EVALUATION OF A CLAM SHELL EMBANKMENT BRIDGING MARSHLAND SOIL

FINAL REPORT

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IMPLEMENTATION STATEMENT

Consideration should be given to construction of a clam shell embankment to bridge marshland soils such as those encountered on the experimental project. This method of construction requires no muck excavation, no side berms, and no surcharge. However, a clam shell embankment should be built to a minimum height of five feet above the marsh surface in one lift and maintained at plan elevation and crown width as construction proceeds. Continuity of placement is critical.

The Louisiana Department of Highways has awarded contracts for construction of two shell bridge approaches and one shell embankment. The design of the embankment requires 426, 418 cubic yards of clam shell to be placed in the heart of Louisiana's mucklands (State Project Number 700-06-83, Relocation of Route U. S. 90 between Raceland and Gibson). The designs of these bridge approaches and this embankment were very much influenced by findings from the clam shell test embankment.

Louisiana State University's Division of Engineering Research has initiated a two-year study to analyze the stability of the clam shell embankment - marshland soil system proposed for State Project Number 700-06-83. A field instrumentation phase of the work plan requires installation of piezometers, total stress cells, and slope indicator casing in the soft soil to monitor pore pressures, stresses, and displacements, respectively, therein. A laboratory soils testing phase will determine properties of the organic soils before and after loading by the shell embankment. A numerical analysis phase will apply data from the field instrumentation and laboratory soils testing phases in order to verify the output (stresses, displacements, and pore pressures) of the soft soils computer program SSOILS. This new study holds promise of richly enhancing our state of knowledge concerning the performance of a clam shell embankment - marshland soil system.

SYNOPSIS

Abstract

The Louisiana highway network extends southward to the Gulf Coast where it serves a populace which is rapidly expanding as oil companies increase their activities in the area. The swamplands and marshlands which comprise much of south Louisiana represent construction problems which are perhaps best appreciated by the highway engineer. The root of these problems is the soft compressible organic deposits which lie beneath the swamp grass and, oftentimes, the swamp water. These subgrade conditions deprive the highway engineer of a foundation for his roads.

Economics has forced the Louisiana Department of Highways to consider the merits of "floating" an embankment of shell upon these mucklands. Engineering curiosity provided additional impetus for the initiation of a research project to determine the feasibility of constructing a clam shell test embankment directly upon marshland and to evaluate the facility so constructed. This report relates the findings of such a project.

Conclusions

I. It is physically feasible to construct a clam shell embankment directly upon in-situ marshland without muck excavation or other subgrade preparation. The following steps will help ensure the success of this type construction:

A. The clam shell embankment should be built to a minimum height of five feet above the marsh surface in one lift.

B. The shell should be initially dumped at the centerline of the embankment and worked forward and outward with bulldozer-type equipment. The nose of the construction zone should be built on a 45 degree angle with respect to the embankment centerline. This process is geared to avoid the formation of mudwaves.

C. Full embankment height and crown width should be maintained as construction proceeds. Continuity of construction is critical.

D. If a median ditch is required, it should be constructed by the excavation of shell at the tail end of the construction zone.

E. Loaded trucks should use each half of the embankment alternately so that each half receives uniform compaction under construction traffic.

F. Density control should not be required. However, the top six inches (150 mm) of the surface should be uniformly compacted by 12 passes of a sheepsfoot roller.

G. The method of payment for the shell should be by truck measurement.

II. It is economically feasible to construct a shell embankment over marshland soil. The cost of a shell embankment falls far below the cost of a hydraulically placed sand fill in marsh areas. In comparing costs of these two types of embankments, savings of 50 to 75 percent can be achieved through application of the shell embankment concept.

III. A properly constructed embankment of clam shell will perform as an integral unit under the forces of its own dead load and the vibration effects of simulated truck traffic. Such a structure should be capable of supporting allowable traffic loads.

IV. The apparent compaction factor of a clam shell embankment of an approximate 5.0 (1.5 m) foot height above existing ground level is 1.45.

V. Observation of the experimental shell embankment indicates that the major subsidence of this type embankment would occur during the first four to six months from the time of general construction of the fill to reasonable grade.

VI. A computer program has been developed by others which will predict the approximate subsidence of a shell embankment bridging marshland soil.

Recommendations

I. Consideration should be given to construction of a clam shell embankment to bridge marshland soils such as those encountered on the experimental project.

II. Additional research is recommended wherein a stability analysis of a shell embankment-marshland soil system would be effected. A full-scale heavily-instrumented test section would appear to be the best means of accomplishing such an analysis.*

III. Research should be undertaken to investigate the merits of constructing an embankment of reef shell. This is an aggregate of much larger particle size than clam shell. Extending acceptance of the shell embankment concept to reef shell could immediately reduce the cost of proposed highway construction over the state's mucklands.

* Since the original draft of this report was written, Louisiana State University's Division of Engineering Research has initiated a research project designed to effect a stability analysis of the clam shell embankment proposed for construction on State Project Number 700-06-83, Relocation of Route U. S. 90 (Raceland-Gibson Highway).

INTRODUCTION

A significant portion of south Louisiana is overlain by saturated organic mixtures which reflect the geologic history of the area. For example, in the Pontchartrain Basin of southeast Louisiana, geologic events over the past 35,000 years have resulted in land subsidence, sediment deprivation, and extensive vegetative decay. This process produced the mat of organic deposits found in the swamplands and marshlands of that area. Wet mucklands such as these stretch across Louisiana's Gulf Coast and have become the trademark of the state.

However, scenic as it may be, the terrain just described presents major problems to the highway engineer who must provide lines of communications for the rapidly expanding populace of south Louisiana. Bridges have proven to be effective but expensive means of crossing the marshes and swamps. Excavation-backfill operations have been costly and, although generally successful, have produced localized problems (1)*. Chemical stabilization has not yet been effectively extended to soft organic material. Hence, it appears that new methods of constructing highways across the state's mucklands should be considered.

This report discusses a research project to evaluate the concept of constructing an embankment by end-dumping clam shell directly on marshland soil without muck excavation or any other subgrade preparation.

* Underlined numbers in parenthesis refer to "Cited References."

SCOPE

The scope of the study is as follows:

I. To establish the feasibility of constructing a shell embankment directly upon in-situ marshland without muck excavation or other subgrade preparation.

II. To determine the structural support which such an embankment would afford to traffic.

III. To determine the subsidence characteristics of the clam shell embankment and of the underlying marshland soil.

IV. To study the results of previous research as applied to the construction of a shell aggregate fill placed directly upon the surface of in-place marshland material.

V. To assist in the decision of the type of construction to be used on State Project Number 700-06-83, Raceland-Gibson Highway.

METHOD OF PROCEDURE

Selection of Test Site

Design and research personnel of the Department decided to build the test embankment along the proposed corridor for the relocation of Route U.S. 90 between Raceland and Gibson in the extreme part of south Louisiana. Two and one-half feet (0.8 m) of organic material overlies more than 50 feet (15 m) of very soft organic clays in this area. Three and one-half foot high (1 m) swamp grass disguise these mucklands. The fact that these terrain conditions typify the marshlands of south Louisiana was a major reason for selection of a test site therein. The site was located close to the existing Route U.S. 90 for ease of accessiblity.

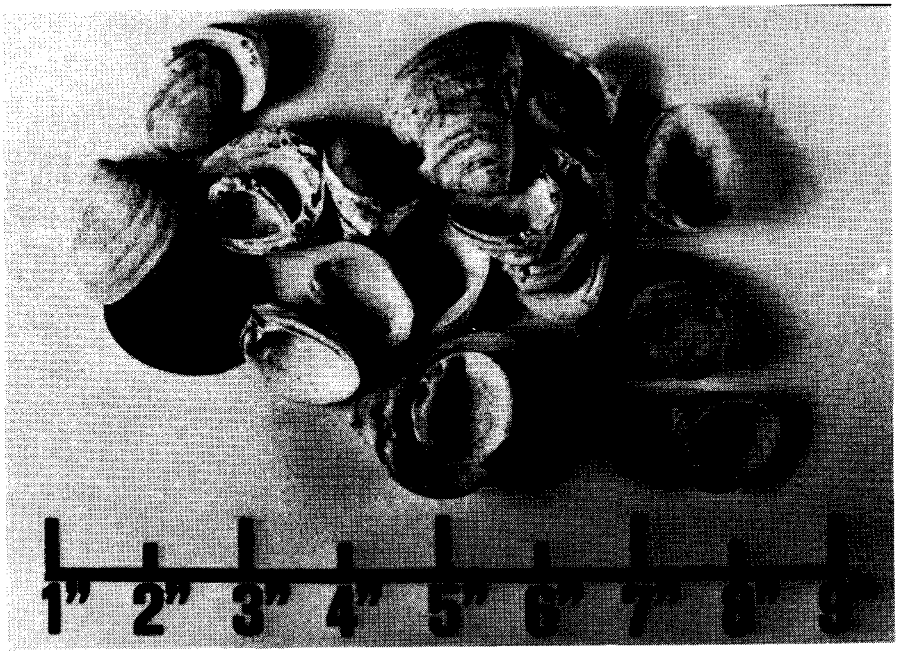
Securing Clam Shell

Member firms of the Louisiana Shell Producers Association acquired clam shell from beds in the New Orleans area and transported it by barge along bayous to Raceland. From stockpiles at that point, trucks hauled the shell the few miles to the test site. Figure 1 shows a close-up view of typical clam shell, varying in size from 1/4 inch (6.4 mm) to 1 1/2 inches (3.8 mm) in diameter.

Construction of the Haul Road

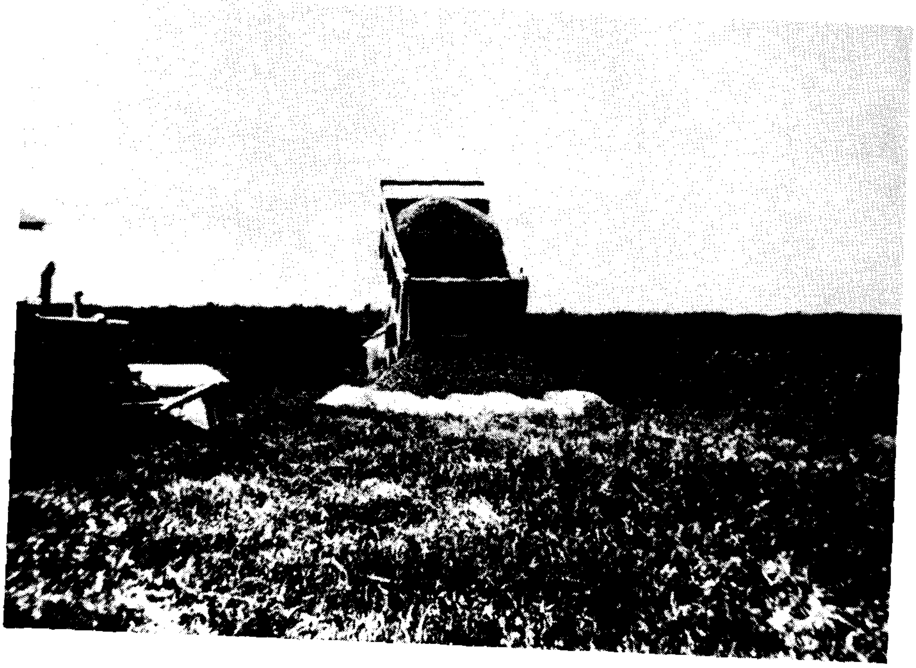
Haul trucks could cross only a portion of the terrain from the existing Route U. S. 90 to the test site before encountering soft soil conditions. At that point an organic mat at the surface exhibited a crusty appearance due to drying; however, immediately beneath that was the wet, soft organic clay which would not support traffic (see Figure 2). Hence, trucks transported shell to the outer limits of the stable area and began end-dumping at that point (Figure 3) to establish a haul road.

The trucks and a bulldozer engaged in somewhat of a leapfrog operation, dumping and spreading just enough shell to enable passage of a single truck. This process produced a haul road of about two and one-half to three foot (0.9 m) depth.



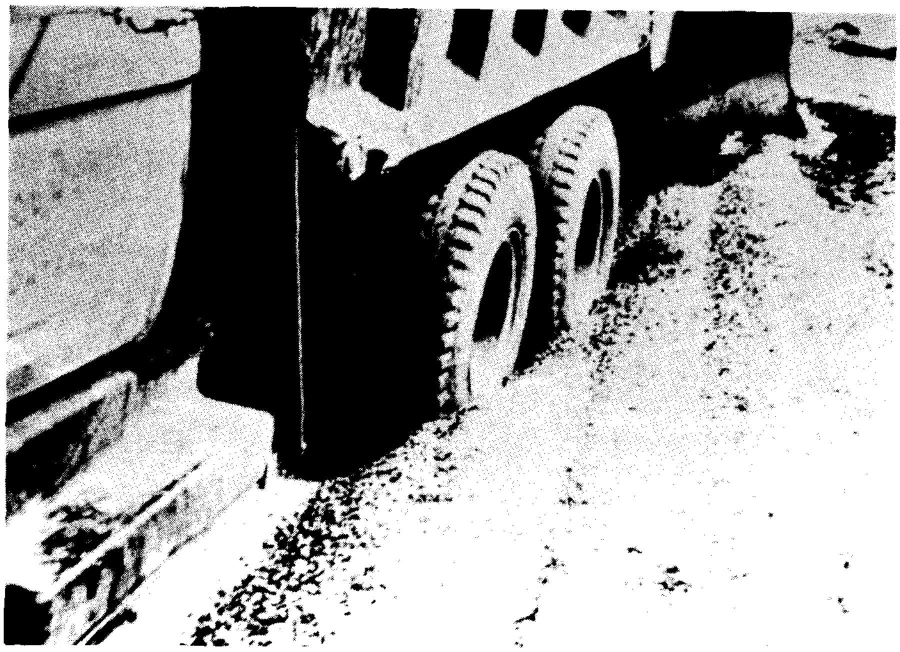
Close-up View of Clam Shell
FIGURE 1

Moisture Conditions and Organic Soil at the Test Site
FIGURE 2



Initiating Construction of the Haul Road
FIGURE 3

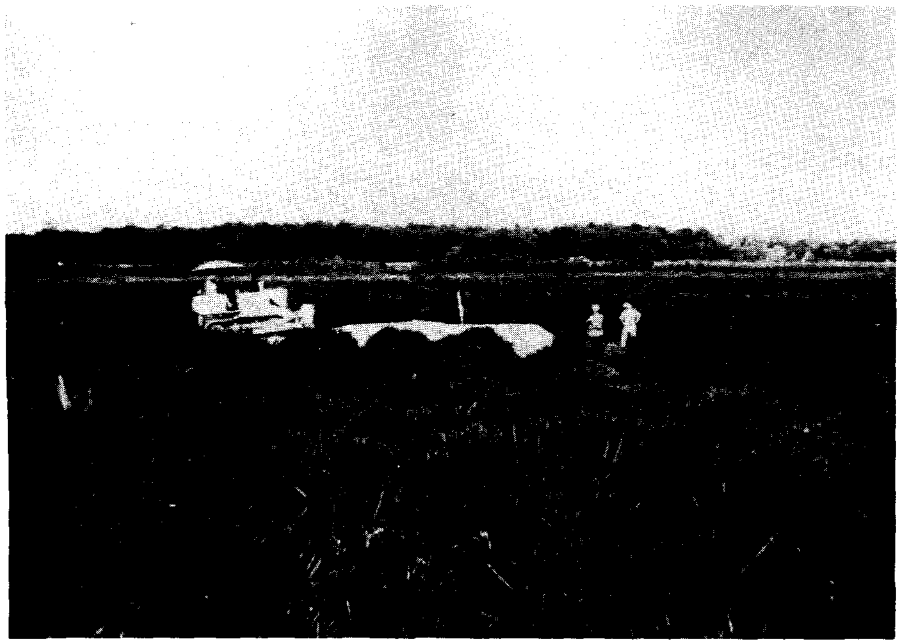
The road had to be beefed-up occasionally when the trucks penetrated the shell and brought organic material to the top (as in Figure 4).



Breaking Through the Haul Road
FIGURE 4

Constructing the Test Embankment

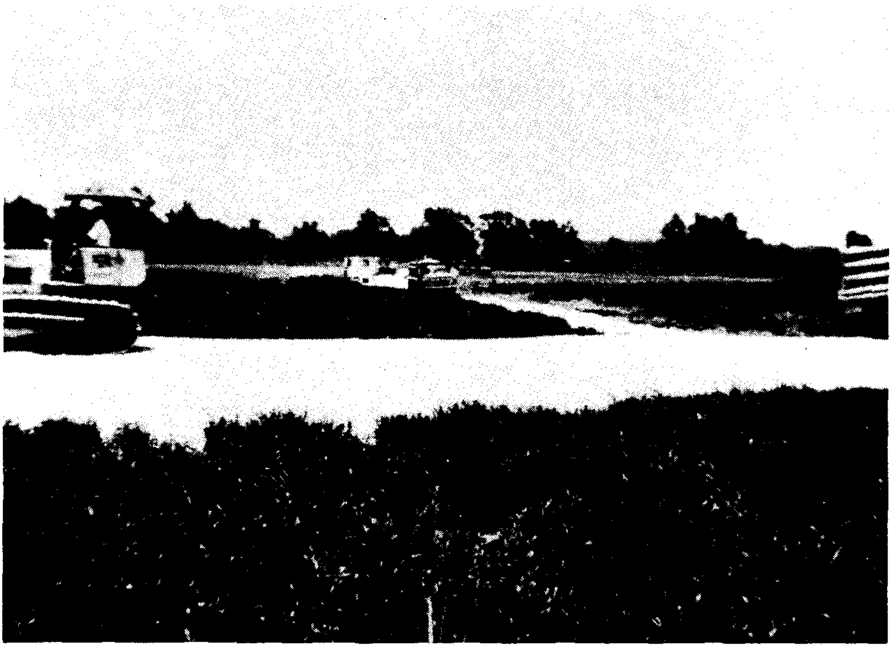
The haul road was built more or less perpendicular to the proposed test embankment. Hence, haul road construction was just continued across the width of the embankment as a starting point for construction. Figure 5 shows this continuation, with the white flag representing the centerline of the embankment. From that point, construction turned in the direction of the test facility along the right of way of State Project 700-06-83.



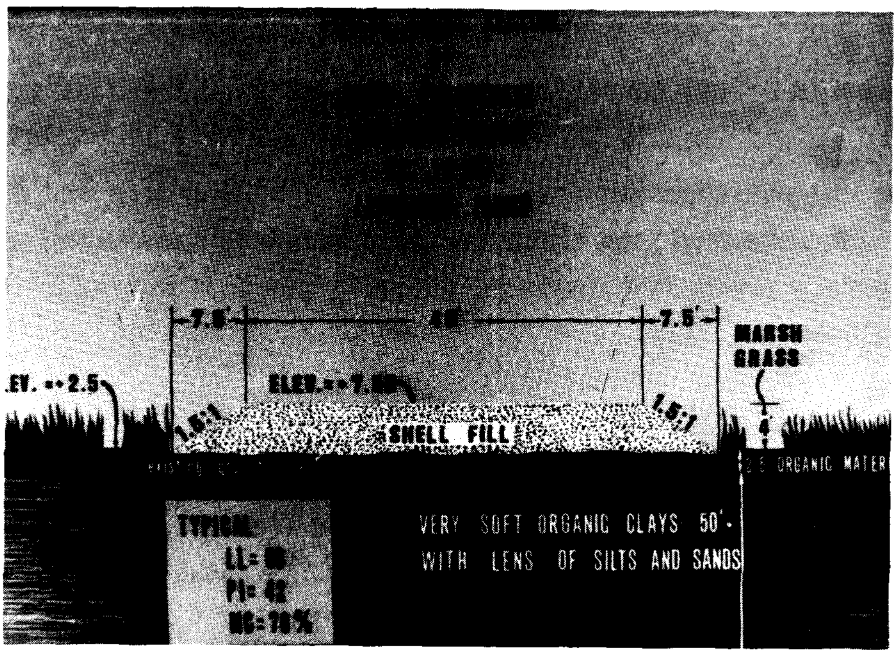
Continuation of the Haul Road Across the Width of the Test Embankment
FIGURE 5

Figure 6 shows the construction train comprised of haul trucks and bulldozer. The trucks dumped adequate shell to establish plan elevation and crown width (as shown in Figure 7) before proceeding in order to avoid the failures experienced on the relatively shallow haul road.

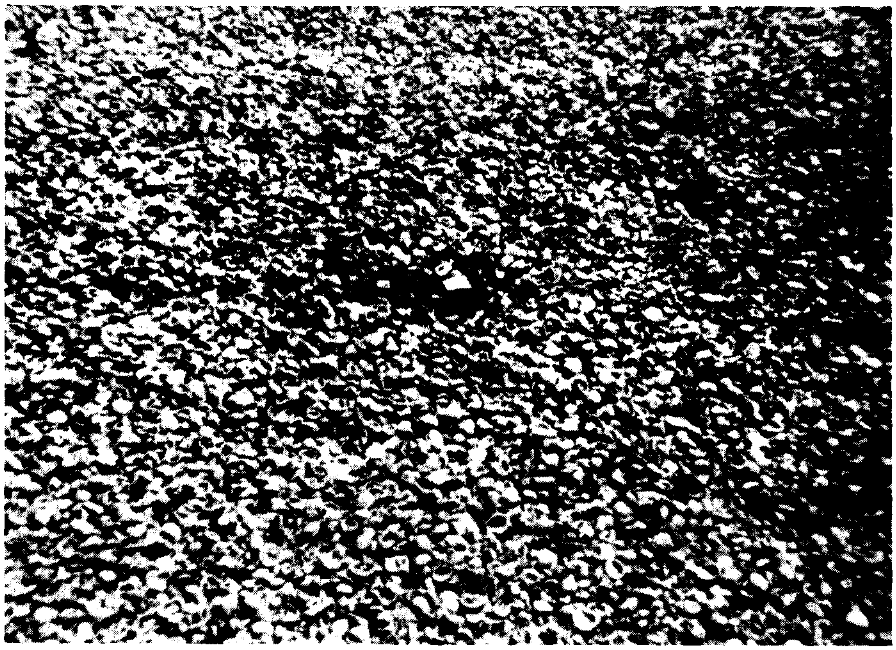
Research and design personnel supervised the construction, taking elevations to control the height of the embankment. Level readings were referenced with respect to a benchmark on a tree located in a more stable area about one-half mile (0.8 km) from the site. Hubs were placed flush with the finished surface to facilitate acquiring the as-constructed elevations (see Figure 8).



The Construction Train
FIGURE 6



Typical Section of the Raceland-Gibson Test Embankment
FIGURE 7



Hub Placed in the Shell Embankment for As-Constructed Elevation
FIGURE 8

A layout of the haul road and test embankment is presented at this point (Figure 9) for future reference.

Construction-Related Operations

Department personnel placed four-foot (1.2 m) square aluminum settlement plates along the natural ground of the test site before placing the shell (see Figure 10). These plates were placed at the centerline and at points 20 feet (6 m) left and 20 feet (6 m) right of the centerline at three stations along the 340-foot (104 m) long embankment. Research personnel periodically measured the thickness of the embankment by means of these settlement plates.

As an additional operation, a D-6 caterpillar tractor (bulldozer) made 2000 passes over the embankment to simulate the effects of live traffic loads. This bulldozer weighed approximately 29,000 pounds (13,000 kg) and had track dimensions of 1.6 feet (0.5 m) by 8.0 feet (2.4 m). The remote location and short length of the test section had precluded application of actual traffic loads for evaluation purposes.

Layout of Test Section and Haul Road

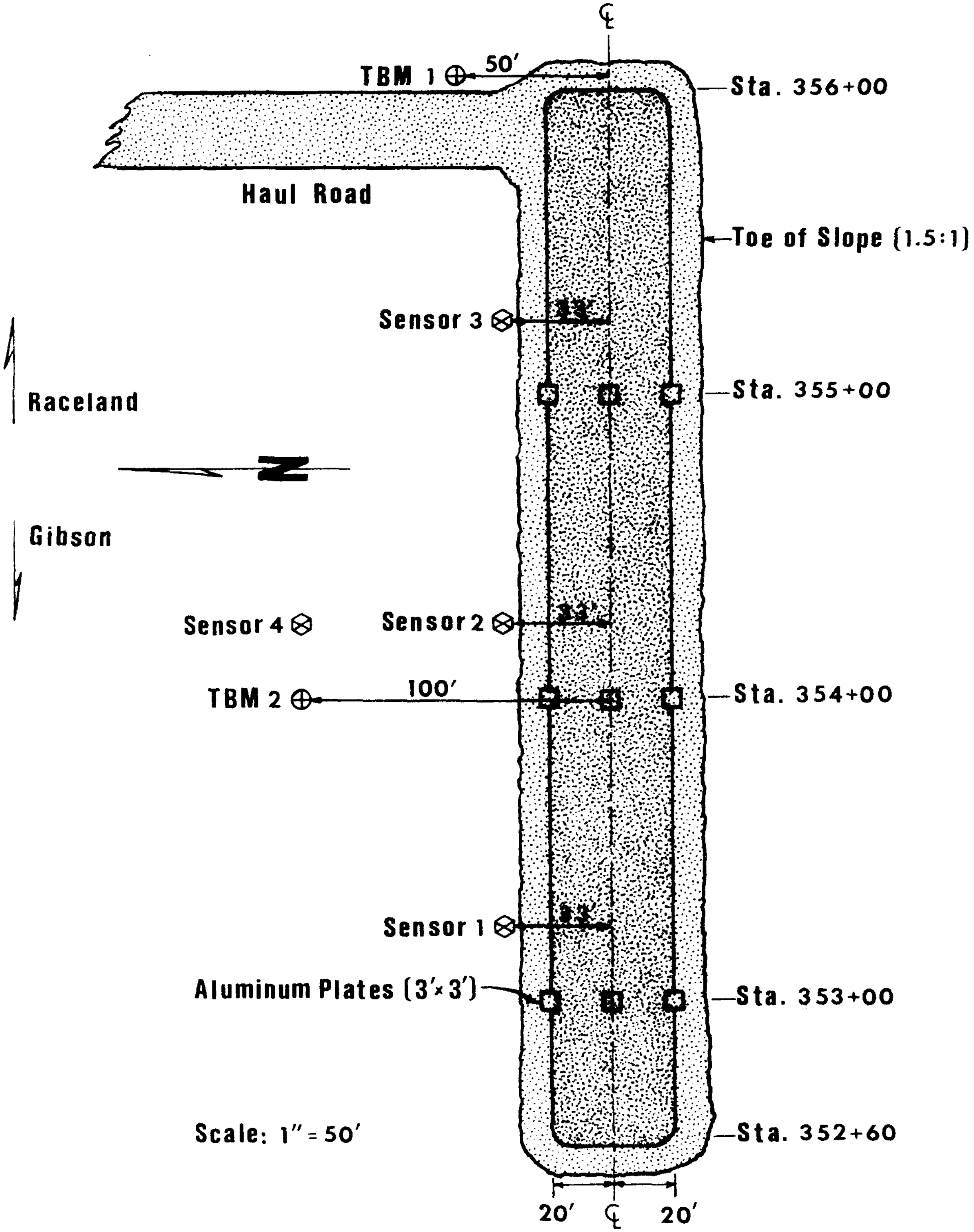


Figure 9

Settlement Plates
FIGURE 10

Sampling and Measurements Program

The following activities comprised this program:

1. Acquisition of elevations before, during, and after construction of the embankment.

2. Acquisition of nuclear moisture-density measurements periodically at depths of six inches (0.15 m), twelve inches (0.3 m), twenty-four inches (0.6 m), thirty-six inches (0.9 m), and forty-eight inches (1.2 m) beneath the surface of the embankment.

3. Acquisition of embankment thickness measurements by drilling to the settlement plates at the base of the facility.

4. Measurement of the magnitude of vibrations induced by the D-6 bulldozer by means of seismic sensors and accompanying visicorder.

5. Pre-construction coring of the in-place marshland soil at the centerline and at 20 (6 m) and 25 feet (7.4 m) offset from the centerline to depths of 36 feet (11 m) for plain-strain chamber testing.

DISCUSSION OF RESULTS

Feasibility of Construction

This research proved that it is feasible to construct a shell embankment directly upon in-situ marshland without muck excavation or other subgrade preparation. The test embankment was successfully built of 100 percent clam shell, being built to a minimum five foot (1.5 m) elevation above the marsh surface in one lift. Plan elevation and crown width were maintained as construction progressed from one station to the next. This is a recommended procedure for construction, as a thinner lift may not bridge the soft underlying material sufficiently to support the loads imposed during construction and by in-service traffic. This point was illustrated when loaded trucks broke through the haul road constructed of clam shell which had been placed in a single two and one-half foot lift.

Compaction Achieved

During construction of the embankment, no attempt was made to prescribe and control compaction of the shell. However, nuclear moisture-density measurements were taken after construction to determine the degree of compaction achieved.

Density tests were conducted with a Troxler Model 2401 nuclear device in the top foot of the embankment one week after construction. This was to ascertain the density achieved as a result of haul trucks and a caterpillar tractor traversing the fill during the spreading and leveling operations. A wide range of dry unit weights from 87.25 (1402 kg/m^3) to 102.75 pounds per cubic foot (p.c.f.) (1646 kg/m^3) was obtained, with the average being 94.9 pounds per cubic foot (1520 kg/m^3) (see Table 1). This 15.5 pounds per cubic foot (248 kg/m^3) range reflects the greater compaction at the haul road end (which experienced the greater amount of construction traffic) than at the remote end of the embankment. Consideration should be given to requiring the use of an approved sheepsfoot roller pulled by a crawler tractor in order to assure uniform densification of the top foot of a shell embankment.

Surface nuclear-density readings after 1000 passages and after 1700 passages of a D-6 bulldozer are also presented in Table 1. The vibrations so induced increased the average density at the three stations evaluated from 94.9 p.c.f. (1520 kg/m^3)

TABLE 1

NUCLEAR DRY WEIGHT DENSITY VALUES AT SURFACE OF SHELL EMBANKMENT, POUND PER CUBIC FOOT

Time After Construction, Months	Station	10 Feet Left of Centerline	At Centerline	10 Feet Right of Centerline
	354+90 (near haul road)			
0.25*		98.75	102.75	97.25
3.25**		101.50	105.00	98.75
4.0***		102.25	106.50	99.75
	353+90			
0.25*		101.00	97.00	87.50
3.25**		102.00	95.30	96.75
4.0***		97.50	98.75	104.75
	352+90 (remote from haul road)			
0.25*		90.25	87.25	92.25
3.25**		96.55	94.75	101.00
4.0***		94.25	99.00	98.00

* Prior to application of vibratory load by a moving caterpillar tractor (i.e., as constructed).

** After 1000 passes by a D-6 caterpillar tractor.

*** After a total of 1700 passes by a D-6 caterpillar tractor.

(as-constructed) to 99.1 (1587 kg/m^3) and 100.1 p.c.f. (1603 kg/m^3) after 1000 and 1700 passes of the bulldozer, respectively. Hence, significantly large vibrations did not shake the clam shell embankment apart; on the contrary, it tightened up at least that top one foot which was evaluated before and after vibration.

At 11 weeks after construction (prior to the vibratory loading by the D-6 bulldozer), nuclear-density measurements were taken at randomly selected sites to depths of four feet (1.2 m) below the surface of the shell embankment. Through much effort, research personnel manually excavated five (5) holes with dimensions four feet (1.2 m) by three feet (0.9 m) by four feet (1.2 m) deep. Density readings were taken at each foot (0.3 m) of depth. The average density results (shown in Table 2) were 100.7 p.c.f. (1613 kg/m^3) for the first foot, 87.5 p.c.f. (1402 kg/m^3) for the second foot, 75.0 p.c.f. (1201 kg/m^3) for the third foot, and 68.2 p.c.f. (1092 kg/m^3) for the fourth foot from the surface. The dry unit weight of the clam shell (as determined in the laboratory by L.D.H. TR 417) was only 63.7 p.c.f. (1020 kg/m^3). Hence, the clam shell was knit very tightly in that top four feet which the researchers investigated in detail.

Structural Support for Traffic

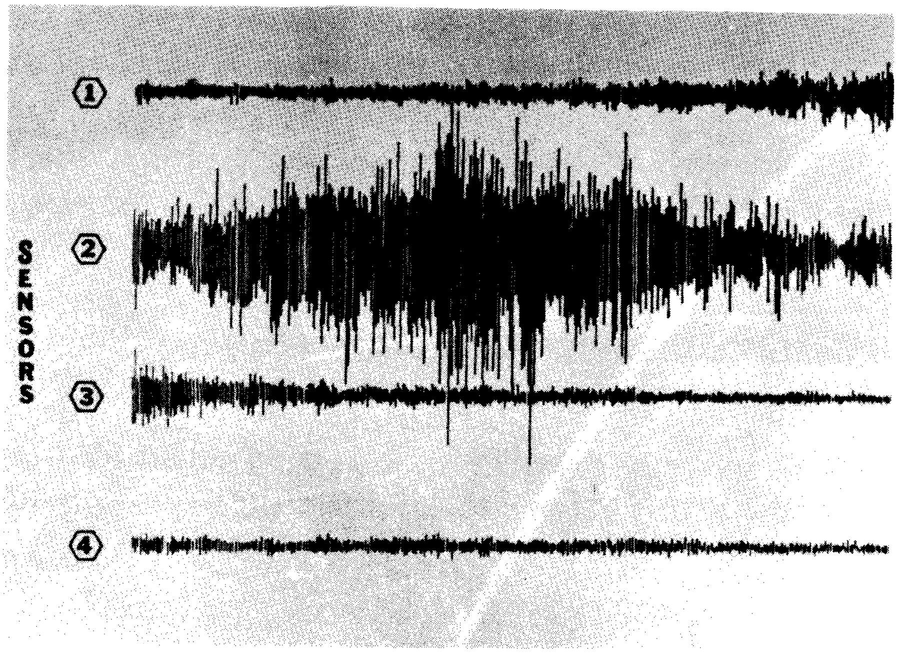
The clam shell test embankment proved to be a very sound structure capable of supporting loads which traffic might impose. The remote location and short length of the test section precluded the application of live truck loads and evaluation of the effect of the accompanying vibrations. This effect was simulated by repeatedly passing a caterpillar tractor (D-6 bulldozer) over the section and carefully inspecting the embankment for deterioration.

The magnitude of the vibrations induced by the tractor was measured by a system of seismic sensors and a visicorder. The sensors were installed in the natural ground adjacent to the embankment as depicted previously in Figure 9. The visicorder printout depicted graphically the vibrations transmitted through the embankment to the natural ground. A typical visicorder printout is displayed in Figure 11. In this figure, the trace with the greatest amplitude reflects vibrations induced as the dozer was closest to sensor number 2.

TABLE 2

NUCLEAR DRY WEIGHT DENSITY VALUES WITH DEPTH IN SHELL EMBANKMENT, POUNDS PER CUBIC FOOT

Station	Transverse Location	Depth from Surface of Embankment 12"	24"	36"	48"
355+13	9 feet left of centerline	100.75	92.50	83.95	70.50
354+14	11 feet right of centerline	103.25	91.00	73.25	68.50
353+84	5 feet left of centerline	102.25	87.00	70.50	67.25
353+38	7 feet right of centerline	96.63	79.25	72.00	68.00
	AVERAGE	100.70	87.5	75.00	68.20



Visicorder Printout for Vibrations
FIGURE 11

For comparison purposes highway research personnel measured vibrations induced by heavy truck traffic at a site on existing Route U.S. 90 between Raceland and Houma where similar marsh deposits underlie the road. For a similar frequency range, the vibrations produced by the caterpillar tractor were on the order of ten times the magnitude of those produced by the heavy truck traffic and (because of the slower speed) were of longer duration as well.

After 2000 passes of the caterpillar tractor, no appreciable change in the integrity of the shell embankment was observed.

Subsidence Characteristics

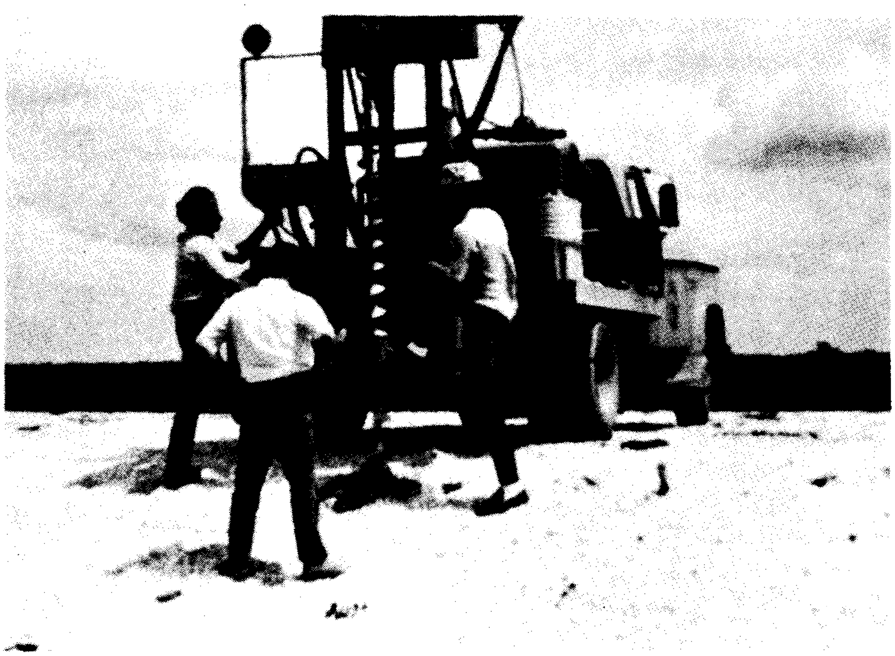
CONSTRUCTION SUBSIDENCE OF THE EMBANKMENT-MARSHLAND SYSTEM

During construction, the shell aggregate is simultaneously consolidating within itself and intruding into the marshland. It appears that this construction subsidence can be compensated for by proper design.

Comparison of truck hauled quantities and of resulting thicknesses on the center 200 feet (61 m) of the test section indicates that a factor of 1.4 could be applied in computing the volume of shell required to construct such an embankment. A slightly higher factor of 1.5 would reflect all the shell hauled in to form the entire 340-foot (104 m) long experimental embankment. Hence, use of a compaction compensation factor of 1.45 could be recommended at this time. That is, 1.45 cubic yards (1.1 m) of shell could be placed for every cubic yard of shell required to establish the theoretical net design typical section above the original ground line.

POST-CONSTRUCTION CONSOLIDATION WITHIN THE SHELL EMBANKMENT

The depth of the embankment was monitored by periodically (on four occasions) measuring the depths to the nine settlement plates installed during construction of the facility. Figure 12 illustrates research and district laboratory personnel drilling to one of these plates in order to obtain the depth measurement.



Measurement of Embankment Height by Drilling to Settlement Plates
FIGURE 12

The data in Table 3 illustrate the consistency of the thickness of shell embankment with respect to time. This table includes the time span (three to four months after construction) during which 2000 passes of a D-6 bulldozer were applied.

A perhaps significant degree of densification (0.5 foot) (0.15 m) within the shell occurred at the centerline of station 353+00. That point received a significantly low degree of compaction during construction because of its remote location from the haul road.

All other variations in thickness of embankment with respect to time are considered minor. This opinion considers discrepancies possible when varying personnel made the somewhat awkward measurements of lengths of drill stems, and disturbance of the surface of the embankment by cattle which frequented the site.

In summary, the shell mass seems to be acting as a monolithic unit.

POST-CONSTRUCTION INTRUSION OF THE SHELL EMBANKMENT INTO THE MARSHLAND

At 1.25, 3.0, and 12.0 months after erecting the embankment, Department personnel took settlement plate measurements and cross-sectional elevations concurrently (i.e., within a week's period of time). This data coupled with the original ground elevation enabled those personnel to depict the configuration of the embankment with respect to original ground elevation. Figure 13 and Figures 25 and 26 in the Appendix present these cross-sectional views.

Cross-sectional elevations were taken quite often after construction of the embankment. These measurements revealed a significant (although not intolerable) drop in the surface of the facility. However, the periodic settlement plate measurements mentioned previously showed that the embankment was maintaining a constant thickness. Hence, the bulk of the subsidence was attributable to intrusion of the shell into the marshland. An examination of the subsidence of the surface of the embankment will thus reveal the major action of the embankment marshland subsidence.

Figure 14 and Figures 27, 28, 29, and 30 in the Appendix depict the cross- sectional settlements of the surface of the embankment over a year's time. The top line

TABLE 3

SHELL EMBANKMENT THICKNESS, FEET

Time After Construction, Months	Station	20 Feet Left of Centerline	At Centerline	20 Feet Right of Centerline
	353+00			
1.25		5.3	6.4	5.4
2.0		5.2	6.5	5.0
3.0		5.1	6.1	5.4
11.75		5.0	6.0	5.5
	354+00			
1.25		5.5	6.1	5.5
2.0		5.7	6.1	5.6
3.0		5.6	6.1	5.6
11.75		5.6	6.0	5.5
	355+00			
1.25		*	6.7	*
2.0		*	6.9	*
3.0		*	6.6	*
11.75		*	6.5	5.6

* Indicates settlement plates were not located due to lateral displacement during construction.

Configuration of Shell Embankment
Station 354+00

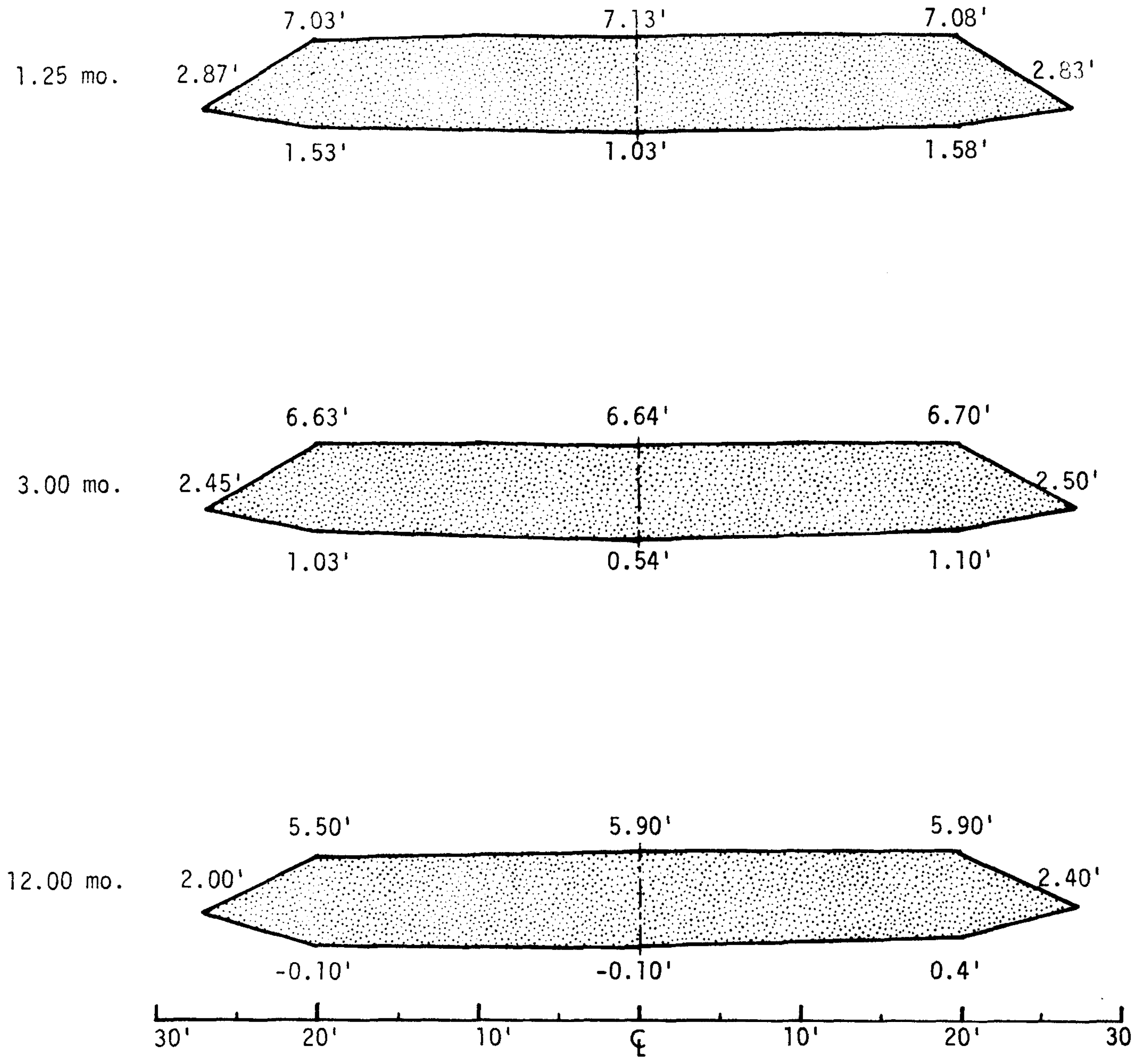


FIGURE 13

Initial Elevations and Subsequent Subsidence at Surface of Shell Embankment
Station 354+00

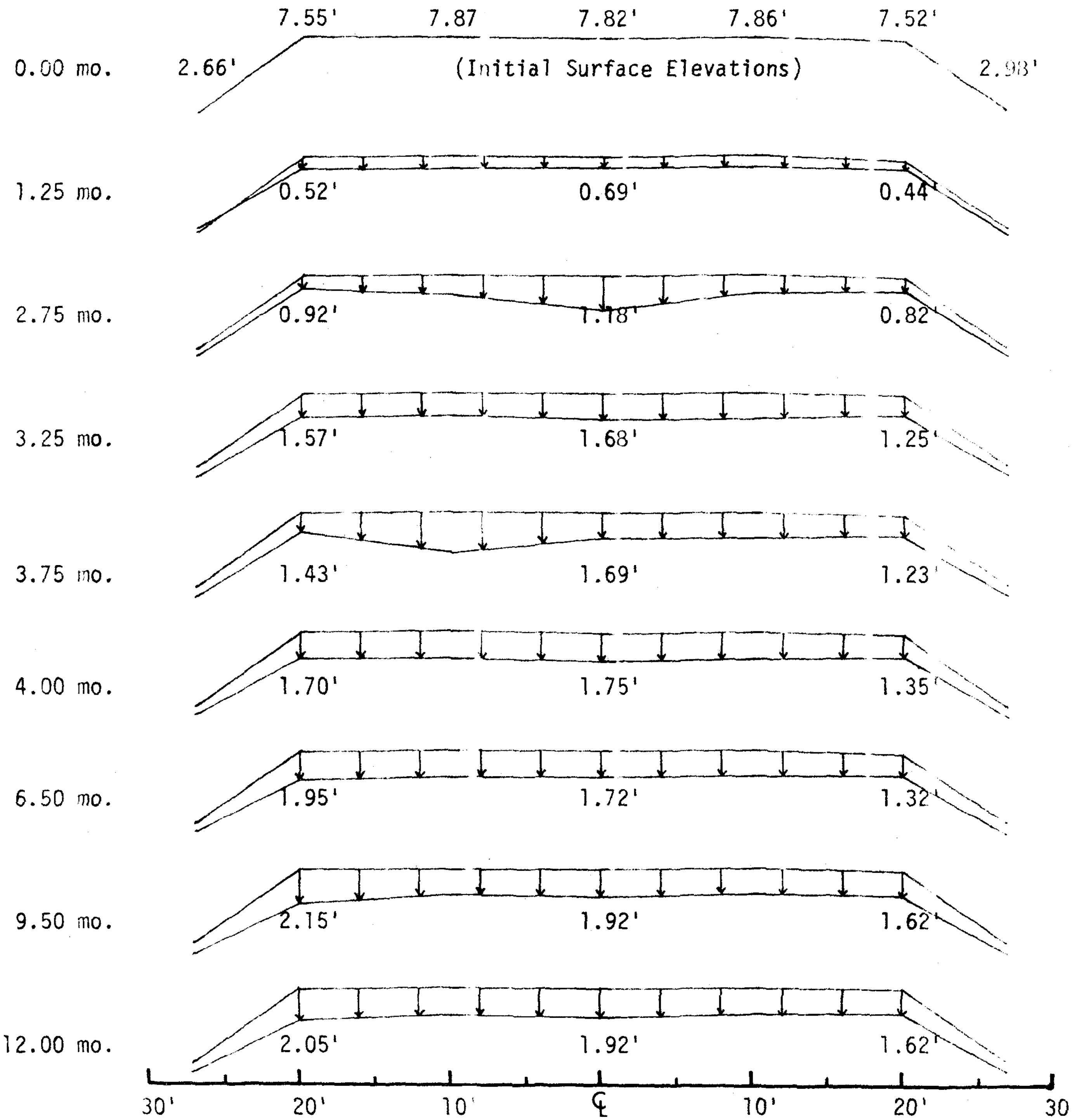


FIGURE 14

represents the as-built cross section of the facility for a given station. Subsequent configurations follow. Feet of subsidence at the centerline and at points 20 feet (6 m) left and right of the centerline are shown.

Table 4 supplements the figures last mentioned by presenting in tabular form the progressive cross-sectional settlement at five stations along the embankment. Examination of the "grand average" settlement values in this table reveals that about one-third of the year's subsidence took place during the first 1.25 months after construction of the embankment. Fifty-six percent occurred by the age of 2.75 months. This subsidence occurred prior to application of 2000 bulldozer passes to the embankment.

Thirty-three percent of the year's subsidence occurred during the one month period beginning at age 3.0 months during which the bulldozer vibrated the embankment extensively.

Eleven percent of the subsidence took place during the final eight months of the evaluation period. During this final eight-month period, torrential rains hit the test site and precipitated wave action along one side and one end of the structure. High water left a stain 0.7 foot (0.2 m) high along one side of the embankment.

In overall review of Table 4, the authors feel that the shell embankment settled uniformly as a unit. This conclusion considers the problem that surveyors had in monitoring elevations of a surface comprised of aggregate of varying size and susceptible to disturbance by cattle. This conclusion is reassuring in light of the non-uniform construction compaction previously shown to have been applied in the top foot of the facility (Table 1).

One last approach will now be taken to relate the post-construction intrusion of the shell into the marshland (as reflected by subsidence at the surface). This will be an examination of the profile of the embankment at various stages during the evaluation period. Figure 15 and Figures 31 and 32 in the Appendix illustrate by means of a very large scale the subsiding profile of the

TABLE 4

TABULATION OF CUMULATIVE SETTLEMENT, FEET,
AND PERCENTAGE OF TOTAL YEAR'S SETTLEMENT (% IN PARENTHESIS)

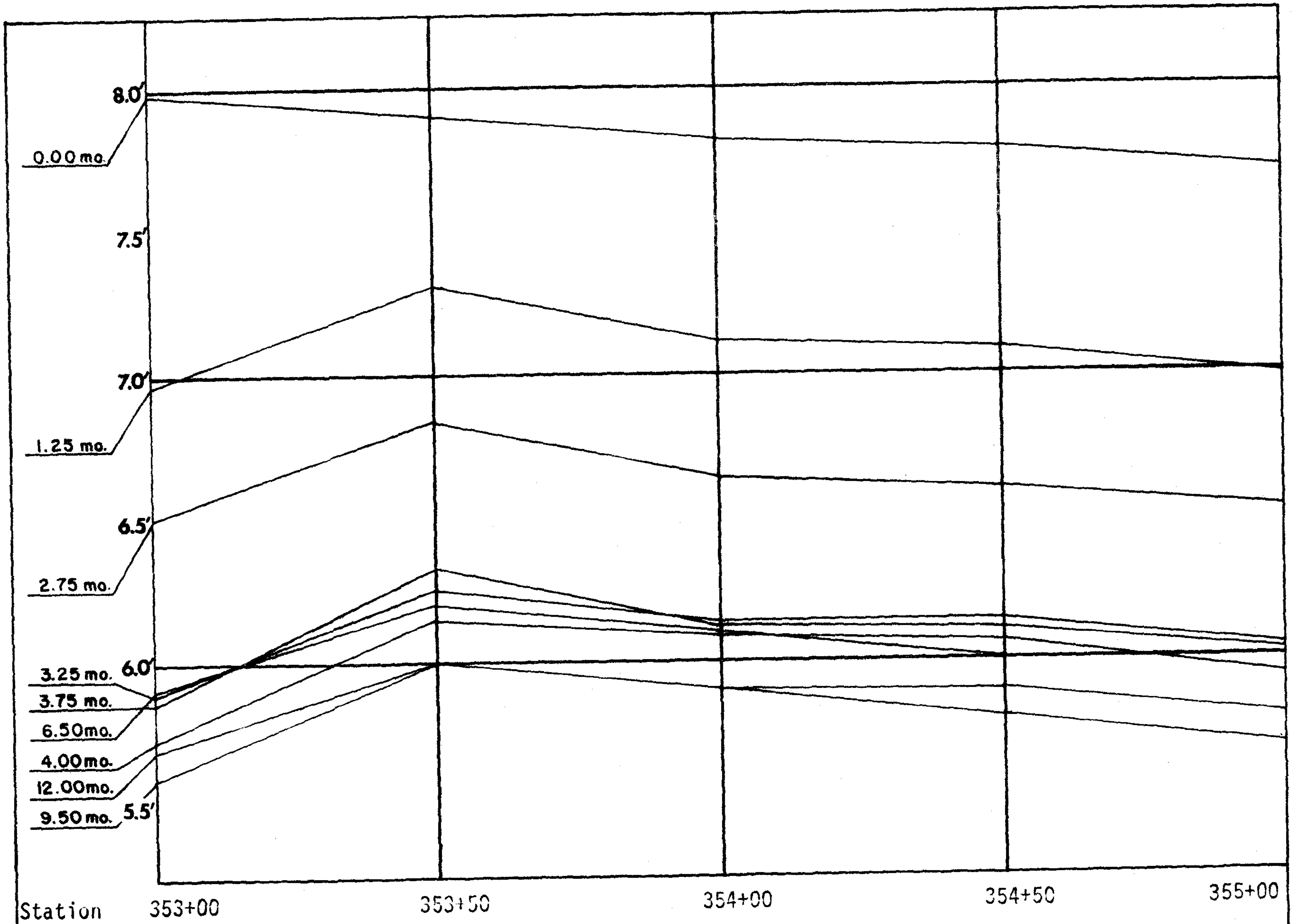
Location	Time After Construction, Months							
	1.25	2.75	3.25	3.75	4.0	6.5	9.5	12.0
Station 353+00								
At ℄	1.01 (44)	1.46 (64)	2.09 (92)	2.11 (92)	2.25 (99)	2.08 (91)	2.38 (100)	2.28 (100)
20' Left of ℄	0.47 (27)	0.90 (52)	1.32 (76)	1.43 (82)	1.58 (91)	1.34 (77)	1.74 (100)	1.74 (100)
20' Right of ℄	1.04 (47)	1.33 (60)	1.71 (78)	1.80 (82)	1.90 (86)	2.00 (91)	2.10 (95)	2.20 (100)
Station 353+50								
At ℄	0.59 (31)	1.06 (56)	1.64 (86)	1.57 (83)	1.75 (92)	1.70 (89)	1.90 (100)	1.90 (100)
20' Left of ℄	0.51 (27)	0.96 (50)	1.56 (82)	1.52 (80)	1.72 (90)	1.71 (90)	2.01 (100)	1.91 (100)
20' Right of ℄	0.41 (26)	0.98 (62)	1.19 (75)	1.22 (77)	1.39 (88)	1.38 (87)	1.68 (100)	1.58 (100)
Station 354+00								
At ℄	0.69 (36)	1.18 (61)	1.68 (88)	1.69 (88)	1.75 (91)	1.72 (90)	1.92 (100)	1.92 (100)
20' Left of ℄	0.52 (25)	0.92 (45)	1.57 (76)	1.43 (70)	1.70 (83)	1.95 (95)	2.15 (100)	2.05 (100)
20' Right of ℄	0.44 (27)	0.82 (51)	1.25 (77)	1.23 (76)	1.35 (83)	1.32 (81)	1.62 (100)	1.62 (100)

TABLE 4 (CONTINUED)

TABULATION OF CUMULATIVE SETTLEMENT, FEET,
AND PERCENTAGE OF TOTAL YEAR'S SETTLEMENT (% IN PARENTHESIS)

Location	Time After Construction, Months							
	1.25	2.75	3.25	3.75	4.0	6.5	9.5	12.0
Station 354+50								
At ℄	0.70 (37)	1.18 (63)	1.64 (87)	1.67 (89)	1.72 (91)	1.78 (95)	1.98 (100)	1.88 (100)
20' Left of ℄	0.82 (38)	1.04 (48)	1.66 (77)	1.68 (78)	1.84 (86)	1.85 (86)	2.05 (100)	2.15 (100)
20' Right of ℄	0.56 (32)	0.93 (53)	1.30 (74)	1.28 (73)	1.43 (82)	1.45 (83)	1.75 (100)	1.75 (100)
Station 355+00								
At ℄	0.73 (38)	1.17 (61)	1.68 (88)	1.69 (88)	1.77 (92)	1.72 (90)	2.02 (100)	1.92 (100)
20' Left of ℄	0.81 (37)	1.13 (51)	1.71 (77)	1.70 (77)	1.97 (89)	2.01 (91)	2.31 (100)	2.21 (100)
20' Right of ℄	0.64 (33)	1.11 (57)	1.51 (77)	1.50 (77)	1.77 (91)	1.65 (85)	1.85 (95)	1.95 (100)
AVERAGE								
At ℄	.74 (37)	1.21 (61)	1.75 (88)	1.75 (88)	1.85 (93)	1.80 (91)	2.04 (100)	1.98 (100)
20' Left of ℄	.63 (31)	.99 (49)	1.56 (78)	1.55 (77)	1.76 (88)	1.77 (88)	2.05 (100)	2.01 (100)
20' Right of ℄	.62 (34)	1.03 (56)	1.39 (76)	1.41 (77)	1.57 (86)	1.56 (86)	1.80 (99)	1.82 (100)
GRAND AVERAGE	.66 (34)	1.08 (56)	1.57 (81)	1.57 (81)	1.72 (89)	1.71 (88)	1.96 (101)	1.94 (100)

FIGURE 15



Elevations of the Centerline Profile of the Shell Embankment

embankment along the centerline, 20 feet (6 m) left of the centerline, and 20 feet (6 m) right of the centerline, respectively.

Upon examining Figure 15, one's initial observation might well be the hinged effect which occurred near station 353+50 at the end of the embankment remote from the haul road. That effect can be observed at the test site as well. Compaction due to construction traffic was least at this end. Hence, research personnel placed additional loose shell at this end in anticipation of consolidation within the shell mass. Subsequent settlement plate measurements revealed that the thickness of the embankment at the centerline of station 353+00 did decrease about 0.5 foot (0.15 m) in a 12 month period. Simultaneously, the shell intruded into the marshland about 1.8 feet (0.55 m) at this far end of the embankment.

In spite of the hinged effect, the profiles at 12 months of age are tolerable with respect to uniformity of elevations. Our limited knowledge indicates that a comparable structure of sand would have figuratively "dropped out of sight" due to lack of particle interlock.

The salvation of the shell embankment concept seems to be that the bulk of the subsidence occurs within the first few months after construction. Hence, the idea should be coupled with stage construction plans.

Application of Previous Research Findings

BACKGROUND

Louisiana State University's Division of Engineering Research has done extensive research regarding the classification and behavior of soft organic soils (2,3,4). Several staff members of that agency took advantage of the clam shell test embankment to employ and evaluate their laboratory research findings.

Thoms, Pecquet, and Arman (2) had previously combined and adapted computer programs by E. L. Wilson and R. E. Nickell (5,6) to formulate a program entitled SSOILS. The original programs were developed to analyze stresses, strains and transient temperature distribution in linear elastic two-dimensional solids. Thoms, Pecquet, and Arman revised and coupled those original programs and made analogous applications to determine stresses, settlements, and pore pressures in soft organic deposits overlain by embankments. Hence the SSOILS computer program evolved.

Full application of SSOILS requires the following input as regards the material properties of the embankment and underlying organic deposits:

- E, Effective Reaction Modulus (force per unit area)
- μ, Poisson's Ratio (dimensionless)
- C_v, Coefficient of Consolidation (area per unit time)
- M_u, Coefficient of Volume Change (area per unit force)
- F, Pressure Fraction (dimensionless)
- A, Creep Law Constant (dimensionless)
- B, Creep Law Constant (dimensionless)
- H, Creep Law Constant (units of length, force, and time raised to various powers)

These parameters are best derived by conducting soil tests with a plane-strain test chamber such as the one that Thoms, et.al., used. Alternately, the above list of parameters can be derived from consolidation and triaxial test results in conjunction with engineering judgment.

SSOILS accepts the above data and auxillary input and performs finite element analysis to predict stresses, strains (settlements), and pore pressure in the embankment-marshland system. This output is both written and plotted. The initial plot (prior to loading) depicts a mesh of rectangular and triangular (finite) elements superimposed upon a cross-section of the embankment-marshland system. Loading causes the mesh to distort just as the actual system does. Settlements are measured from the scaled plot, while vertical and maximum shear stress ranges are printed out for given elements.

PREDICTION OF SETTLEMENTS OF THE RACELAND-GIBSON TEST SECTION

Thoms, Pecquet, and Arman employed the SSOILS program to predict the settlements (as well as stresses) which would occur due to construction of the shell embankment upon organic soil. Material properties of the organic soil were deduced from plane-strain test results on samples acquired from the area beneath the embankment. Materials properties of the clam shell were assigned based upon the researchers knowledge of those properties in soil and upon engineering judgment. The state of knowledge concerning clam shell has not yet advanced to the point where the parameters needed for the SSOILS program have been defined.

Figure 16* depicts the nodal point numbering and unloaded configuration of one-half of the test embankment. Settlements predicted by computer were referenced to the nodes of this mesh.

Figures 17* through 20* depict the predicted configuration of the test embankment immediately upon construction and for six months thereafter. SSOILS predicted the cumulative settlement at the centerline of the embankment to be 1.0 foot (0.3 m) upon construction, 3.30 feet (1.0 m) at one month, 3.30 feet (1.0 m) at three months, and 3.57 feet (1.1 m) at six months. Settlement at 20 feet (6 m) right and (by mirror image) 20 feet (6 m) left of the centerline would be .57 foot (0.17 m) upon construction and would level off at 1.86 feet (0.57 m) after one month. The plot printouts show that these settlements reflect intrusion of the shell into the marshland.

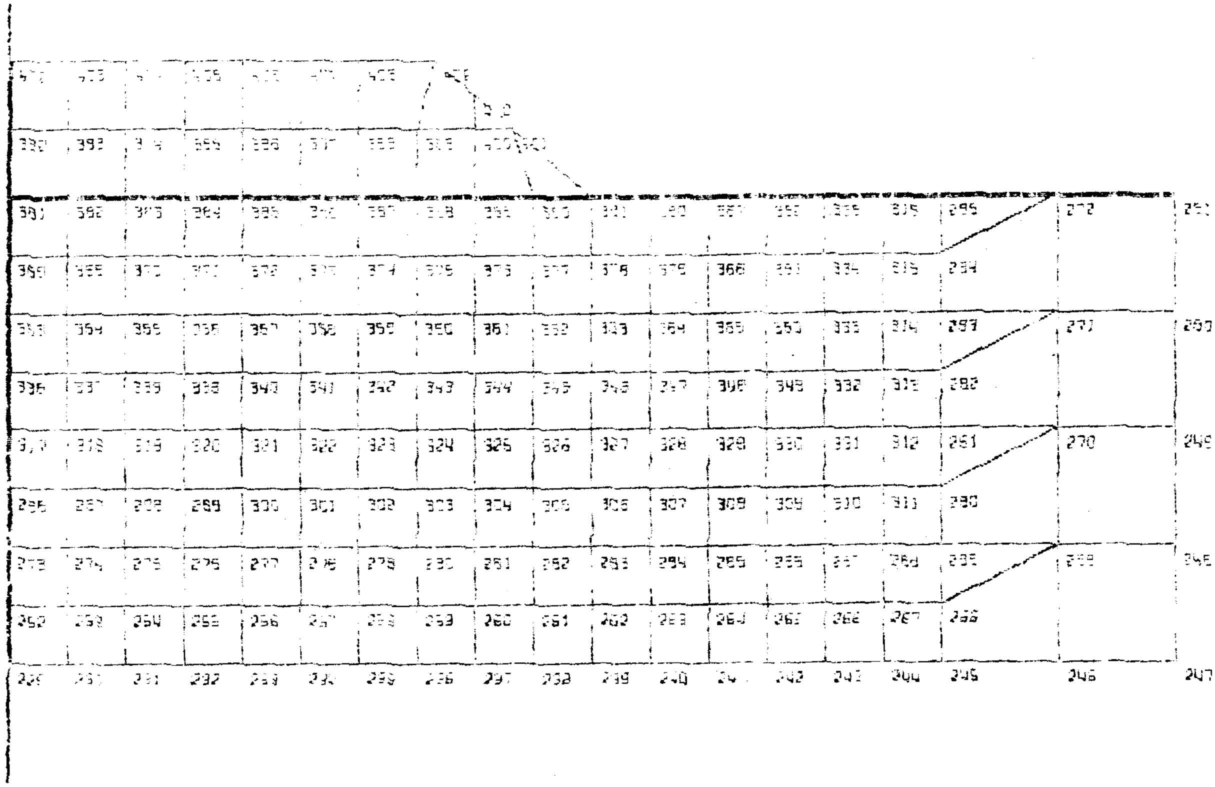
COMPARISON OF PREDICTED AND ACTUAL SETTLMENT OF THE SHELL EMBANKMENT

The SSOILS program predicts a total subsidence comprised of construction displacement, consolidation settlement, and creep (or secondary consolidation) settlement. Hence, actual settlement values presented in this section will include the initial intrusion of the shell into the marshland during placement as well as subsequent subsidence of the surface of the facility. Settlement values mentioned heretofore in this report have reflected only post-construction subsidence, since construction displacements were offset by bringing the embankment up to grade.

Actual settlements of the embankment at the centerline and at 20 feet (6 m) left and right of the centerline of station 354+00 will be compared with the settlements predicted by the SSOILS printouts. The authors of this report chose station 354+00 to discuss because this station typifies the clam shell test embankment.

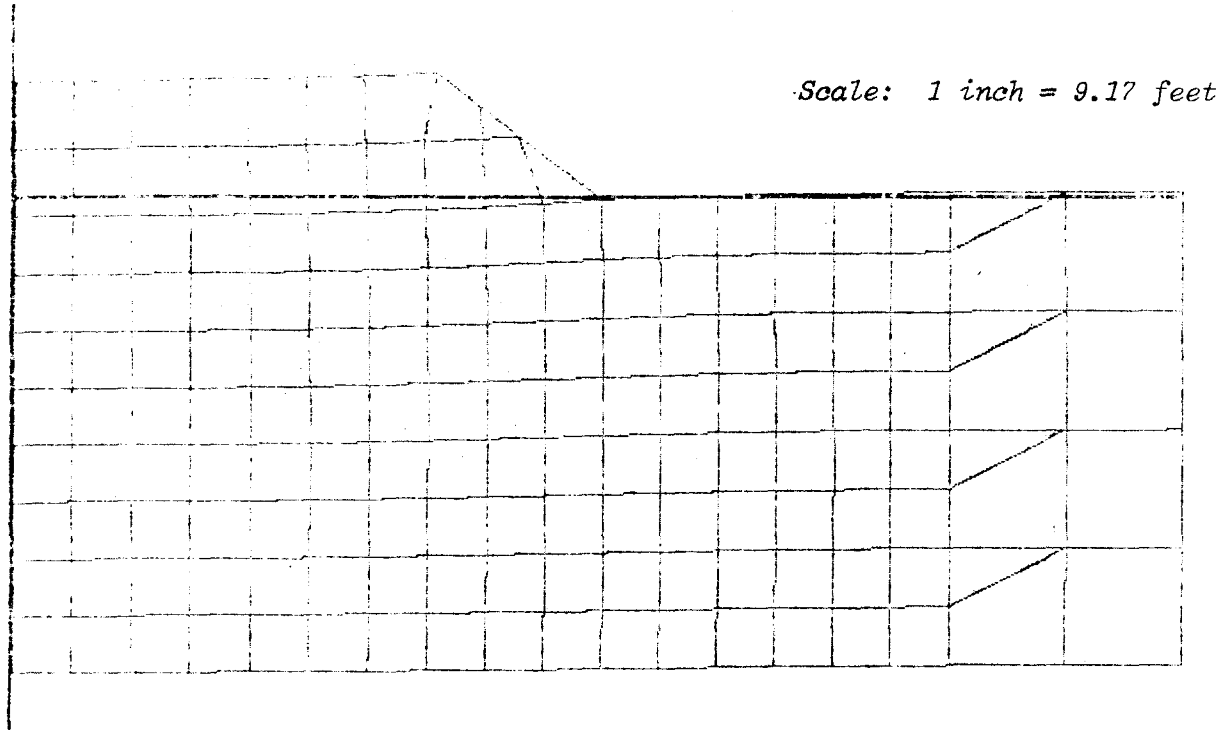
* Reprinted with permission of Thoms and Arman, Reference (2).

Scale: 1 inch = 9.17 feet

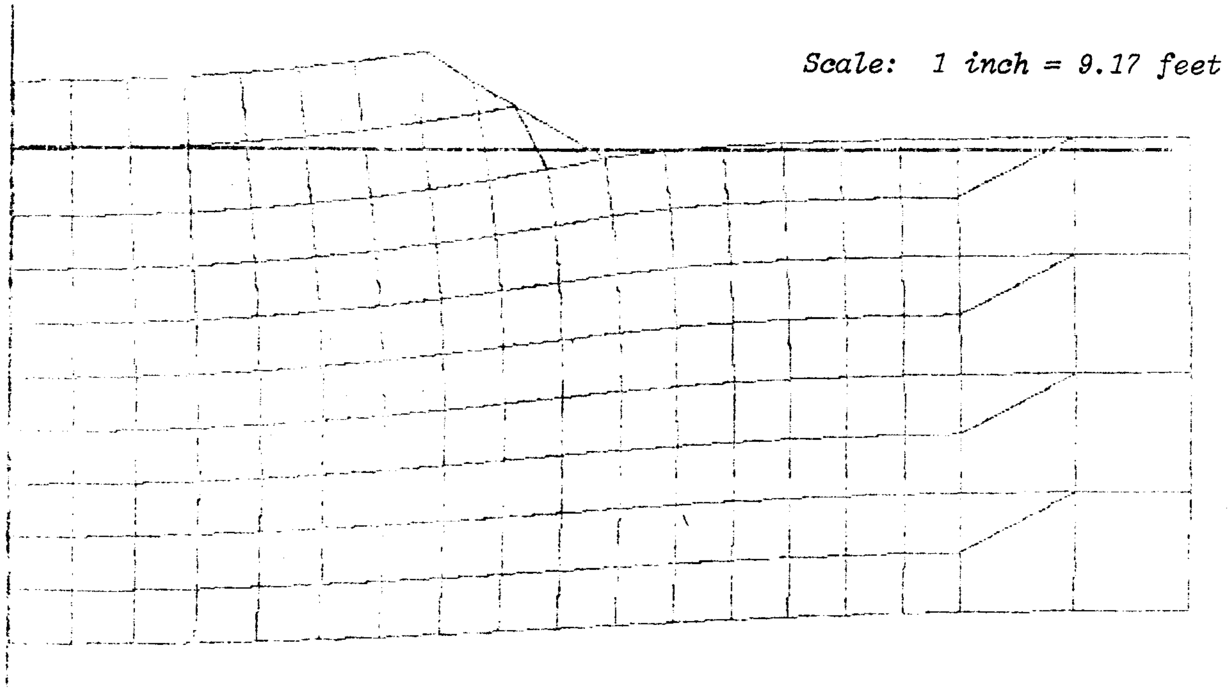


SSOILS Nodal Point Numbering and Unloaded Configuration of Test Embankment

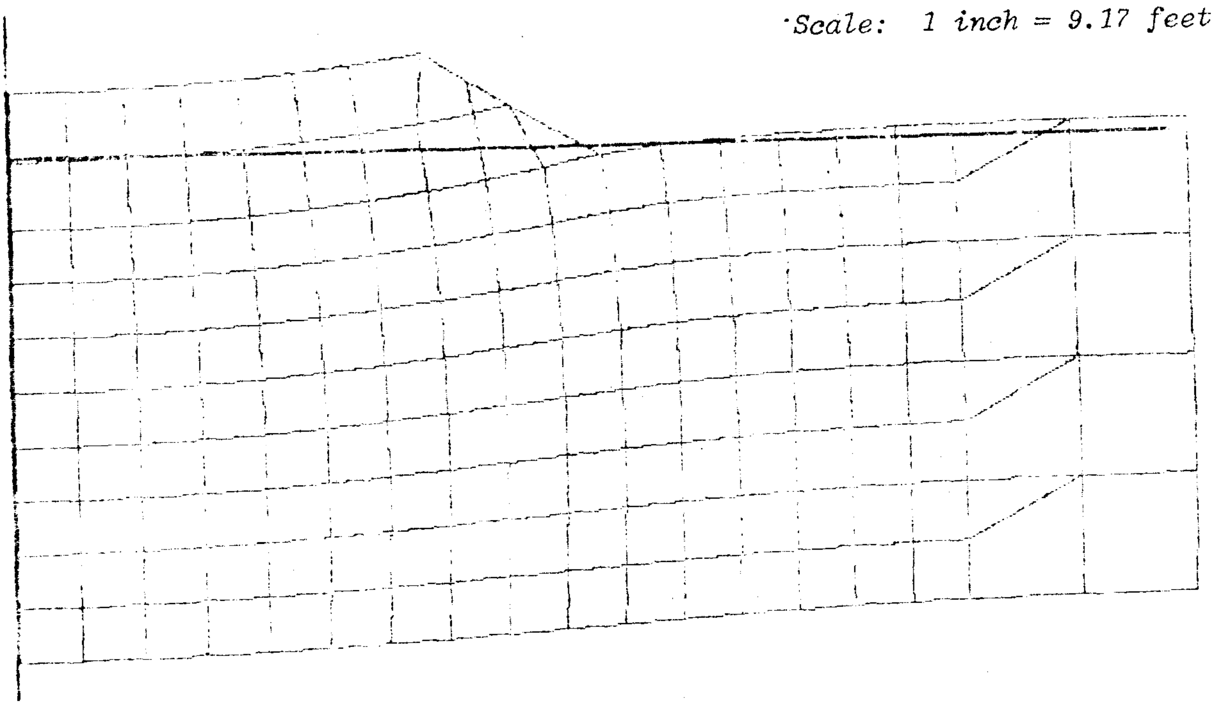
FIGURE 16



SSOILS Predicted Configuration of Test Embankment Immediately After Construction
FIGURE 17

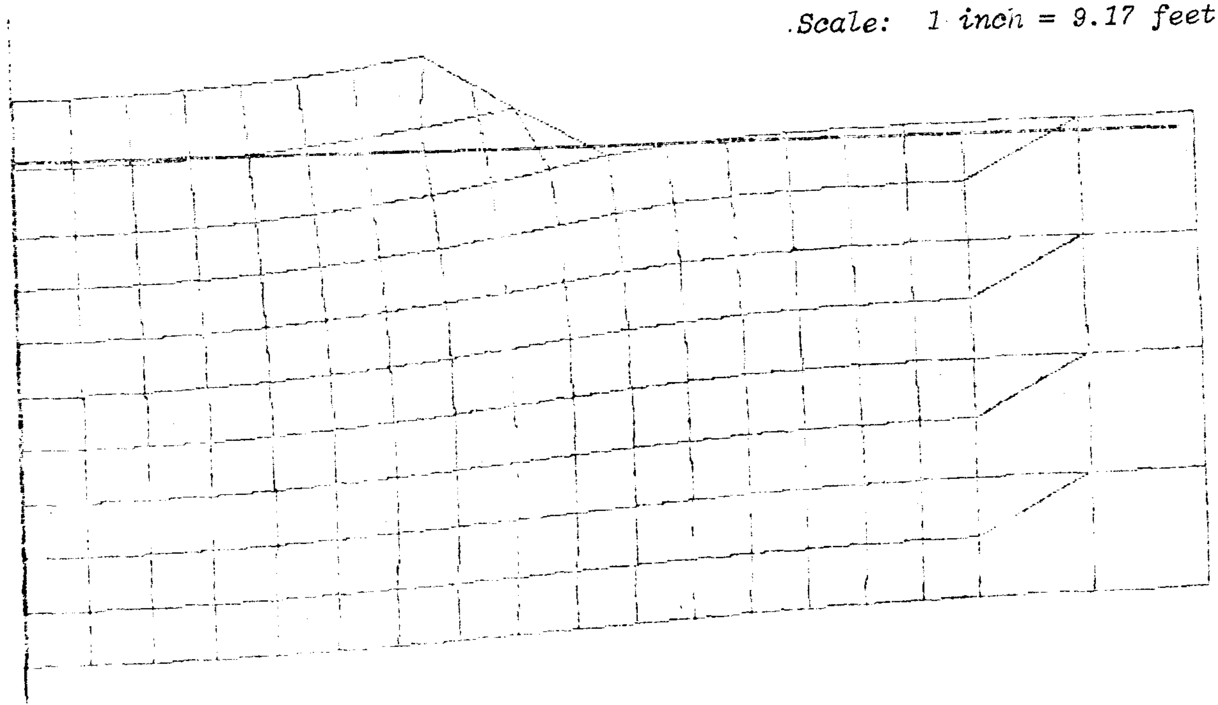


SSOILS Predicted Configuration of Test Embankment at One Month
FIGURE 18



SSOILS Predicted Configuration of Test Embankment at Three Months

FIGURE 19



SSOILS Predicted Configuration of Test Embankment at Six Months

FIGURE 20

This station lies between the most heavily-compacted juncture of the haul road and test embankment and the most lightly compacted end of the embankment which was constructed last. Furthermore, settlement plate measurements at station 354+00 show a constant thickness of shell for the 12-month evaluation period.

Figure 21 illustrates predicted and actual settlements at the centerline of station 354+00. Figure 22 presents actual and predicted settlements at 20 feet (6 m) left and at 20 feet (6 m) right of the centerline of that station.

These two figures tend to contradict the convex cross section which the SSOILS printouts depicted (as shown in the previous section). That is, actual centerline subsidence at six months is less than predicted, while subsidence at points 20 feet (6 m) offset from the centerline equals or exceeds that which was predicted. The surface of the embankment actually settled in a generally uniform manner.

Thoms, et al, acknowledge two reasons why the shell mass tends to act as a "rigid raft" and more or less floats as a unit upon the marshland. First, the clam shell is lightweight. It is lighter than typical native sands and clays. Secondly, the particles of shell tend to interlock and the mass produces a bridging effect across the marshland.

It appears that Thoms, Pecquet, and Arman have developed a very useful and workable tool in the SSOILS computer program. The reader is reminded that the input efforts of those gentlemen were hampered by a lack of knowledge of the behavioral characteristics of shell. Determinations of those shell properties and of pore pressure distribution in the muck beneath such an embankment is sorely needed to effectively employ SSOILS. This data would enable those researchers to apply "loop-back procedures" wherein computer input would be modified and verified until the output and actual embankment behavior match. Such research is recommended.

Decision on Type of Construction for State Project 700-06-83

Route U.S. 90 has for many years connected the eastern and western borders of south Louisiana. This highway is a major artery for Gulf Coast traffic, and has proven invaluable as an evacuation route during time of hurricane.

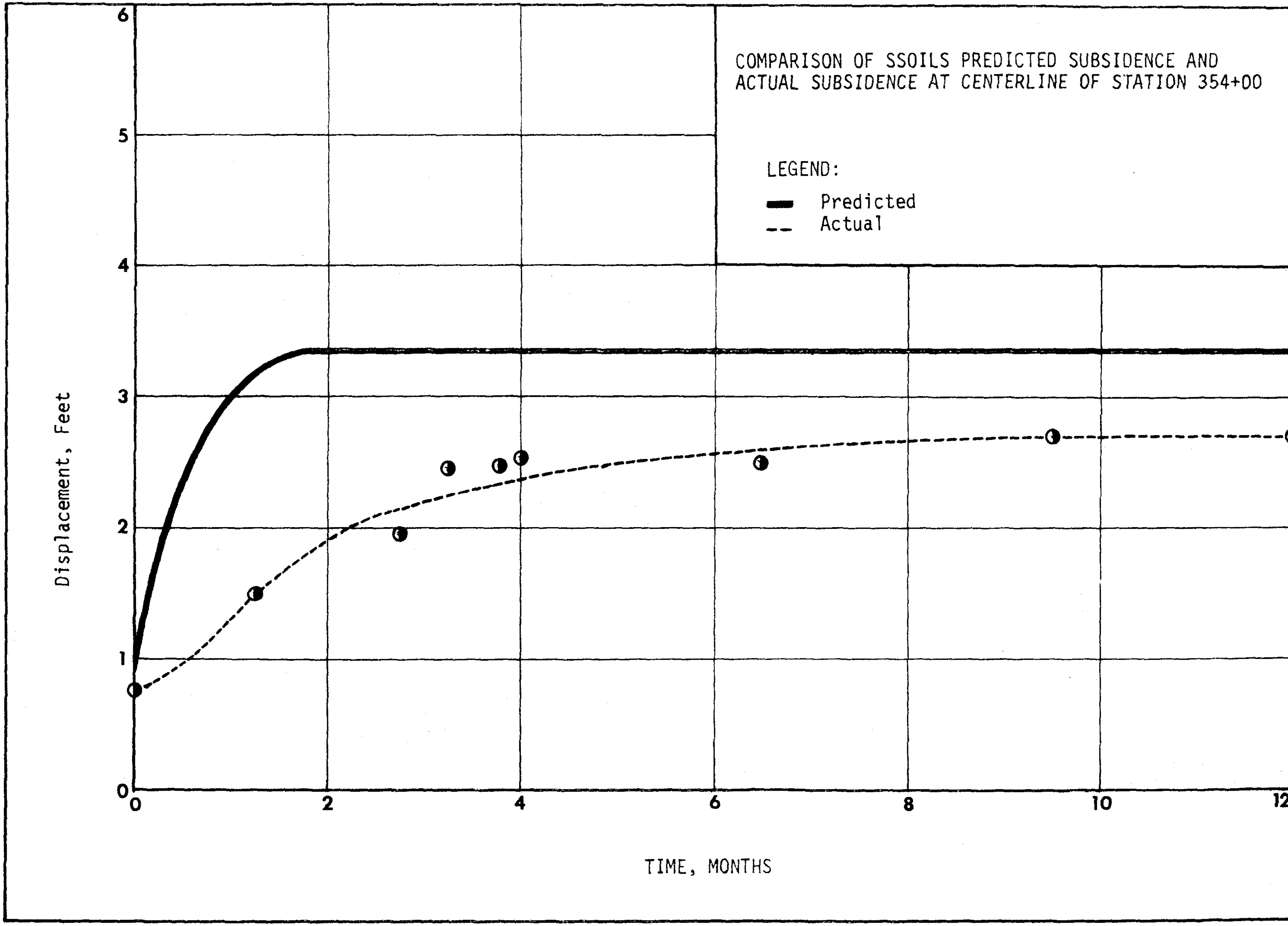

COMPARISON OF SSOILS PREDICTED SUBSIDENCE AND
ACTUAL SUBSIDENCE AT CENTERLINE OF STATION 354+00
LEGEND:
Predicted
Actual
Displacement, Feet
0
1
2
3
4
5
6
0
2
4
6
8
10
12
TIME, MONTHS

FIGURE 21

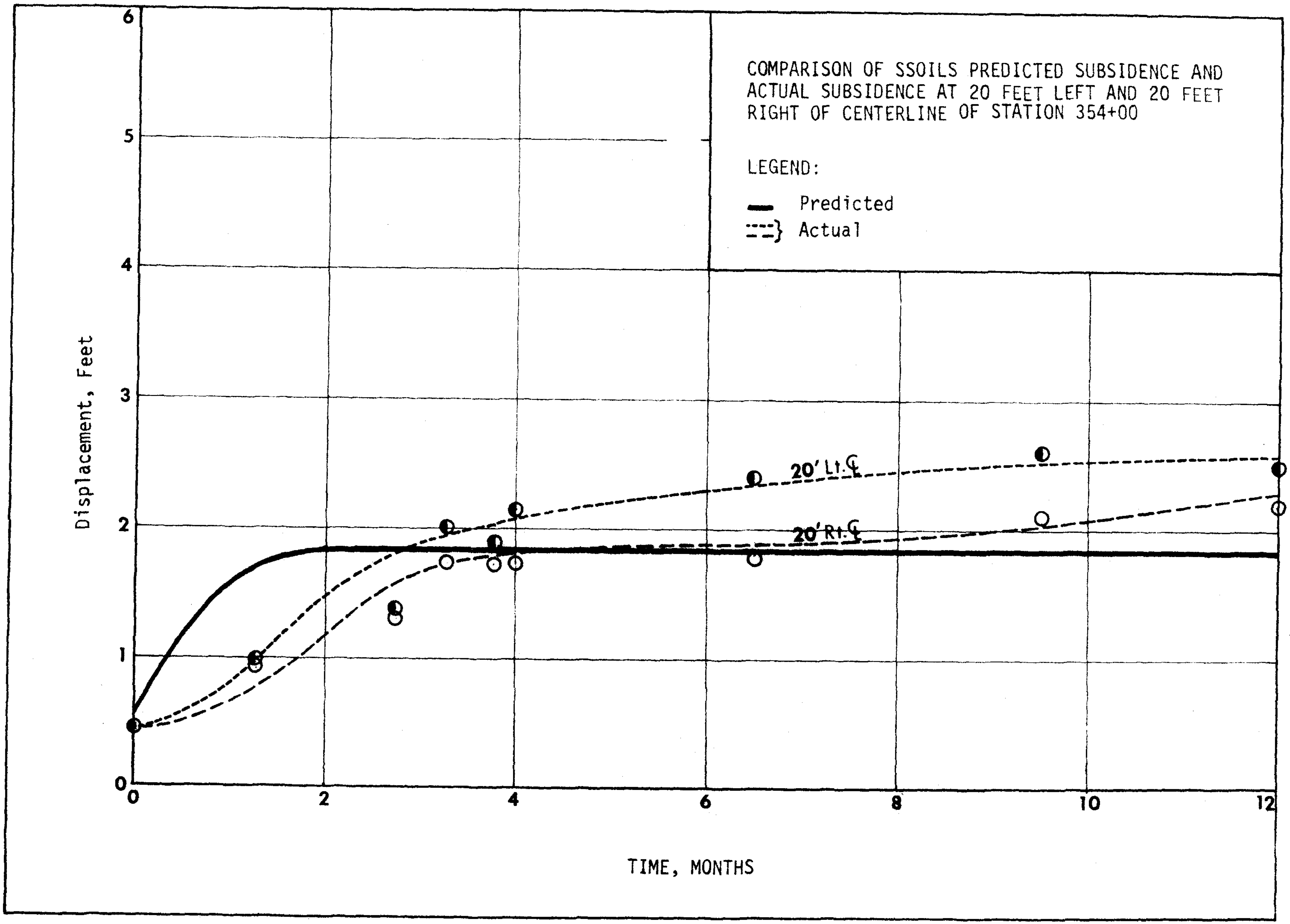

COMPARISON OF SSOILS PREDICTED SUBSIDENCE AND ACTUAL SUBSIDENCE AT 20 FEET LEFT AND 20 FEET RIGHT OF CENTERLINE OF STATION 354+00
LEGEND:
Predicted
Actual
20' Lt. ℄
20' Rt. ℄
Displacement, Feet
TIME, MONTHS
0
1
2
3
4
5
6
0
2
4
6
8
10
12

FIGURE 22

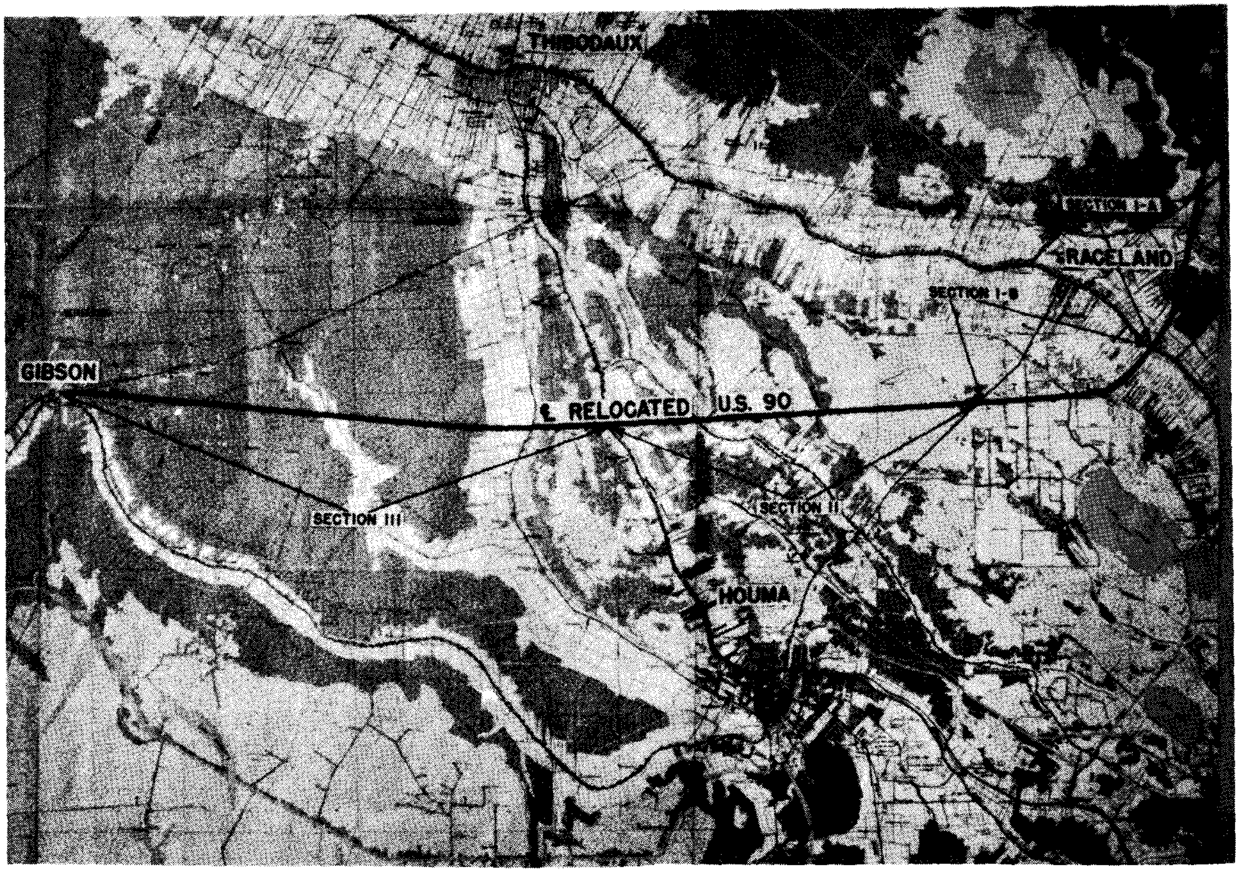
The Department of Highways has decided to upgrade Route U. S. 90 from a two-lane to a four-lane highway. In the Raceland, Louisiana, area, this upgrading will include a re-routing as well as expansion to four-lane.

Figure 23 depicts State Project 700-06-83, the relocation of Route U.S. 90 from Raceland to Gibson. The corridor for this proposed highway is approximately 29 miles (47 km) long and passes mostly through swampland and marshland. Design and construction of a road over this terrain must be done with discretion. Economic considerations match the value of sound engineering in a venture such as this.

The Department simply could not afford to build an elevated structure from Raceland to Gibson. Investigation of the costs of excavating the muck and backfilling with sand embankment began to appear economically questionable as well.

As an example of the costs of a sand fill, consider Section II of Figure 23. The Department's Soils Design Engineer advised that a typical sand embankment cross-section for this terrain would require muck excavation to a depth of ten feet (3.0 m) and placement of side berms 120 feet (37 m) in width to hold up the embankment and necessary surcharge. This would cost an estimated 0.6 million dollars per mile. The cost of a sand embankment for the total Raceland-Gibson project would vary from 0.4 to 1.0 million dollars per mile, depending upon the severity of the marsh/swamp conditions. The total cost of a sand fill began to approach 17 million dollars, which, as stated above, was an economically questionable sum. Hence, the Department's design personnel began to wonder if another material such as clam shell might prove to be an economical alternate for sand on this project. The clam shell test embankment previously described in this report was appropriately located in Section II of State Project 700-06-83 so as to assist designers and administrators alike in deciding on whether to allow the use of shell on the project.

By letter dated February 2, 1973, the Research and Development Engineer advised the Highway Assistant Director of the following findings from the clam shell test embankment.



Layout of State Project No. 700-06-83, Raceland-Gibson Highway (Relocated Route U. S. 90)

FIGURE 23

A. A properly constructed embankment of clam shell will perform as an integral unit under the forces of its own dead load and the vibration effects of simulated truck traffic.

B. A fill of this nature must be constructed in an initial minimum lift thickness of five feet. Additional application of shell to meet or maintain finished grade can be applied in a more normal construction manner.

C. From the experimental installation, it appears that the major subsidence of this type of embankment would be during the first four to six months from the time of general construction of the fill to reasonable grade.

D. The apparent compaction factor of a clam shell embankment of an approximate 5.0 foot (1.5 m) height above existing ground level would be 1.45.

That letter also presented the conclusion that strong consideration can be given to construction of a shell embankment to bridge marshland soils such as those encountered on the experimental project. A copy of this letter is attached as Appendix I.

Of course, the biggest advantage of the clam shell embankment involves economics. In those areas of State Project 700-06-83 where a shell embankment without mucking and without side berms would be an alternate to a sand embankment requiring mucking and side berms, the volume ratio between the sand and shell alternates would be about three to one. The difference in costs of materials and construction techniques for these two types of structures indicates the shell embankment would cost about one-fourth to one-half of the comparable sand embankment. (Although, in those areas where a sand embankment could be placed without mucking and without side berms, the cost advantage of shell over sand would be reduced substantially as the two volumes would be comparable).

Another cost-related advantage of the shell embankment concept is that the ease with which a contractor can mobilize for this type construction would make it feasible for the Department to award small contracts as funds are available.

Contractors hesitate to establish the costly pumping operations often required in constructing sand fills unless the scope of the project is sufficiently large to merit such mobilization efforts.

As an appropriate sequel to this shell embankment study, Section I-B (Figure 23) was designed with clam shell embankment and clam shell embankment/sand embankment alternates. This design requires placement of 426, 418 cubic yards of clam shell across marshland. The Department has awarded the contract based on bids reviewed May 29, 1974. Construction should begin in the near future.

CONCLUSIONS

It is physically feasible to construct a clam shell embankment directly upon in-situ marshland without muck excavation or other subgrade preparation. The following steps will help ensure the success of this type construction:

A. The clam shell should be placed by a dumping operation wherein each lift so placed shall extend at least five feet (1.5 m) above the existing ground level.

B. The shell should be initially dumped at the centerline of the embankment and worked forward and outward with bulldozer-type equipment. The nose of the construction zone should be built on a 45 degree angle with respect to the embankment centerline. This process is geared to avoid the formation of mudwaves.

C. Full embankment height and crown width should be maintained as construction proceeds. Continuity of construction is critical.

D. If a median ditch is required, it should be constructed by the excavation of shell at the tail end of the construction zone.

E. Loaded trucks shall use each half of the embankment alternately so that each half receives uniform compaction under construction traffic.

F. Density control should not be required. However, the top six inches (0.15 m) of the surface should be uniformly compacted by 12 passes of a sheepsfoot roller.

G. The method of payment for the shell should be by truck measurement.

II. It is economically feasible to construct a shell embankment over marshland soil. The cost of a shell embankment falls far below the cost of a hydraulically placed sand fill in marsh areas. In comparing costs of these two types of embankments, savings of 50 to 75 percent can be achieved through application of the shell embankment concept.

III. A properly constructed embankment of clam shell will perform as an integral unit under the forces of its own dead load and the vibration effects of simulated truck traffic. Such a structure should be capable of supporting allowable traffic loads.

IV. The apparent compaction factor of a clam shell embankment of an approximate 5.0 foot (1.5 m) height above existing ground level is 1.45.

V. Observation of the experimental shell embankment indicates that the major subsidence of this type embankment would occur during the first four to six months from the time of general construction of the fill to reasonable grade.

VI. A computer program has been developed by others which will predict the approximate subsidence of a shell embankment bridging marshland soil.

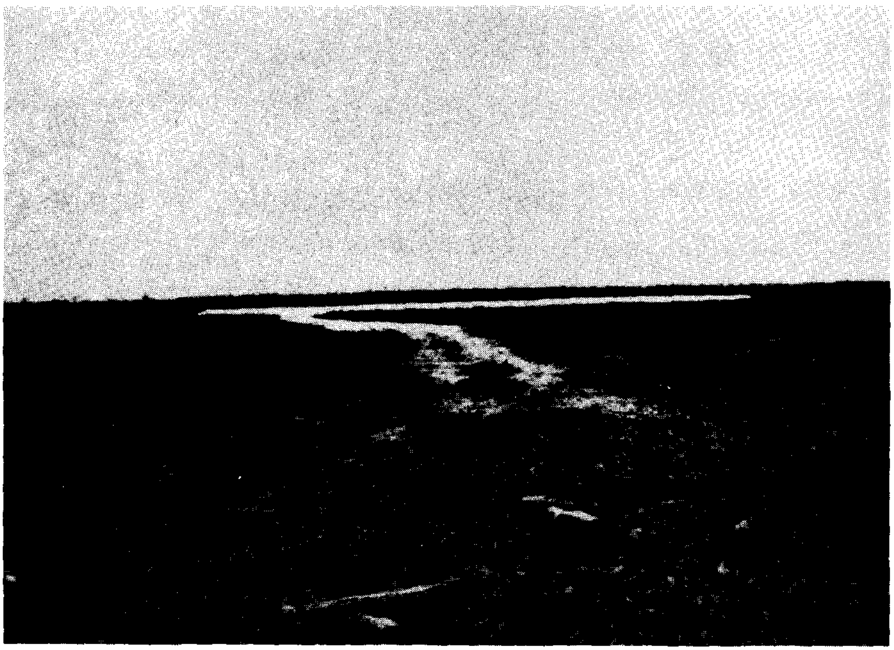
RECOMMENDATIONS

I. Consideration should be given to construction of a clam shell embankment to bridge marshland soils such as those encountered on the experimental project.

II. Additional research is recommended wherein a stability analysis of a shell embankment-marshland soil system would be effected. A full-scale, heavily instrumented test section would appear to be the best means of accomplishing such an analysis.*

III. Research should be undertaken to investigate the merits of constructing an embankment of reef shell. This is an aggregate of much larger particle size than clam shell. Extending acceptance of the shell embankment concept to reef shell could immediately reduce the cost of proposed highway construction over the state's mucklands.

* Since the original draft of this report was written, Louisiana State University's Division of Engineering Research has initiated a research project designed to effect a stability analysis of the clam shell embankment proposed for construction on State Project Number 700-06-83, Relocation of Route U. S. 90 (Raceland-Gibson Highway).



The Clam Shell Test Embankment
FIGURE 24

The End
(Or a Point of Beginning?)

CITED REFERENCES

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2. Thoms, R. L., R. A. Pecquet, and A. Arman. Numerical Analysis of Embankments Over Soft Soils. Interim Report, Division of Engineering Research, Louisiana State University, 1974.

3. Arman, A. A Definition of Organic Soils. Engineering Research Bulletin No. 101, Division of Engineering Research, Louisiana State University, 1969.

4. Arman, A, and G. A. Munfakh. The Effect of Densification on the Engineering Characteristics of Organic Soils. Engineering Research Bulletin No. 113, Division of Engineering Research, Louisiana State University, 1974.

5. Wilson, E. L. "Structural Analysis of Axisymmetric Solids", A.I.A.A. 1964, pp. 2269-2274.

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APPENDIX I

Letter

to

Highway Assistant Director

STATE OF LOUISIANA
DEPARTMENT OF HIGHWAYS
INTRADEPARTMENTAL CORRESPONDENCE

REFERRED TO

______ REFERRED FOR ACTION
______ ANSWER FOR MY SIGNATURE
______ FOR FILE
______ FOR YOUR INFORMATION
______ FOR SIGNATURE
______ RETURN TO ME
______ PLEASE SEE ME
______ PLEASE TELEPHONE ME
______ FOR APPROVAL
______ PLEASE ADVISE ME

BY ______ DATE ______
BY ______ DATE ______
BY ______ DATE ______
BY ______ DATE ______

IN REPLY PLEASE REFER TO
FILE NO.

February 2, 1973

SHELL EMBANKMENT STUDY
RESEARCH PROJECT NO. 72-1G(B)
LOUISIANA HPR 1(10)

M E M O R A N D U M   T O:

MR. S. L. POLEYNARD
HIGHWAY ASSISTANT DIRECTOR

Attached is a summary report of the installation and evaluation of the experimental shell embankment constructed on the captioned research effort for the proposed Raceland - Gibson relocation of U. S. 90 in Lafourche Parish. This report contains the results of our evaluation of the constructability and performance of a thick lift clam shell embankment placed directly upon in-situ wet marsh land soils.

The findings of this report are:

1. A properly constructed embankment of clam shell will satisfactorily perform as an integral unit under the forces of its own dead load and the vibration effects of simulated truck traffic.

2. A fill of this nature must be constructed in an initial minimum lift thickness of 5 feet. Additional application of shell to meet or maintain finished grade can be applied in a more normal construction manner.

3. From the experimental installation, it appears that the major subsidence of this type of embankment would be during the first four to six months from the time of general construction of the fill to reasonable grade.

RECOMMENDED FOR APPROVAL ______ DATE ______

RECOMMENDED FOR APPROVAL ______ DATE ______

RECOMMENDED FOR APPROVAL ______ DATE ______

4. The apparent compaction factor of a clam shell embankment of an approximate 5.0 fill height above existing ground level would be 1.45.

The conclusion to date is that strong consideration can be given to construction of a shell embankment to bridge marsh land soils such as that encountered on the experimental project as a design selection or alternate.

Verdi Adam
Materials & Research Engineer

ORIGINAL
Signed by J. W. LYON, JR.

By: J. W. Lyon, Jr.
Research & Development Engineer

JWL:mm
cc: Mr. A. B. Ratcliff, Jr.
Mr. Jack Reid
Mr. Ali Kemahli

APPENDIX II

Supplemental Figures

Configuration of Shell Embankment
Station 353+00

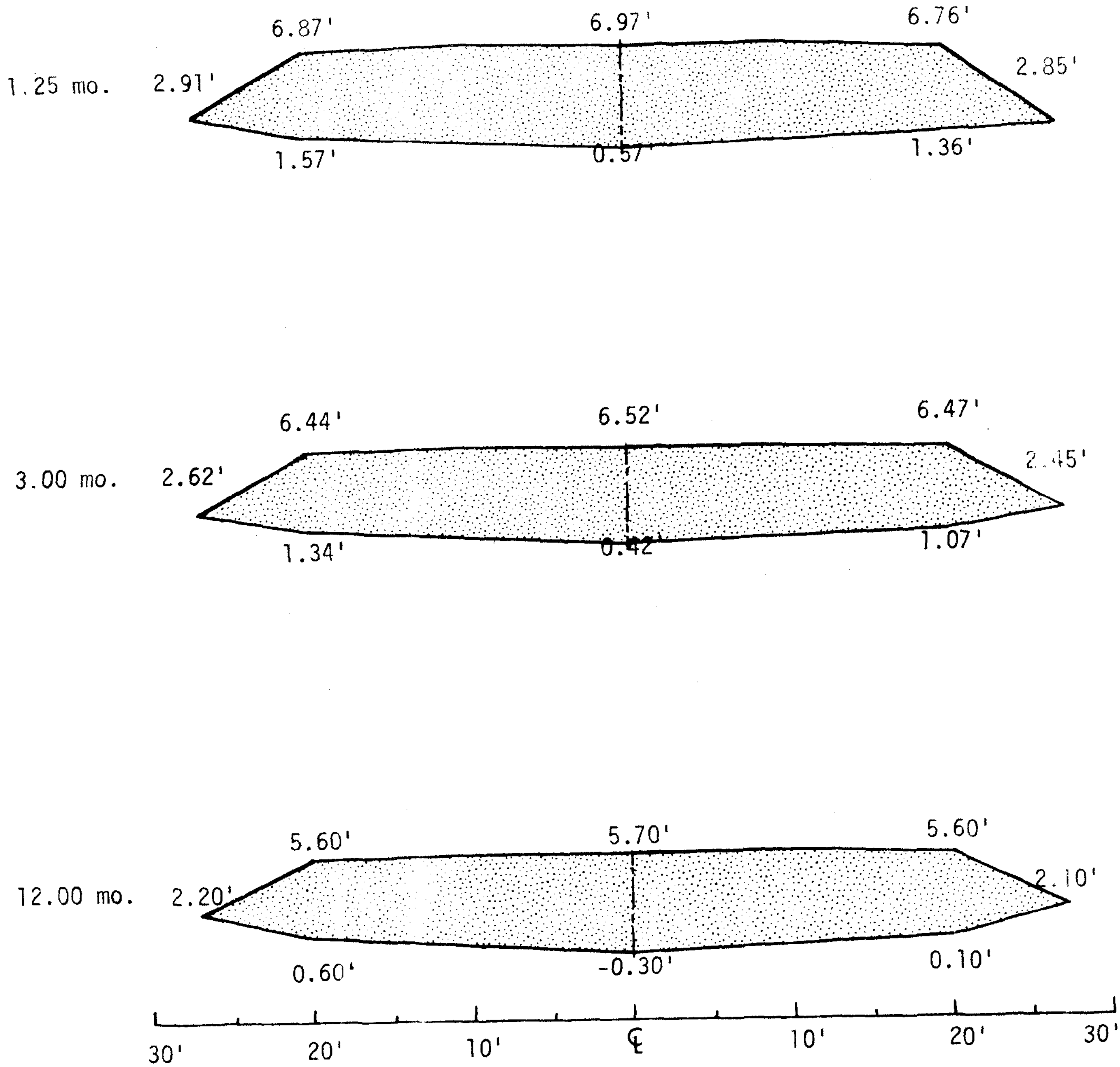

FIGURE 25

Configuration of Shell Embankment
Station 355+00

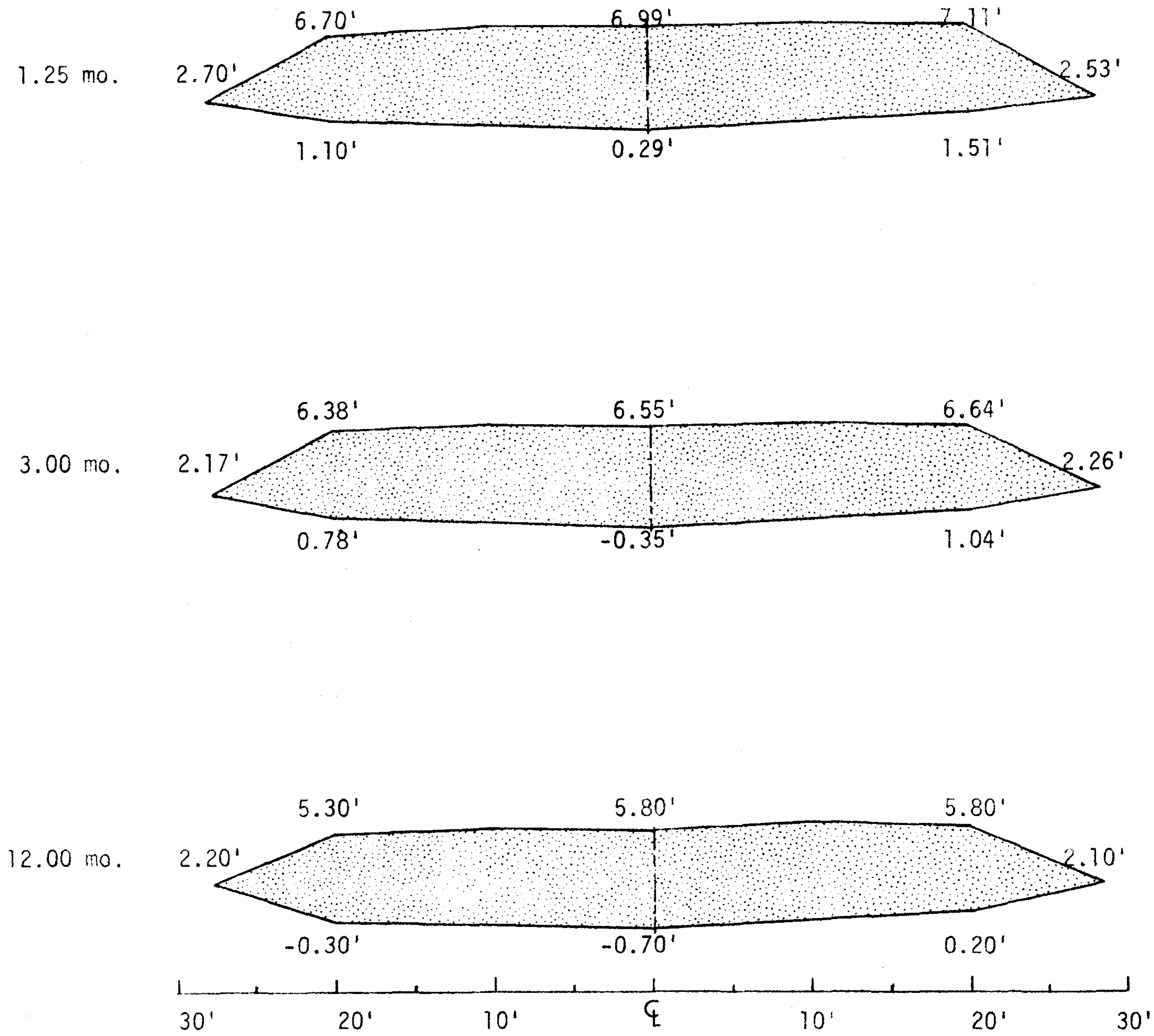

FIGURE 26

Initial Elevations and Subsequent Subsidence at Surface of Embankment,
Station 353+00

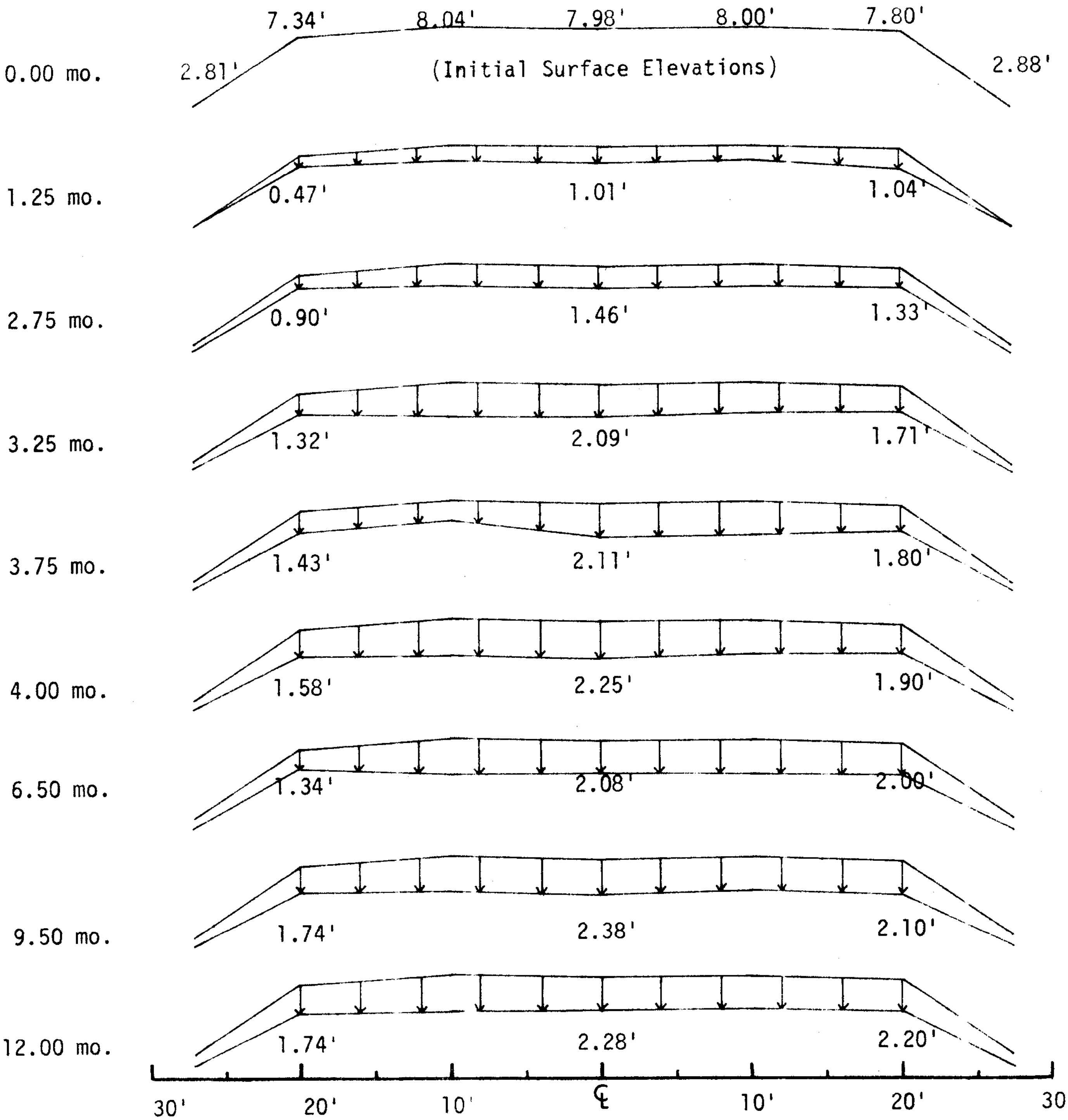

FIGURE 27

Initial Elevations and Subsequent Subsidence at Surface of Embankment, Station 353+50

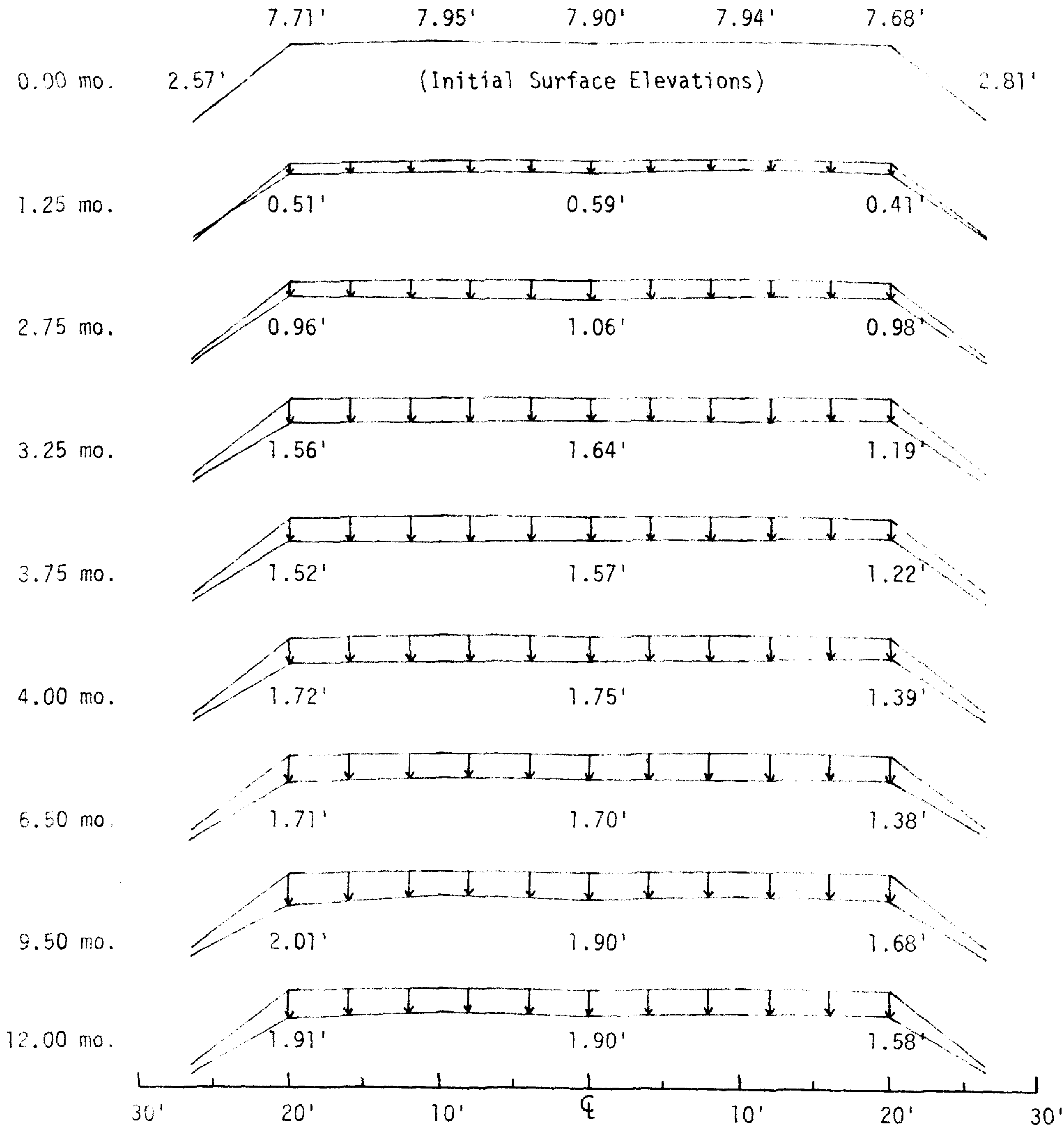

FIGURE 28

Initial Elevations and Subsequent Subsidence at Surface of Embankment
Station 354+50

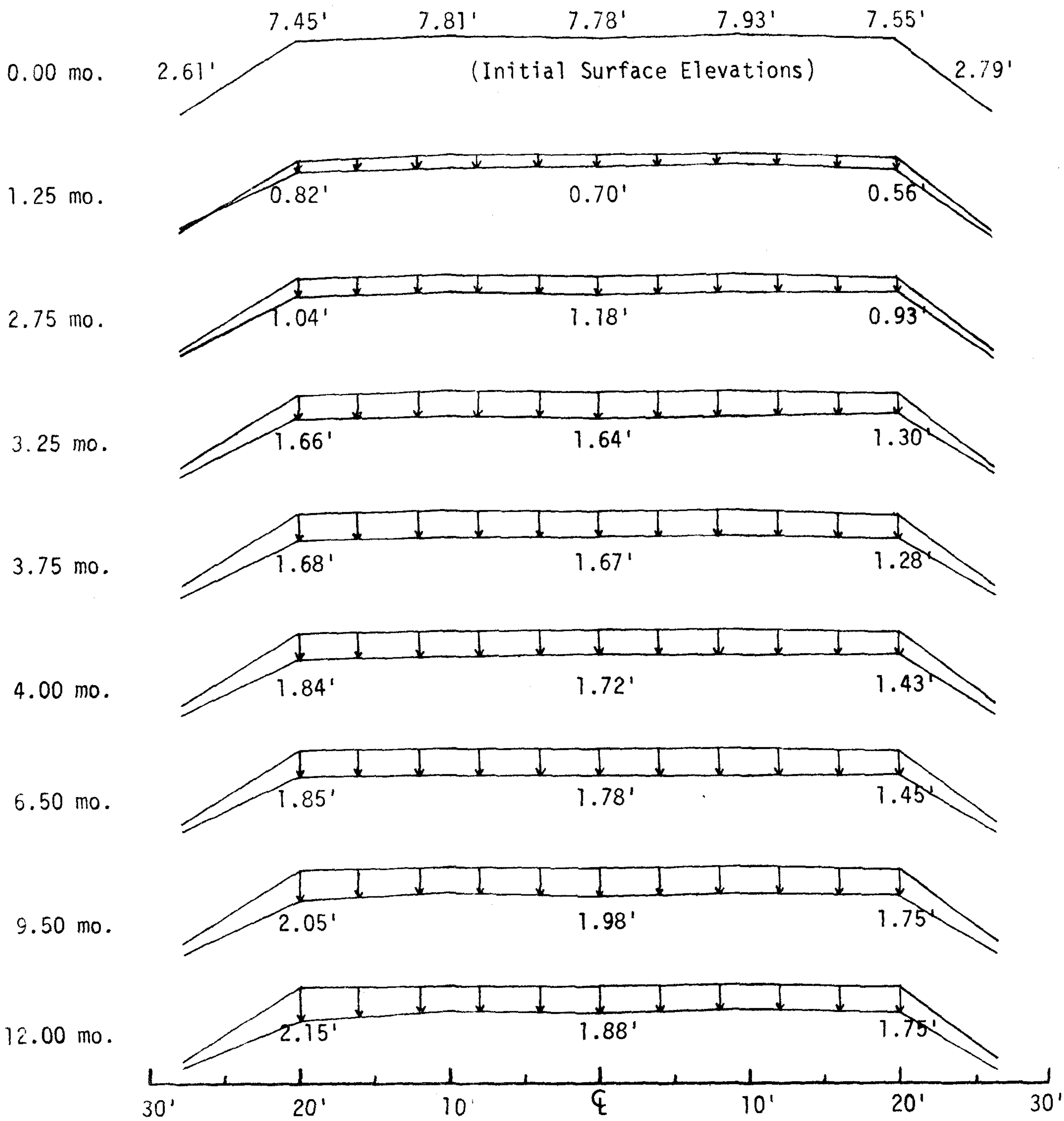

FIGURE 29

Initial Elevations and Subsequent Subsidence at Surface of Embankment, Station 355+00

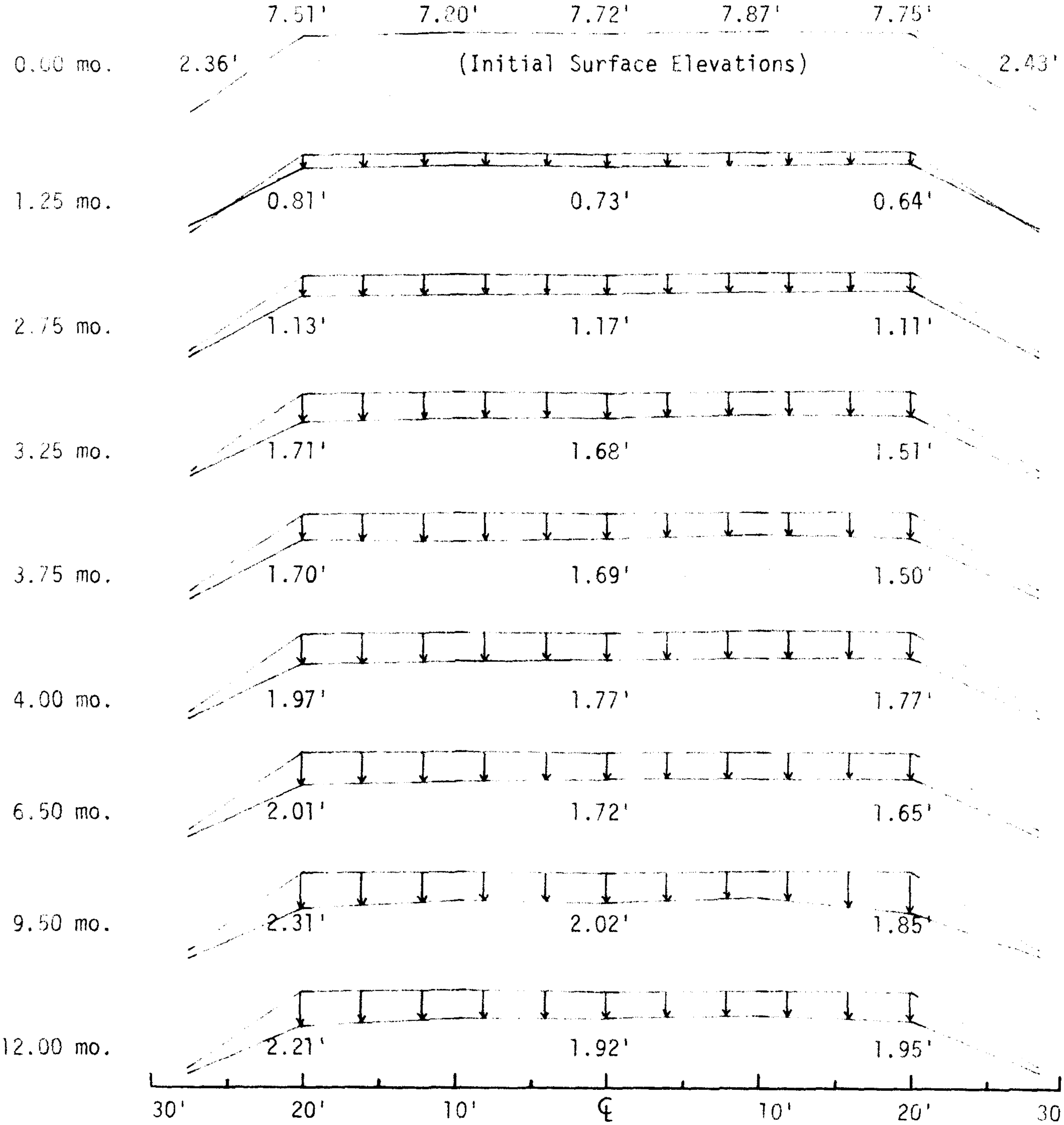

FIGURE 30

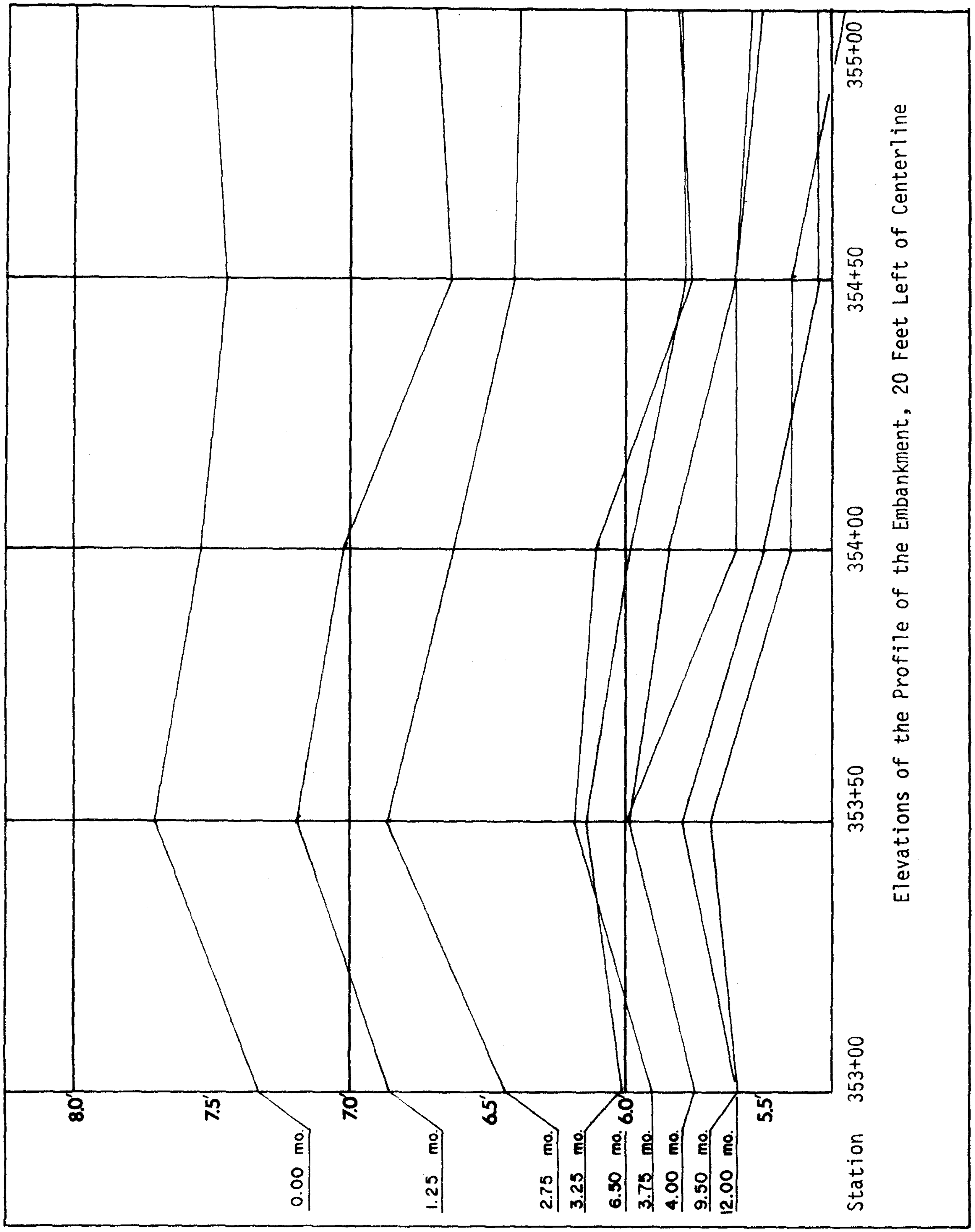
Elevations of the Profile of the Embankment, 20 Feet Left of Centerline
Station
353+00
353+50
354+00
354+50
355+00
8.0'
7.5'
7.0'
6.5'
6.0'
5.5'
0.00 mo.
1.25 mo.
2.75 mo.
3.25 mo.
6.50 mo.
3.75 mo.
4.00 mo.
9.50 mo.
12.00 mo.

FIGURE 31

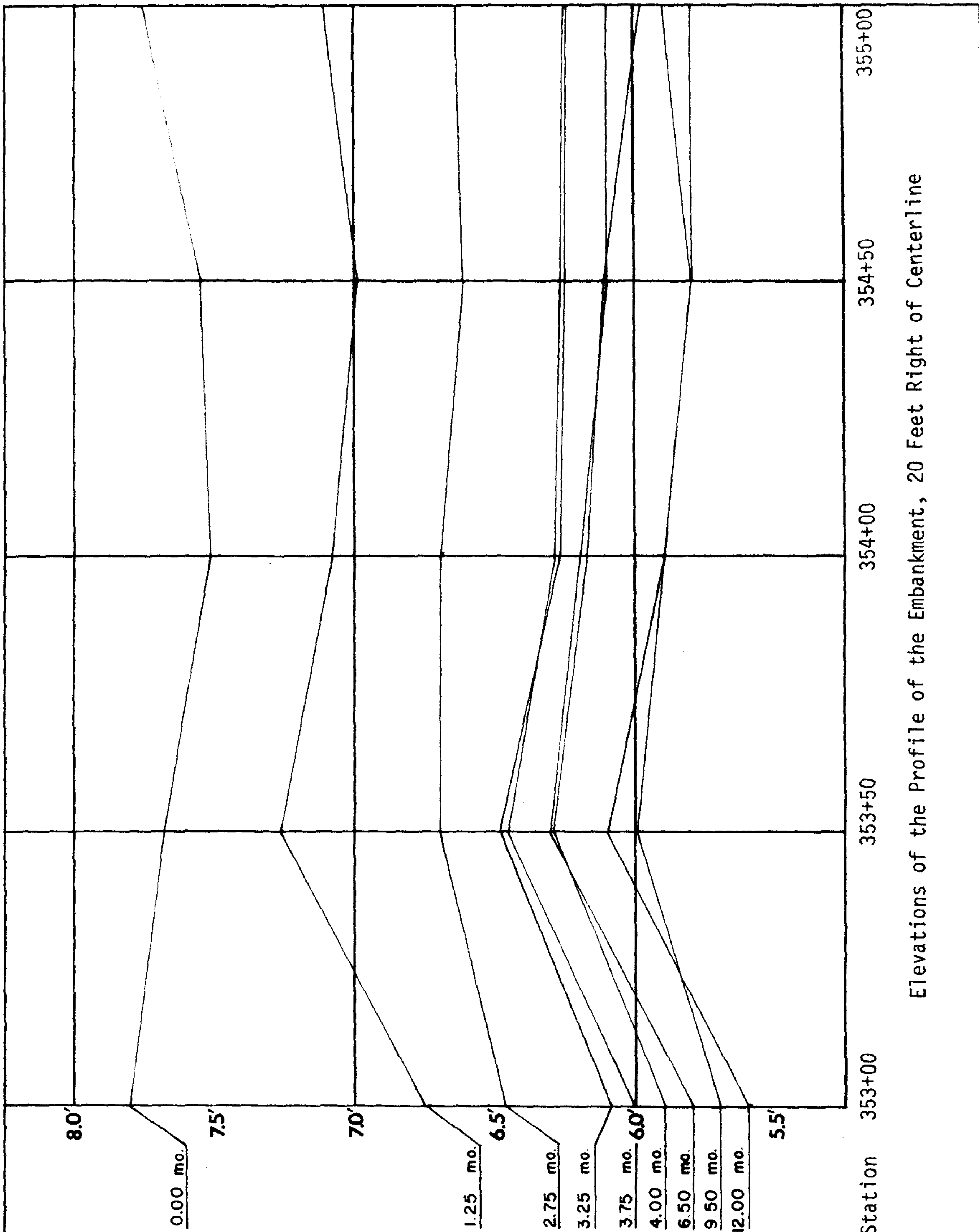
Elevations of the Profile of the Embankment, 20 Feet Right of Centerline
8.0'
7.5'
7.0'
6.5'
6.0'
5.5'
Station
353+00
353+50
354+00
354+50
355+00
0.00 mo.
1.25 mo.
2.75 mo.
3.25 mo.
3.75 mo.
4.00 mo.
6.50 mo.
9.50 mo.
12.00 mo.

FIGURE 32