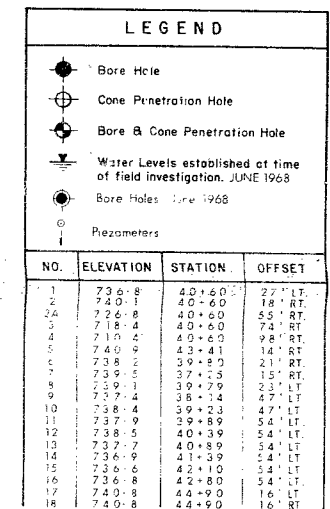
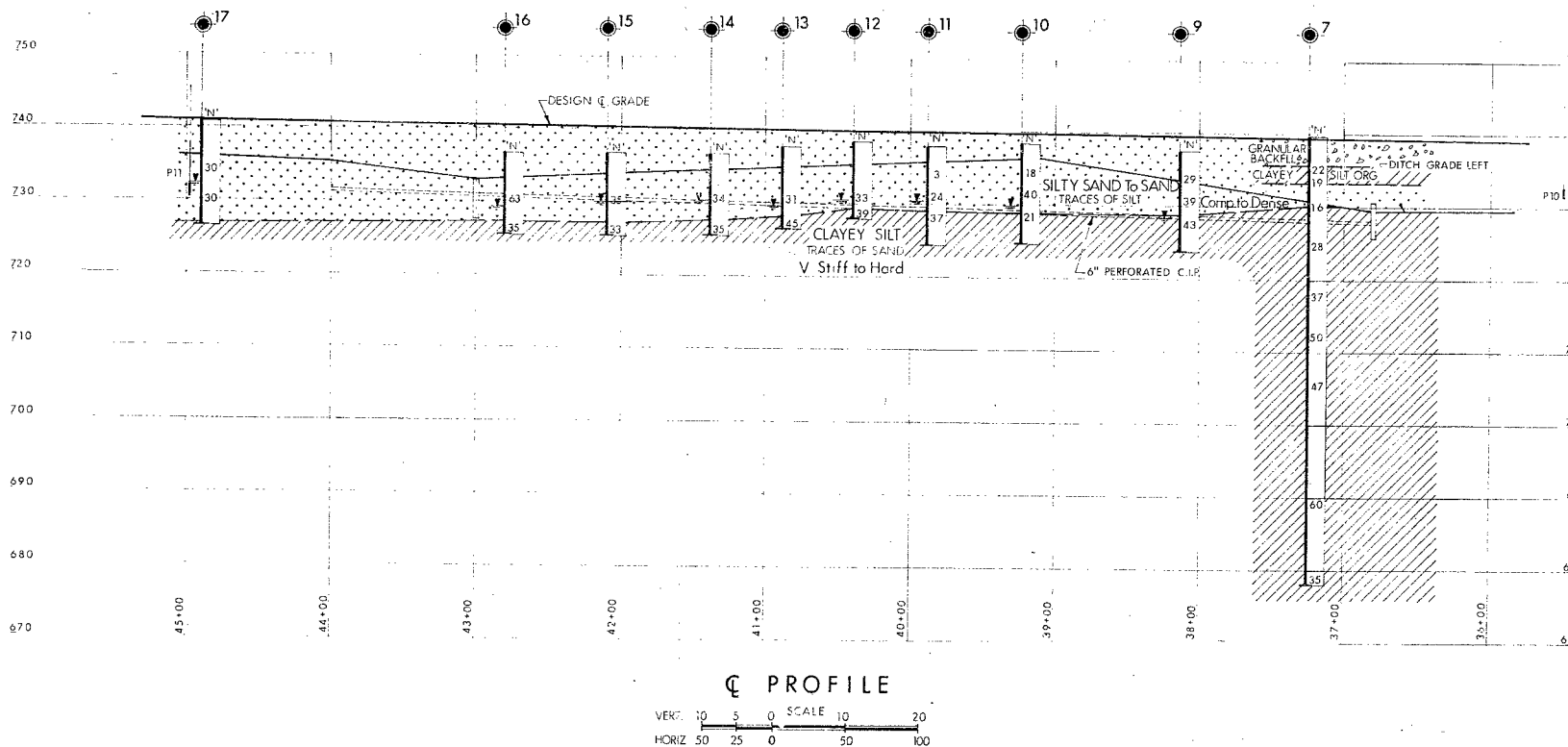


#67-F-95-1

DEVELOPMENT

ROAD\* 724

STATIONS 35<sup>TO</sup>45

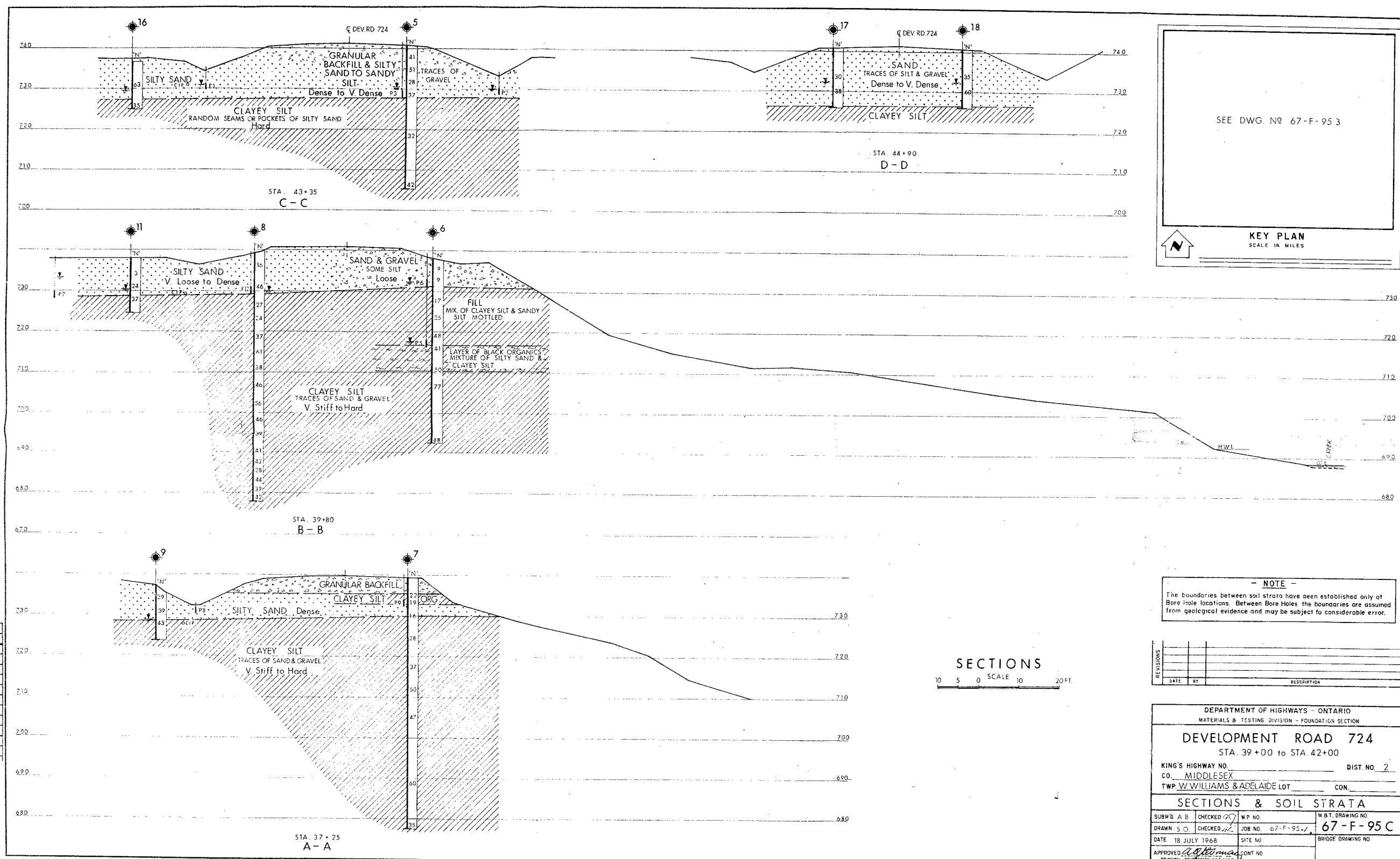


- NOTE -

The boundaries between soil strata have been established only at Bore Hole locations. Between Bore Holes the boundaries are assumed from geological evidence and may be subject to considerable error.

REVISIONS			
	DATE	BY	DESCRIPTION

DEPARTMENT OF HIGHWAYS - ONTARIO			
MATERIALS & TESTING DIVISION - FOUNDATION SECTION			
DEVELOPMENT ROAD 724			
STA. 39 + 00 TO STA. 42 + 00			
KING'S HIGHWAY NO. _____		DIST. NO. 2 _____	
CO. MIDDLESEX			
TWP. W. WILLIAMS & ADELAIDE LOT _____		CON. _____	
BORE HOLE LOCATIONS & SOIL STRATA			
SUBWD. A B	CHECKED <i>19</i>	W.P. NO. _____	M.S.T. DRAWING NO. _____
DRAWN S.O.	CHECKED _____	JOB NO. 67 - F - 95-1	67 - F - 95 B.
DATE 18 JUL 1968	SITE NO. _____	BRIDGE DRAWING NO. _____	
APPROVED <i>A. B. Thomas</i>	CONT. NO. _____		

[illegible]

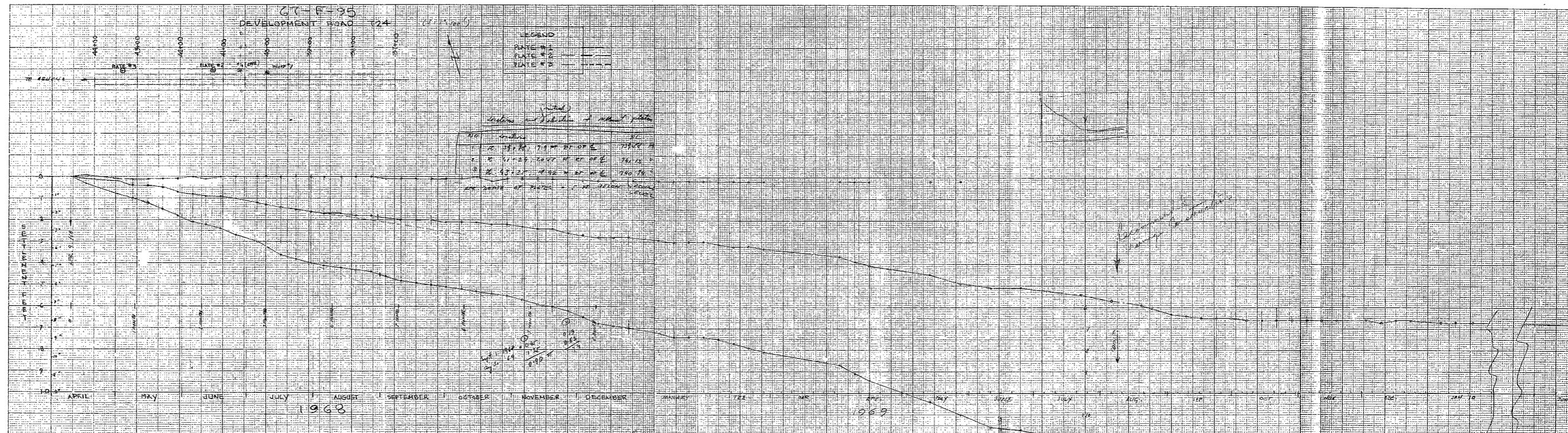


FIG. # 1

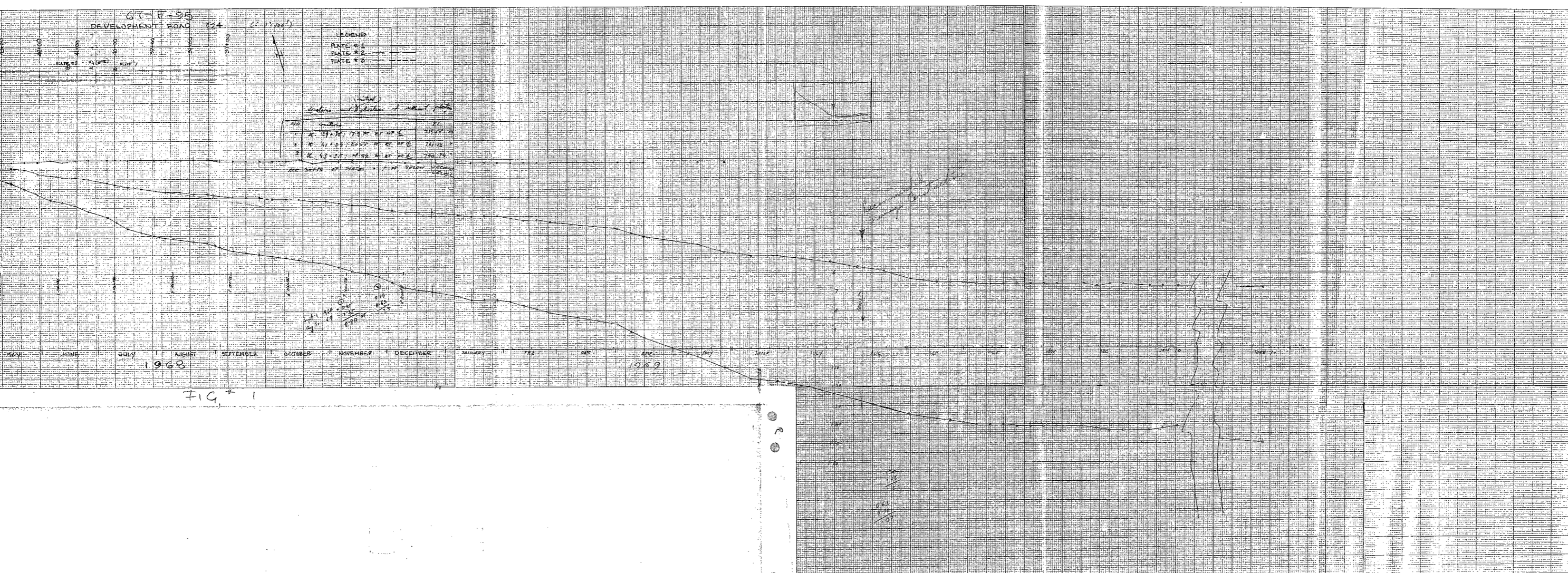
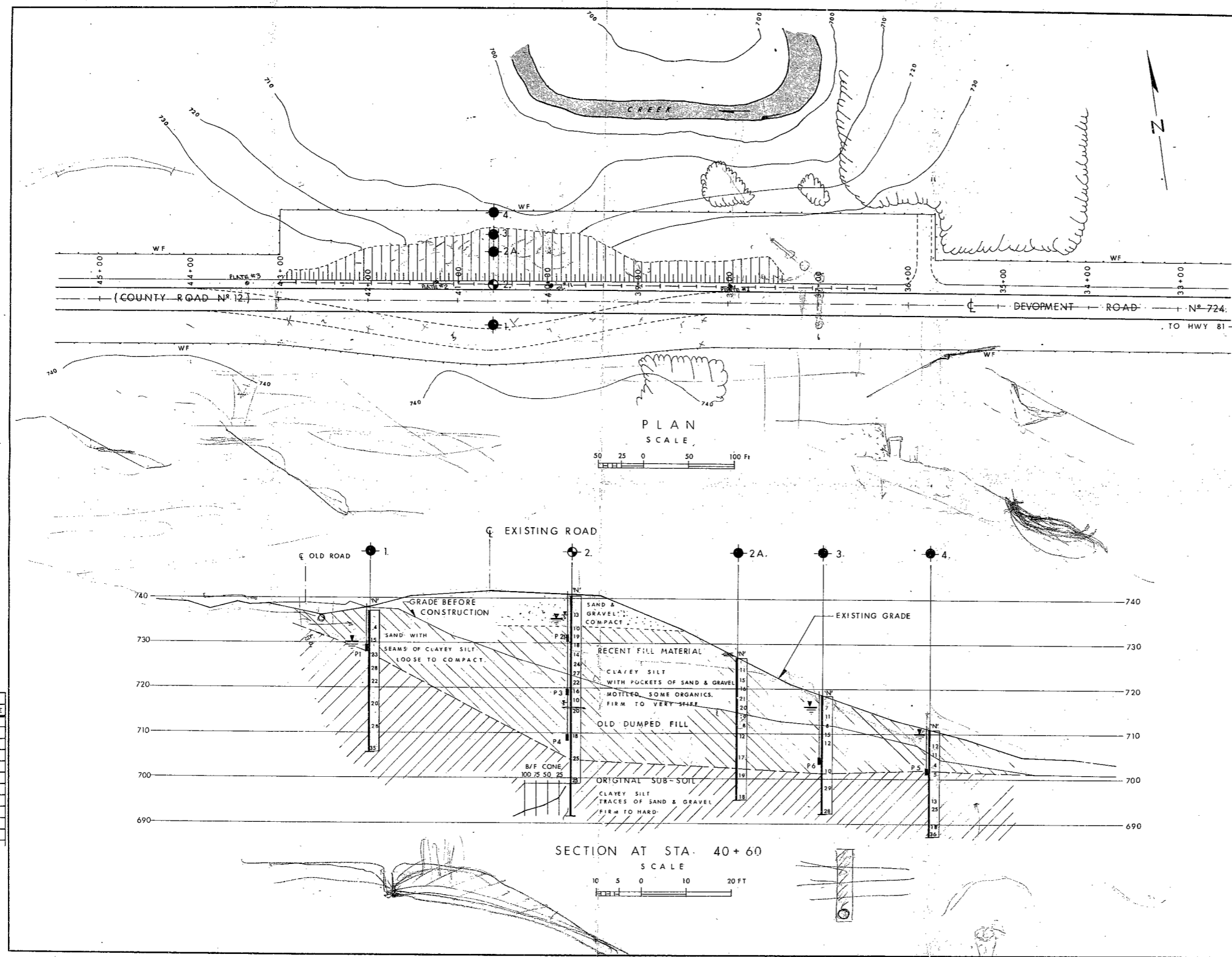


Fig. 1

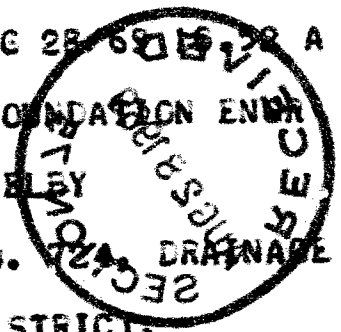


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1153



DOWN LOND 4 AUG 28 69 10 58 A PRIORITY  
A C STERNAC FOUNDATION ENGR MAT AND TESTING  
ATTENTION K SELEY  
RE: DEV RD NO. 12A DRAINAGE IMPROVEMENTS, STATION 35-45,  
LONDON DISTRICT.

THE CONTRACTOR HAS COMPLETED WORK ON THIS PROJECT SO THAT READINGS  
CAN BE TAKEN NOW IF YOU WISH TO DO SO. TWO PIEZOMETERS (P2 & P3)  
HAD TO BE REMOVED DURING CONSTRUCTION. THESE HAVE BEEN STORED AT OUR  
LAB AT LITTLE SIMCOE STREET.

J FORSTER FOR J ROY REG MAT ENGR MAT AND TEST LONDON

## MEMORANDUM

To: Mr. J. Roy,  
Regional Materials Engineer,  
South-Western Region,  
LONDON, Ontario.

FROM: FOUNDATION Section,  
Material & Testing Div.,  
Room 107, Lab. Bldg.

DATE: July 19, 1968

OUR FILE REF.

IN REPLY TO

JUL 26 1968

SUBJECT:

SUPPLEMENTARY REPORT ON THE SOILS  
INVESTIGATION AT THE FAILURE AREA

On Development Road #724  
Sta. 39+00 to Sta. 42+00  
County of Middlesex  
W.J. 67-P-95-1 -- Dist. #2 (London)

Attached, we are forwarding to you, our report dealing with the results of the recent soils investigation at the above site.

You will note that we recommend - as the immediate measure - the construction of an improved drainage system. We believe that by preventing the groundwater from entering the failing area, the larger portion of the subsidence will be eliminated. It is also suggested that after the construction of the recommended C.I.P.'s, the settlement plates and piezometers be observed for a further period of time. Paving this section of the road should commence only after a favourable conclusion of the observations.

We assume that you will find the information in this report sufficient for your purposes. Should you have any additional queries, please contact this Office.

AGS/MdeP

Attach.

cc: Messrs. J. Roy (2)

B. R. Heavysege (Mun. Roads)

F. B. D. Arnold (County Engr.)

H. C. Dernier

*Afternoon*  
A. G. Sternac

PRINCIPAL FOUNDATION ENGINEER

Foundations Files ✓

Gen. Files

## **TABLE OF CONTENTS**

1.     **INTRODUCTION.**
  2.     **FIELD AND LABORATORY INVESTIGATION.**
  3.     **DISCUSSION.**
  4.     **RECOMMENDATIONS.**
  5.     **MISCELLANEOUS.**
-

**SUPPLEMENTARY REPORT ON THE SOILS  
INVESTIGATION AT THE FAILURE AREA**

On Development Road #724

Sta. 39+00 to Sta. 42+00

County of Middlesex

W.J. 67-F-95-1 -- Dist. #2 (London)

**1. INTRODUCTION:**

A preliminary soils investigation was carried out last fall at the site of the failing section (Sta. 39+00 - 42+00) along Development Rd. #724 in the County of Middlesex. In our first report, dated October 31, 1967, the probable causes of occurred settlements were briefly discussed. In the same report it was recommended that settlement plates be installed and periodically observed by the District, along the length of the subsidence. It was believed that the observations of further settlements would cast a better light on the causes of failure so that corrective measures could be decided upon.

The settlement plates have been installed and observed now by the District for a period of 14 weeks. The locations of the plates and the observations of settlements are plotted on Figures #1 and #2. By the end of May 1968, it became obvious that the settlements at the approx. centre of the failure area (Plate #1) proceeded at a constant rate, averaging about  $3/16"$  -  $1/4"$  per week. Due to the fast rate of settlement, it was decided that further field investigation and instrumentation be implemented in order to present some remedial measures at an early date.

Accordingly, a field and laboratory study was undertaken by this Section, the results of which are reported below.

**2. FIELD AND LABORATORY INVESTIGATIONS:**

In addition to the five boreholes put down last September,

cont'd. /2 ...

2. FIELD AND LABORATORY INVESTIGATIONS: (cont'd.) ...

14 new borings were carried out during the recent investigation. For the observation of subsurface drainage and seepage, 12 piezometers have been installed in strategic places. The locations and elevations of the boreholes and the piezometers are marked on Drawing #67-P-95B. The borings were carried out by means of a continuous flight auger. The piezometers installed were of the Norwegian porous brass type. The sampling and testing techniques were the same as described in the preliminary report W.J. 67-P-95. Boreholes #5, 6, 7 and 8 were placed along the shoulders of the investigated section. The principal purpose of these borings was to compare soil properties within the sound and within the failing area. Boreholes #9 to 16 inclusive were placed along the existing perforated drain pipe in order to ascertain whether the pipe lies within the rather impervious clayey silt or within the overlying sand. Holes #17 and 18 were intended to establish the extent of the upper sand layer, west of the failure area.

3. DISCUSSION:

As was mentioned earlier in our previous report, the settlements might have been caused by: (a) poor compaction of the fill, and (b) by seepage forces along the slopes. The recent field and laboratory investigations were, therefore, directed towards these two causes.

3.1) Compaction and Consolidation Properties:

Various physical properties of the soil samples of B.H.'s #5, 6 and 7 were studied in order to compare the soils within the sound and within the failing area. B.H.'s #5 and #7 were assumed to lie within the relatively sound section, whereas B.H. #6 was placed on the approx. centre of the failure. Drawing #67-P-95C shows cross sections at or near above boreholes. On Figures #3 to 6 inclusive, there are graphical presentations of

cont'd. /3 ...

3. DISCUSSION: (cont'd.) ...

3.1) Compaction and Consolidation Properties: (cont'd.) ...

certain physical properties of the samples. By examining the graphs it may be noted, that the values of the standard penetration tests are lower at the centre of the failure than at the sound zones. The weaker layer extends to approx. 20 ft. below shoulder level, corresponding to the depth of the new fill (Fig. #3). By comparing the undrained shear strength values, the difference appears to be even more pronounced. The upper approx. 40 ft. of material exhibits shear strengths lower in B.H. #6 than in B.H.'s #5 and 7. The 40 ft. includes the old dumped fill as well, indicating that this material, however dense it is, shows a great deal of disturbance and remoulding. On Fig. #5, a comparison is made of the liquidity indices. From the figure it is postulated that certain layers within the failure zone are wet, likely being caused by percolating groundwater. (See Fig. #5 - Elevation above 731 ft. again around El. 716 ft. and 697 ft.)

No variations of the bulk densities were noticed (Fig. #6) within the sound and the failing sections, suggesting that it is the disturbance of the soil structure rather than the overall density which can cause larger settlements. It has been published by investigators (Rutledge, 1944, Schmertmann, 1953) that sample disturbance decreases the void ratio at which the soil will carry any given vertical stress. The void ratio log pressure curve of a disturbed or remoulded sample is displaced downwards; however, the initial void ratio ( $e_0$ ) of the undisturbed and remoulded samples may be very similar.

3.2) Groundwater and Drainage Conditions:

Groundwater observations by means of piezometers were carried out, the results of which are plotted on the borelog sheets and on the cross sections on Drawing #67-P-95C. Very high groundwater level was established along the entire area. Along the embankment slope free water flow was noticed at two or

cont'd. /4 ...

3. DISCUSSION: (cont'd.) ...

3.2) Groundwater and Drainage Conditions: (cont'd.) ...

three locations, together with surface sloughing and local slip failures. Piezometric readings proved that groundwater enters the failing area below the road from a westerly direction. It has also been clearly established that the interception drain, some 40 ft. south of the road centre-line, is not embedded in the clayey silt subsoil as it should be. Instead, along its larger part, it is within the permeable surficial sand and silty sand. At the time of the field investigation (June, 1968) the groundwater level south of the C.I.P. drain was around El. 733.5 ft. (Piezometer #7) or some 4 - 5 ft. below ground surface. The C.I.P. was found to depress the water level to the elevation of the pipe, but since the permeable layer extends below the pipe, groundwater can enter the settling area, where it softens, lubricates and seeps along layers of the least resistance. The seepage forces also cause local failures and washouts.

Stability analyses of the slopes were carried out in terms of total stresses by means of an electronic computer. No seepage forces and no excess pore pressure were assumed for the calculations, which resulted in factors of safety  $F.S. = 1.7$  and over.

4. RECOMMENDATIONS:

Since the settlements have been progressing at a constant, probably even at an increasing rate, it is postulated that the high water level and the seepage forces constitute the main reason for the movements.

It appears, therefore, both rational and economical that as an immediate measure, the seepage be eliminated by an improved drainage system. It is hoped that by preventing the groundwater from entering the fill, the settlements will be greatly reduced, thus the future excavation and reconstruction of the fill may be avoided.

4. RECOMMENDATIONS: (cont'd.) ...

The improvements of the subsurface and surface drainage should include:

(a) Reconstruction of the Existing Perforated C.I.P. South of the Road.

The drainage pipe should be lowered to such an extent that it is within the relatively impermeable clayey silt subsoil along its entire length. On the soil profile on Drawing #67-P-95B the approx. upper surface of this clayey silt is marked. Since the observations were carried out at borehole locations only, it is recommended that the soil be checked during construction, by a qualified Soils Engineer, who should approve the depth of the ditch prior to placing the C.I.P.

(b) Construction of Additional Drainage:

Groundwater seeping into the fill from the westerly direction should also be intercepted. To this end, a perforated C.I.P. should be installed perpendicular to the centre-line of the road. This pipe should be connected to the longitudinal C.I.P. with a manhole or catchbasin. This drain should also be lowered below the upper surface of the clayey silt. The location of the cross drain should be between Station 44+00 and Station 45+00. Cross sections CC and DD on Drawing #67-P-95C show the approximate elevations of the clayey silt surface for estimating purposes. The longitudinal drain will likely need to be extended westward between Station 44+00 and Station 45+00.

(c) The Drainage Outlets at the North Side of the Fill -

should be reconstructed. Both existing outlets are damaged or broken, thus water seeps into the fill along the side slopes. The new outlets should be constructed in granular material and they should be extended down to the toe of the slope.

cont'd. /6 ...

4. RECOMMENDATIONS: (cont'd.) ...

(c) (cont'd.) ...

In order to ensure that the drainage scheme will be adequate, it is recommended that any proposed design be reviewed by the Foundation Section.

(d) In order to improve surface runoff, the road and the shoulders should be reconstructed to the true grade and cross section. Paving this section of the road is, however, not recommended for another year or so after completion of the drainage improvement. The slope of the fill section should be corrected according to the original design; all surplus material should be hauled away. The slope should be sodded.

(e) Further Observations of Settlements:

After completion of the suggested reconstruction, new settlement plates, similar to the existing ones, or the latter extended, should be installed. Observations of these settlement points should be carried out for a further period. Piezometric readings of the existing and probably new piezometers should also be implemented, according to the recommendations of the Foundation Section. It is requested that this Section be notified two weeks prior to the construction of the drainage system, so that piezometers - which would interfere with the operations - could be removed.

5. MISCELLANEOUS:

The field work was carried out during the period June 10 to 19, 1968, under the supervision of Messrs. A. K. Barsvary, Senior Foundation Engineer, and D. Davis, Project Foundation Engineer. Equipment used was owned and operated by Dominion Soil Investigation Ltd., London, Ontario. This report was prepared by Mr. A. K. Barsvary with the assistance of Mr. D. Davis. Mr. K. G. Selby, Supervising Foundation Engineer, reviewed the report.

July, 1968.

**APPENDIX I**

DEPARTMENT OF HIGHWAYS - ONTARIO

## MATERIALS & TESTING DIVISION

100 67-P-95

W.P.

DATUM 02-02-10

## RECORD OF BOREHOLE NO. 5

LOCATION Sta. 43 + 41 14' E. of E

BORING DATE June 10-11, 1968

BOREHOLE TYPE Cent. Flight Agent

### FOUNDATION SECTION

ORIGINATED BY AKB

COMPILED BY                      **413**

CHECKED BY

SOIL PROFILE			SAMPLES			DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT					LIQUID LIMIT ——— % PLASTIC LIMIT ——— % WATER CONTENT ——— %			BULK DENSITY PCF	REMARKS		
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS / FOOT	ELEV. SCALE	SHEAR STRENGTH P.S.F. • Unconfined					WATER CONTENT %					
740.9	Ground Level						500	1000	1500	2000	2500	10	20	30			
0.0	Granular backfill & silty sand to sandy silt, traces of gravel. Dense to very dense.		1	SS	h1	740										79 ( 1h )	
			2	SS	51												48 ( 52 )
			3	SS	28		730										730.4
727.9	Brown.		4	SS	37												
13.0	Clayey silt, random seams or pockets of silty sand.		5	TM	Drive										135	176 ( 23 )	
			6	TM	Drive												
			7	SS	32	720											
	Hard.		8	TM	Drive												
			9	TM	Drive												
	Grey					710											
705.4			10	SS	h2												
35.5	End of Borehole					700											

DEPARTMENT OF HIGHWAYS - ONTARIO

**MATERIALS & TESTING DIVISION**

JOB 67-1-95

LOCATION Sta. 39 + 80 21' Rt. of g

ORIGINATED BY AKB

W P

BORING DATE June 11-12/1968

COM. LED BY AKS & DWD

DATUM Geodetic

BOREHOLE TYPE Cont. Flight Auger

CHECKED BY

[illegible]

REPORTING OFF HIGHWAYS - ONTARIO

## MATERIALS & TESTING DIVISION

100-67-7-95

LOCATION Sta. 37 + 25 15' Rt. of R

ORIGINATED BY AKB

22

BORING DATE JUNE 13, 1968

COMPILED BY \_\_\_\_\_ END

**DATUM** Geodetic

**BOREHOLE TYPE** Cent. Flight Auger

CHECKED BY                     

[illegible]

CHECKED BY

### FOUNDATION SECTION

[illegible]

**MATERIALS & TESTING DIVISION**

RECORD OF BOREHOLE NO. 9

### FOUNDATION SECTION

JOE 67-5-95

LOCATION Sta. 38 + 14 47' Lt. of g

ORIGINATED BY AKB

17 18

BORING DATE June 18, 1968

COMPILED BY \_\_\_\_\_ WB

DATUM Geodetic

BOREHOLE TYPE Cont. Flight Auger

CHECKED BY \_\_\_\_\_

SOIL PROFILE			SAMPLES			ELEV SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT		LIQUID LIMIT ——— % PLASTIC LIMIT ——— % WATER CONTENT ——— % <div style="text-align: center;"> <p>W<sub>p</sub> ——— W<sub>L</sub></p> <p>10 — 20 — 30</p> </div>		BULK DENSITY PCF	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	BLOWS / FOOT		SHEAR STRENGTH P.S.F. • Unconfined ○ Triaxial 500 1000 1500 2000 2500		WATER CONTENT %			
737.4	Ground Level											
0.0	Silty sand. Dense. Brown	...	1	SS	29	730						0 63 (37) 728.5
728.5			2	SS	39							
8.9	Clayey silt, traces of sand.	///	3	SS	43							
723.9	Hard.	///	4	TW	Drive		5390				137	
13.5	End of Borehole					720						

DEPARTMENT OF HIGHWAYS - ONTARIO

## MATERIALS &amp; TESTING DIVISION

## RECORD OF BOREHOLE NO. 10

FOUNDATION SECTION

JOB 67-F-95LOCATION Sta. 39 + 23 47' Lt. of EORIGINATED BY AKB

W P \_\_\_\_\_

BORING DATE June 18, 1968COMPILED BY WBDATUM GeodeticBOREHOLE TYPE Cont. flight augerCHECKED BY [Signature]

SOIL PROFILE			SAMPLES			ELEV SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT		LIQUID LIMIT _____ WL PLASTIC LIMIT _____ WP WATER CONTENT _____ W			BULK DENSITY PCF	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLT	NUMBER	TYPE	BLOWS / FOOT		SHEAR STRENGTH P S F ● Unconfined ○ Triaxial 500 1000 1500 2000 2500		WATER CONTENT % 10 20 30				
736.4	Ground Level												Gr. Ss. Sl. Cl.
0.0	Sand, traces of silt. Compact to dense. Brown.		1	SS	18	730							190 (9) W.L. 729.9
728.7			2	SS	10								
9.7	Clayey silt.		3	SS	21								
724.9	Gray		4	TV	17								
13.5	End of Borehole					720						137	

DEPARTMENT OF HIGHWAYS - ONTARIO

**MATERIALS & TESTING DIVISION**

JOB 67-F-95

LOCATION Sta. 39 + 89 54' Lt. of g

## RECORD OF BOREHOLE NO. 11

**FOUNDATION SECTION**

W P

BORING DATE June 18, 1968

ORIGINATED BY AKB

**DAYUM** Coedatio

BOREHOLE TYPE Cont. flight auger

COMPILED BY \_\_\_\_\_ WB

CHECKED BY

SOIL PROFILE			SAMPLES			ELEV SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT					LIQUID LIMIT ——— W <sub>L</sub> PLASTIC LIMIT ——— W <sub>P</sub> WATER CONTENT ——— W			BULK DENSITY P.C.F.	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS / FOOT		SHEAR STRENGTH P.S.F. ● Unconfined ○ Triaxial					WATER CONTENT % W <sub>P</sub> ——— W <sub>L</sub>				
							500	1000	1500	2000	2500	10	20	30		
737.9	Ground Level															
0.0	Silty sand. Very loose to compact. Brown.		1	SS	3	730									136	
726.9			2	SS	24											
9.0	Clayey silt, traces of sand. Hard.		3	SS	37											
724.4			4	TV	Drill											
13.5	End of Borehole					720										

DEPARTMENT OF HIGHWAYS - ONTARIO

**MATERIALS & TESTING DIVISION**

JOB 67-F-95

DATUM Geodetic

LOCATION Sta. 40 + 39 54' Lt. of R

BORING DATE June 18, 1968

**BOREHOLE TYPE** Cont. flight sugar

**FOUNDATION SECTION**

ORIGINATED BY AKB

COMPILED BY \_\_\_\_\_

CHECKED BY \_\_\_\_\_

# RECORD OF BOREHOLE NO. 12

SOIL PROFILE			SAMPLES			ELEV SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT	Liquid Limit ——— w <sub>L</sub> Plastic Limit ——— w <sub>p</sub> Water Content ——— w	BULK DENSITY  pcf	REMARKS
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS / FOOT		SHEAR STRENGTH P.S.F.	w <sub>p</sub> ————— w <sub>L</sub>		
738.5	Ground Level						500    1000    1500    2000    2500	WATER CONTENT % 10      20      30		
0.0	Silty sand. Dense. Brown	[Pattern]	1	SS	33	730				730.5
729.5										
728.0	Clayey silt. Hard.	[Pattern]	2	SS	39					
10.5	End of Borehole					720				





**CHECKED BY**

[illegible]

DEPARTMENT OF HIGHWAYS - ONTARIO

## MATERIALS & TESTING DIVISION

JOB 67-P-15

LOCATION Sta. 42 + 80 54' Lt. of R

—

BORING DATE June 18, 1968

**DATUM** Geodetic

BOREHOLE TYPE Cont. flight auger

### FOUNDATION SECTION

CLASSIFIED BY AKB

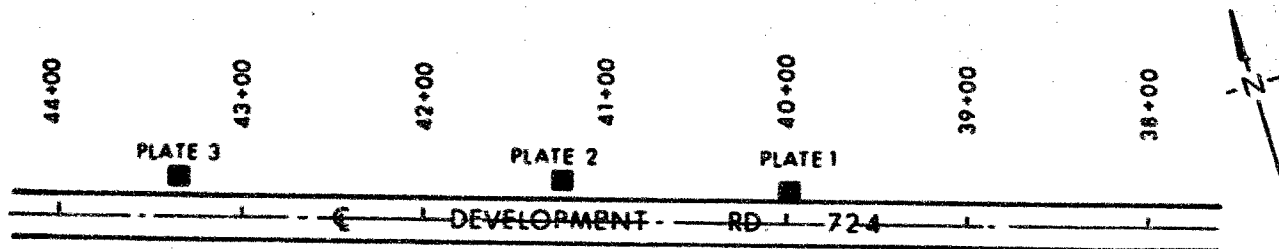
**SECRET**

4400

[illegible]







PLAN  
SCALE 1 in. = 100 ft.

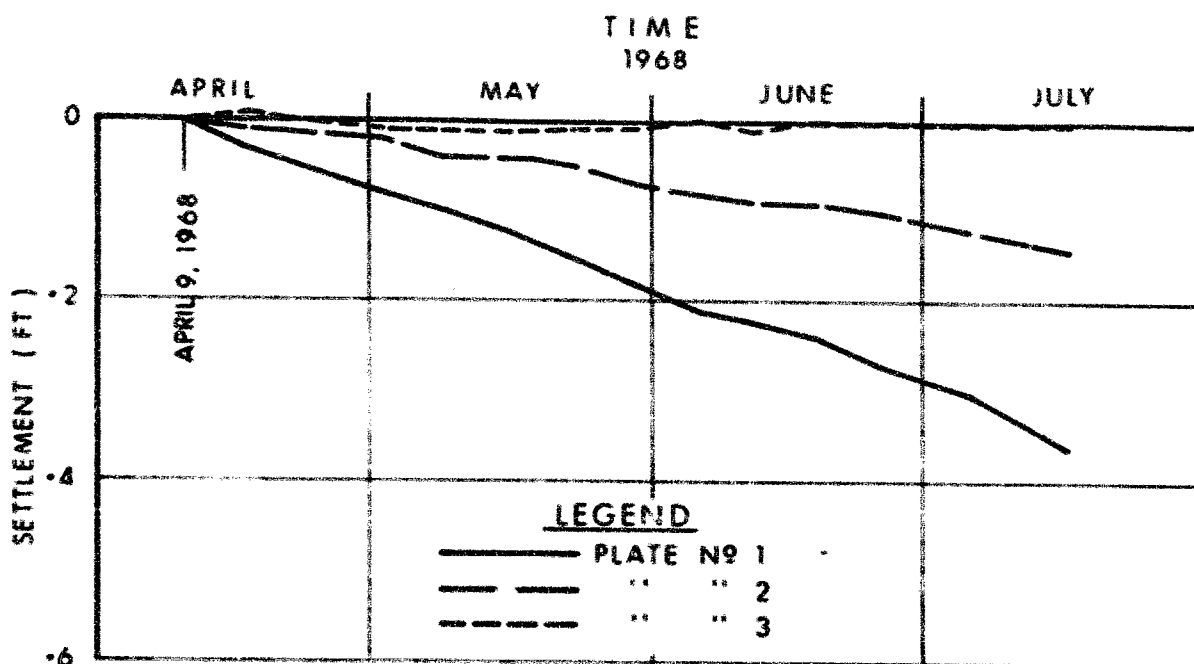


PLATE NO	INITIAL PLATE ELEVATION	STATION	OFFSET
1	739.6	39+98	17.9' RT
2	741.2	41+24	20.6' RT
3	740.9	43+35	18.9' RT

APPROX DEPTH OF PLATES 5 Ft BELOW GROUND LEVEL

FIG. 1

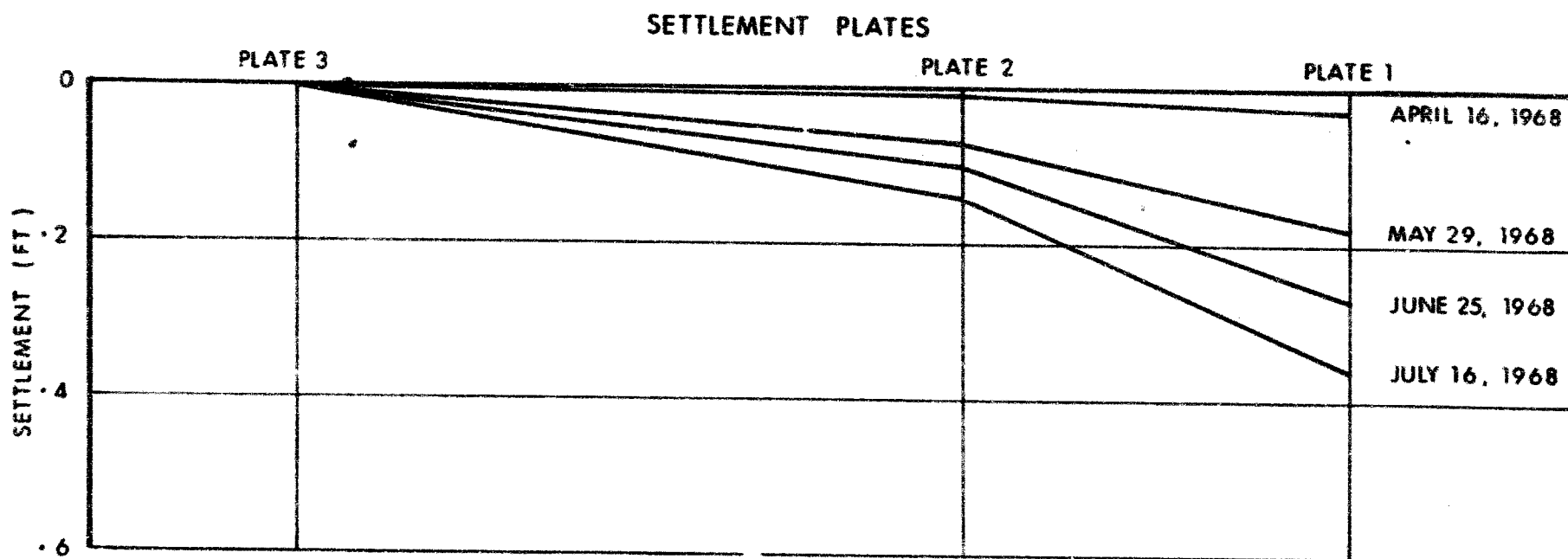
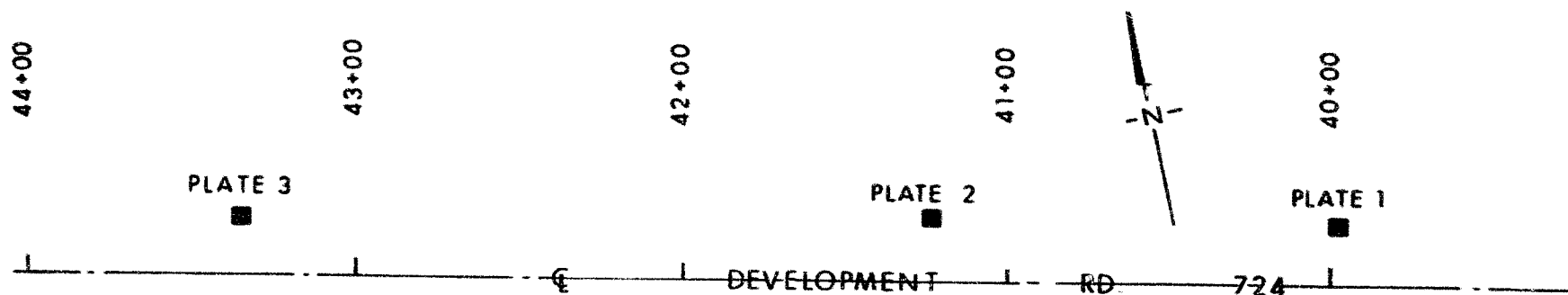


FIG. 2

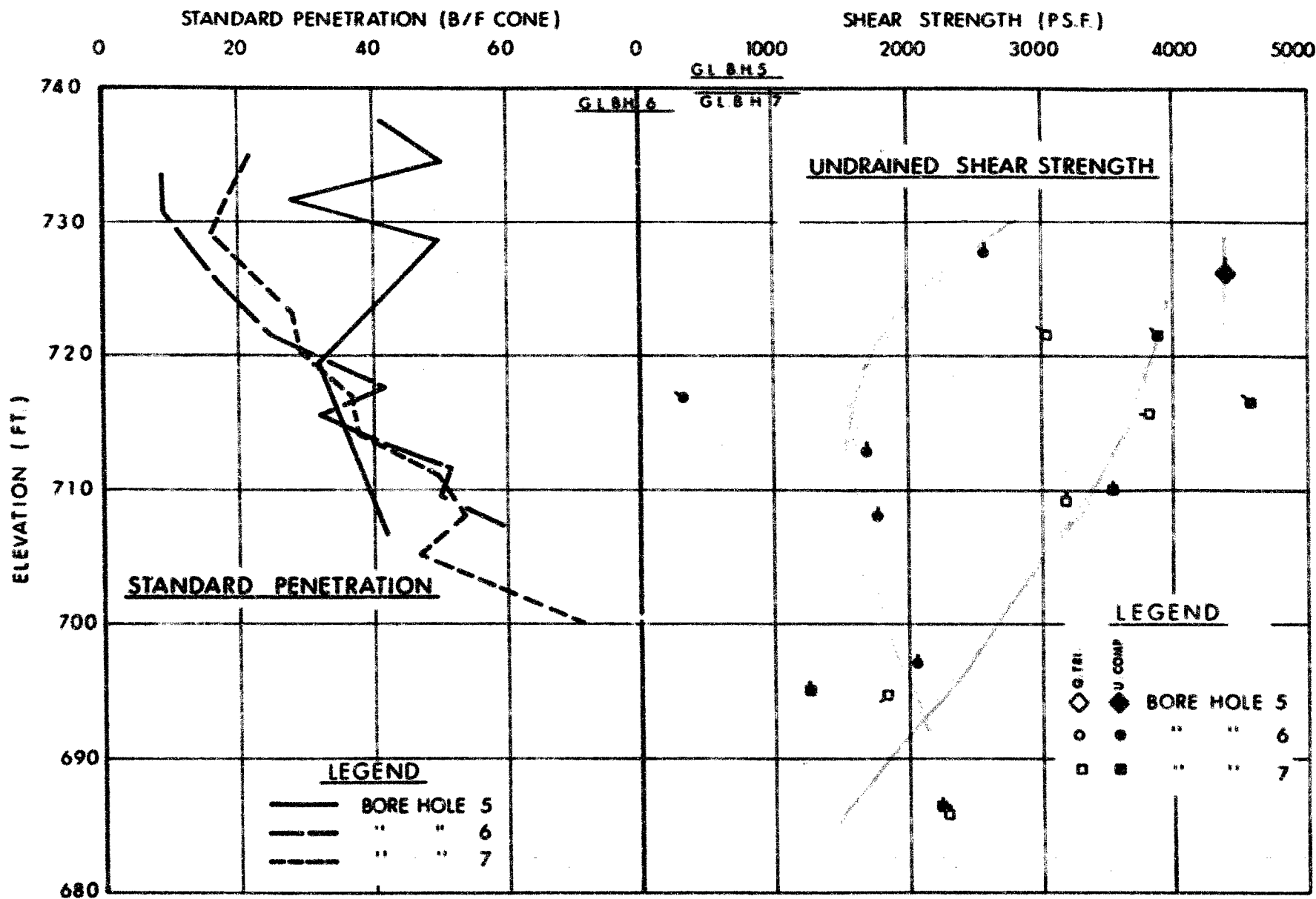


FIG. 3

FIG. 4

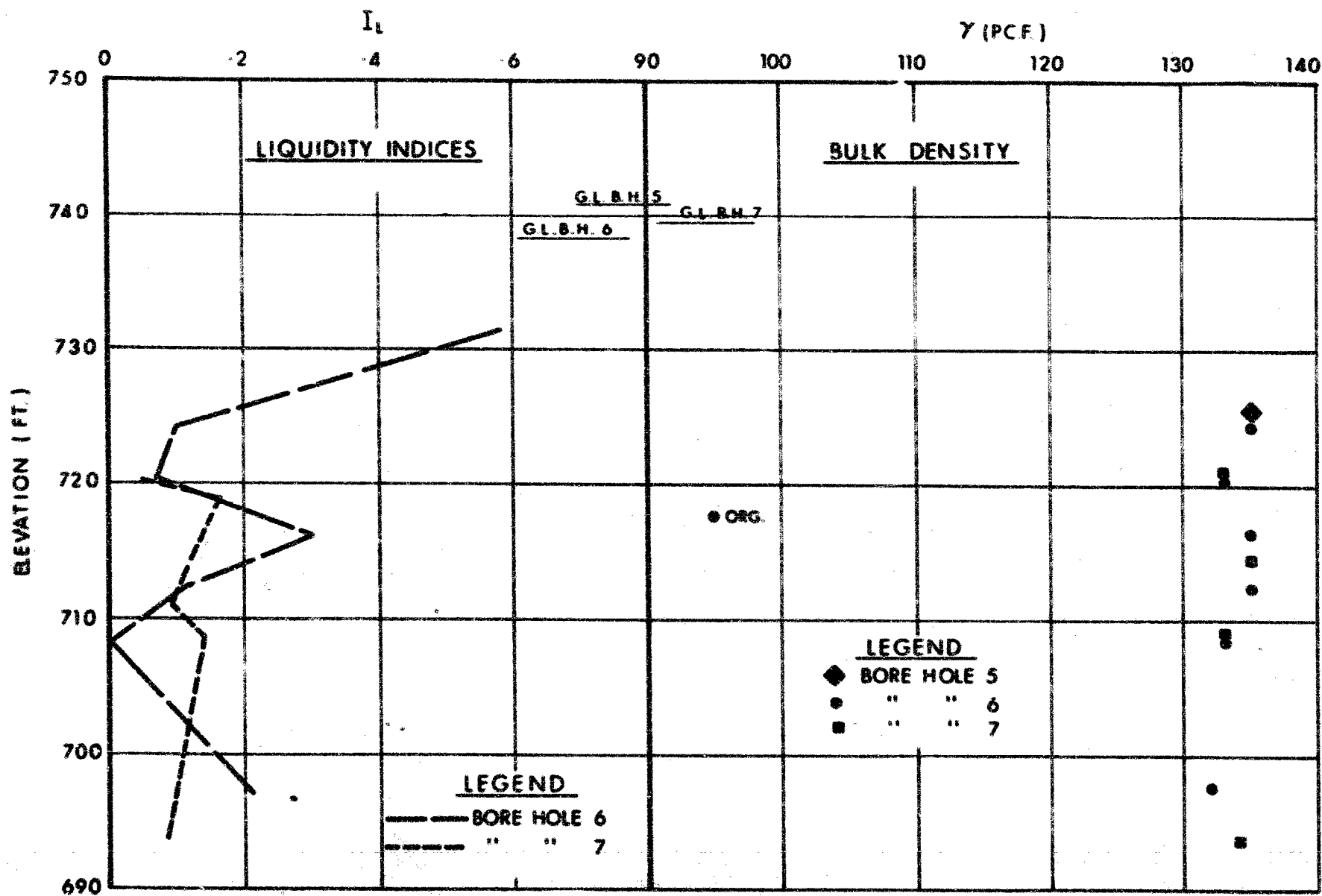


FIG. 5

FIG. 6

## ABBREVIATIONS USED IN THIS REPORT

### PENETRATION RESISTANCE

STANDARD PENETRATION RESISTANCE 'N' - THE NUMBER OF BLOWS REQUIRED TO ADVANCE A STANDARD SPLIT SPOON SAMPLER 12 INCHES INTO THE SUBSOIL, DRIVEN BY BEANS OF A 140 POUND HAMMER FALLING FREELY A DISTANCE OF 30 INCHES.

DYNAMIC PENETRATION RESISTANCE - THE NUMBER OF BLOWS REQUIRED TO ADVANCE A 2 INCH, 60 DEGREE CONE, FITTED TO THE END OF DRILL RODS, 12 INCHES INTO THE SUBSOIL. THE DRIVING ENERGY BEING 350 FOOT POUNDS PER BLOW.

### DESCRIPTION OF SOIL

THE CONSISTENCY OF COHESIVE SOILS AND THE RELATIVE DENSITY OR DENSENESS OF COHESIONLESS SOILS ARE DESCRIBED IN THE FOLLOWING TERMS:-

<u>CONSISTENCY</u>	<u>'N' BLOWS / FT.</u>	<u>c LB. / SQ. FT.</u>	<u>DENSENESS</u>	<u>'N' BLOWS / FT.</u>
VERY SOFT	0 - 2	0 - 250	VERY LOOSE	0 - 4
SOFT	2 - 4	250 - 500	LOOSE	4 - 10
FIRM	4 - 8	500 - 1000	COMPACT	10 - 30
STIFF	8 - 15	1000 - 2000	DENSE	30 - 50
VERY STIFF	15 - 30	2000 - 4000	VERY DENSE	> 50
HARD	> 30	> 4000		

### TYPE OF SAMPLE

S.S	SPLIT SPOON	T.W	THINWALL OPEN
WS	WASHED SAMPLE	T.P	THINWALL PISTON
S.B	SCRAPER BUCKET SAMPLE	O.S	OESTERBERG SAMPLE
A.S	AUGER SAMPLE	F.S	FOIL SAMPLE
C.S	CHUNK SAMPLE	R.C	ROCK CORE
S.T	SLOTTED TUBE SAMPLE		
	P.H. SAMPLE ADVANCED HYDRAULICALLY		
	P.M. SAMPLE ADVANCED MANUALLY		

### SOIL TESTS

Q <sub>u</sub>	UNCONFINED COMPRESSION	L.V	LABORATORY VANE
Q	UNDRAINED TRIAXIAL	F.V	FIELD VANE
Q <sub>cs</sub>	CONSOLIDATED UNDRAINED TRIAXIAL	C	CONSOLIDATION
Q <sub>d</sub>	DRAINED TRIAXIAL	S	SENSITIVITY

## ABBREVIATIONS USED IN THIS REPORT

### SOIL PROPERTIES

$\gamma$	UNIT WEIGHT OF SOIL (BULK DENSITY)
$\gamma_s$	UNIT WEIGHT OF SOLID PARTICLES
$\gamma_w$	UNIT WEIGHT OF WATER
$\gamma_d$	UNIT DRY WEIGHT OF SOIL (DRY DENSITY)
$\gamma'$	UNIT WEIGHT OF SUBMERGED SOIL
$G$	SPECIFIC GRAVITY OF SOLID PARTICLES $G = \frac{\gamma_s}{\gamma_w}$
$e$	VOID RATIO
$n$	POROSITY
$w$	WATER CONTENT
$S_r$	DEGREE OF SATURATION
$w_L$	LIQUID LIMIT
$w_p$	PLASTIC LIMIT
$I_p$	PLASTICITY INDEX
$s$	SHRINKAGE LIMIT
$I_L$	LIQUIDITY INDEX $= \frac{w - w_p}{I_p}$
$I_c$	CONSISTENCY INDEX $= \frac{w_p - w}{I_p}$
$e_{max}$	VOID RATIO IN LOOSEST STATE
$e_{min}$	VOID RATIO IN densest STATE
$I_D$	DENSITY INDEX $= \frac{e_{max} - e}{e_{max} - e_{min}}$
	RELATIVE DENSITY $D_r$ IS ALSO USED
$h$	HYDRAULIC HEAD OR POTENTIAL
$q$	RATE OF DISCHARGE
$v$	VELOCITY OF FLOW
$i$	HYDRAULIC GRADIENT
$k$	COEFFICIENT OF PERMEABILITY
$j$	SEEPAGE FORCE PER UNIT VOLUME
$m_v$	COEFFICIENT OF VOLUME CHANGE $= \frac{-\Delta e}{(1+e)\Delta\sigma}$
$c_v$	COEFFICIENT OF CONSOLIDATION
$C_c$	COMPRESSION INDEX $= \frac{\Delta e}{\Delta \log_{10} \sigma}$
$T_v$	TIME FACTOR $= \frac{c_v t}{d^2}$ ( $d$ , DRAINAGE PATH)
$U$	DEGREE OF CONSOLIDATION
$\tau$	SHEAR STRENGTH
$c'$	EFFECTIVE COHESION INTERCEPT
$\phi'$	EFFECTIVE ANGLE OF SHEARING RESISTANCE, OR FRICTION
$c_u$	APPARENT COHESION
$\phi_u$	APPARENT ANGLE OF SHEARING RESISTANCE, OR FRICTION
$\mu$	COEFFICIENT OF FRICTION
$S_t$	SENSITIVITY

### GENERAL

$\pi$	$= 3.1416$
$e$	BASE OF NATURAL LOGARITHMS 2.7183
$\log_e \sigma$ OR $\ln \sigma$	NATURAL LOGARITHM OF $\sigma$
$\log_{10} \sigma$ OR $\log \sigma$	LOGARITHM OF $\sigma$ TO BASE 10
$t$	TIME
$g$	ACCELERATION DUE TO GRAVITY
$V$	VOLUME
$W$	WEIGHT
$M$	MOMENT
$F$	FACTOR OF SAFETY

### STRESS AND STRAIN

$u$	PORE PRESSURE
$\sigma$	NORMAL STRESS
$\bar{\sigma}$	NORMAL EFFECTIVE STRESS ( $\bar{\sigma}$ IS ALSO USED)
$\tau$	SHEAR STRESS
$\epsilon$	LINEAR STRAIN
$\gamma$	SHEAR STRAIN
$\nu$	POISSON'S RATIO ( $\mu$ IS ALSO USED)
$E$	MODULUS OF LINEAR DEFORMATION (YOUNG'S MODULUS)
$G$	MODULUS OF SHEAR DEFORMATION
$K$	MODULUS OF COMPRESSIBILITY
$\eta$	COEFFICIENT OF VISCOSITY

### EARTH PRESSURE

$z$	DISTANCE FROM TOP OF WALL TO POINT OF APPLICATION OF PRESSURE
$\delta$	ANGLE OF WALL FRICTION
$K$	DIMENSIONLESS COEFFICIENT TO BE USED WITH VARIOUS SUFFIXES IN EXPRESSIONS REFERRING TO NORMAL STRESS ON WALLS
$K_0$	COEFFICIENT OF EARTH PRESSURE AT REST

### FOUNDATIONS

$B$	BREADTH OF FOUNDATION
$L$	LENGTH OF FOUNDATION
$D$	DEPTH OF FOUNDATION BENEATH GROUND
$N$	DIMENSIONLESS COEFFICIENT USED WITH A SUFFIX APPLYING TO SPECIFIC GRAVITY, DEPTH AND COHESION ETC. IN THE FORMULA FOR BEARING CAPACITY
$k_s$	MODULUS OF SUBGRADE REACTION

### SLOPES

$H$	VERTICAL HEIGHT OF SLOPE
$D$	DEPTH BELOW TOE OF SLOPE TO HARD STRATUM
$\beta$	ANGLE OF SLOPE TO HORIZONTAL

401 & Keele St.  
Downsview, Ontario

July 8, 1968

Dominion Soil Investigation  
77 Crockford Blvd.  
Scarborough, Ontario

Dear Sirs:

This is to confirm our request of June 7, 1968 for the supply of Pennsylvania Auger together with all necessary equipment, as specified under the terms of our Contract Agreement, at Arcona, Ontario on June 10, 1968. Mobilization to be from London

This project bears Job Number 67-F-95.

Yours truly,

*K. G. Selby*

EDS:mt

K. G. Selby  
Supervising Foundation Engineer  
for: A. G. Starnes  
Principal Foundation Engineer

cc: H. Konings  
Foundation Files /10  
General File

*agf*

Mr. John Roy,  
Regional Materials Engineer,  
Regional Office,  
LONDON, Ont.

Foundation Section,  
Materials & Testing Div.,  
Room 107, Lab. Bldg.

October 18, 1968

Repairs to Development Road #724  
W.J. 67-F-25 -- District #2 (London)

We have reviewed the drawings of the drainage repairs along Development Rd. #724, prepared by the consultant, K. H. Dillon Ltd.

It appears that the vertical and horizontal alignment of the newly designed drainage complies with our recommendations.

We also agree with your notes of October 13, 1968, namely that seeding of the restored slope will be more economical than sodding, and that a 2" - 3" depth of granular fill below the perforated pipes will be adequate.

It is believed to be imperative that a member of your Section be present during the construction of the new drainage system in order to ensure that the pipes are placed within the silty clay layer. The settlement plates and piezometers - if they do not interfere with the construction - should be left in place. If the construction necessitates the removal of the instruments, they should be reinstalled after completion of the restoration. The reinstallation of the piezometers may be supervised by our Section if you so desire.

*M. C. Selby*

HGS/WJef

cc: Messrs. H. Greenland  
B. H. Newington  
W. Lonnberg

Foundations Files /  
Gen. Files

M. C. Selby,  
SUPERVISING FOUNDATION ENGR.  
For:  
A. G. Sternac,  
PRINCIPAL FOUNDATION ENGR.

**M. M. DILLON LIMITED**

CONSULTING ENGINEERS

6388-01

9 October 1968

Department of Highways, Ontario  
Box 4544 - Station C  
London, Ontario

Attn: Mr. J. R. Roy, P.Eng.  
Regional Materials Engineer

Repairs to Development Road No. 724

Dear Sirs:

We are submitting for your approval 2 sets of Drawings 1 to 5 inclusive showing the drainage repairs and slope restoration to Development Road 724. The proposed repairs are in accordance with the recommendations of the Soils Report of July 1968 prepared as a result of the investigation of failure area.

We suggest that you might want to review the recommendation of sodding the slope. Perhaps seeding would be just as effective and much more economical.

Would you kindly forward one set of the plans to the Foundation Section in Downsview for their review. We would appreciate receiving approval at an early date since it is hoped to construct the work this Fall.

Yours truly,

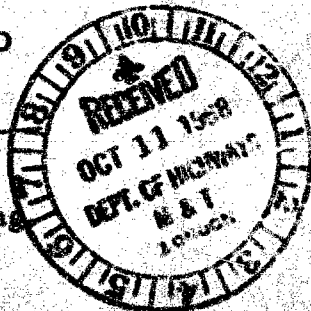
M. M. DILLON LIMITED

*K. R. Nauman*

K. R. Nauman, P.Eng.  
for J. L. Mitchell, P.Eng.  
Project Manager

KRN:mm  
Encl.

c.c. T. S. Caldwell  
F. B. D. Arnold



DEFECTS IN NEGATIVE DUE TO  
CONDITION OF ORIGINAL DOCUMENT

MEMORANDUM

Mr. J. Roy,  
Regional Materials Engineer,  
South-Western Region,  
LONDON, Ontario.

FROM: Foundation Section,  
Materials & Testing Div.,  
Room 107, Lab. Bldg.

DATE: October 31, 1967

Our File Ref.

IN REPLY TO

NOV 3 1967

SUBJECT:

FOUNDATION INVESTIGATION REPORT  
At the  
Failure Area on Development Rd. #724  
Station 39+00 to Station 42+00  
County of Middlesex  
W.J. 67-F-95 - Dist. #2 (London)

Attached, we are forwarding to you, our detailed foundation investigation report outlining the subsoil conditions existing at the above failure site.

We believe that the factual data and recommendations contained therein, will prove adequate for your use. Should you require additional information, or should there be any queries in connection with this report, please do not hesitate to contact our Office.

ACS/HdeP  
Attach.

*A. G. Storey*  
A. G. Storey  
PRINCIPAL FOUNDATION ENGINEER

cc: Messrs. J. Roy (2)  
B. R. Heavyside (Mun. Roads)  
P. B. D. Arnold (County Engr.)  
H. C. Deraier

Foundations Files ✓  
Gen. Files

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    - 4.2) Clayey Silt (Fill).
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  5. GROUNDWATER OBSERVATIONS.
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FOUNDATION INVESTIGATION REPORT  
At the  
Failure Area on Development Rd. #724  
Station 39+00 to Station 42+00  
County of Middlesex  
W.J. 67-F-95 - Dist. #2 (London)

1. INTRODUCTION:

In a memo, dated September 20, 1967, Mr. J. R. Roy, Regional Materials Engineer, requested a foundation investigation at the site of the occurred settlements under Development Rd. #724. Subsequently a field and laboratory investigation was carried out by this Section, to determine the possible cause of the subsidence.

Presented in this report are the results of the investigation, as well as recommendations for further action.

2. DESCRIPTION OF THE SITE, CONSTRUCTION AND SETTLEMENT RECORDS:

The investigated area is located at some 4000 ft. west of Hwy. #81, on County Rd. #12 (Dev. Rd. #724), between Stations 39+00 and 42+00. The north side of the road is the recent fill, sloping down to the floodplain of the creek, which is some 200 ft. north of the road. Before the reconstruction of the road, it had bent around the meandering slopes of the floodplain. In 1964 - 1965 the curve was eliminated by the construction of the embankment and the realignment of the road on the new fill.

Considerable settlements were observed ever since the pavement of the road had been placed in September 1965. According to the memo of Mr. A. M. Batten of the London Region, the section was refilled and repatched with hot-mix asphalt in late spring 1966, and again in late fall, 1966. Rough measurements taken during our field work in September 1967, showed that the settlements reached 35 inches below the north edge of the road and some 26 inches below the south edge. Some 34 inches of settlement was measured beneath

2. DESCRIPTION OF THE SITE, CONSTRUCTION AND SETTLEMENT RECORDS:

(cont'd.) ...

the centre-line of the road. No lateral displacement of the fill material has been noticed. It has also been reported that the County dumped large quantities of excavated - mainly clay material - on the original slope in 1951 and prior to that date.

Geologically, the area belongs to the physiographic region known as the "Horseshoe Moraines". This portion of the region consists of knobby ridges of clay, described by the Ontario Soil Survey under the name of Huron Clay Loam.

3. FIELD AND LABORATORY INVESTIGATION PROCEDURE:

Some 5 boreholes were carried out during the field investigation procedure, the holes having been placed at Sta. 40+60, at the approx. centre of the failing area. Borings were put near the shoulders of the road, along the slope and at the toe of the fill, as shown on the appended Drawing #67-P-95A. A conventional diamond drill rig, adapted for soil sampling purposes, was used for the investigation. Continuous sampling technique was followed mainly with split-spoon sampler and, where the consistency of the soil made it possible, with Shelby tubes. Standard penetration tests and field vane tests were performed by conventional methods. In addition, six piezometers were installed at various depths adjacent to the borings, in order to observe groundwater conditions. The piezometers were of the Norwegian porous brass type, known as Geonor piezometers.

Soil samples were visually examined and identified upon recovery, and again in the laboratory. Tests of Atterberg limits, natural moisture contents, unconfined and triaxial shear strengths and consolidation, were carried out on representative samples.

Field and laboratory test results are marked on the borelog sheets, accompanying this report.

cont'd. /3 ...

#### 4. SOIL CONDITIONS:

##### 4.1) General:

The subsoil, revealed by the borings, was found to consist of a clayey silt fill material of a rather heterogeneous nature, followed by the original stratum of grey clayey silt. A brief description of the deposits follows:

##### 4.2) Clayey Silt (Fill):

The surficial layer was found to be a cohesive clayey silt fill in every borehole, except in the holes placed on, or near the shoulders (B.H.'s #1 and #2), where the clayey silt underlay a 7 - 9 ft. thick sandy roadbed. The thickness of the fill was some 36 ft. below the right shoulder of the road, diminishing towards the toe of the embankment. From the boreholes, it was rather difficult to differentiate between the recent (1964 - 65) fill and the reported dumped material prior to 1951. It was, however, observed that within the lower portion of the fill, lower values of penetration resistances were obtained, indicating a loosely packed deposit. This portion of the fill is the material dumped in 1951 and before, and was already in place at the time of the construction of the existing embankment. The compaction and consolidation of the fill beneath the top of the embankment appeared to be somewhat better than along the slope. In spite of this, however, the consistency of the soils cannot be considered satisfactory since it varies widely between firm and very stiff. Penetration 'N' values ranged from 7 to over 20 blows/ft. - very poor indeed, for a compacted material.

Laboratory unconfined shear tests on samples taken below the slope yielded values between 500 and 1000 p.s.f. Within the mixed fill some seams of organic material were also noted. The natural moisture contents of the samples taken from these black organic seams were considerably higher than those of the rest of the samples.

cont'd. /4 ...

4. SOIL CONDITIONS: (cont'd.) ...

4.3) Grey Clayey Silt:

Underlying the fill material, the original grey clayey silt overburden was established in every borehole. On the attached stratigraphical cross section the estimated boundaries between the recent fill, the dumped material prior to the construction of the present road, and the original overburden are shown. The consistency of the original clayey silt is slightly higher than that of the overlying fill, again being stiffer below the top of the embankment and softer towards the toe of the slope. It was established that below el. 690 ft. the consistency of the material improved considerably, so that no appreciable settlement is considered to have occurred below that depth. All the boreholes were terminated within the clayey silt stratum between el. 687 ft. and 705 ft.

5. GROUNDWATER OBSERVATIONS:

Observations of piezometers show that there is a fairly high water level within the new portion of the fill. Piezometer #1 adjacent to the intercepting drain at the left side of the road, indicated groundwater around 7 ft. below ground surface. This depth is assumed to be below the invert elevation of the drainage pipe, implying that the pipe functions. Beneath the right shoulder, however, the water level was established at 4.5 ft. below ground; at the slope it was found at 2.5 ft. below ground surface. It is evident that such a high water level within the embankment is not desirable since it can soften the soil and create seepage forces.

6. SUMMARY AND CONCLUSIONS:

The soil investigation has proved that the dumped material, below the recent fill, had the poorest consistency. The thickness of this layer varies between 10 ft. at the left side of the road and 18 ft. below the right shoulder. The recent fill material cannot be considered well compacted either, based on penetration 'N' values.

cont'd. /5 ...

6. SUMMARY AND CONCLUSIONS: (cont'd.) ...

The slightly improved 'N' values beneath the top of the fill are believed to be due to the effect of consolidation settlements rather than to the compaction of the fill during construction. As was mentioned earlier, it is assumed that no appreciable settlement has occurred within the original clayey silt stratum on account of the fairly high shear strength of the deposit.

It can be concluded, therefore, that the settlements were the results of:

- (a) Poor compaction of the recent embankment.
- (b) The probable complete lack of compaction of the previously dumped material; and
- (c) High water level within the new fill.

The heterogeneous nature of the two fill deposits makes settlement calculations very difficult. Some computations were, however, carried out, based on laboratory consolidation tests. It is suggested that the obtained values be considered as rough guides only. According to the calculations, some 9" - 12" of settlements are still anticipated. It appears that the larger portion of the subsidence has already been completed; further settlements will take a longer period of time with diminishing rate.

In order to observe the magnitude and rate of further settlements, it is recommended that settlement plates be installed outside the travelled portion of the road, at three or more stations within the failure area. Settlement readings of the plates should be carried out regularly at least twice monthly for a period of 6 - 7 months. A general layout of the installed settlement points and the subsequent settlement readings, should be forwarded to the Foundation Section (Attn: Mr. A. K. Barsvary, Senior Foundation Engineer) as soon as possible, for further study. It is believed that a period of 6 - 7 months of observation would be adequate for a more accurate prediction of further settlements. Only then should the remedial measures to be adopted, be decided upon.

7. MISCELLANEOUS:

The field investigation, undertaken between the period September 26 - October 4, 1967, was supervised by Mr. A. K. Barsvary, Senior Foundation Engineer, who also prepared this report.

Equipment for the field work was owned and operated by Master Soil Investigations Ltd.

Mr. K. G. Selby, Supervising Foundation Engineer, reviewed the report.

October 1967.

**APPENDIX I**



**MATERIALS & TESTING DIVISION**

RECORD OF BOREHOLE NO. 2

FOUNDATION SECTION

JOA 67-P-25

LOCATION Sta. 40 + 60 18' Rt. of R

ORIGINATED BY AKB



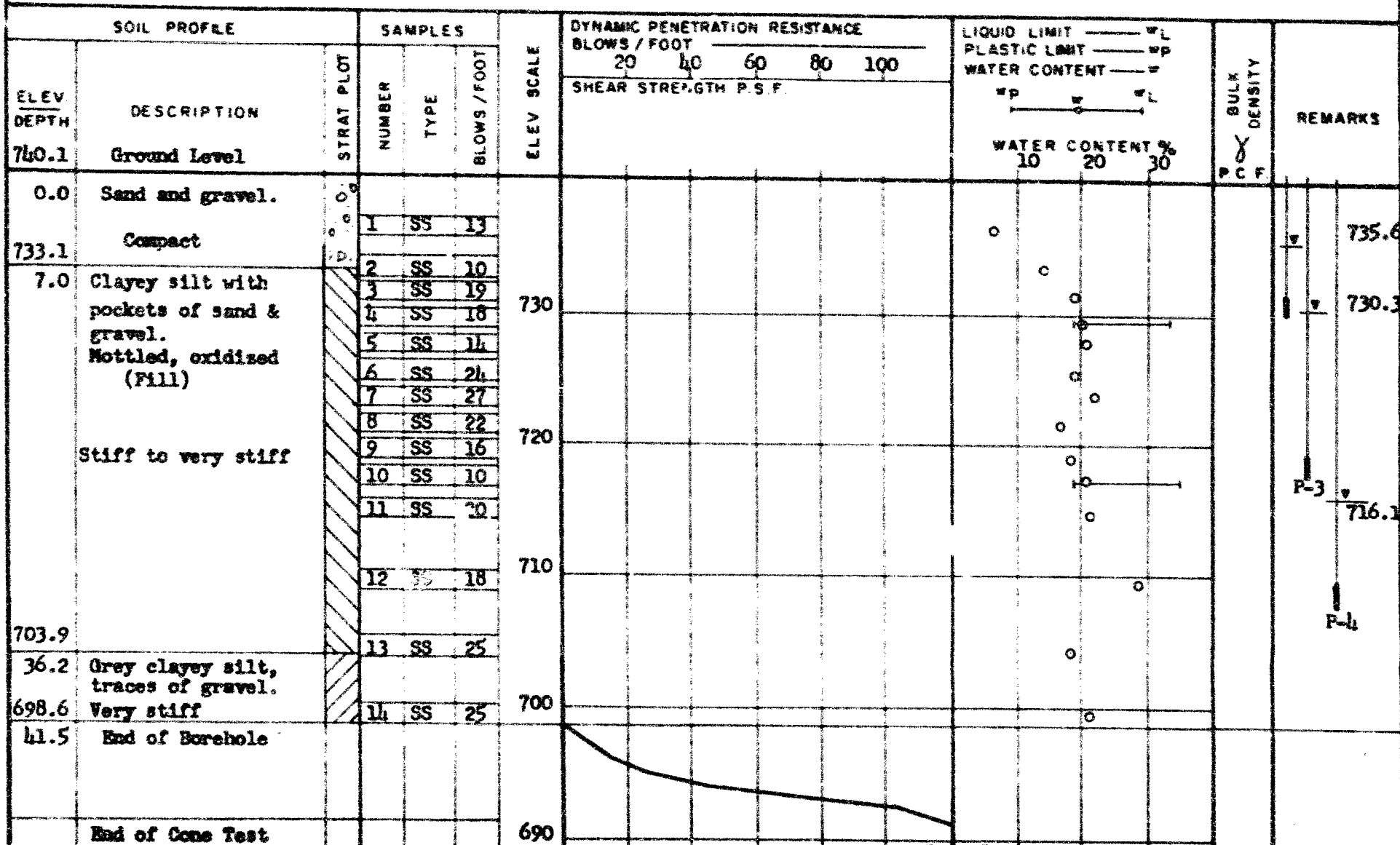
BORING DATE Sept. 27, 1967

COMPILED BY AK

DATUM Geodetic

BOREHOLE TYPE Washboring, NX Casing

CHECKED BY                     





DEPARTMENT OF HIGHWAYS - ONTARIO

**MATERIALS & TESTING DIVISION**

67-P-95

LOCATION Sta. 40 + 60 74' Rt. of g

BOHRING DATE Oct. 2/67

04764 040401c


BOREHOLE TYPE Washboring, NX Casing

FOUNDATION SECTION

ORIGINATED BY AKB

COMPILED BY AKB

CHECKED BY                     

SOIL PROFILE			SAMPLES			ELEV SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT				LIQUID LIMIT _____ w <sub>L</sub> PLASTIC LIMIT _____ w <sub>p</sub> WATER CONTENT _____ w			BULK DENSITY P.C.F.	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	BLOWS / FOOT		SHEAR STRENGTH P.S.F. ● - Unconfined				WATER CONTENT %				
							500	1000	1500	2000	10	20	30		
718.4	Ground Level														
0.0	Clayey silt with pockets of sand & gravel. Oxidized, some org. Firm to stiff.  (Fill)		1	SS	7	710									v 716.0
			2	SS	11										
			3	SS	8										
			4	SS	15										
			5	ES	12										
			1A	TW	P									134 129	P.6
700.9			2A	TW	P										
			6	SS	10										
17.5	Grey clayey silt, traces of sand & gravel.		3A	TW	P	700									
			7	SS	29										
691.9	Very stiff.		8	SS	28										
26.5	End of Borehole					690									

CHECKED BY

SOIL PROFILE			SAMPLES			ELEV SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT				LIQUID LIMIT ——— w <sub>L</sub> PLASTIC LIMIT ——— w <sub>p</sub> WATER CONTENT ——— w			BULK DENSITY P.C.F.	REMARKS
ELEV DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	BLOWS / FOOT		SHEAR STRENGTH P.S.F. x Field Vane • Unconfined				WATER CONTENT % w <sub>p</sub> ——— w ——— w <sub>L</sub>				
							500	1000	1500	2000	10	20	30		
710.4	Ground Level														
0.0	Clayey silt, some sand and organics. Firm to stiff. (PM11)		1	SS	12	700									709.4
			2	SS	11										
			3	SS	4										
701.4			4	SS	5										
9.0	Grey clayey silt, traces of sand and gravel.  Firm to hard.		1A	TW	P										
			2A	TW	P										
			5	SS	13										
			6	SS	25										
		7	SS	18	690										
		8	SS	36											
23.5	End of Borehole					680									

## ABBREVIATIONS USED IN THIS REPORT

### PENETRATION RESISTANCE

STANDARD PENETRATION RESISTANCE 'N' - THE NUMBER OF BLOWS REQUIRED TO ADVANCE A STANDARD SPLIT SPOON SAMPLER 12 INCHES INTO THE SUBSOIL, DRIVEN BY MEANS OF A 140 POUND HAMMER FALLING FREELY A DISTANCE OF 30 INCHES.

DYNAMIC PENETRATION RESISTANCE :- THE NUMBER OF BLOWS REQUIRED TO ADVANCE A 2 INCH, 60 DEGREE CONE, FITTED TO THE END OF DRILL RODS, 12 INCHES INTO THE SUBSOIL, THE DRIVING ENERGY BEING 350 FOOT POUNDS PER BLOW.

### DESCRIPTION OF SOIL

THE CONSISTENCY OF COHESIVE SOILS AND THE RELATIVE DENSITY OR DENSENESS OF COHESIONLESS SOILS ARE DESCRIBED IN THE FOLLOWING TERMS :-

<u>CONSISTENCY</u>	<u>'N' BLOWS / FT.</u>	<u>c LB. / SQ. FT.</u>	<u>DENSENESS</u>	<u>'N' BLOWS / FT.</u>
VERY SOFT	0 - 2	0 - 250	VERY LOOSE	0 - 4
SOFT	2 - 4	250 - 500	LOOSE	4 - 10
FIRM	4 - 8	500 - 1000	COMPACT	10 - 30
STIFF	8 - 15	1000 - 2000	DENSE	30 - 50
VERY STIFF	15 - 30	2000 - 4000	VERY DENSE	> 50
HARD	> 30	> 4000		

### TYPE OF SAMPLE

S.S	SPLIT SPOON	T.W	THINWALL OPEN
W.S	WASHED SAMPLE	T.P	THINWALL PISTON
S.B	SCRAPER BUCKET SAMPLE	O.S	OESTERBERG SAMPLE
A.S	AUSER SAMPLE	F.S	FOIL SAMPLE
C.S	CHUNK SAMPLE	R.C	ROCK CORE
S.T	SLOTTED TUBE SAMPLE		

P.H. SAMPLE ADVANCED HYDRAULICALLY

P.M. SAMPLE ADVANCED MANUALLY

### SOIL TESTS

Q <sub>u</sub>	UNCONFINED COMPRESSION	L.V	LABORATORY VANE
Q	UNDRAINED TRIAXIAL	F.V	FIELD VANE
Q <sub>cu</sub>	CONSOLIDATED UNDRAINED TRIAXIAL	C	CONSOLIDATION
Q <sub>d</sub>	DRAINED TRIAXIAL	S	SENSITIVITY

# ABBREVIATIONS USED IN THIS REPORT

## SOIL PROPERTIES

$\gamma$	UNIT WEIGHT OF SOIL (BULK DENSITY)
$\gamma_s$	UNIT WEIGHT OF SOLID PARTICLES
$\gamma_w$	UNIT WEIGHT OF WATER
$\gamma_d$	UNIT DRY WEIGHT OF SOIL (DRY DENSITY)
$\gamma'$	UNIT WEIGHT OF SUBMERGED SOIL
G	SPECIFIC GRAVITY OF SOLID PARTICLES $G = \frac{\gamma_s}{\gamma_w}$
e	VOID RATIO
n	POROSITY
w	WATER CONTENT
$S_r$	DEGREE OF SATURATION
$w_L$	LIQUID LIMIT
$w_p$	PLASTIC LIMIT
$I_p$	PLASTICITY INDEX
s	SHRINKAGE LIMIT
$I_L$	LIQUIDITY INDEX = $\frac{w - w_p}{I_p}$
$I_c$	CONSISTENCY INDEX = $\frac{w_L - w}{I_p}$
$e_{max}$	VOID RATIO IN LOOSEST STATE
$e_{min}$	VOID RATIO IN DENSEST STATE
$I_D$	DENSITY INDEX = $\frac{e_{max} - e}{e_{max} - e_{min}}$
	RELATIVE DENSITY $D_r$ IS ALSO USED
h	HYDRAULIC HEAD OR POTENTIAL
Q	RATE OF DISCHARGE
v	VELOCITY OF FLOW
i	HYDRAULIC GRADIENT
k	COEFFICIENT OF PERMEABILITY
j	SEEPAGE FORCE PER UNIT VOLUME
$m_v$	COEFFICIENT OF VOLUME CHANGE = $\frac{-\Delta e}{(1+e)\Delta\sigma}$
$c_v$	COEFFICIENT OF CONSOLIDATION
$C_c$	COMPRESSION INDEX = $\frac{\Delta e}{\Delta \log_{10} \sigma}$
$T_v$	TIME FACTOR = $\frac{c_v t}{d^2}$ (d, DRAINAGE PATH)
U	DEGREE OF CONSOLIDATION
$\tau_1$	SHEAR STRENGTH
c'	EFFECTIVE COHESION INTERCEPT
$\phi'$	EFFECTIVE ANGLE OF SHEARING RESISTANCE, OR FRICTION
$c_u$	APPARENT COHESION
$\phi_u$	APPARENT ANGLE OF SHEARING RESISTANCE, OR FRICTION
$\mu$	COEFFICIENT OF FRICTION
$S_i$	SENSITIVITY

## GENERAL

$\pi$	= 3.1416
e	BASE OF NATURAL LOGARITHMS 2.7183
$\log_e a$ OR $\ln a$	NATURAL LOGARITHM OF a
$\log_{10} a$ OR $\lg a$	LOGARITHM OF a TO BASE 10
t	TIME
g	ACCELERATION DUE TO GRAVITY
V	VOLUME
W	WEIGHT
M	MOMENT
F	FACTOR OF SAFETY

## STRESS AND STRAIN

u	PORE PRESSURE
$\sigma$	NORMAL STRESS
$\bar{\sigma}$	NORMAL EFFECTIVE STRESS ( $\bar{\sigma}$ IS ALSO USED)
$\tau$	SHEAR STRESS
$\epsilon$	LINEAR STRAIN
$\gamma$	SHEAR STRAIN
$\nu$	POISSON'S RATIO ( $\mu$ IS ALSO USED)
E	MODULUS OF LINEAR DEFORMATION (YOUNG'S MODULUS)
G	MODULUS OF SHEAR DEFORMATION
K	MODULUS OF COMPRESSIBILITY
$\eta$	COEFFICIENT OF VISCOSITY

## EARTH PRESSURE

d	DISTANCE FROM TOP OF WALL TO POINT OF APPLICATION OF PRESSURE
$\delta$	ANGLE OF WALL FRICTION
K	DIMENSIONLESS COEFFICIENT TO BE USED WITH VARIOUS SUFFIXES IN EXPRESSIONS REFERRING TO NORMAL STRESS ON WALLS
$K_0$	COEFFICIENT OF EARTH PRESSURE AT REST

## FOUNDATIONS

B	BREADTH OF FOUNDATION
L	LENGTH OF FOUNDATION
D	DEPTH OF FOUNDATION BENEATH GROUND
N	DIMENSIONLESS COEFFICIENT USED WITH A SUFFIX APPLYING TO SPECIFIC GRAVITY, DEPTH AND COHESION ETC. IN THE FORMULA FOR BEARING CAPACITY
$k_s$	MODULUS OF SUBGRADE REACTION

## SLOPES

H	VERTICAL HEIGHT OF SLOPE
D	DEPTH BELOW TOE OF SLOPE TO HARD STRATUM
$\beta$	ANGLE OF SLOPE TO HORIZONTAL

67-F-05

DEPARTMENT OF HIGHWAYS ONTARIO  
MEMORANDUM

To: Mr. A. G. Stermac,  
Principal Foundation Engineer,  
Materials and Testing Division,  
Downsview.

From: Materials and Testing,  
London.

DATE: September 20, 1967.

OUR FILE REF.

IN REPLY TO

---

SUBJECT: - Development Road 724, Highway #81 to Arkona,  
Pavement Failure, Station 39 to Station 42.  
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This failure which occurred shortly after construction has been repaired several times since, and has continually failed. No explanation for the failure is obvious from inspection or from the limited amount of investigation we have carried out from this office.

We would be pleased if you would arrange to instrument the failure area so that we can find the reason and consider some permanent repair.

The Department still maintains the road and is desirous of reverting it to the County authority.



J. R. ROY,  
REGIONAL MATERIALS ENGINEER.

JRR:hp.

C.C. - T. S. Caldwell,  
File.

DEPARTMENT OF HIGHWAYS ONTARIO

MEMORANDUM

To: Mr. A. Barsvary,  
Senior Foundations Engineer,  
Foundation Section,  
Materials and Testing Division,  
DOWNSVIEW.

FROM: Materials and Testing,  
London.

DATE: October 6, 1967.

Our File Ref.

IN REPLY TO

SUBJECT: - Development Road #724,  
Pavement Failure,  
Station 39 /- to Station 42 /-.

Further to our discussion at the above mentioned site, our records show that the fill construction was carried out during the Fall, 1964 and the Summer of 1965. Original paving was placed in September 1965. Settlement up to approximately 4" in depth was noted on December 15, 1965. The section was patched with hot mix in late Spring, 1966 and again in late Fall 1966.

The County Engineer indicates that the County dumped considerable clay material in the area in 1951 and that excess material from excavations had been dumped in the area prior to 1951.

*A. M. Batten*  
A. M. BATTEN,

FOR: J. R. ROY,  
REGIONAL MATERIALS ENGINEER.

AMB:hp.

C.C. - File.

401 & Keele Street  
Downsview, Ontario

October 13, 1967

Master Soil Investigation  
104 Kenhar Drive  
Weston, Ontario

Dear Sirs:

This is to confirm our request of September 25, 1967 for the supply of a Diamond Drill together with all necessary equipment, as specified under the terms of our Contract Agreement, at County Road #12, Arkona, Ontario, September 26, 1967.

This project bears Job Number 67-F-95.

Yours truly,

*H. L. Selby*

Encmt

K. G. Selby  
Supervising Foundation Engineer  
for: A. G. Stermac  
Principal Foundation Engineer

cc: H. Konings  
Foundation Files 110  
General File

1968 DEC 13 AM 11:57

00189

DOWN LOND 12 DEC 13/68

11:50 AM

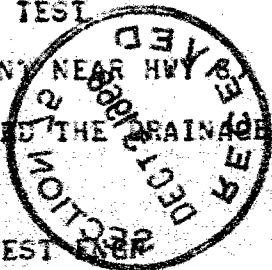
PRIORITY

X SELEY MAT AND TEST

OR 724 SETTLEMENT NEAR HWY

IT IS ANTICIPATED THE DRAINAGE IMPROVEMENTS WILL BE CARRIED OUT  
NEXT SPRING

J ROY MAT AND TEST



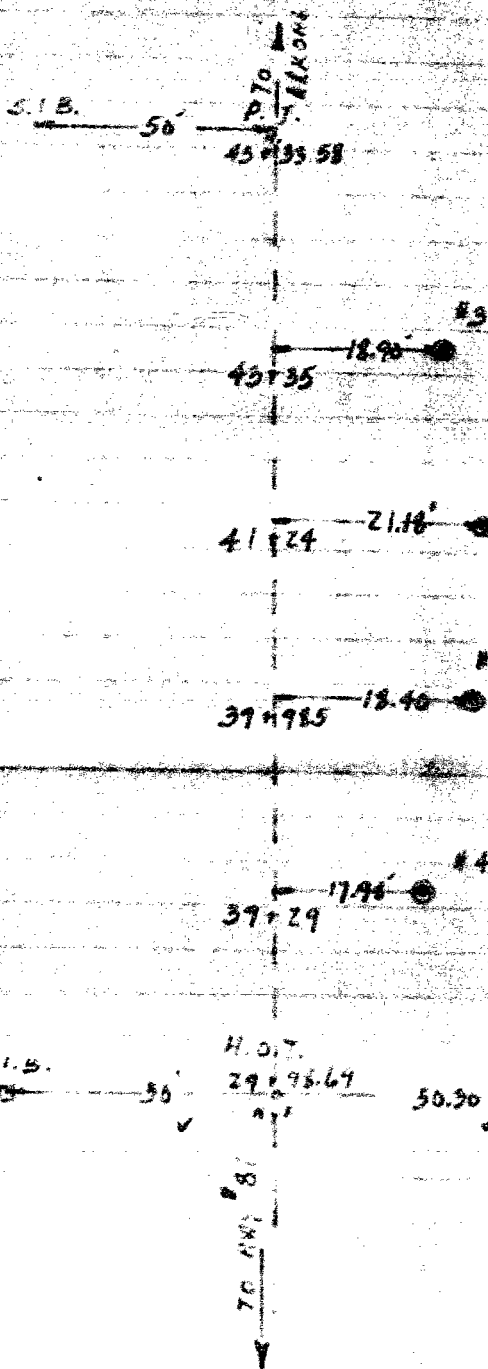
WEN: IT WILL BE INTERESTING TO SEE THE PERFORMANCE  
OF THIS ROAD NEXT SPRING.

TOWY

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# LAYOUT OF TEST PIPES

DEVELOPMENT ROAD # 724 (CO RD # 12)



SURVEYED BY:

S. ANCANI

J. CAMERON

R. McANLEY

APRIL 13/1971

DEFECTS IN NEGATIVE DUE TO  
CONDITION OF ORIGINAL DOCUMENT

APRIL 13/1971

REPORT  
RE. DEVELOPM. RD # 724

ON APRIL 9/1968 I AND ERIC JAMIESON ARRIVED ON DEVEL. RD # 724 ON THE SITE OF SIDE FILL FAILURE AND WE WERE MET BY MURRAY DATTEN FROM MATERIALS & TESTING BRANCH SW. REGION - LONDON.

WE WERE ASKED TO DO THE SURVEY - TO TIE IN THREE TEST PIPES (ALREADY PLACED ON SHOULDER) INTO CENTRE LINE OF ROAD, TO MAKE A SKETCH SHOWING LOCATIONS (CHAINAGE TO THE CLOSEST FOOT) AND OFFSET DISTANCES FROM CENTRE LINE TO THE PIPES (TO THE NEAREST HUNDRETH). WE ALSO WERE ASKED TO TAKE ELEVATIONS ONCE A WEEK (EVERY TUESDAY) SHOWING THE ELEVATIONS OF TOP OF PIPES. ELEVATIONS HAD TO BE RECORDED IN FIELD BOOK AND TELETYPE TO TORONTO - MATERIALS & TESTING DIVISION.

WE WERE ASKED TO USE GEODETIC BENCH MARKS. IN THE VICINITY MIDDLESEX COUNTY ENGINEERING CREW HAD ESTABLISHED TWO GEODETIC B.M.'s

- "1 - N 1/4 IN N ROOT OF 24" MAPLE LT. STA 36+50 ELEV. 737.23
- "2 - N 1/4 IN N ROOT OF 30" MAPLE 69' LT STA 41+75 ELEV. 739.08

B<sub>1</sub> CHECKING THESE ELEVATIONS WE FOUND B<sub>1</sub> DISCREPANCY. THEREFORE WE DECIDED TO RUN FLY LEVELS FROM HWY #81, STARTING WITH B.M. AT THE INTERSECTION OF HWY #81 & DEVELOPM. RD # 724. (N 1/4 IN NW ROOT OF 8" B.M. OF N SIDE OF HWY #81. ~~ELEV~~ 91' AT STA 7+09 ELEV. 732.02). DIFFERENCE OR ERROR IN ELEVATIONS BETWEEN THIS B.M. & #2 WAS -.12

BUT SINCE THERE WERE NO OTHER B.M.'s IN VICINITY TO CHECK INTO AND SINCE B.M. #2 APPEARED TO BE IN VERY GOOD CONDITION, WE ASSUMED B.M.'s #2 ELEV. 739.08 AS A CORRECT ONE AND WE USED THIS B.M.

EVERY WEEK CHECKING TEST PIPE ELEVATIONS (ADDITIONAL TEST PIPE) WAS PLACED BY MATERIALS TESTING BRANCH IN SEPT 1970.

SINCE APRIL 1962 ON THIS LOCATION ADDITIONAL SURVEY WAS CARRIED OUT BY M.M. DILLON LTD. CONSULTING ENGINEERS (PROJECT 6388-01) THEIR PLAN SHOWS TWO ESTABLISHED CRODGETIC B.M. ON DEVELOP. RD. #724:

B.M. ELFV. 735.97 - 1" S.I.B. 50' LT STA. 29+98.69 AND

B.M. ELFV. 739.02 - N.W. IN N. ROOT OF 30" MAPLE LT. STA. 41+25

THE DESCRIPTION OF SECOND B.M. CORRESPONDS WITH THE ONE ESTABLISHED BY MIDDLESEX COUNTY, ~~ERR~~ AND THE ONE WE WERE USING, EXCEPT FOR ITS ELEVATION. THEY SHOW IT AS 739.02 INSTEAD OF 739.08

ON APRIL 13/1971 WE CHECKED : 1) THE CONDITION OF B.M. USED ;  
2) RAN FLY LEVELS FROM HWY #81 B.M. TO THE ONE WE ARE USING ;  
3) CHECKED THE CHAINAGE AND OFFSET DISTANCES FROM CENTRE LINE OF ROAD TO CENTRE OF TEST PIPE CASINGS. OUR FINDINGS :

1) THE CONDITION OF B.M. IS VERY GOOD, ALTHOUGH THE RIGHT DESCRIPTION SHOULD BE: NAIL AND NAILER IN N. ROOT OF 42" MAPLE 69' LT STA. 41+20 ;

2) OUR ELEVATIONS AGREE WITH THE ONES ESTABLISHED BY M.M. DILLON LTD CONSULTING ENGINEERS ; (FLY LEVELS FROM B.M. AT HWY #81 - TO B.M. ON DEV. RD. STA. 7+09 STA. 41+25 LT.)

3) ATTACHED SKETCH SHOWS THE LOCATIONS OF TEST PIPES. ~~END~~

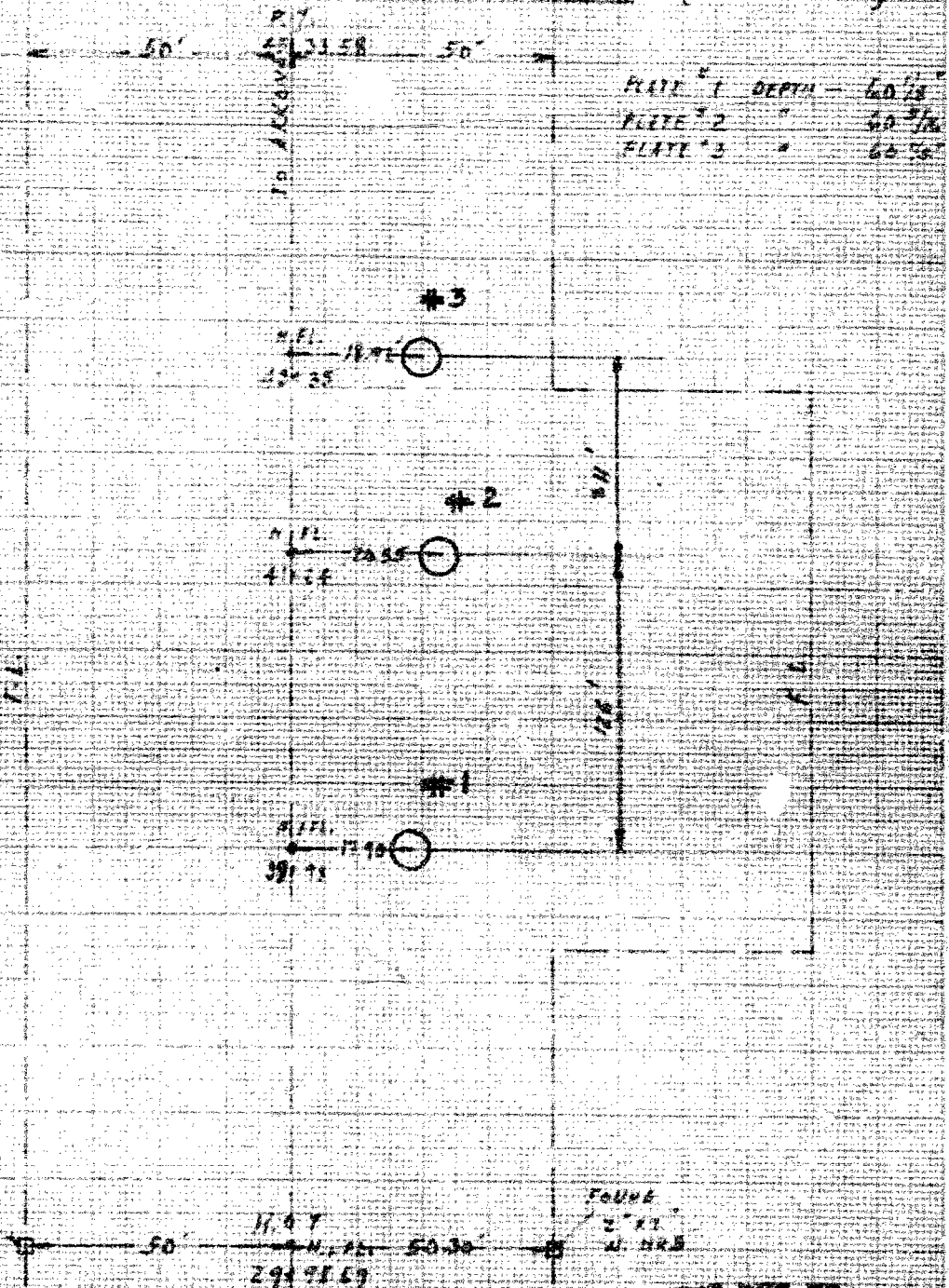
Stanley Pincus  
TECHNICIAN - SURVEY

APRIL 9 1964

# SKETCH

OF

LOCATION OF TEST PIPES (SIDE FILL FAILURE)  
DEVELOPMENT ROAD "72" (CO RD # 12)



DEFECTS IN NEGATIVE DUE TO  
CONDITION OF ORIGINAL DOCUMENT

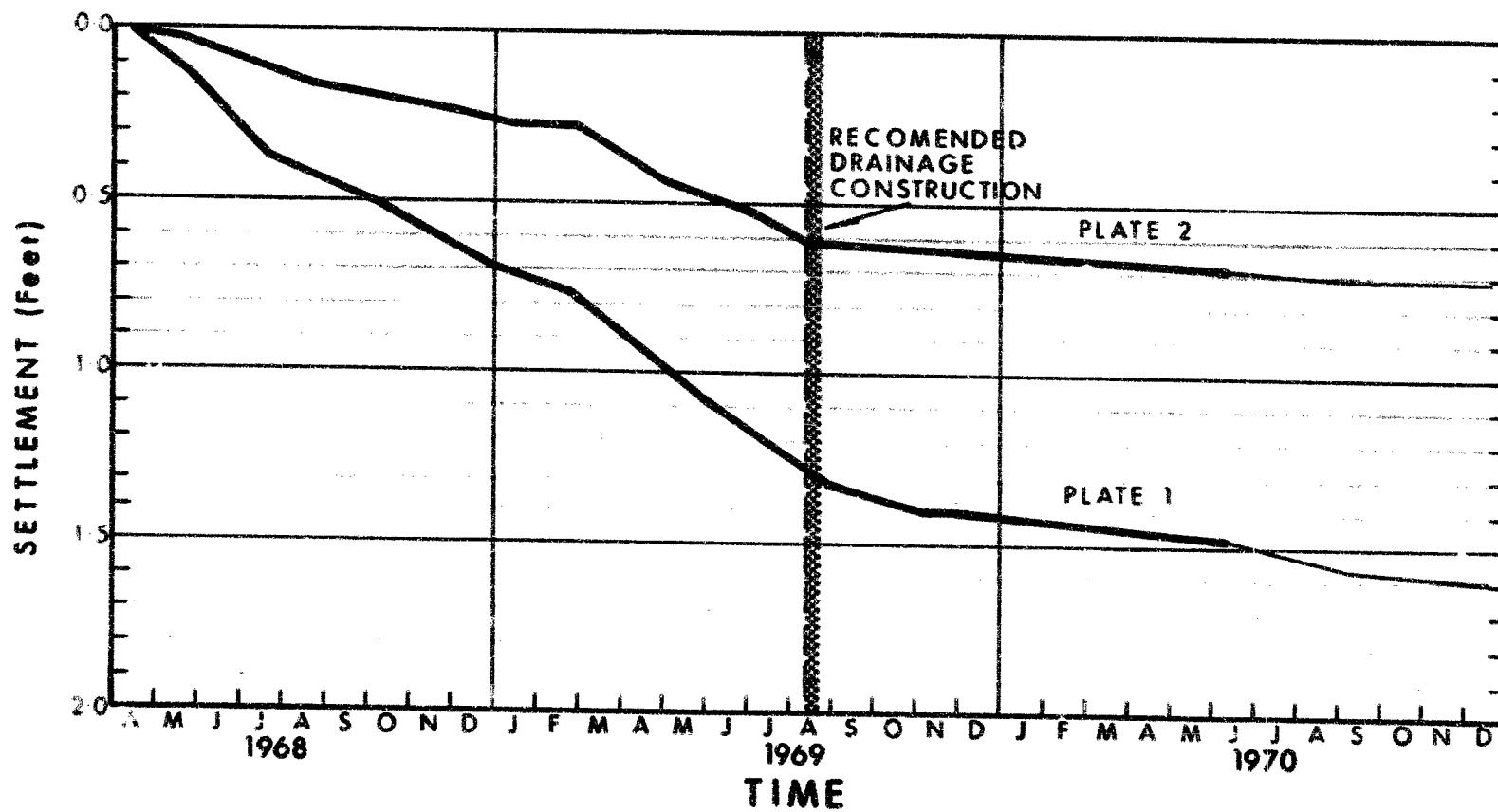
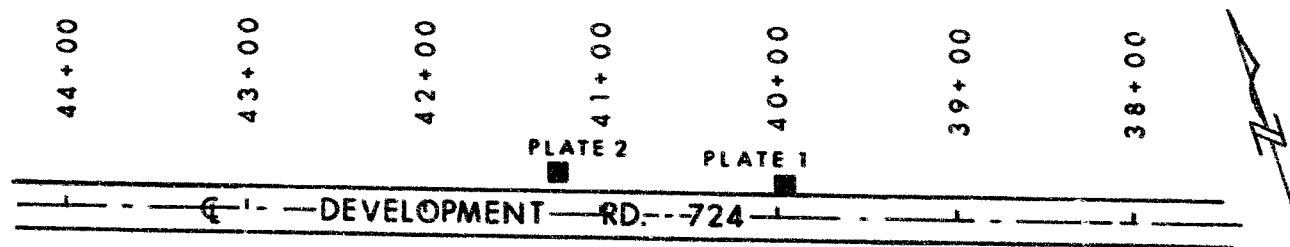


FIG. 1

PLAN  
 1" = 50'

STA: 44+00 43+00 42+00 41+00 40+00 39+00 38+00

PI<sup>3</sup>

PI<sup>2</sup>

PI<sup>1</sup>

DEVELOPMENT 22' 72'

0  
2  
4  
6  
8  
10

1'  
2'  
3'  
4'  
5'

ADD 9/62 = 0.00  
 100' ✓  
 124' ✓  
 130' ✓  
 135' ✓  
 140' ✓  
 145' ✓  
 150' ✓  
 155' ✓  
 160' ✓  
 165' ✓  
 170' ✓  
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 820' ✓  
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 935' ✓  
 940' ✓  
 945' ✓  
 950' ✓  
 955' ✓  
 960' ✓  
 965' ✓  
 970' ✓  
 975' ✓  
 980' ✓  
 985' ✓  
 990' ✓  
 995' ✓  
 1000' ✓

FIG 2

STANDARD DEVIATIONS								OVER	
DATE	PIPE #1	PIPE #2	PIPE #3	PIPE #4	PIPE #5	PIPE #6	PIPE #7		
APRIL 14	789.56	741.13	740.89						
APR 16	29.75	41.12	40.95						
MAY 1	29.70	41.18	40.95						
MAY 8	41.32	29.70	40.95						
MAY 10	46.10	19.00	40.95						
MAY 22	43.32	38.01	41.32						
MAY 29	40.31	36.36	40.95						
JUNE 8	37.63	35.31	40.95						
JUNE 11	36.01	34.01	40.95						
JUNE 18	34.71	34.71	40.95						
JUNE 25	31.23	33.01	40.95						
JULY 5	28.23	31.62	40.95						
JULY 13	22.33	29.99	40.95						
JULY 23	20.22	28.61	40.95						
JULY 30	18.32	27.01	40.95						
AUG 5	17.01	26.01	40.95						
AUG 13	16.01	26.00	40.95						
AUG 26	15.01	25.01	40.95						
AUG 27	14.01	24.01	40.95						
SEPT 2	12.02	24.01	40.95						
SEPT 10	10.34	23.01	40.95						
SEPT 17	09.31	22.01	40.95						
SEPT 24	08.31	21.00	40.95						
SEPT 31	07.01	20.01	40.95						
OCT 8	06.01	19.00	40.95						
OCT 15	04.01	18.01	40.95						
OCT 22	03.31	17.01	40.95						
OCT 29	02.31	16.00	40.95						
NOV 5	01.02	15.01	40.95						
NOV 12	00.31	14.01	40.95						
NOV 19	00.01	13.00	40.95						
NOV 26	00.00	12.01	40.95						
DEC 3	00.01	11.01	40.95						
DEC 10	00.01	10.01	40.95						
DEC 17	00.01	9.01	40.95						
DEC 24	00.01	8.01	40.95						
DEC 31	00.01	7.01	40.95						
JAN 7	00.01	6.01	40.95						
JAN 14	00.01	5.01	40.95						
JAN 21	00.01	4.01	40.95						
JAN 28	00.01	3.01	40.95						
FEB 4	00.01	2.01	40.95						
FEB 11	00.01	1.01	40.95						
FEB 18	00.01	0.01	40.95						
FEB 25	00.01	0.00	40.95						
MAR 4	00.01	0.00	40.95						
MAR 11	00.01	0.00	40.95						
MAR 18	00.01	0.00	40.95						
MAR 25	00.01	0.00	40.95						
APR 1	00.01	0.00	40.95						
APR 8	00.01	0.00	40.95						
APR 15	00.01	0.00	40.95						
APR 22	00.01	0.00	40.95						
APR 29	00.01	0.00	40.95						
MAY 6	00.01	0.00	40.95						
MAY 13	00.01	0.00	40.95						
MAY 20	00.01	0.00	40.95						
MAY 27	00.01	0.00	40.95						
JUN 3	00.01	0.00	40.95						
JUN 10	00.01	0.00	40.95						
JUN 17	00.01	0.00	40.95						
JUN 24	00.01	0.00	40.95						
JUN 30	00.01	0.00	40.95						
JUL 7	00.01	0.00	40.95						
JUL 14	00.01	0.00	40.95						
JUL 21	00.01	0.00	40.95						
JUL 28	00.01	0.00	40.95						
AUG 4	00.01	0.00	40.95						
AUG 11	00.01	0.00	40.95						
AUG 18	00.01	0.00	40.95						
AUG 25	00.01	0.00	40.95						
SEP 1	00.01	0.00	40.95						
SEP 8	00.01	0.00	40.95						
SEP 15	00.01	0.00	40.95						
SEP 22	00.01	0.00	40.95						
SEP 29	00.01	0.00	40.95						
OCT 6	00.01	0.00	40.95						
OCT 13	00.01	0.00	40.95						
OCT 20	00.01	0.00	40.95						
OCT 27	00.01	0.00	40.95						
NOV 3	00.01	0.00	40.95						
NOV 10	00.01	0.00	40.95						
NOV 17	00.01	0.00	40.95						
NOV 24	00.01	0.00	40.95						
DEC 1	00.01	0.00	40.95						
DEC 8	00.01	0.00	40.95						
DEC 15	00.01	0.00	40.95						
DEC 22	00.01	0.00	40.95						
DEC 29	00.01	0.00	40.95						
JAN 5 1971	00.01	0.00	40.95						
JAN 12	00.01	0.00	40.95						
JAN 19	00.01	0.00	40.95						
JAN 26	00.01	0.00	40.95						
FEB 2	00.01	0.00	40.95						
FEB 9	00.01	0.00	40.95						
FEB 16	00.01	0.00	40.95						
FEB 23	00.01	0.00	40.95						
MARCH 2	00.01	0.00	40.95						
MARCH 9	00.01	0.00	40.95						
MARCH 16	00.01	0.00	40.95						
MARCH 23	00.01	0.00	40.95						
MARCH 30	00.01	0.00	40.95						
APR 6	00.01	0.00	40.95						
APR 13	00.01	0.00	40.95						
APR 20	00.01	0.00	40.95						
APR 27	00.01	0.00	40.95						
MAY 4	00.01	0.00	40.95						
MAY 11	00.01	0.00	40.95						
MAY 18	00.01	0.00	40.95						
MAY 25	00.01	0.00	40.95						
JUNE 1	00.01	0.00	40.95						
JUNE 8	00.01	0.00	40.95						
JUNE 15	00.01	0.00	40.95						
JUNE 22	00.01	0.00	40.95						
JUNE 29	00.01	0.00	40.95						
JULY 6	00.01	0.00	40.95						
JULY 13	00.01	0.00	40.95						
JULY 20	00.01	0.00	40.95						
AUG 3	00.01	0.00	40.95						
AUG 10	00.01	0.00	40.95						
AUG 17	00.01	0.00	40.95						
AUG 24	00.01	0.00	40.95						
SEP 7	00.01	0.00	40.95						
SEP 14	00.01	0.00	40.95						
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SEP 28	00.01	0.00	40.95						
OCT 5	00.01	0.00	40.95						
OCT 12	00.01	0.00	40.95						
OCT 19	00.01	0.00	40.95						
OCT 26	00.01	0.00	40.95						
NOV 2	00.01	0.00	40.95						
NOV 9	00.01	0.00	40.95						
NOV 16	00.01	0.00	40.95						
NOV 23	00.01	0.00	40.95						
NOV 30	00.01	0.00	40.95						
DEC 7	00.01	0.00	40.95						
DEC 14	00.01	0.00	40.95						
DEC 21	00.01	0.00	40.95						
DEC 28	00.01	0.00	40.95						
JAN 4 1972	00.01	0.00	40.95						
JAN 11	00.01	0.00	40.95						
JAN 18	00.01	0.00	40.95						
JAN 25	00.01	0.00	40.95						
FEB 1	00.01	0.00	40.95						
FEB 8	00.01	0.00	40.95						
FEB 15	00.01	0.00	40.95						
FEB 22	00.01	0.00	40.95						
FEB 29	00.01	0.00	40.95						

Plate # 3 at the road section it is found, no cracks or  
 pavement

around station 37+00 culvert seems working, quite a flow  
 but side ditches especially south side still wet. Ends!

around station 34+00 failure developing at north slope



at around station 37 failure some 50 ft length with side indicated  
 side movements.

around station 39+10 with slope 10' behind grade, north slope  
 and local failure! lower slope!

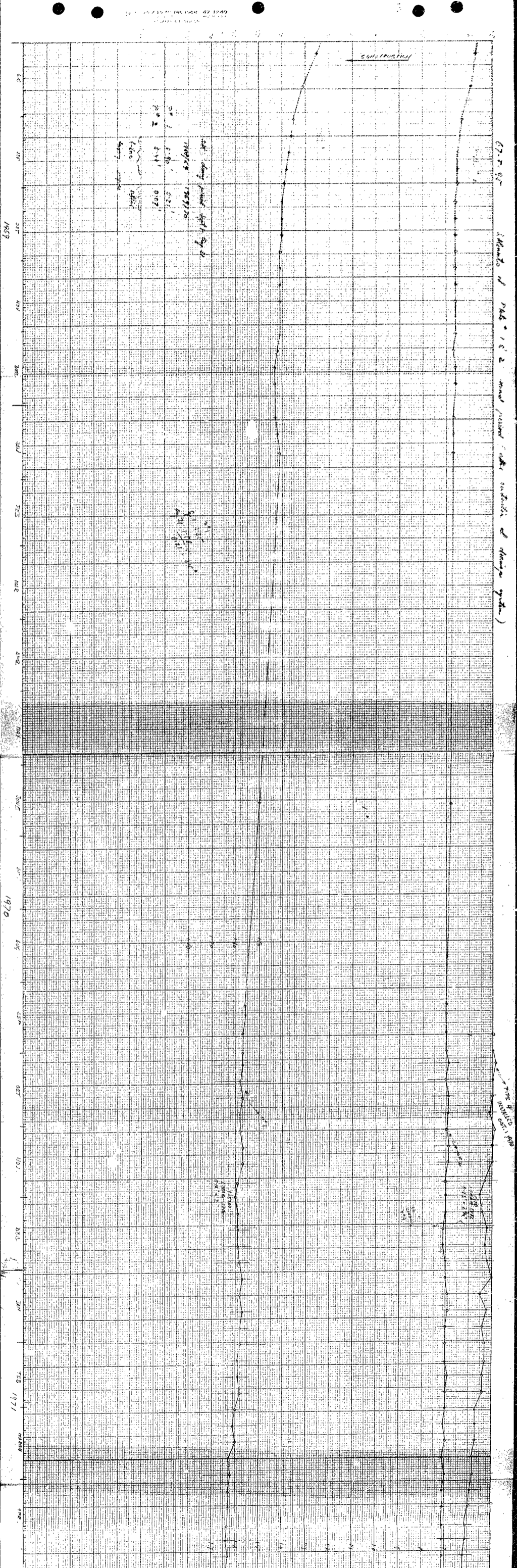
worst condition seems to be at station 37+50 - 39+50.

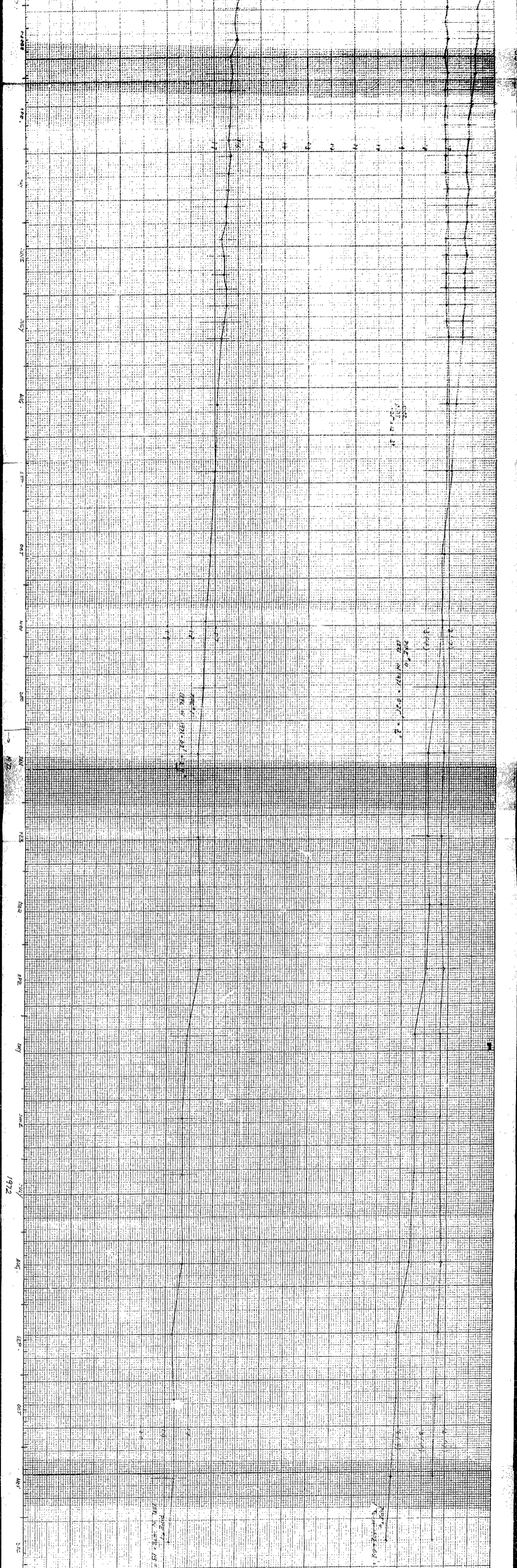
40+00 Seepage on and along north slope

Plate # 1. It appears 39+90 and not 37+90 as indicated  
 on drawing. This is approx middle of failure and approx 50'  
 east of our bridge!

Small seepage along the length of north slope

38+40 have slope surface failure with seepage  
 intercepting drain works but not adequate. Either deeper  
 intercepting drain or counterfoot drains should be necessary.  
 Depth of granular no more than 3' at middle of  
 failure!





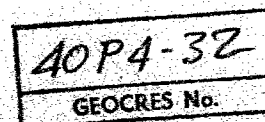
Mr. J. R. Roy,  
Manager, Engineering Services,  
Southwestern Region,  
London, Ontario.

Foundations Office,  
Design Services Branch,  
West Bldg., Downsview.

July 26, 1973.

Mr. J. G. Forester.

Embankment Settlements on Dev. Rd. #724,  
Stas. 38+00 - 42+00,  
County of Middlesex, District #2 (London)  
W.O. 67-11095



Since April 1968 settlements at the above-mentioned location have been monitored and records kept by this Office. These records have recently been reviewed with a view to determining what action if any can be taken now to correct or alleviate the continuing problem of settlement and pavement cracking which occurs over an approximate 300 - 400 ft. length of the road.

This portion of road was constructed under the supervision of Middlesex County in 1966-67. In the fall of 1967 settlements in the order of about 2 ft. occurred between Stas. 38+00 & 42+00, necessitating continuous maintenance. An investigation was carried out by this Office and reported under Report #67-F-95. This report identified the main cause of subsidence as being a layer of clayey silt containing organics which had been dumped on the surface of the original slope some years before construction of the new embankment took place. This layer was believed to be consolidating under the weight of the fill and possibly also being displaced laterally. Seepage water entering the fill was thought to be softening the layer thus aggravating the problem. In April of 1968 three settlement plates were installed along the north shoulder of the road between Stas. 40+00 and 43+35. During the next two months the maximum settlement rate was about 1/4 inch per week. In June 1968 further investigation was carried out by this Office, the main purpose being to study the groundwater conditions and the existing drainage facilities. This work was reported under Report #67-F-95-1, which recommended that a new drainage system be installed since the existing facilities permitted a large amount of ground and surface water to find its way into the fill material. It was believed that these measures would reduce the problem if not actually eliminate it altogether. By August 1969 a new drainage system had been installed and monitoring of the settlement plates continued from that time until the present day.

A study of the settlement records (see attached Drawing 67-F-95D) shows that the immediate result of the new drainage system was a significant decrease in the rate of settlement; i.e., at Sta. 40+00 the rate decreased from 1/4 inch per week to 1/25 inch per week. West of Sta. 41+25 the rate decreased from 1/10 inch per week to zero. In the fall of 1970 the new pavement cracked over an area some 200 ft. long centred about Sta. 39+30. A new settlement plate was installed at Sta. 39+25 in October 1970 and subsequent records show a steady rate of settlement of about 1/20 inch per week. It is now evident that settlement is likely to continue at more or less the same rate along the entire area between Stas. 38+00 and 41+00 for many years to come.

On May 24 the site was visited by Mr. J. R. Roy and Mr. J. G. Forester of Southwestern Region together with the writer. At that time the drainage system appeared to be functioning properly but the north slope of the embankment contained a very wet area between elevations 725+ and 710+ at approximate Sta. 40+00. It appears, therefore, that seepage water is still entering the fill probably at some level below the drainage system. It is also probable that this water is being partially retained by the less pervious soil on the slope surface and that some advantage might be gained by installing a drain running down the slope surface in the centre of the wet area. Such a drain should consist of a trench about 8 ft. deep and about 6 feet wide backfilled with Granular 'A' material to act as a filter and prevent piping. It should be noted that the installation of this drain will probably not cure the main problem of settlement but it is possible that some reduction in the rate might result.

The situation can be summarized as follows:

- 1) The main cause of the settlement is a poorly compacted layer of clayey silt with organics which was dumped on the old slope surface prior to construction of the new embankment.
- 2) The installation of the drainage system has considerably improved, but not cured the settlement problem. Some seepage water is still entering the fill, as is evident from the existence of a wet area on the north slope.
- 3) Further improvement to the problem might result if a drain and filter is provided in the wet zone on the north slope of the embankment. The purpose of this drain would be to release water trapped in the fill and the purpose of the filter to prevent piping.
- 4) Without major reconstruction of this embankment it appears likely that settlement will be a continuing problem for the foreseeable future.

The foregoing was discussed in some detail at a meeting on May 24, 1973, between Mr. F. B. D. Arnold, Middlesex County Engineer, Mr. J. G. Forester, and the writer.

We would be pleased to assist further in this matter in any way we can.

*K. G. Selby*

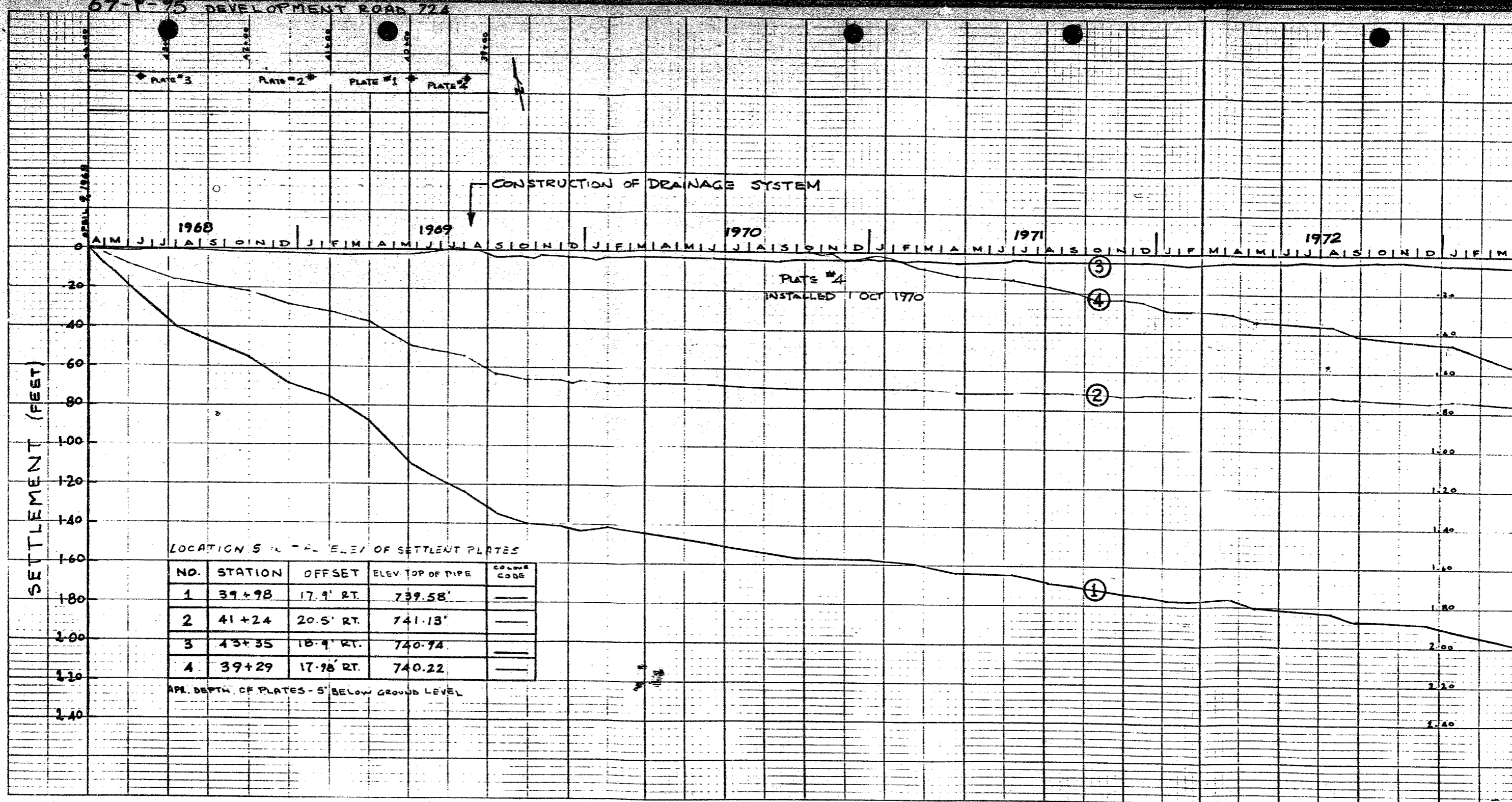
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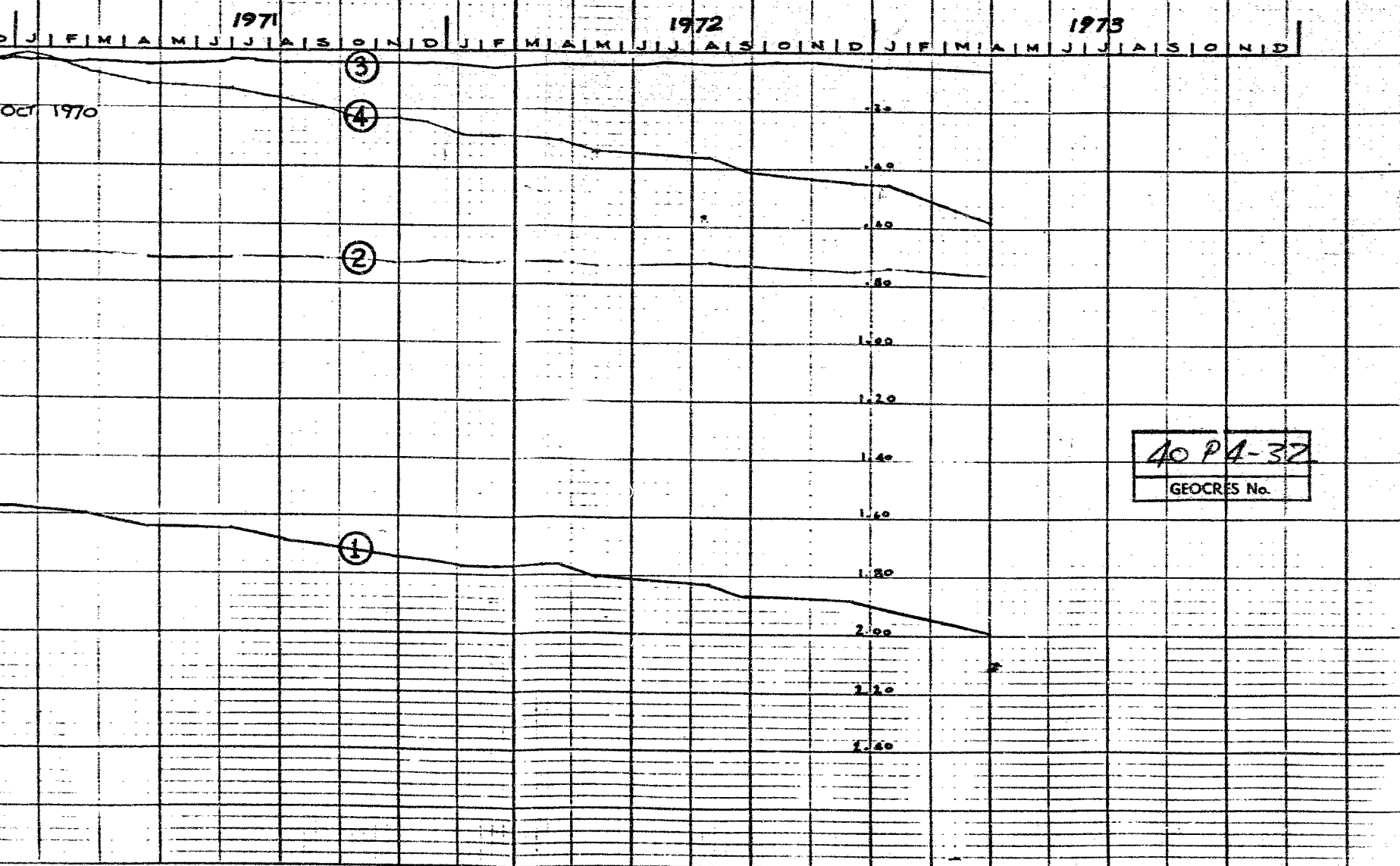
Attch.

C.C. H. H. Greenly  
F. B. D. Arnold

K. G. Selby,  
SUPERVISING FOUNDATIONS ENGINEER.

Foundations Files ✓  
Documents





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