25-92	9
8-28-92	7
8-29-92	0
8-31-92	0*
9-09-92	11
9-10-92	11
9-11-92	6

*Date of the meeting on corrective action.

Figure 18. Panel cracked due to misaligned supports during stacking.

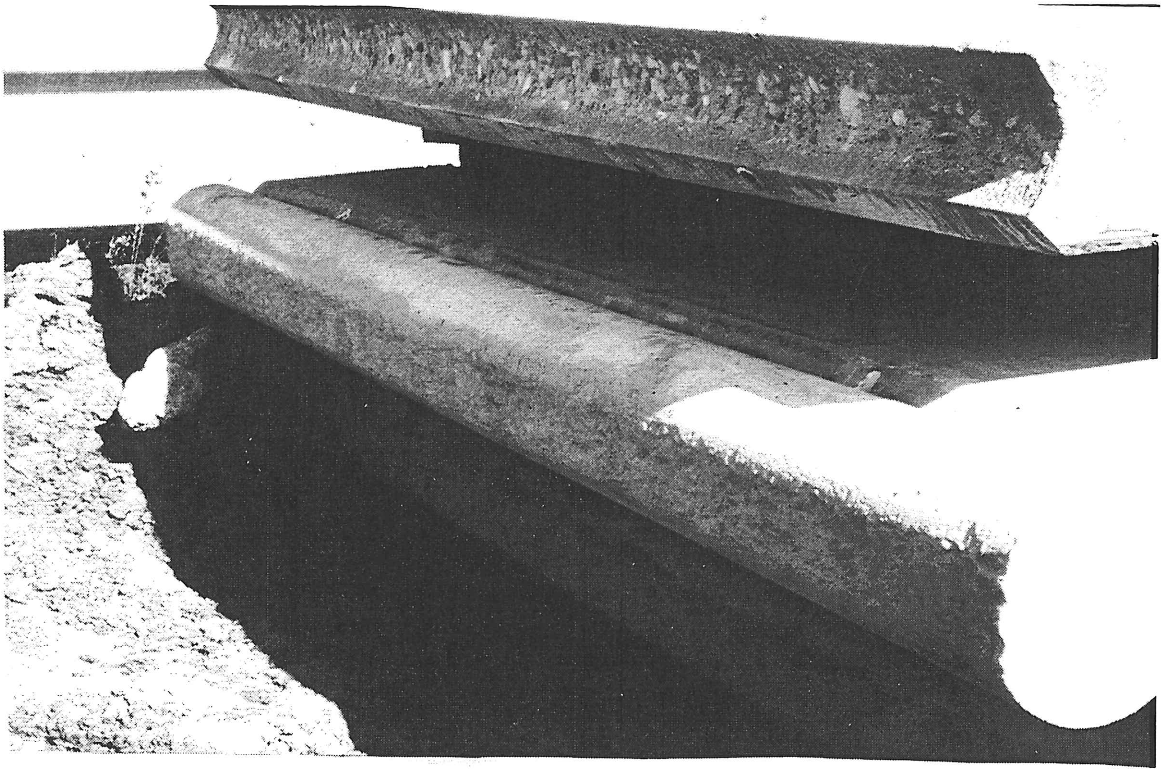


Figure 18. Sandblasted Joints.

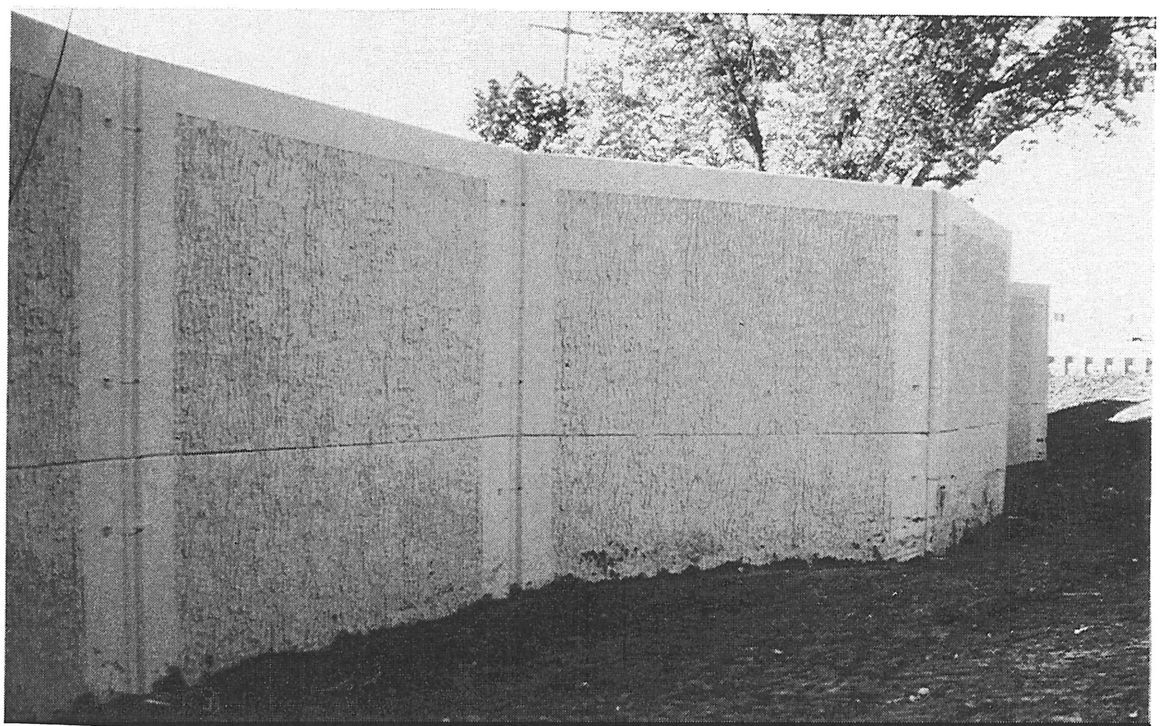


Figure 19. Completed FANWALL, After Backfilling.

Cost

The IR-240-1(338)000 contract price for FANWALL was $19.60 per square foot. Cast in Place Sound Barrier Wall cost $13.92 per square foot. The difference in cost was expected to be offset, at least to some extent, by relatively lower labor costs for FANWALL construction. Actual labor costs were not lower than those for an equal length of Cast in Place Wall. This was due to problems during FANWALL construction, which increased construction time, as discussed in the preceding section of this report.

Costs were increased slightly by the addition of two panels. The plans called for 21 "top" and 21 "bottom" FANWALL panels to cover a 295.97 foot length of curve. When survey for the levelling pad was done, it was discovered that 22 top and 22 bottom panels were required. ODOT paid for the two additional panels. This added $4704.00 to the FANWALL cost (2 each X 8 ft. X 15 ft. X $19.60 per square foot).

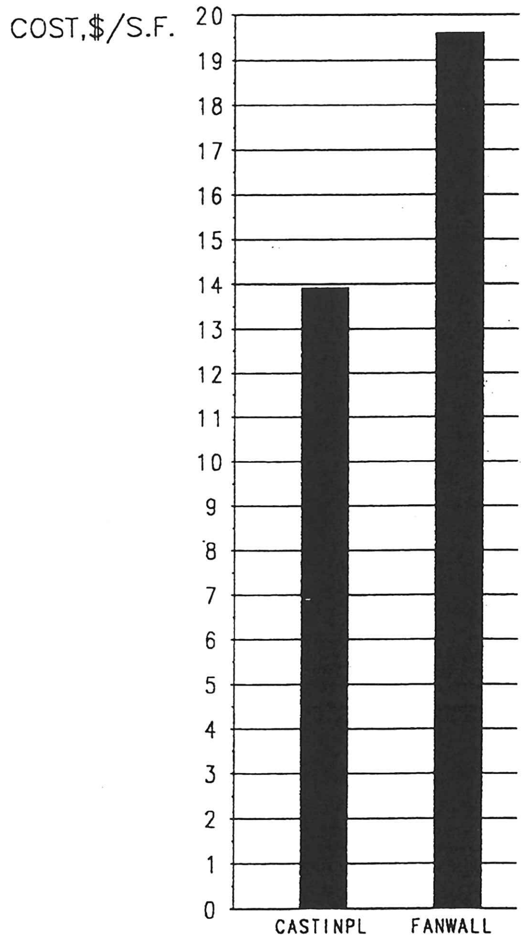


Figure 21. Contract Prices, FANWALL and Cast in Place Wall.

Conclusions

The labor savings expected due to using FANWALL rather than Cast in Place Wall did not occur. Time required to complete the FANWALL covering a 295.97 foot length of curve was 324 man-hours. This is roughly equivalent to the number of man-hours required to complete the same length of Cast in Place Wall.

A one foot thick by three feet wide concrete levelling pad was substituted for the gravel pad that normally supports the FANWALL. This was required due to soil conditions (expansive soils) on the IR-240-1(338)000 site. Expansive soils are common in Oklahoma and it is likely that a similar levelling pad would be required on any future FANWALL projects. The rigid levelling pad under the FANWALL was a contributing factor to the difficulties in getting a good fit between panels.

Inaccuracy in casting the panels also contributed to delays in constructing the FANWALL. According to the manufacturer's representative, this inaccuracy was caused by a twist in the form used to cast bottom panels. The probability of this happening could be reduced if panels could be cast in a horizontal position. Since ODOT requires a textured architechtural finish on both sides of the FANWALL panels, they must be cast with forms in a vertical position, or it is impossible to strip the forms. If conditions on future projects would allow FANWALL without the architechtural finish, or or with the finish on one side only, the panels could be cast in a horizontal position, probably with greater accuracy.

Once the inaccurately cast panels were put into use on IR-240-1(338)000, the contractor had difficulty fitting the panels together, and producing a wall that was plumb. The additional time used trying to fit panels was the primary reason for the high number of man-hours per square feet of FANWALL erected. Where panels with slight inaccuracies must be used, the most effective corrective action (on this project), appeared to be measuring panel dimensions, then selecting panels to be put up so that a short dimension on one panel is adjacent to a panel with the same dimension long. Corrections in fit may also be made by providing additional space at the joints, either by corrective action, such as sandblasting, or changes in design dimensions.

Monitoring and Reporting.

The completed FANWALL will be monitored for lateral movement, settlement, and tilting. The general condition of the wall will also be observed.

The above items will be checked bi-weekly for the first three months after construction of the FANWALL is complete. From three months after completion of the FANWALL until December 31, 1993, these items will be monitored monthly.

Lateral movement will be monitored by measuring the distance from permanent points on the FANWALL to five PK nails. The PK nails are set in the asphalt pad located behind the curb along the southeast edge of the I-44 to I-240 entrance ramp (Figure 22.).

Settlement will be monitored by determining elevations, with a rod and level, at twelve permanent points marked on top of the FANWALL. An "X" cut into the middle of the ball, of the ball and socket joint marks each of the points. Points where measurements are made are referred to by joint number.

Tilting will be checked, at the socket end of each panel. with a carpenter's level and a ruler (Figures 23.). Two measurements will be made at each joint. The measurement will be made on the socket side of the joint, with the level in line with the capscrews on both the top and bottom panels. One measurement will be made on the top panel and one on the bottom panel.

Initial measurements after completion , made on October 16, 1992, are listed in Appendix B.

Any lateral movement, settlement, or tilting will be reported to the members of the Noise Barrier/ Retaining Wall Committee as soon as possible after it is noted. A Final Report, summarizing field performance, will be written by May, 1994. If a substantial failure should occur before that time, The ODOT Noise Barrier/Retaining Wall Committee will be notified as soon as possible, and the Final Report will be written within three months of the failure.

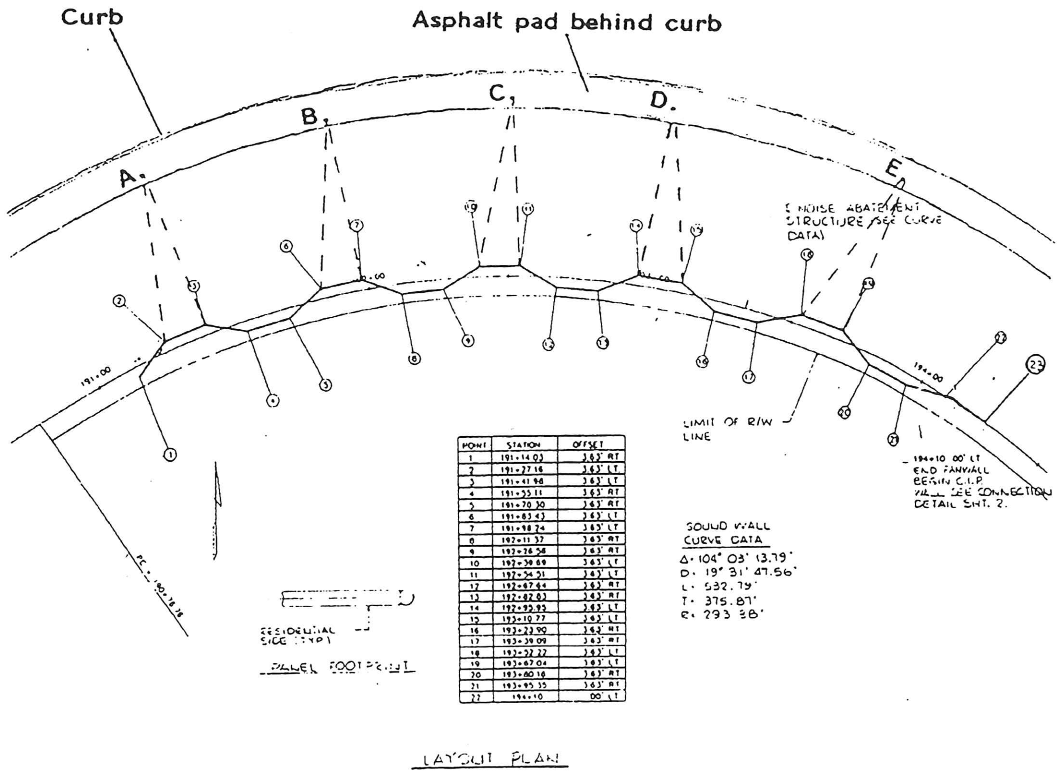


Figure 22. Measurement Points, Used to Monitor Any Lateral Movement.

Figure 23. Making Measurements Used to Monitor FANWALL for Tilting.

Appendix A, ODOT Special Provision Covering FANWALL.

OKLAHOMA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISIONS
FOR
MECHANICALLY STABILIZED EARTH RETAINING WALLS
PROJECT BRO-55(605), OKLAHOMA COUNTY

These Special Provisions revise, amend, and where in conflict, supersede applicable Sections of the Standard Specifications for Highway Construction, Edition of 1988, and the Supplement thereto, Edition of 1991.

508.01. DESCRIPTION. The Contractor shall have the option of constructing precast retaining wall systems in place of all or part of cast-in-place reinforced concrete walls shown in the plans. In urban areas, facing shall be entirely concrete.

OPTIONAL RETAINING WALLS SHALL BE ONE OF THE FOLLOWING MECHANICALLY STABILIZED TYPES:

Reinforced Earth	- The Reinforced Earth Company 1905 Central Drive, Suite 100 Bedford, Texas 76021
Retained Earth	- VSL Corporation 1414 Post and Paddock Grand Prairie, Texas 75050
Tensar	- Contech Construction Products 9925 S. Pennsylvania, Suite 100 Oklahoma City, OK 73159
Hilfiker Walls	- Hilfiker Texas Corporation 637 W. Hurst Blvd. Hurst, TX 76053

508.02. MATERIALS.

(a) GENERAL REQUIREMENTS. The Contractor shall make his own arrangements to purchase or manufacture the facing elements, reinforcing mesh or strips, attachment devices, joint filler, and all other necessary components from sources listed above.

Materials not conforming to this section of the specifications or from sources not listed above shall not be used without written consent from the Engineer.

1. CONCRETE FACING PANELS.

1.1. COMPRESSIVE STRENGTH. The Concrete Facing Panels shall be formed with Class AA concrete having a minimum compressive strength of 4000 psi at 28 days. The units shall not be stripped from their forms until they can be removed without damaging the unit and until the concrete in the unit reaches the minimum stripping compressive strength specified on the approved shop drawings. The stripping strength shall be based on the fabricators calculations for stripping strength. Acceptance of concrete panels with respect to compressive strength will be determined on the basis of production lots. A production lot is defined as a group of panels that will be represented by a single compressive strength sample and will consist of either 40 panels or a single day's production, whichever is less.

1.2. CONCRETE TESTING. Testing shall be in accordance with Section 701.01(d) of the Standard Specifications unless otherwise specified by the Engineer. A single compressive strength sample shall consist of a minimum of two samples taken randomly in accordance with AASHTO T-141. All tests, on a given production lot, shall be taken with the same concrete sample. Air content and slump tests shall be determined at the beginning of each production day (prior to placement of concrete) and at the same time as compressive strength samples are taken. Compressive tests shall be made at 28 days and at stripping, if prior to 28 days. Additional cylinders may be made from the concrete sample, if desired, to facilitate the testing for stripping the forms. The Engineer may require additional testing of other loads of concrete within a production lot if, in the opinion of the Engineer, it is warranted. The Engineer shall reject loads of concrete and/or panels poured with loads of concrete that do not meet this specification. The Engineer shall have the right to witness any tests he or she so desires.

1.3. SURFACE FINISH. The finished appearance of the optional walls shall conform to the architectural treatment and finish specified for cast-in-place walls. Surface defects on smooth formed surface measured on a length of 5 feet shall not exceed 1/8 inch. Surface defects on the textured finish measured over a length of 5 feet shall not exceed 5/16 inch. Color variations on the front face of the panels shall be cause for rejection. The rear face of the panel shall be screeded to eliminate open pockets of aggregate and surface distortions in excess of 1/4 inch. The panels shall be cast on a flat area. The coil embeds, tie strip guide, or other galvanized devices shall not contact or be attached to the face panel reinforcement steel.

1.4. MARKING. The date of manufacture, the production lot number, and the piece mark, shall be clearly scribed on an unexposed face of each panel.

1.5. HANDLING, STORAGE, AND SHIPPING. All units shall be handled, stored, and shipped in such a manner as to eliminate the dangers of chipping, discoloration, cracks, fractures, and excessive bending stresses. Panels in storage shall be supported on firm blocking to protect the panel connection devices and the exposed exterior finish.

1.6. TOLERANCES. Position of panel connection devices shall be within 1 inch. All other dimensions shall be within 3/16 inch.

2. WIRE FACING.

2.1. FACING MESH. Facing mesh shall be formed by a 90-degree bend of the soil reinforcement mesh and shall have a prebent tie to connect to the soil reinforcing mesh above. Galvanization shall be applied after the mesh is fabricated and conform to the minimum requirements of AASHTO M-111.

2.2. BACKING MAT. Backing mat shall be 2"x6" - W1.7 X W1.7 welded wire fabric meeting ASTM A-185 and galvanized in accordance with AASHTO M-111. The backing mat height shall be approximately 2 inches smaller than the facing mesh height.

2.3. HARDWARE CLOTH. Hardware cloth with openings not exceeding 1/4 inch shall be placed between the backfill and backing mat to retain the soil. Galvanization shall conform to AASHTO M-111. To avoid the loss of backfill fines, the height of hardware cloth shall be equal to the facing mesh height plus 3.0 inches.

3. SOIL REINFORCING AND ATTACHMENT DEVICES. All reinforcing and attachment devices shall be carefully inspected to insure they are true to size and free from defects that may impair their strength and durability.

3.1. REINFORCING STRIPS. Reinforcing strips shall be hot rolled from bars to the required shape and dimensions. Their physical and mechanical properties shall conform to ASTM A-572 Grade 65 (AASHTO M-223) or equal. Galvanization shall conform to the minimum requirements of AASHTO M-111.

3.2. REINFORCING WIRE MESH. The reinforcing wire mesh shall be shop fabricated of cold drawn steel wire conforming to the minimum requirements of ASTM A-82 and shall be welded into the finished mesh fabric in accordance with ASTM A-185. Galvanization shall be applied after the mesh is fabricated and conform to the minimum requirements of AASHTO M-111. Any damage done to the mesh galvanization prior to the installation shall be repaired in an acceptable manner and provide a galvanized coating comparable to that provided by AASHTO M-111.

3.3. REINFORCING GEOGRIDS. The geogrid shall be a high density polyethylene (HDPE) grid specifically fabricated for use as a soil reinforcement. The geogrid shall be an integrally formed grid structure with high tensile modulus in relation to the material being reinforced with large apertures and thick ribs and junctions to permit significant mechanical interlock with the material being reinforced and with high continuity of tensile strength through all ribs and junctions of the structure. The geogrid shall have high resistance to deformation under sustained long term load and shall be resistant to both ultraviolet degradation and all forms of biological or chemical degradation normally encountered in the material being reinforced. The geogrid shall meet or exceed the physical property requirements of Tensar SR2. At each geogrid splice, a 1/2 inch diameter Schedule 80 polyvinyl chloride plastic pipe, ASTM D 1785, or a 1/2" x 1/4" HDPE bar shall be used as connector pins.

3.4. TIE STRIPS. The tie strips shall be shop fabricated of a hot rolled steel conforming to the minimum requirements of ASTM-570, Grade 50 or equivalent. Galvanization shall conform to AASHTO M-111.

3.5. COIL EMBED. 1-inch coil embed shall be fabricated of cold drawn steel wire conforming to AISI C1035. It shall be galvanized in accordance with ASTM B-633 or equal.

3.6. COIL EMBED GREASE. The cavity of each coil embed shall be completely filled with no-oxid type grease or equal.

3.7. COIL BOLT. The 1-inch diameter coil bolt shall have 2 inches of thread. It shall be cast of 80-55-06 ductile iron conforming to ASTM A-536. Galvanization shall conform to ASTM B-633 or equal.

3.8. FASTENERS. Fasteners shall consist of 1/2-inch diameter, hexagonal cap screw bolts and nuts, which are galvanized and conform to the requirements of AASHTO M-164 or equivalent.

3.9. CONNECTOR PINS. Connector pins and mat bars for the Reinforced Soil Embankment system shall be fabricated from ASTM A-709 Grade 36 (AASHTO M-270) and welded to the soil reinforcement mats as shown on the Plans. Galvanization shall conform to AASHTO M-111.

3.10. Panel Anchors. Panel anchors shall be cold formed of cold drawn wire conforming to the minimum requirements of ASTM A-82 (AASHTO M-32). Anchors shall be galvanized after forming to the minimum requirements of AASHTO M-111.

4.0. JOINT MATERIALS. Installed to the dimensions and thicknesses in accordance with the Plans or approved shop drawings.

4.1. Eighteen (18) inch wide strips of filter cloth shall be placed on the back face of the panel over all panel joints. The filter cloth shall be adhered to the back face of the panels using an adhesive compound. Adhesive shall be applied to the back face of the panel and not to the filter cloth. The filter cloth must meet the following requirement to avoid piping:

$$095 / d85 < 3$$

095 is the apparent opening size of the geotextile in mm., 95% of which are finer. d85 is the soil particle size corresponding to 85% finer in mm.

4.2. Provide either preformed cork conforming to AASHTO M-153 Type II in horizontal joints between panels, preformed EPDM rubber pads conforming to ASTM D-2000 for 4AA, 812 rubbers or neoprene elastomeric pads having a Durometer Hardness of 55 plus/minus 5.

5.0. RETAINING WALL GRANULAR BACKFILL. The retaining wall granular backfill material shall meet the requirements in Section 703A. The granular backfill material shall also meet the following requirements.

5.1. ANGLE OF INTERNAL FRICTION REQUIREMENTS. The granular backfillmaterial shallexhibit an angleof internal friction of not less than 34 degrees, as determined by the standard Direct Shear Test, AASHTO T-236, or the Triaxial Test, AASHTO T-234 on the portion finer than the #10 sieve, utilizing a sample of the material compacted to 95 percent of AASHTO T-99, Methods C or D (with oversized correction as outlined in Note 7) at optimum moisture content.

5.2. ELECTROCHEMICAL REQUIREMENTS. The granular backfill materials shall meet the following criteria:

Property	Standard	Test Procedures
Resistivity, ohm/cm.	>5000	ASTM G-57-78(Lab.)
pH	4.5<pH<9.5	ASTM G-51-77
Organic Content	0.01%	AASHTO T-267-86

Soils with resistivities of less than 5000 ohm/cm but greater than 2000 ohm/cm may be accepted if they meet the following additional requirements:

Property	Limits	Test Procedures
Chlorides	< 100 PPM	ASTM D-512,ASTM D-4327
Sulfates	< 200 PPM	ASTM D-516(B),ASTM D-4327

6.0. ACCEPTANCE OF MATERIAL. The Contractor shall furnish the Engineer a Certificate of Compliance certifying the above materials, excluding granular backfill, comply with the applicable contract specifications. A copy of all test results performed by the Contractor necessary to assure contract compliance shall also be furnished to the Engineer.

Acceptance will be based on the Certificate of Compliance, accompanying test reports, and visual inspection by the Engineer.

Materials certifications shall conform to the requirements of Subsection 106.12 of the Standard Specifications. Testing methods and results shown on the certificate shall conform to these Special Provisions. A Type A certificate shall be provided.

The Contractor shall test the granular backfill for the angle of internal friction requirements and the electrochemical requirements. The Department of Transportation shall test the granular backfill material for the retaining wall pursuant to Section 703A. The requirements for the retaining wall granular backfill material will be stated on the Shop Drawings provided by the proprietary wall company.

508.03. DESIGN PROCEDURE. Optional retaining walls shall be designed by a registered Professional Engineer, registered in Oklahoma. Design shall be in accordance with current AASHTO Standard Specifications for Highway Bridges and in accordance with these Specifications. Design methods for structure types or elements not covered by these Specifications may be used if documented in published literature, proven adequate through use by expert personnel performing the design for these walls, and acceptable to the Engineer.

(a) Backfill design parameters for mechanically stabilized retaining walls shall be as follows, unless otherwise shown in the Plans:

The maximum friction angle used in the computation of the horizontal stress within the mechanically stabilized earth mass shall be 34 degrees. The cohesion shall be equal to 0 and the minimum unit weight shall be 120 pounds per cubic foot.

(b) When the optional precast retaining wall system is constructed in cut areas and/or hill sides with established piezometric levels, a drainage blanket shall be required in back and possibly beneath the stabilized zone. For mechanically stabilized earth structures, drainage measures shall be considered for all structures to prevent saturation of the stabilized backfill or to intercept any surface flows containing aggressive elements such as deicing chemicals.

The drainage and/or intercept system shall be shown on the Shop Drawings provided by the proprietary wall company.

(c) An internal and external stability analysis shall be required for the optional retaining wall. The Contractor shall perform the internal stability analysis. ODOT will be responsible for the external or global stability analysis for the cast-in-place retaining wall. ODOT will provide the external stability analysis calculations to the Contractor. If the optional retaining wall alters the external stability analysis performed by ODOT, the Contractor must also perform an external stability analysis for the optional retaining wall.

Unless otherwise noted on the Plans, the stability analysis of optional retaining walls with parapet walls or concrete railing shall include the effects of a 10 kip rail load applied at the top of the parapet as a Group III loading. The rail load shall be distributed in accordance with AASHTO 3.24.5.2 where X is the height from the base of the parapet to the point in question. Live load surcharge shall be included with the Group I loading and should not be applied with the rail load.

The following minimum factors of safety shall be used in the internal stability analysis:

Factor of Safety in sliding along the base of the structure shall be greater than 1.5.

Factor of Safety in overturning shall be greater than 2.0.

Factor of Safety for bearing capacity shall be greater than 2.5 unless the structure is founded in cohesive soils or shales. Factor of safety for bearing capacity in cohesive soils and shales shall be greater than 3.0.

For mechanically stabilized retaining walls, the Factor of Safety for pullout resistance shall be greater than 1.5.

Allowable longitudinal differential settlements for mechanically stabilized earth structures are largely a function of panel size and joint design. For discrete modular panels, less than 30 sq. ft. in area with a minimum design joint of 3/4 inches, differential settlements in the longitudinal direction one percent are allowable. For panels with smaller design joints, or of larger size, this allowance shall be proportionally reduced.

Allowable transverse differential settlements are a function of reinforcement length, size and ability of the panel connection to rotate. The differential vertical movements between the panel connection and the reinforcement must be controlled or limited to insure that reinforcement yield strains are not reached.

If additional soil testing is required for the internal stability analysis of the optional retaining wall, the Contractor shall provide the additional soil testing. A copy of these stability computations shall be submitted to the Bridge Engineer for approval along with shop drawings of the retaining wall. It is understood that the Engineer's examination of the shop drawings, as submitted or corrected, in no way relieves the Contractor of responsibility for obtaining satisfactory results.

The service life of mechanical stabilized embankment (MSE) structures shall be a minimum of 100 years. Reinforcing elements shall be designed with an additional area of metal which corresponds to the mass presumed to be affected by corrosion at the end of the 100 year period. The design section shall be based on the area "Ac" defined by the relationship Ac=An-As where As is the sacrificial section lost to corrosion and An is the original reinforcement area. The Contractor will provide data for Resistivity, pH, Chlorides, and Sulfates as required for each specific site. For structures exposed to deicing salts, it is assumed that the upper 7.5 feet of backfill (as measured from the roadway surface) will be affected by the increased concentration of chlorides. Service life computations shall be in accordance with the Federal Highway Administration "Geotechnical Engineering Notebook", Chapter 5, Section 3, Subsection 4. A copy of these service life computations shall be submitted to the Bridge Engineer.

Prior to fabrication or construction of an optional retaining wall, the Contractor shall submit copies of design calculations, shop drawings, working drawings, and material and construction specifications for this wall to the Engineer for approval.

508.04 CONSTRUCTION METHODS.

(a) WALL EXCAVATION. Unclassified excavation shall be in accordance with the requirements of Section 202.02(c) of the Standard Specifications and in reasonably close conformity to the limits and construction stages shown on the plans.

(b) FOUNDATION PREPARATION. The foundation for the structure shall be graded level for a width equal to or exceeding the length of reinforcement elements plus 1.0 foot or as shown on the plans. Prior to wall construction, except where constructed on rock, the foundation shall be compacted by two passes of a vibratory drum compactor. Any foundation soils below the elevation of the bottom of the footing found to be unsuitable as determined by the Engineer shall be removed and replaced with suitable material.

At each panel foundation level, a cast-in-place unreinforced concrete leveling pad of the type shown on the plans shall be provided. The leveling pad shall be cured a minimum of 12 hours before placement of wall panels and shall have a minimum backfill cover of two (2) feet.

(c) WALL ERECTION. A field representative from the proprietary wall system being used shall be available, as needed, during the erection of the wall. The services of the representative shall be at no additional cost to the project.

Precast concrete panels shall be placed so that their final position is vertical or battered as shown on the plans. For erection, panels are handled by means of lifting devices connected to the upper edge of the panel. Panels should be placed in successive horizontal lifts in the sequence shown on the plans as backfill placement proceeds. As backfill material is placed behind the panels, the panels shall be maintained in vertical position by means of temporary wedges or bracing according to the wall suppliers recommendations. For structures with precast facing panels, concrete vertical tolerances and horizontal alignment tolerances shall not exceed 3/4 inch when measured with a 10 foot straight edge. During construction, the maximum allowable offset in any panel joint shall be 3/4 inch. The overall vertical tolerance of the wall (top to bottom) shall not exceed 1/2 inch per 10 feet of wall height. The plumbness and tolerances of each panel row at the face shall be checked prior to erection of the next panel row. Should any panels be out of tolerance, the backfill shall be removed, and panels reset to their proper tolerances. Horizontal, vertical and slope joint openings between panels shall be uniform and no larger than 1 1/4 inch and no smaller than 1/2 inch.

For wire faced structures, backing mats and 1/4 inch hardware cloth shall be placed in successive horizontal lifts in the sequence shown on the plans as backfill placement proceeds. Vertical tolerance (plumbness) and horizontal alignment tolerance shall not exceed 2 inches when measured at the junction of the wire facing and soil reinforcement along a 10 foot straight edge. The overall vertical tolerance of the wall (top to bottom) shall not exceed 1 inch per 10 feet of wall height. These criteria are applicable to both vertical and battered structures.

Reinforcement elements shall be placed normal to the face of the wall, unless otherwise shown on the plans. Prior to placement of the reinforcing elements, backfill shall be compacted in accordance with Backfill Placement.

Approved optional precast retaining wall systems not covered by the above shall be constructed as directed by the Engineer in consultation with a field representative from the proprietary wall system.

(d) BACKFILL PLACEMENT. Backfill placement shall closely follow erection of each course of panels. Backfill shall be placed in such a manner as to avoid any damage or disturbance of the wall materials or misalignment of the facing panels. Any wall materials which become damaged during backfill placement shall be removed and replaced at the Contractor's expense. Any misalignment or distortion of the wall facing panels due to placement of backfill outside the limits of this specification shall be corrected by the Contractor, at his expense.

Backfill shall be compacted to 95 percent of the maximum density as determined by AASHTO T-99, Method C or D (with oversize correction as outlined in Note 7 of that test).

Completed backfill material, when compacted to 95 percent of AASHTO T-99, at optimum moisture content shall exhibit an angle of internal friction of not less that 34 degrees, as determined in the standard direct shear test (AASHTO T-236) or the triaxial test (AASHTO T-234).

The moisture content of the backfill material prior to and during compaction shall be uniformly distributed throughout each layer. Backfill materials shall have a placement moisture content less than or equal to the optimum moisture content. Backfill material with a placement moisture content in excess of the optimum moisture content shall be removed and reworked until the moisture content is uniformly acceptable throughout the entire lift.

The maximum lift thickness after compaction shall not exceed 8 inches. The Contractor shall decrease this lift thickness, if necessary, to obtain the specified density.

Compaction within 3 feet of the backface of the wall facing shall be achieved by at least three passes of a lightweight mechanical tamper, roller, or vibratory system.

At the end of each day's operation, the Contractor shall slope the last level of backfill away from the wall facing to rapidly direct runoff away from the wall face. In addition, the Contractor shall not allow surface runoff from adjacent areas to enter the wall construction site.

508.05. METHOD OF MEASUREMENT. Retaining walls, whether cast-in-place or optional, shall be measured for payment by the square foot of the wall as measured from the top of the footing to the top of the wall according to the cast-in-place design shown in the Plans with no increase or decrease due to the use of an optional wall unless a change is made in the original conditions, such as a change in wall height, then the measured pay quantity shall be adjusted accordingly after written consent has been obtained from the Engineer.

Changes or additional quantities of wall shall be based on original design concept and parameters.

The removal and replacement of unsuitable foundation soils below the elevation of the bottom of the footing shall be paid for as structural excavation, unclassified for removal and structural excavation, unclassified for backfilling.

508.06. BASIS OF PAYMENT. Accepted retaining walls, measured as provided above, will be paid for at the contract unit price for cast-in-place retaining walls as provided in the Special Provision for Cast-In-Place Retaining Walls which shall be full compensation for all excavation and backfilling and for furnishing all materials including concrete; reinforcing steel; wire facing; soil reinforcing and attachment devices; joint materials; drilled shafts; piles; retaining wall backfill;

drainage system including perforated pipe underdrain and pipe underdrain material necessary to complete the drainage system within the extents of the retaining wall; equipment; sheeting and shoring; labor and incidentals necessary for a complete retaining wall. If a drainage and/or intercept system is shown on the Shop Drawings to prevent the saturation of the stabilized backfill or to intercept any surface flows containing aggressive elements such as deicing chemicals, the material required for the system shall be included in the contract unit price for cast-in-place retaining walls.

The removal and replacement of unsuitable foundation soils below the elevation of the bottom of the footing shall be measured by the cubic yard as provided above and shall be paid for at the contract unit price for Structural Excavation, Unclassified.

Drilled shafts and piling for retaining walls as shown on the Plans shall be included in the square foot cost of retaining walls. Drilled shafts and piles shall not be individually paid by the linear foot. If drilled shafts and piles are required for mechanically stabilized earth retaining walls, the Contractor will not be paid for drilled shafts or piles. All cost for drilled shafts and piling for proprietary mechanically stabilized earth retaining walls shall be included in the price bid per square foot of retaining wall.

Top soil shall be included in roadway quantities and not in the cost of retaining walls.

Appendix B, Measurements After FANWALL Completion.

Table 2. Distances-Used to Determine Lateral Movement.*
October 16, 1992

From (PK Nail)	To (Cap Screw)	Distance
A.	4.	32.91
B.	8.	32.84
C.	12.	36.93
D.	16.	38.20
E.	20.	39.15

From (PK Nail)	To (Connector Channel)	Distance
A.	5.	32.74
B.	9.	32.72
C.	13.	36.72
D.	17.	37.84
E.	21.	37.13

*Measurement locations are shown on Figure 20.

Table 3. Elevations on Top of FANWALL.
October 16, 1992

Location (Joint)	Elevation
2.	1294.06
4.	1294.11
5.	1294.11
7.	1294.08
9.	1294.09
11.	1294.12
13.	1294.08
15.	1294.14
17.	1294.15
19.	1294.10
21.	1294.12
23.	1294.13

Table 4. Measurements for Tilting, October 16, 1992.

Joint	Bottom Panel	Top Panel
Number	Inches in 4.0 feet.	Inches in 4.0 feet.
1.	0.0	0.0
2.	-0.0	0.0
3.	0.0	0.0
4.	0.0	0.0
5.	-0.2	0.0
6.	0.0	0.0
7.	0.1	0.0
8.	0.0	0.0
9.	-0.2	0.0
10.	-0.2	0.0
11.	0.0	0.0
12.	0.0	0.0
13.	-0.1	0.0
14	0.0	0.0
15.	0.0	0.0
16.	0.0	0.0
17.	-0.3	0.0
18.	0.0	0.0
19.	0.0	0.0
20.	0.2	0.0
21.	-0.2	0.0
22.	0.0	0.0
23.	0.0	0.0

* Negative values mean the top of the panel tilts toward entrance ramp.