DEPARTMENT OF HIGHWAYS ONTARIO

MEMORANDUM

To: Mr. B. R. Davis,
Bridge Engineer,
Bridge Office,
Admin. Bldg.

Attention: Mr. F. I. Hewson,
Sr. Bridge Liaison Engr.

Our File Ref

From: Foundation Section,
Materials & Testing Office,
Room 107, Lab. Bldg.

Date: February 12, 1969

In reply to: FEB 12 1969

Subject

REPORT ON
RESULTS OF LABORATORY TESTING
VARIOUS MIXTURES OF GRANULAR 'A'
AND BENTONITE
PROPOSED CROSSING OF THE RE-ALIGNED
WELLAND CANAL, MAIN ST. EAST TUNNEL
WELLAND, ONT., DIST. #4 (HAMILTON)
W. J. 68-F-71-2 -- W. P. 240-66

Attached, please find two copies of the above mentioned report for your use. We believe that the report contains all the necessary information. Should there, however, be any queries you would like to discuss, or should you require additional information, please feel free to call on this Office.

One copy of the report was sent directly to the tunnel consultants, Gibb, Albery, Pullerits and Dickson.

A. G. Stermac
PRINCIPAL FOUNDATION ENGINEER

AGS/MdeF
Attach.
cc: Messrs. B. R. Davis (2)
H. A. Tregaskes
D. W. Farren
G. K. Hunter
H. Greenland
W. S. Melinyshyn
T. J. Kovich
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H. Q. Golder & Assoc. Ltd.
Gibb, Albery, Pullerits & Dickson

Foundations Files
Gen. Files

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REPORT ON

RESULTS OF LABORATORY TESTING

VARIOUS MIXTURES OF GRANULAR 'A' AND BENTONITE

PROPOSED CROSSING OF THE RE-ALIGNED

WELLAND CANAL

MAIN STREET EAST TUNNEL

WELLAND ONTARIO

W.J. 68-F-71 -- W.P. 240-66

1. INTRODUCTION:

During construction of the Main Street East Tunnel, a temporary dewatering scheme, to sufficiently lower the piezometric water level, will be required in order to

a) prevent basal heave of the excavation bottom;

b) enable construction in a relatively dry condition.

The permanent dewatering system contemplated for the completed Tunnel structure will only lower the piezometric water level below the approach grades, but not below the Tunnel invert, so that here, upward flow of the groundwater from the bedrock aquifer can be expected. The thickness and properties of the material overlying the bedrock, within the Tunnel area, are such that the overburden would not provide an adequately impermeable natural barrier to the upward flowing water. In addition, the top of the Tunnel will be very near to the invert elevation of the Canal. It is therefore considered that water-proofing of the Tunnel is desirable, since any leakage of water into the Tunnel could lead to poor appearance, ice formation in joints causing cracking, deposition of dissolved salts, and hazardous driving due to wet conditions.

1. INTRODUCTION: (cont'd.) ...

This report deals only with the artificial waterproof barrier required at the base of the Tunnel. The material or materials to be used for this purpose should satisfy the following requirements:

1) reasonably low in-place permeability,
2) adequate strength to sustain all superimposed loads without detrimental settlements, and
3) relatively facile for handling, placement and control.

The use of locally available clayey material was considered not suitable owing to the fact that the variable moisture content and the heterogeneous composition of the material would not satisfy all of the aforementioned requirements. It was therefore decided to investigate the various properties of a mixture of granular material and a swelling type of clay to satisfy, respectively, the requirements for adequate strength and low permeability.

Extensive laboratory tests were carried out on various mixtures of Granular Base Course 'A' (G.B.C. 'A') and bentonite ('Volclay 90' - trade name). The results of these tests are presented in this report, together with recommendations for the most suitable mixture, as well as for the handling, placing and control of the mixture.

2. SOURCE AND DESCRIPTION OF MATERIALS USED:

2.1) General:

In order to design the most appropriate waterproof mixture from a granular material and a swelling type of clay mineral, so that the necessary requirements for compaction, strength, permeability and swelling would be met, consideration was given to using G.B.C. 'A' material and a bentonitic clay,

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2. SOURCE AND DESCRIPTION OF MATERIALS USED: (cont'd.) ...

2.1) General: (cont'd.) ...

available commercially as 'Volclay 90'. In addition, water from various sources was also used in the mixtures in order to evaluate the effect of various electrolytes in the water on the behaviour of the G.B.C. 'A' and 'Volclay 90' mixtures.

2.2) G.B.C. 'A' Material:

The nearest source of granular material, meeting the D.H.O. specifications for G.B.C. 'A', is located in Fonthill, Ontario, some 10 miles from the Main St. East site; it is available from the Moyer and Fonthill Sand and Gravel Pits. A major portion of the testing reported herein was performed on G.B.C. 'A' obtained from the above mentioned source. Some testing was also carried out with a crushed stone satisfying the G.B.C. 'A' requirements, obtained from the R.E. Law Pit in Port Colborne, and the St. Catharines Sand and Gravel Pit in St. Catharines. The physical properties of the G.B.C. 'A' material from the aforementioned sources are shown on Figures 1 and 7 in the Appendix to this report, and are summarized in the table, as follows:

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2. SOURCE AND DESCRIPTION OF MATERIALS USED: (cont'd.) ...

2.3) 'Volclay 90':

Processed bentonite is available in various forms ranging from powders to granular mixtures and pellets. The 'Volclay 90' used in the tests reported herein, is a processed bentonite having a "sugary" texture; it was supplied by the American Colloid Company, Skokie, Illinois. Some of the physical properties of 'Volclay 90', as supplied in a 100-lb. multipaper bag, are listed below:

Gradation - 75 - 90% by wt. retained between the No. 40 and No. 120 USS sieve sizes (medium to fine sand size range).

- less than 5% passing the No. 200 USS sieve size (silt and clay size range).

Atterberg Limits

- Liquid Limit (W_L) - 536%
- Plastic Limit (W_P) - 46%

- using distilled water

Bulk Density (γ)

- 66 PCF (as supplied, loose, dry state).

2.4) Water:

Water, from three sources, was used in the tests performed on the various mixtures of G.B.C. 'A' and 'Volclay 90'. Chemical analyses were carried out on the various sources of water to determine the calcium and sulphate in p.p.m.; this testing was performed by the Chemical Section of the D.H.O. The results of these analyses are tabulated as follows:

Source of G.B.C. 'A'	Gradation (Avg.) % by Wt.			COMPACTION				VOID RATIO (e) & PERMEABILITY (k)	
				St. Proctor		Mod. Proctor			
	Gr.	Sa.	Si.& Cl.	γ Dry (OPT) PCF	WCPT %	γ Dry (OPT) PCF	WOPT %	(e)	(k) cm./sec.
Moyer & Fonthill Sand & Gravel Pits, Fonthill, Ont.	57	37	6	137.4	6.7	140.7	6.1	0.22 to 0.17	1×10^{-3} to 4×10^{-3}
R. E. Law Pit, Port Colborne, Ont.	52	43	5	133.6	6.2	-	-	0.25	2×10^{-3}
St. Catharines Sand & Gravel Pit, St. Catharines, Ont.	49	43	8	138.0	7.0	-	-	-	6×10^{-3}

2. SOURCE AND DESCRIPTION OF MATERIALS USED: (cont'd.) ...

2.4) Water: (cont'd.) ...

SOURCE	AVERAGE CONTENTS IN PPM OF	
	CALCIUM $(Ca)^{++}$	SULPHATE $(SO_4)^{--}$
Distilled Water	Nil	Nil
Tap Water, Downsview, Ont. (Domestic Water)	42	26
Groundwater from Aquifer at site of East Main St. Tunnel	542	2,089

3. LABORATORY TESTING PROCEDURE:

The testing programme was designed to provide information on the compaction, permeability, strength and swelling characteristics of various mixtures of G.B.C. 'A' and 'Volclay 90'. Mixtures of G.B.C. 'A' to 'Volclay 90' in the ratios of 3:1, 3½:1, and 4:1 by volume were tested. Predetermined amounts of either distilled water, tap (domestic) water, or groundwater from the Tunnel site, were added to large batches of these mixtures, which were then allowed to "cure", for various lengths of time, in watertight plastic bags, before testing.

The compaction characteristics were studied by performing both standard and modified Proctor density tests in accordance with ASTM specifications. Permeability measurements were carried out using constant head as well as falling head permeameters adapted especially for this testing programme. The swell ratio of 'Volclay 90' was determined by gradually adding 2 cc's of the as-received 'Volclay 90' to 100 cc's of water, in a graduated cylinder, and noting the final volume occupied by the expanded clay. The swell ratio is defined as the ratio of the final volume occupied by the expanded clay to its initial volume.

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3. LABORATORY TESTING PROCEDURE: (cont'd.) ...

Swelling pressures of the various mixtures were measured by allowing samples to expand against a proving ring. The strength characteristics were determined in the conventional manner using undrained triaxial compression tests.

The test results are presented in Figures 1 to 7 inclusive, located in the Appendix of this report. The specific details of sample preparation and testing procedures are shown on the Figures, as listed below:

Compaction Testing -- Figure 1

Permeability Testing -- Figure 3
- Procedure A - Falling Head
- Procedure B - Constant Head

Shear Strength Testing -- Figure 5
- Procedure A - Standard Triaxial Test
- Procedure B - Triaxial Test on Soaked Samples - ("Soaked" Test)

Swelling Tests -- Figure 6
- Procedure A - Free Swell
- Procedure B - Swelling Pressure Measurement

4. DISCUSSION OF LABORATORY TEST RESULTS:

The test results obtained for mixtures, prepared with G.B.C. 'A' from the Fonthill source, are summarized on Figures 1 to 6, inclusive. Test results for mixtures, prepared with G.B.C. 'A' from the Port Colborne and St. Catharines sources are given on Figure 7, and are discussed elsewhere in this report.

4.1) Compaction:

All compaction tests on the mixtures of G.B.C. 'A' and 'Volclay 90' were carried out using Standard Proctor methods. The effects of varying the mix ratio, water used in moulding the samples, and curing period, were investigated. The test results, summarized on Figures 1 and 2, show that:

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4. DISCUSSION OF LABORATORY TEST RESULTS: (cont'd.) ...

4.1) Compaction: (cont'd.) ...

i) The dry density - moisture content relationship is more or less independent of the mix ratio (3:1, 3½:1 or 4:1) and the water (domestic tap, groundwater from aquifer at site) used in preparing the samples. The optimum dry density ranges from 117 pcf to 124 pcf with the corresponding moisture contents ranging from 13 to 9 percent, and averaging about 11.5 percent. The optimum dry density of the mixtures is therefore some 10 to 12 percent less than that of the G.B.C. 'A' material.

ii) The curing period has a significant effect on the value of the optimum dry density. As shown on Figure 2, for a 4:1 mix ratio of G.B.C. 'A' to 'Volclay 90', the samples tested immediately following mixing, gave lower values of dry density than those tested after curing periods of 2½ and 10 days. In addition, no significant difference is evident for samples tested after curing for 2½ or more days, indicating that a curing period of more than about 2 days is generally sufficient to ensure a maximum degree of compaction.

4.2) Permeability:

The results of permeability tests, carried out on samples prepared from mix ratios ranging from 3:1 to 4:1, and moulded both with domestic (tap) and groundwater from the site, are shown on Figures 3 and 4, together with the specific procedural details.

For the first series of constant head tests (Figure 3) a constant head of 30 psi was applied, since this pressure is considered equivalent to the maximum unbalanced hydrostatic head expected within the natural confined aquifer located immediately beneath the deepest section of the Tunnel structure. Both the falling head and constant head permeameter tests, performed on compacted samples of the various mixtures, indicate the following:

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4. DISCUSSION OF LABORATORY TEST RESULTS: (cont'd.) ...

4.2) Permeability: (cont'd.) ...

i) The permeability of the mixture for any given mix ratio, is not significantly affected by the water content of the compacted sample.

ii) The permeability of the samples prepared from various mix ratios is more or less independent of the density of the samples. In this regard, it should be noted that no difficulty was encountered in the laboratory in compacting samples to a degree in excess of the Standard Proctor density for any given mix ratio and moulding water content.

iii) In general, the permeability is slightly lower for samples moulded using domestic (tap) water than those moulded using groundwater from the site. It is believed that the high concentration of calcium and sulphates, in the groundwater from the aquifer at the site, suppresses the swelling characteristics of 'Volclay 90', resulting in a relatively higher void ratio of the compacted sample and, therefore, a higher permeability.

iv) Tests, carried out on samples prepared from various mix ratios, reveal that the permeability decreases as the quantity of 'Volclay 90' increases in the mixture. Provided that the various mixtures of G.B.C. 'A' and 'Volclay 90' are compacted to a degree in excess of Standard Proctor dry density, the following range of permeabilities could be expected:

Mix Ratio G.B.C. 'A' : 'Volclay 90'	Range in Coefficient of Permeability (k) - cm./sec.
3:1	5×10^{-9} to 0
$3\frac{1}{2}$:1	1×10^{-8} to 0
4:1	8×10^{-8} to 1×10^{-8}

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4. DISCUSSION OF LABORATORY TEST RESULTS: (cont'd.) ...

4.2) Permeability: (cont'd.) ...

Following this first series of permeability tests, it was noted that at the end of each test, the water content of the samples was some 60 to 100 percent higher than the initial content of the compacted samples. It appeared, therefore, that during the permeameter tests, the 'Volclay 90' had absorbed an additional quantity of water over an extended period of time.

It was further decided to carry out a stage test in order to determine the effect various hydrostatic pressures have on the permeability of the mixture. For this test a sample with a mix ratio of 3½:1 was used. The constant head applied to the sample was varied from 15 to 45 psi. The test was carried out in stages. At each stage, the constant head was maintained over a period of time and the permeabilities measured. The results of this test are shown on Fig. 4.

The test commenced with a pressure head of 15 psi. At this pressure the permeability decreased from about 5×10^{-6} cm./sec. to 0 (impermeable) over a 20-hr. period. The permeability remained unchanged when the pressure head was increased to 30 psi; however, when an increment of 15 psi was added to bring the total pressure head to 45 psi, the permeability immediately increased to something of the order of 5×10^{-5} cm./sec. When the pressure head was again reduced to 30 psi the permeability decreased slightly, to about 10^{-6} cm./sec.

From these results it can be stated that:

i) for hydrostatic pressures less than 30 psi, the permeability will tend to decrease with time, making the mixture impervious; and

ii) for pressure increments in excess of 30 psi, the permeability increases at a rapid rate.

4. DISCUSSION OF LABORATORY TEST RESULTS: (cont'd.) ...

4.3) Undrained Shear Strength:

The undrained shear strength of the various mixtures was determined by carrying out quick, undrained, triaxial tests on compacted samples. The results are presented on Figure 5 and indicate that:

i) the undrained shear strength of the compacted samples decreases almost linearly, for mix ratios between 3:1 and 4:1, as the moisture content at compaction increases. In general, the undrained shear strengths vary from about 3,500 psf at a moisture content approximately 4 percent dry of optimum to 1,500 psf at a moisture content about 3 percent wet of optimum, being about 2,000 psf at optimum.

ii) the undrained shear strength does not vary significantly with a change in mix ratio, or with a variation in the type of water added during the compaction phase (either groundwater or domestic water).

iii) for a 4:1 mix ratio, curing periods of between $2\frac{1}{2}$ and 10 days do not significantly alter the shear strength. It is inferred that the same would apply for other mix ratios.

Upon completion of the Tunnel structure and flooding of the Canal, the waterproofing membrane provided at the base of the Tunnel, will be submerged. The strength characteristics of the compacted base, in such a case, would therefore be controlled by the "soaked" undrained shear strength. Additional tests were, therefore, carried out on compacted, "soaked" samples. The results, shown on Figure 5, indicate that the reduction in the undrained shear strength (of a compacted sample) is more pronounced for samples compacted at moisture contents dry of the optimum than those compacted on the wet side of optimum. For example, the reduction in the undrained shear strength, for samples compacted at moisture contents 4 percent dry of the optimum, was

4. DISCUSSION OF LABORATORY TEST RESULTS: (cont'd.) ...

4.3) Undrained Shear Strength: (cont'd.) ...

measured to be as much as 3,000 psf (from 4,000 psf in standard test to 1,000 psf in soaked test), whereas the reduction was often found to be negligible for samples compacted at moisture contents 4 percent wet of the optimum.

4.4) Swelling:

4.4.1) 'Volclay 90':

Determination of the swelling characteristics of 'Volclay 90', when suspended in distilled water, domestic (tap water) and groundwater from the site, gave swell ratios of 13, 8 and 3, respectively. The absence of electrolytes in the distilled water resulted in maximum dispersion and swelling of the clay particles, whereas the high Ca^{++} and SO_4^{--} content of the groundwater suppressed the swelling of the clay because these ions are strong electrolytes.

4.4.2) Mixture of G.B.C. 'A' and 'Volclay 90':

Tests were carried out on two different mix ratios of G.B.C. 'A' and 'Volclay 90', namely: 3:1 and 3½:1, by volume. The test results are shown on Figure 6. The pertinent observations are:

i) Samples of the 3½:1 mix underwent an increase in height of 13 to 17 percent (referenced to its original height) in a tank full of groundwater from the site. The percentage swell is greater for samples compacted on the dry side of the optimum moisture content. By comparison, swelling tests, performed by H. Q. Golder and Associates Ltd., on pre-formed bentonite panels, indicated that they underwent an increase in height of the order of 125 percent. The swell ratio of the G.B.C. 'A' and 'Volclay 90' mixture is, therefore, considerably less than that of the bentonite panels.

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4. DISCUSSION OF LABORATORY TEST RESULTS: (cont'd.) ...

4.4) Swelling: (cont'd.) ...

4.4.2) Mixture of G.B.C. 'A' and 'Volclay 90': - (cont'd.) ...

ii) The effect on the swelling pressure of mixtures, when soaked in waters from various sources, was studied on a controlled mix of 3:1. The samples were compacted at a moisture content 3 to 4 percent dry of the optimum. The results are tabulated below:

SOAKING MEDIA	'VOLCLAY 90' SWELL RATIO	G.B.C. 'A' & 'VOLCLAY 90' 3:1 MIX RATIO MAX. RECORDED SWELLING PRESSURE TSF
Distilled water	13	1.1
Domestic (tap) water	8	0.75
Groundwater from site	3	0.5

It should be pointed out that the swelling potential of the mixture, as measured by the above pressures, decreases with the decreasing swell ratios of the 'Volclay 90'. In contrast to the above, swelling pressures of up to 6 to 7 tsf have been measured in tests performed on pre-formed bentonite panels (work done by others).

iii) The variation in swelling pressures, measured on samples of G.B.C. 'A' and 'Volclay 90', compacted on the dry and wet sides of the optimum moisture content, was studied on a 3½:1 mix ratio. The results are tabulated below:

MOISTURE CONTENT DURING COMPACTION - %	G.B.C. 'A' & 'VOLCLAY 90' 3½:1 MIX RATIO SWELLING PRESSURE - TSF
4% Dry of optimum (approx.)	0.35
2% Wet of optimum (approx.)	0.35

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5. RESULTS OF LABORATORY TESTING - G.B.C. 'A' FROM ALTERNATE SOURCES:

The testing, carried out on mixtures composed of G.B.C. 'A' material obtained from the R. E. Law and St. Catharines Sand and Gravel Pits, and 'Volclay 90', is given on Figure 7. In order to compare these results with those given previously, a mixture of 3½ parts G.B.C. 'A' to 1 part 'Volclay 90' was used throughout.

Referring to Figure 7, it can be seen that the compaction and undrained shear strength characteristics of the mixtures formed with G.B.C. 'A', from the alternate sources, are similar to those of the mixtures formed with material from Fonthill, Ontario. There is significant variation in the permeability properties, however, as discussed below:

Typical values for the permeability of the various mixtures, as determined using Constant Head Testing procedures (30 psi pressure), are given below:

Source of G.B.C. 'A' In Mixture (3½:1 by Vol.)	Coefficient of Permeability of 3½:1 Mixture (cm./sec.)
Fonthill, Ontario	2×10^{-8}
R. E. Law Pit	4×10^{-6}
St. Catharines Pit	2×10^{-5}

It is obvious that the mixtures, composed of granular 'A' from the alternate sources, are more pervious than the control mix. In view of this, it may be uneconomical to use G.B.C. 'A' material from the alternate sources since an additional quantity of 'Volclay 90' will be required to fill the voids to achieve the required degree of imperviousness.

6. RECOMMENDATIONS:

6.1) Waterproofing Mixture:

The pertinent engineering properties for the various mix ratios of G.B.C. 'A' and 'Volclay 90' studied, namely: 3:1, 3½:1 and 4:1 (by volume), are presented in the table located at the end of this sub-section. The comparative cost of each mix ratio is also given in this table. Based on the results of this testing, it is recommended that, the waterproof barrier required beneath the Main Street East Tunnel, be composed of a 3½:1 mixture by volume of G.B.C. 'A' (from the Fonthill source) and 'Volclay 90'. The thickness of the barrier should be at least 12 inches, and preferably 18 inches, at any location beneath the Tunnel structure.

The recommended mixture will have the desired low permeability ($K \leq 10^{-8}$ cm./sec.), and also adequate strength (C_u = 2,500 psf at optimum moisture content), thus satisfying two of the three basic requirements for the artificially prepared waterproofing barrier. This mixture will also satisfy the third requirement, which specifies that the material should be easy to prepare, handle and control, as discussed in sub-section 6.2) to follow.

The complete waterproofing scheme proposed for the Tunnel, is shown on Figure 8, located in the Appendix of this report.

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	MIXTURE OF G.B.C. 'A' AND 'VOLCLAY 90' (BY VOLUME)		
	3:1	3½:1	4:1
Coefficient of Permeability (K) (cm./sec.)	5×10^{-9} - 0	1×10^{-8} - 0	8×10^{-6} - 1×10^{-8}
Dry Density (δ_d - psf) at optimum moisture content (W - %)	121 (9.5)	123.5 (11.5)	122 (11.0)
Undrained Shear Strength (C_u - psf) - Standard Test (i.e., as moulded) - After soaking	 3,000 1,000	 2,500 1,200	 2,000 1,000
Maximum Swelling Pressure (psf)	0.5	0.35	-
*Cost (per cu. yd. of mixture at optimum dry density)	$ 15.02	$ 14.51	$ 13.33

*Cost of 'Volclay 90' - $45. per ton
Cost of G.B.C. 'A' - $ 2. per ton

SUMMARIZED RESULTS OF LABORATORY TESTING -
MIXTURE OF G.B.C. 'A' AND 'VOLCLAY 90'

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

6.2) Control and Suggested Field Handling Procedures:

Since the behaviour of the G.B.C. 'A' and 'Volclay 90' mixture has been shown to depend on the mix ratio, moisture content and curing period, it is necessary to exercise close control over proportioning and mixing operations. It is therefore suggested that the 3½:1 mix ratio (by volume) of G.B.C. 'A' and 'Volclay 90' be pre-mixed with the required amount of tap water prior to placement and compaction. It would be desirable to allow the mixture to cure for at least a day or two prior to placement and compaction. The G.B.C. 'A' material used in the 3½:1 mixture should be similar to the material obtained from the Fonthill source, which was used in the testing programme described earlier in this report.

In order to achieve the required compaction, it is recommended that:

i) the pre-mixed and cured material (3½:1 G.B.C. 'A' & 'Volclay 90') should be placed in 6-inch lifts.

ii) Each lift should be compacted to the equivalent of 100 percent of the maximum dry density as determined by the Standard Proctor test. The surface of each compacted layer should be suitably scarified prior to addition of the next lift.

iii) The mixture should not be placed in areas containing ponded or running water.

iv) At placement, the moisture content of the mixture should be maintained to within ± 1% of the optimum moisture content.

v) In-situ density and moisture content tests should be carried out in order to exercise close control over field compaction operations.

The weight ratio of G.B.C. 'A' and 'Volclay 90' required to obtain a 3½:1 mix by volume, is equivalent to 5.5 parts of G.B.C. 'A' to 1 part of 'Volclay 90'.

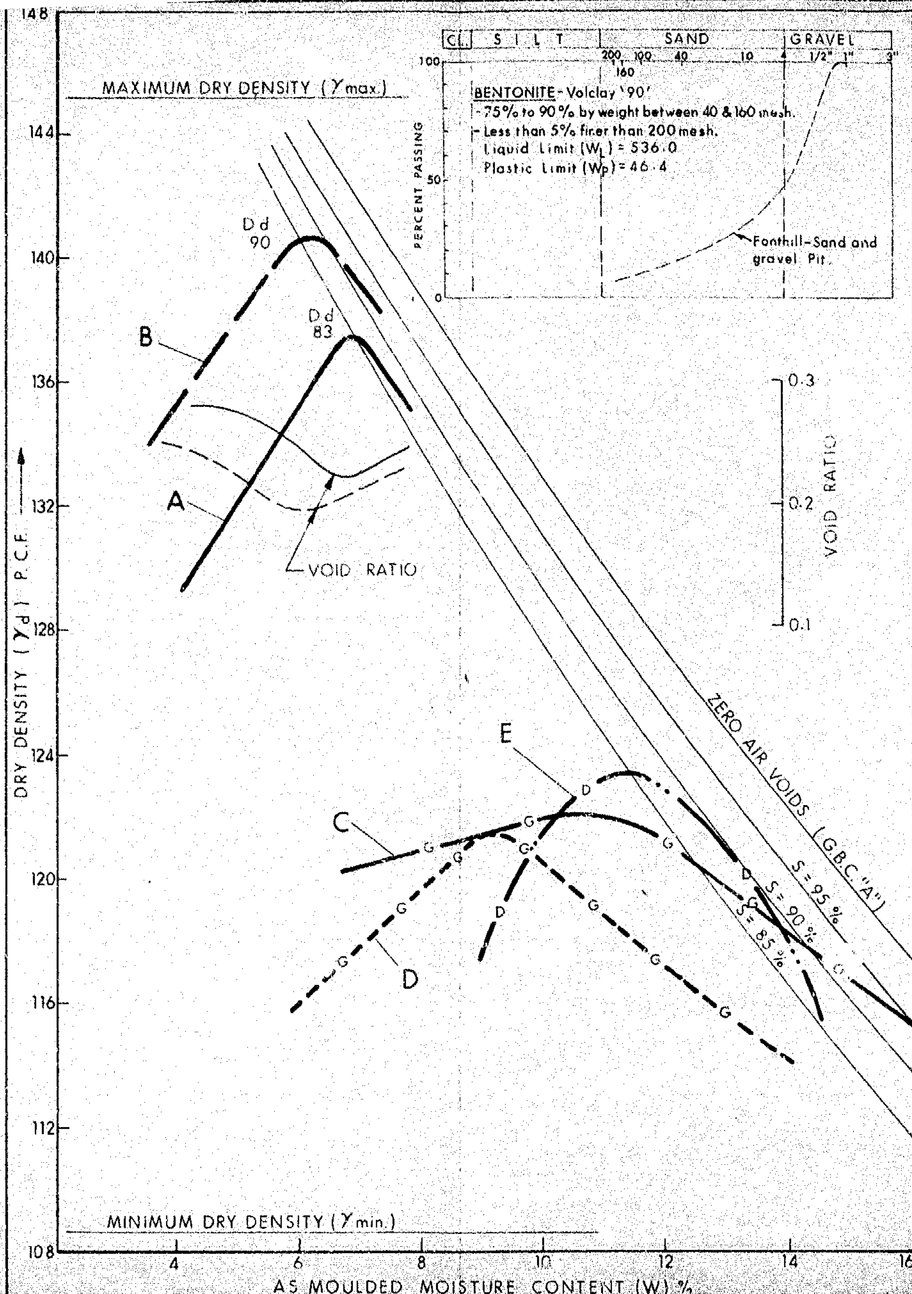
7. MISCELLANEOUS:

The laboratory testing programme was carried out by Mr. N. Aelbers, capably assisted by Messrs. J. Nadal and W. Wagner. The project was under the immediate supervision of Mr. B. T. Darch, Senior Foundation Engineer, who also prepared this report. The entire project was carried out under the general supervision of Mr. M. Devata, Supervising Foundation Engineer, who also reviewed this report.

The Foundation Section would like to acknowledge the assistance and constructive advice provided by Messrs. D. R. Straub (deceased) and C. Morris of the American Colloid Company. In addition, we would like to express our appreciation to Mr. R. Sterk, Chemical Section, Materials and Testing Office, D.H.O., for all his valuable assistance.

February 1969

APPENDIX I



SYMBOL	CURVE NO.	MATERIAL TESTED	COMPACTIVE EFFORT	TYPE OF WATER ADDED	CURING PERIOD	OPT. DRY DENSITY (P.C.F.)	OPT. MOIST. CONTENT (%)	REL. DEN. (AT OPT. DRY DEN.) Dd
———	A	G.B.C. "A"	STANDARD PROCTOR	DOMESTIC	—	137.4	6.7	83
— — —	B	G.B.C. "A"	MODIFIED PROCTOR	DOMESTIC	—	140.7	6.1	90
—G—	C	G.B.C. "A" & BENTONITE (4:1 BY VOL.)	STANDARD PROCTOR	GROUND WATER FROM SITE	2 ½ DAYS	122.0	10.5	—
---G---	D	G.B.C. "A" & BENTONITE (3:1 BY VOL.)	STANDARD PROCTOR	GROUND WATER FROM SITE	1 DAY	121.4	9.2	—
·—D—··	E	G.B.C. 'A' & BENTONITE (3½:1 BY VOL.)	STANDARD PROCTOR	DOMESTIC	2½ DAYS	123.5	11.5	—

SAMPLE PREPARATION AND COMPACTION TESTING PROCEDURE

1) G.B.C. "A" AND BENTONITE PRE-MIXED IN NATURAL STATE.

2) PRESCRIBED AMOUNT OF WATER ADDED AND SAMPLE MIXED.

3) PRE-MIXED SAMPLE, THEN CURED (VARIABLE PERIOD).

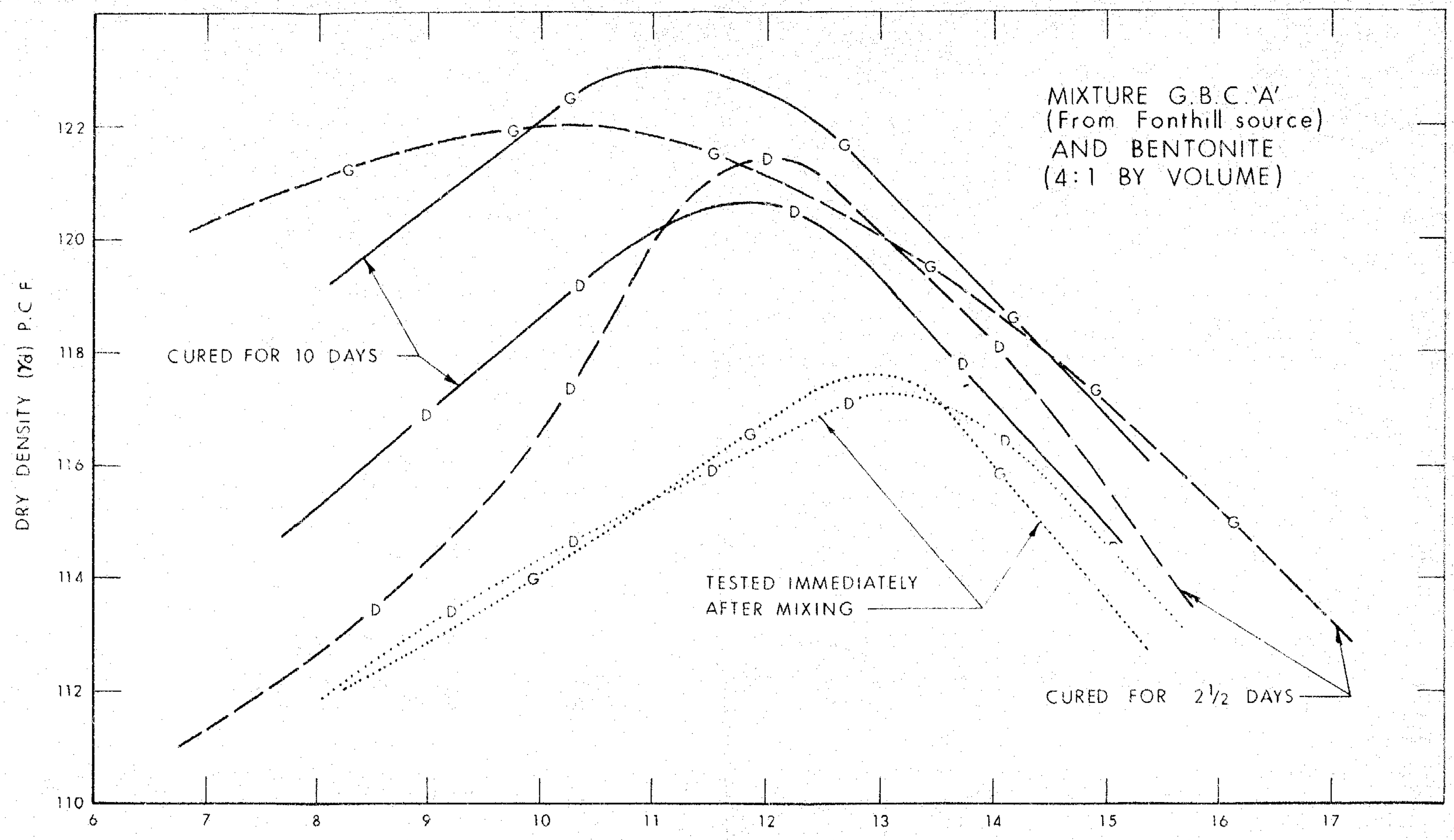
4) CURED SAMPLE COMPACTED IN A PROCTOR MOULD 6" IN DIA. AND 4.6" HIGH. (AS PER ASTM STANDARD D1557-64T.)

5) THE FOLLOW COMPACTIVE EFFORTS USED AS PER THE ASTM. SPECIFICATION.
   a) STANDARD PROCTOR COMPACTION: 3 layers - 56 blows per layer with 5.5 lb. hammer falling 12". (Energy 12,400 ft.lb./cu.ft.)
   b) MODIFIED PROCTOR COMPACTION: 5 layers - 56 blows per layer with 10 lb. hammer falling 18". (Energy 56,300 ft.lb./cu.ft.)

DEPARTMENT OF HIGHWAYS
MATERIALS and TESTING DIVISION
ONTARIO

COMPARISON OF LAB. COMPACTION RESULTS ON
1) G.B.C. 'A' MATERIAL (Fonthill source)
2) MIXTURE OF G.B.C. 'A' & BENTONITE

DATE Jan. 3, 1969 | APPROVED | FIG. NO. 1



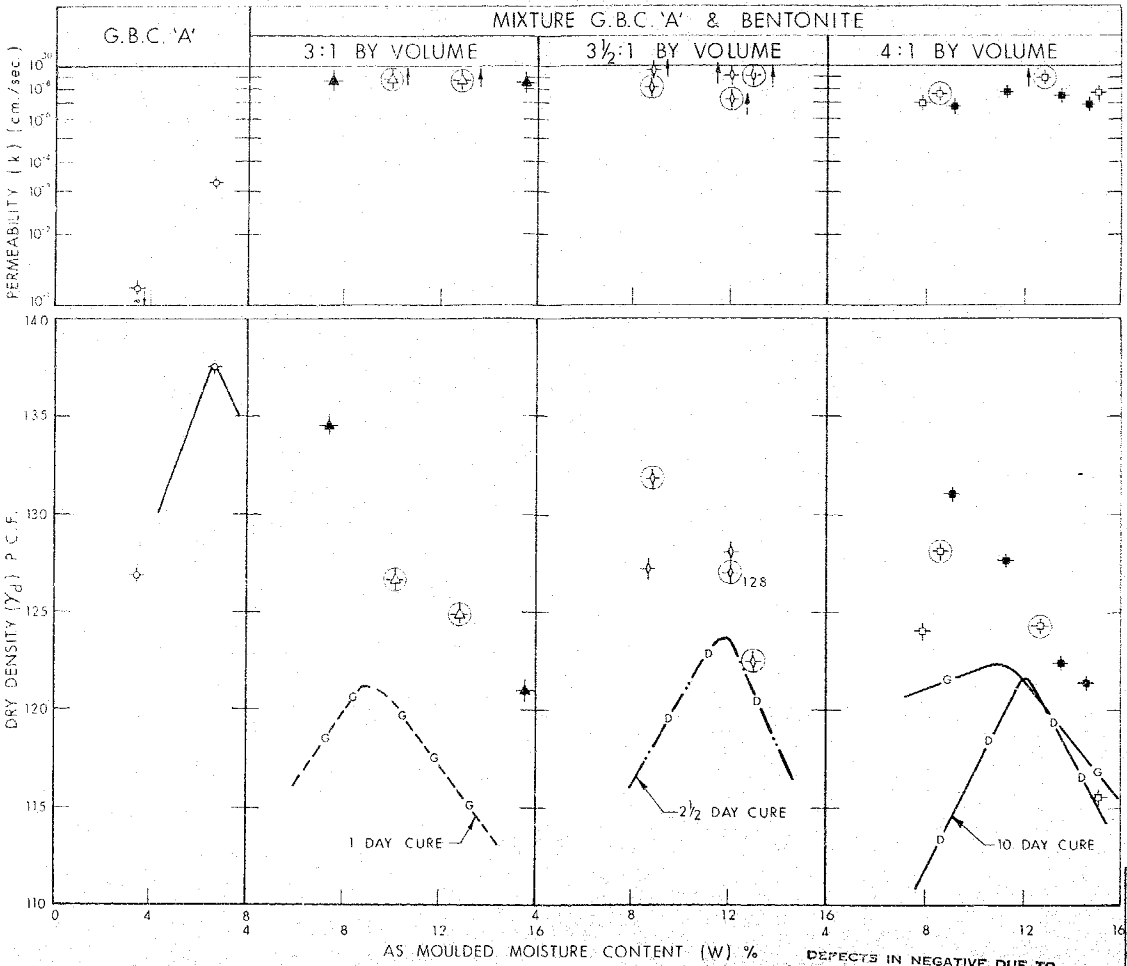
SOURCE OF WATER ADDED

—D— DOMESTIC (TAP)

—G— GROUNDWATER FROM SITE

DEFECTS IN NEGATIVE DUE TO CONDITION OF ORIGINAL DOCUMENT

ONTARIO DEPARTMENT OF HIGHWAYS MATERIALS and TESTING DIVISION	VARIATION IN LABORATORY STANDARD PROCTOR DRY DENSITY TESTS with 1) TIME ALLOWED FOR CURING and 2) TYPE OF WATER ADDED
DATE Jan. 6, 1969	APPROVED
	FIG. NO. 2



DEFECTS IN NEGATIVE DUE TO CONDITION OF ORIGINAL DOCUMENT

MATERIAL TESTING	TYPE OF TEST	TYPE OF WATER ADDED (During Compaction)	STANDARD PROCTOR DRY DENSITY CURVE	PERMEABILITY TEST ON COMPACTED SAMPLES
*G.B.C. 'A'	FALLING HEAD	DOMESTIC (D)	———	
*G.B.C. 'A' & BENTONITE 3:1 BY VOL.	FALLING HEAD	GROUND WATER FROM SITE (G)	— — G — — G	
	CONSTANT HEAD 30 p.s.i.			
*G.B.C. 'A' & BENTONITE 3½:1 BY VOL.	FALLING HEAD	DOMESTIC (D)	—··—D—··—	
	CONSTANT HEAD 30 p.s.i.			
*G.B.C. 'A' & BENTONITE 4:1 BY VOL.	FALLING HEAD	DOMESTIC (D)	—— D ——	
	FALLING HEAD	GROUND WATER FROM SITE (G)	—— G ——	
	CONSTANT HEAD 30 p.s.i.			

* G.B.C. 'A' Material from Fonthill sand and gravel pits.

SAMPLE PREPARATION AND LABORATORY TESTING PROCEDURES

'A' – FALLING HEAD TEST

1) Samples prepared as per steps 1 & 2 on fig. no 1.
2) Pre-mixed sample then cured for 2½ days or more.
3) Cured samples tamped, in thin layers, directly into permeameter unit;
   Area of permeameter = 23.2 sq. in.
   Height of permeameter = 7.5 in.
   Area of standpipe = 0.196 sq. in.
4) Permeability determined using the falling head procedure (as per A.S.T.M. Standards).

'B' – CONSTANT HEAD TEST

1) Steps 1, 2 & 3 listed above apply. The water added prior to compaction was, however, always domestic (tap water).
2) A 30 p.s.i. head was then applied to the prepared sample. At this stage ground water was used as the surrounding medium.
3) Permeability determined using the Constant Head procedure (as per A.S.T.M. Standard D2434 – 65T)

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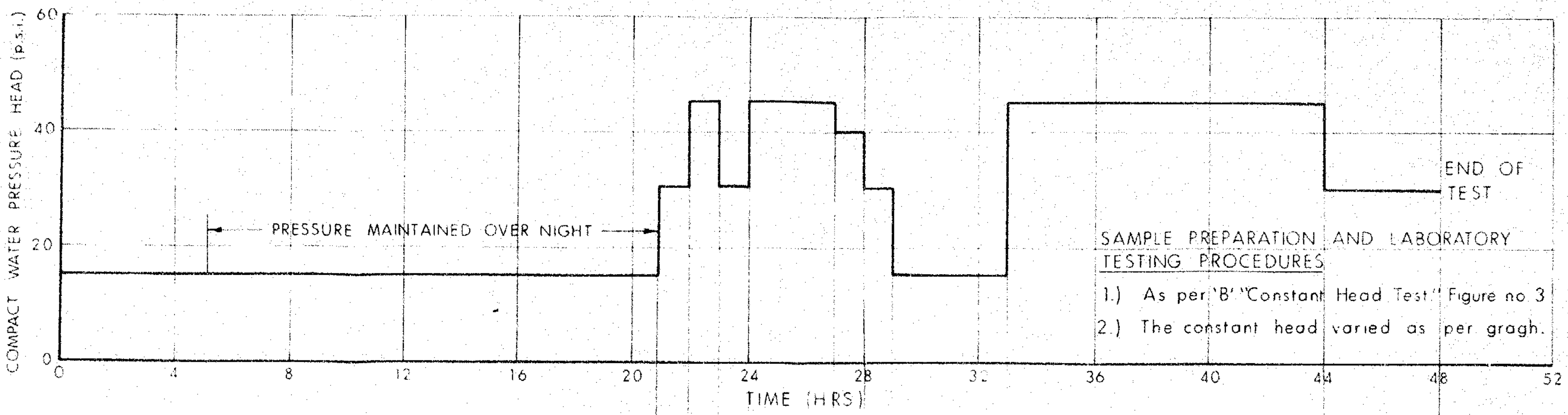
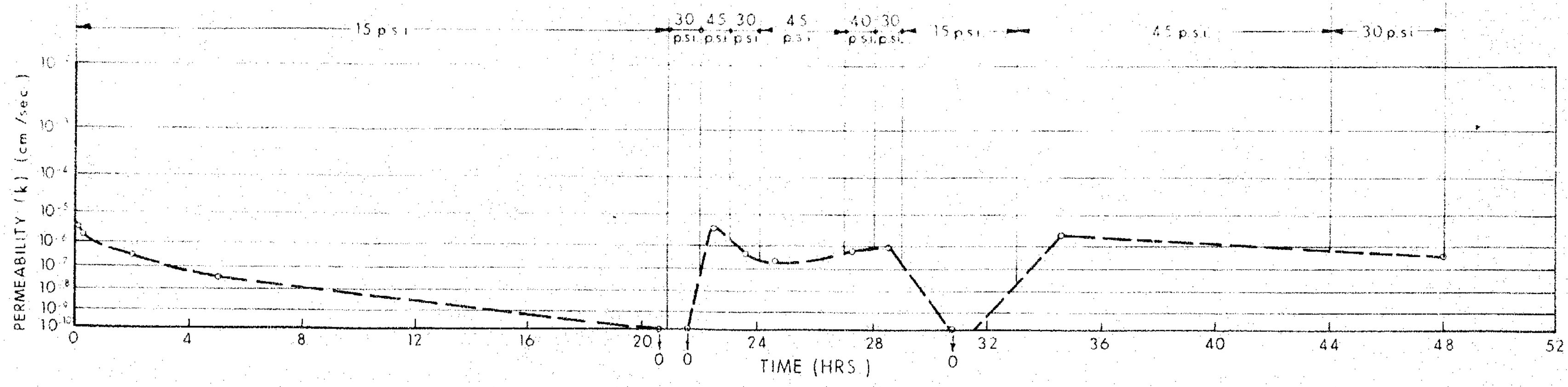
SUMMARIZED RESULTS OF PERMEABILITY TESTING CARRIED OUT ON COMPACTED SAMPLES

DATE Jan. 7, 1969	APPROVED	FIG. NO. 3





NOTE: G.B.C.'A' Material from Fonthill source.

TEST DATA

DRY DENSITY (P.C.F.)	INITIAL MOIST. CONTENT (%)	APPROX. RELATIONSHIP TO OPT. COMP. WATER CONTENT	AVERAGE FINAL MOIST. CONTENT (%)
124.9	11.3	within $1/2$ %	19.5

DEFECTS IN NEGATIVE DUE TO CONDITION OF ORIGINAL DOCUMENT

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ONTARIO

VARIATION OF PERMEABILITY WITH DIFFERENT WATER PRESSURE HEADS

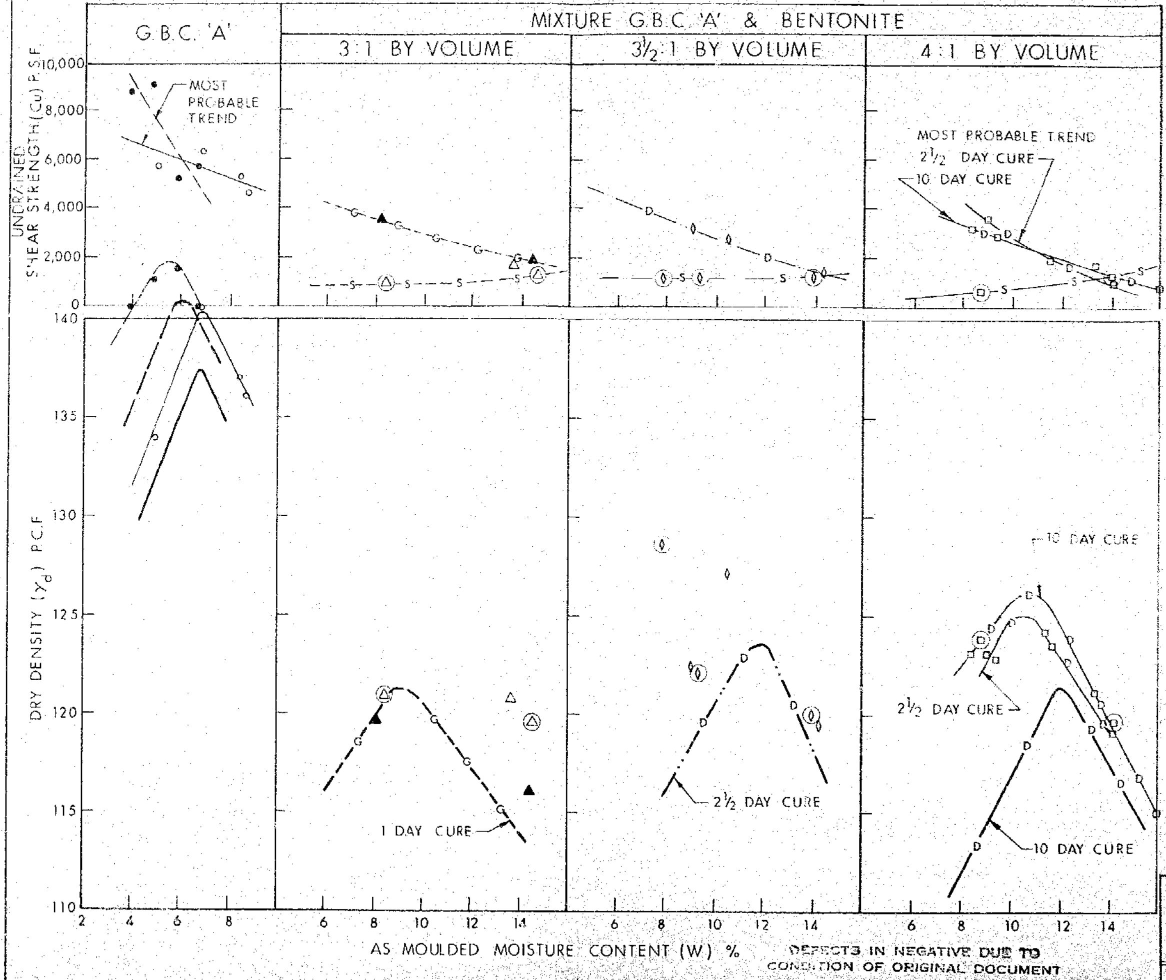
—STAGE TEST—

G.B.C."A" MATERIAL & BENTONITE ($3\frac{1}{2}$:1 BY VOL.)

DATE Jan. 8, 1969

APPROVED

FIG. NO. 4



MATERIAL TESTED	TYPE OF TEST (defined in notes)	TYPE OF WATER ADDED (Compaction Phase)	** STANDARD PROCTOR DRY DENSITY CURVE	APPROXIMATE CURVE FOR SAMPLES TESTED (PREPARED IN SPLIT-MOULD)	UNDRAINED SHEAR STRENGTH (cu) psf
*G.B.C. 'A'	STANDARD	DOMESTIC	—— ——	—— ——	○
	STANDARD	DOMESTIC	—— MODIFIED	——	●
*G.B.C. 'A' & BENTONITE 3:1 BY VOL.	STANDARD	DOMESTIC			△
	STANDARD	GROUNDWATER	— — —G— — —	— — —G— — —	▲
	SOAKED			— — —S— — —	(△)
*G.B.C. 'A' & BENTONITE 3½:1 BY VOL.	STANDARD	DOMESTIC	—··—D—··—	— —D— · —	◊
	SOAKED			— —S— · —	(◊)
*G.B.C. 'A' & BENTONITE 4:1 BY VOL.	STANDARD	DOMESTIC	——D——	——D——	□
	SOAKED			——S——	(□)

* G.B.C. 'A' From Fonthill sand and gravel pits

** Unless otherwise noted.

SAMPLE PREPARATION AND LABORATORY TESTING PROCEDURES

A) STANDARD TESTS

1) Sample prepared as per steps 1 to 3 given on Figure No. 1
2) Cured Sample compacted in a split mould 4" dia. and 8" high.
3) The following compactive effort used - 5 layers - 26 blows per layer with a 5.5 lb. hammer falling 12". (energy 12,400 ft.-lb/cu.ft. - equivalent to St'd. Proctor Dry Density energy)
4) Immediately following compaction sample tested in an undrained state in triaxial cell. Confining pressure - 10 p.s.i., rate of strain 0.15 in./min.

B) SOAKED TESTS

1) G.B.C. 'A' and bentonite pre-mixed in natural state.
2) Prescribed amount of Domestic water added and sample mixed.
3) Pre-mixed sample then cured for 1 day.
4) Cured sample compacted as per steps 2 & 3 in section A.
5) A membrane with numerous perforations, placed over compacted sample, which is then placed in a triaxial cell.
6) Sample submerged in groundwater and immediately confined by a pressure of 10 p.s.i.
7) Sample allowed to soak in triaxial cell for from 2½ to 3 days.
8) Sample then sheared in an undrained state. Rate of strain 0.15 in./min.

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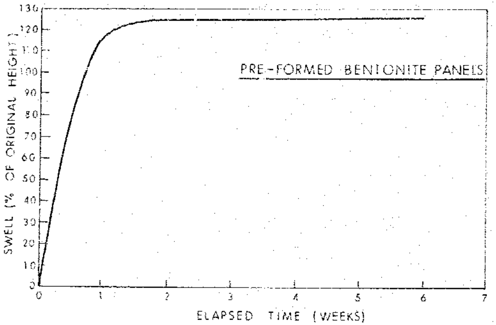
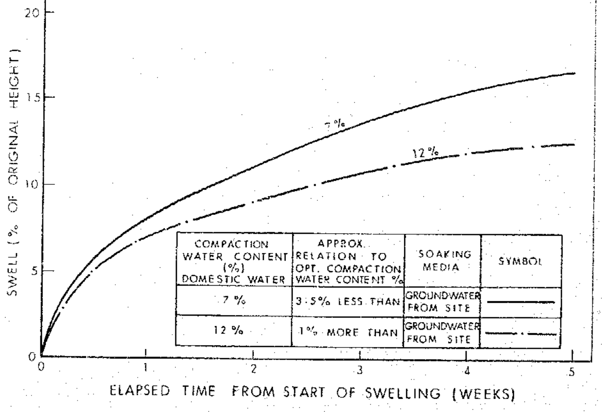
SUMMARIZED RESULTS OF UNDRAINED SHEAR STRENGTH TESTING ON COMPACTED SAMPLES

DATE Jan. 8, 1969 | APPROVED | FIG. NO. 5

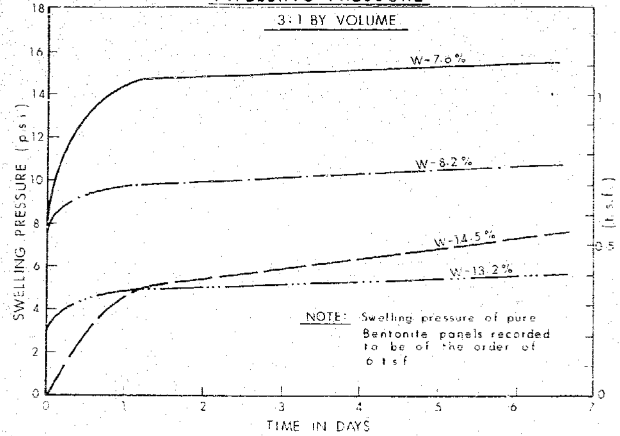
FREE SWELL TESTING

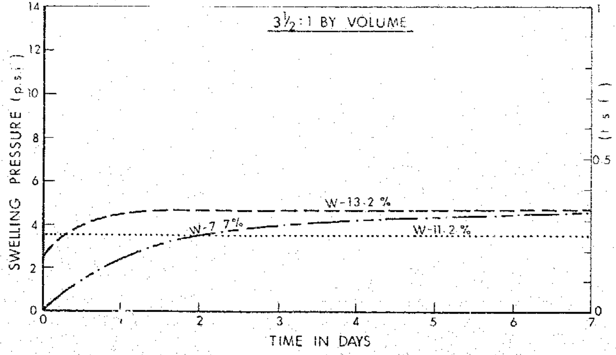




COMPACTION WATER CONTENT (%) DOMESTIC WATER	APPROX. RELATION TO OPT. COMPACTION WATER CONTENT %	SOAKING MEDIA	SYMBOL
7 %	3·5% LESS THAN	GROUNDWATER FROM SITE	———
12 %	1% MORE THAN	GROUNDWATER FROM SITE	—·—·—

SWELLING PRESSURE





DEFECTS IN NEGATIVE DUE TO CONDITION OF ORIGINAL DOCUMENT

MIXTURE G.B.C. 'A' & BENTONITE

TYPE OF TEST	COMPACTION WATER CONTENT DOMESTIC WATER (%)	APPROXIMATE RELATION TO OPT. COMPACTION WATER CONTENT (%)	SOAKING MEDIA	SYMBOL
3:1 BY VOLUME				
SOAKED IN TRIAXIAL CELL	7·6 %	4 % LESS THAN	DISTILLED	———
	14·5 %	2-3 % MORE THAN	GROUNDWATER FROM SITE	— — —
SOAKED IN WATER BATH G.B.R. MOULD	8·2 %	3-4 % LESS THAN	DOMESTIC	—·—·—
	13·2 %	1-2 % MORE THAN	GROUNDWATER FROM SITE	—··—··
3½:1 BY VOLUME				
SOAKED IN TRIAXIAL CELL	13·2 %	1·2 % MORE THAN	GROUNDWATER FROM SITE	— — — —
	7·7 %	4% LESS THAN	GROUNDWATER FROM SITE	—·—·—
SOAKED IN WATER BATH G.B.R. MOULD	11·2 %	APPROX. OPT.	GROUNDWATER FROM SITE	········

G.B.C 'A' materials from Fonthill sand and gravel pits.

SAMPLE PREPARATION AND LABORATORY TESTING PROCEDURES

A) FREE SWELL TEST

1) G.B.C. 'A' and Bentonite pre-mixed .. natural state.
2) Prescribed amount of domestic water added and sample mixed
3) Pre-mixed sample cured for 2½ day.
4) Cured sample compacted in a C.B.R. mould 6" in dia. by 4·6" high. Standard Proctor Energy applied.
5) Sample submerged in a bath filled with groundwater from the site. Water accessible from top and bottom only.

B) MEASUREMENT OF SWELLING PRESSURE

i) SPECIMEN SOAKED IN C.B.R. MOULD

1) Steps 1 to 4 as above in "A".
2) Sample surcharged to half the anticipated swelling pressure (6 p.s.i.) then submerged in a water bath (type of water in bath varies.) Water accessible from top and bottom only.
3) Any further was limited by additional surcharge loading ie (ΔV=0).

ii) SPECIMAN SOAKED IN TRIAXIAL CELL

1) Steps 1 to 3 in "A" above followed.
2) Cured sample compacted in a perforated steel mould 4" in dia. by 9" high. Standard Proctor Energy.
3) Sample placed in triaxial cell, a surcharge of 7·5 p.s.i. applied by means of a proving ring.
4) Cell then filled with water (type of water variable.) Water accessible from top, bottom and sides.
5) Volume change not allowed (ΔV=0). Swelling arrested by applying additional load.

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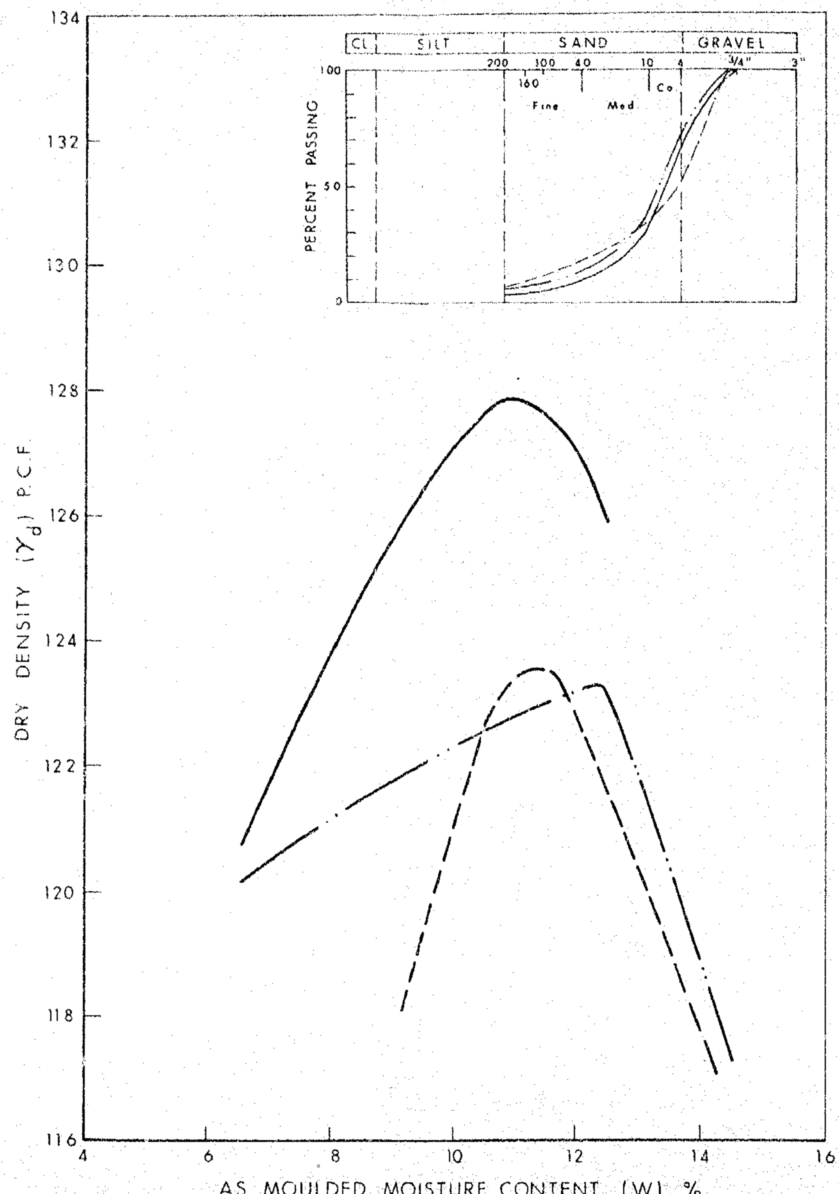
SUMMARIZED RESULTS OF SWELLING TESTING ON COMPACTED MIXTURE G.B.C.'A' & BENTONITE

DATE Jan. 9, 1969 | APPROVED | FIG. NO. 6



SYMBOL	SOURCE OF G.B.C. 'A'	* PERMEABILITY cm./sec.	** UNDRAINED SHEAR STRENGTH (P.S.F.)
— — — —	FONTHILL PITS	8.7×10^{-9}	FROM 5,000 (DRY OF OPT.) TO 1,800 (WET OF OPT.)
—·—·—	ST. CATHERINES CRUSHED STONE LTD.	1.5×10^{-5}	FROM 4,700 (DRY OF OPT.) TO 1,700 (WET OF OPT.)
———	R. E. LAW SAND & GRAVEL (PORT COLBORNE ONT.)	2.1×10^{-6}	FROM 3,200 (DRY OF OPT.) TO 1,440 (WET OF OPT.)

* PERMEABILITY TESTING DETERMINED BY CONSTANT HEAD-TEST PROCEDURE AS OUT-LINED IN FIG. NO. 3

** UNDRAINED SHEAR STRENGTH TESTING-DETERMINED BY STANDARD TEST PROCEDURE AS ON FIG. NO. 5

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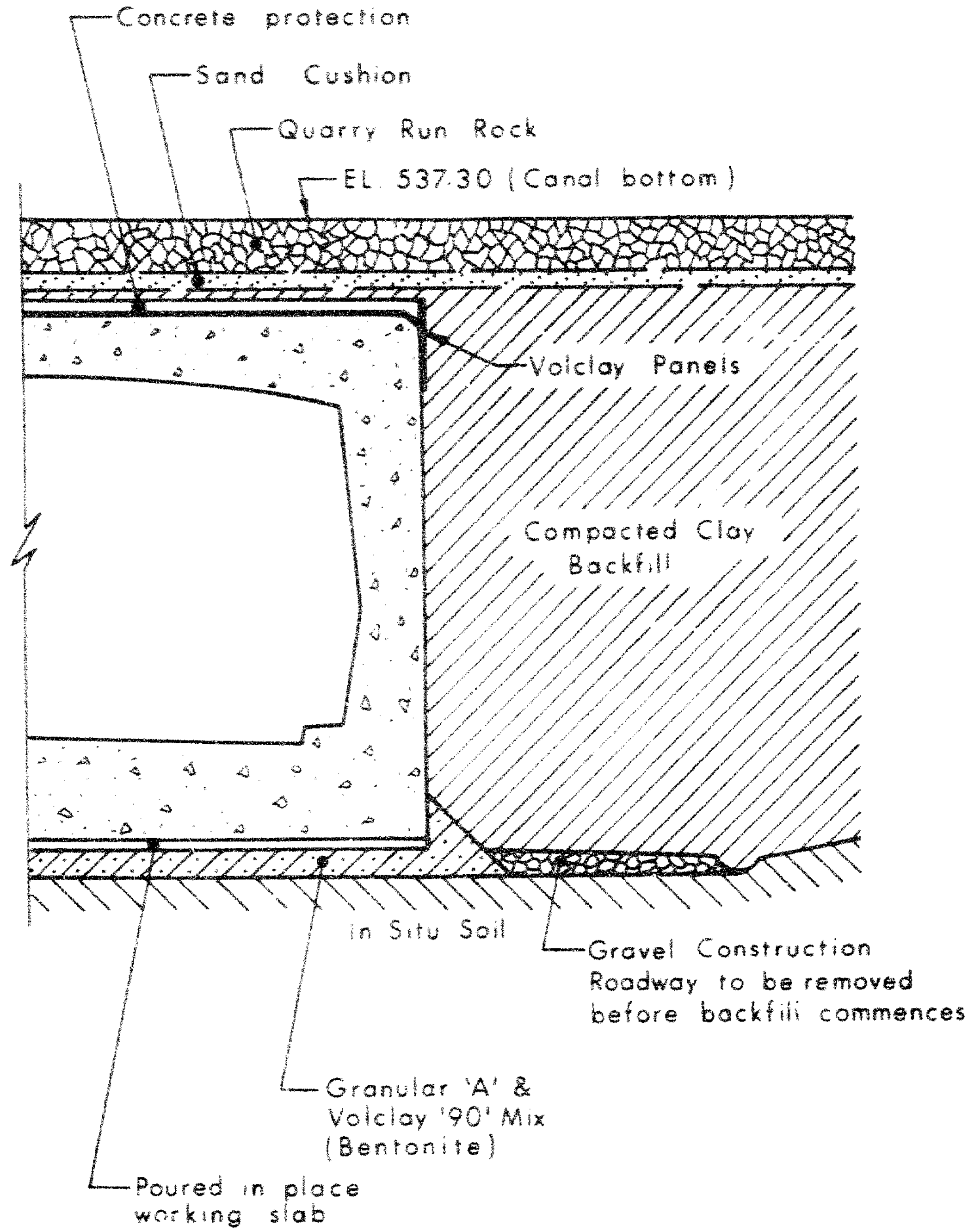
MATERIALS and TESTING DIVISION
ONTARIO

COMPARISON OF ENGINEERING PROPERTIES G.B.C. 'A' (FROM THREE SOURCES) EACH MIXED WITH BENTONITE ($3\frac{1}{2}$:1 BY VOLUME)

DATE Jan. 15, 1969 | APPROVED | FIG. NO. 7

WATER PROOFING DETAILS

MAIN STREET EAST WELLAND CANAL TUNNEL



SCALE 1/8" = 1'-0"

Fig. No. 8

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 :-

CONSISTENCY	'N' BLOWS/FT.	c LB./SQ.FT.	DENSENESS	'N' BLOWS/FT.
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	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

Qu	UNCONFINED COMPRESSION	L.V	LABORATORY VANE
Q	UNDRAINED TRIAXIAL	F.V	FIELD VANE
Qcu	CONSOLIDATED UNDRAINED TRIAXIAL	C	CONSOLIDATION
Qd	DRAINED TRIAXIAL	S	SENSITIVITY

ABBREVIATIONS USED IN THIS REPORT

SOIL PROPERTIES

γ	UNIT WEIGHT OF SOIL (BULK DENSITY)
γ_s	UNIT WEIGHT OF SOLID PARTICLES
γ_w	UNIT WEIGHT OF WATER
γ_d	UNIT DRY WEIGHT OF SOIL (DRY DENSITY)
γ'	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
τ_f	SHEAR STRENGTH
c'	EFFECTIVE COHESION INTERCEPT } IN TERMS OF EFFECTIVE STRESS $\tau_f = c' + \sigma' \tan \phi'$
ϕ'	EFFECTIVE ANGLE OF SHEARING RESISTANCE, OR FRICTION } IN TERMS OF EFFECTIVE STRESS $\tau_f = c' + \sigma' \tan \phi'$
c_u	APPARENT COHESION } IN TERMS OF TOTAL STRESS $\tau_f = c_u + \sigma \tan \phi$
ϕ_u	APPARENT ANGLE OF SHEARING RESISTANCE, OR FRICTION } IN TERMS OF TOTAL STRESS $\tau_f = c_u + \sigma \tan \phi$
μ	COEFFICIENT OF FRICTION
S_t	SENSITIVITY

GENERAL

π	= 3.1416
e	BASE OF NATURAL LOGARITHMS 2.7183
$\log_e a$ OR $\ln a$	NATURAL LOGARITHM OF a
$\log_{10} a$ OR $\log a$	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
σ	NORMAL STRESS
σ'	NORMAL EFFECTIVE STRESS ($\bar{\sigma}$ IS ALSO USED)
τ	SHEAR STRESS
ε	LINEAR STRAIN
γ	SHEAR STRAIN
ν	POISSON'S RATIO (μ IS ALSO USED)
E	MODULUS OF LINEAR DEFORMATION (YOUNGS MODULUS)
G	MODULUS OF SHEAR DEFORMATION
K	MODULUS OF COMPRESSIBILITY
η	COEFFICIENT OF VISCOSITY

EARTH PRESSURE

d	DISTANCE FROM TOP OF WALL TO POINT OF APPLICATION OF PRESSURE
δ	ANGLE OF WALL FRICTION
K	DIMENSIONLESS COEFFICIENT TO BE USED WITH VARIOUS SUFFIXES IN EXPRESSIONS REFERRING TO NORMAL STRESS ON WALLS
K_o	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
β	ANGLE OF SLOPE TO HORIZONTAL

DEPARTMENT OF HIGHWAYS ONTARIO

MEMORANDUM

TO: Mr. B. R. Davis,
Bridge Engineer,
Bridge Office,
Admin. Bldg.

ATTENTION: Mr. F. I. Hewson,
Executive Bridge Engr.

OUR FILE REF.

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

DATE: July 17, 1970

IN REPLY TO

SUBJECT:

REPORT ON
RESULTS OF LABORATORY TESTING
VARIOUS MIXTURES OF GRANULAR 'A'
AND BENTONITE
PROPOSED CROSSING OF THE RE-ALIGNED
WELLAND CANAL, MAIN ST. EAST TUNNEL
WELLAND, ONT., DIST. #4 (HAMILTON)
W. J. 68-F-71 -- W. P. 240-66

(Report distributed February 12, 1969)

R E V I S I O N S

1. Page 4 - Table re G.B.C. 'A' material.

2. Appendix - Figures No. 1 and 7.

Please delete (and destroy) the above items from your copy(s) of the mentioned report, and replace with revised pages, attached hereto.

Thank you.

M. Devata,
SUPERVISING FOUNDATION ENGR.
For:
A. G. Stermac,
PRINCIPAL FOUNDATION ENGR.

MD/MdeF
Attach.

cc: Messrs. B. R. Davis (2)
H. A. Tregaskes
D. W. Farren
G. K. Hunter
~~H. Greenland~~ C. R. ROBERTSON
W. S. Melinyshyn
T. J. Kovich
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