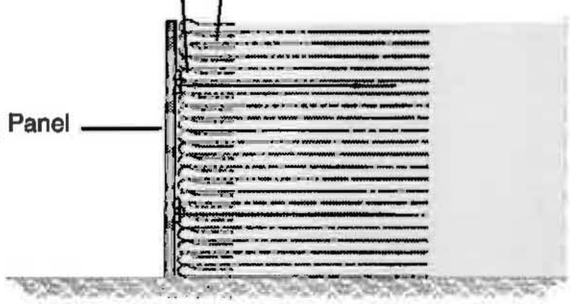
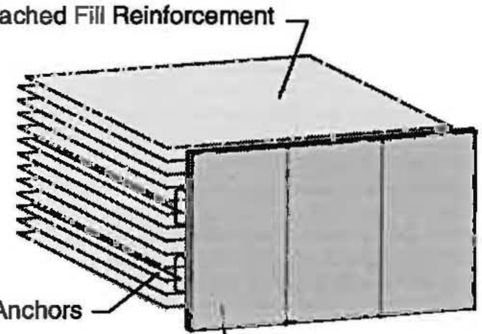
CDOT-CTI-CU-3-94



Section



General View

Independent Facing Panels for Mechanically Stabilized Earth Walls

George Hearn
Scott Myers

for
Colorado Transportation Institute

Robert K. Barrett
Manager of Geoservices Research

University of Colorado at Boulder December 1993

The contents of this report reflect the views of authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

REPORT DOCUMENTATION PAGE

FORM APPROVED
OMB NO. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1993	Final

4. TITLE AND SUBTITLE
Independent Facing Panels for Mechanically Stabilized Earth Walls

5. FUNDING NUMBERS
270.01

6. AUTHORS(S)
George Hearn, Scott Myers

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(S)
University of Colorado
Boulder, Colorado 80309-0428

8. PERFORMING ORGANIZATION REPORT NUMBER
CDOT-CTI-CU-3-94

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(S)
Colorado Department of Transportation
4201 E. Arkansas Ave.
Denver, Colorado 80222

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

12a. DISTRIBUTION/AVAILABILITY STATEMENT
No Restrictions: This report is available to the public through the National Technical Information Service. Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
Analysis, design and testing of independent reinforced concrete facing panels for mechanically stabilized earth (MSE) walls are reported. Panels are intended for use as full height facing for a variety of mechanical reinforcements for fills including geotextiles, geogrids, and bar mats. Panels provide a forming surface and permanent facing for MSE walls, but are independent of the MSE mass. Panels are attached to stable MSE constructions with flexible anchors that limit earth pressures on panels. Loads on panels are minimal, and panel size and appearance may be tailored to the requirements of individual projects and sites. This offers options in construction operations and in appearance of the finished wall not previously available for MSE constructions.

This report presents the basis for design of independent facing systems, presents methods for stress analysis of independent facing panels, reviews options for full-height and for stacked panel facing systems, outlines construction procedures for MSE walls with independent facing, and presents options for anchors and panels for independent facings. The report also presents the design, fabrication, testing and performance of a prototype independent facing panel used in MSE wall tests.

14. SUBJECT TERMS
Retaining Walls
Reinforced Fills
Facing Panels

15. NUMBER OF PAGES
78

16. PRICE CODE

17. SECURTITY	18. SECURITY	19. SECURITY	20. LIMITATION OF
Unclassified	Unclassified	Unclassified	

INDEPENDENT FACING PANELS FOR MECHANICALLY STABILIZED EARTH WALLS

George Hearn, Scott Myers
University of Colorado at Boulder

Contents:

INDEPENDENT FACING PANELS FOR MECHANICALLY STABILIZED EARTH WALLS

George Hearn, Scott Myers
University of Colorado at Boulder

OVERVIEW

Mechanically stabilized earth (MSE) walls are used in many applications in highway projects. MSE walls are durable and cost-effective. MSE walls do deform, however. During wall construction, deformation occurs naturally as reinforcements in the earth mass are mobilized. Horizontal deformation, a bulge in the front of the wall, places specific demands on wall facing. For articulated facing, the demand is movement; for rigid facing, the demand is force. Articulation is the common choice. Many commercial wall systems use flexible facings such as synthetic fabric or steel chain link, or use modular facing systems. If facing is rigid, it is subject to significant earth pressure as the MSE wall deforms.

Facing as a structural feature in MSE walls is a design solution to a boundary problem. At the front of an MSE wall, fill can be lost and fill reinforcements may not be effective. Facings constructed of timbers, concrete blocks or reinforced concrete panels can contain fill and can anchor the tensions in fill reinforcements. MSE walls constructed with wrapped reinforcement at the front of the wall contain fill without separate facing. A protective coating such as gunite is applied after wall construction to protect reinforcements against UV degradation, but this coating is not a load-carrying feature. This 'facing' as such is nonstructural. Timber facing used at the front of a wrapped-reinforcement face is similarly a nonstructural, protective feature.

Modular block or panel facing units are typically attached directly to fill reinforcements, and in standard design methods attached facing has a structural function. The facing is the anchor for tensions in fill reinforcements. As a result, there are load demands on the facing and on connections to reinforcements. In addition, attached facing must accommodate deformation in the MSE mass. Several commercial systems are available using modules of plain concrete blocks or reinforced concrete panels.

Facing modules are short in comparison to the height of the finished wall. Modular construction produces many horizontal joints in facing giving walls a characteristic appearance and affording the articulation needed to accommodate deformations in the MSE mass. Minor slips and rotations at joints allow the facing to conform to the MSE mass. Where taller facing units are used, the completed facing has fewer horizontal joints, is less flexible overall, and is less able to conform to deformations in the MSE mass. In the limit, a full-height panel has no horizontal joints and no articulation in the manner of modular facing.

A second mode of articulation is available. Facing may tilt about its base. Tilt is the articulation that is available for full height panels; that is, facing without intermediate horizontal joints. By tilting, facing can accommodate horizontal deformation but will not conform to the MSE mass. Earth pressures can be high if a tilting panel is attached directly to fill reinforcements. To prevent high forces, connections between facing and the MSE mass must be flexible. In turn, flexible connections and limited restraining force at panels require that the MSE mass be stable without facing. Flexible connections protect facing panels against high restraining forces, but this precludes the use of facing as the anchor for fill reinforcements.

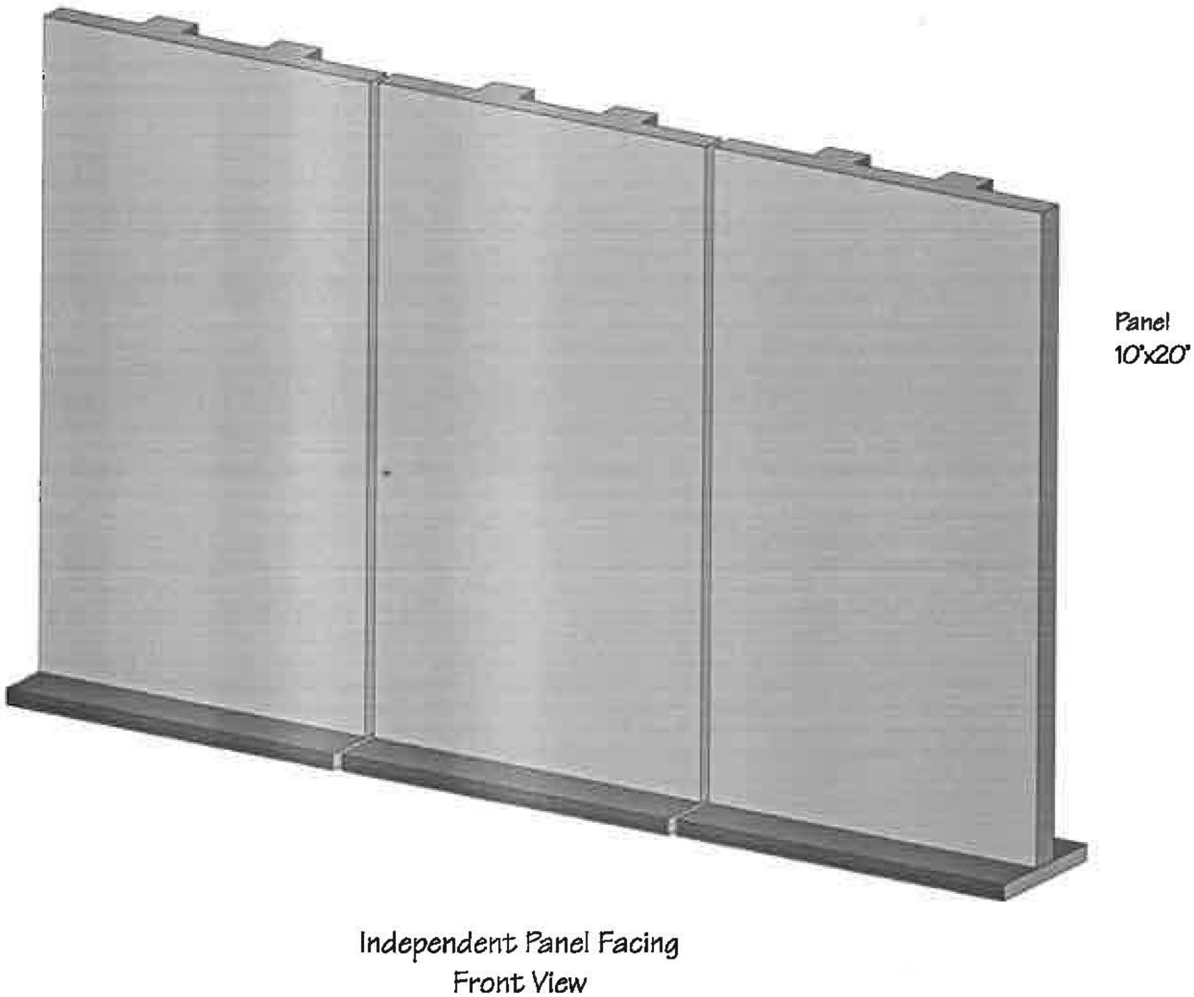


Figure 1 - Full Height Independent Panel Facing

With flexible anchors, facing panels are independent. Therefor, the completed MSE mass must be able to retain and reinforce fill material at the front of the wall without a reliance on facing. A wrapped-reinforcement front is suitable, but there are other options. The experiments in prototype walls with independent facing, reported here, indicate that unwrapped, unattached fill reinforcements used with full height panels may be able to adequately retain and reinforce fill.

Independent, nonstructural facings of rigid panels can be fabricated in reinforced concrete, timber, metals, fiberglas or other materials. Panels in any of these materials will provide UV protection for fill reinforcements, and each material offers the advantages of a finished wall free of horizontal joints, and of rigid panels to serve as a forming surface during placement of fill and reinforcements. To accommodate horizontal deformation in the MSE mass, rigid panel facing should have flexible anchors independent of fill reinforcements to allow panels to tilt.

MSE walls with independent facing have three components:

- A self-stable MSE mass.
- Independent facing allowed to tilt about its base.

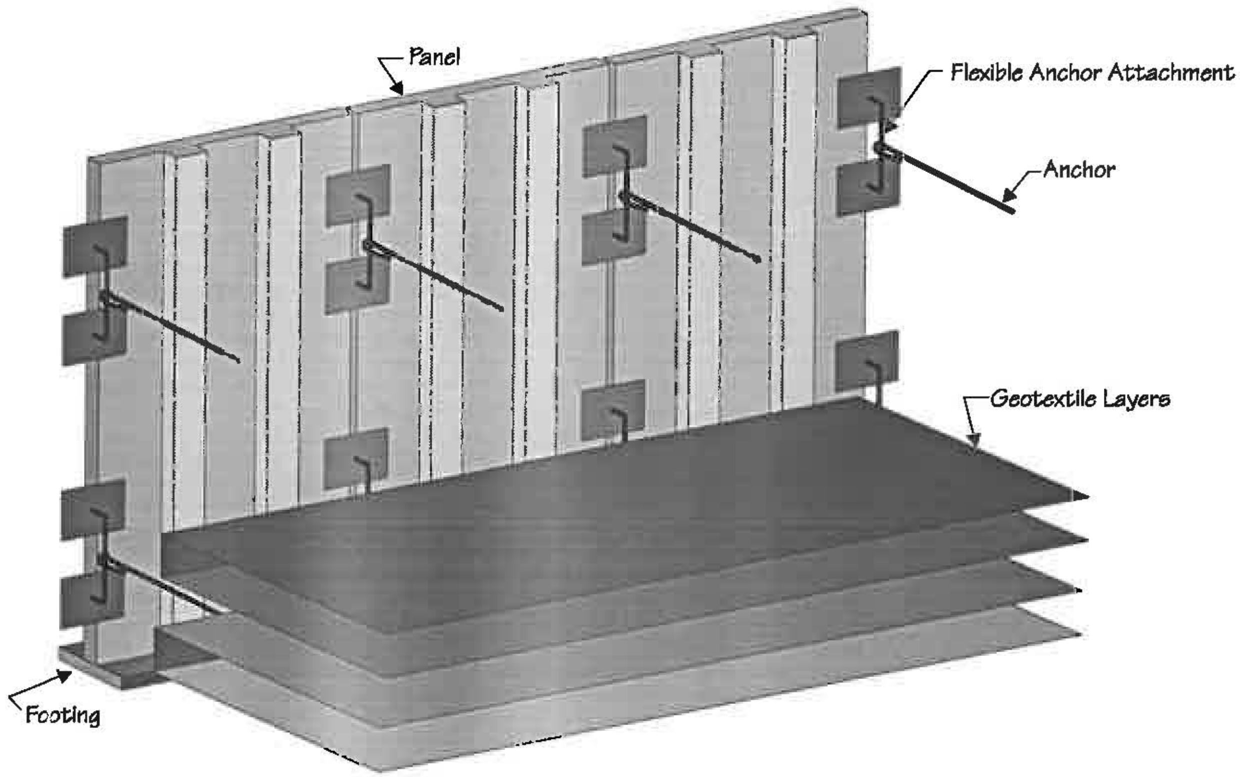


Figure 2 - Back View of Independent Panel Facing

- Flexible connections between panels and the MSE mass to limit restraining force.

Examples of independent facing systems using reinforced concrete panels are shown in Figure 1 through Figure 3. The first is a system of full-height facing panels. The facing is composed of single panels attached to the MSE mass by steel anchors. The size of full-height panels is limited only by considerations of handling and of temporary support (if panels are used as a forming surface for the MSE construction). A second type of independent facing system uses stacked panels to construct tall MSE walls. The smaller panel height is easier to handle and to support during MSE wall construction. Flexible anchors for independent facing panels are shown in Figure 4. All three types of anchor rely on flexural yielding of a loop bar to allow facing panels to tilt at known and limited force.

STRUCTURAL DESIGN OF INDEPENDENT FACING

Because the facing and the MSE mass are independent, design of an MSE mass and of its facing are effectively divorced. Independent facing may be attached to any stable MSE mass without impairing MSE performance. The specific strength and deformation characteristics of a reinforced fill do not, within broad limits, influence the design of an independent facing system.

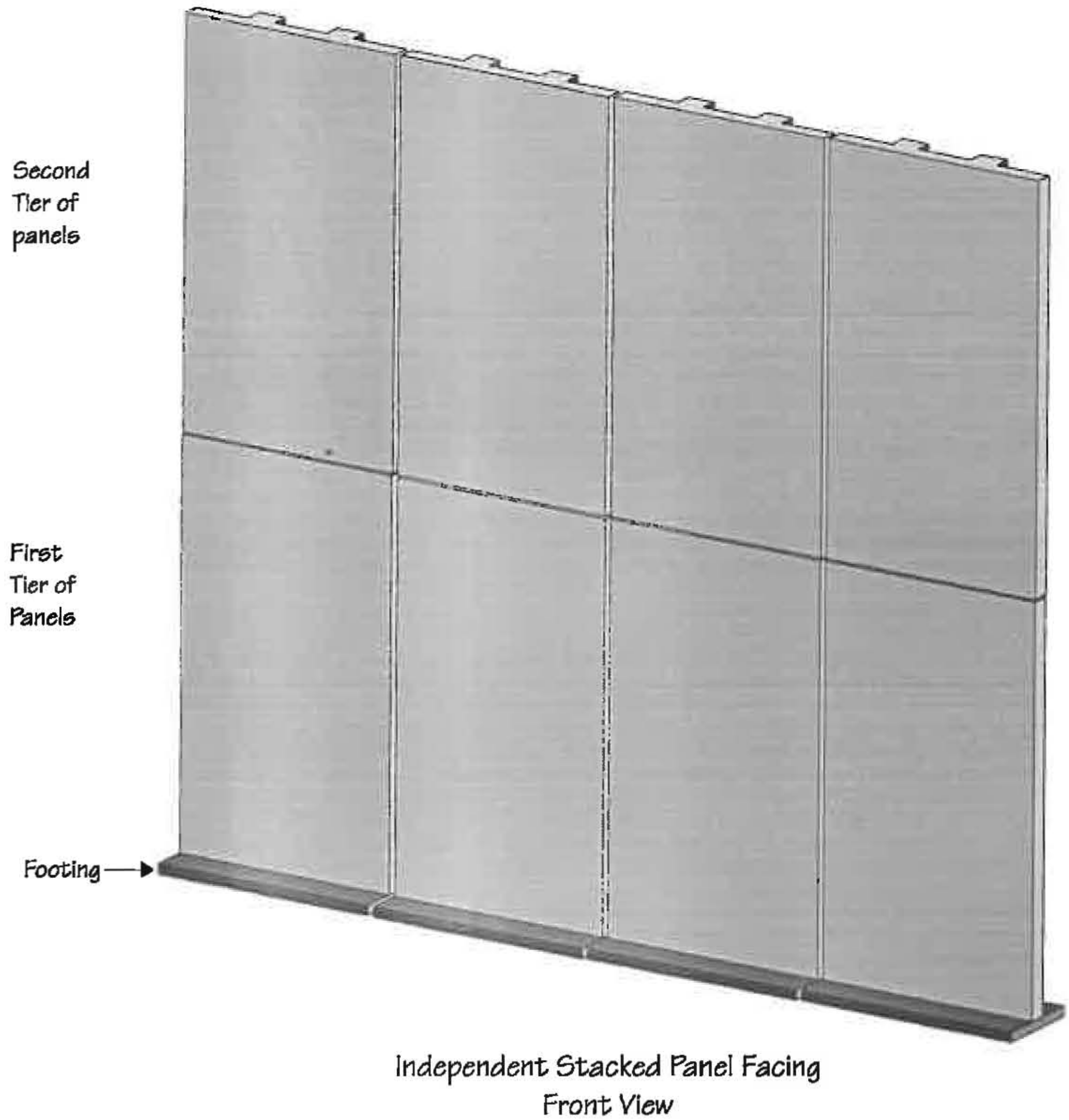


Figure 3 - Independent Stacked Panel Facing

The concept of independent facing does not require the use of a particular panel material, or size of panel, or design of anchors. Rather, the concept provides a design basis for both panels and anchors with associated requirements for self-stable MSE constructions. Specifically, anchors must be flexible for a range of movement required for the expected horizontal bulging and vertical settlement of the MSE mass as construction proceeds. This movement of panels and anchors must occur under moderate earth pressure. At the same time, anchors must provide an adequate permanent connection of facing panels to the MSE mass. Steel anchors, designed to yield in flexure, meet the simultaneous requirements of deformation at moderate earth pressures, and of adequate strength for permanent connection of facing panels. The yield load of anchors is selected to provide adequate permanent strength for support of facing panels against the MSE mass.

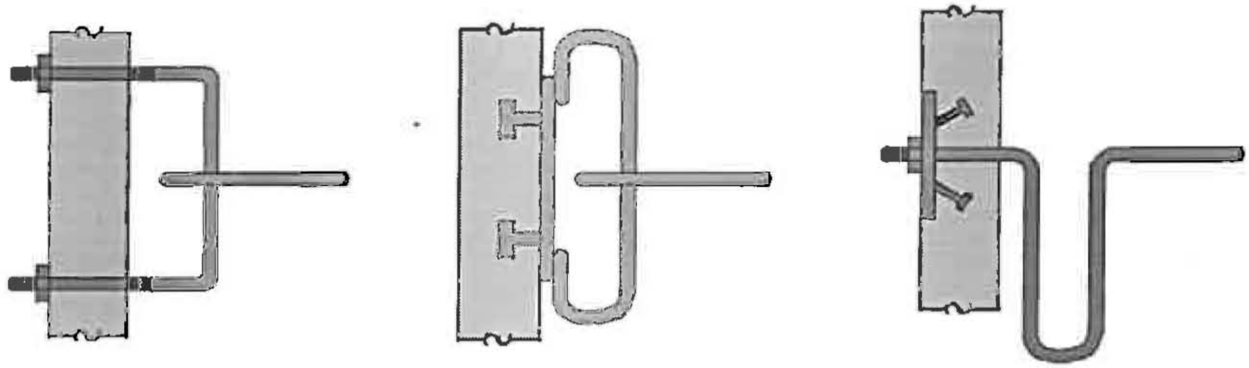


Figure 4 - Flexible Anchors for Independent Facing

STRUCTURAL DESIGN OF PANELS FOR INDEPENDENT FACING

Independent facing panels in service are exposed to earth pressures from the MSE mass. The magnitude of earth pressure is limited by the yield capacity of the set of anchors supporting the panel. The distribution of earth pressures on independent facing panels is not known. A triangular pressure distribution is often used for design of modular facing[1]. Triangular pressure distributions have been measured in standing MSE walls, but other forms of pressure distribution have been measured as well. The movements of facing panels that occur as fill reinforcements are mobilized determine the particular distribution of earth pressures at a wall. As such, the distribution of earth pressure at service can differ among walls of similar construction.

To identify appropriate limit states for strength design of facing panels to withstand earth pressures in service, it is necessary to consider possible pressure distributions, and to identify the largest moment, *M*, and shear, *V*, demands that may come to exist. Here, three pressure distributions are considered: 1) Triangular distribution ; 2) Rectangular distribution, and; 3) Tschebotarioff distribution. The three pressure distributions correspond to loads on facing that are dominated by 1)Self weight of the wall; 2) High surcharge, and; 3) Stiff anchors for panels. For each of these pressure distributions, bending moments and shears in facing panels are computed for patterns of four, six and eight anchors per panel. Limiting moments and shears are computed by assuming that anchors yield at a known load *A*, and that the panel base is free to rotate but fixed against translation. Using these assumptions, peak soil pressures at facing, P_{max}, and reactions, *R*, at the panel base are computed along with section forces in panels.

Pressure distributions, associated statical relations for P_{max} and *R*, and expressions for panel moments and shears are shown in Figures 5, 6, and 7. For full height panels, the largest section forces occur under a triangular pressure distribution. The anchor force, *A*, controls the moments and shears in panels. This is the key feature in the design of independent facing

[1] Christopher,B.R., Safdar,A.G., Giroud,J-P., Juran,H., Mitchell,J.K., Schlosser,F., and Dunnicliff,J. (1989). "Reinforced Soil Structures" FHWA, McLean, VA.

Panel Height (ft)	Anchor Force (lbs)		
	Tilt A_T	Wind A_W	Ultimate A_U
Full Height Panels			
10	12.5	600	797
15	22.5	600	807
20	30.0	600	816
Stacked Panels			
2 Tiers	45	600	839
3 Tiers	75	600	878

Table 1 - Design Data for Panel Anchors

panels. The choice of a yield capacity for anchors determines, and controls, moments and shears in panels.

Taller panels require additional sets of anchors. For a typical vertical spacing between anchors of 5 feet, the expressions of four, six and eight anchors correspond to panels of 10, 15 and 20 foot height, respectively. An increase in panel height of independent facing corresponds to a fixed value of maximum earth pressure and an increase in maximum moments and shears in panels. For all heights, moments and shears in facing panels are controlled by the yield load of the anchors.

For stacked facing panels, the situation is only slightly different. One additional loading case is considered in which a nonuniform pressure distribution selectively loads a single panel in the stack. Here, the panel is restrained by its own anchors and by contributions from anchors in adjacent panels that are attached through shear keys in joints in the facing. The total restraining force for one panel is increased and the moment and shear demands on the panel are increased as well (Figure 7).

Expressions for moment and shear relations are used for the preliminary design of panels for both full-height and stacked panel systems. Panel heights of 10, 15 and 20 feet are considered. The results are summarized in Table 1 and Table 2. Note that flat panels are possible for panel heights up to 15 feet and that a ribbed panel is recommended for a 20 foot panel. Facing panels are reinforced with a single two-way mat of rebars. Rebar size and spacing are listed in Table 2. Shear keys in the edges of panels maintain a smooth profile in the finished wall.

Structural Design of Anchors

Anchors must allow movement of panels at moderate load, and must provide a positive, permanent attachment of facing panels to the MSE mass. The requirement for panel movement imposes an upper bound on anchor yield force. This upper bound controls the design loads in facing panels. The need for permanent attachment of facing panels and for stability of the facing under self-weight, wind loads, and incidental loads imposes a lower bound on yield force in anchors. Anchors must meet two requirements on deflections as well. During the construction of the MSE wall, anchors must allow movement of panels. In service, anchors must restrain panels under wind loads and under eccentric dead loads with no deflections beyond a normal (and small) elastic response. The constraints on the design of anchors therefore are:

Panel Height (ft)	Pmax (psf)	Moments in Panels (ft-lbs)} Tilt M_e	Wind M_w	Earth Press. M_p	Ultimate M_u	Panel Thickness (in)	Rebars Gr 60 Two Way
Full Height Panels							
10	120	-20	-750	2150	2390	5	#4@12"
15	121	-24	-750	5380	5980	6	#4@8"
20	122	-24	-750	9430	10480	6[a]	#4@8"
Stacked Panels							
2 Tiers	84	-169	-750	4195	4660	6	#4@8"
3 Tiers	88	-319	-750	4390	4880	6	#4@8"

a - Panel with two 10" deep webs.

Table 2 - Design Data for Independent Panels

1) A tolerance of large movements of panels during construction, and;
2) A capacity for adequate lower bound force at small, elastic deflections.

These constraints may be met by steel anchors that are designed to yield at moderate load, that are capable of large movement during yielding, and that provide elastic response up to a lower bound force required for wind loads and for dead loads. Anchors should also be able to tolerate vertical settlement of the MSE mass.

Three designs of anchors for panels have been developed as examples (Figure 4). The first is a two-part design using a straight anchor bar in the MSE mass attached to a loop bar on the panel. The straight anchor bar is immovable; the loop bar provides articulation. The loop bar yields for horizontal (outward) tilt of facing panels. The vertical length of the loop bar allows the straight anchor bar to slip as fill materials settle, and the vertical length provides a tolerance for anchor placement during construction. The loop bar can be bolted through a sleeve at the front of facing panels, or can be attached to a plate at the vertical joint between panels. Design relations for two part anchors are shown in Figure 8. A general view of panels and anchors is provided in Figure 9. The bolted attachment allows an outward adjustment of panels that may be required to correct the alignment and attitude of facing panels after wall construction is complete.

The second design for anchors is a similar two-part design using a straight anchor and a loop bar, but the loop bar is blind. The design is shown in Figures 10 and 11. The loop bar is welded to a steel plate embedded in the facing panel. No correction of panel attitude is available in this design.

The third design is a single part, gooseneck anchor shown in Figures 12 and 13. The length of straight anchor extending into the MSE mass is immovable. Yielding is provided by the gooseneck. The anchor is installed with the gooseneck horizontal. Torsional yielding of the anchor bar provides a limited capacity for vertical movement.

Relations for the plastic strength of each anchor are developed in Figures 8, 10 and 12. Anchor force and the capacity for movement may be selected through a choice of bar diameter, ***d***, and loop (or gooseneck) length, ***l***. The yield force of loop bar anchors depends on the placement of the straight bar. The standard position for this anchor is at the mid-height of the loop bar. An extreme position at the quarter height of the loop bar is considered to establish a likely maximum anchor force for selected bar diameters and loop bar lengths. Relations are shown in the figures.

Lower bound strength must be provided by anchors to restrain facing panels against wind loads, to support eccentric dead loads of single panels, and to support eccentric dead loads of stacked panels. Design wind loads are taken as 30 PSF outward (inward loads do not exercise panel anchors). Accidental eccentricities are taken as $e/h = 1/100$ for both full height and stacked panel facing systems. Design forces for anchors are listed in Table 1.

Structural Design of Stabilized Earth Mass

Independent facing panels are not attached to reinforcements in the MSE mass, do not provide an anchorage for tensions in reinforcements, and offer only a limited capacity for retaining fill at the front of an MSE wall. MSE wall constructions may take advantage of facing panels as a forming surface during construction, but otherwise MSE walls employing independent facing panels must be stable within themselves. Standard design procedures are available to ensure that MSE walls have adequate margins of safety against external failure mechanisms such as sliding, bearing failure and overturning, and against internal failure mechanisms such as rupture, pull-out and degradation of reinforcements. In addition, methods and analyses are available for design of MSE walls to satisfy limits on defections. Designers must ensure an adequate MSE structure without a reliance on anchorage, support or fill containment by the facing panels.

Backfills for mechanically stabilized walls with independent panel facing may be earth, or may be other fill materials such as sawdust, shredded tires, or expanded polystyrene. These lightweight materials offer advantages at sites with weak foundation soils, and fill for walls is a positive use for chemically stable waste materials. Where earth fill is used, fill shall conform to Colorado DOT Bridge Specification Class II-A Structural Backfill with not more than 50% passing a #200 sieve and a maximum particle size not greater than 6 inches.

Independent panel facing may be used with any fill reinforcement that can be constructed with a wrapped front similar to geotextile wall constructions. Where geotextile is used, the wall design should limit fabric elongation to 1.5% or less. Design procedures for geotextile walls should be based on limited deformation using the Colorado DOT analysis method developed by Dr. Nelson Chou. Designs based on safety factors for strength are not, by themselves, sufficient. Design by safety factors alone may not achieve an acceptable limit on wall deformation.

CONSTRUCTION OF MSE WALLS WITH INDEPENDENT FACING SYSTEMS

Construction of MSE walls with independent facing is similar to construction of walls with modular facing. Facing elements are a forming surface and their placement must precede placement of fill and reinforcements. At the same time, the MSE mass is the permanent support for facing, and so facing assembly and MSE construction are linked.

A construction sequence for an MSE wall with full-height panels is shown in Figure 17. Here, footings for panels are placed, and facing panels are moved into position and braced. Construction of the reinforced fill begins using the facing panels as forming surfaces. Anchors for panels are installed as the MSE construction proceeds. After the MSE mass is complete, bracing at the front of panels is removed. Finally, panel attitude may be adjusted if necessary.

A construction sequence for a wall with two-tier stacked panel independent facing is shown in Figure 18. To begin, footings and the first tier of panels are placed and supported by temporary bracing. The MSE mass is constructed to a height of 10 feet. Panel anchors are installed as the MSE mass reaches heights of 2.5 feet and 7.5 feet, and bridging for the second tier is installed as well. After the first 10 feet of MSE wall construction is complete the second tier of panels is placed and supported by bridging to the first tier. MSE wall construction proceeds to a height of 20 feet. Anchors for second tier panels are installed as the MSE mass reaches appropriate heights. Bracing at the front of the wall can be removed once the first anchors at all second tier panels are installed and covered by at least one full lift of fill. When all anchors are in place for the second tier, bridging to the first tier may be removed. Bridging may also remain in place throughout the construction without harm. Left in place, bridging will aid in keeping tiers aligned. Erection of a third tier of panels, if needed, proceeds in the same manner as the second tier.

During construction the MSE mass will experience horizontal deformations that will demand movement of the facing. Panels are protected by their flexible anchor connections, but temporary bracing at the front of panels (the first tier in stacked systems) must also allow movement. Bracing supports panels only and must not restrain (buttress) the MSE mass. Bracing should include an adjustment mechanism such as turnbuckles to allow release of loads. Adjustment mechanisms should be checked on a regular schedule, usually once each day. As an option, loads in bracing can be measured and adjustments made as necessary.

Panel movement during construction may result in an unacceptable facing alignment. Two measures in construction offer remedies. At initial placement, facing units should be battered in anticipation of a horizontal deformation. Batter on the order of 2 to 3 inches per 10 feet of wall height is usually adequate. After wall construction is complete, anchor connections may be loosened at the front of the wall and panels pulled forward to vertical if necessary. For this operation, panels may be gripped at vertical edges, or through the mounting holes for bridging.

Specific design of temporary bracing is left to the construction contractor. Modest panel size makes this bracing operation equivalent to bracing formwork for cast-in-place concrete construction.

DESIGN ALTERNATIVES FOR INDEPENDENT FACING PANELS

The designs shown for 10, 15 and 20 foot tall facing panels as well as the stacked 10x8 panels are feasible systems for independent facing, but any of these may be altered to suit individual projects or to accommodate a modified construction sequence. Specifically:

1. Panel appearance may be modified. For example, the rusticated design used on walls for the Interstate 70 Glenwood Canyon project can be applied to facing panels as an added thickness.
2. Panel size may be changed. The panel sizes considered in this report are convenient for most projects. Other sizes may be designed by the methods outlined.
3. Panel anchors may be modified. Where fill reinforcements are steel, anchor loop bars connected directly to fill reinforcements, and separate straight anchor bars are omitted.

Connection of steel loop bars to plastic grid or to geotextiles may be impractical. In any use of fill reinforcements to anchor panels, the connection must be to a loop bar or similar yielding element.

ALTERNATIVE SYSTEMS FOR INDEPENDENT FACING

Concepts for facing different from the full height and stacked-panel systems can be developed into workable designs. Three considerations are important in design development: 1) A tolerance for movement of the MSE mass; 2) Permanent strength of panels and connections of panels to the MSE mass; 3) Ease of construction. To meet these considerations several ideas may be advanced.

- **Weak Fill for MSE Deformation**
  Independent facing panels may be backed by a thin layer of a weak, deformable fill. This layer will absorb deformation of the MSE mass making panel movement (tilt) unnecessary. Panels then could be attached with comparatively strong anchors. To use panels as forming elements, the weak fill must be placed along with panels. This might be accomplished with weak fill in bags (resembling mattresses) attached to the back of panels. Weak fill should be adequate to support MSE fill placement and compaction, but weak enough to crush as the MSE wall deforms.

- **Panel Material**
  Independent facing panels may be constructed of timber, metal or fiberglas, and can be used in essentially identical full height or stacked-panel systems. Details of anchors and recommendations for construction sequence can remain unchanged. Timber panels are especially attractive since they are both inexpensive and lightweight.

- **Construction Sequence**
  The use of facing as a forming surface for MSE construction is a common practice, but the use of a separate system for forming followed by a later installation of facing panels on a completed MSE structure is possible. Installing the facing as a last step eliminates the need for temporary bracing. Discarded automobile tires (whole, not shredded) are inexpensive forming, and tires are already used for MSE forming by Colorado DOT. There is no need for tight control of the alignment of forming elements for MSE constructions that will be covered by a separate facing. Proper alignment of the wall face is achieved during placement of independent facing panels.

LABORATORY DEMONSTRATION OF INDEPENDENT FACING FOR MSE WALLS

A full-height independent facing panel was used in the construction and load testing of two prototype walls in the laboratory. The prototypes were geotextile-reinforced earth walls approximately 10 feet tall, 4 feet wide and 8 feet deep. The prototypes each represent a slice of a wall of large lateral extent. The test fixture is a box constructed of steel strongbacks. The text fixture has greased membranes along the sidewalls to allow the MSE mass to deform with little

Unit weight (ASTM D-3776)	1.93 N/m^2
Grab tensile (ASTM D-4632)	890 N
Elongation at break (ASTM D-4632)	60%
Modulus at 10% elongation (ASTM D-4632)	4.45 KN/m
Coefficient of permeability	1.99*10-4 cm/sec
Nominal thickness	0.508 mm

Table 3 - Properties of Soil Reinforcements in Prototype Tests

friction force. The test setup approximates plane strain conditions. The development and use of the test fixture are reported by Wu[2]. A general view of a prototype is provided in Figure 19.

The wall tests had two purposes. The first was a demonstration of the performance of an independent facing panel. The second was an investigation of the feasibility of using MSE walls with unwrapped reinforcement at the face. While it is common practice to anchor reinforcements by attachment to facing units or by wrapping back into the MSE mass, reinforcements in prototype walls were neither attached to facing panels nor wrapped.

Independent facing for MSE test walls was a single reinforced concrete panel approximately 10'x4'x4". The panel was reinforced with a two-way mat of #4 reinforcing bars at 5 inch spacing. The compressive strength of the concrete was 5000 psi. Concrete reinforcing steel was grade 60. The panel had sleeves to accommodate adjustable loop-bar anchors. The panel was also provided with six block-outs, each approximate 2"x2"x7", to accommodate soil pressure cells mounted in the panel. Details of this facing panel are shown in Figures 20 to 23. Anchors were two-part, adjustable anchors. Loop bars were 1/2" diameter and 18" long fabricated from smooth round bars. The steel had a yield strength of 42 ksi.

Loading on the wall was a surcharge made up of a 16" layer of sand and an additional air pressure applied at the top of the wall. The air pressure was taken as high as 20 psi, a load that is equivalent to a surcharge of 26 feet of a 110 PCF material. Air pressure was controlled by a standard gas control valve, and pressure could be held constant over time to observe creep effects in walls. The execution of load tests included the application of air-pressure at 1 psi and 5 psi increments, and the maintenance of air pressure to observe creep. Loads were increased until some portion of the test setup failed. Failures included a failure of seals around the panel and a failure of the pressurized air bag applying the surcharge.

Two walls were built and load tested. The walls differed only in the choice of fill material. One wall used an Ottawa sand fill, and the other used a fill of Colorado DOT Class 1 roadbase. For both fills, fill reinforcements were geotextile reinforcements. Properties of soil reinforcements shown in Table 3.

Ottawa sand used for fill had a specific gravity of 2.65 and maximum and minimum unit weights per ASTM D-854 of 112.2 PCF and 97.5 PCF, respectively. The sand reached a compacted density of 107 PCF determined using a nuclear density meter.

CONSTRUCTION OF PROTOTYPE WALLS

Construction of the prototype MSE walls proceeded by:

[2] Wu,J.T.H. (1992) "Predicting Performance of the Denver Walls: General Report" *in* Geotextile- Reinforced Soil Retaining Walls, J.T.H.Wu, ed., Balkema, 2-20.

1. Placement of the facing panel in the front opening of the test fixture, and support of the panel by bracing. The panel served as a forming element for the front of the MSE wall.
2. Delivery of fill materials at the top of wall by a mechanical belt conveyor. Compaction of materials by hand-operated mechanical vibrator in 12" lifts.
3. Placement of geotextile reinforcements after each lift.
4. Placement of anchors for panels as the fill advanced. Anchors were placed approximately 4" above the midheight of loop bars to allow for settlement in the fill.
5. Removal of bracing at the front of the facing panel after fill materials are placed.
6. Topping out with placement of a 16" layer of uncompacted, unreinforced sand. This is a surcharge on the MSE wall. The sand layer served to distribute the air pressure exerted at the top of the wall.
7. Placement of air bags and the lid of the test fixture. The lid is a reaction surface for the pressurized air bags.

Instrumentation for the tests included resistance strain gages on all four anchors, six soil pressure cells mounted in the facing panel, resistance strain gages on selected geotextile layers, dial gages at five locations on the front (outer) surface of the facing panel, and a scribed grid on the sidewall membranes of the MSE mass. To monitor the performance of facing panels and of anchors, the needed information is provided by strain gages on anchors and by dial gages on the panel.

Strain gages on anchors were mounted in pairs on the straight-bar portion of the anchor near the connection to the loop bar. The pair of active gages were wired in a full bridge with two additional gages mounted on an unloaded length of steel round stock to serve as temperature compensation. For the Ottawa sand test, a single pair of strain gages was mounted on each anchor. The pair of gages on anchor #4 stopped functioning during the test. For the roadbase test, two pairs of gages were mounted on each anchor. All gages functioned in the roadbase test.

Four dial gages were mounted at the corners of the facing panel and a fifth dial gage was mounted at the middle of the top edge of the panel. From this pattern of gages, it is possible to compute the translation, tilt, and twist of the panel. These computations are present in Figures 24 and 25.

Prototype Wall with Ottawa Sand Fill

In testing of the wall with Ottawa sand fill, air-pressure was applied at 1, 5, 10, 15 and 20 psi. The test was stopped after the failure of seal between the facing panel and the sidewall of the test fixture. The duration of loadings varied. The 1 psi surcharge was held for approximately 75 hours (this was over a weekend). The 5 psi surcharge was held for 30 minutes. The 10 psi surcharge was held for 12 hours (overnight). The 15 psi surcharge was held for 30 minutes. The 20 psi surcharge was not held for any appreciable time. The load history of the test is listed in Table 4 and shown in Figure 26.

Dial gage readings were used to compute panel translation, tilt and twist. These are plotted against time in Figure 27 and 28, and plotted against surcharge in Figures 29 and 30. Loads in anchors are plotted against time in Figures 31 to 34; against surcharge in Figures 35 to 38; and against panel movement (at the point of anchor attachment) in Figures 39 to 42.

From these figures several aspects of the performance of independent facing may be noted:

1. Under load, panel movement occurs by a combination of tilting and sliding. Tilting is the larger mechanism. Slip of the panel at the base is not more that 0.25 inch. Movement at the top of the panel is a total of 1 inch; of this 0.75 inch is due to panel tilting.
2. Anchors exhibit a yielding response to increasing surcharge. Forces in two (of three) anchors show an upper bound load of about 800 pounds. The third anchor showed an upper bound load slightly greater than 1000 pounds. All anchors exhibit a greater stiffness initially, followed by a softening response at increasing surcharge (Figures 35 to 38).
3. Anchor forces did not appear to vary with time at constant surcharge. However, two surcharge levels were maintained for periods of less than 1 hour. Long term behavior of the system was not established in this test.
4. Anchor forces exhibit a yielding response as a function of panel movement. For these figures, dial gage data are used to compute the net panel movement at the location of each anchor. This movement is accommodated by an extension of the two-part anchor. Anchors exhibit a greater stiffness initially followed by a softening response at increasing panel movement (Figures 39 to 42). This is the expected behavior of flexible anchors.

Prototype Wall with Class 1 Roadbase Fill

The wall using roadbase as a fill material was loaded by air-pressure at 1, 5, 10 and 15 psi. The test was ended by the rupture of an air-pressure bag at 15 psi. As each level of pressure was applied, the system was maintained at a constant pressure until it appeared that equilibrium had been reached, then the anchors for the facing panel were loosened. This was done to determine if the MSE mass could reach a new equilibrium position without restraint by the panel.

Figures for the roadbase wall test are similar to the figures for the Ottawa sand test. Table 5 and Figure 43 present the chronology of the test. Figures 44 to 47 show panel tilt and translation as a function of time and of surcharge, respectively. Figures 48 to 59 show anchor forces as a function of time, of surcharge, and of panel movement.

The following statements may be made:

1. Panel movement occurs equally by translation and by tilt. Significant movements, as much as 0.75 inch, occur as anchors are loosened.
2. Forces in anchors are limited by an upper bound force of about 800 pounds. There is no consistent relation of anchor force to surcharge. The loosening of anchors during the test effectively divorces the anchor forces and surcharge. For the same reason, there is no consistent relation between anchor force and panel movement.

Step	Time (hrs)	Action	Surcharge (psi)	*D1* (in)	*D2* (in)	*D3* (in)	*D4* (in)	*D5* (in)	Trans (in)	Tilt (in)
1	0	Wall completed	0	0	0	0	0	0	0	0
2	39.7	Applied 1 psi	1	0.002	0.003	0.011	0.014	0	0.0075	0.0056
3	115.6	Additional 4 psi	5	0.035	0.040	0.284	0.283	0.274	0.16	0.14
4	116.0	Additional 5 psi	10	0.081	0.088	0.552	0.554	0.538	0.32	0.26
5	137.2	Additional 5 psi	15	0.142	0.161	0.885	0.907	0.899	0.52	0.41
6	137.8	Additional 5 psi	20	0.204	0.250	1.29	1.290	1.285	0.76	0.59

Table 4 - Loading Sequence for Test with Ottawa Sand Fill

Step	Time (hrs)	Action	Surcharge (psi)	*D1* (in)	*D2* (in)	*D3* (in)	*D4* (in)	*D5* (in)	Trans (in)	Tilt (in)
1	0	Wall completed	0	0	0	0	0	0	0	0
2	2.5	Applied 1 psi	1	0.101	0.107	0.464	0.489	0.452	0.290	0.207
3	4.0	Additional 4 psi	5	0.120	0.164	0.644	0.720	0.671	0.412	0.301
4	75.5	Loosened nuts	5	0.144	0.197	0.850	0.937	0.887	0.532	0.402
5	95.0	Tightened nuts	5	0.146	0.199	0.910	0.996	0.948	0.562	0.434
6	96.0	Additional 5 psi	10	0.146	0.199	0.910	0.996	0.948	0.562	0.434
7	99.0	Loosened nuts	10	0.369	0.462	2.084	2.220	2.198	1.284	0.967
8	119.0	Tightened nuts	10	0.369	0.474	2.297	2.257	2.411	1.349	1.033
9	120.0	Additional 5 psi	15	0.369	0.475	2.310	2.272	2.418	1.357	1.040
10	121.0	Failure	15	0.593	0.689	2.716	2.642	2.806	1.660	1.134

Table 5 - Loading Sequence for Test with Roadbase Fill

ANALYSIS OF PANELS AND ANCHORS IN PROTOTYPE TESTS

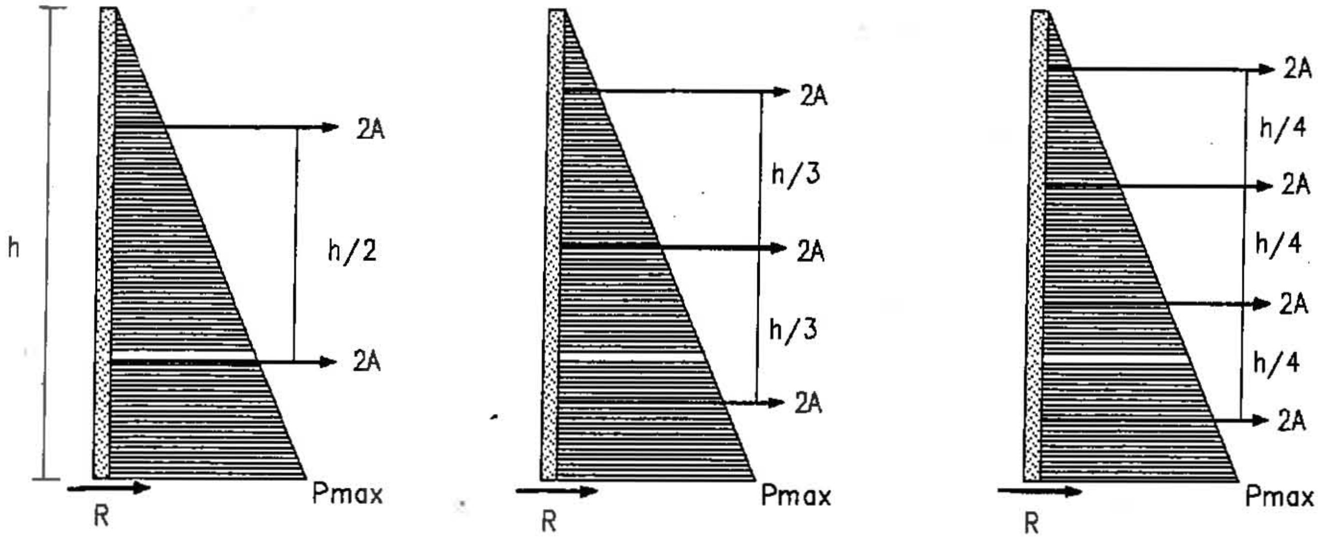
Section forces in panels are computed from the measured anchor loads. Following the procedures developed for design of panels, anchor loads are used to compute peak earth pressures for three distributions: 1) Triangular distribution; 2) Rectangular distribution, and; 3) Tschebotarioff distribution. These computed pressure distributions are used to evaluate peak moments and shears in panels. These are limiting cases, and are not an attempt to uniquely identify the pressure distribution on facing. The computations are shown in Figures 60 to 65. For each distribution, the maximum soil pressure is plotted against surcharge. The yielding of anchors and the protection that anchors afford to panels under increasing surcharge are apparent in the plots. Peak soil pressures are comparable for the two fills tested. Moments in panels were as great as 3750 ft-lbs, a moment that is nearly equal to the strength of the panel.

Cracks appeared in the panel during the testing of the MSE wall with roadbase fill. Cracks are associated with blockouts for load cells and with holes drilled in the panel to accommodate wiring for load cells and strain gages. All cracks originate in disturbed areas. Drilling, and chipping to enlarge one of the blockouts caused considerable local damage of the panel. The appearance of cracks in this panel is not significant.

CONCLUSIONS

Independent facing for MSE walls offers important options in design, in construction and in aesthetics. Facing may be installed as full-height panels or stacked panel systems. Full-height panels produce sleek walls free of horizontal joints. Stacked panel systems allow for the construction of tall walls with panels of moderate size.

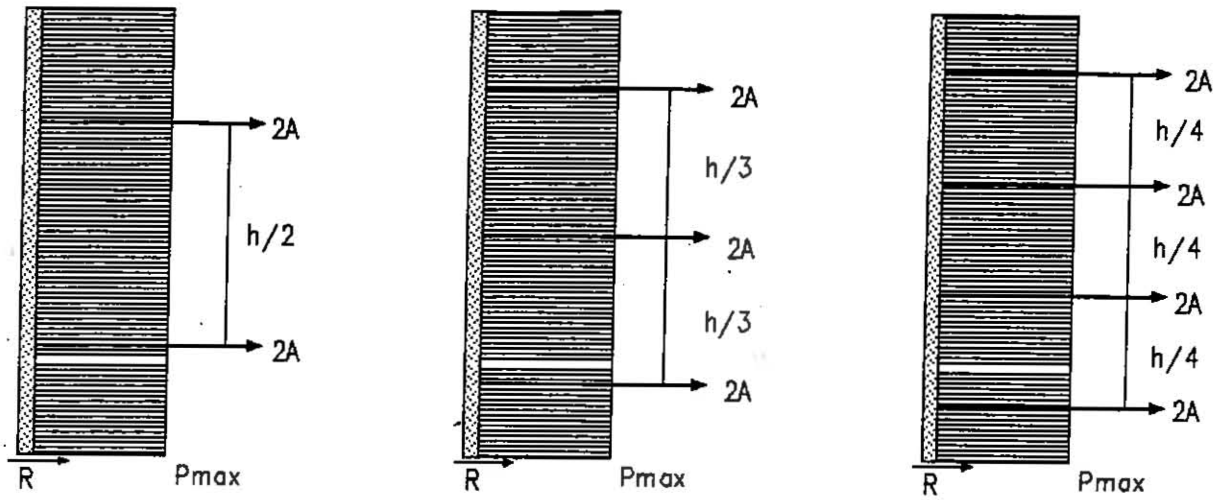
Independent facing performed as expected in tests of two prototype walls. Independent facing panels enjoy articulation by a combination of sliding and tilting. Anchors for panels provide an upper bound load associated with the yield capacity of the loop bar. Once yielding is initiated, anchor forces do not continue to increase with increasing surcharge or increasing panel movement. Anchors can be expected to provide adequate support of facing panels and at the same time will protect panels against high earth pressures.



$\boldsymbol{h}$	Height of Panel (ft)
$\boldsymbol{b}$	Width of Panel (ft)
$\boldsymbol{A}$	Force in one Anchor (lbs)
$\boldsymbol{P_{max}}$	Maximum Earth Pressure (psf)
$\boldsymbol{R}$	Reaction at Base of Panel (lbs)
$\boldsymbol{X_m}$	Location of Maximum Moment (ft)
$\boldsymbol{M_{max}}$	Maximum Moment (ft - lbs)
$\boldsymbol{V_{max}}$	Maximum Shear (lbs)

	P_{max}	R	X_m	M_{max}	V_{max}
4 Anchors	$\frac{12*A}{h*b}$	$2*A$	$\frac{1}{\sqrt{3}}*h$	$0.27\ Ah$	R
6 Anchors	$\frac{18*A}{b*h}$	$3*A$	$\frac{2}{3}*h$	$0.44\ Ah$	R
8 Anchors	$\frac{24*A}{h*b}$	$4*A$	$\frac{1}{\sqrt{2}}*h$	$0.58\ Ah$	R

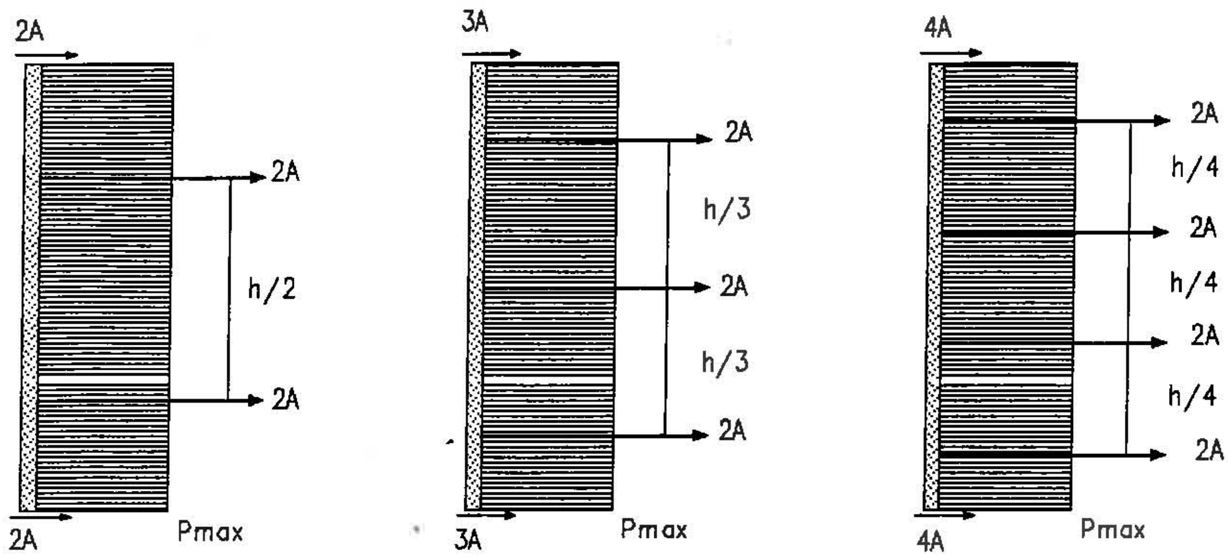
Figure 5: Statics for Independent Facing - Triangular Earth Pressure Distribution



h	Height of Panel (ft)
b	Width of Panel (ft)
A	Force in one Anchor (lbs)
P_{max}	Maximum Earth Pressure (psf)
R	Reaction at Base of Panel (lbs)
X_m	Location of Maximum Moment (ft)
M_{max}	Maximum Moment (ft - lbs)
V_{max}	Maximum Shear (lbs)

	P_{max}	R	X_{max}	M_{max}	V_{max}
4 Anchors	$\frac{4*A}{h*b}$	0	$\frac{h}{4}$	$\frac{h*A}{8}$	A
6 Anchors	$\frac{6*A}{b*h}$	0	$\frac{h}{6}$	$\frac{h*A}{12}$	A
8 Anchors	$\frac{8*A}{h*b}$	0	$\frac{h}{8}$	$\frac{h*A}{16}$	A

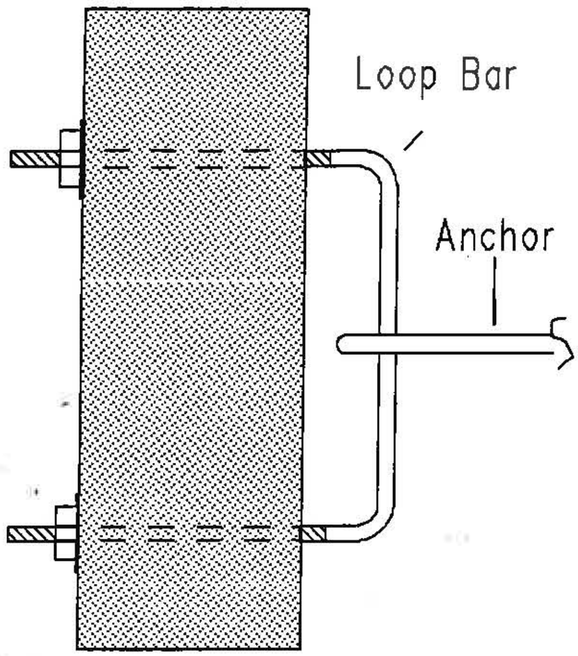
Figure 6: Statics for Independent Facing - Rectangular Earth Pressure Distribution



h	Height of Panel (ft)
b	Width of Panel (ft)
A	Force in one Anchor (lbs)
P_{max}	Maximum Earth Pressure (psf)
X_m	Location of Maximum Moment (ft)
M_{max}	Maximum Moment (ft - lbs)
V_{max}	Maximum Shear (lbs)

	P_{max}	X_m	M_{max}	V_{max}
4 Anchors	$\frac{8*A}{h*b}$	$\frac{h}{2}$	$\frac{h*A}{2}$	$2*A$
6 Anchors	$\frac{12*A}{b*h}$	$\frac{h}{2}$	$\frac{2*h*A}{3}$	$3*A$
8 Anchors	$\frac{16*A}{h*b}$	$\frac{h}{2}$	$h*A$	$4*A$

Figure 7: Earth Pressure on Stacked Panels



$\boldsymbol{l}$	Length of loop bar (in)
$\boldsymbol{l_a}$	Location of anchor (in)
$\boldsymbol{d}$	Loop bar diameter (in)
$\boldsymbol{A}$	Anchor yield force (lbs)
$\boldsymbol{M_p}$	Plastic moment capacity of loop bar (in-lbs)

$$A = 2\ M_p\left(\frac{1}{l_a} + \frac{1}{l - l_a}\right)$$

A36 Anchors
$\boldsymbol{l}$= 18 in, $\boldsymbol{l_a}$ = 9 in

d in	A lbs
0.50	333
0.75	1125
1.00	2666

A36 Anchors
$\boldsymbol{l}$= 18 in, $\boldsymbol{l_a}$ = 4.5 in

d in	A lbs
0.50	444
0.75	1500
1.00	3555

Figure 8: Adjustable Loop Bar Anchor

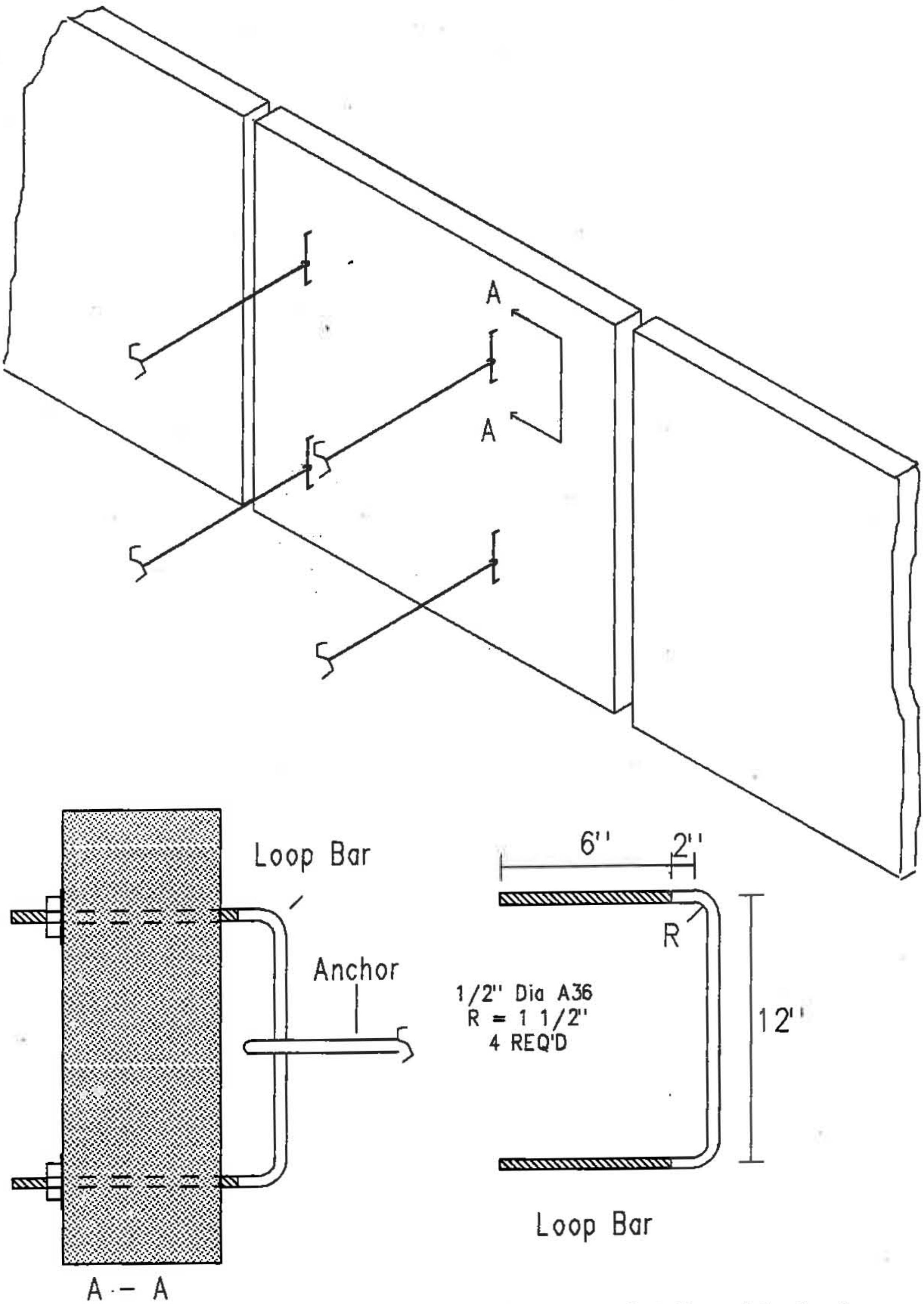
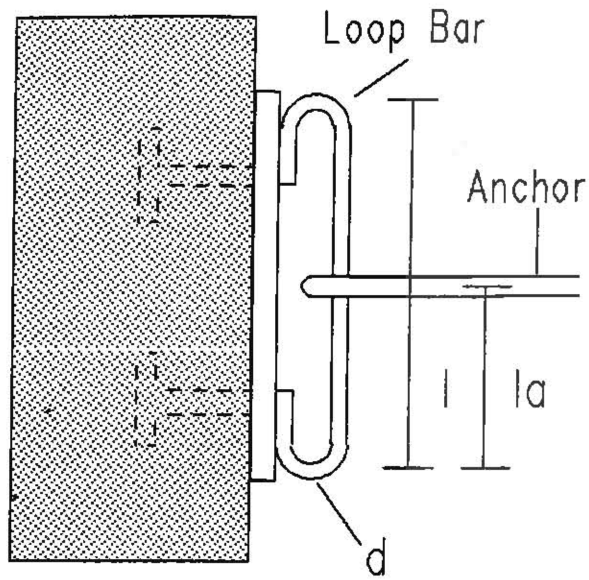


Figure 9: General View - Panels and Adjustable Anchors



l	Length of loop bar (in)
l_a	Location of anchor (in)
d	Loop bar diameter (in)
A	Anchor yield force (lbs)
M_p	Plastic moment capacity of loop bar (in-lbs)

$$A = 2\ M_p\left(\frac{1}{l_a} + \frac{1}{l - l_a}\right)$$

A36 Anchors
l = 18 in, l_a = 9 in

d in	A lbs
0.50	333
0.75	1125
1.00	2666

A36 Anchors
l = 18 in, l_a = 4.5 in

d in	A lbs
0.50	444
0.75	1500
1.00	3555

Figure 10: Blind Loop Bar Anchor

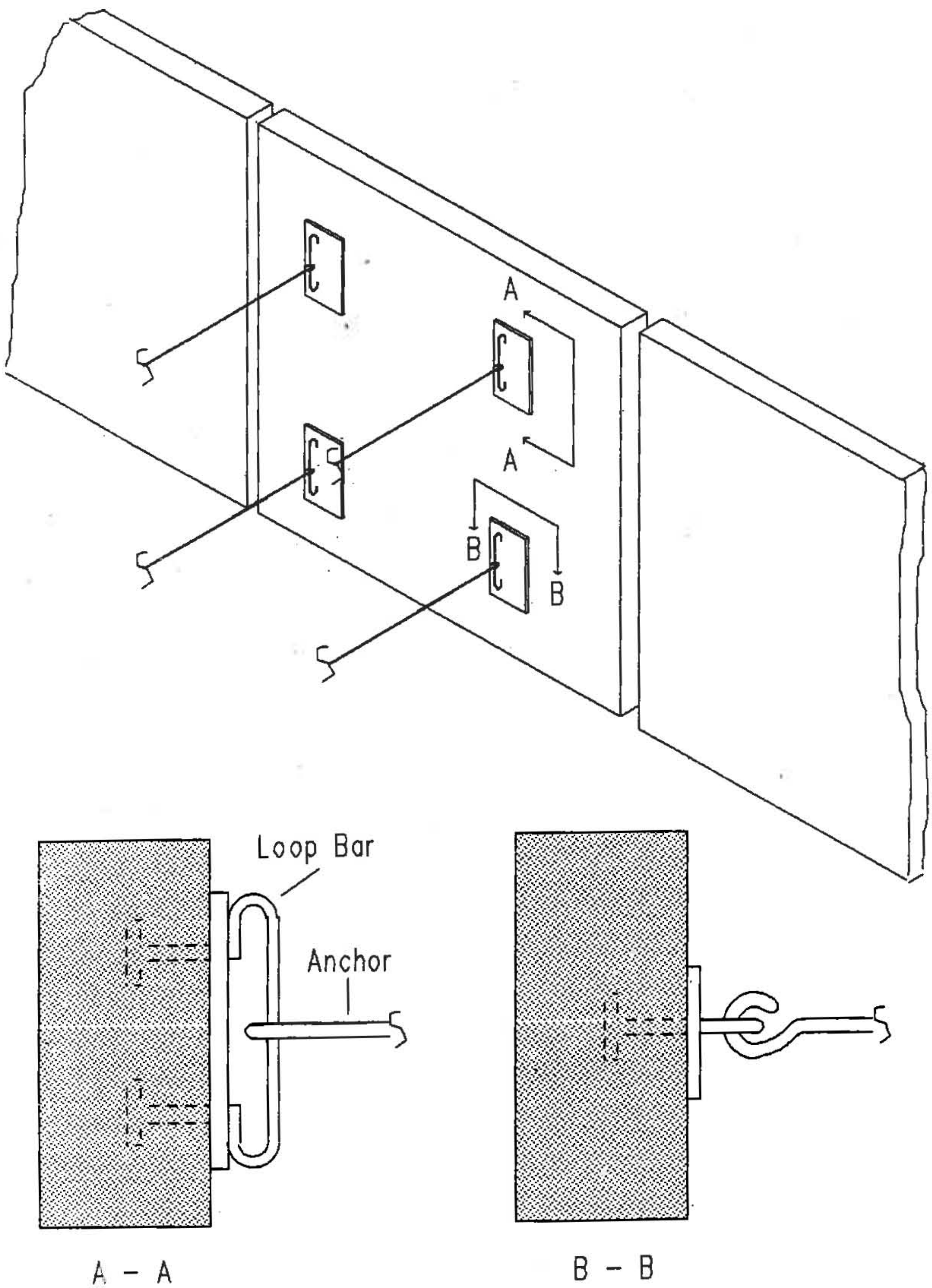
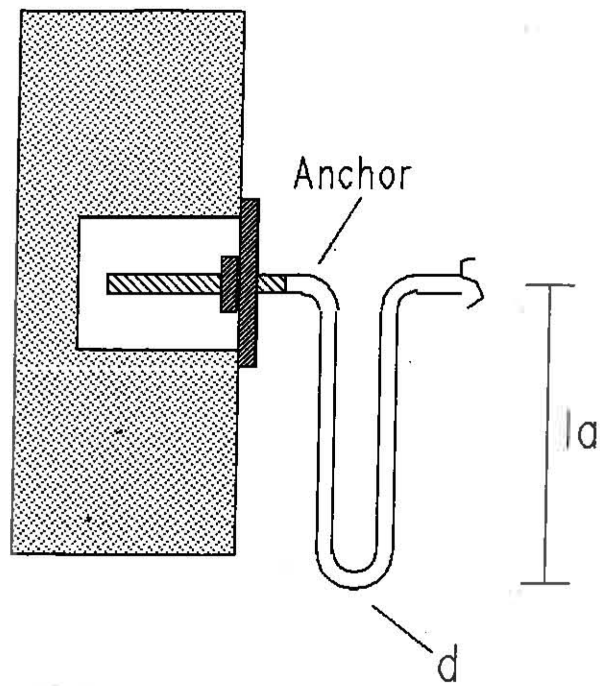


Figure 11: General View - Panels and Blind Anchors



$\boldsymbol{l}$	Length of gooseneck (in)
$\boldsymbol{d}$	Bar diameter (in)
$\boldsymbol{A}$	Anchor yield force (lbs)
$\boldsymbol{M_p}$	Plastic moment capacity of gooseneck (in-lbs)

$$\boldsymbol{A} = \frac{\boldsymbol{2M_p}}{\boldsymbol{l}}$$

A36 Anchors

$\boldsymbol{l}$= 12 in

d in	A lbs
0.50	125
0.75	422
1.00	1000

Figure 12: Gooseneck Anchor

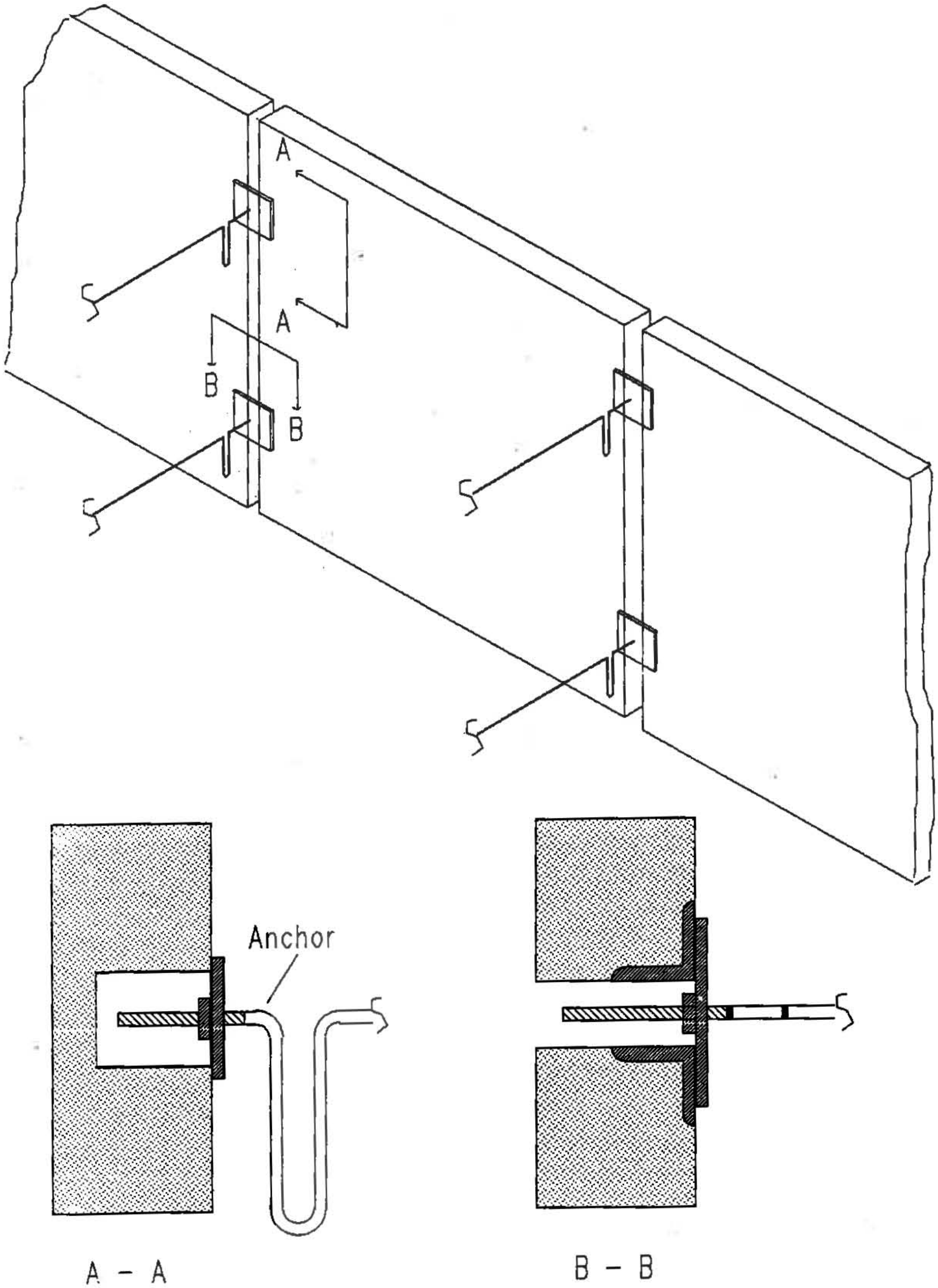
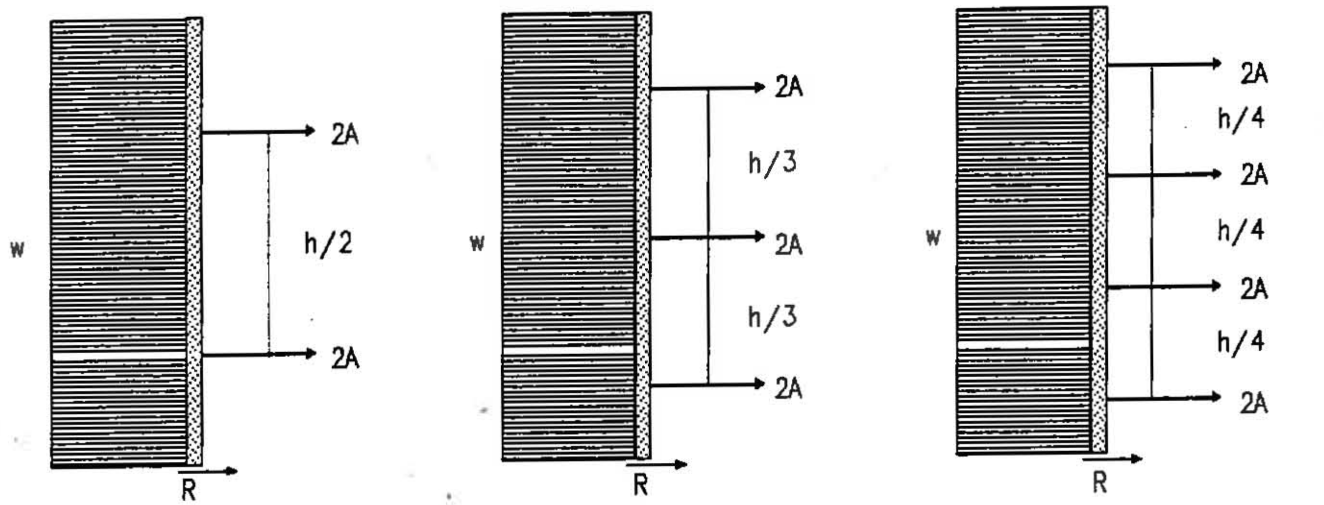


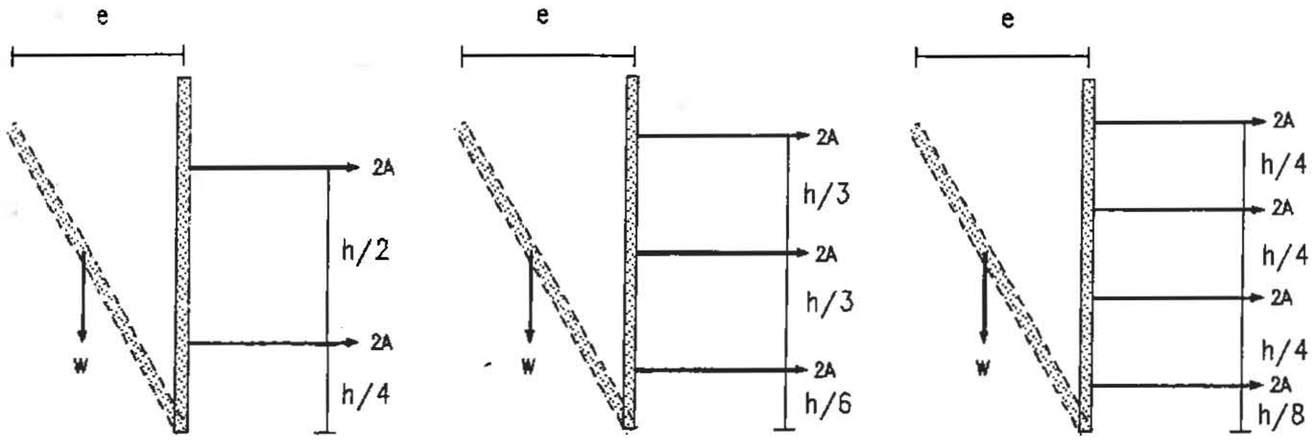
Figure 13: General View - Panels and Gooseneck Anchors



$\boldsymbol{h}$	Height of Panel (ft)
$\boldsymbol{b}$	Width of Panel (ft)
$\boldsymbol{A}$	Force in one Anchor (lbs)
$\boldsymbol{w}$	Wind Pressure (psf)
$\boldsymbol{R}$	Reaction at Base of Panel (lbs)
$\boldsymbol{X}_m$	Location of Maximum Moment (ft)
$\boldsymbol{M}_{max}$	Maximum Moment (ft - lbs)
$\boldsymbol{V}_{max}$	Maximum Shear (lbs)

	w	R	X_{max}	M_{max}	V_{max}
4 Anchors	$\frac{4*A}{h*b}$	0	$\frac{h}{4}$	$\frac{h*A}{8}$	A
6 Anchors	$\frac{6*A}{b*h}$	0	$\frac{h}{6}$	$\frac{h*A}{12}$	A
8 Anchors	$\frac{8*A}{h*b}$	0	$\frac{h}{8}$	$\frac{h*A}{16}$	A

Figure 14: Wind Load Demand on Anchors



W	Panel Weight (lbs)
e	Panel Tilt Displacement (ft)
A	Anchor Load (lbs)

4 Anchors

$$W * \frac{e}{2} \leq 2 * A * (\frac{h}{4} + \frac{3}{4} * h)$$
$$A \geq \frac{W * e}{4 * h}$$

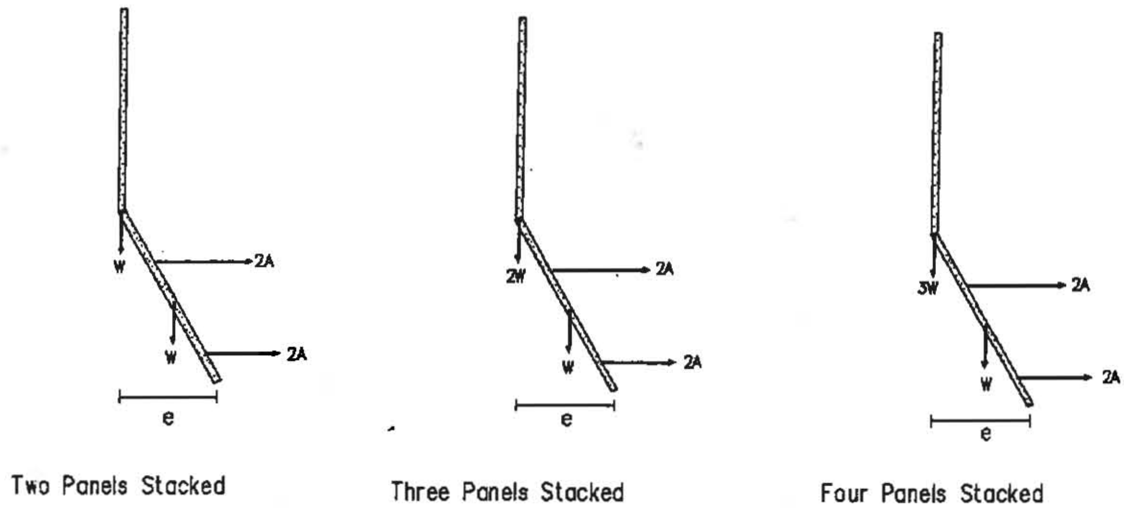
6 Anchors

$$W * \frac{e}{2} \leq 2 * A * (\frac{h}{6} + \frac{3}{6} * h) + \frac{5}{6} * h)$$
$$A \geq \frac{W * e}{6 * h}$$

8 Anchors

$$W * \frac{e}{2} \leq 2 * A * (\frac{h}{8} + \frac{3}{8} * h) + \frac{5}{8} * h + \frac{7}{8} * h)$$
$$A \geq \frac{W * e}{8 * h}$$

Figure 15: Stability of Full Height Panels



W	Panel Weight (lbs)
e	Panel Tilt Displacement (ft)
A	Anchor Load (lbs)

2 Stacked Panels

$$W * \frac{e}{2} + W * e \leq 2 * A * (\frac{h}{4} + \frac{3}{4} * h)$$
$$A \geq \frac{3}{4} * \frac{W * e}{h}$$

3 Stacked Panels

$$W * \frac{e}{2} + 2 * W * e \leq 2 * A * (\frac{h}{6} + \frac{3}{6} * h) + \frac{5}{6} * h)$$
$$A \geq \frac{5}{4} * \frac{W * e}{h}$$

4 Stacked Panels

$$W * \frac{e}{2} + 3 * W * e \leq 2 * A * (\frac{h}{8} + \frac{3}{8} * h) + \frac{5}{8} * h + \frac{7}{8} * h)$$
$$A \geq \frac{7}{4} * \frac{W * e}{h}$$

Figure 16: Stability of Stacked Panels

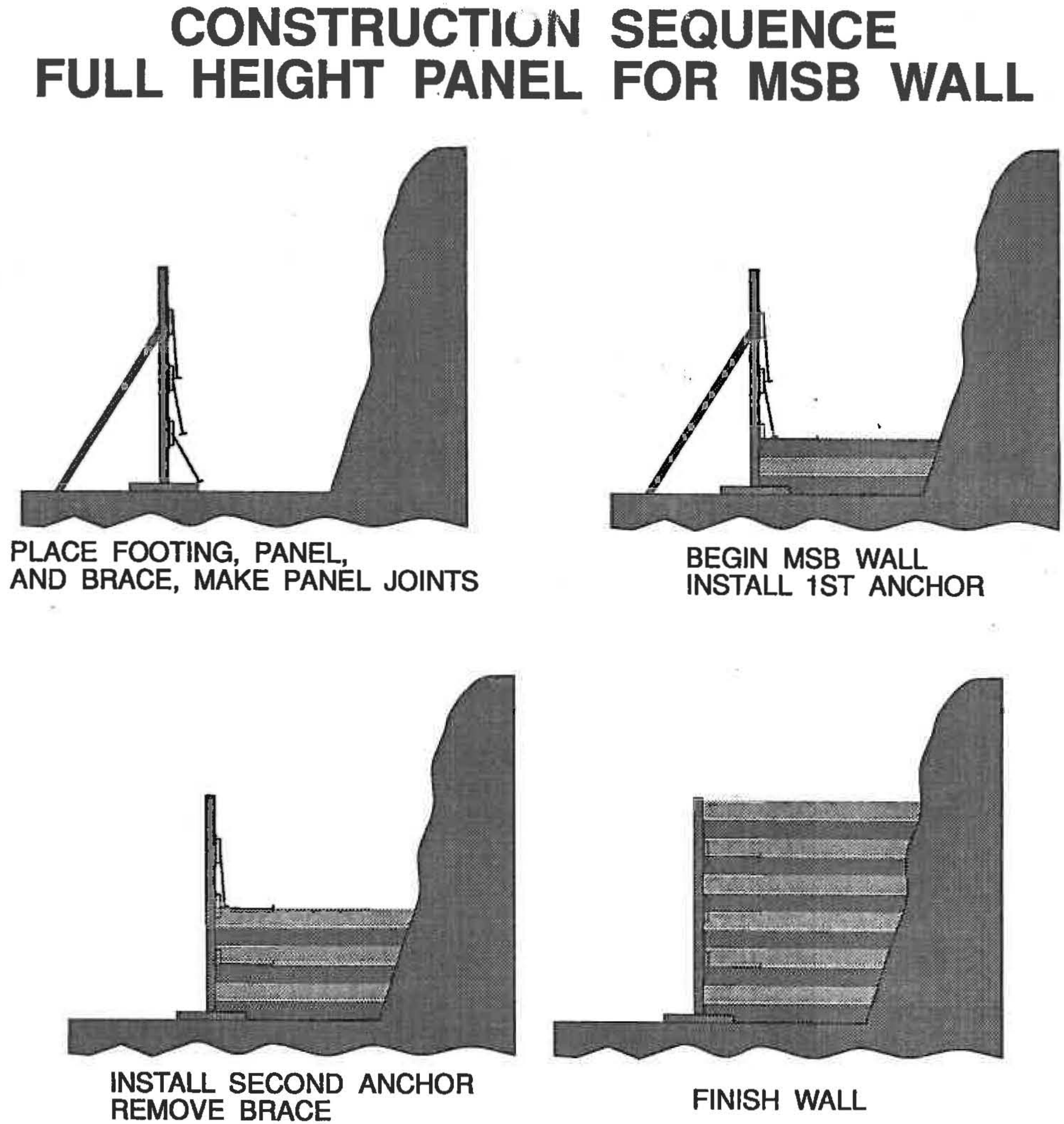


Figure 17: Construction Sequence for Full Height Panels

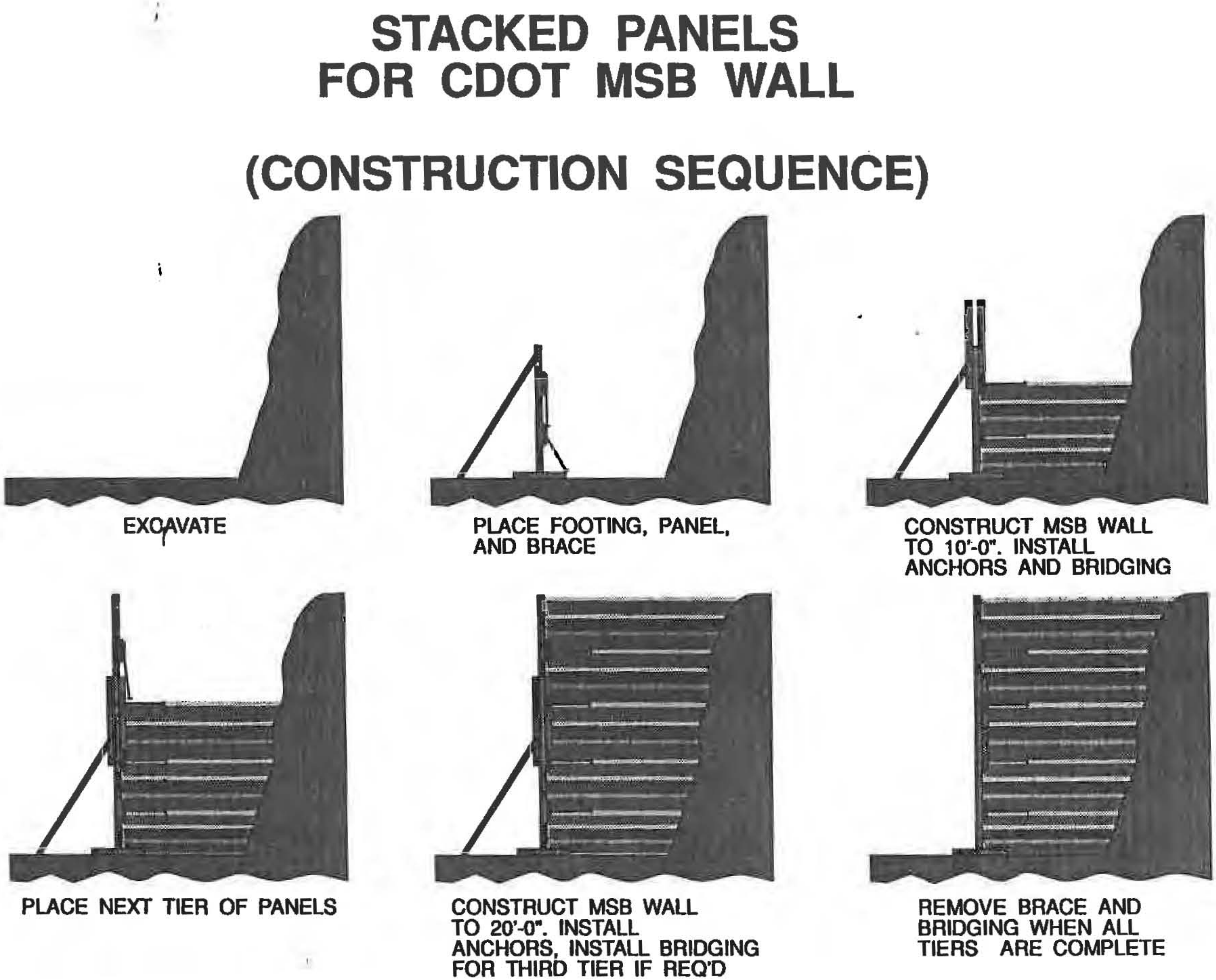


Figure 18: Construction Sequence for Stacked Panels

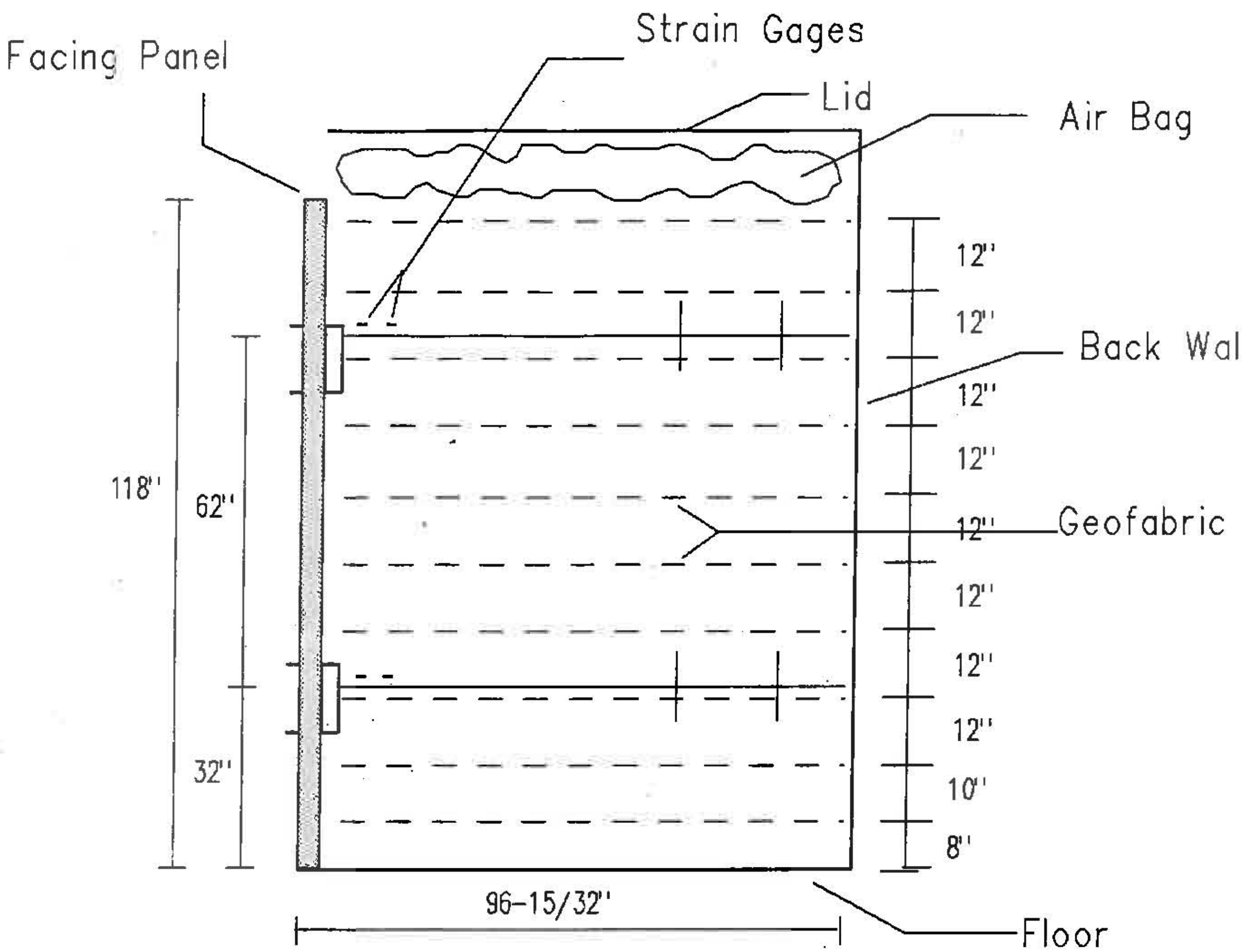


Figure 19: General View of Prototype Wall

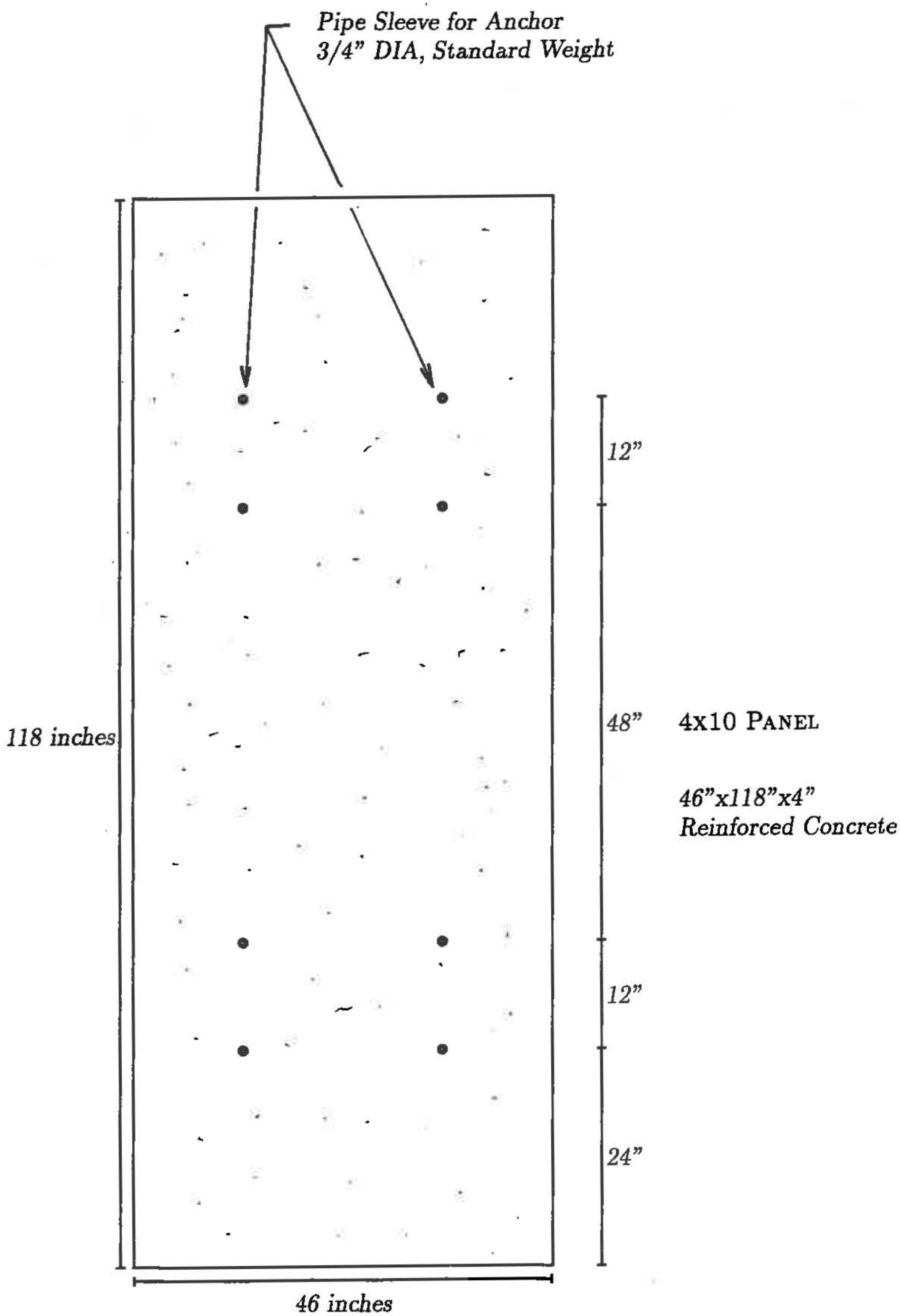


Figure 20: Front View of Prototype Panel

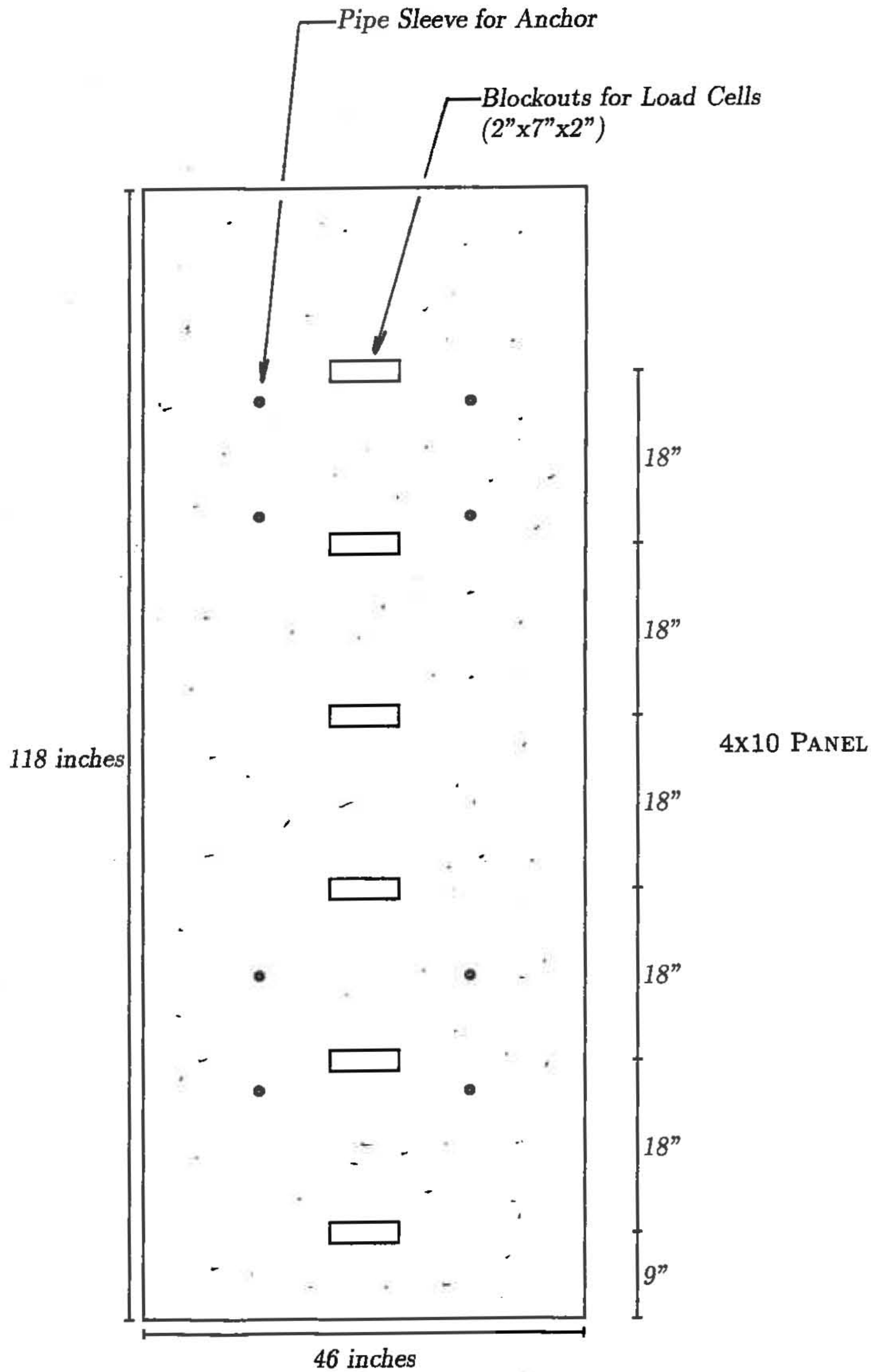
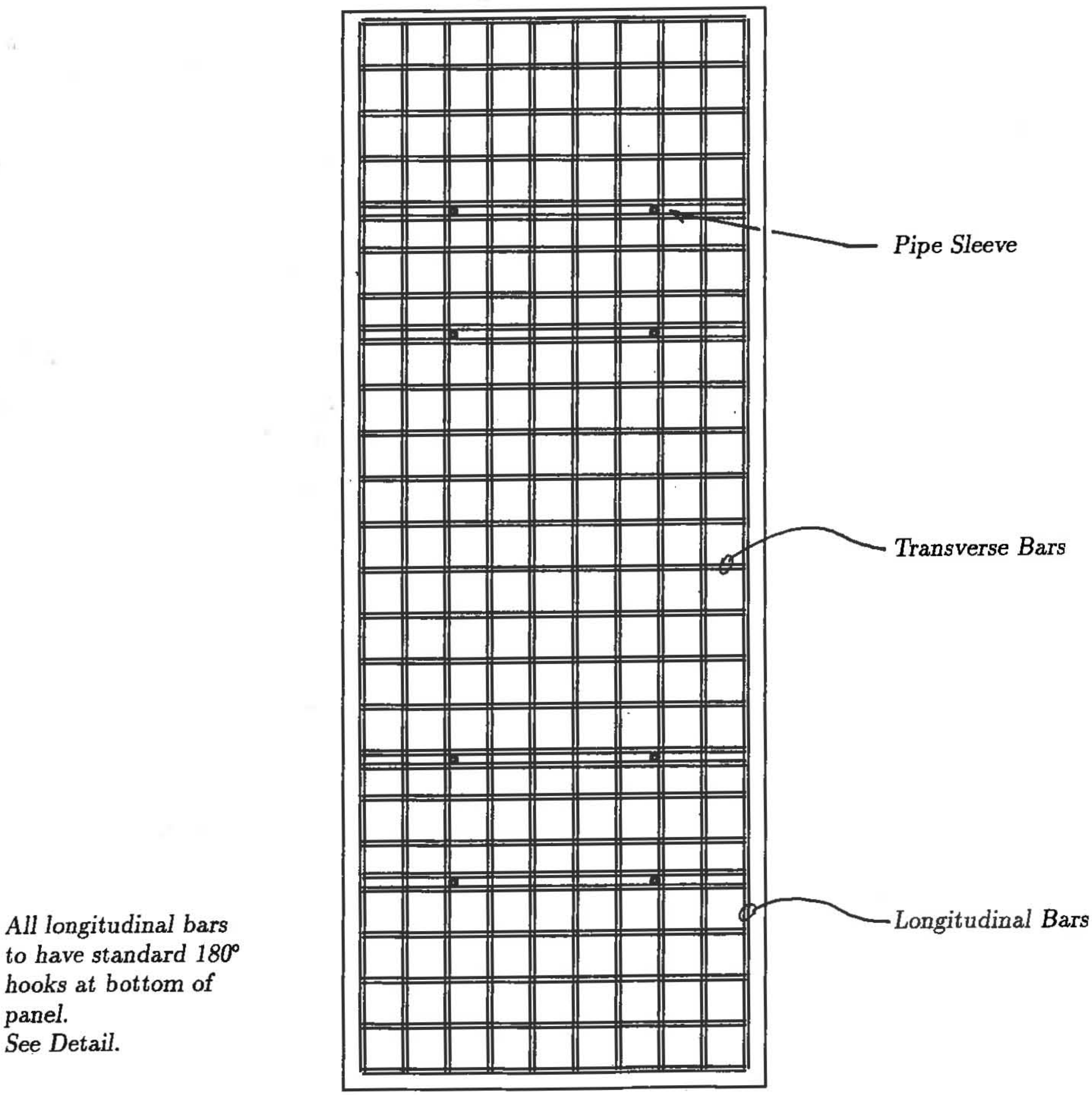
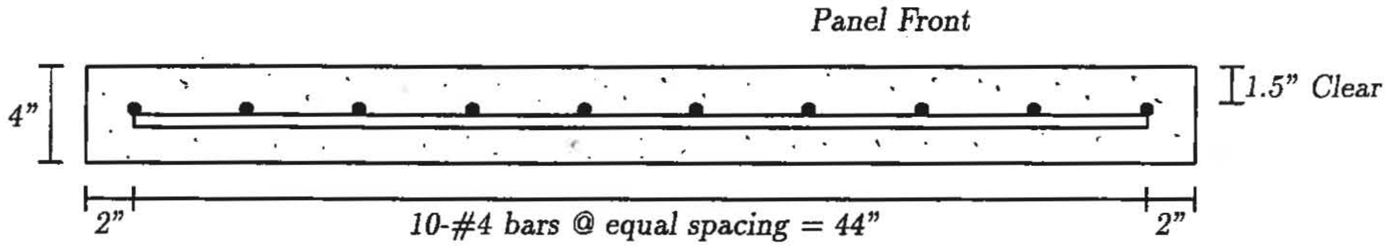


Figure 21: Back View of Prototype Panel

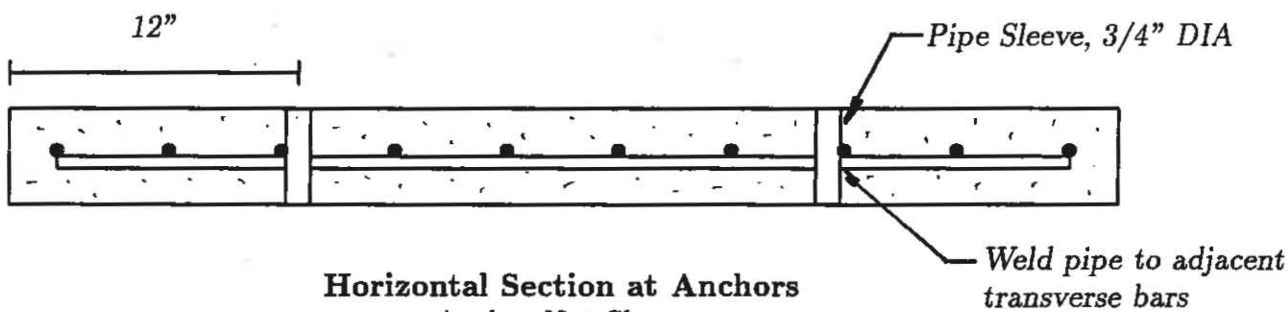


Note: All rebars shall be #4 Grade 60 deformed bars.

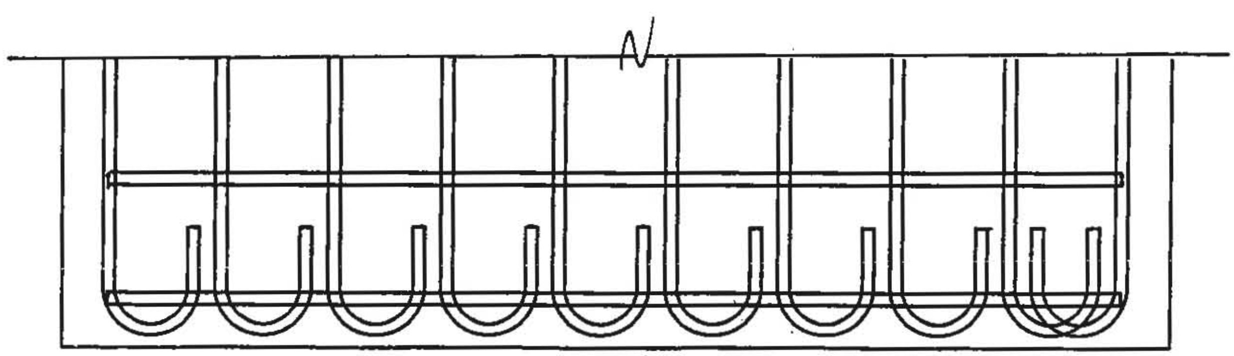
Figure 22: Plan of Reinforcing Steel for Panel



Horizontal Section

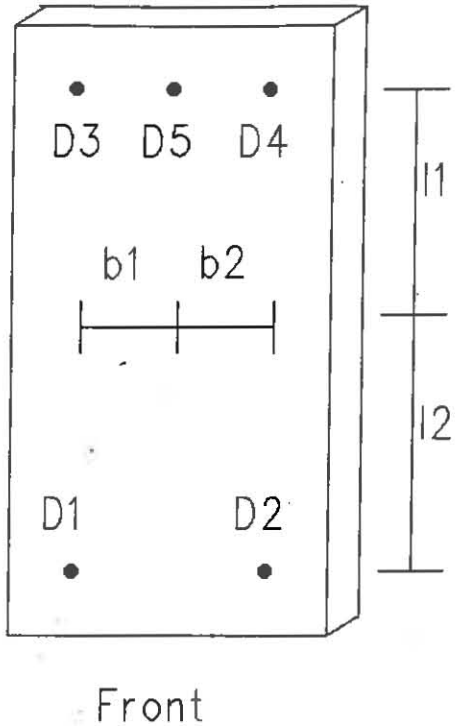


Horizontal Section at Anchors
Anchor Not Shown



Detail at Bottom of Panel

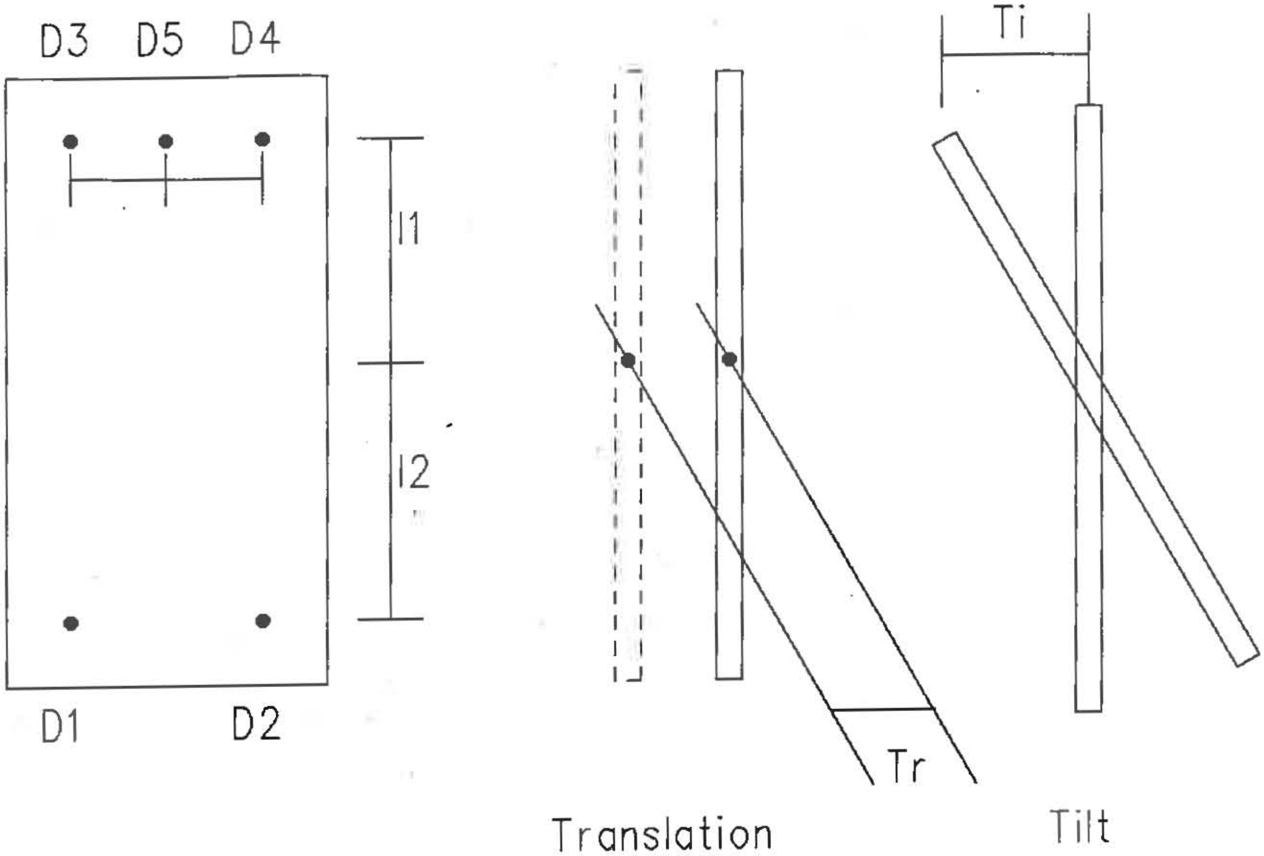
Figure 23: Sections and Details for Panel



D_1, D_2, D_3, D_4, D_5	Dial Gages
l_1	Distance from the center of the panel to the bottom gages (in)
l_2	Distance from the center of the panel to the top gages (in)
b_1	Distance from the center of the panel to the left gages (in)
b_2	Distance from the center of the panel to the right gages (in)

	l_1 (in)	l_2 (in)	b_1 (in)	b_2 (in)
D_1		53	18	
D_2		53		18
D_3	53		18	
D_4	53			18
D_5	53		0	0

Figure 24: Location of Dial Gages



b	Width (in)
h	Height (in)
T_r	Translation (in)
T_i	Tilt (in)
T_w	Twist (in)

$$
\begin{aligned}
top_1 &= (D_3 - D_4) * b_1/(b_1 + b_2) + D_4 \\
bot_1 &= (D_1 - D_2) * b_1/(b_1 + b_2) + D_2 \\
T_r &= (top_1 - bot_1) * l_1/(l_1 + l_2) + b_1
\end{aligned}
$$

$$
T_i = (top_1 - bot_1) * \frac{h}{2}/(l_1 + l_2)
$$

$$
\begin{aligned}
right_1 &= (D_4 - D_2) * l_1/(l_1 + l_2) + D_2 \\
left_1 &= (D_3 - D_1) * l_1/(l_1 + l_2) + D_1 \\
T_w &= (right_1 - left_1) * \frac{b}{2}/(b_1 + b_2)
\end{aligned}
$$

Figure 25: Panel translation and tilt defined

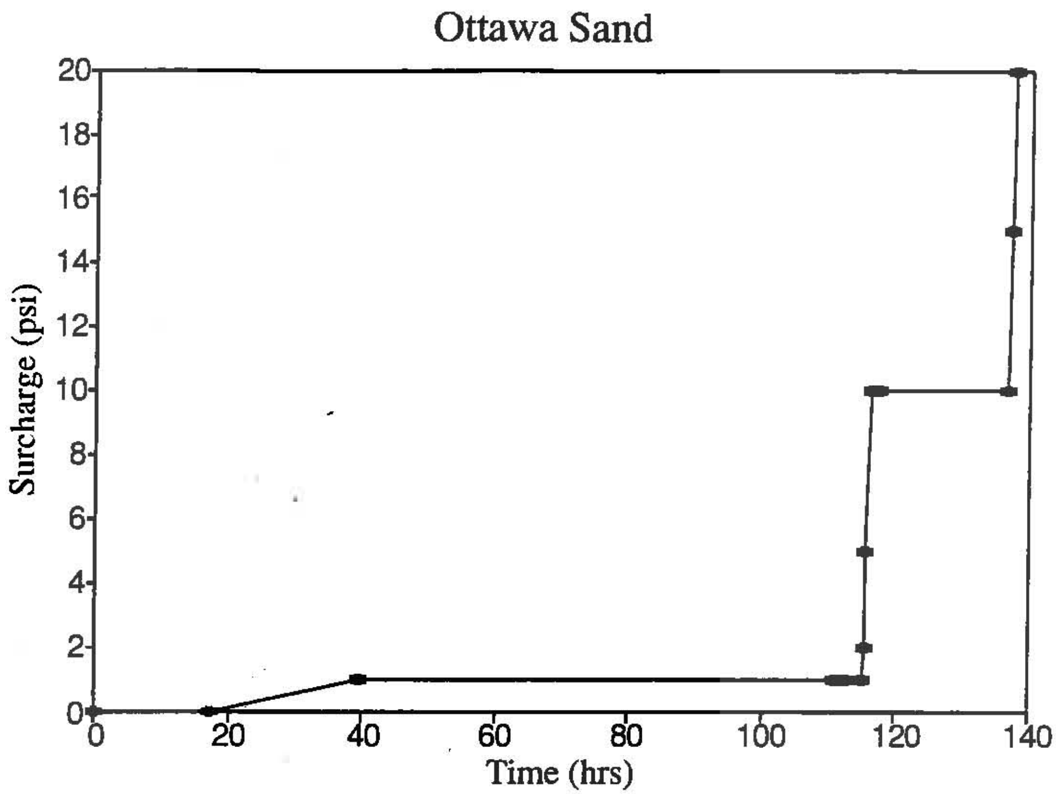


Figure 26: Sand: Surcharge vs Time

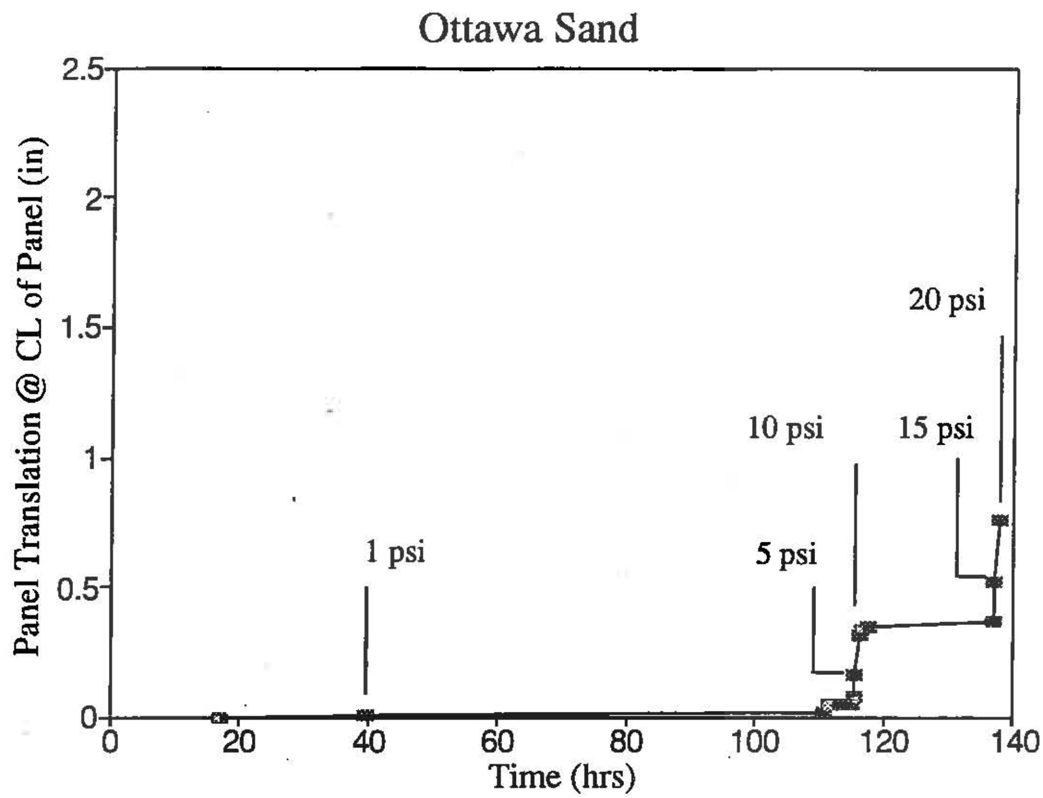


Figure 27: Sand: Panel translation vs Time

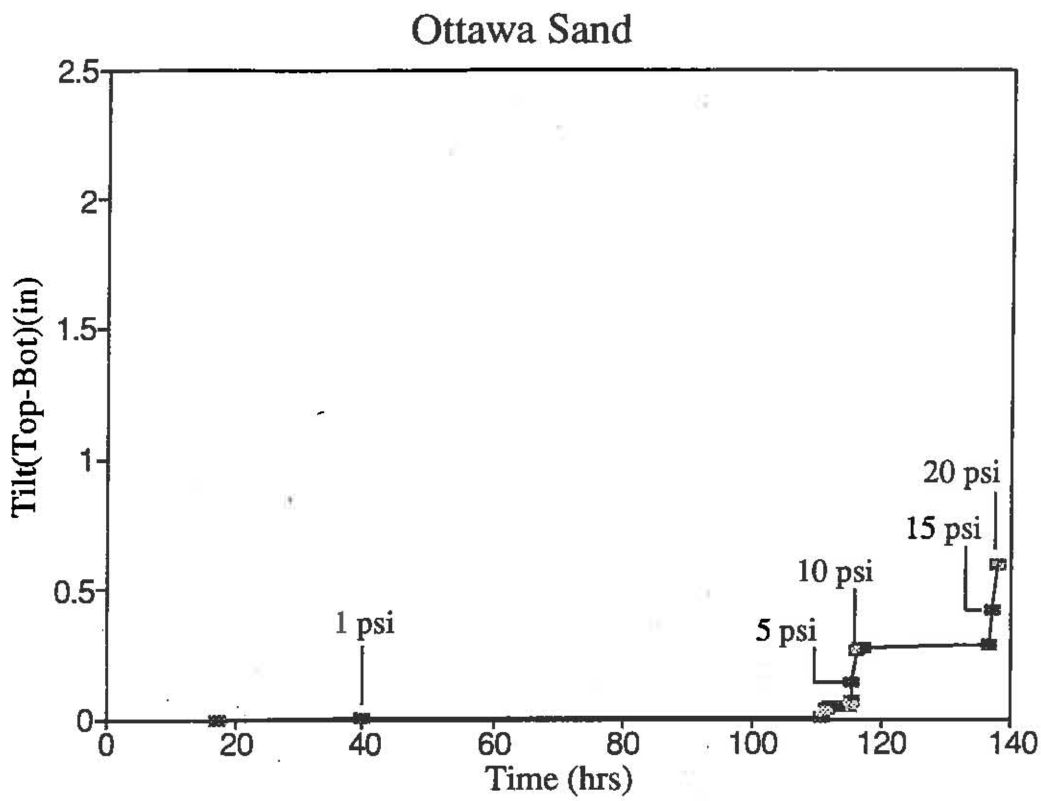


Figure 28: Sand: Panel tilt vs time

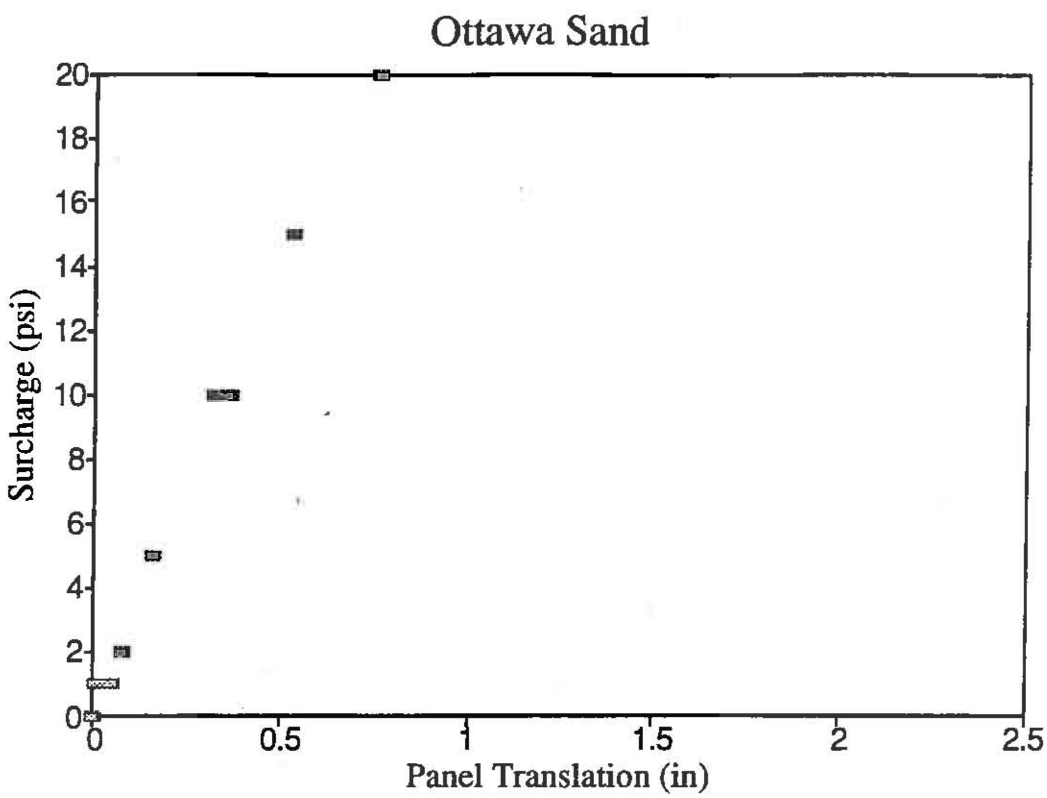


Figure 29: Sand: Surcharge vs Panel translation

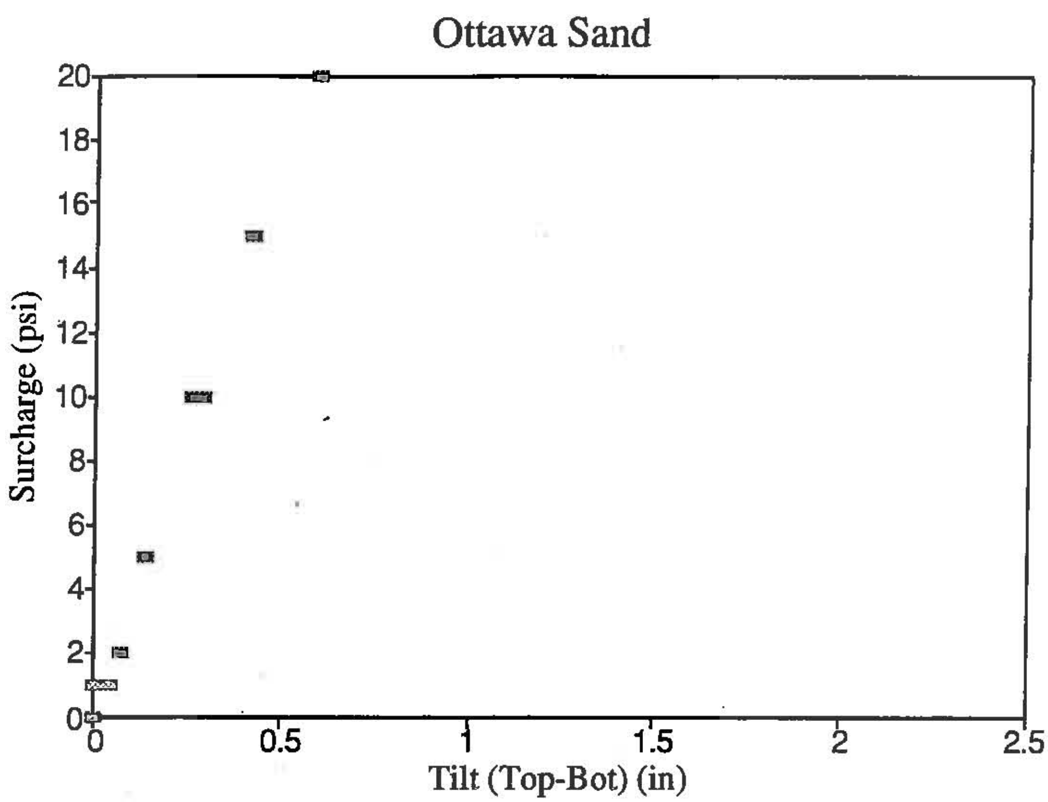


Figure 30: Sand: Surcharge vs Panel tilt

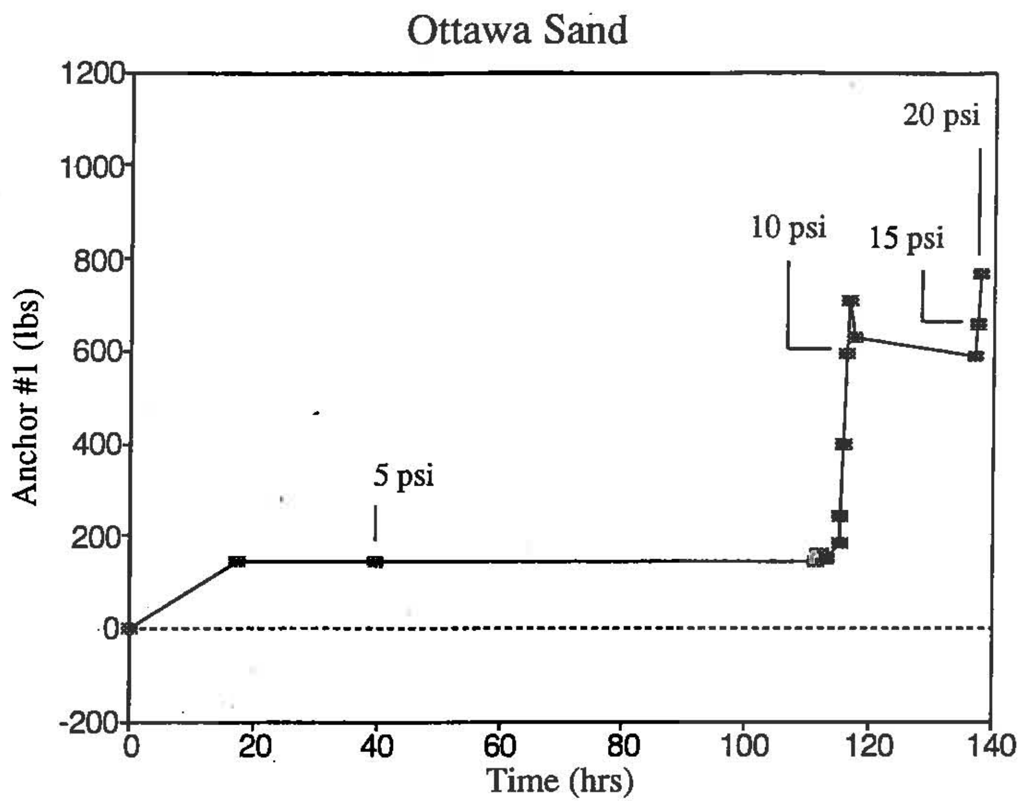


Figure 31: Sand: Anchor A1 - Load vs Time

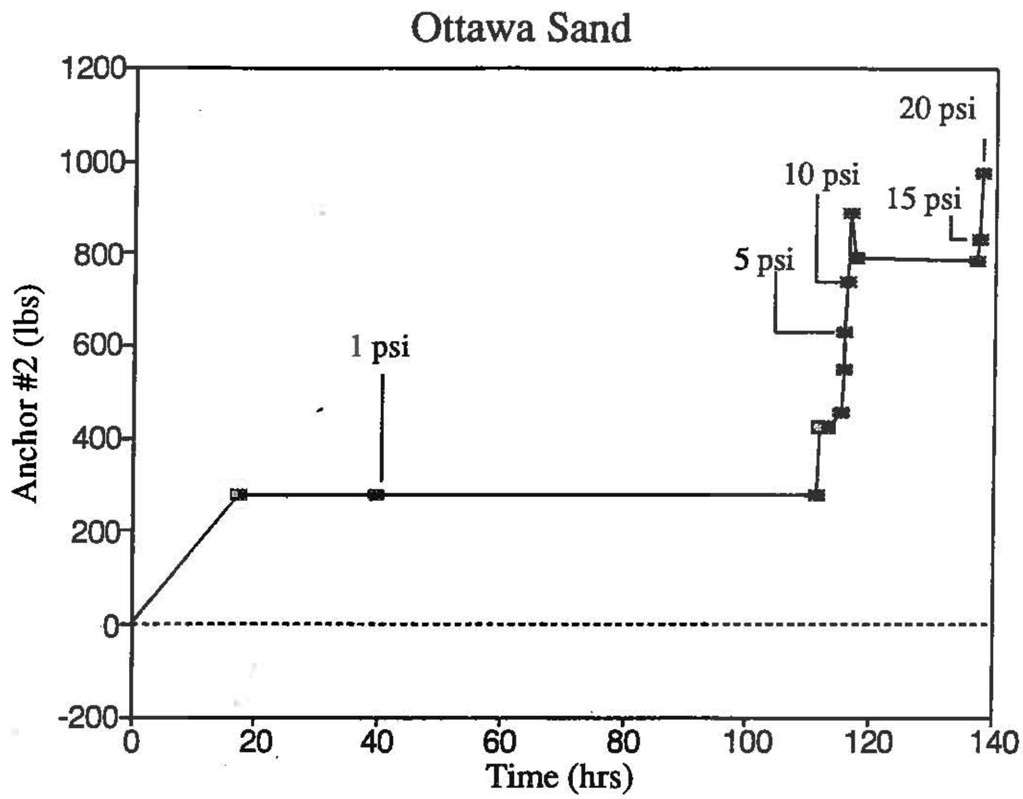


Figure 32: Sand: Anchor A2 - Load vs Time

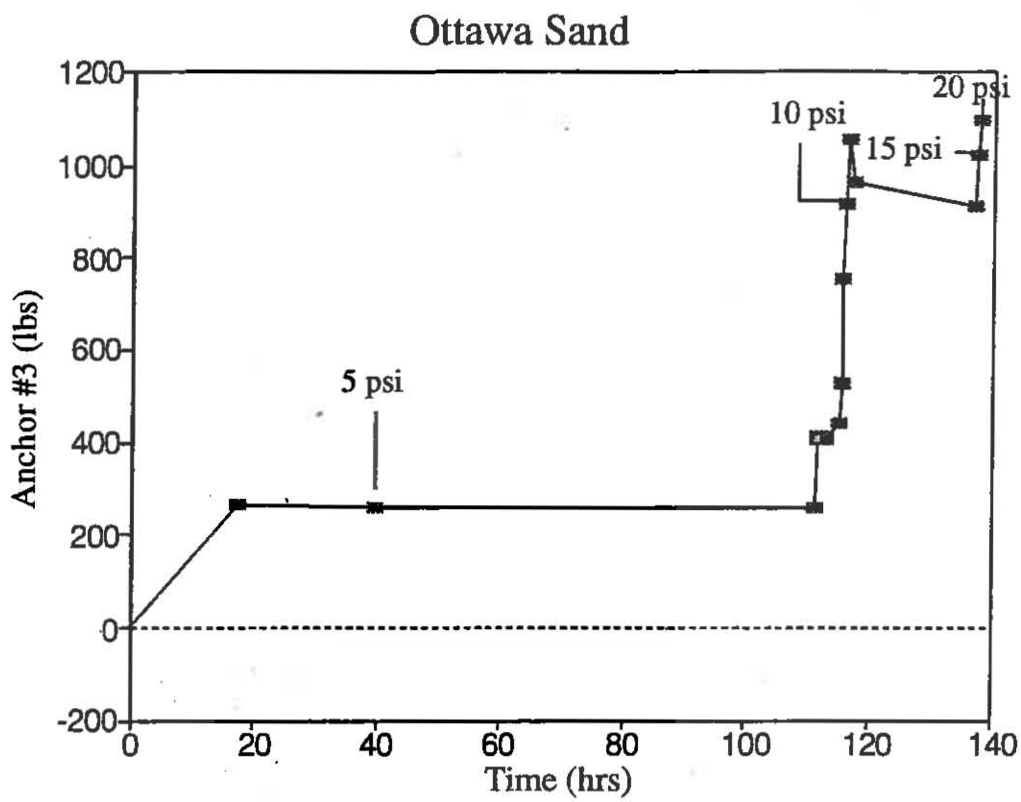


Figure 33: Sand: Anchor A3 - Load vs Time

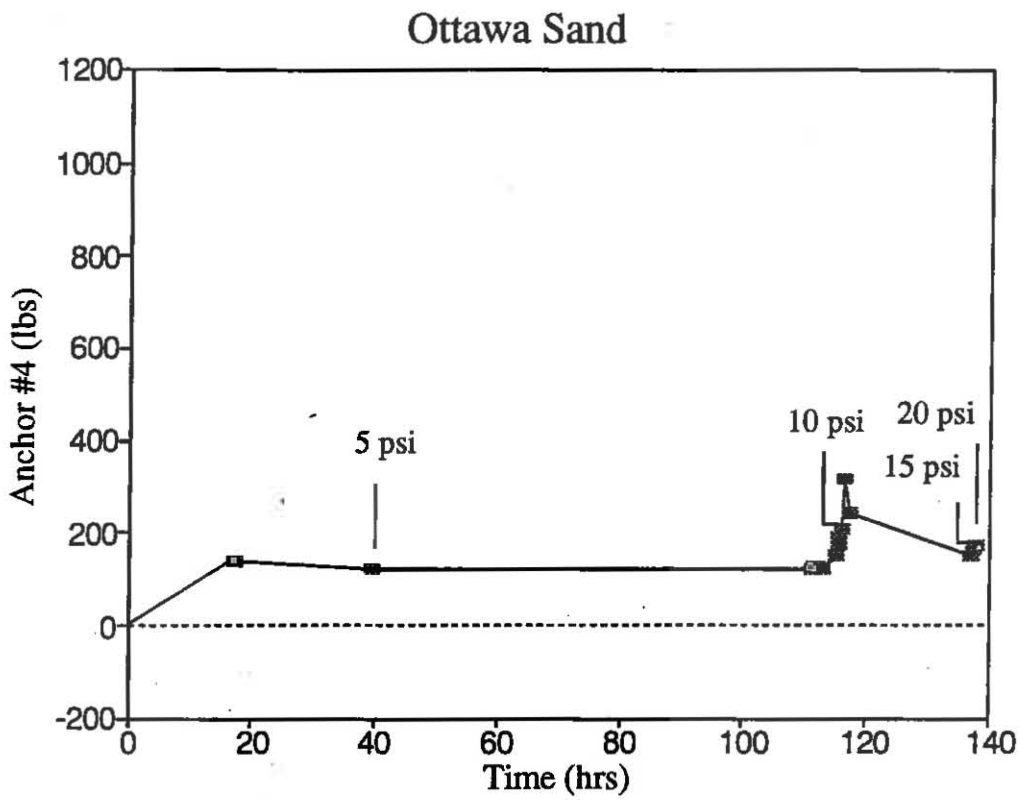


Figure 34: Sand: Anchor A4 - Load vs Time

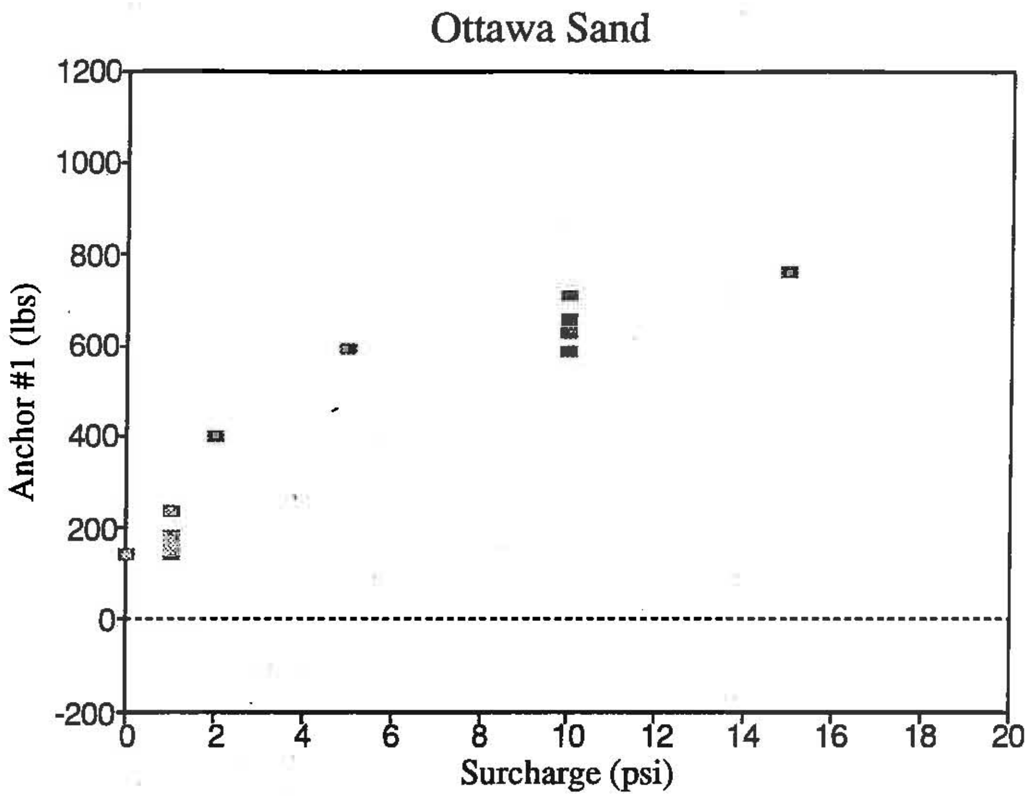


Figure 35: Sand: Anchor A1 - Load vs Surcharge

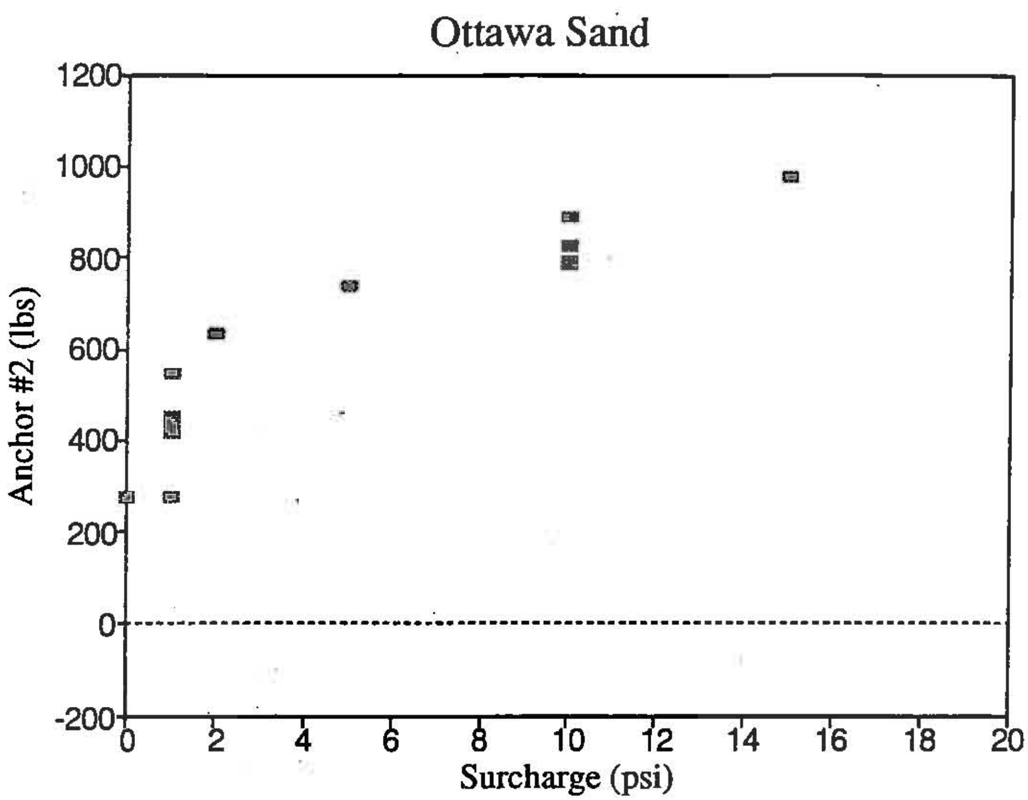


Figure 36: Sand: Anchor A2 - Load vs Surcharge

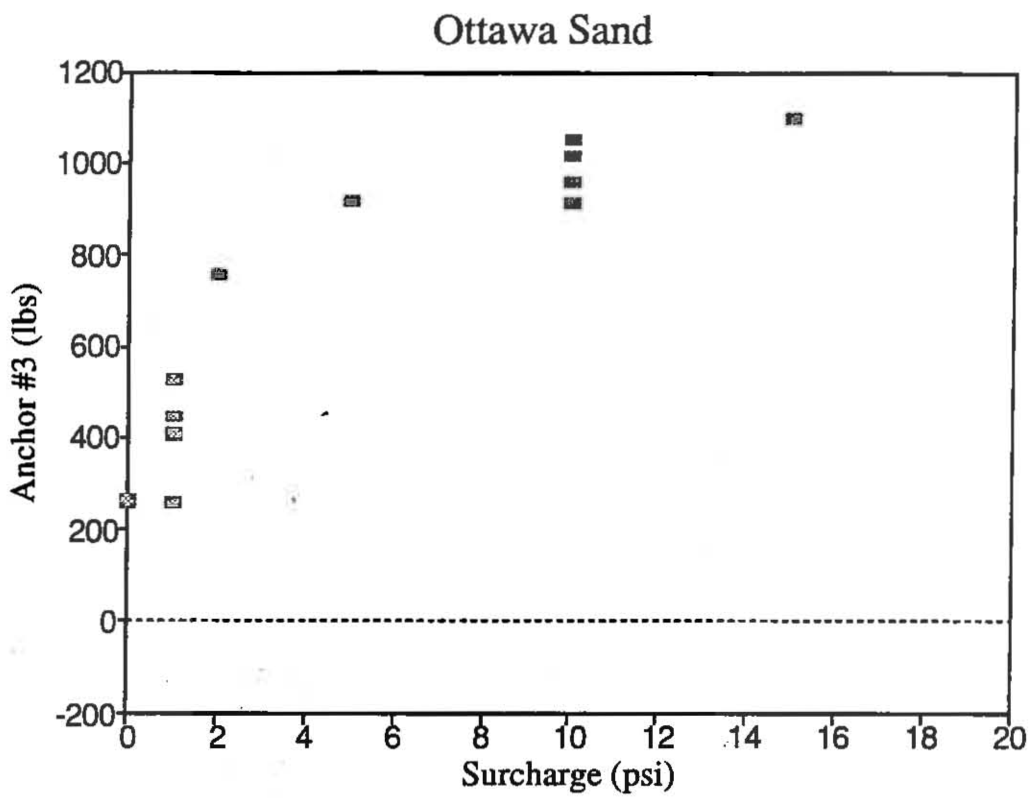


Figure 37: Sand: Anchor A3 - Load vs Surcharge

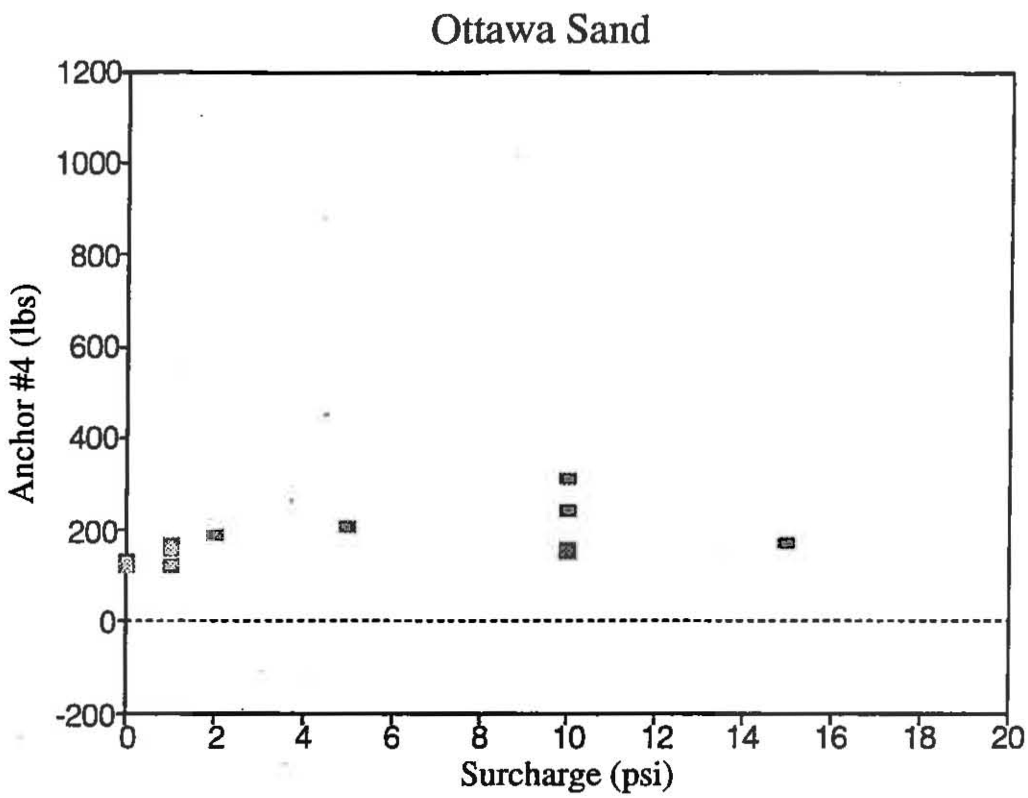


Figure 38: Sand: Anchor A4 - Load vs Surcharge

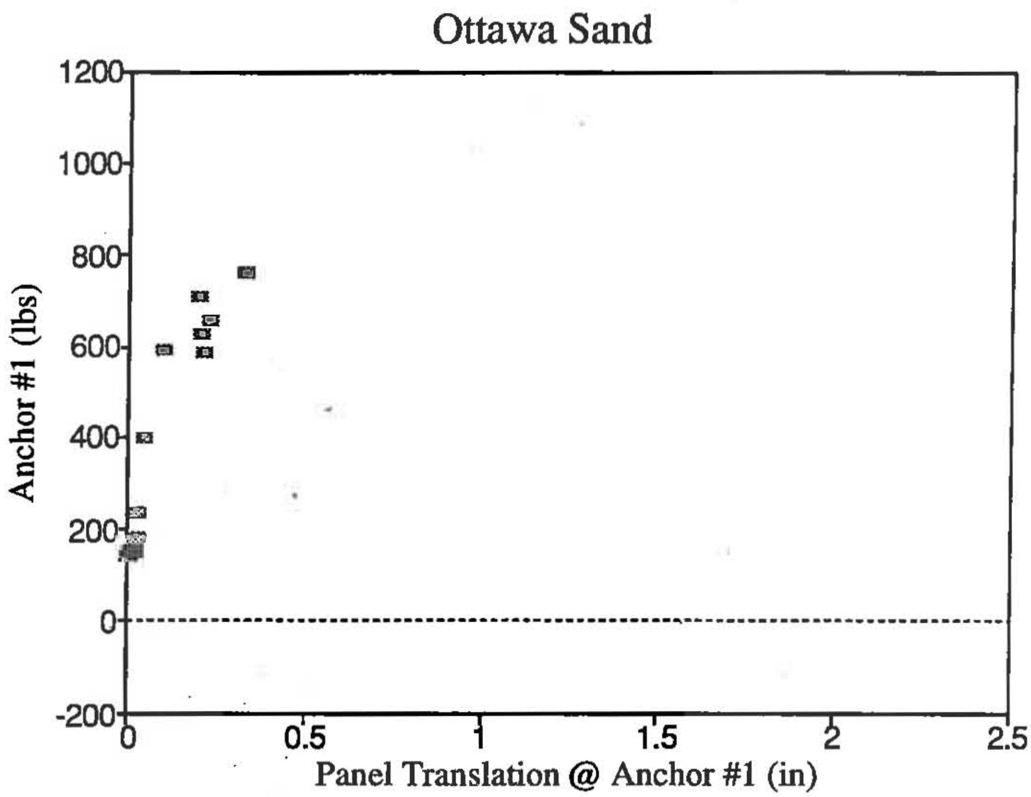


Figure 39: Sand: Anchor A1 - Load vs Panel Movement

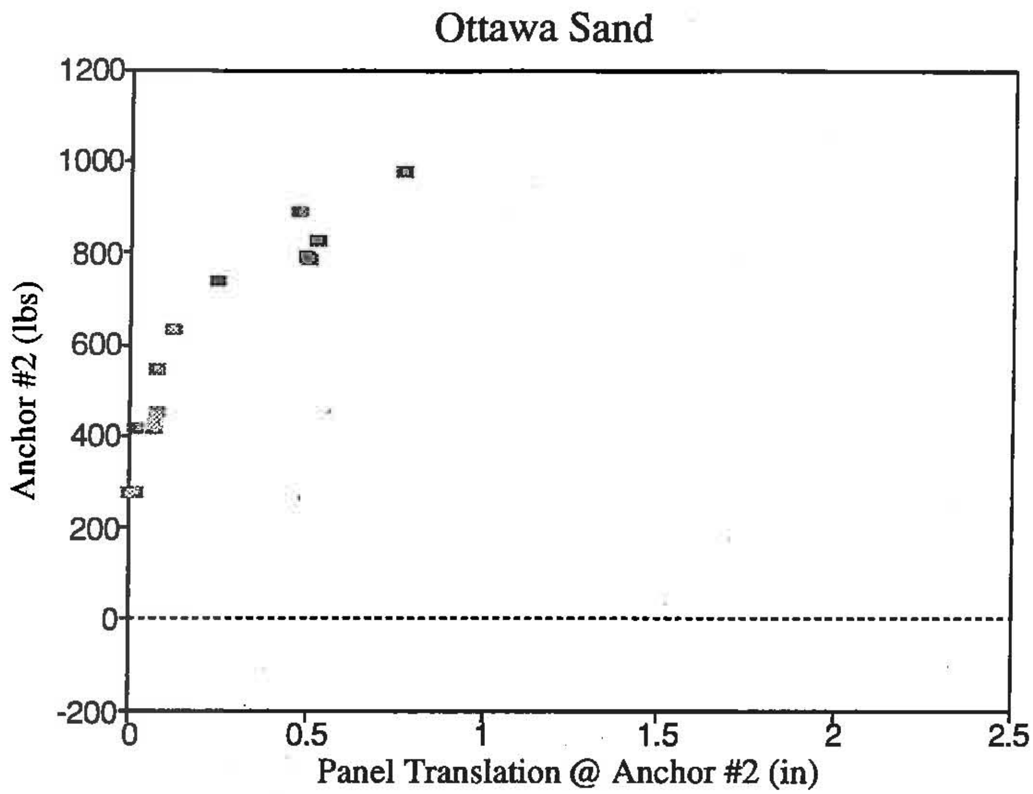


Figure 40: Sand: Anchor A2 - Load vs Panel Movement

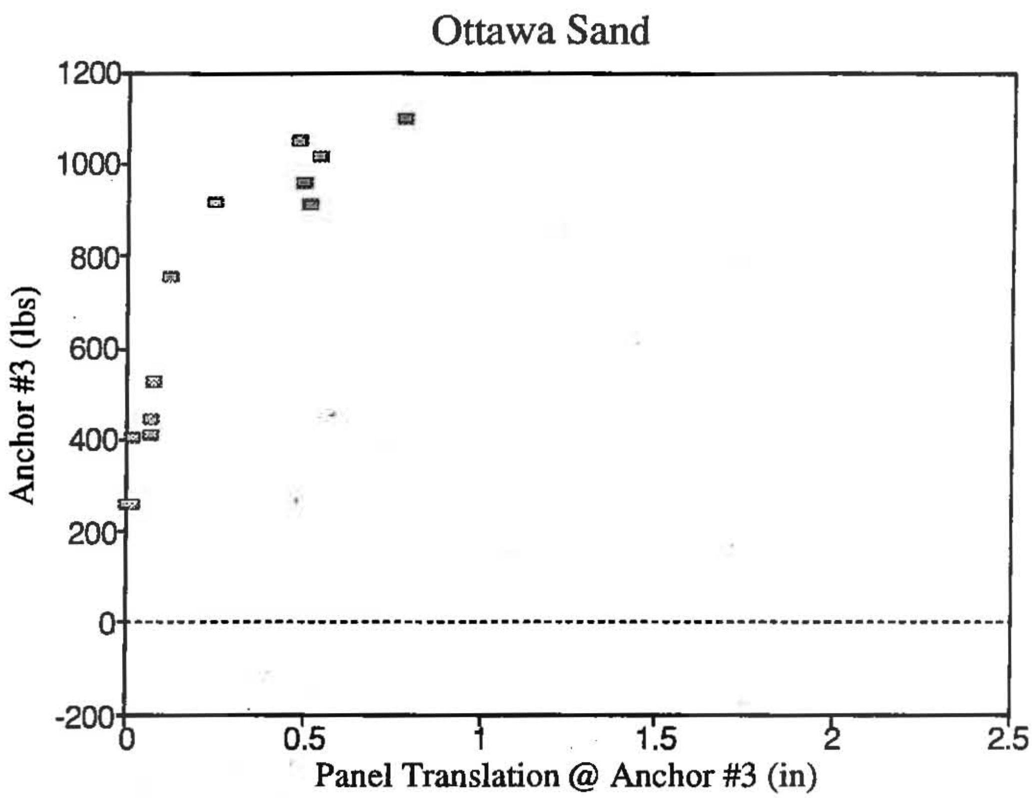


Figure 41: Sand: Anchor A3 - Load vs Panel Movement

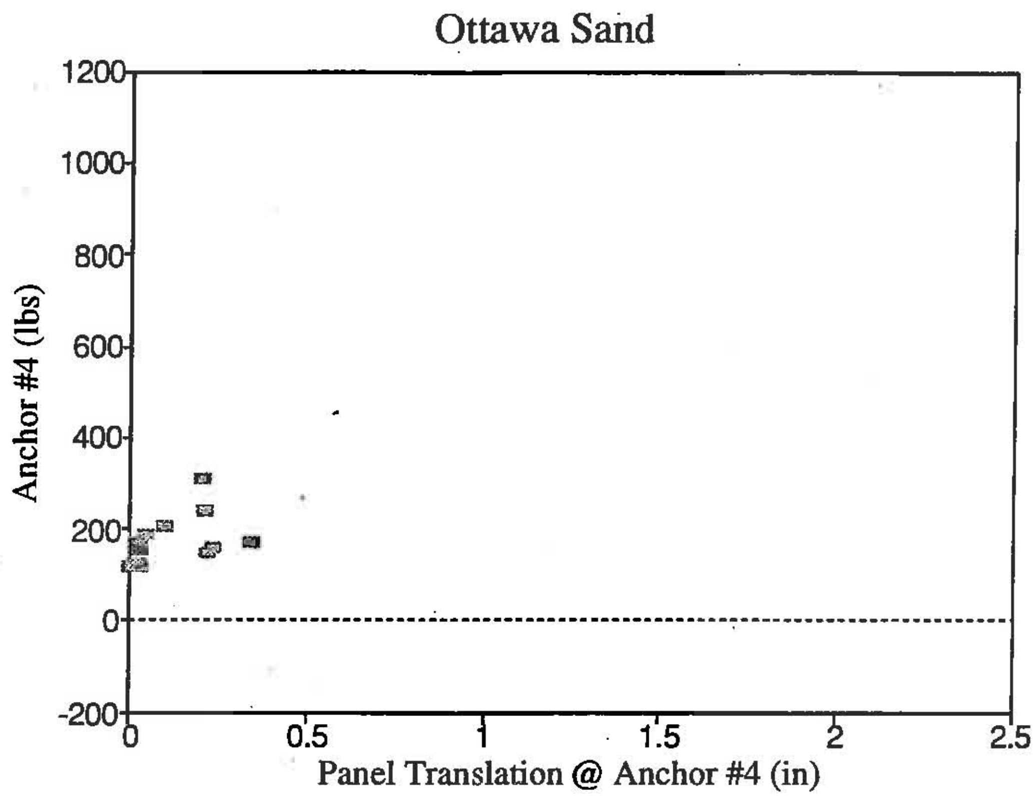


Figure 42: Sand: Anchor A4 - Load vs Panel Movement

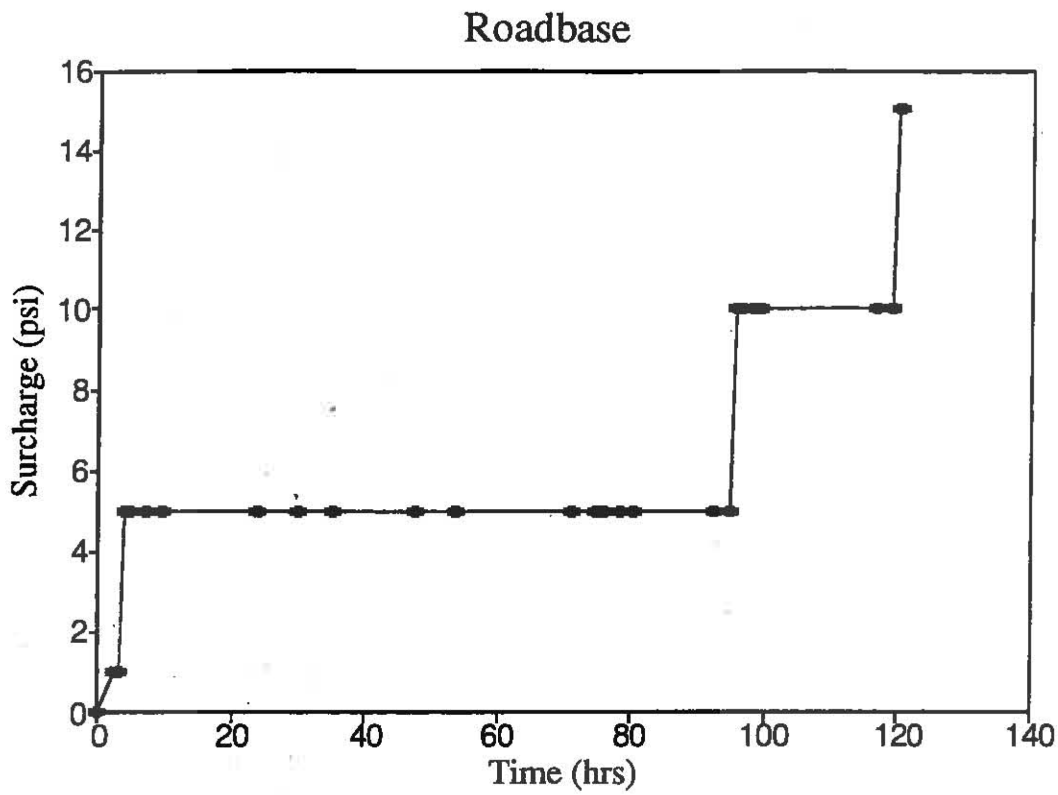


Figure 43: Roadbase: Surcharge vs Time

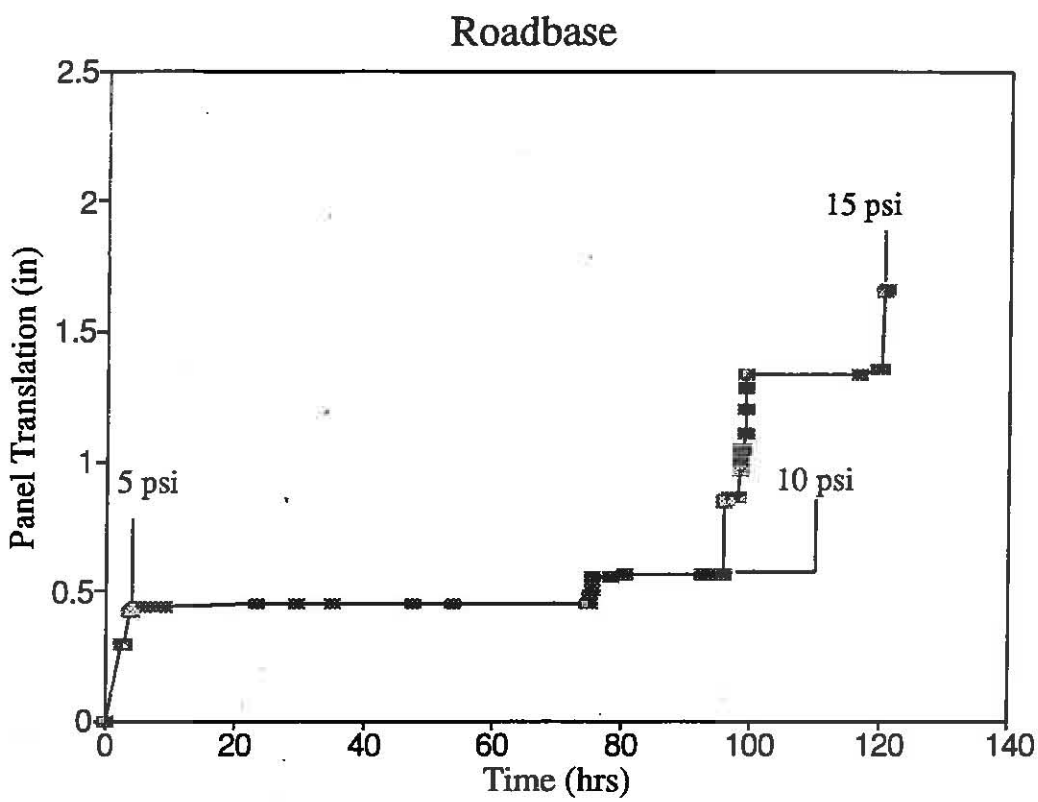


Figure 44: Roadbase: Panel translation vs Time

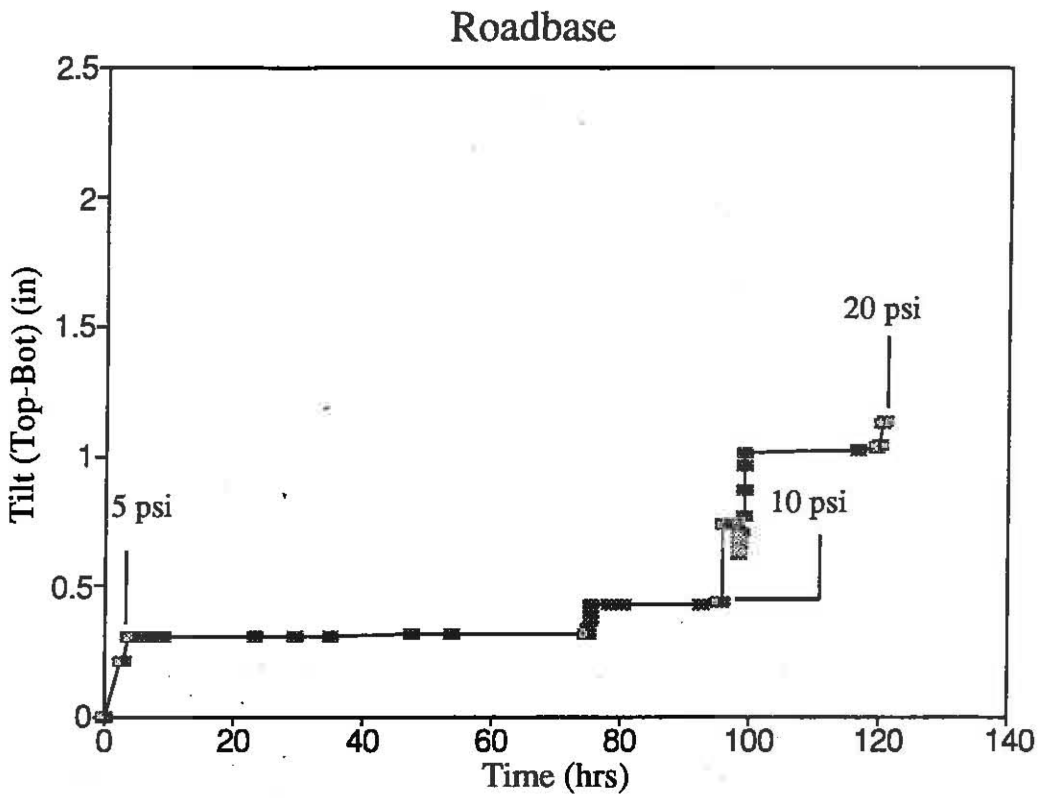


Figure 45: Roadbase: Panel tilt vs time

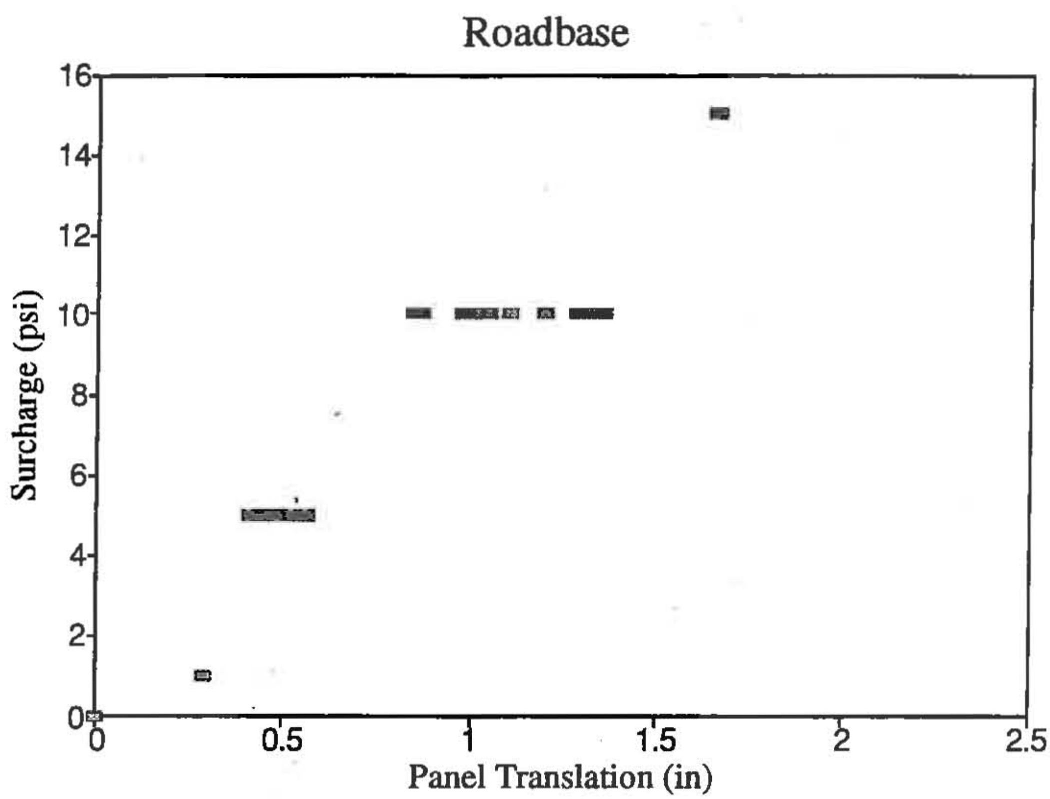


Figure 46: Roadbase: Surcharge vs Panel translation

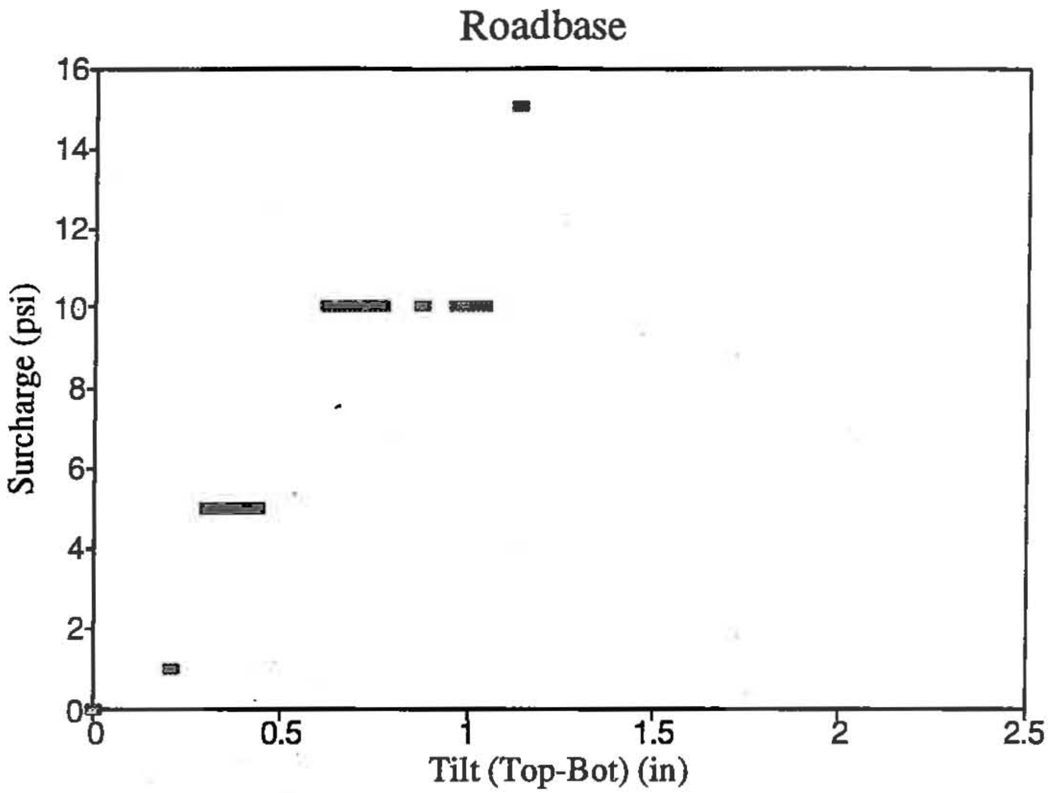


Figure 47: Roadbase: Surcharge vs Panel tilt

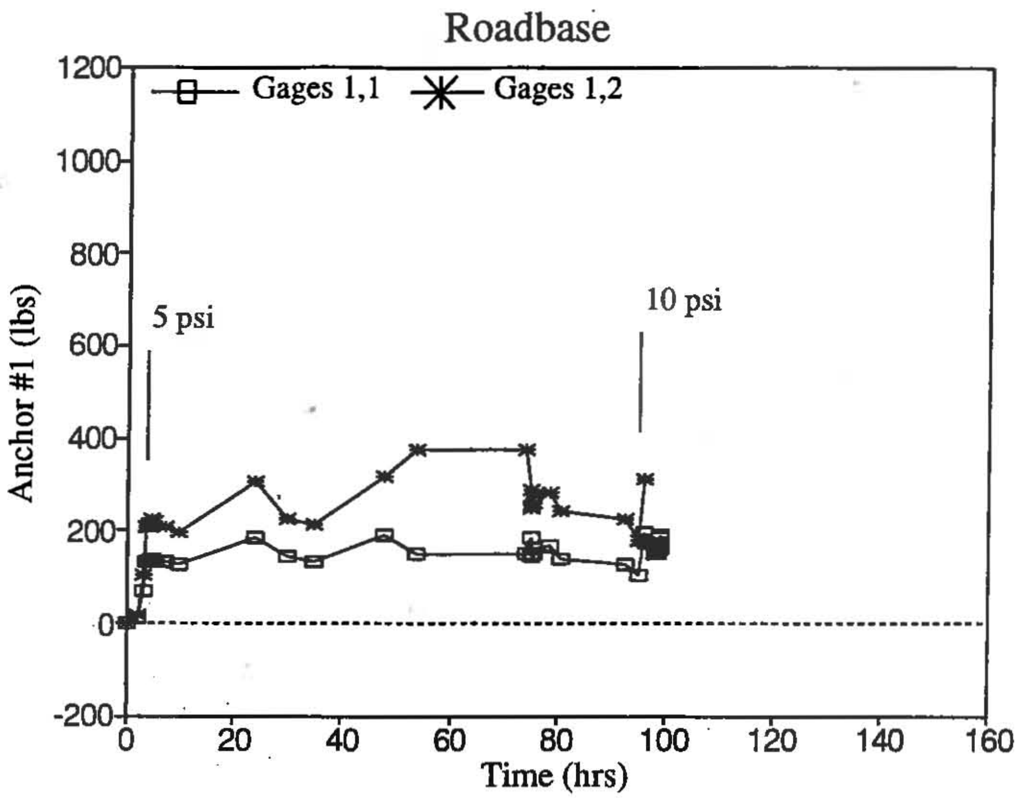


Figure 48: Roadbase: Anchor A1 - Load vs Time

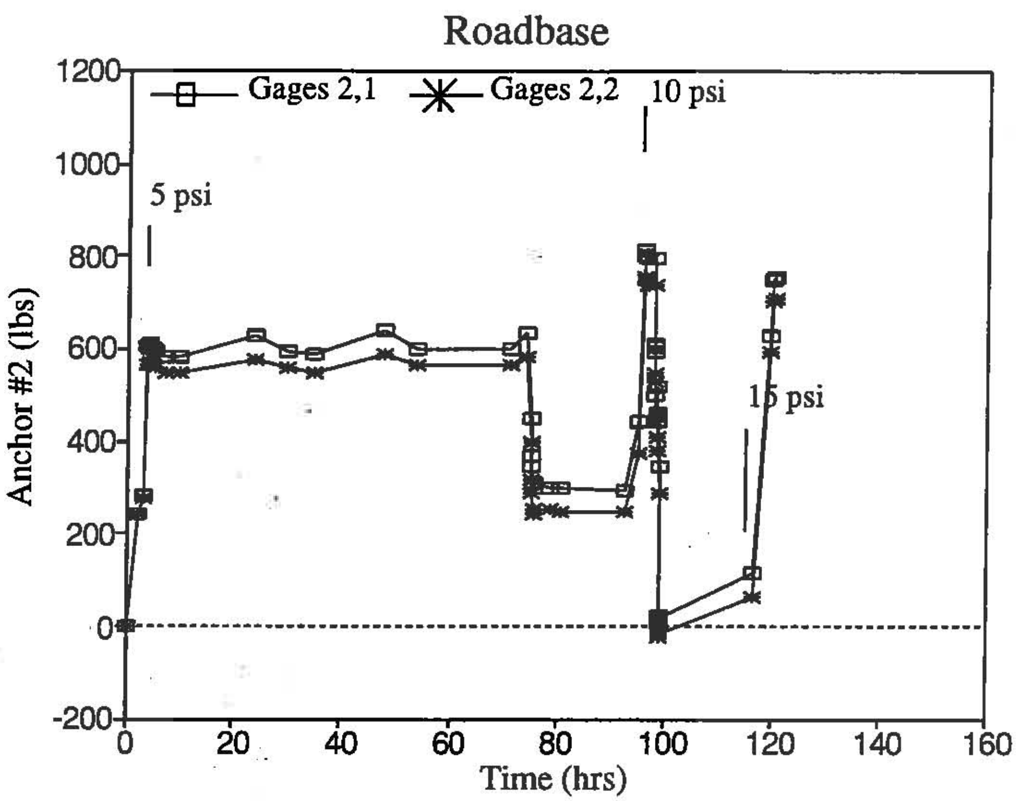


Figure 49: Roadbase: Anchor A2 - Load vs Time

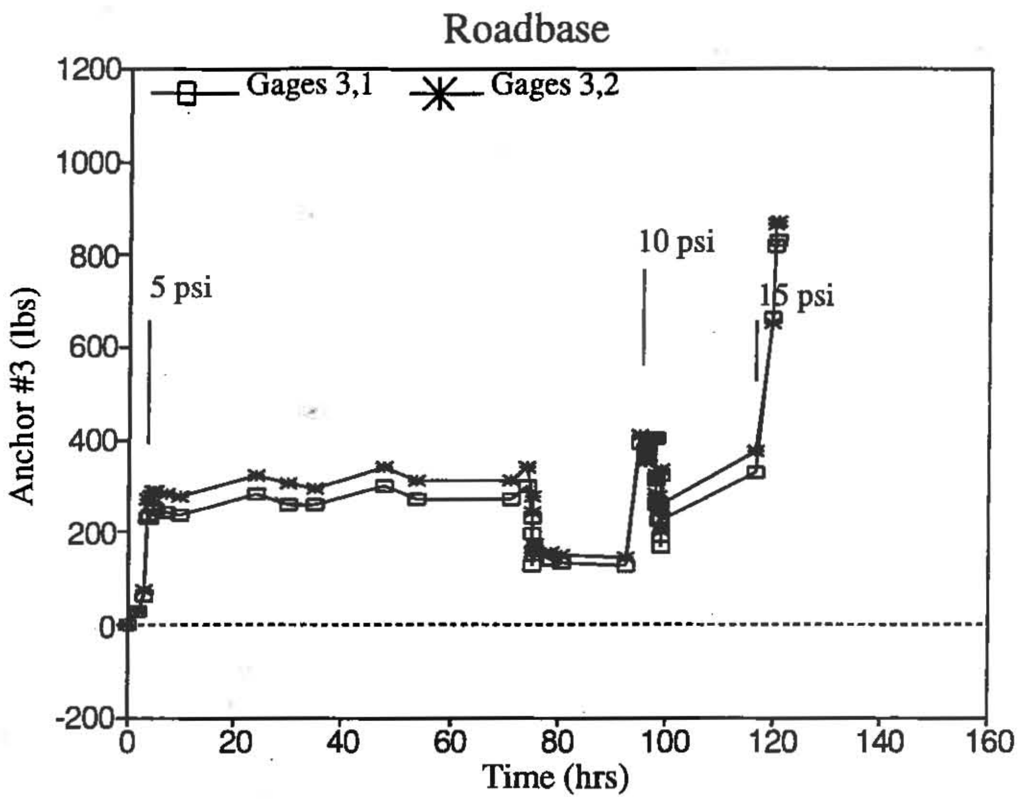


Figure 50: Roadbase: Anchor A3 - Load vs Time

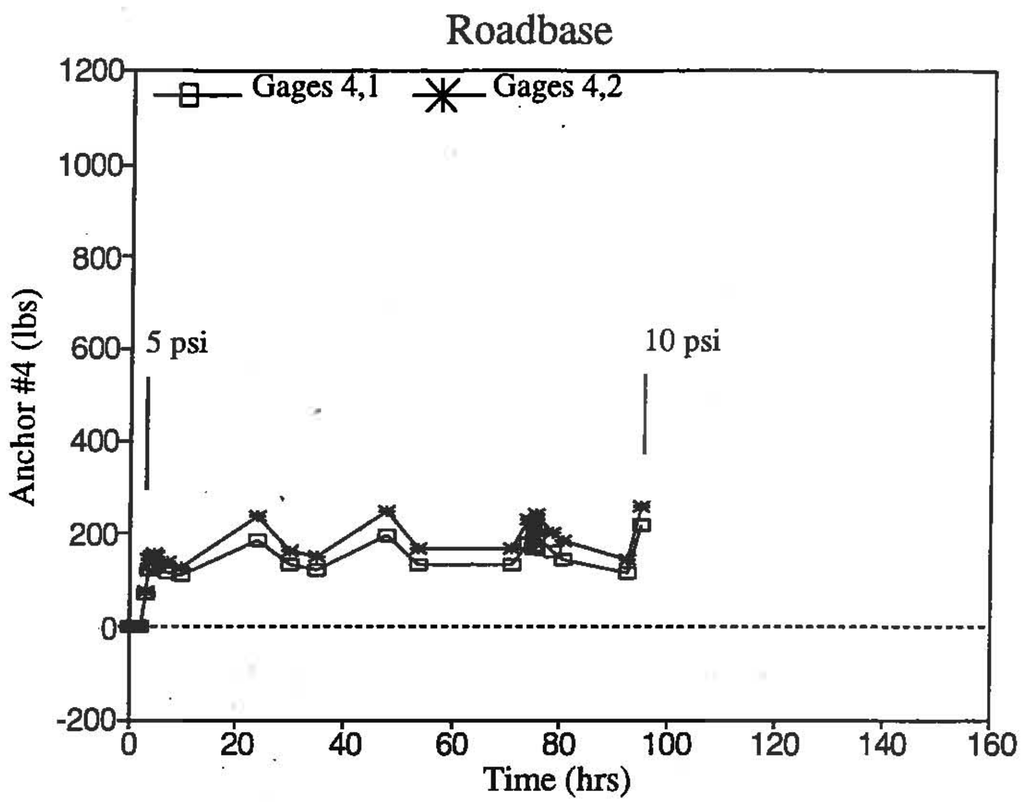


Figure 51: Roadbase: Anchor A4 - Load vs Time

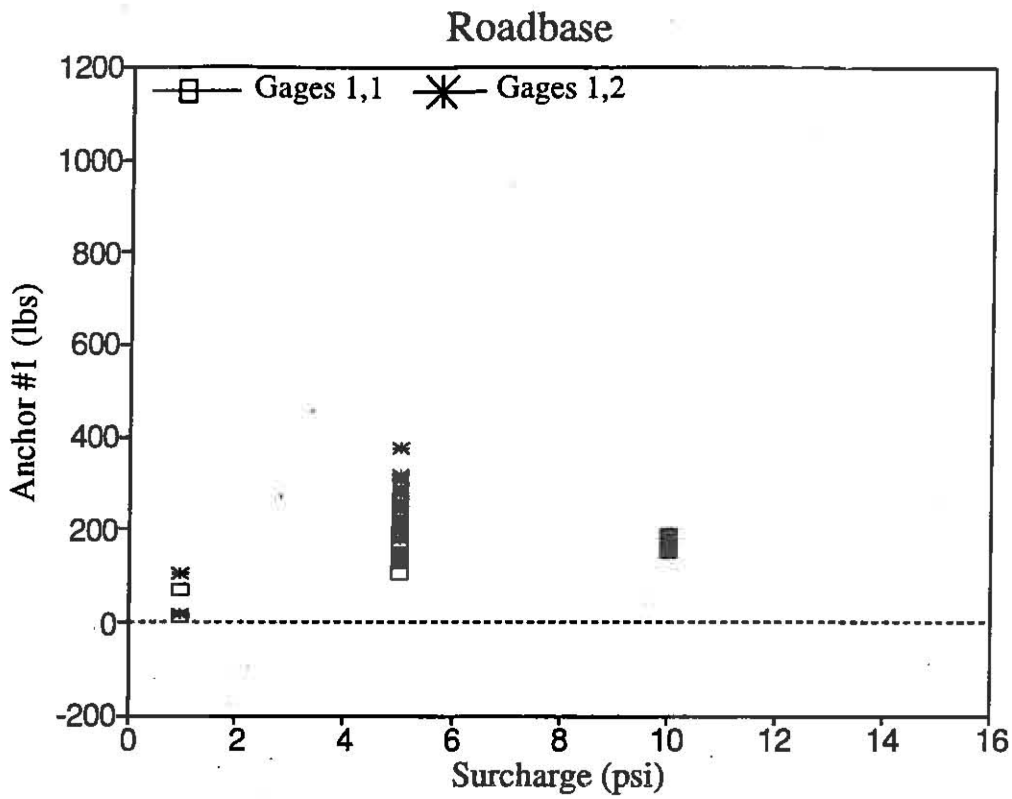


Figure 52: Roadbase: Anchor A1 - Load vs Surcharge

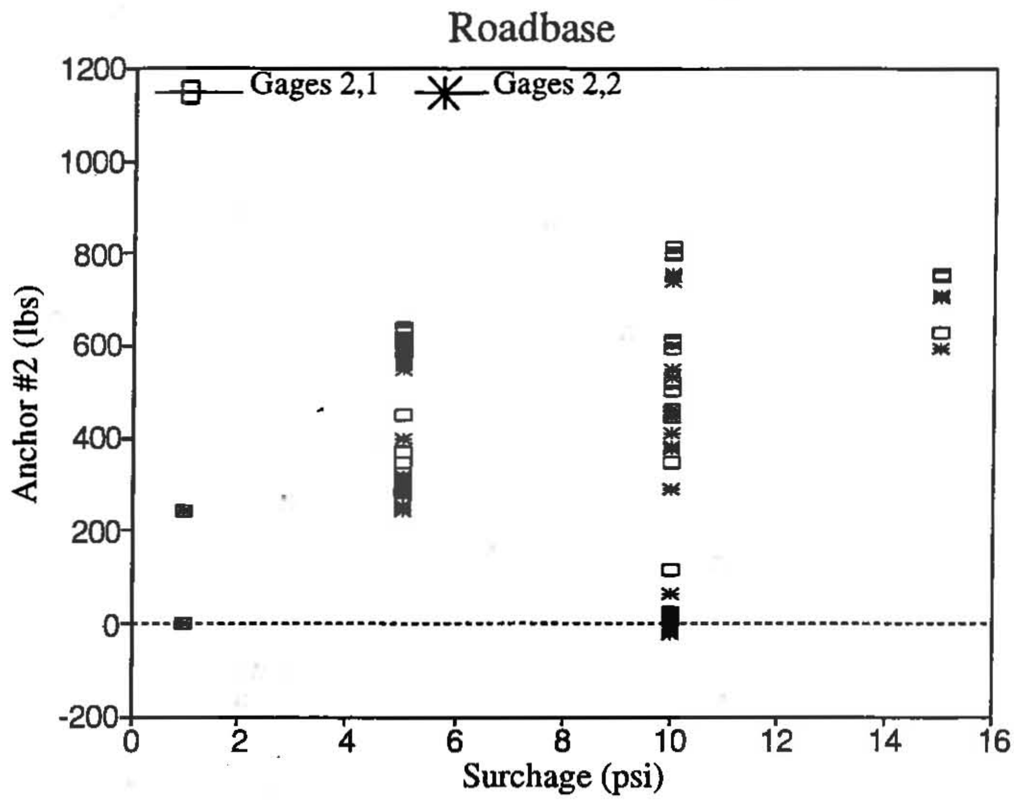


Figure 53: Roadbase: Anchor A2 - Load vs Surcharge

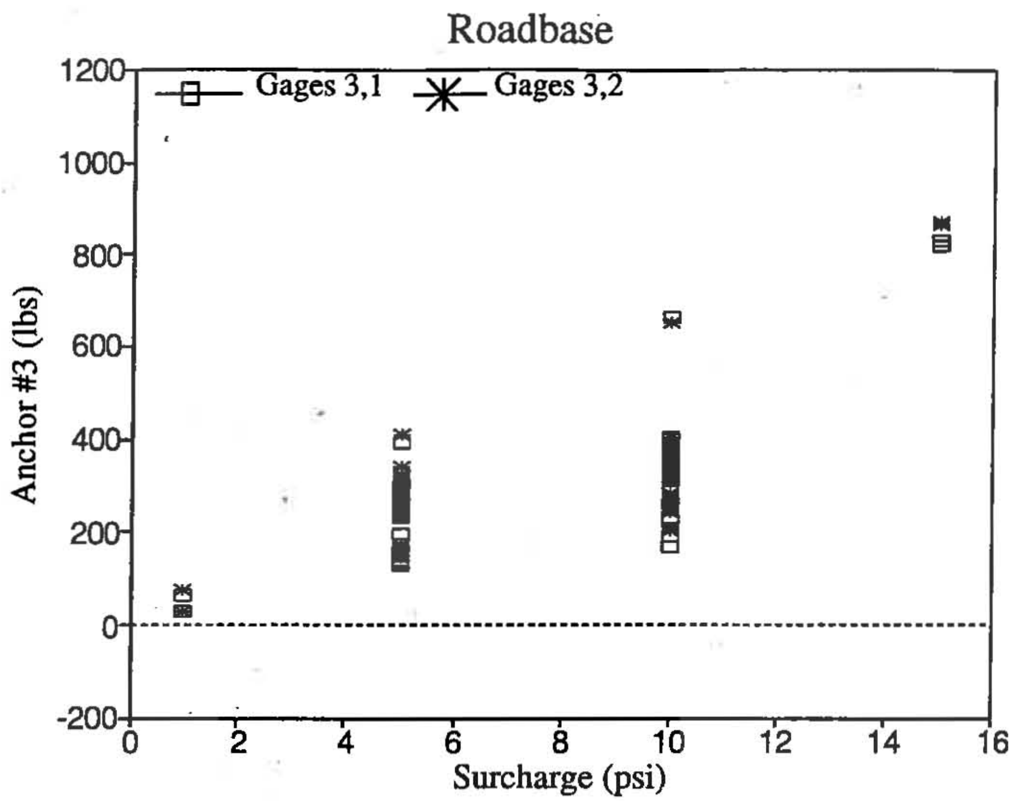


Figure 54: Roadbase: Anchor A3 - Load vs Surcharge

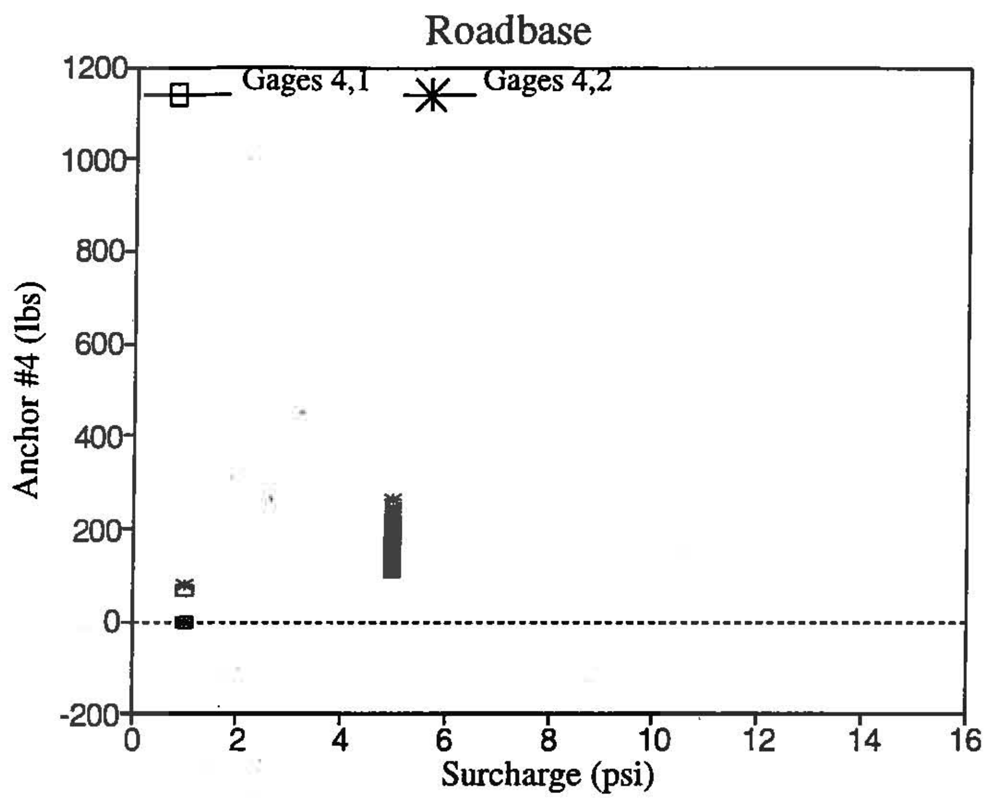


Figure 55: Roadbase: Anchor A4 - Load vs Surcharge

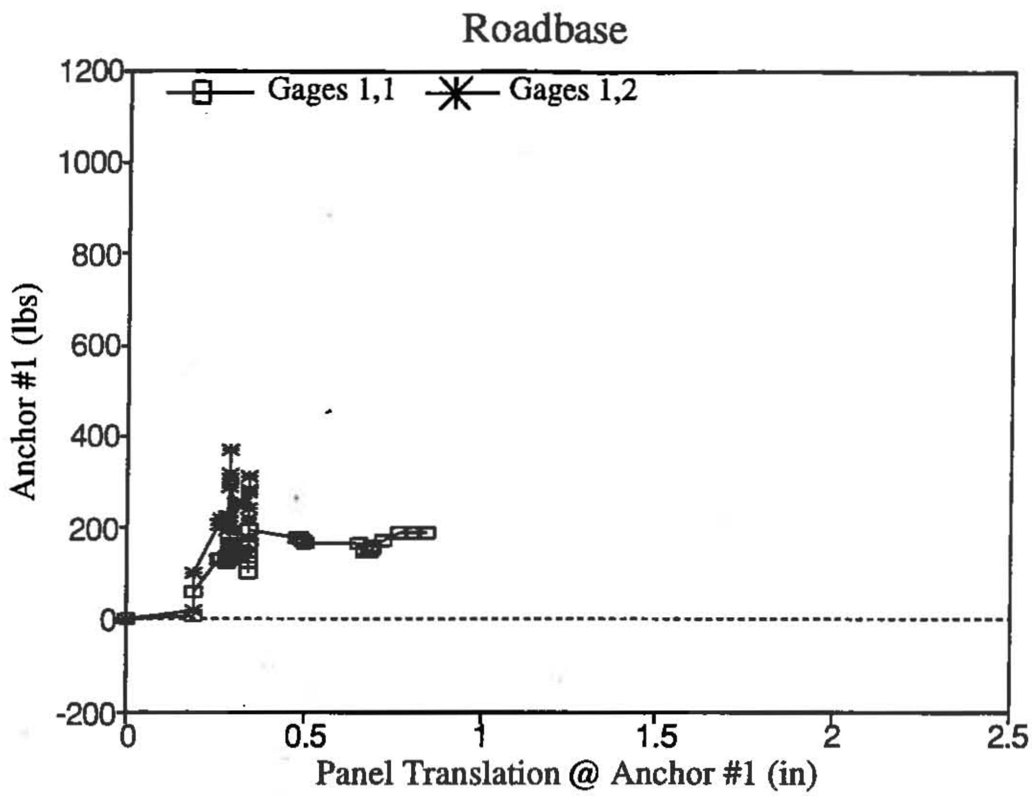


Figure 56: Roadbase: Anchor A1 - Load vs Panel Movement

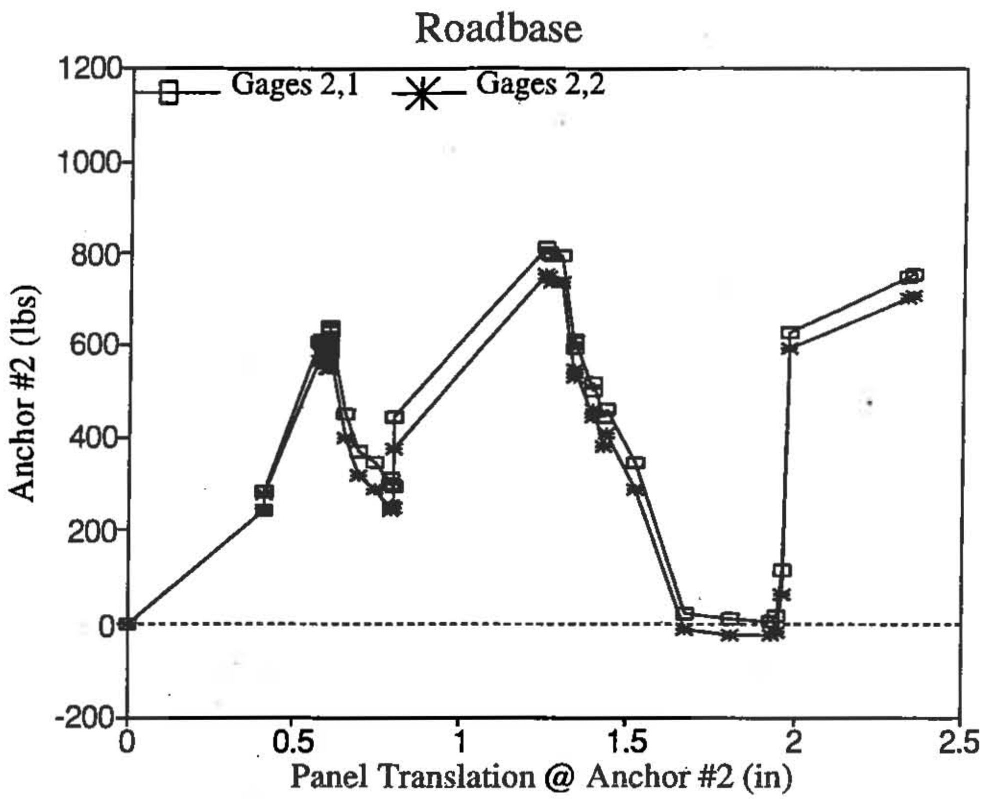


Figure 57: Roadbase: Anchor A2 - Load vs Panel Movement

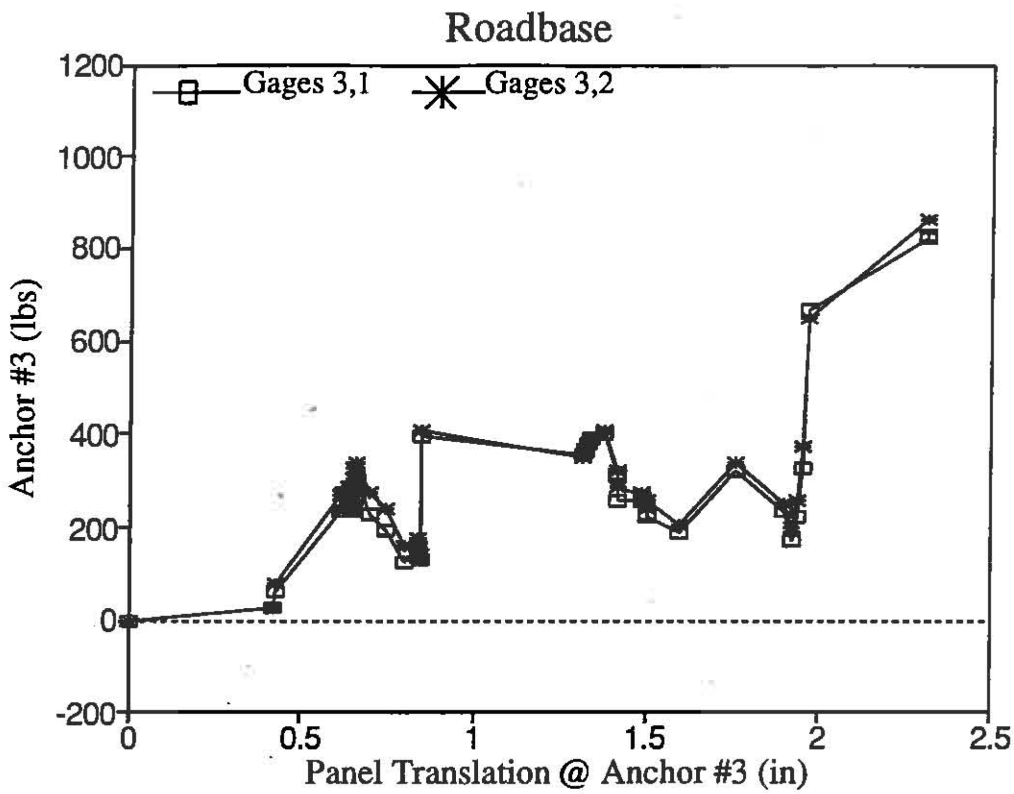


Figure 58: Roadbase: Anchor A3 - Load vs Panel Movement

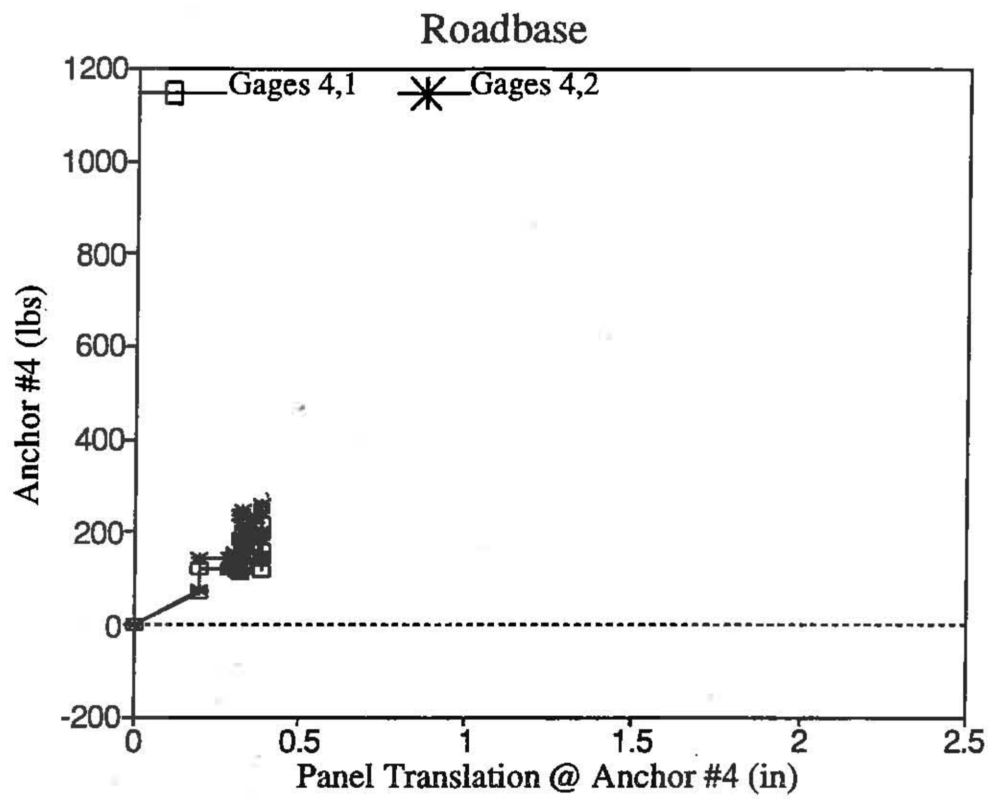
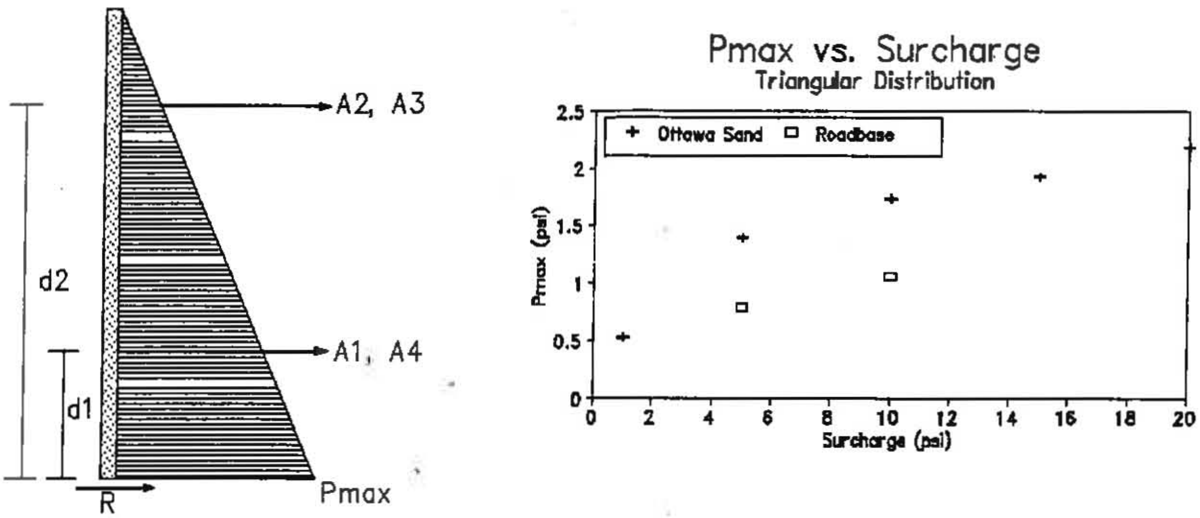


Figure 59: Roadbase: Anchor A4 - Load vs Panel Movement

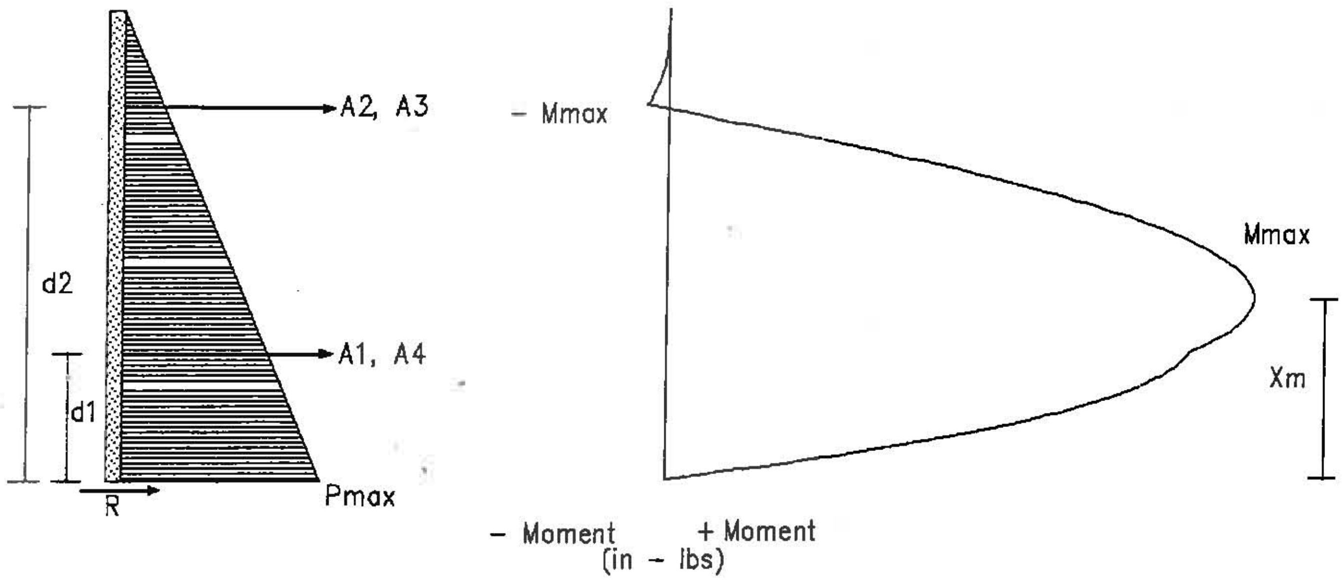


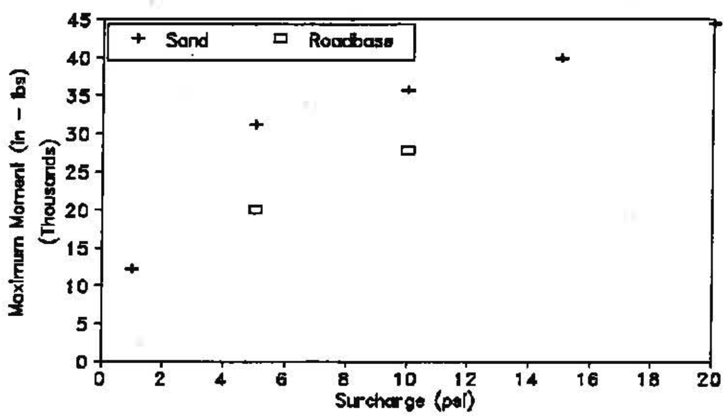
Triangular Pressure Distribution

Fill	Surcharge (psi)	P_{max} (psi)	R (lbs)
Sand			
	1	0.53	686.
	5	1.40	1770.
	10	1.73	2070.
	15	1.93	2320.
	20	2.18	2590.
Roadbase			
	5	0.790	1104.
	10	1.062	1547.

P_{Max} Computed Maximum Soil Pressure (psi)
R Computed Reaction at Base of Panel (lbs)

Figure 60: Pressure on Panel - Triangular Distribution

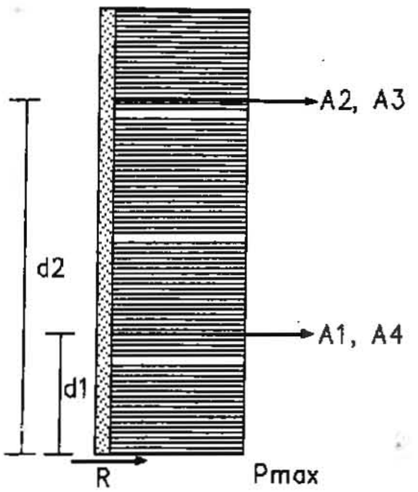


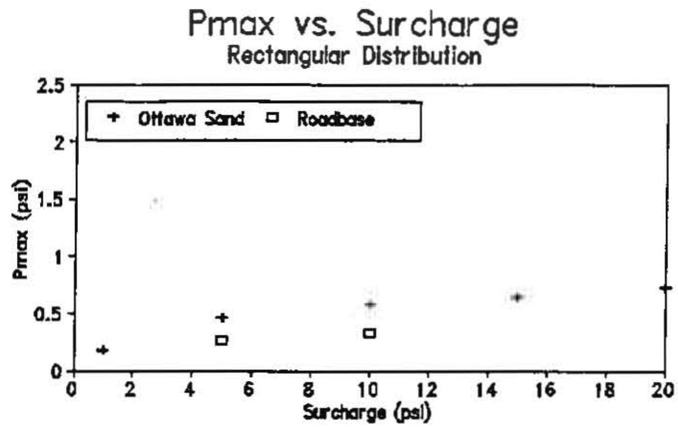


Triangular Moment Distribution

Fill	Surcharge (psi)	X_m (in)	M_{max} (in-lb)
Sand			
	1	70.13	12108.
	5	69.80	31170.
	10	68.43	35708.
	15	68.47	39868.
	20	68.24	44444.
Roadbase			
	5	72.07	20065.
	10	72.55	27697.

Figure 61: Moments in Panel - Triangular Distribution



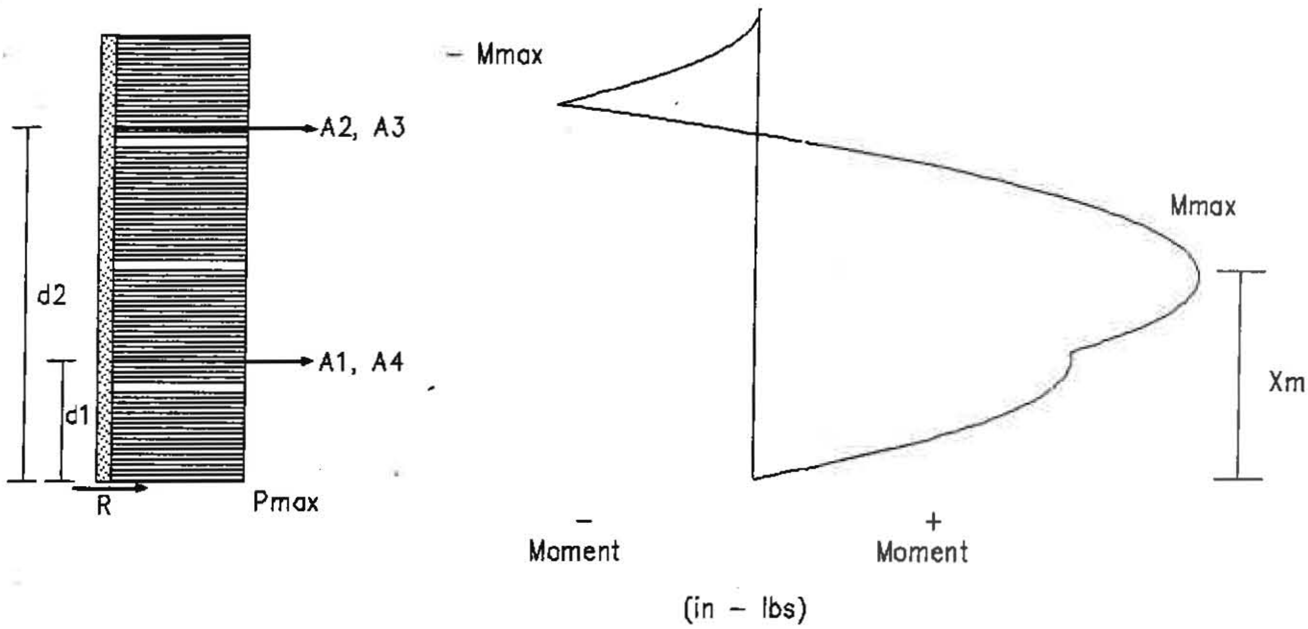


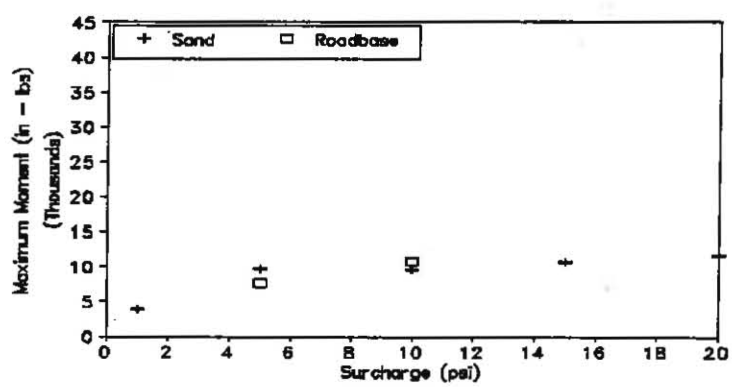
Rectangular Pressure Distribution

Fill	Surcharge (psi)	P_{max} (psi)	R (lbs)
Sand			
	1	0.177	183.
	5	0.465	457.
	10	0.578	438.
	15	0.644	493.
	20	0.728	529.
Roadbase			
	5	0.263	358.
	10	0.354	593.

P_{Max} Computed Maximum Soil Pressure (psi)
R Computed Reaction at Base of Panel (lbs)

Figure 62: Pressure on Panel - Rectangular Distribution

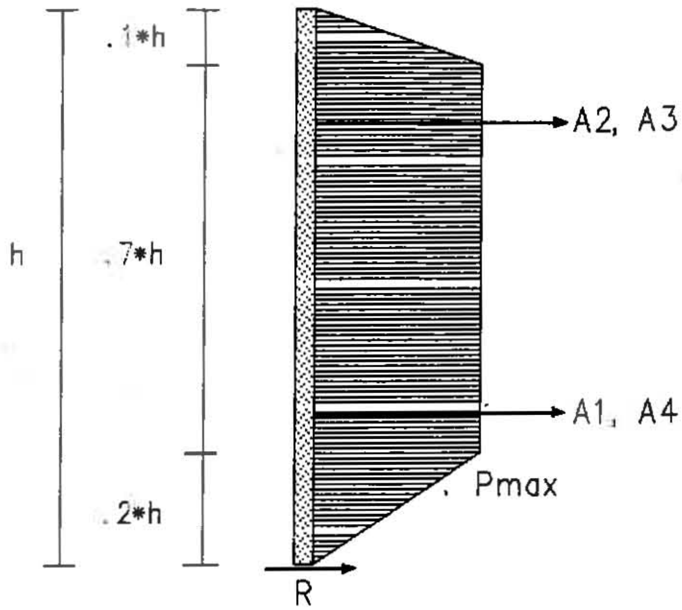


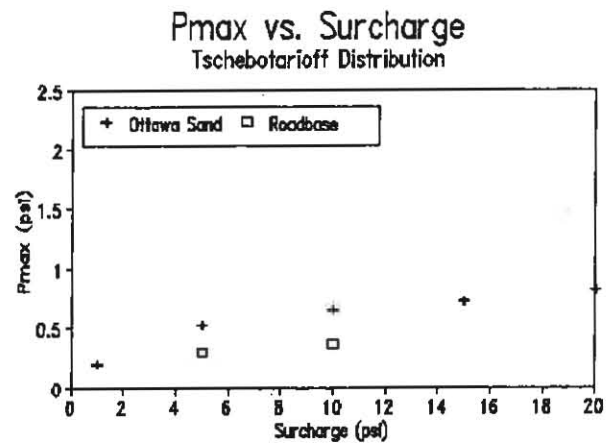


Rectangular Moment Distribution

Fill	Surcharge (psi)	X_{max} (in)	M_{max} (in-lb)
Sand			
	1	62.64	3894.
	5	61.98	9666.
	10	59.53	9520.
	15	59.57	10655.
	20	59.17	11550.
Roadbase			
	5	66.10	7554.
	10	66.90	10744.

Figure 63: Moments in Panel - Rectangular Distribution



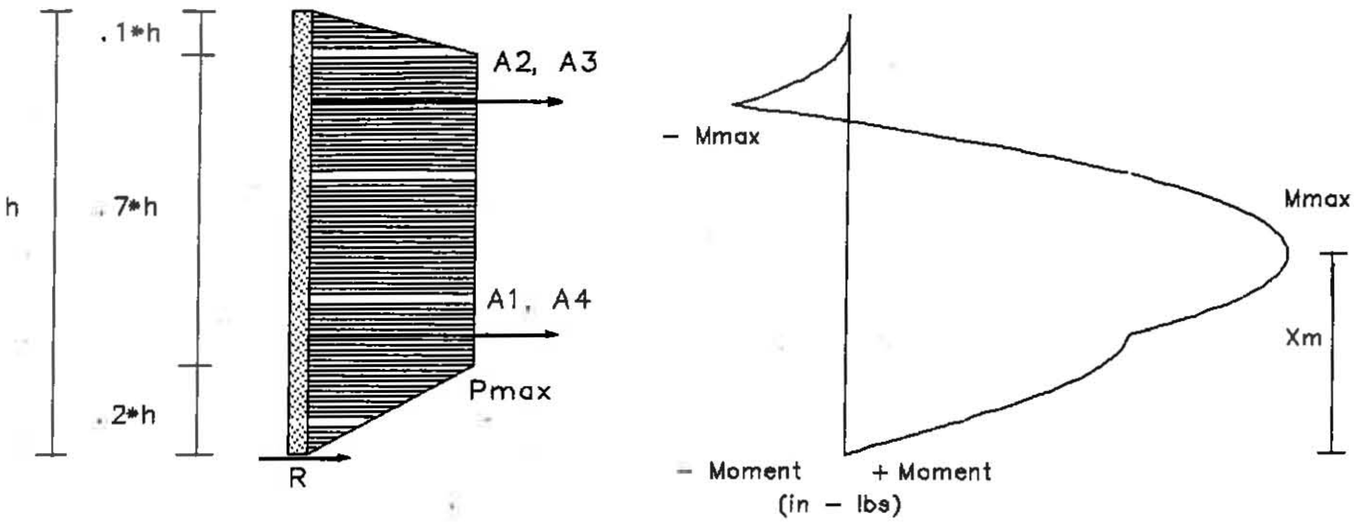


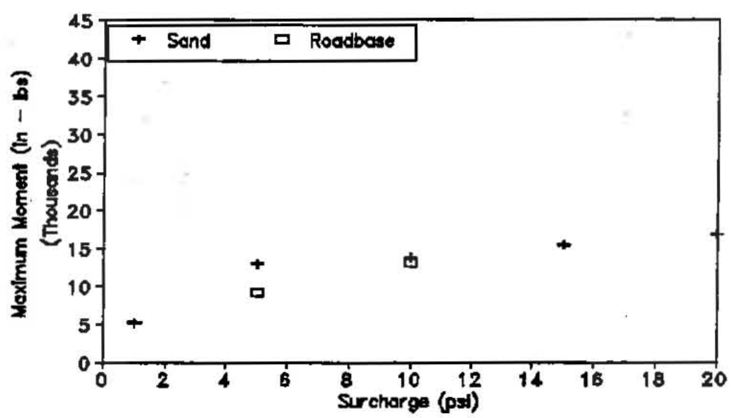
Tschebotarioff Pressure Distribution

Fill	Surcharge (psi)	P_{max} (psi)	R (lbs)
Sand			
	1	0.199	152.
	5	0.523	377.
	10	0.649	339.
	15	0.723	382.
	20	0.818	403.
Roadbase			
	5	0.297	313.
	10	0.371	535.

P_{Max} Computed Maximum Soil Pressure (psi)
R Computed Reaction at Base of Panel (lbs)

Figure 64: Pressure on Panel - Tschebotarioff Distribution





Tschebotarioff Moment Distribution

Fill	Surcharge (psi)	X_{max} (in)	M_{max} (in-lb)
Sand			
	1	61.61	5136.
	5	61.00	12928.
	10	58.92	13705.
	15	58.96	15325.
	20	58.56	16791.
Roadbase			
	5	64.44	9237.
	10	65.26	13051.

Figure 65: Moments in Panel - Tschebotarioff Distribution