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Use of Flowable Fill (CLSM) for Trench
Backfill

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Research Report
KTC-94-24

USE OF FLOWABLE FILL (CLSM)
FOR TRENCH BACKFILL

by

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in cooperation with
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November 1994

METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO METRIC UNITS					APPROXIMATE CONVERSIONS FROM METRIC UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH					LENGTH				
in.	inches	25.40000	millimetres	mm	mm	millimetres	0.03937	inches	in.
ft	feet	0.30480	metres	m	m	metres	3.28084	feet	ft
yd	yards	0.91440	metres	m	m	metres	1.09361	yards	yd
mi	miles	1.60934	kilometres	km	km	kilometres	0.62137	miles	mi
AREA					AREA				
in. ²	square inches	645.16000	millimetres squared	mm ²	mm ²	millimetres squared	0.00155	square inches	in. ²
ft ²	square feet	0.09290	metres squared	m ²	m ²	metres squared	10.76392	square feet	ft ²
yd ²	square yards	0.83613	metres squared	m ²	m ²	metres squared	1.19599	square yards	yd ²
ac	acres	0.40469	hectares	ha	ha	hectares	2.47103	acres	ac
mi ²	square miles	2.58999	kilometres squared	km ²	km ²	kilometres squared	0.38610	square miles	mi ²
VOLUME					VOLUME				
fl oz	fluid ounces	29.57353	millilitres	ml	ml	millilitres	0.03381	fluid ounces	fl oz
gal.	gallons	3.78541	litres	l	l	litres	0.26417	gallons	gal.
ft ³	cubic feet	0.02832	metres cubed	m ³	m ³	metres cubed	35.31448	cubic feet	ft ³
yd ³	cubic yards	0.76455	metres cubed	m ³	m ³	metres cubed	1.30795	cubic yards	yd ³
MASS					MASS				
oz	ounces	28.34952	grams	g	g	grams	0.03527	ounces	oz
lb	pounds	0.45359	kilograms	kg	kg	kilograms	2.20462	pounds	lb
T	short tons (2000 lb)	0.90718	megagrams	Mg	Mg	megagrams	1.10231	short tons (2000 lb)	T
FORCE AND PRESSURE					FORCE				
lbf	pound-force	4.44822	newtons	N	N	newtons	0.22481	pound-force	lbf
psi	pound-force per square inch	6.89476	kilopascal	kPa	kPa	kilopascal	0.14504	pound-force per square inch	psi
ILLUMINATION					ILLUMINATION				
fc	foot-candles	10.76426	lux	lx	lx	lux	0.09290	foot-candles	fc
fl	foot-Lamberts	3.42583	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.29190	foot-Lamberts	fl
TEMPERATURE (exact)					TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F

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EXECUTIVE SUMMARY

Controlled Low Strength Material (CLSM), commonly referred to as flowable fill, has been used for years as a trench backfill for utility repairs in Kentucky, and is now being used by the Kentucky Department of Highways (KDOH) on a limited basis. Flowable fill, when used as trench backfill, typically consists of natural sand, fly ash, cement, and water with a design compressive strength of 50 to 100 psi at 28 days. Flowable fill was used on two KDOH projects in 1991. One project was new construction in the widening and realignment of Breckinridge Lane in Louisville and the other was a maintenance project involving the replacement of cross drains on US 25 in Fayette County. These two uses of flowable fill were monitored for material engineering performance and characteristics, construction procedures, and cost effectiveness. Field observation and testing, laboratory testing, and determination of remedial costs from sites not using flowable fill were all components of the study.

Flowable fill is a very effective trench backfill when mixed properly. Both laboratory and field experience indicate that flowable fill should be exactly what the name implies; that is flowable. The material performs best when sufficient water is available in the mix to initiate almost immediate bleeding or separation of the water and solid particles. The bleeding is essential to densification of the backfill and the development of early strength. The inclusion of cement and fly ash increases flowability and long-term strength but early strength depends on densification and friction in the backfill. Long-term strength is an important consideration in that flowable fill should be readily excavatable in case of future repairs. Methods of predicting long-term strength, based on the mixes used for this study, and removability have been developed. The methods have been compared to excavations and compressive strength measured over a curing time of one year.

A cost comparison of CLSM and conventional backfill (manufactured limestone sand) indicates that when all factors are considered flowable fill is a cost effective trench backfill method. When compared on direct costs (materials, labor, and equipment) with identical conditions, flowable fill costs approximately \$9.50 per linear foot of pipe more than conventional backfill for a six-foot by six-foot trench; however, other factors such as trench dimension reduction permitted by use of flowable fill, increased alternatives in pipe permitted resulting from decreased pipe stress, decreased liability, and especially the reduction or elimination of remedial work result in a much lower unit cost for flowable fill. Many highways require patching of cross drain trench settlement within two years of being opened for service. The direct cost of one patch across 24 feet of pavement could pay the premium for several hundred feet of flowable fill.

INTRODUCTION

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A construction material referred to as Controlled Low Strength Material (CLSM) or flowable fill has been used frequently throughout Kentucky by private industry, utilities and local government. The material is typically used for utility repair trench backfill. Other uses include but are not limited to; pavement base, structural fill, and bridge and culvert renovation. Flowable fill is a self-leveling material composed primarily of water, portland cement, natural sand, and fly ash. This material was designated CLSM by the American Concrete Institute (ACI) Committee 229 and low strength was defined as less than 1,200 psi compressive strength at 28 days.

Since 1992, the Department of Highways (DOH) has used flowable fill on a limited bases. The first two DOH projects where flowable fill was used are the subjects of this investigation. The objectives of the investigation are;

- A. To document construction procedures and evaluate CLSM as a backfill material,
- B. to analyze the cost effectiveness of the use of CLSM, and
- C. to make recommendations relative to future use of CLSM.

The work plan consisted of two parts with Part 1 being the documentation of construction procedures and evaluation of field performance. To be included were site and trench conditions, construction personnel required, placement techniques, workability and other characteristics of CLSM, quantities placed, and production comparing CLSM and conventional backfill. Part 2 consists of a laboratory evaluation of engineering characteristics including mix design, flowability, compressive strength, permeability, air content, density, yield, and shrinkage. Other factors considered were conduit stresses, pavement settlement, possible changes in trench dimensions, and variables encountered with use of CLSM and various conduit materials (metal, concrete, and plastic). A previous report (1) documented site conditions, construction procedures, short-term performance, preliminary cost analysis, and results of the laboratory evaluation.

SITES

Site One is located in Jefferson County at the reconstruction of Breckinridge Lane in Louisville. Flowable fill was used for all storm drain trench backfill. All storm drains were reinforced concrete pipe ranging from 15 to 42 inches in diameter. Approximately

3,125 cubic yards of flowable fill were used to backfill approximately 7,081 feet of trench.

Site Two is located at US 25 in southern Fayette County. The project consisted of the removal and replacement of ten cross drains beginning at mile point 3.548 and extending to mile point 7.470. The cross drains were steel pipes ranging from 30-inch equivalent (horizontal elliptical) to 42-inch circular.

FIELD PERFORMANCE

Construction and Short-Term Performance

After some adjustments to the initial mix design at Site 1, the mix used was 50 pounds cement, 300 pounds fly ash, 2,750 pounds natural sand, and 583 pounds water. This mix produces a very flowable product that bleeds rapidly (begins within 2 to 3 minutes and is usually complete in 10 to 15 minutes) and develops sufficient strength to allow covering and light traffic in as little as one hour. Compressive strength (28 days) of the CLSM at Site 1 typically ranged from 50 to 150 psi. Dry density of this mix ranged from 120 to 122 pounds per cubic foot and in-situ moisture content ranges from 12 to 14 percent.

Placement required only a worker to direct the delivery vehicle and monitor retention forms for stability. The limits of a particular backfill were established by cutting a plywood template to culvert and trench dimensions and placing the template around the culvert and on the bedding. Three culverts (cross drains) at Site 1 (Stations 94+44, 97+60, and 103+98) were selected for observation. The culvert trenches at the stations were backfilled with flowable fill from centerline to the outlet end or junction box (western end) and backfilled at the inlet end (eastern end) with conventional backfill.

The mix at Site 2 was 40 pounds cement, 300 pounds fly ash, 2,750 pounds natural sand, and 500 pounds water. This mix was too dry to flow or bleed properly and voids were observed at some of the culverts. As work progressed, water was added to the mix for later pours and a more satisfactory product resulted. The drier CLSM did not noticeably bleed or develop sufficient strength to support traffic even after 3 to 4 hours curing. The addition of sufficient water to initiate bleeding within five minutes after placement produces a product having higher early strength.

Stress

Pressure meters were installed to monitor loads on the culverts. Site One culverts at Stations 94+44 (24-inch), 97+60 (18-inch equivalent), and 103+98 (36 inch) were monitored. Pressure meters were installed at the flowable fill backfilled section at each culvert and at the conventional backfilled section at Station 97+60. Meters were installed at the bottom of each culvert and at the top of the culvert at Stations 94+44 and 97+60. A pressure meter was installed at the flowable fill/bedding interface at Station 103+98. Typical locations of the pressure meters on the culverts are shown in Figures 1 and 2.

Pressure data indicate that as flowable fill was placed culvert loading was at its highest and as the flowable fill bled water, the pressure decreased rapidly. In every case, the meter at the bottom of the culvert indicated higher pressure than the meter at the top of the culvert. The highest pressure at any location where flowable fill was used was approximately 11 psi as of 1994. The highest pressure recorded at a flowable fill location was 32 psi immediately after placement of the backfill. Pressure data for the flowable fill culverts are shown in Figures 3, 4, and 5. It should be noted that negative data are usually due to initial readings being obtained after the meter has been placed in the trench or on the culvert. Apparently, in some cases there was an existing pressure at the time of the initial reading.

Pressure data for the culvert having conventional backfill are significantly different than at the flowable fill locations. Pressure has continued to increase since installation and is approaching 50 psi at the bottom of the culvert. This magnitude of pressure cannot be due to weight of the fill but must be due to differential settlement or some other condition. Pressure data for the meters at the culvert having conventional backfill are shown in Figure 6.

Meters were placed on two culverts at Site Two. At each site, the meter at the top of the culvert was destroyed during the backfill operation. Meters located at the bottom of the culverts indicate very low pressure at the two to three psi range. Data from these meters are shown in Figure 7.

Settlement

Settlement monitoring points were established on the pavement surface at both Site One and Site Two. Monitoring points at Site One were painted on one foot intervals parallel to centerline, approximately one foot from the curb, for a distance of 25 feet at Stations 94+44 and 97+60. A junction box was located near the center of the south-bound lanes

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at Station 103+98. From the junction box to the curb, the culvert ran at a sharp skew therefore the monitoring points at Station 103+98 were located perpendicular to the centerline. Figures 8 and 9 show the layout of settlement monitoring points at Site One.

Site One

Paving was completed at Site One in November 1992. The monitoring points were established and initial data were obtained in February of 1993. Elevation benchmarks were established near each Station to permit precise surveying of the points. Data do not clearly indicate settlement at any of the flowable fill Stations. At Station 94+44, there was settlement of 0.009 foot at one monitoring point but, this was a single point where an error on the initial reading could indicate a false settlement.

Data at the conventional backfill Station indicate settlement up to 0.015 foot over a distance of 10 feet centered over the culvert. A settlement of this magnitude (3/16 inch) does not create a problem with rideability of the pavement but, is clearly different than the flowable fill Stations. Elevations of monitoring points at each Station at Site One are plotted in Figures 10 through 13. Settlement is calculated by subtracting initial elevation from all subsequent elevations and is plotted in Figures 14 through 17.

Site Two

The cross drains were completed and bituminous pavement was in place in October of 1992 at Site Two. At that time, monitoring points were established by painting three points (5, 10, and 15 feet from the west guardrail) at each cross drain. Due to a combination of settlement and uneven initial patching, all ten cross drains were repatched in June 1993. Monitoring points were reestablished after patching was completed.

Due to the disturbance of two bench-marks and the second patching, settlement data at Site Two are somewhat erratic but, it appears that over a two-year period the trenches have settled from 0.018 to 0.035 feet. The greater settlement is located at the deeper trenches and at these culverts cracks extending along the approximate trench sides are visible in the pavement. The earlier report documented the less than standard quality of the flowable fill at Site Two. It is probable that the flowable fill did not densify properly and in some cases voids remained under the culvert pipe. These conditions are probably the cause of the greater settlement at Site Two.

REMOVABILITY

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While the elimination or reduction of trench backfill settlement may be the primary reason for using CLSM, an additional benefit is the stability of the material in subsequent excavations. As the compressive strength of CLSM increases, it will be increasingly difficult to excavate but a material having no cohesion or cementation (jetted sand) presents problems with collapsing excavation walls. The characteristics of CLSM that provide the stability also introduce a concern with the removability of CLSM. In an effort to evaluate the removability of CLSM, an empirical relationship developed by William Brewer (2) was used. Mr. Brewer's relationship yields a removability factor (RF) and is expressed as:

$$RF = \frac{5.27TJ \left[1 + \frac{IP-D^3}{\sqrt{IPD}} \right]}{SA}$$

where:

- RF = Removability factor
- T = Equipment type
- J = Cutting edge used on the excavating equipment
- I = Impact factor
- P = Power factor based on equipment used
- D = Direction of excavation
- A = Area under the stress/strain curve = 0.0094 x [compressive strength]^{1.4} (lb.ft.)
- S = Density (pcf)

Cutting Edge (J)	(J)	Impact (I)	(I)	Equipment (T)	(T)
Blade	50	Low	10	Hand Tool	10
Tooth	100	Average	20	Air Spade	30
Point	150	High	30	Backhoe	50
				Clam Bucket	20
				Dragline	25

Power Factor (P)	
Low	1
Average	5
High	10

Direction of Cut (D)	
Along trench	2
Across trench	1

In Brewer's relationship, the RF value is inversely related to effort required to excavate the material.

The following are the ranges of removability:

<u>RF value</u>	<u>Removability</u>
0 - 20	Unable to excavate
20 - 40	Extremely difficult to remove
40 - 60	Removal with difficulty
60 - 80	Fairly easy to remove
80 - 100	Easy removal

Brewer's relationship was used to evaluate an excavation of CLSM and was judged to accurately reflect the effort required to excavate only if the actual compressive strength of the CLSM at the time of excavation was used rather than the 28-day compressive strength. A method of predicting ultimate strength was developed in the previous report (1). This method involved plotting the compressive strength (dependant variable) at two or more curing ages versus the curing age in days. A hyperbolic function is fitted to the data and the function is converted to a straight line by plotting age/strength (X/Y) as the dependant variable versus age. The inverse slope of the straight line appears to be a reasonable approximation of ultimate strength.

Current practice is not to cast cylinders for breaks at different ages. In order to predict ultimate strength and thus difficulty of removal of CLSM, additional cylinders could be cast to provide additional strength data or a means of predicting ultimate strength from the 28-day test should be developed. Compressive strength testing of four sets of cylinders over time until there was little or no increase in strength indicated that ultimate strength was 2.1 to 4.4 times the 28-day strength of the particular mix used at Site 1. A multiple of 4.5 to 5.0 times the 28-day strength would yield a conservative estimate of removability for that mix or a similar mix.

LABORATORY EVALUATION

Laboratory testing of cylinders cast primarily at Site 1 indicates the following engineering properties of the CLSM mix used at Site 1;

average volumetric shrinkage of 3.1 percent,
resilient moduli of 35,000 and 46,000 psi,

permeability ranging from 5.47×10^{-5} to 1.09×10^{-7} centimeters per second, internal friction angle of 39.5 degrees, cohesion of 3.6 psi, and optimum moisture/density conditions of approximately 10 percent moisture and dry density of 126.5 pounds per cubic foot.

A laboratory mix design analysis addressed the use of manufactured limestone sand (MLS) as a CLSM filler as compared to the normal natural river sand (NRS) filler. Findings were that CLSM with MLS filler exhibits greater ultimate strength, significantly longer bleed time, greater settlement or shrinkage, and requires significantly more time to develop sufficient bearing capacity to accept traffic. The minimal reduction in cost would not negate all the performance liabilities of MLS as a CLSM filler for highway construction purposes.

COST EFFECTIVENESS

A cost comparison between flowable fill and conventional backfill was performed for conditions at Site 1. The comparison included costs of labor, equipment, and materials. The comparison was made by monitoring the costs of a trench backfilled with manufactured sand and calculating the cost to backfill an identical trench with flowable fill based on contract prices and observed construction practices. The trench was 28 feet long and averaged six feet in width and depth. The total direct cost for conventional backfill was \$672.44 and calculated cost of flowable fill backfill was \$938.71 or approximately \$9.51 per linear foot of pipe for a six foot by six foot trench.

Several factors which either increase the cost of conventional backfill or decrease the cost of flowable fill are difficult to assign value to but must be applied where possible. Factors such as liability, productivity, and testing all favor flowable backfill but are very difficult to quantify in the comparison; however, remedial work and trench configuration are factors that can be included.

Conventional backfill must be mechanically compacted, therefore trench width must be sufficiently wide to permit compactors between the pipe and trench sides. Flowable fill is self compacting and permits a trench of lesser width. If the trench dimensions used in the cost comparison were reduced to one foot of clearance on each side of the pipe (4.5 feet width), the cost of flowable fill backfill (\$669.88) would actually be less than conventional backfill.

While trench dimensions may render the costs roughly equivalent, remedial work potentially has the greater impact on costs. US 127 in Anderson County was being widened from two to four lanes at the same time that Breckinridge Lane was being widened. Within months of being put into service, most cross drains on the new

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construction on US 127 were reflected in settlement trenches in the pavement surface. Settlement within some of the trenches are approaching two inches in depth and two required patching in 1994. One of the patching operations was performed in conjunction with other work and one was performed separately. Costs of the patching (labor, equipment, and materials) was \$1,758.10 for the separate work and \$1,083.53 for the other. The lower cost is in part due to the sharing of mobilization costs for the patching performed with other work.

CONCLUSIONS and RECOMMENDATIONS

CLSM or flowable fill is a product that performs very well as a trench backfill when properly mixed. CLSM which includes sufficient water to produce copious bleeding in five minutes or less after placement provides a backfill that will not settle significantly, reduces loading on culverts or pipes, is not labor intensive, provides for quick completion of trench backfill, and develops sufficient strength to support normal traffic in as little as one hour after placement.

Some problems with the use of CLSM is unfamiliarity with the product among inspection and construction personnel and a high initial unit cost. Users and inspectors can be educated concerning the product and due to several factors the final cost of CLSM can be much lower than conventional backfill. The flowable characteristic and elimination of the need for compaction permits more narrow trench width in many cases. This factor alone may reduce the cost of CLSM to approximately the cost of conventional backfill. The reduction of pipe loading could permit the reduction of pipe wall thickness or the use of a different type pipe, but the most significant cost reduction factor is the elimination of remedial work with a minimal inspection and acceptance effort during construction. The rule rather than the exception appears to be trench settlement and pavement patching in either new construction or utility repair sites. Even without reduction of trench width, safety concerns with patching jobs or other cost reductions one patch across two 12-foot lanes on US 127 cost as much as the premium paid for nearly 200 linear feet of CLSM backfill in a 6-foot by 6-foot trench.

CLSM should be designed for 40- to 50-psi compressive strength at 28 days with the understanding that the inclusion of fly ash will probably result in ultimate strengths of 4 to 5 times the 28-day strength. CLSM of 500 psi or more will be difficult to excavate. In the use of flowable fill, it should be noted that target compressive strength is a maximum strength rather than a minimum strength which many inspectors are familiar with as a result of working with concrete specifications.

One test for flowability and acceptance which is included in many Special Notes for flowable fill is the cylinder flow test. The applicability of the flow test is questionable for on-site inspection because of difficulty in completing the test before bleeding and segregation occurs. This test did not produce repeatable results in field tests. A test pour

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with an objective of copious bleeding in less than 5 minutes will produce a satisfactory mix for normal trench backfill purposes.

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2. Brewer and Associates, "Factors Governing The Removability Of Controlled Low Strength Material - Controlled Density Fill - (CLSM-CDF), Cincinnati Gas And Electric Company, Cincinnati, Ohio, May, 1991.

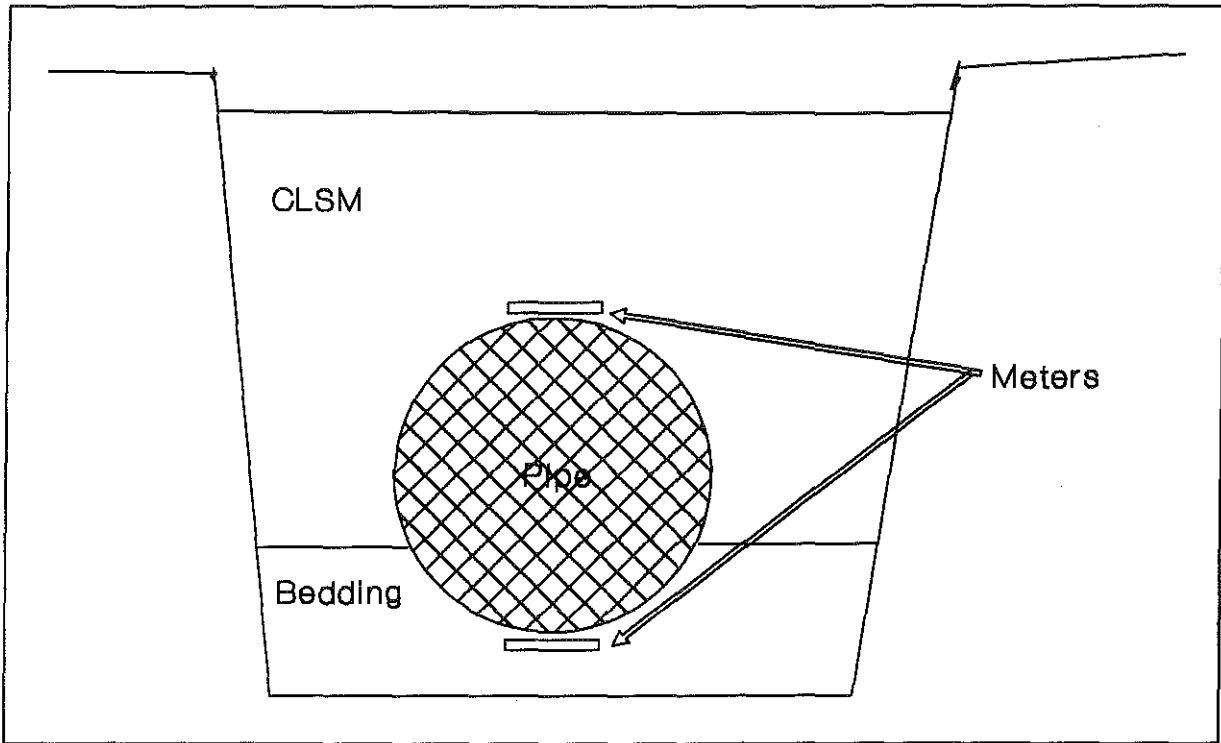


Figure 1. Placement of meters on culverts at Stations 94+44 and 97+60.

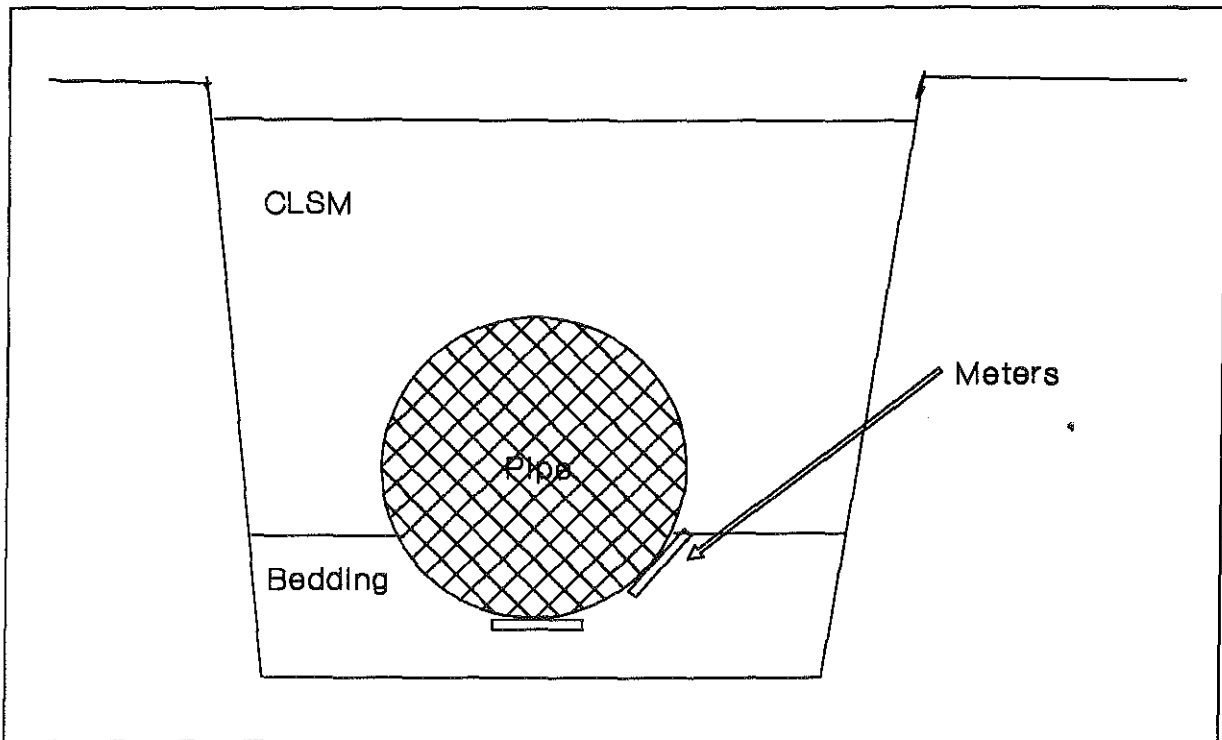


Figure 2. Placement of meters at Station 103+98.

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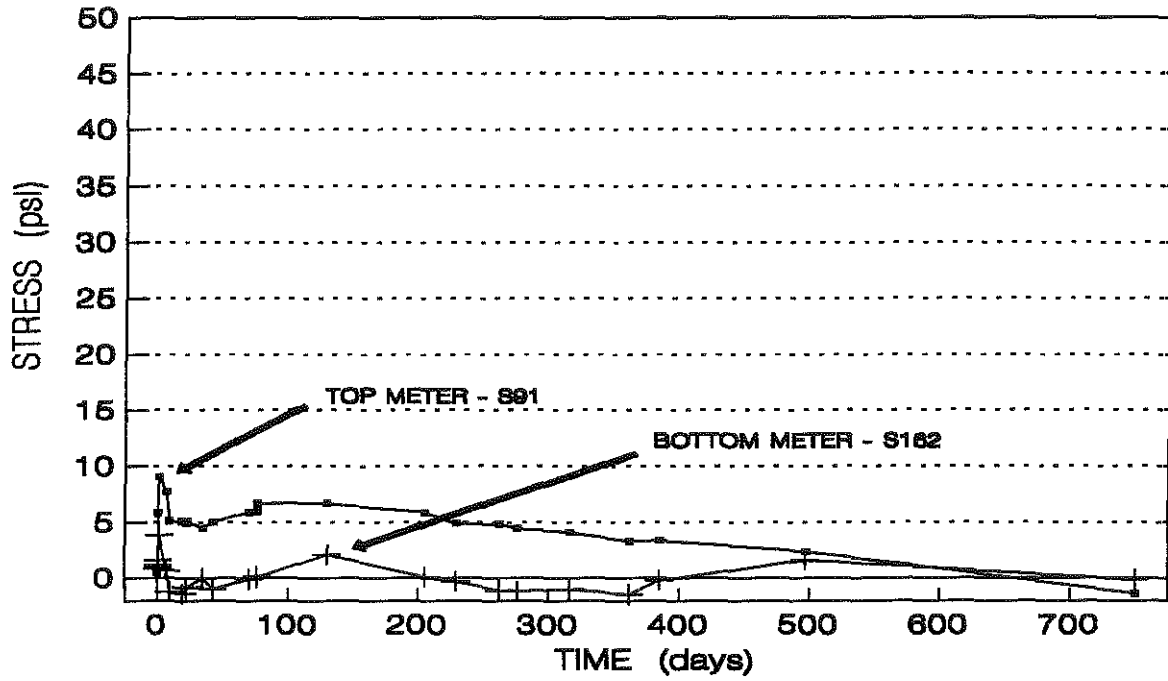


Figure 3. Culvert stress at Station 94+44.

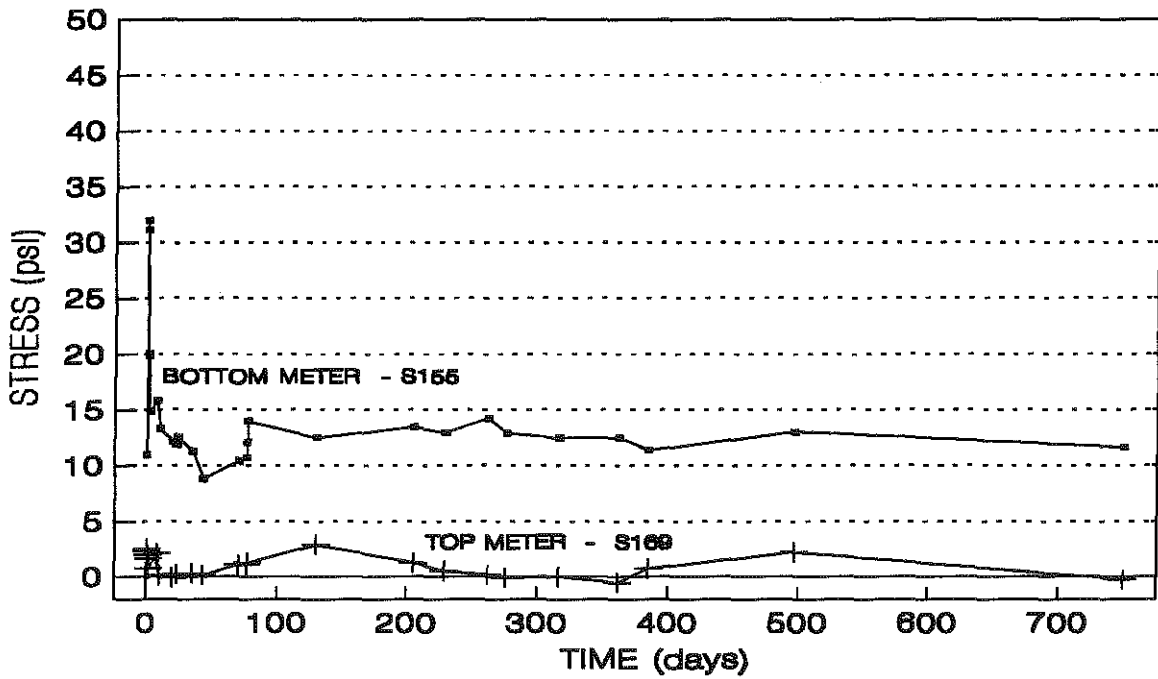


Figure 4. Culvert stress at Station 97+60 - flowable backfill.

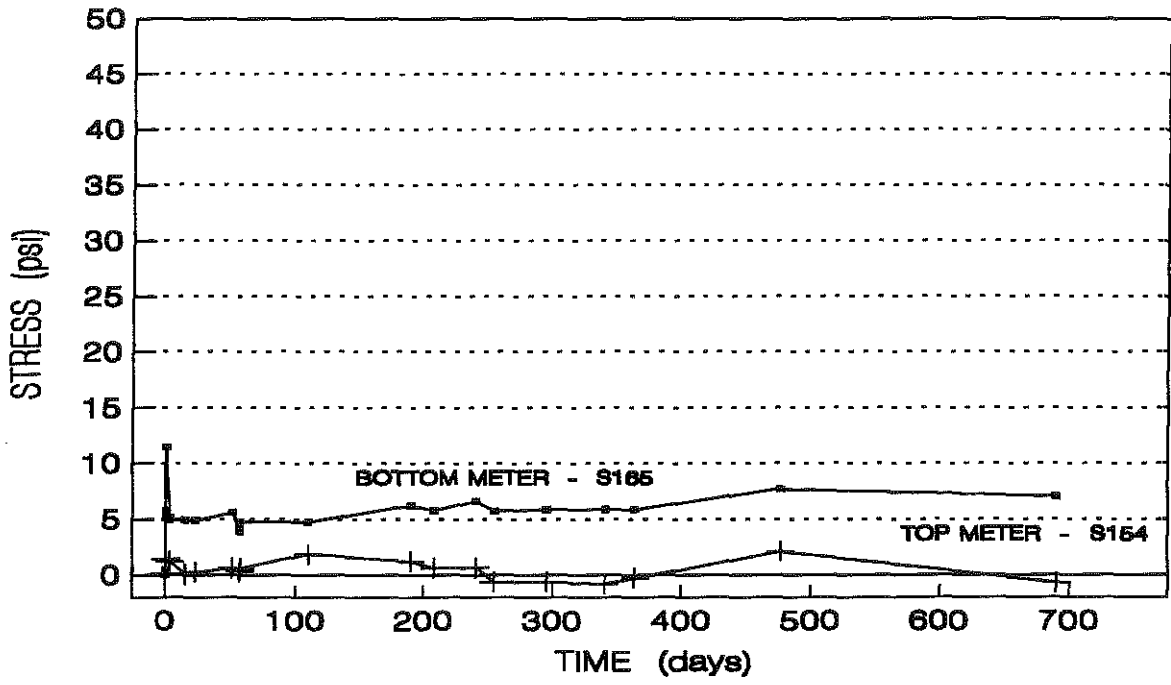


Figure 5. Culvert stress at Station 103+98.

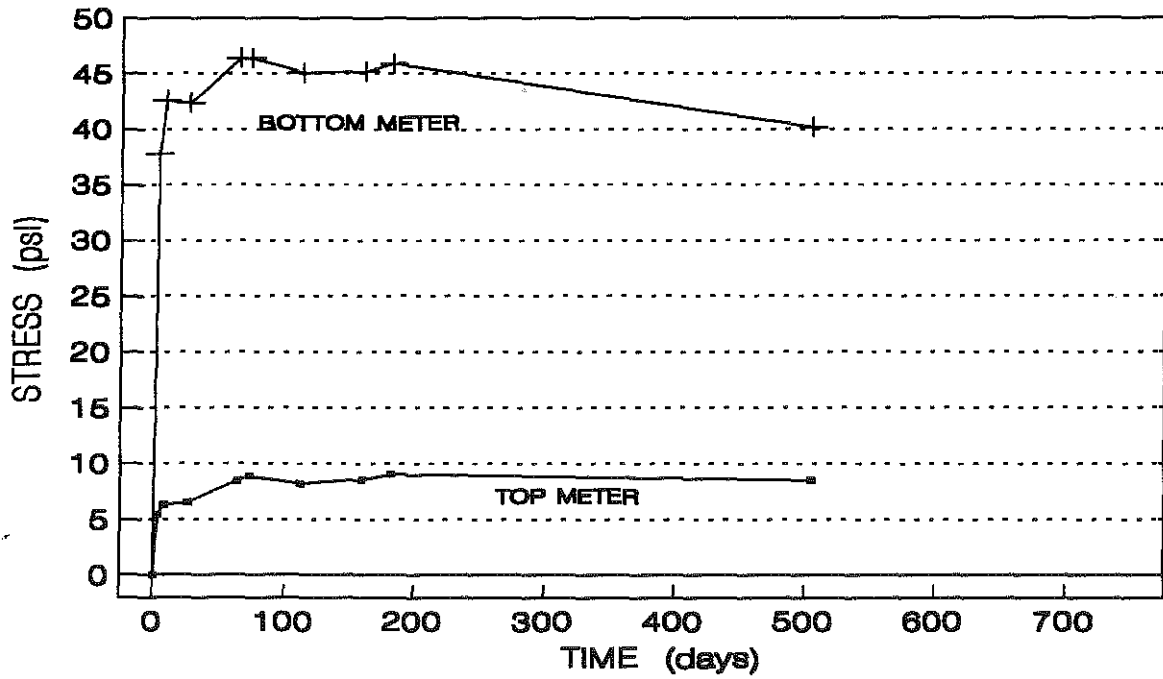


Figure 6. Culvert stress at Station 97+60 - conventional backfill.

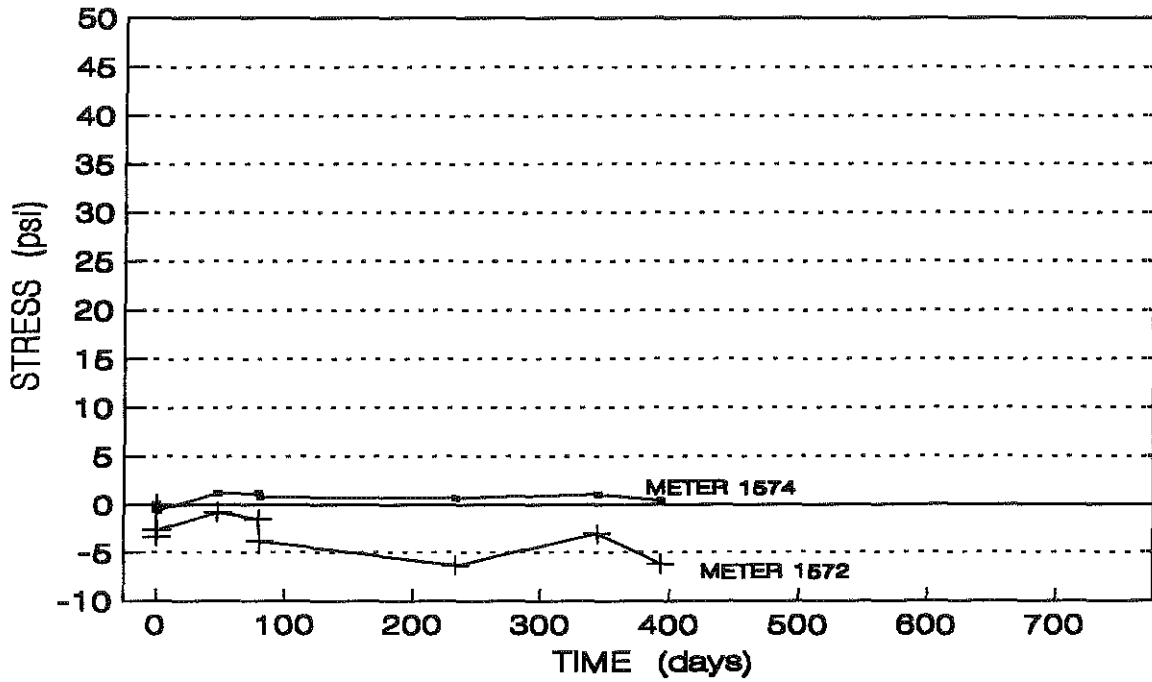


Figure 7. Culvert stress at Site 2. Both meters at bottom of culverts.

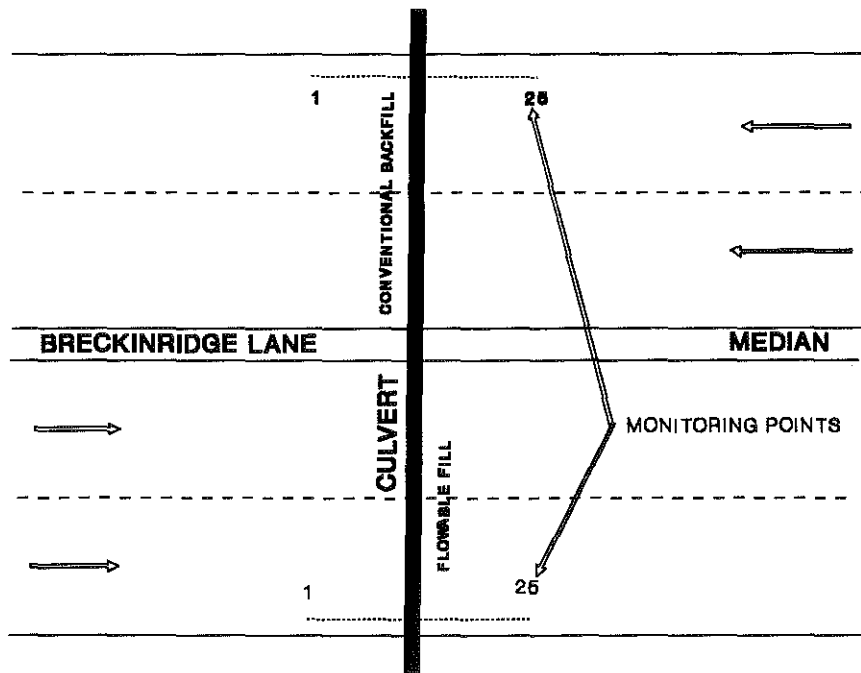


Figure 8. Location of settlement points at Stations 94+44 and 97+60.

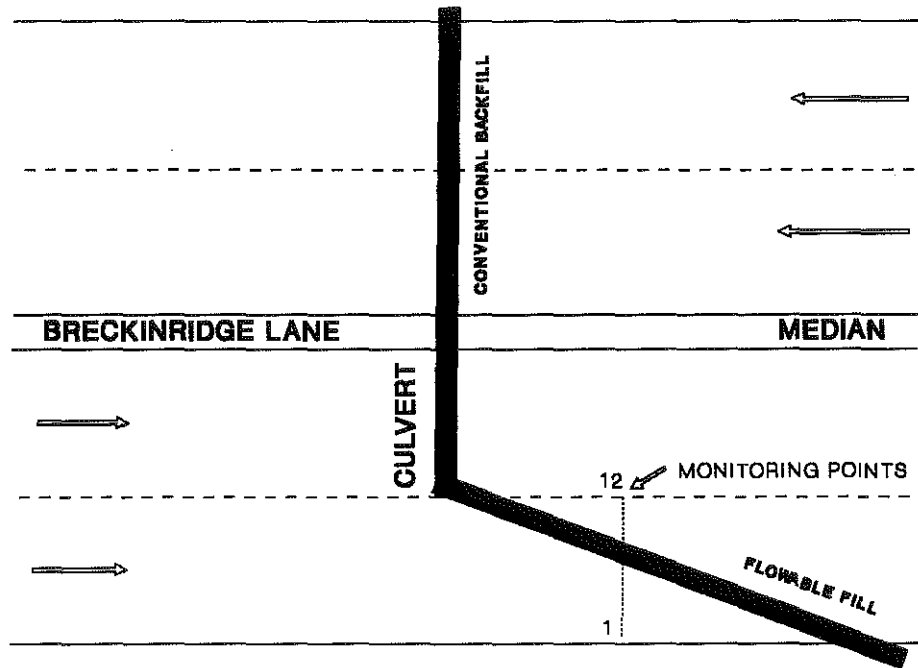


Figure 9. Location of settlement points at Station 103+98.

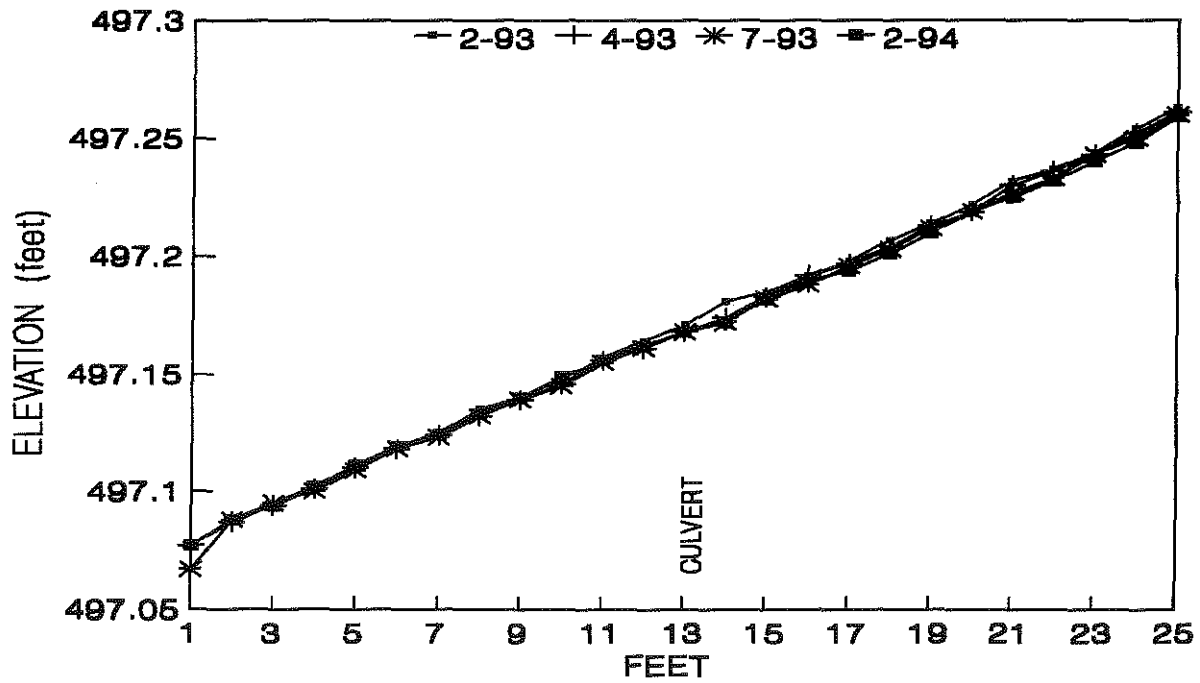


Figure 10. Elevation of settlement points at Station 94+44.

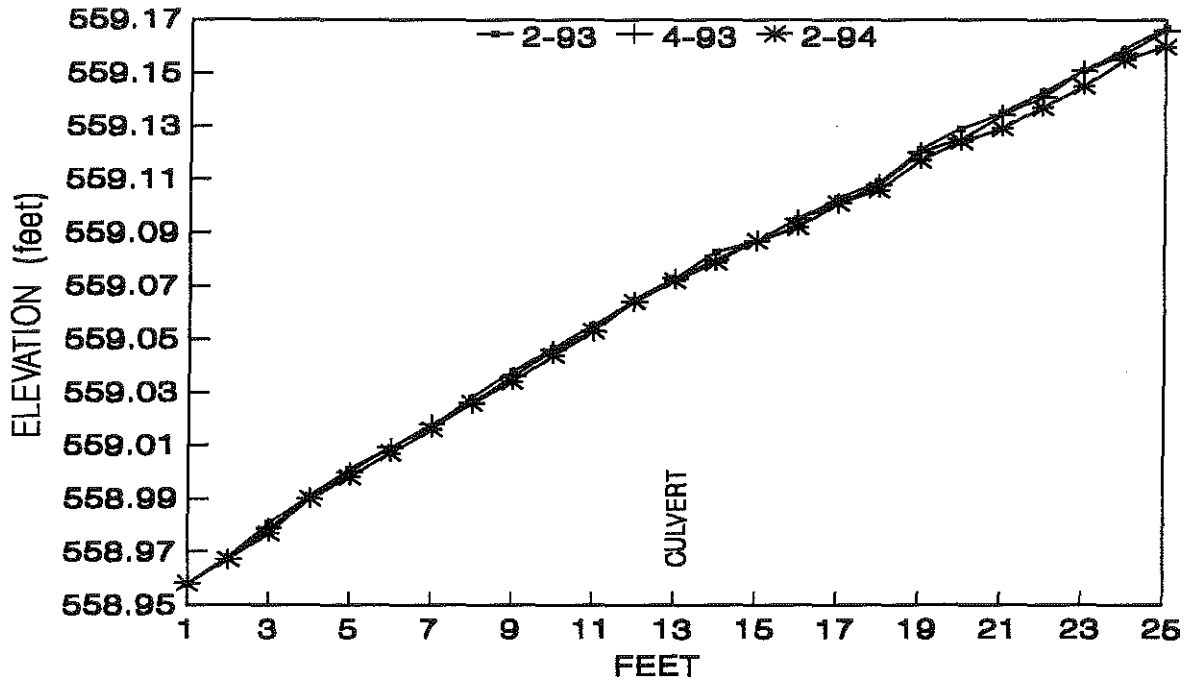


Figure 11. Elevation of settlement points at Station 97+60 - flowable backfill.

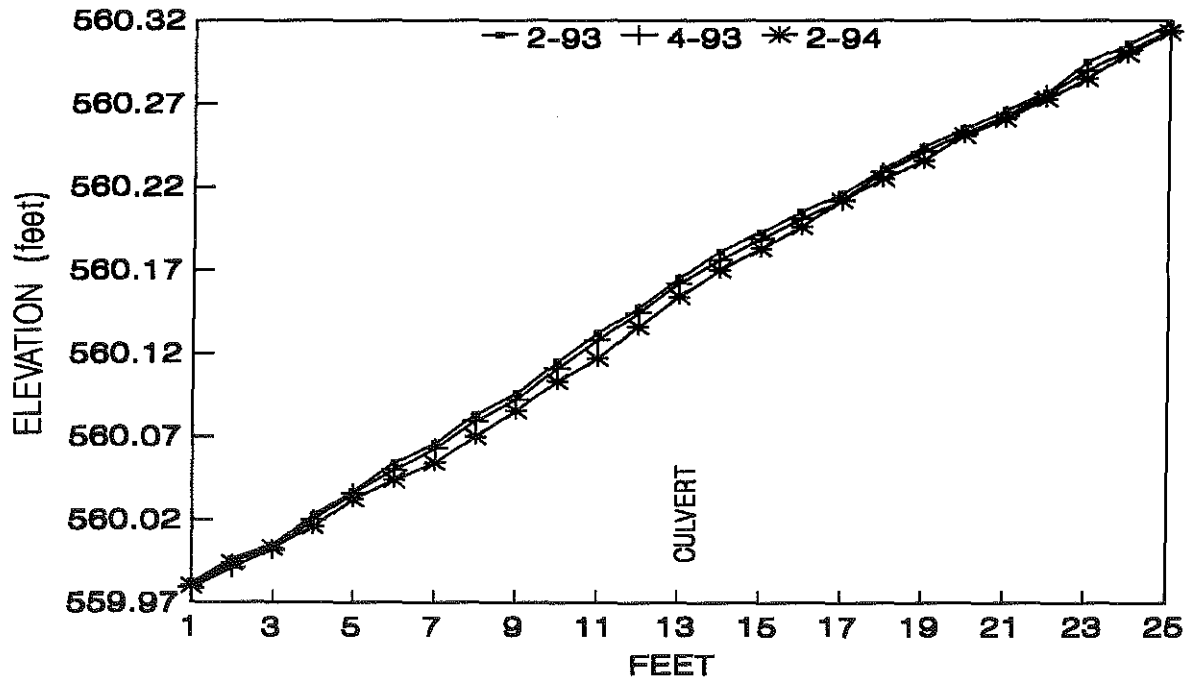


Figure 12. Elevation of settlement points at Station 97+60 - conventional backfill.

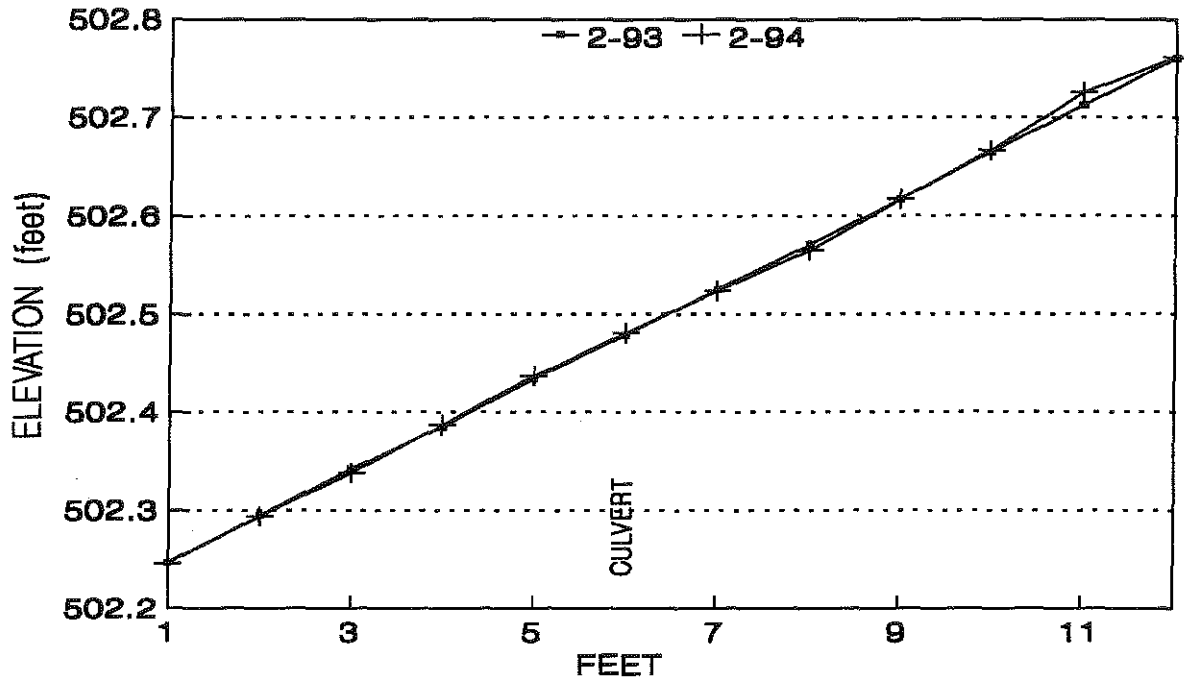


Figure 13. Elevation of settlement points at Station 103+98.

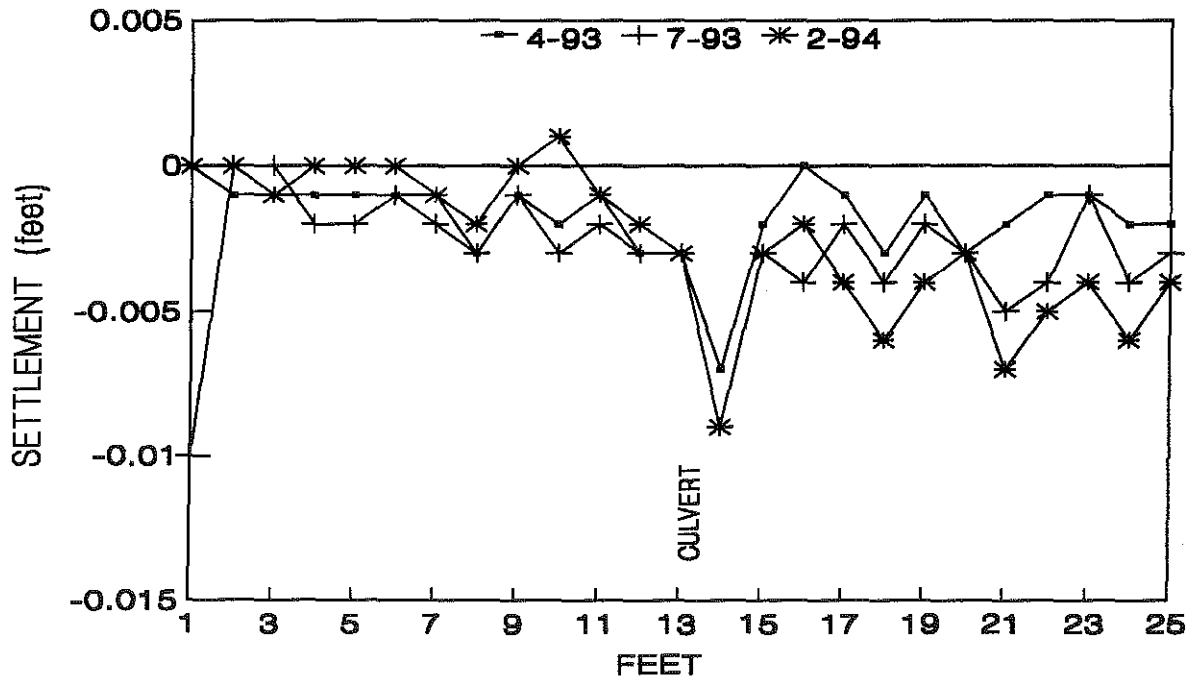


Figure 14. Settlement at Station 94+44.

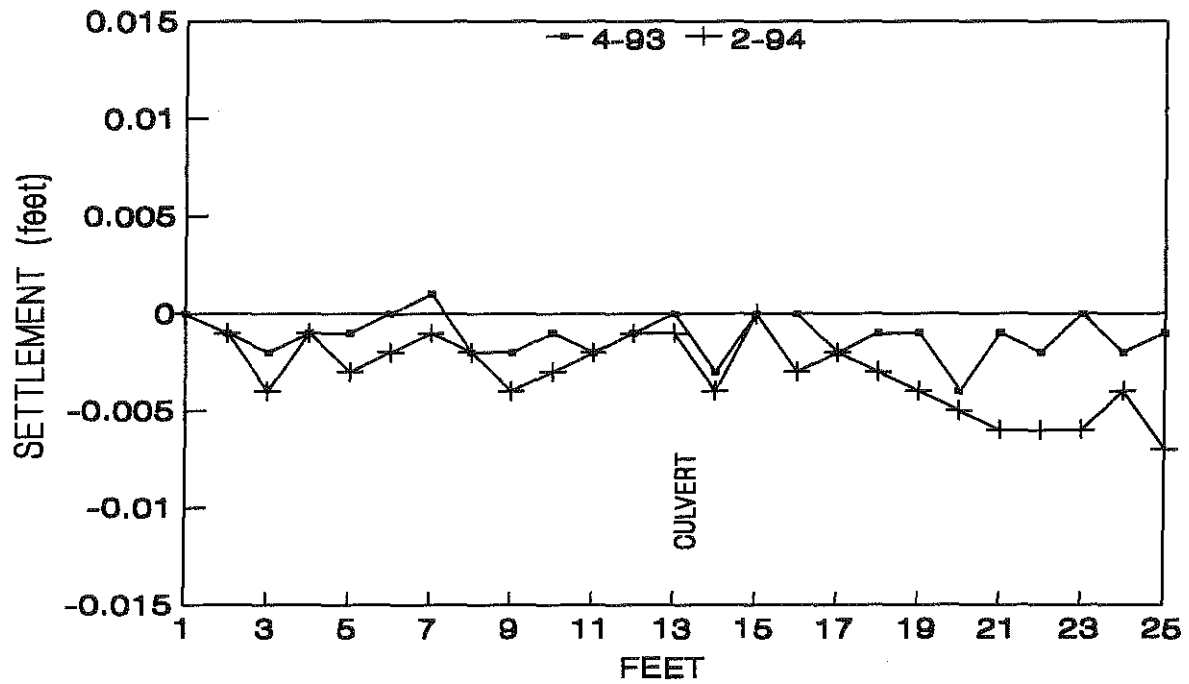


Figure 15. Settlement at Station 97+60 - flowable backfill.

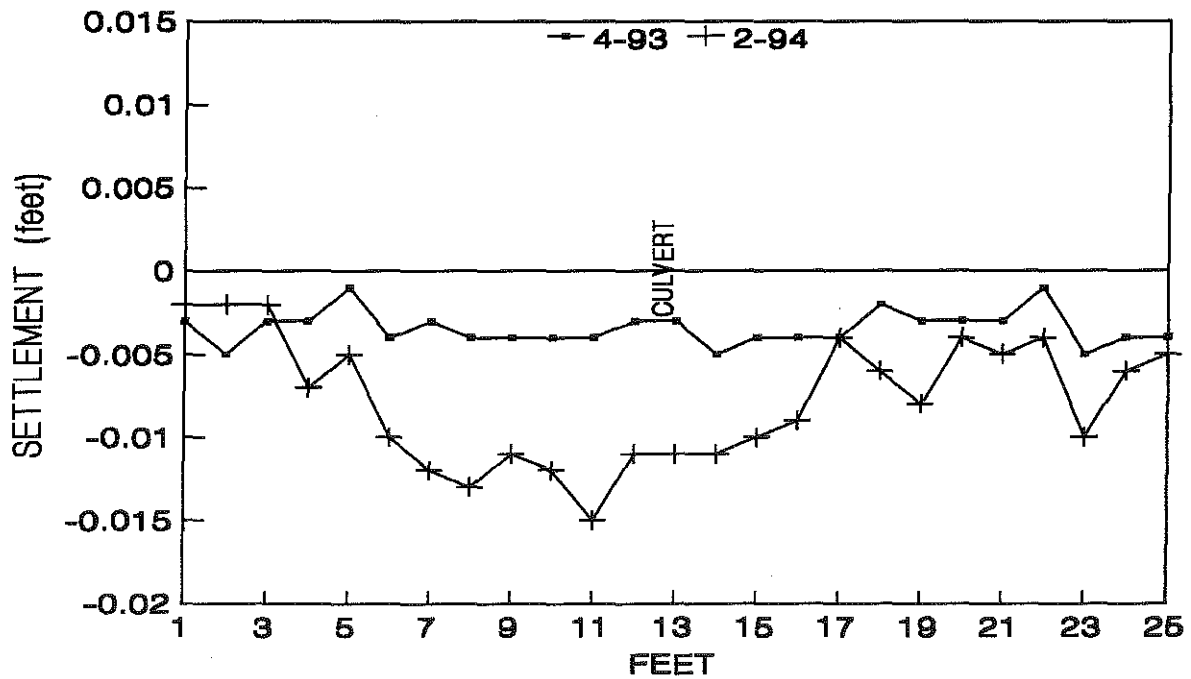


Figure 16. Settlement at Station 97+60 - conventional backfill.

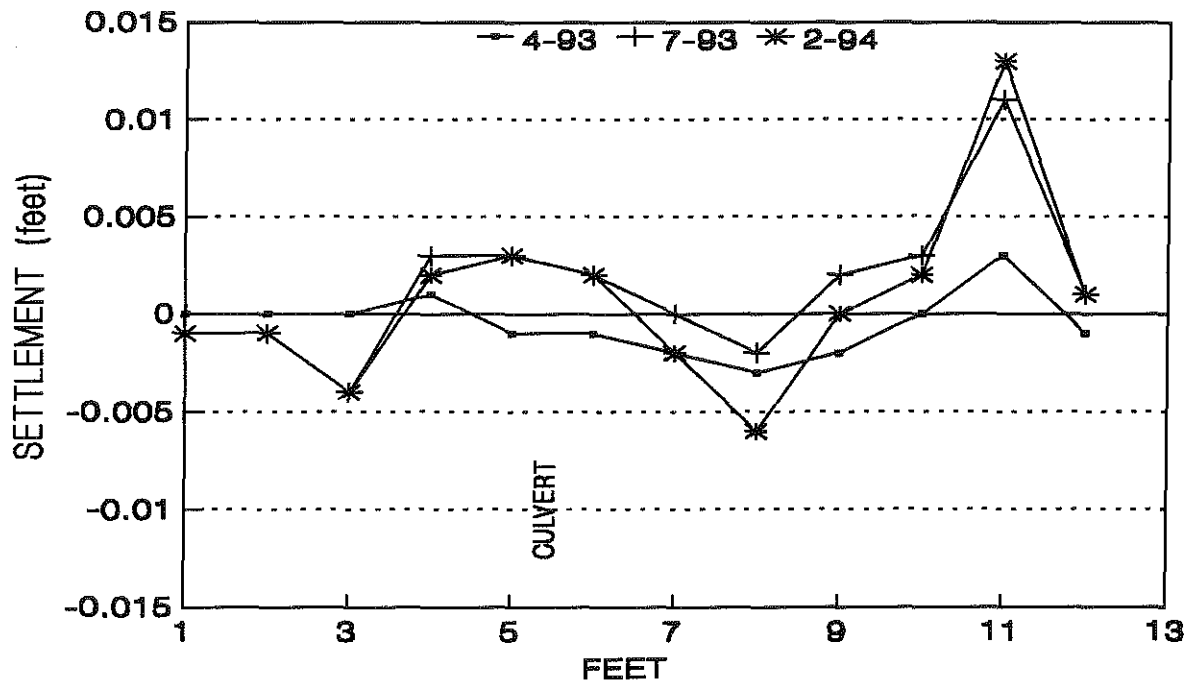


Figure 17. Settlement at Station 103+98.