REINFORCED EARTH AND STONE COLUMNS FOR WEAK SUBSOIL CONDITIONS

Final Report
Project HR - 510

DEPARTMENT OF TRANSPORTATION
IOWA

Highway Division
Office of Road Design

November 1980

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TABLE OF CONTENTS

REINFORCED EARTH AND STONE COLUMNS FOR WEAK SUBSOIL CONDITIONS - THE IOWA EXPERIENCE

DEPARTMENT OF TRANSPORTATION
IOWA

HIGHWAY DIVISION

OFFICE OF ROAD DESIGN

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SOILS GEOLOGIST

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PROJECT: WOODBURY COUNTY
I-IG-F-29-6(13)150--0B-97

INTRODUCTION

Reinforced Earth is a French development that has been used in the United States for approximately ten years. Virbro-Replacement, more commonly referred to as stone columns, is an outgrowth of deep densification of cohesionless soils originally developed in Germany.

Reinforced Earth has applicability when wall height is greater than about twelve feet and deep-seated foundation failure is not a concern. Stone columns are applicable when soft, cohesive subsoil conditions are encountered and bearing capacity and shearing resistance must be increased. The conditions in Sioux City on Wesley Way can be summarized as: (1) restricted right of way, (2) fill height in excess of 25 feet creating unstable conditions, (3) adjacent structures that could not be removed. After analyzing alternatives, it was decided that Reinforced Earth walls constructed on top of stone columns were the most practical approach.

Stone Columns

As previously reported, stone column construction was completed on September 21, 1979. The following is a summary of construction observations and performance to date:.

1. Contractor cooperation was excellent. Their personnel were well trained; proper equipment was available; and production capabilities were as advertized.
2. Minor problems were experienced with the working base provided. The A-3(0) and A-2-4(0) sands which were specified became "quick" under high flow conditions. The contractor elected to stabilize the surface by using the column aggregate at his own cost. This item should be clarified in future contracts.
3. Probe vibrations were transmitted for considerable distances, but were of a nondamaging magnitude. A badly cracked concrete block wall, supported by

spread footings, and located 15 ft. from the columns has shown no apparent change in crack width or pattern since the project began. A hardware store located 100 ft. from the project reported moving items on the display floor but again no apparent damage occurred in the structure.

4. The "jetting" method of drilling will not advance the vibroflot probe through material which cannot be washed up the hole or pushed to the side. Auger drilling equipment, at the cost of $1,000 per foot of obstruction, was used to advance selected holes which could not be jetted. Because of cost considerations, it was decided to remove obstructions only if the column area reduction resulted in a safety factor below 1.3.

Determination of material changes are easily observable by this drilling method with rates of probe penetration changing dramatically according to material type. Very limited training allowed our field inspectors to pick the foundation layer desired and to easily recognize any change in material types.

In the area where column lengths were significantly reduced, a number of the probe holes could not be advanced to the expected elevation. The 36 in. auger equipment obtained excellent samples which verified a 4 to 8 ft. thick boulder layer underlain by weathered shale. Design changes thus were made with confidence and with minimal project delay.

When changed conditions are encountered with this system, it is desirable to <u>not</u> backfill the hole with column aggregate until the extent of the condition is known. On this project these "questionable" holes were backfilled with sand which could easily be jetted. This was not covered as a contract item, and future projects should contain a bid item for uncompleted column footage.

5. As noted by the reduction of actual pay quantities for aggregate, the planned size of column was not totally achieved. Based on stone "take", hole size may vary considerably according to the strength and cohesive properties of the soil as well as the nature of the foundation soils located at the base of the column. Columns which did not have a good base from which to start were difficult to compact throughout their entire length.
6. The stone columns apparently essentially eliminated settlement of the Reinforced Earth wall and the interior sand fill. Our estimated settlements for this 30 ft. high fill were in excess of two feet had the column system not been used.
7. The inability to control column size, the economic considerations for the clearing of obstructions and the inclinometer movements observed, support the 1.5 safety factor design used for this project.

Reinforced Earth Wall

1. Again, contractor cooperation and ability was excellent. Some early misunderstandings as to the application of our standard specifications for the manufacture of concrete items became controversial. This was resolved and concrete face panels delivered to the project were of outstanding quality.
2. The project specifications required the wall backfill be compacted with moisture density control. Density was to exceed 95% of standard proctor density and moisture limits were set at -1% to +3% of optimum standard proctor limits. The sand used for backfill was dredged to the project and stockpiled. To meet the moisture limits, the contractor attempted to dry the material by spreading. This resulted in variable moisture contents and variable densities. Early in the project the upper limit was raised to 6% over optimum. This resulted in a considerable reduction in contractor efforts and a more uniform backfill density. A drain system had been designed for the wall footing which easily controlled excess water.

3. The only real problem encountered during the construction of the Reinforced Earth system resulted from the necessary system movements. These internal "activation" movements did not stop when the wall was completed, as expected, but continued for a period of about one month.

Bridge abutment piling were placed in several of the wall systems. These were encased with a light tubing which was maintained in a "centered" position as the walls were built. These tubes tipped outward (toward the wall face) as much as 6 in. from the constructed position. In one case the movement continued until after the abutment was constructed and the bridge beams had been placed. Fortunately movement stopped before damaging the structure.

This same problem resulted in some sections of the Reinforced walls eventually obtaining an outward lean of 1 in. to 3 in. from the desired vertical alignment. Wall 4, which was built in conjunction with the stone columns and had only minor settlement, presented the most "movement" problems. This wall was built in several stages in addition to the two which were designed. The wall was built with a one-half inch per panel "construction" batter which proved to be insufficient to maintain vertical alignment. Differential movements occurred between the various stages and at one point the construction contractor yielded to temptation and attempted to straighten a section of wall by pushing inward. This only resulted in breaking several panels. The only other panel breakage, noted to date, has occurred at corners and in two cases alignment rods have broken out of the inside of panels. These breaks have occurred in the lower portion of wall 4 where wood "alignment" wedges were left in place during second and later stage additions. Additional driving of these wedges may have occurred as an effort to maintain vertical alignment.

The wall misalignment is not noticeable to the casual observer and since all movements have apparently stopped, does not appear to be detrimental to the structure.

If this project is representative, these walls should have a minimum completed batter of one-half inch per panel to avoid later outward lean.

CONSTRUCTION

Construction photos of both the Reinforced Earth wall and stone column installations are included as Appendix D.

EVALUATION

Settlement plates and slope indicator (inclinometer) wells were installed before construction. In addition, reference marks were placed on the Reinforced Earth wall number 4 to monitor horizontal movements. A diagram locating the instrumentation in relation to survey and wall and column installations is included (page 8).

Settlement Plates

The settlement plates were monitored during fill construction and just before paving. They were destroyed during paving operations. The most settlement occurred in the high part of the mainline fill behind wall 4. That settlement was approximately 0.5 ft. Design estimates for this area were 0.8 feet. Settlement plate readings versus fill height are included as Appendix A.

Slope Indicator (Inclinometer)

Slope indicator wells were installed before construction and have been monitored at regular intervals throughout. There was more or less uniform strains occurring in the subsoils approximately until completion of Reinforced Earth wall number 4. At that time, deflections on the order of one-half inch started to appear at the surface of the reworked shale. The manufacturer of the instrument states that the magnitude of deflection is not an accurate measurement but that the shape of the deflection curve is of significance. The system of stone columns was, therefore, reanalyzed.

Both experience with other landslides in Iowa as well as other research had shown that reworked shale has a very low residual strength. In Iowa, this strength is about 200 psf with an internal friction of 0°. This was the strength used in the analysis. Other soil properties used in the analysis were based on Shelby tube cores in the area.

The analysis used was a computer version of the Simplified Bishop Method of Slices. The results were that failure could be expected and this failure would indeed occur in the reworked shale. The stone column strength, cohesion equal 0 psf and angle of internal friction equal 38°, was then added to the analysis. The factor of safety increased to almost 1.4. The weakest plane was still in the reworked shale.

The angle of internal friction of a soil contributes nothing to the overall system until some strain has taken place. In view of this, and the fact that stone columns are constructed with an aggregate of three inch top size and three-fourths inch minimum, the deflections being experienced were not excessive. Construction was allowed to proceed.

Subsequent inclinometer readings have shown that movement has virtually ceased since fill completion. Excess pore pressures have probably been relieved, and the system has stabilized.

Appendix B contains summary plots of inclinometer deflections and a schematic of the worst case computer analysis.

Reinforced Earth Wall

Reference marks were placed on Reinforced Earth wall number 4 as construction proceeded. Most of the deflection occurred during construction and probably can be attributed to a less than optimum staging of construction.

Loess hills, as occur in western Iowa, quite often have a shale or limestone "dome" in them. The Iowa Department of Transportation was able to find the approximate elevation of the shale under the loess hill to the west of Wesley Way. The stability of the bluff towards Wesley Way was checked. The results show that a long-term slide was occurring towards the road. This was evidenced in the field by the quantity and shape of both the colluvium at the base of the bluff and the nature of the slope on the lee side of the bluff.

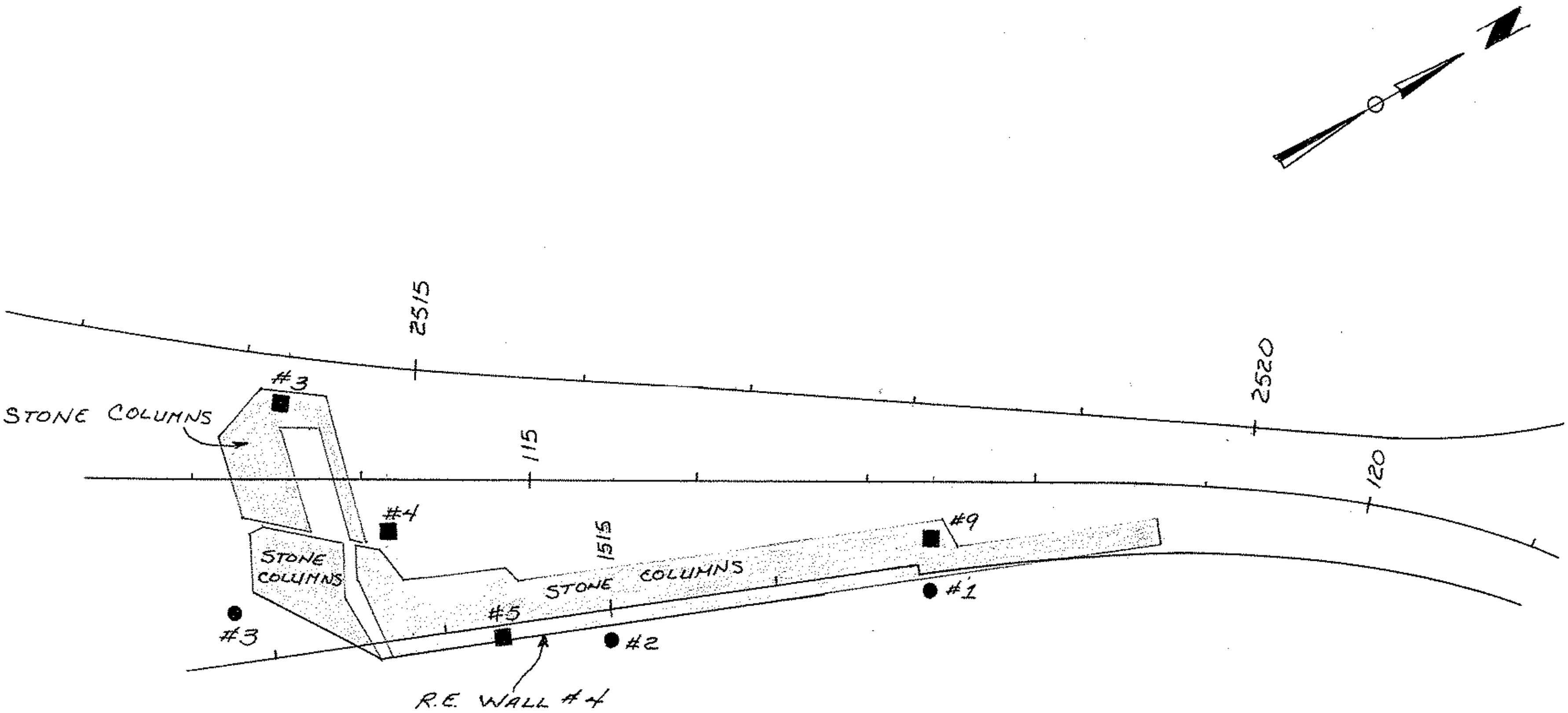
The new Wesley Way is constructed on a sand fill retained by a Reinforced Earth wall. Minor strain, as shown by wall movement readings, were to be expected. The overall factor of safety of the bluff and the road together is in excess of 1.8. The movement can be expected to cease as the long-term bluff failure is eventually stabilized. Appendix C shows the applicable Bishop analysis and wall movement to date.

CONCLUSION

Iowa has limited experience in instrumentation. Instrumentation can be very important in helping to understand the behavior of materials in the field. It also is beneficial in helping to spot potential problems and effect necessary changes before failure is encountered.

Both Reinforced Earth and Vibro-Replacement are an effective, practical means of solving weak foundation/restricted area problems. They both can work well in conjunction and can be constructed with no special problems. As more experience is gained in using these tools, even the minor problems that occurred on this project will eventually be foreseen and avoided.

DIAGRAM SHOWING PLACEMENT OF INSTRUMENTATION



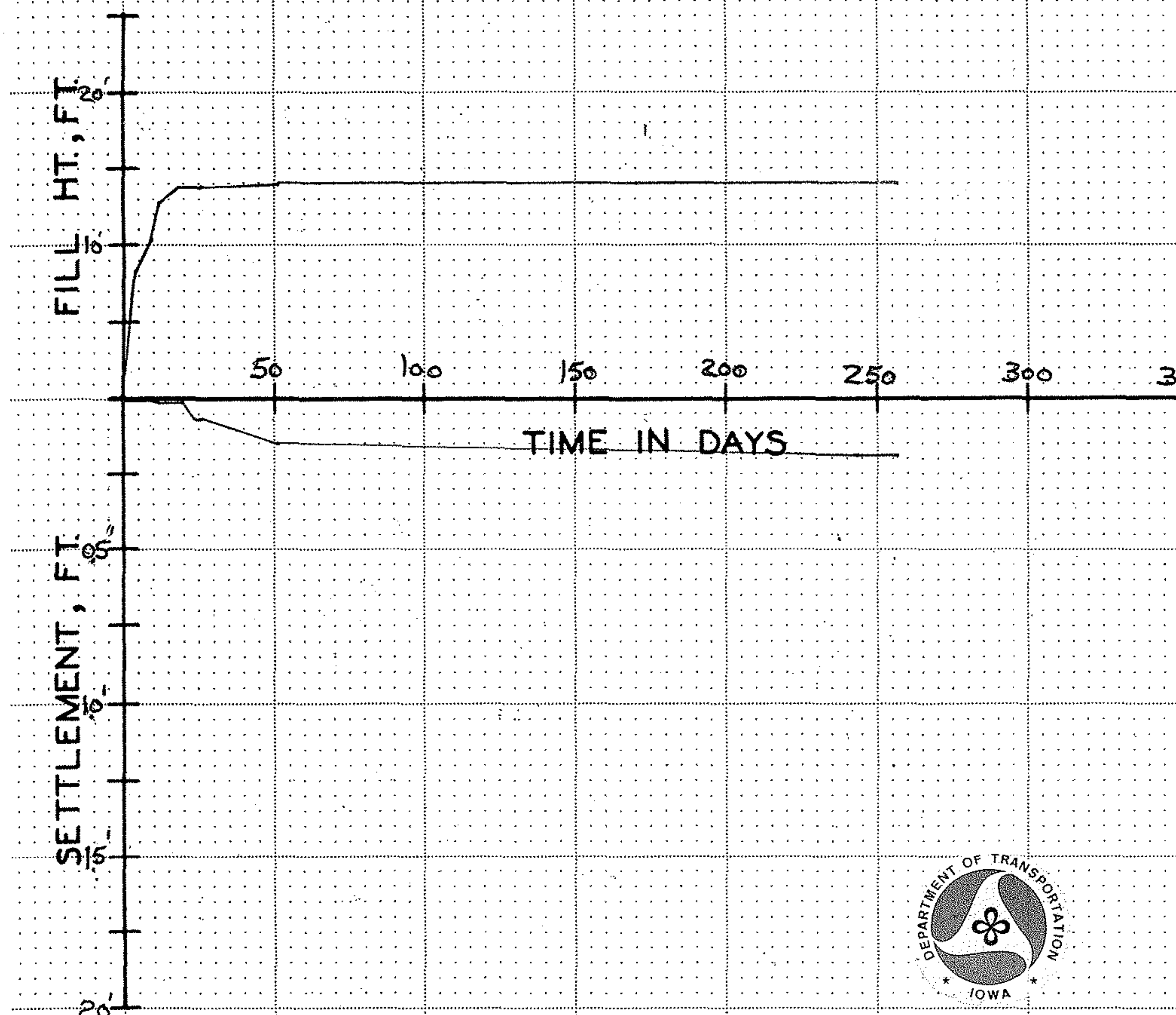
● INCLINOMETER WELLS
■ SETTLEMENT PLATES

DEPARTMENT OF TRANSPORTATION IOWA

HIGHWAY DIVISION

APPENDIX A

SETTLEMENT PLATE READINGS



STATION 117+40

RT./~~LT.~~ 35'

BRIDGE/PLATE NO. 9

SETTLEMENT ___ FT.

TREATMENT ______

START OF FILL ______

SPOT CHECK DATA		
DATE	FILL, FT.	SETTLE

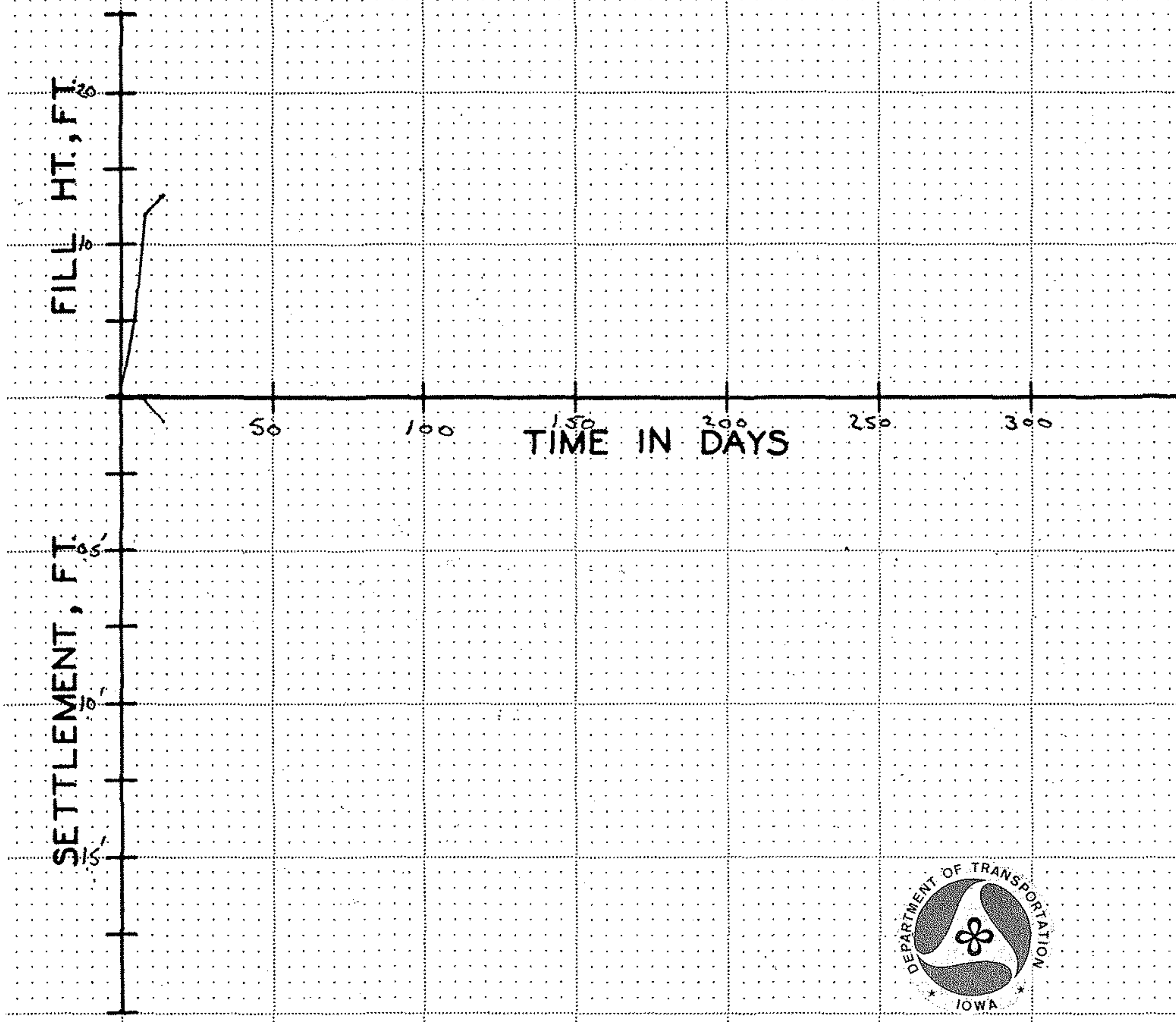
COUNTY
Woodbury Co

PROJECT
I-IG-F-29-7(13) 08-97

DES. NO. ______

DEPARTMENT OF TRANSPORTATION ★ IOWA ★

HIGHWAY DIVISION



STATION S 2514 + 14

RT. / ~~LT.~~ 30'

BRIDGE / PLATE NO. ____

SETTLEMENT ____ FT.

TREATMENT ____

START OF FILL ____

SPOT CHECK DATA		
DATE	FILL, FT.	SETTLE

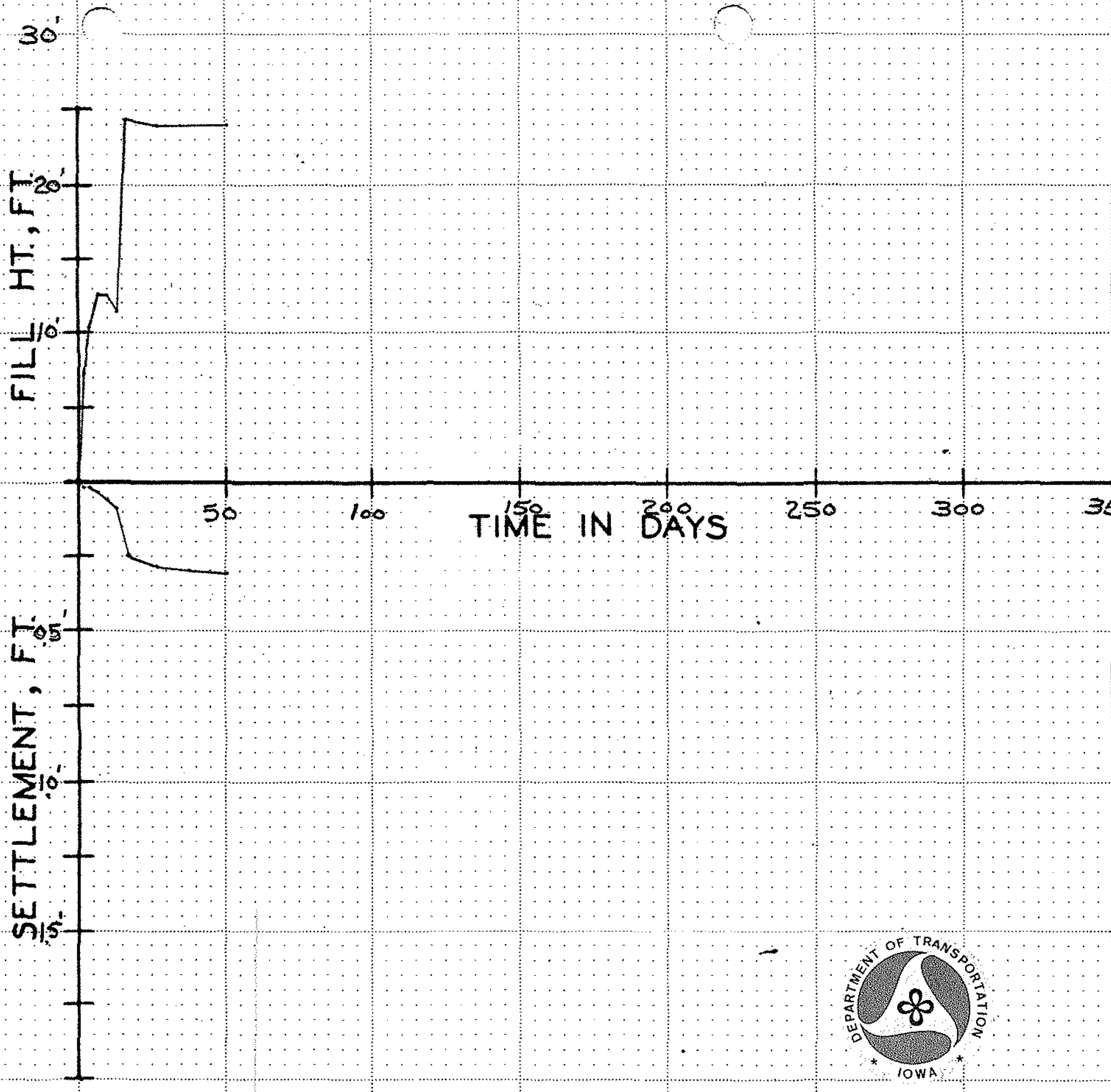
DEPARTMENT OF TRANSPORTATION · IOWA

HIGHWAY DIVISION

COUNTY
Woodbury Co.

PROJECT
I-IG-F-29-7(13)-0B-97

DES. NO. ____



STATION N 1514 + 23

RT. / ~~LT.~~ 8'

BRIDGE / PLATE NO. ___

SETTLEMENT ___ FT.

TREATMENT ___

START OF FILL ___

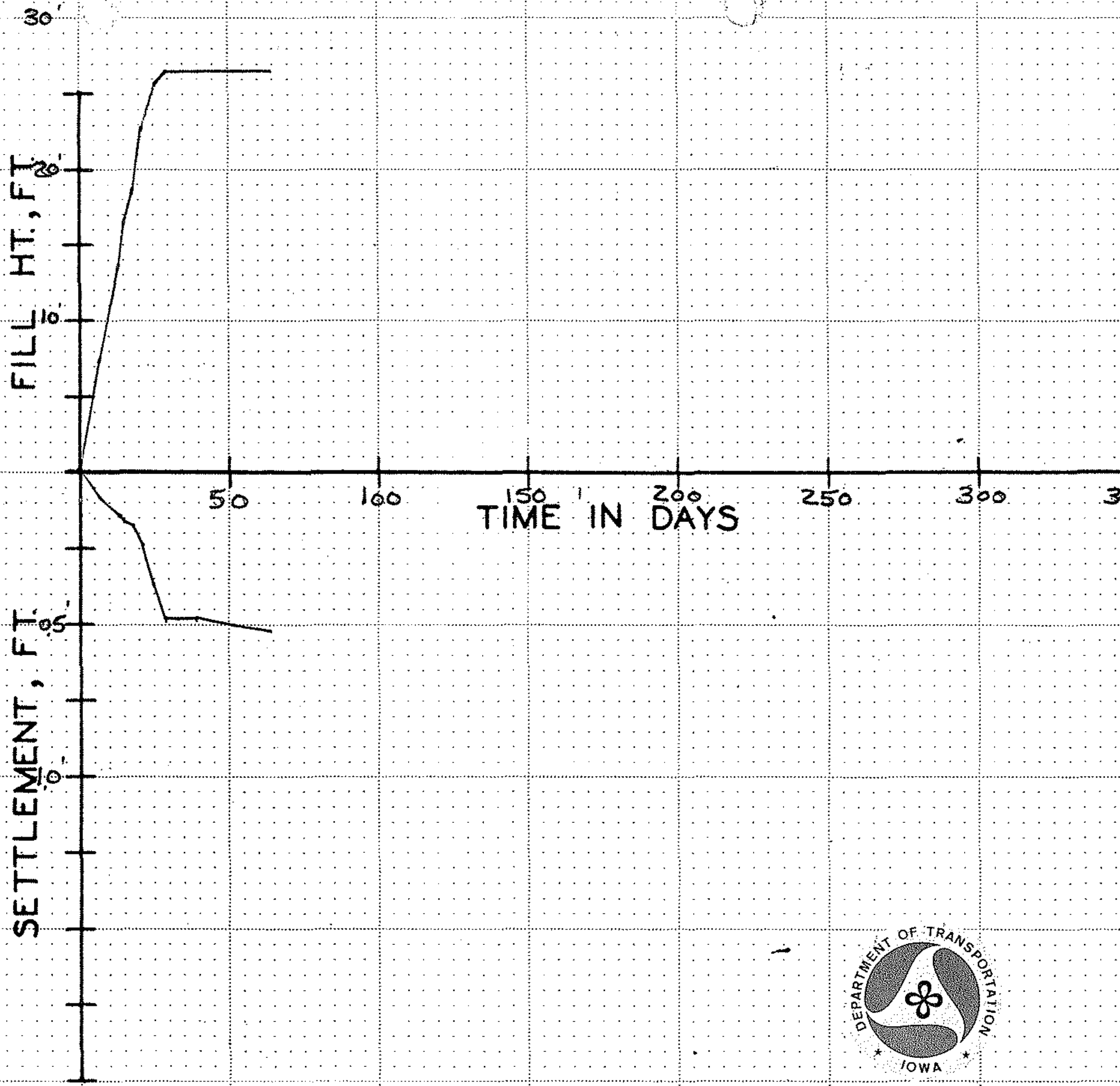
SPOT CHECK DATA		
DATE	FILL, FT.	SETTLE

DEPARTMENT OF TRANSPORTATION IOWA

HIGHWAY DIVISION

COUNTY
Woodbury

PROJECT
I-IG-F-29-7(13) 0B-97



STATION M 114+14

RT. / ~~LT.~~ 33'

BRIDGE / PLATE NO. ____

SETTLEMENT ____ FT.

TREATMENT ____

START OF FILL ____

SPOT CHECK DATA		
DATE	FILL, FT.	SETTLE

DEPARTMENT OF TRANSPORTATION IOWA

HIGHWAY DIVISION

COUNTY
Woodbury

PROJECT
I-IG-F-29-7(13) 0B-97

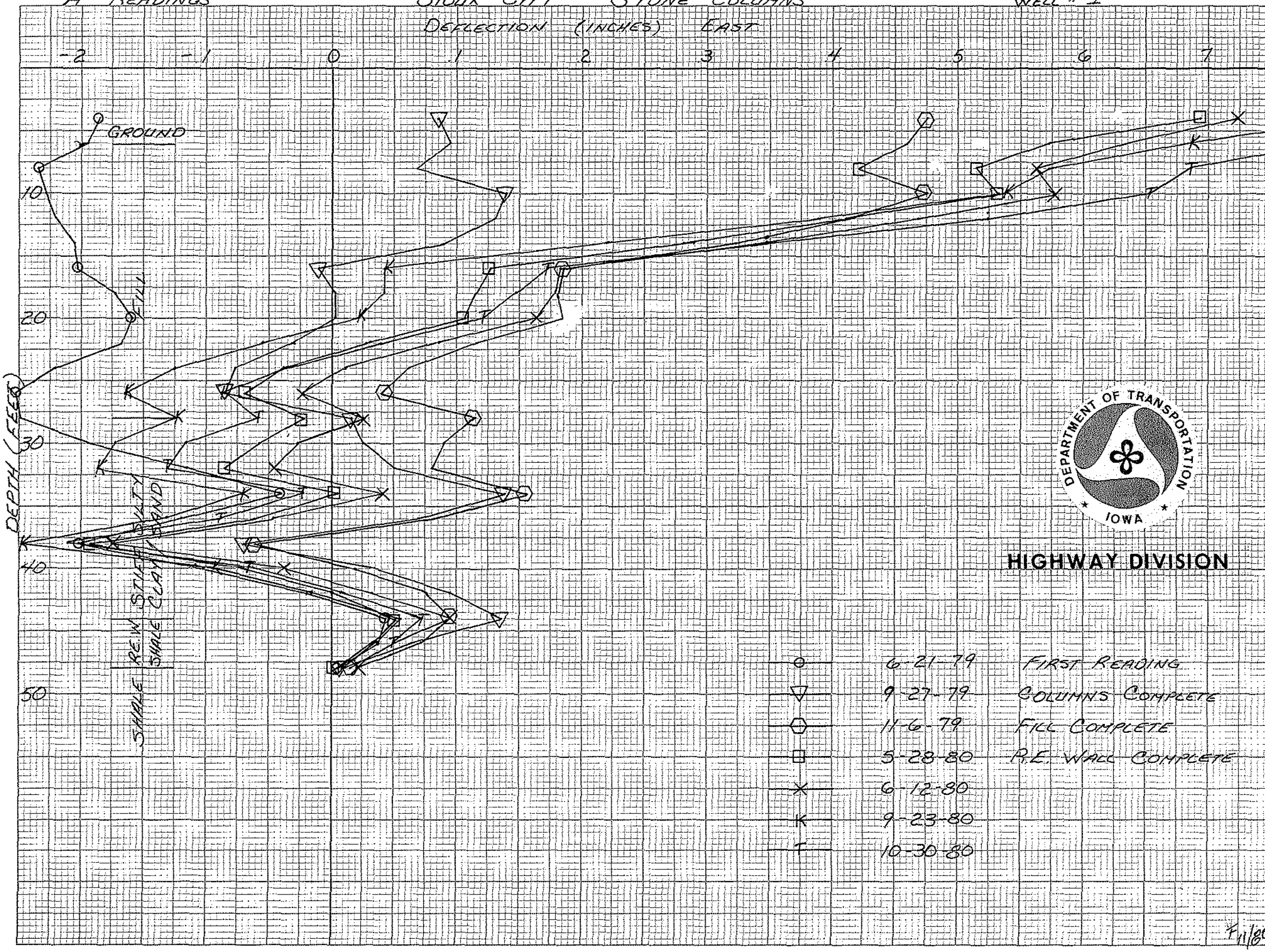
APPENDIX B

Inclinometer Deflection Plots
Simplified Bishop Analysis (Fill)

K+E 10 X 10 TO ½ INCH • 7½ X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1470

"A" READINGS SIOUX CITY STONE COLUMNS WELL # 1



F 11/80

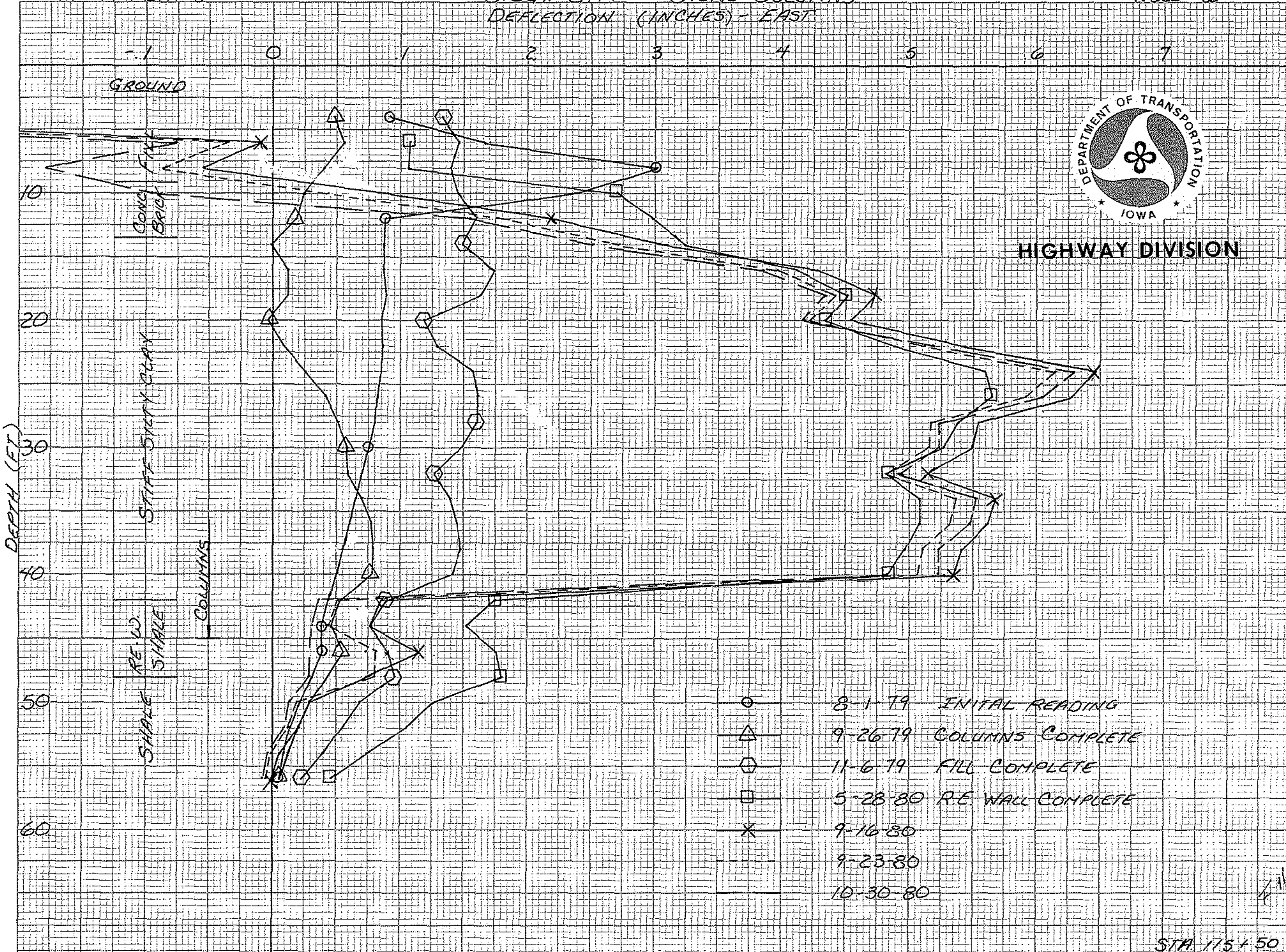
K+E 10 X 10 TO ½ INCH • 7½ X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1470

"A" READINGS

SIOUX CITY STONE COLUMNS

WELL #2



DEPARTMENT OF TRANSPORTATION IOWA

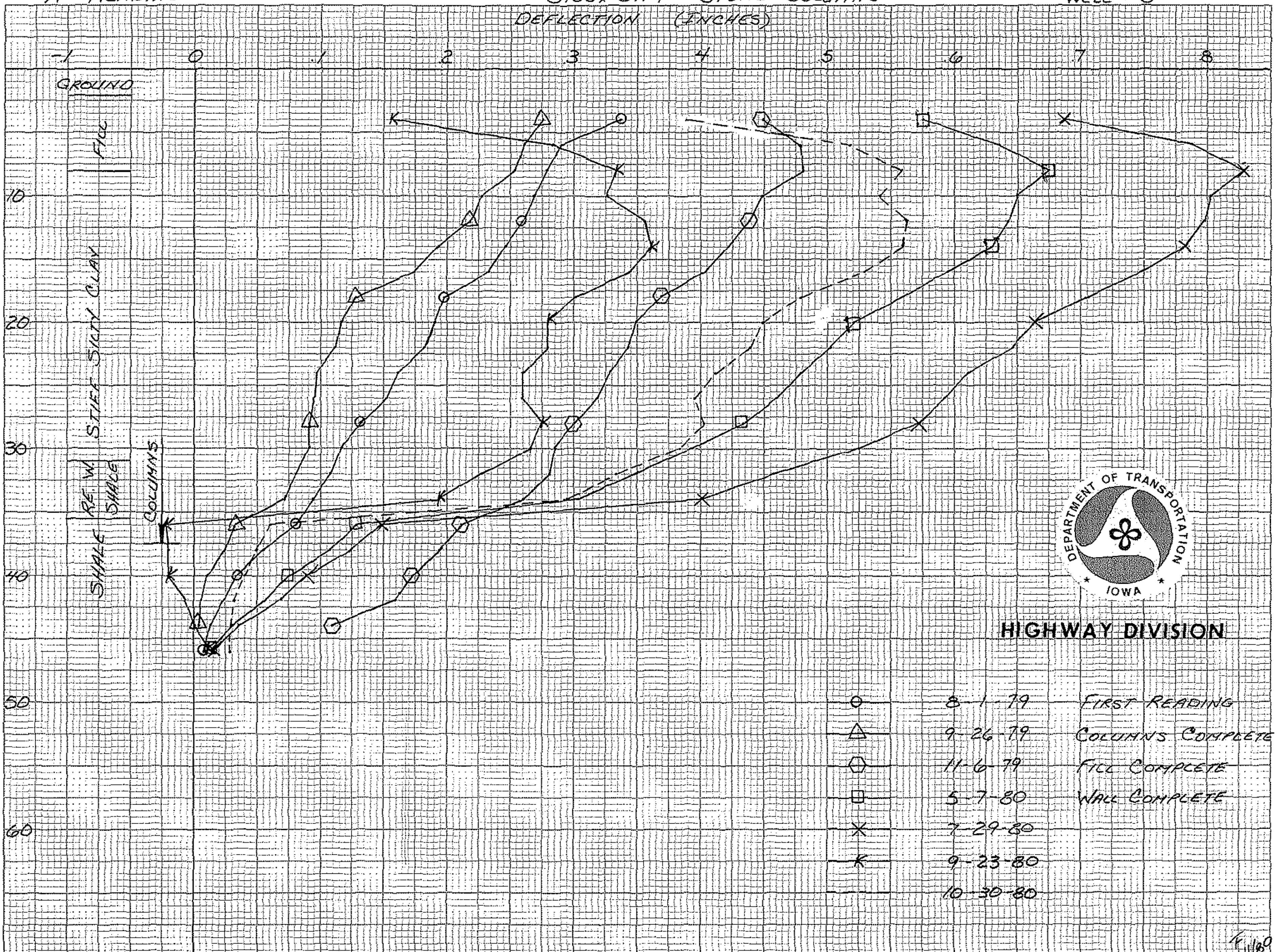
HIGHWAY DIVISION

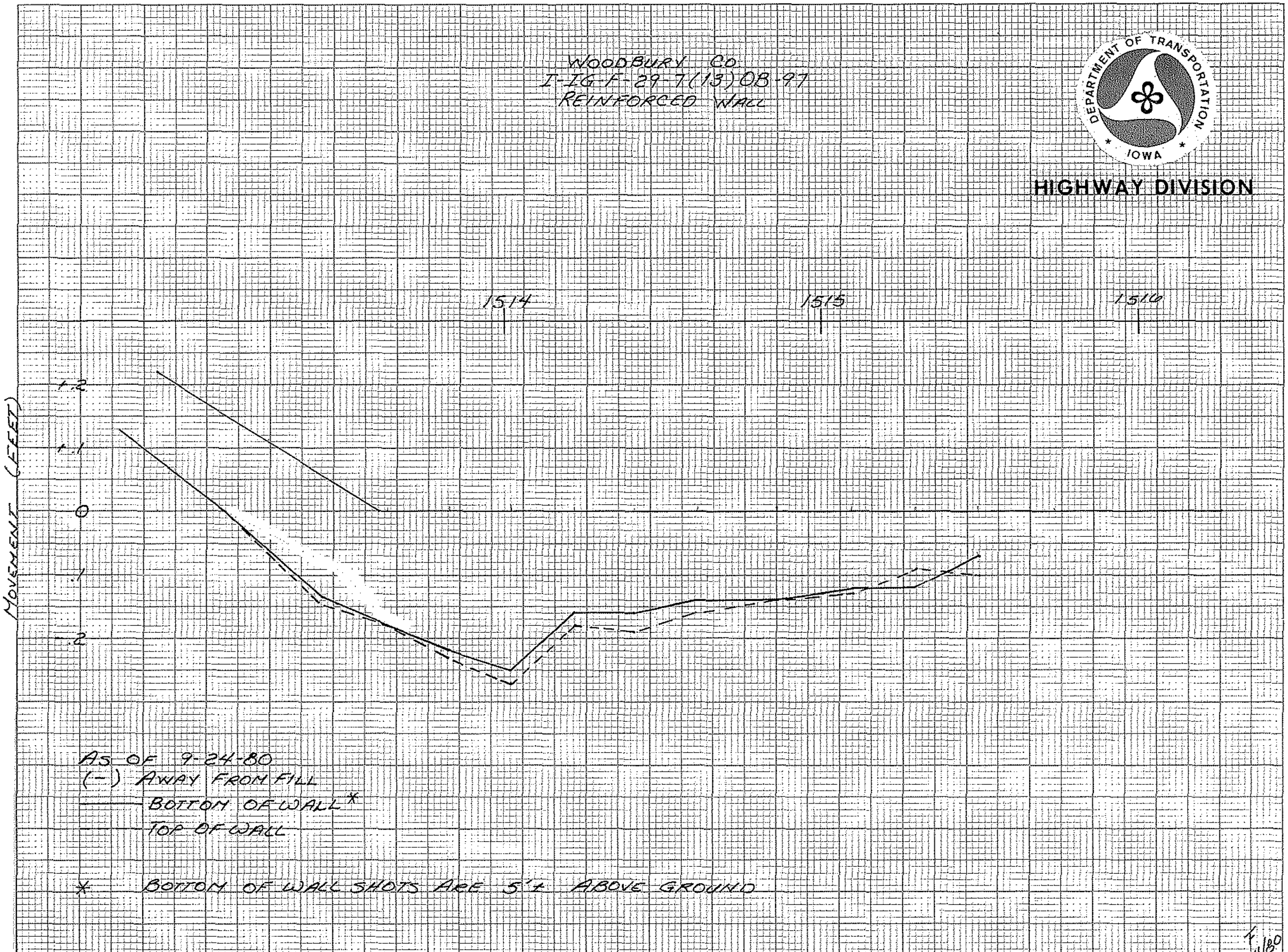
STA. 115+50
RT. 95

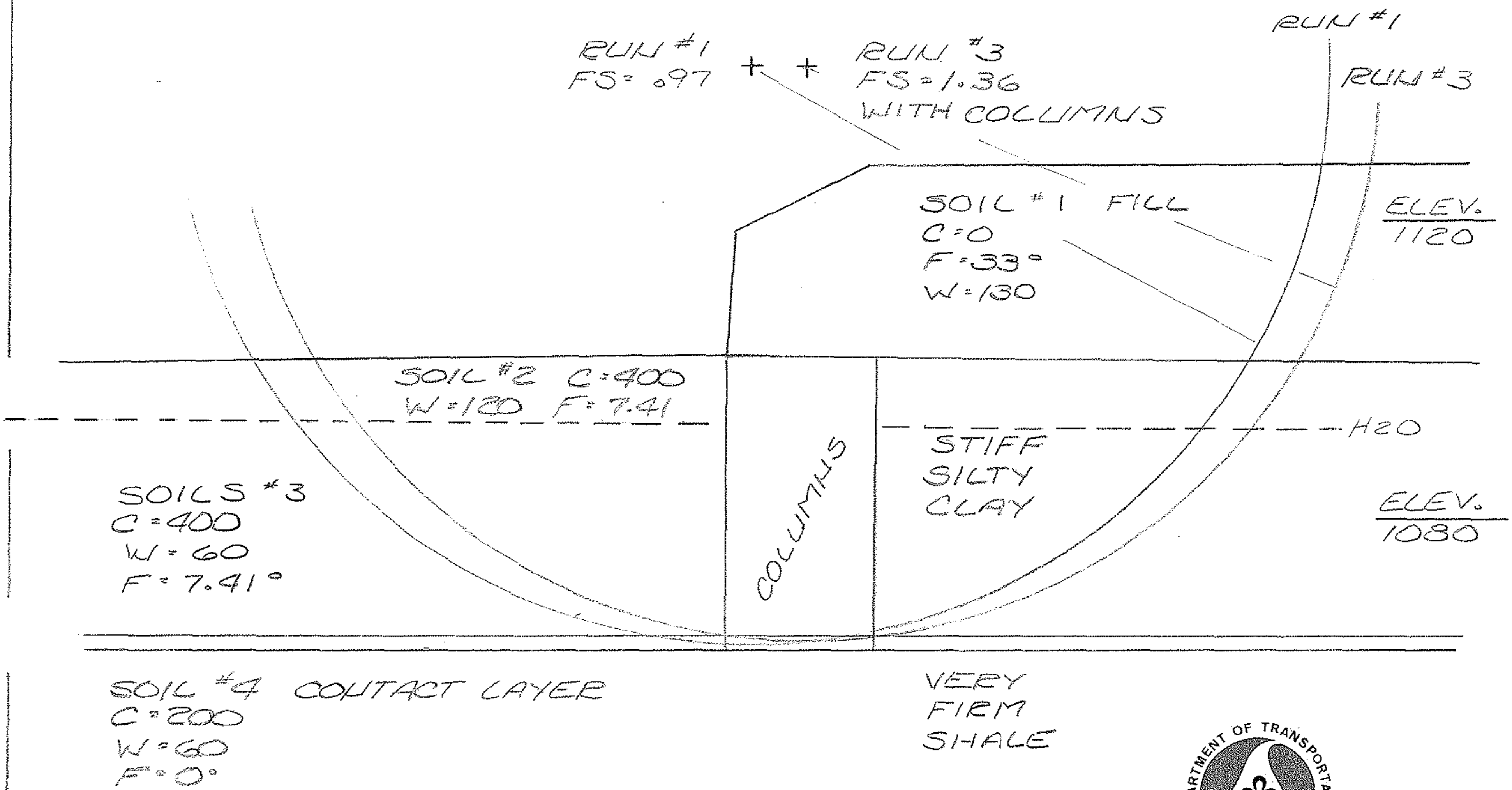
"A" READING

SIOUX CITY STONE COLUMNS

WELL # 3




WOODBURY CO.
I-IG-F-29-7(13)OB-97
REINFORCED WALL
DEPARTMENT OF TRANSPORTATION
IOWA
HIGHWAY DIVISION
1514
1515
1516
+.2
+.1
0
-.1
-.2
MOVEMENT (FEET)
AS OF 9-24-80
(-) AWAY FROM FILL
BOTTOM OF WALL*
TOP OF WALL
* BOTTOM OF WALL SHOTS ARE 5'± ABOVE GROUND
11/80



HIGHWAY DIVISION

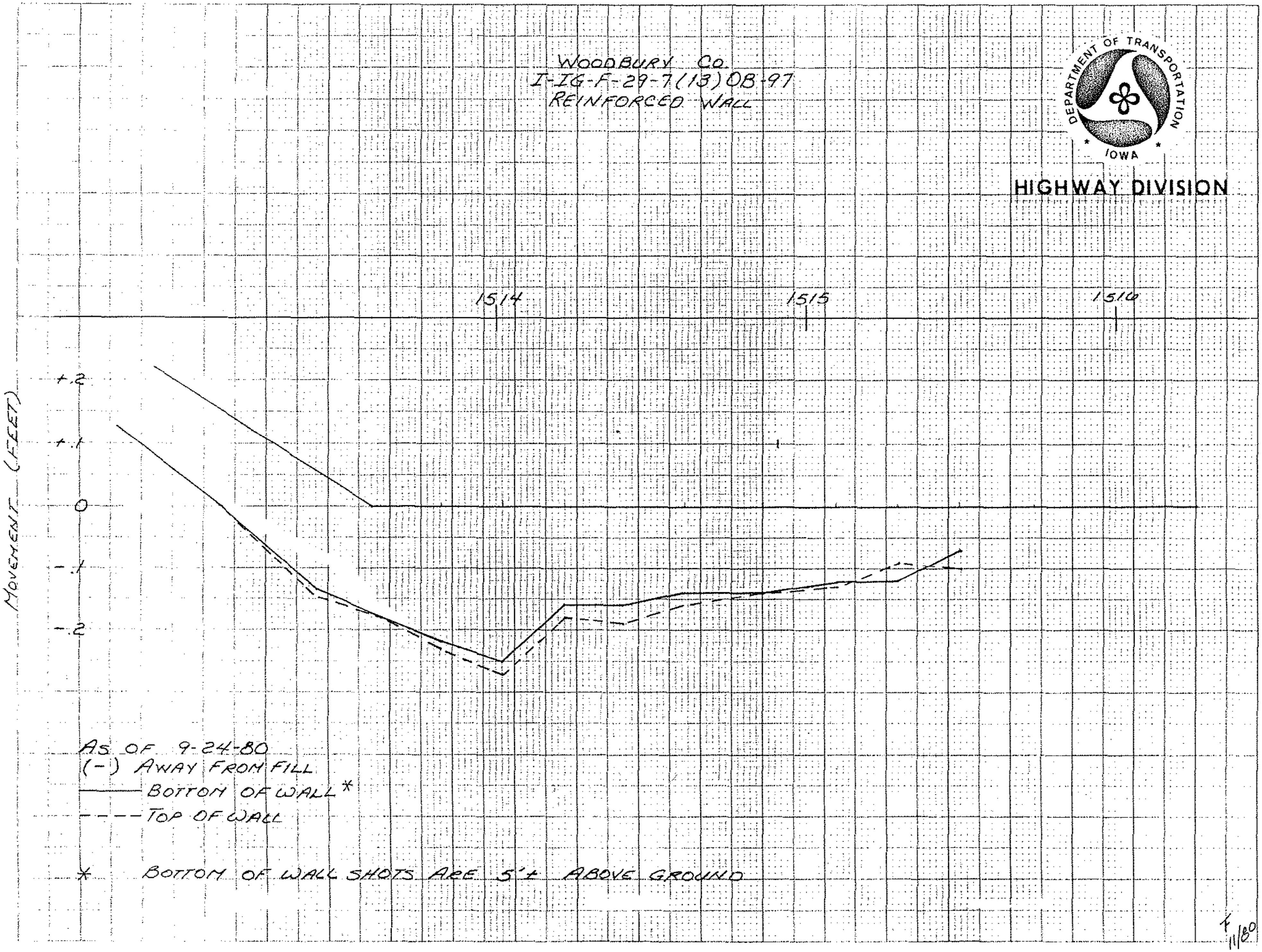
STABILITY ANALYSIS

STA. 1514+00±

APPENDIX C

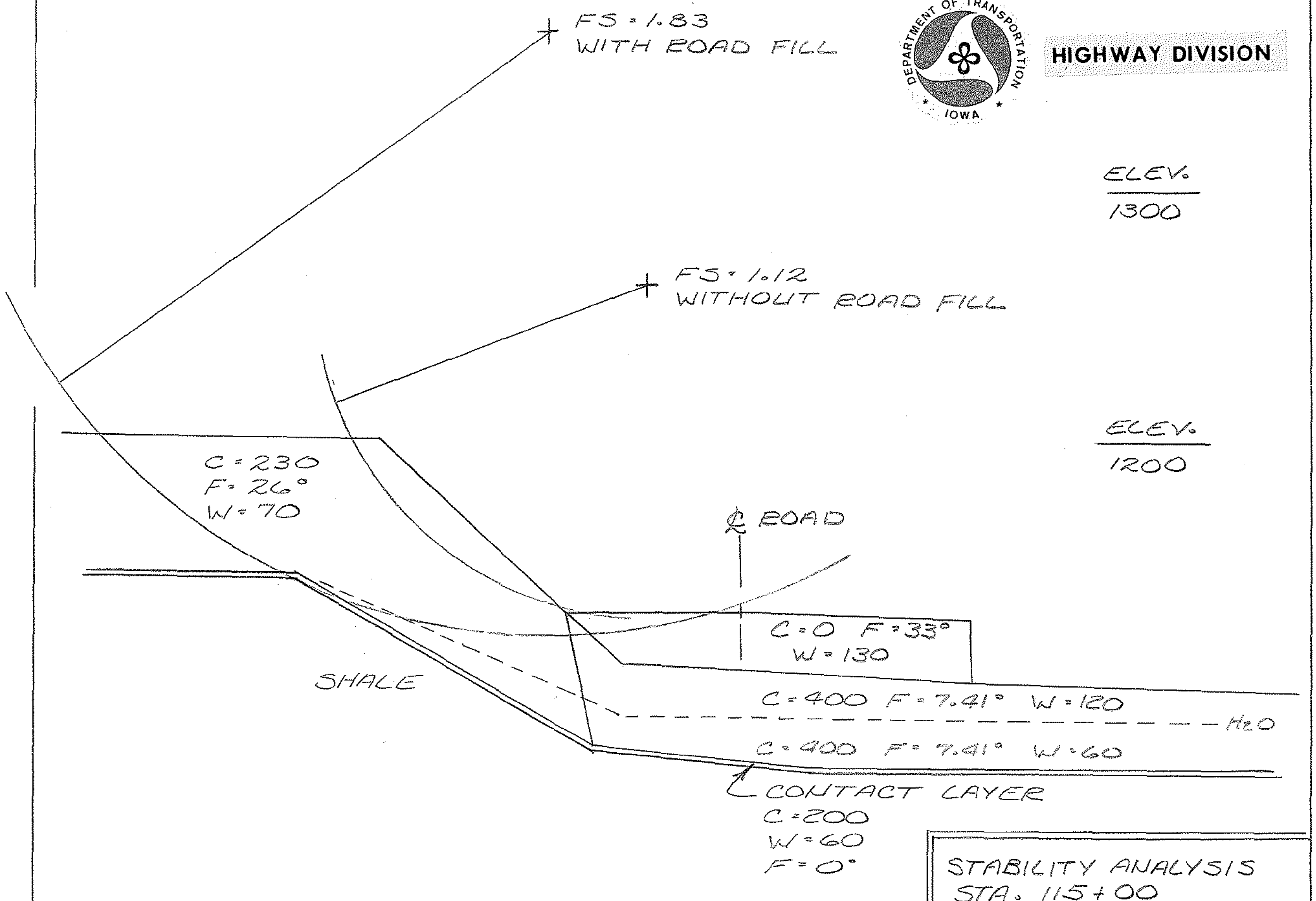
Reinforced Earth Wall Number 4
Movement Diagram
Simplified Bishop Analysis (Bluff)

46 1470


WOODBURY CO.
I-IG-F-29-7(13)OB-97
REINFORCED WALL
DEPARTMENT OF TRANSPORTATION
IOWA
HIGHWAY DIVISION
1514
1515
1516
+.2
+.1
0
-.1
-.2
MOVEMENT (FEET)
AS OF 9-24-80
(-) AWAY FROM FILL
BOTTOM OF WALL*
TOP OF WALL
* BOTTOM OF WALL SHOTS ARE 5'± ABOVE GROUND
F
11/80

DEPARTMENT OF TRANSPORTATION IOWA

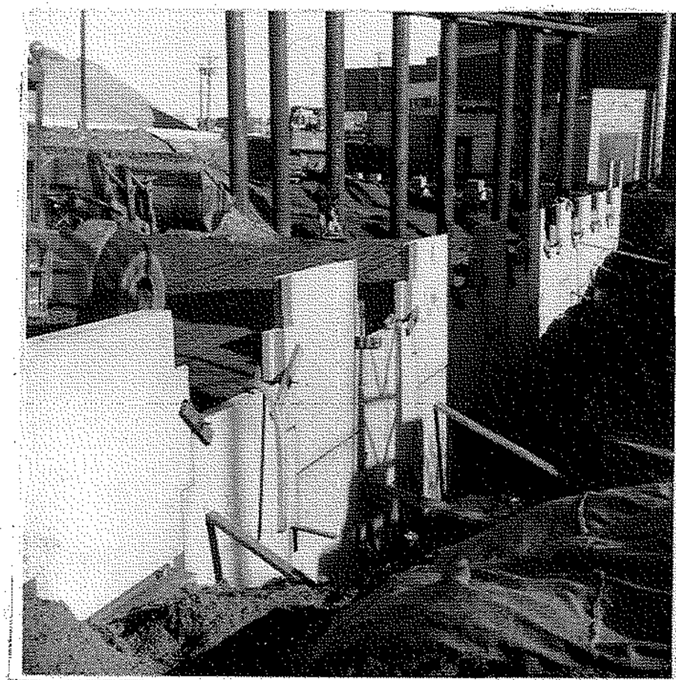
HIGHWAY DIVISION



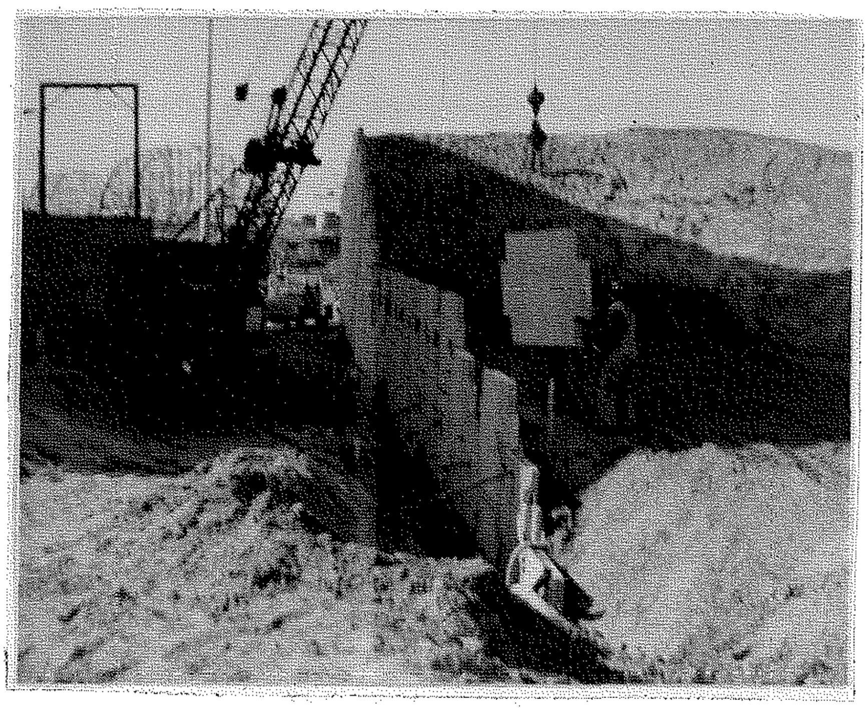
STABILITY ANALYSIS
STA. 115+00

APPENDIX D

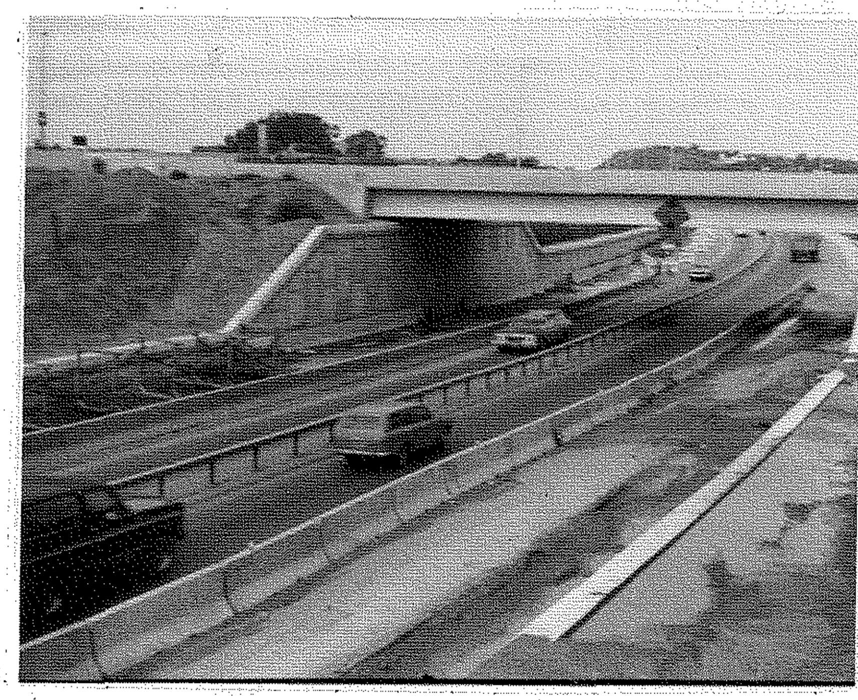
Construction Photos



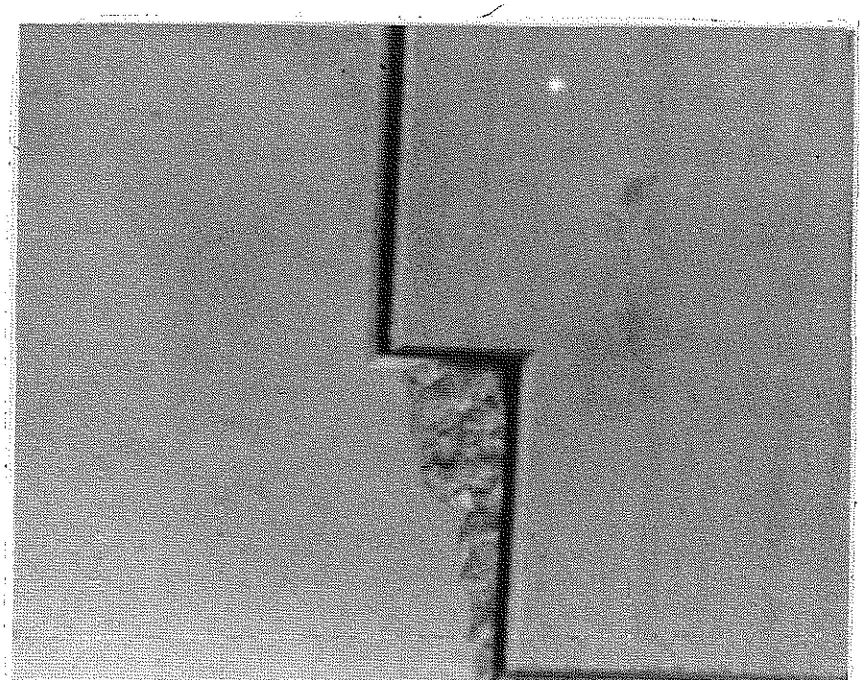
Beginning of construction-Reinforced Earth Wall No. 4
Pile covering can be seen (Page 4)



Reinforced Earth Wall No. 4
Additional Staging (Page 4)

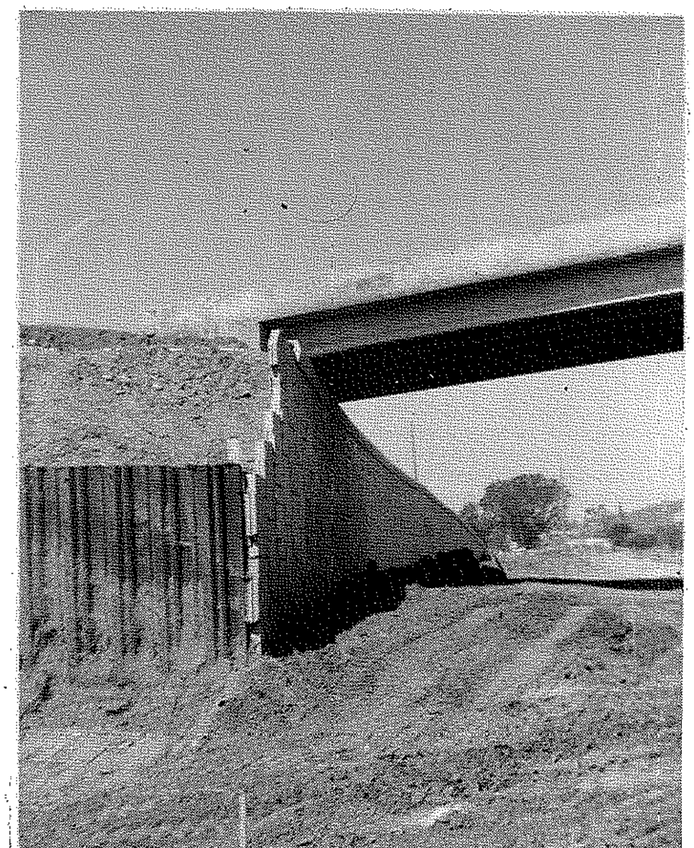


Completed Reinforced Earth Wall No. 1
(Top of Wall 2 is in foreground)

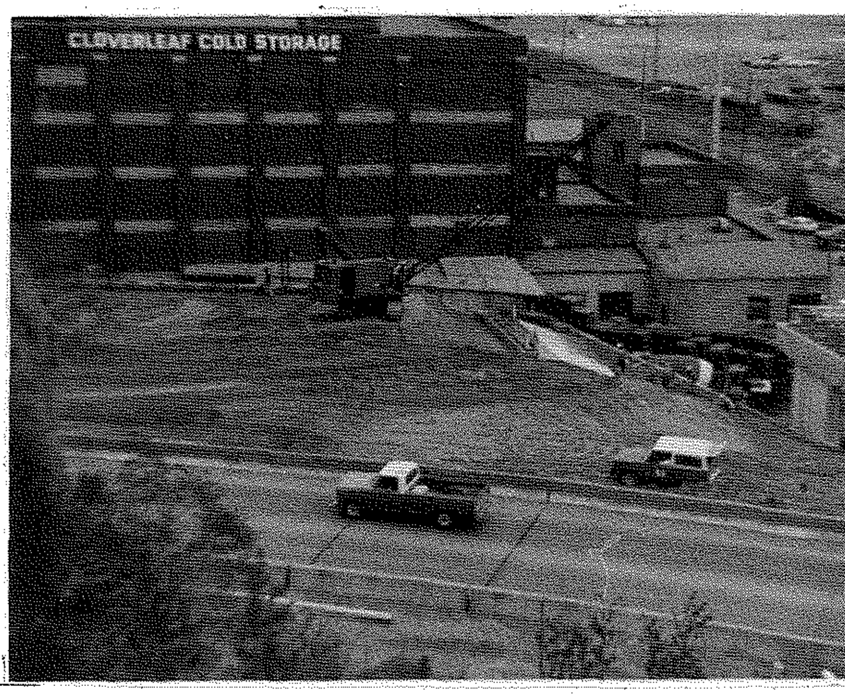


Chipped Reinforced Earth Wall Panel (Typical)
(Page 4)

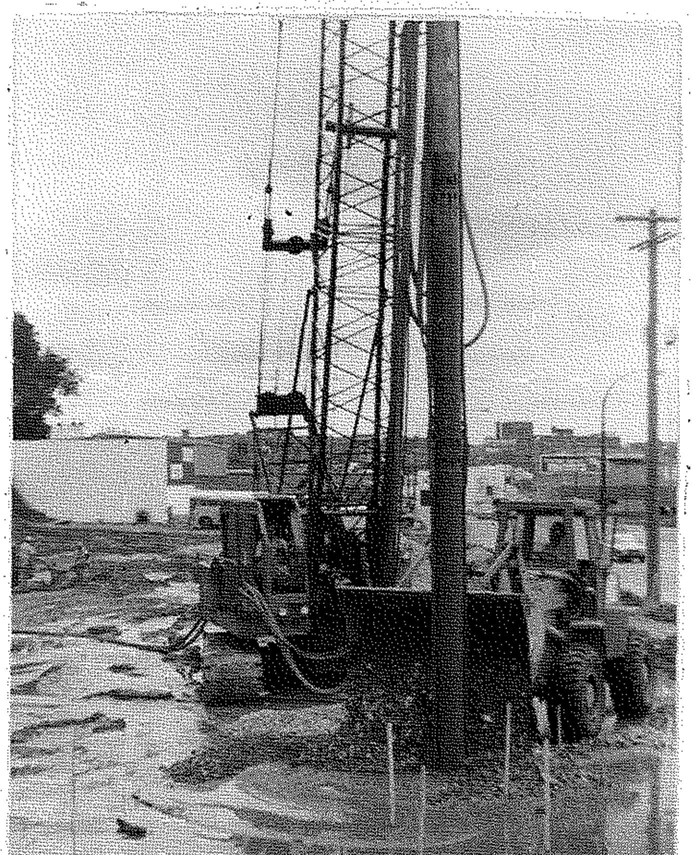
Wall distortion-Reinforced Earth Wall No. 3
West End (Page 4 and 5)



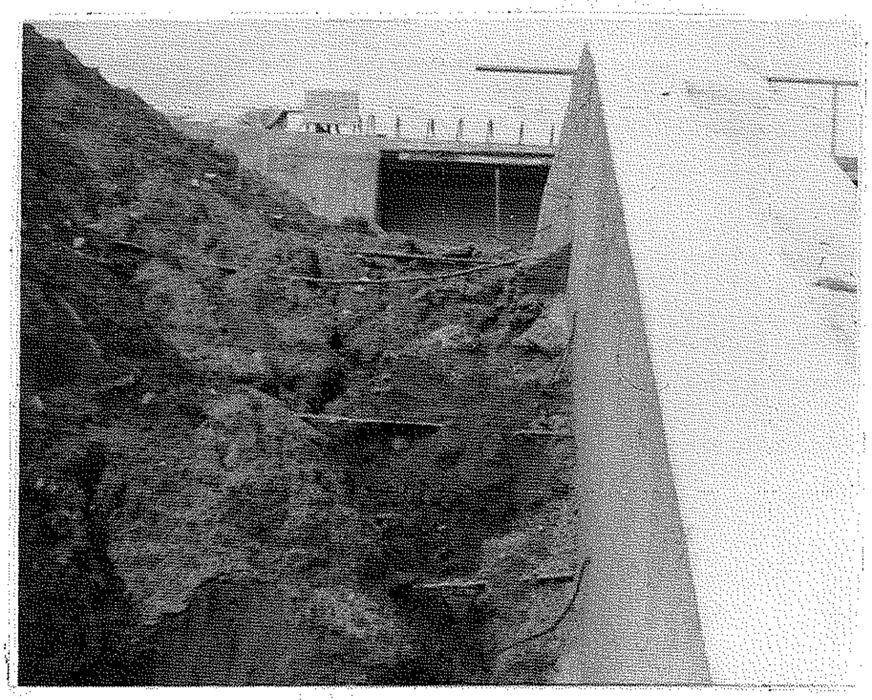
Stage Construction-Reinforced Earth Wall No. 3



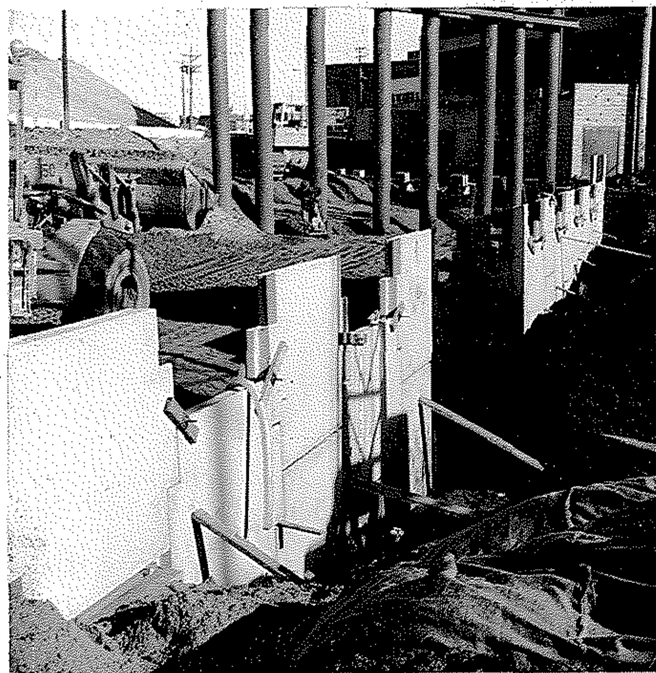
Site Condition showing restricted Right of Way
and adjacent structure



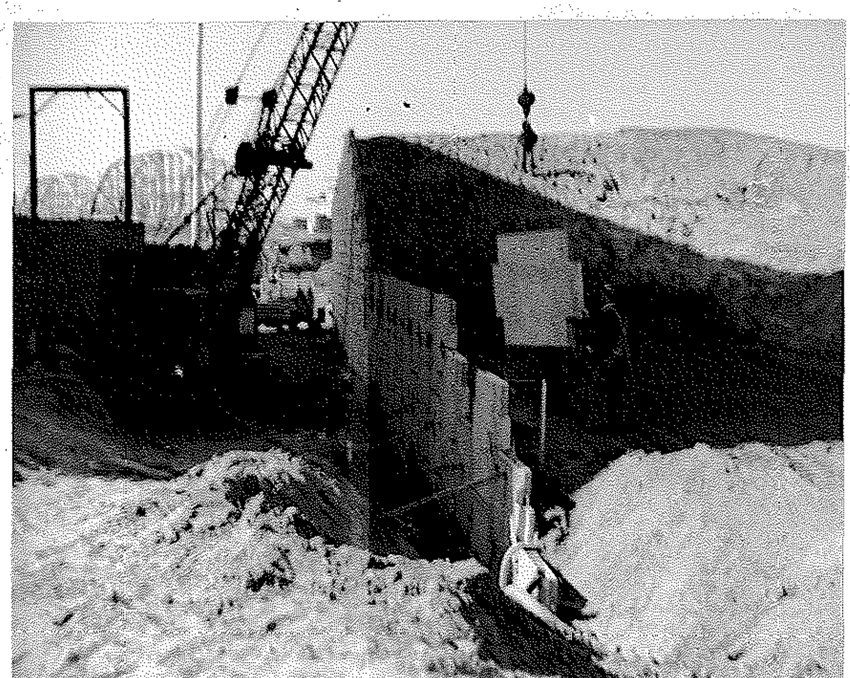
Stone Column Installation



Reinforced Earth Wall No. 3
Strip Exposure from Erosion
between Stages of Construction

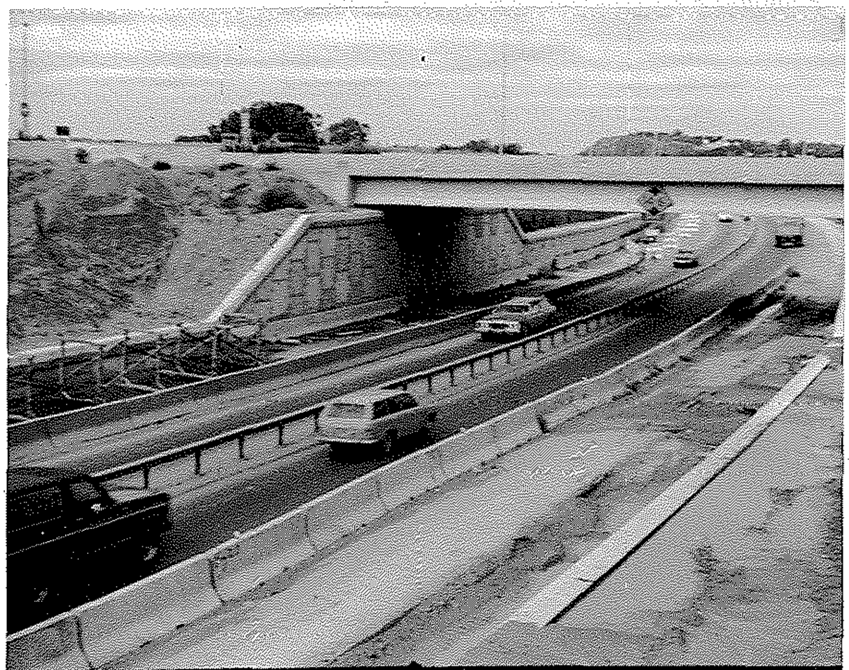


Beginning of construction-Reinforced Earth Wall No.4
Pile covering can be seen (Page 4)

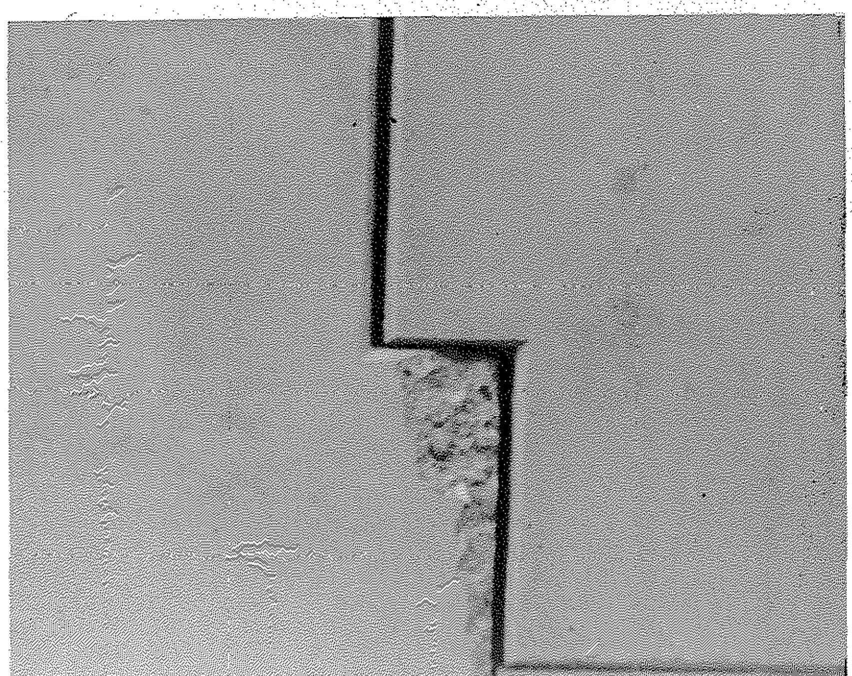


Reinforced Earth Wall No. 4
Additional Staging (Page 4)

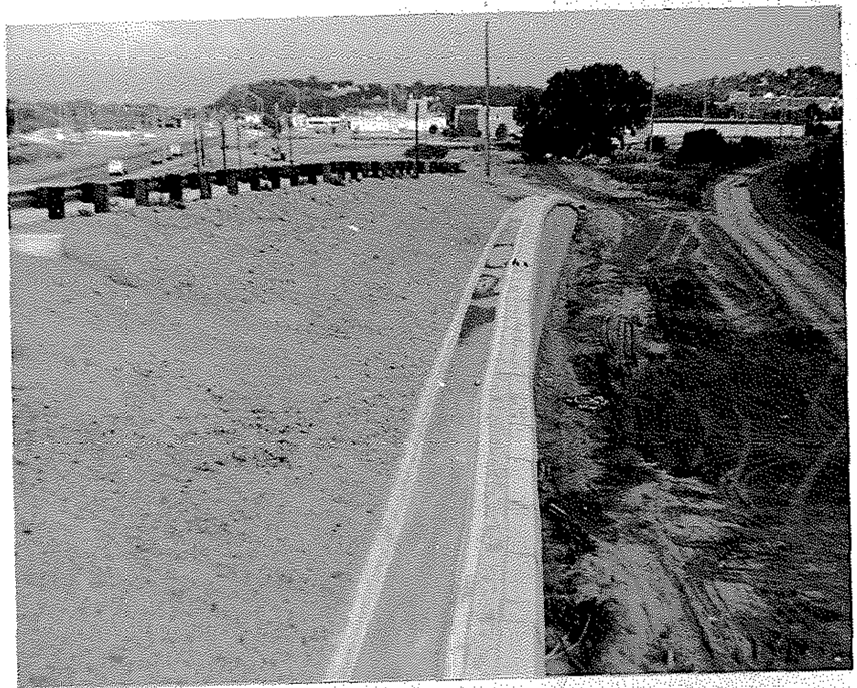
2



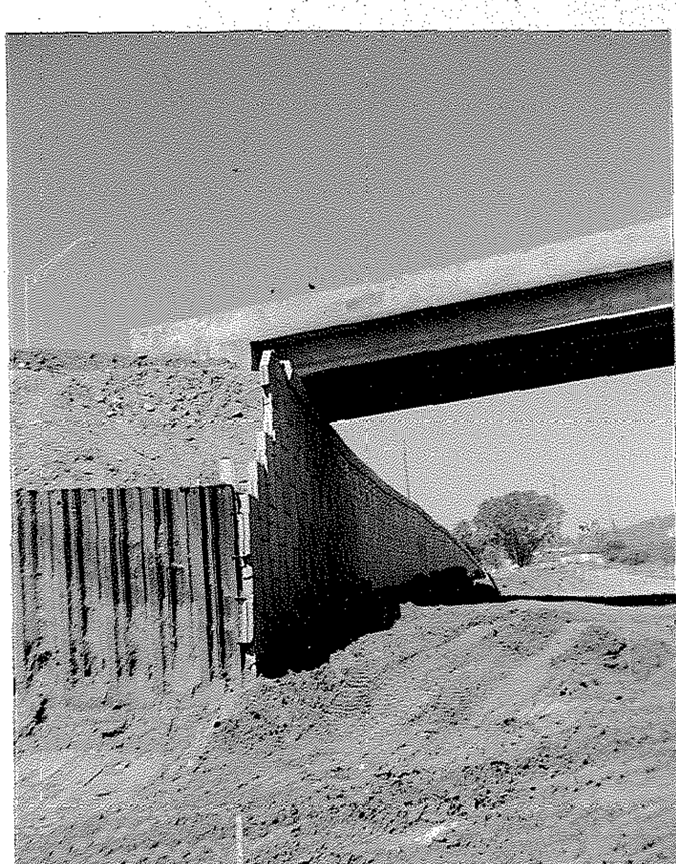
Completed Reinforced Earth Wall No. 1
(Top of Wall 2 is in foreground)



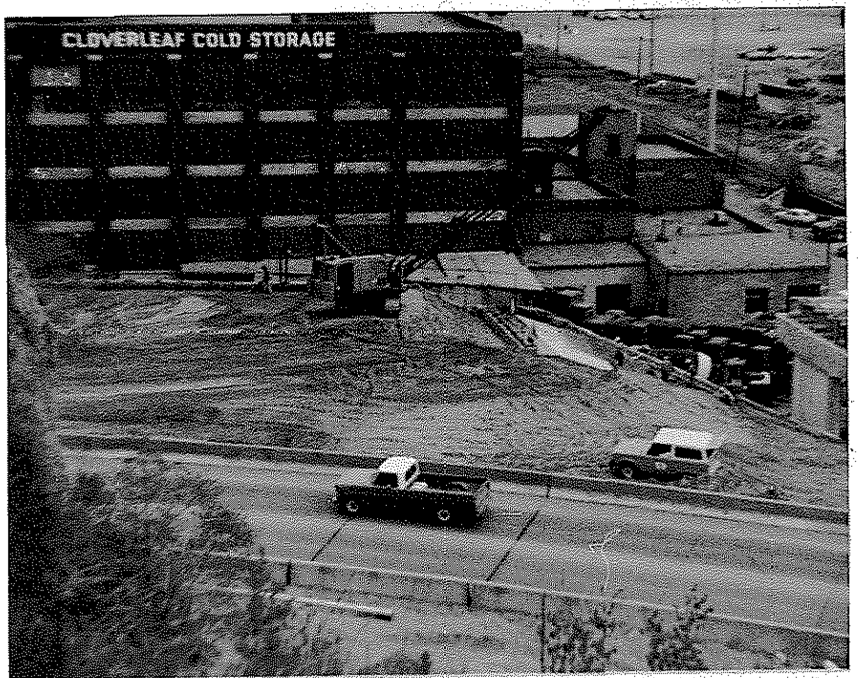
Chipped Reinforced Earth Wall Panel (Typical)
(Page 4)



Wall distortion-Reinforced Earth Wall No. 3
West End (Page 4 and 5)



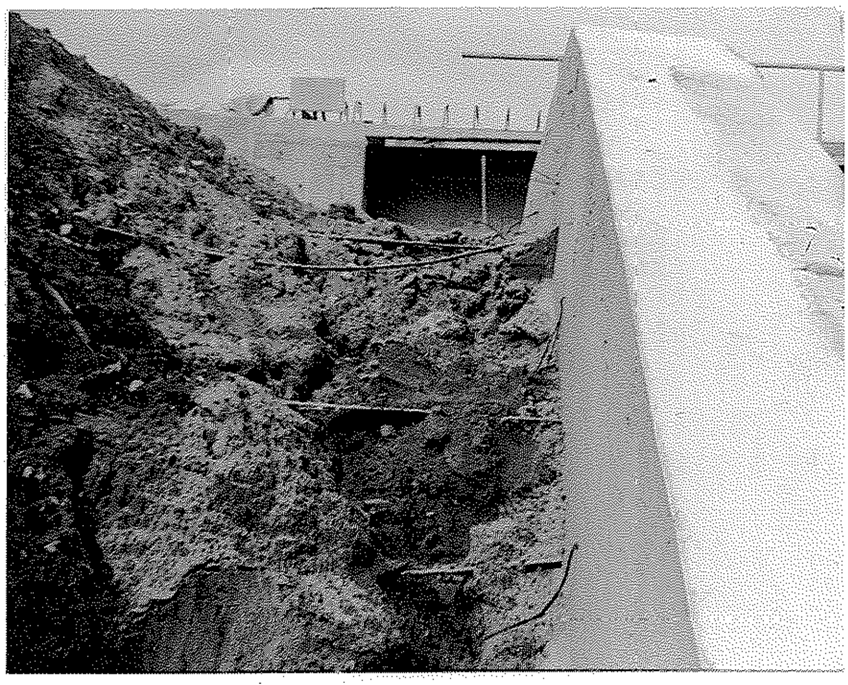
Stage Construction-Reinforced Earth Wall No. 3



Site Condition showing restricted Right of Way
and adjacent structure

Stone Column Installation

5



Reinforced Earth Wall No. 3
Strip Exposure from Erosion
between Stages of Construction