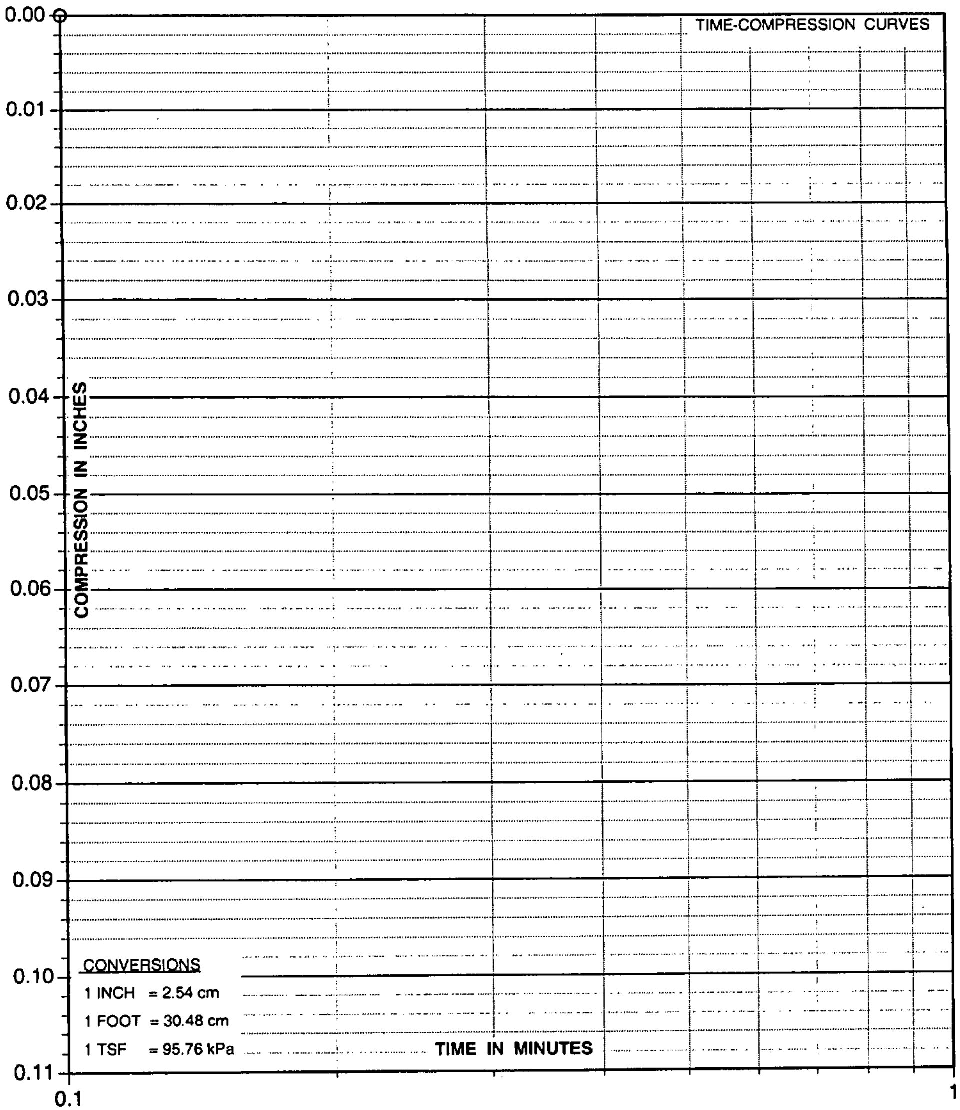


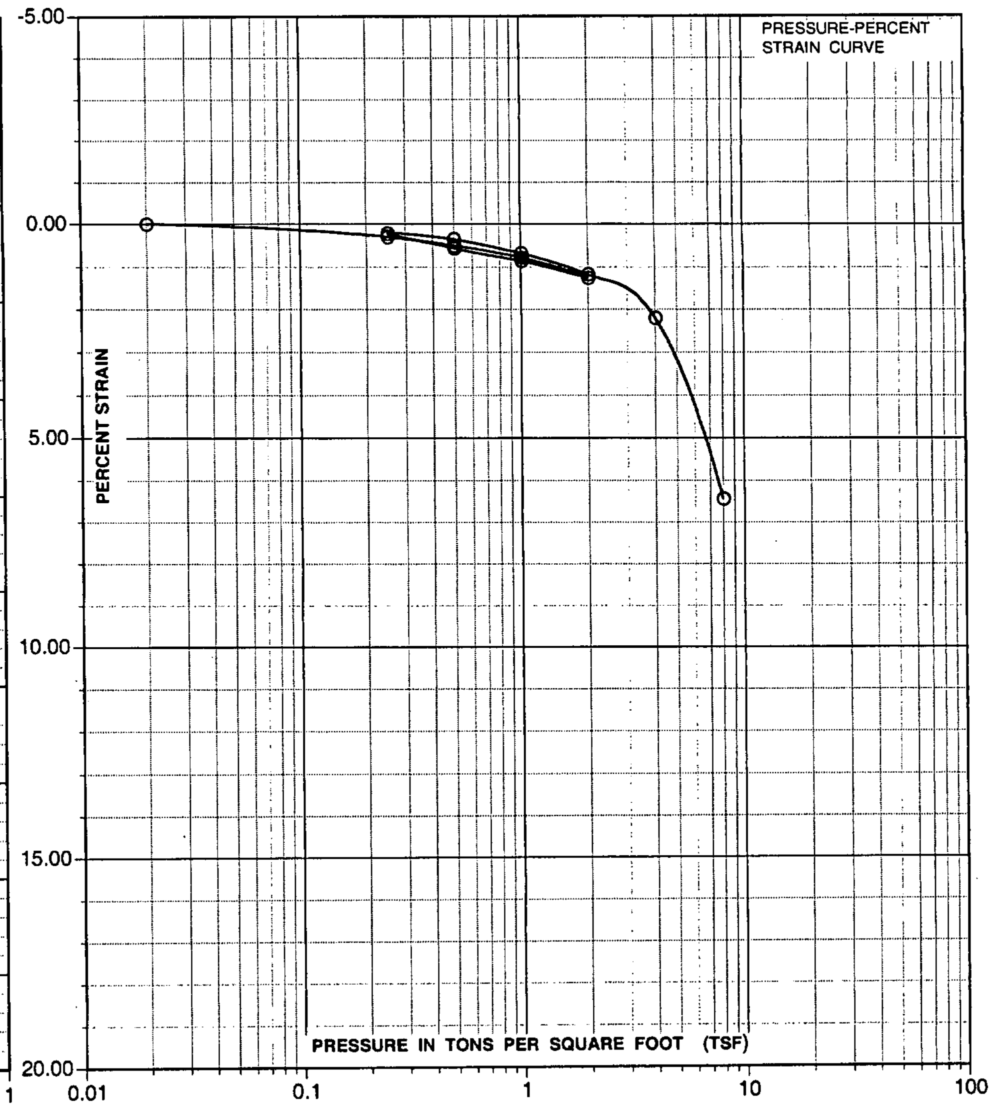


| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
| ① | | |
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PLATE NO. 30

SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, lb/ft$^3$ = 106

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 61
DIAMETER OF SPECIMEN (IN) = 1.75
INITIAL THICKNESS OF SPECIMEN (IN) = 0.50
INITIAL WATER CONTENT, % = 51
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

— — — INITIAL VOID RATIO, $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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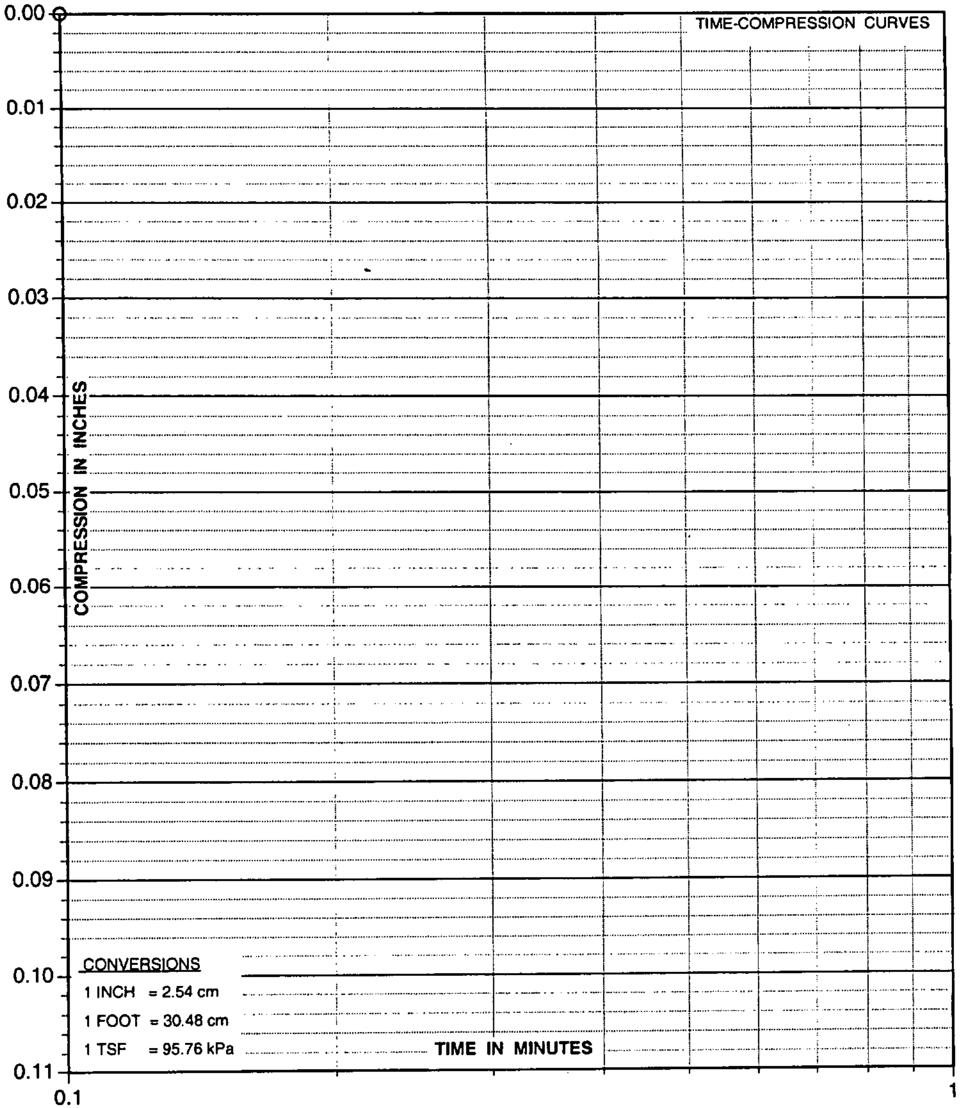
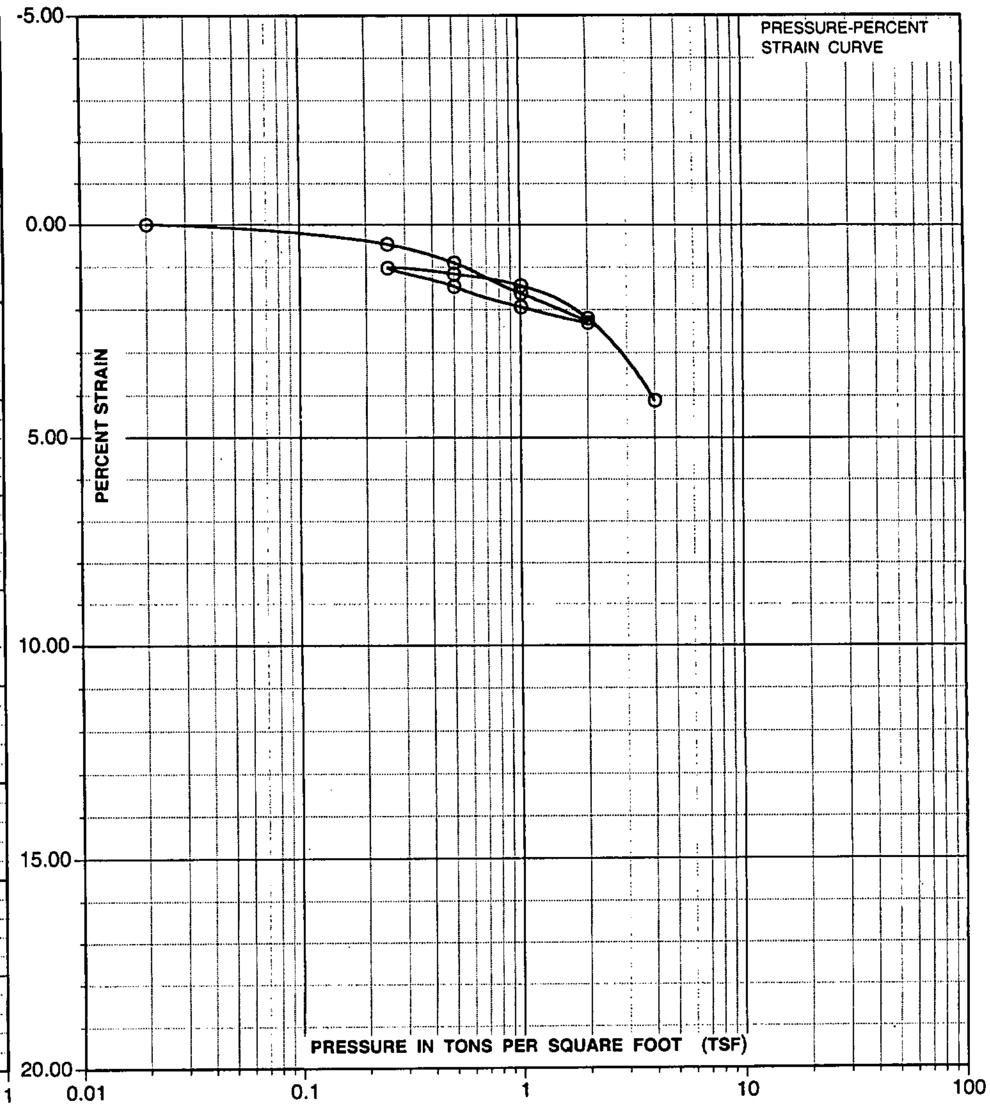
| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |
| **CONSOLIDATION TEST** | | PLATE NO. |
| BORING NO. B-28 | SAMPLE NO. 16 | 30 |




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
| ① | | |
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PLATE NO. 31

**SPECIMEN DESCRIPTION:**

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION - CH
LIQUID LIMIT, $w_L$ = 88
PLASTIC LIMIT, $w_P$ = 31
PLASTICITY INDEX, $I_P$ = 57
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, lb/ft$^3$ = 106

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 67
DIAMETER OF SPECIMEN (IN) = 1.75
INITIAL THICKNESS OF SPECIMEN (IN) = 0.50
INITIAL WATER CONTENT, % = 51
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

**STRATUM**

— — — INITIAL VOID RATIO, $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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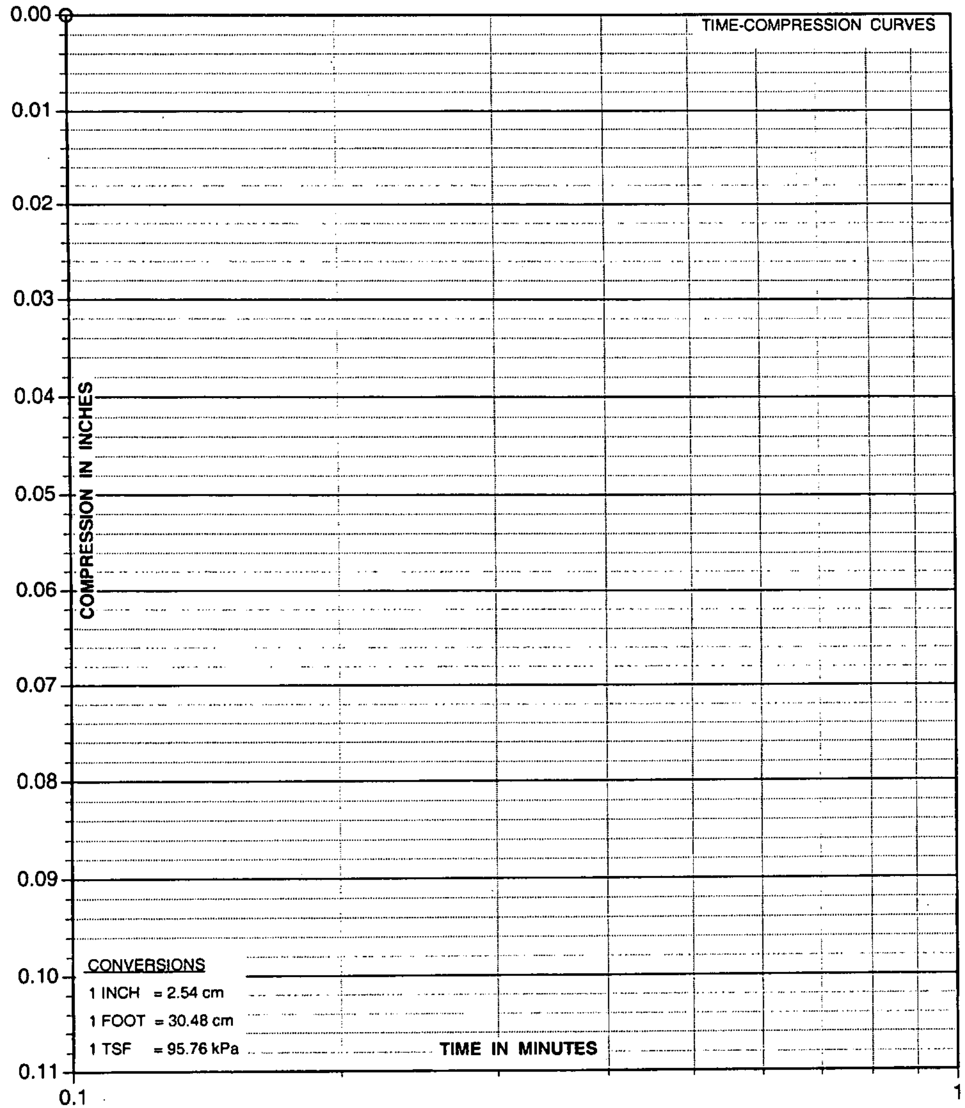
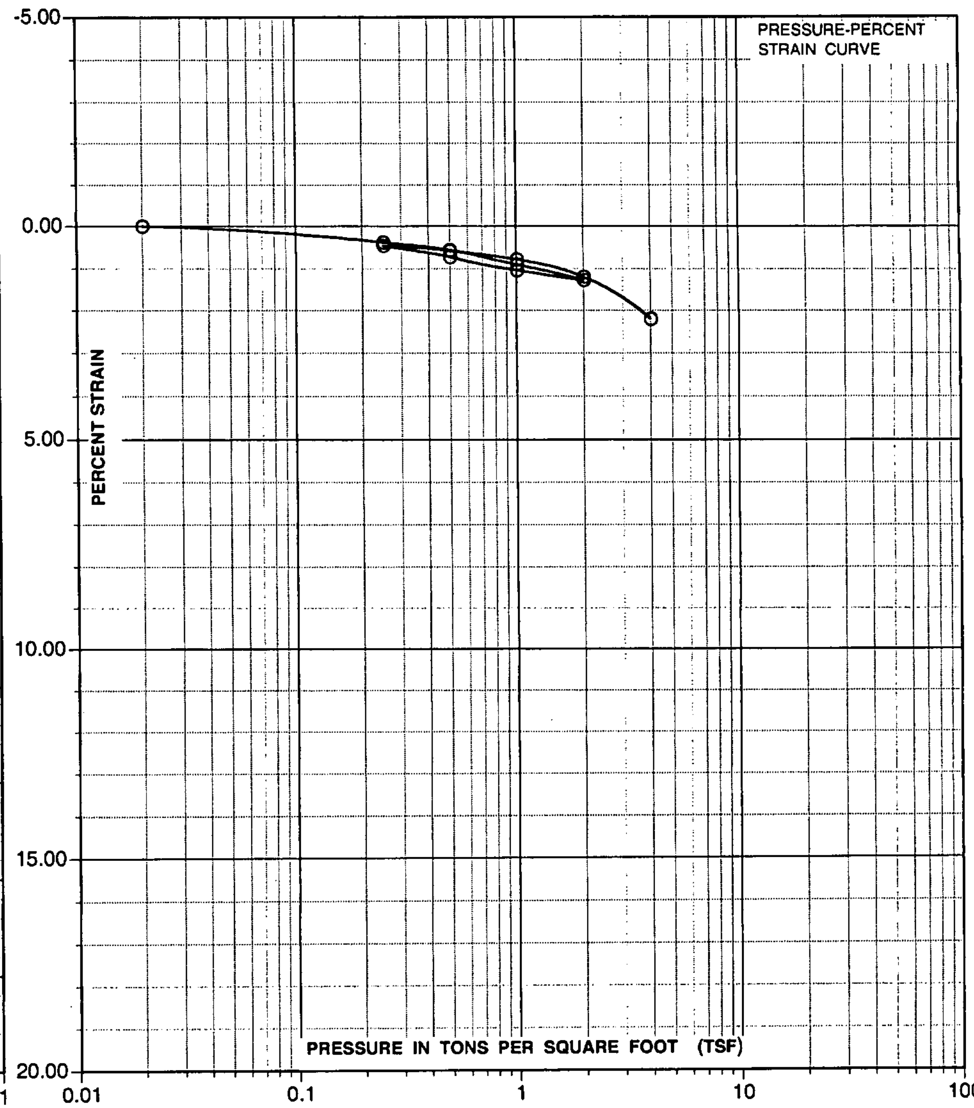
| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |
| **CONSOLIDATION TEST** | | PLATE NO. |
| BORING NO. B-28 | SAMPLE NO. 18 | 31 |




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
| ① | | |
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PLATE NO. 32

SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION - CH
LIQUID LIMIT, $w_L$ = 62
PLASTIC LIMIT, $w_P$ = 22
PLASTICITY INDEX, $I_P$ = 40
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, lb/ft$^3$ = 119

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 66
DIAMETER OF SPECIMEN (IN) = 1.75
INITIAL THICKNESS OF SPECIMEN (IN) = 0.50
INITIAL WATER CONTENT, % = 33
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

— — — INITIAL VOID RATIO, $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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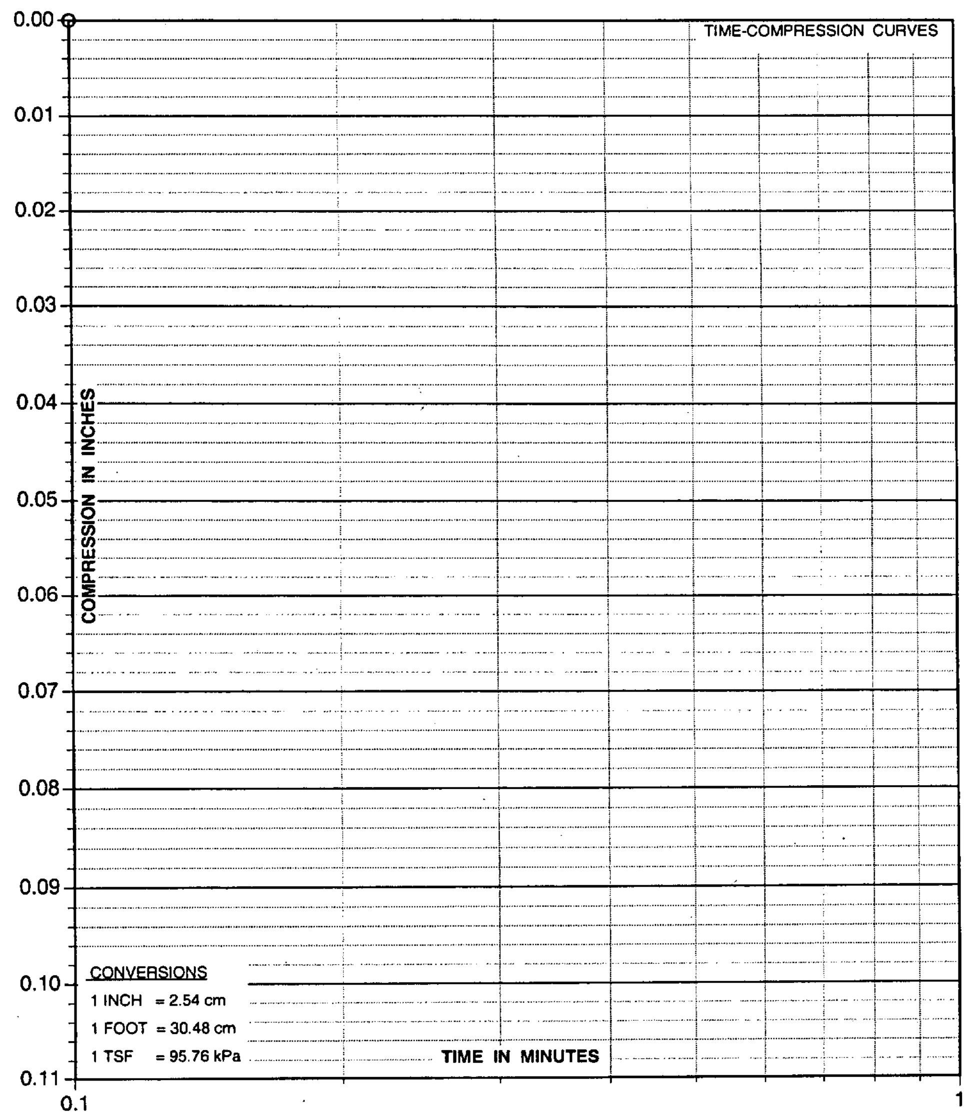
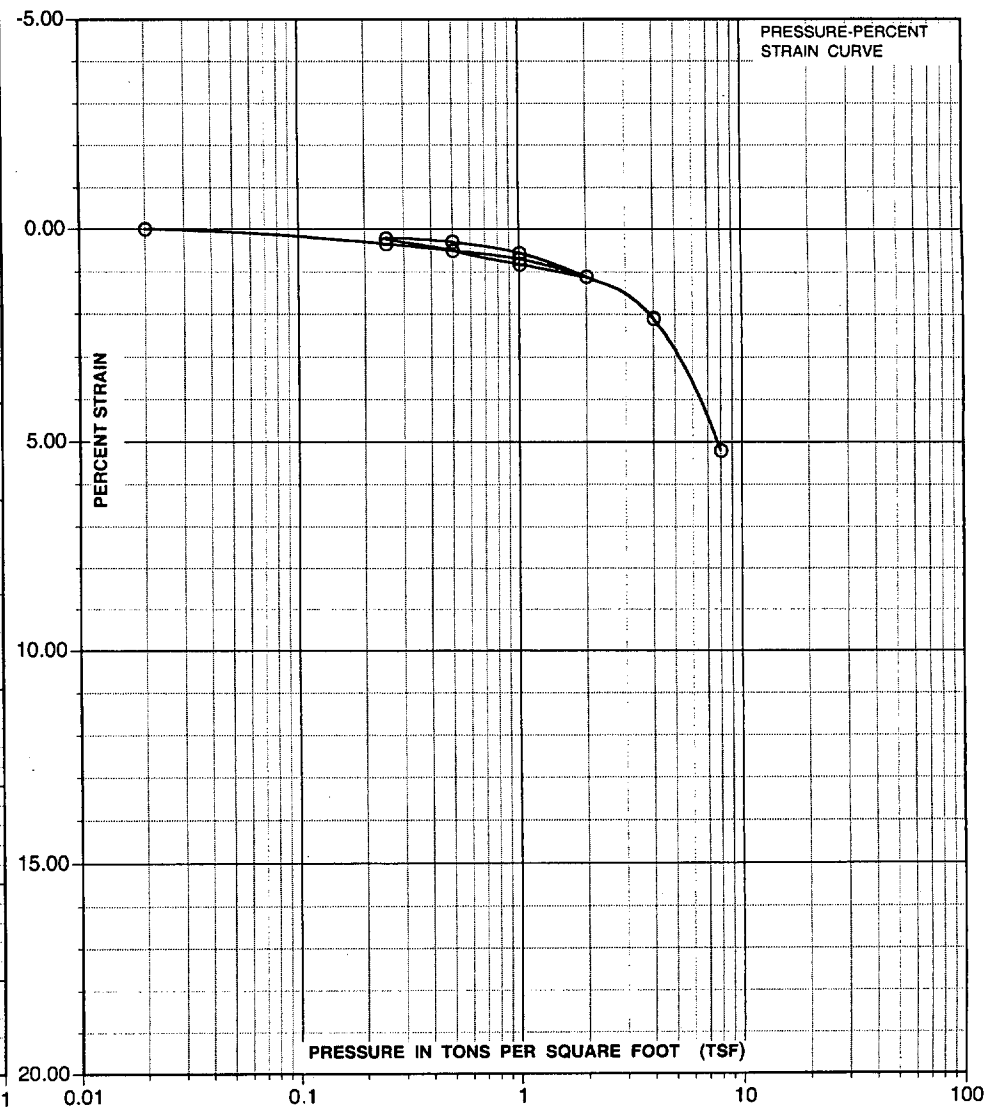
| MADE BY: MM | DATE: 5-23-02 | FILE NO. 9726B |
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | |

**CONSOLIDATION TEST**

BORING NO. B-29 SAMPLE NO. 16 PLATE NO. 32




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
| ① | | |
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PLATE NO. 33

**SPECIMEN DESCRIPTION:**

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ = 108

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 77
DIAMETER OF SPECIMEN (IN) = 1.75
INITIAL THICKNESS OF SPECIMEN (IN) = 0.50
INITIAL WATER CONTENT, % = 44
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

**STRATUM**

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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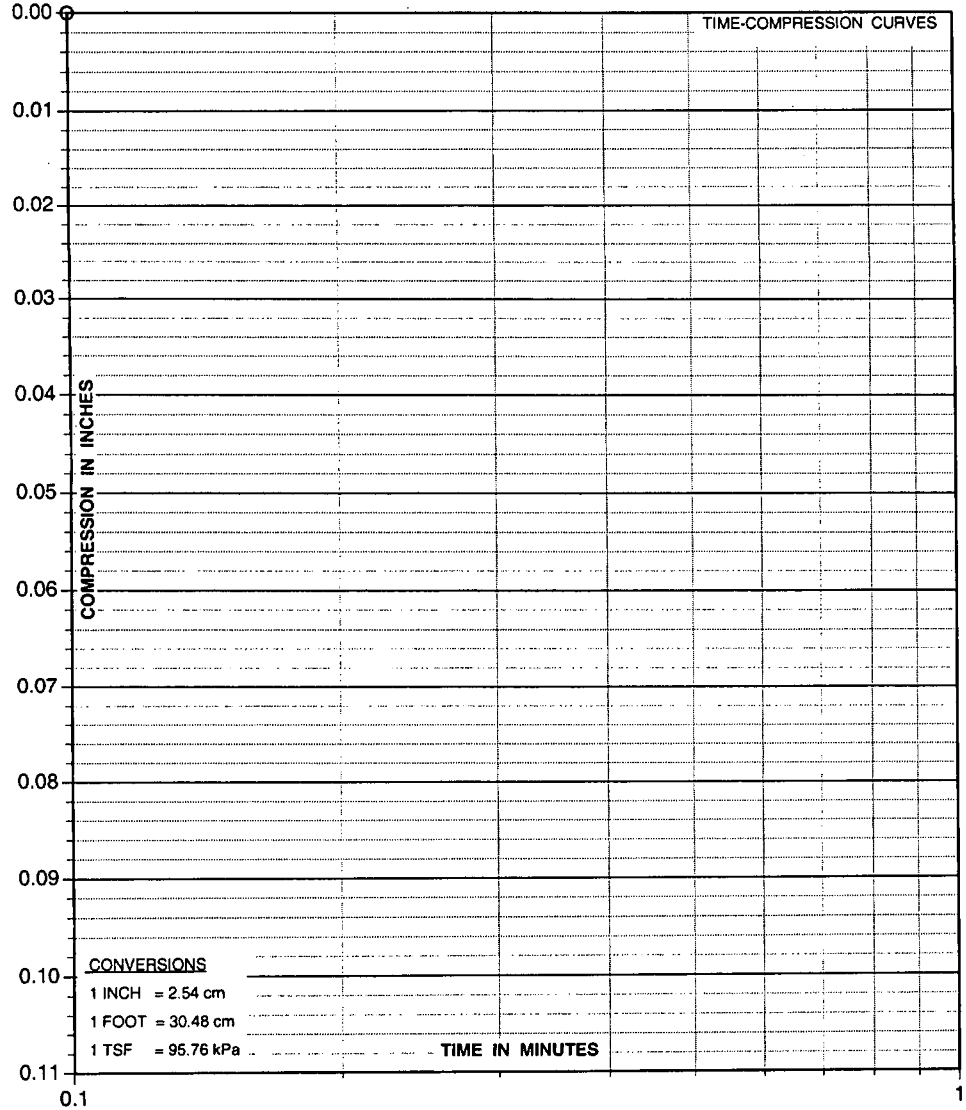
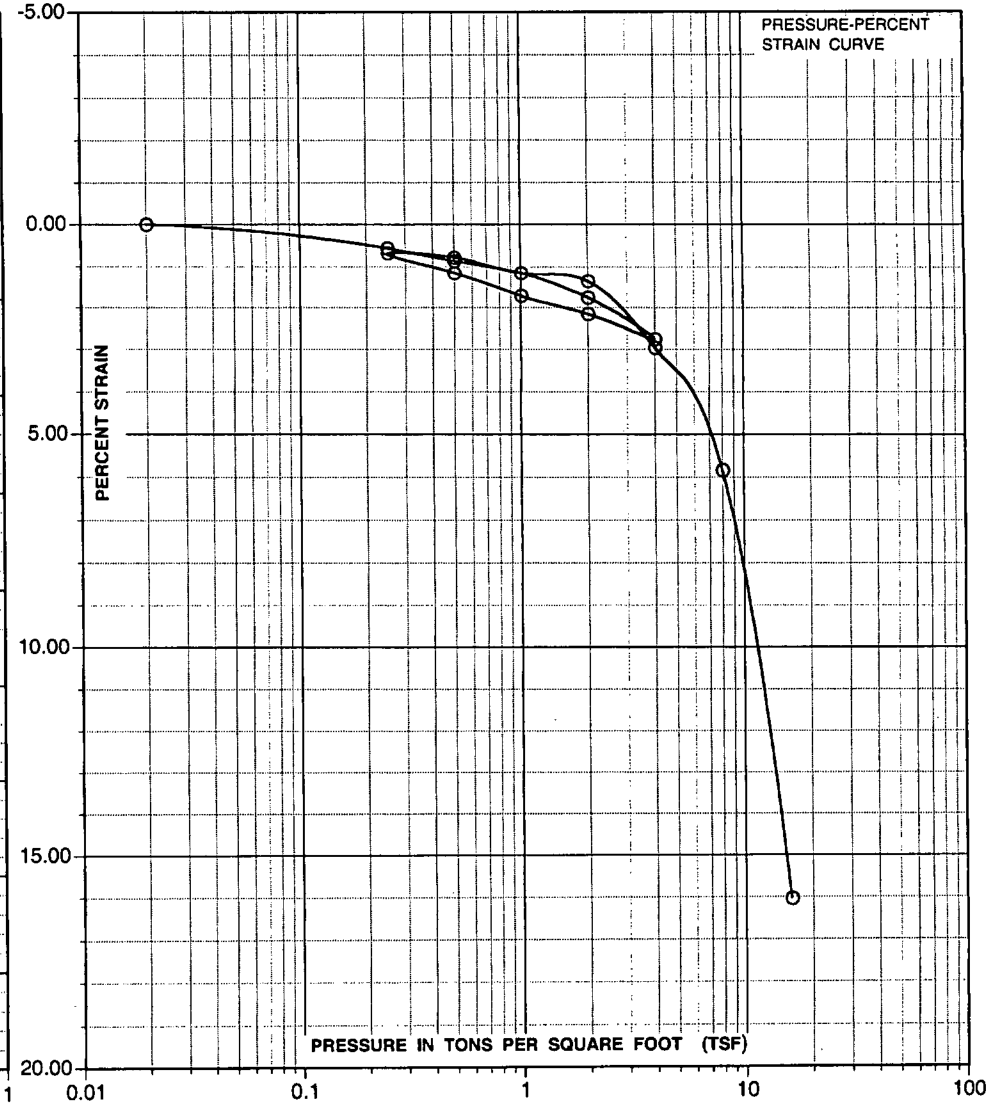
| | | |
|---|---|---|
| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |
| **CONSOLIDATION TEST** | | PLATE NO. |
| BORING NO. B-29 | SAMPLE NO. 19 | 33 |




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
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SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ = 110

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 77
DIAMETER OF SPECIMEN (IN) = 1.75
INITIAL THICKNESS OF SPECIMEN (IN) = 0.50
INITIAL WATER CONTENT, % = 47
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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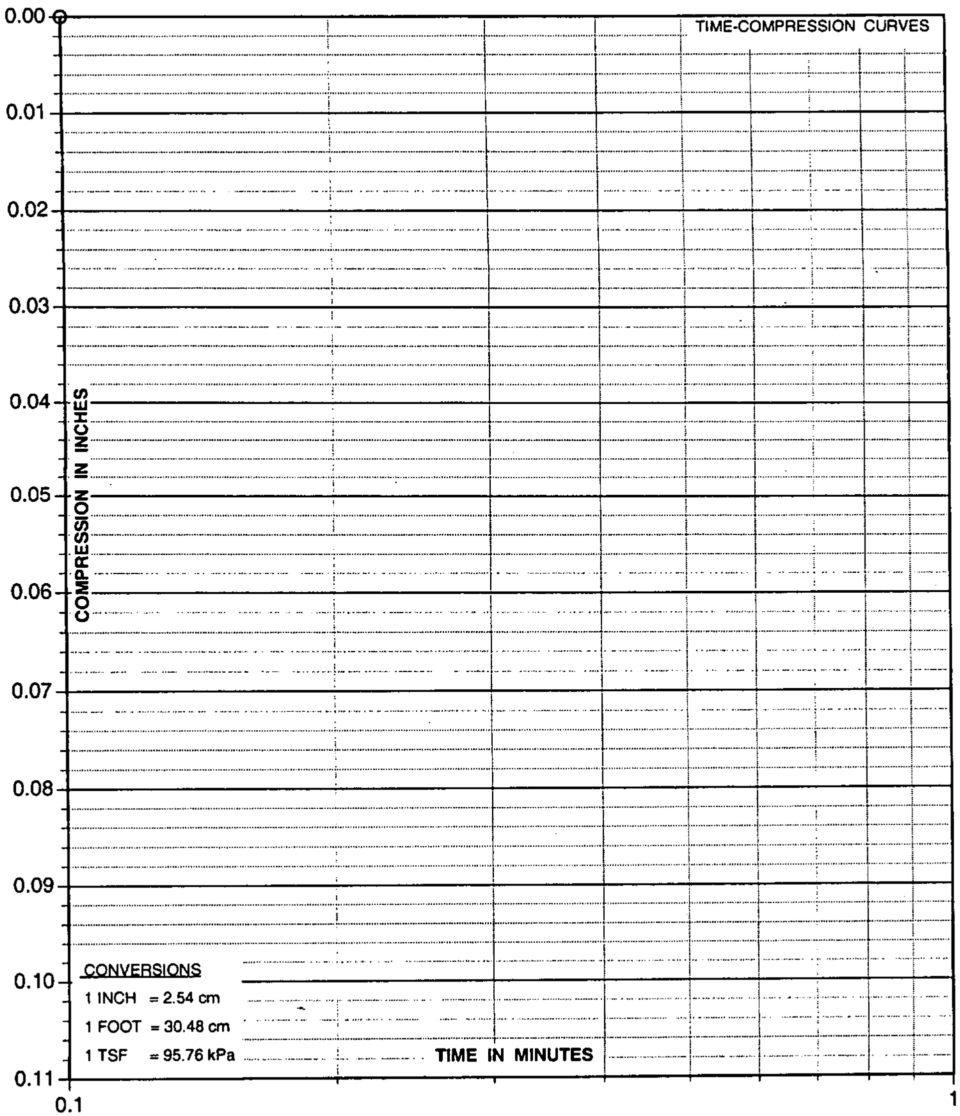
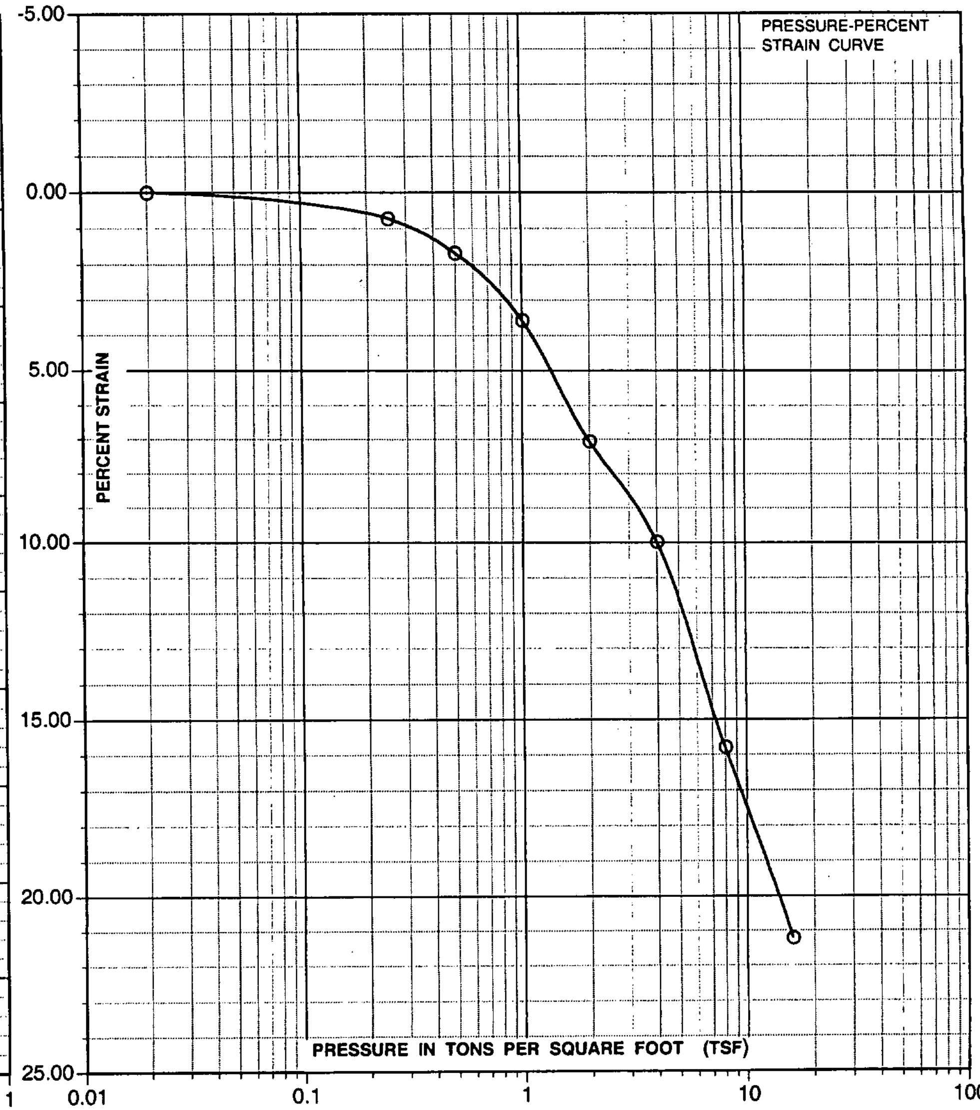
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | |

**CONSOLIDATION TEST**
BORING NO. B-30 SAMPLE NO. 19 PLATE NO. 34




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
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PLATE NO. 35

SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, lb/ft$^3$ = 109

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 82
DIAMETER OF SPECIMEN (IN) = 1.75
INITIAL THICKNESS OF SPECIMEN (IN) = 0.50
INITIAL WATER CONTENT, % = 46
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

— — — INITIAL VOID RATIO, $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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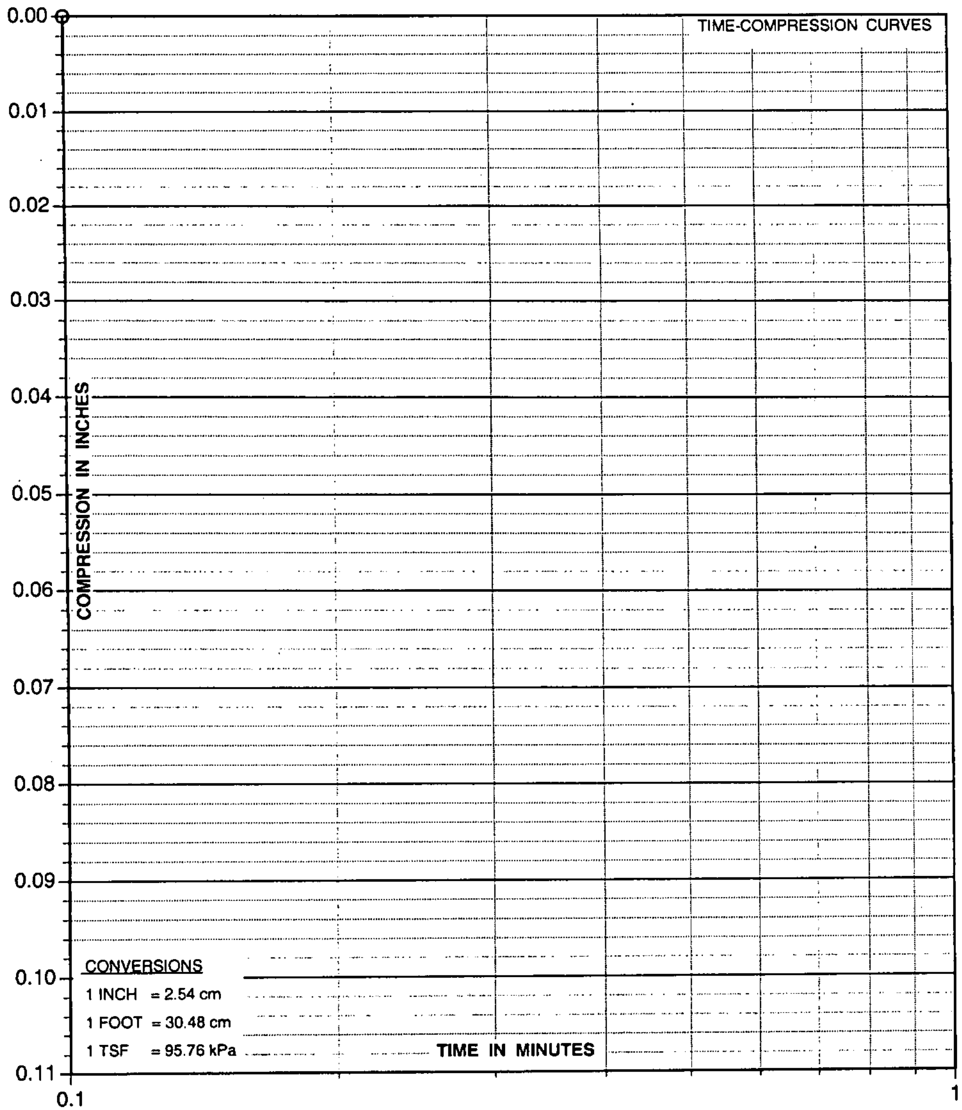
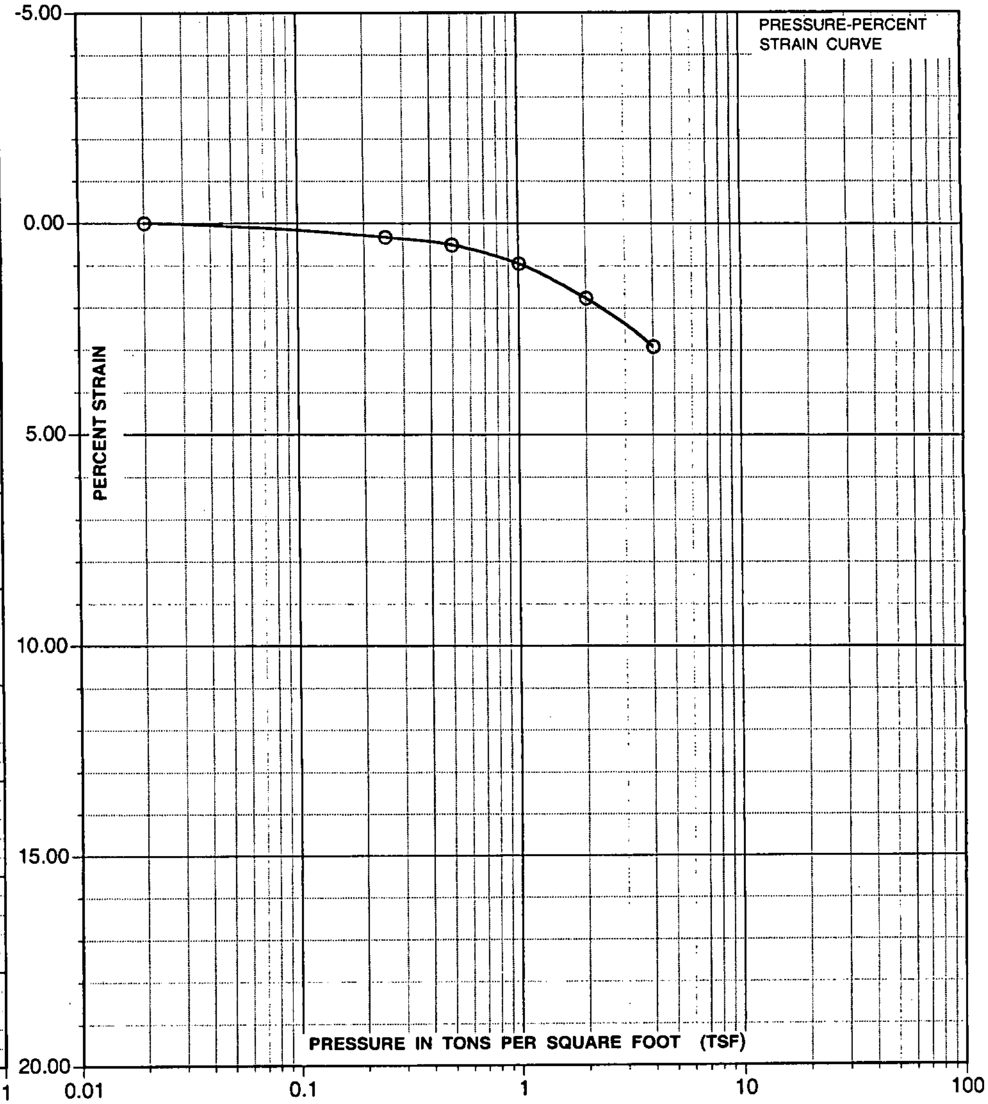
| | | |
|---|---|---|
| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |
| **CONSOLIDATION TEST** | | PLATE NO. |
| BORING NO. B-30 | SAMPLE NO. 21 | 35 |




| CURVE NO. | INCREMENT FROM (TSF) | TO (TSF) |
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| ① | | |
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PLATE NO. 36

SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 84
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

— — — INITIAL VOID RATIO, $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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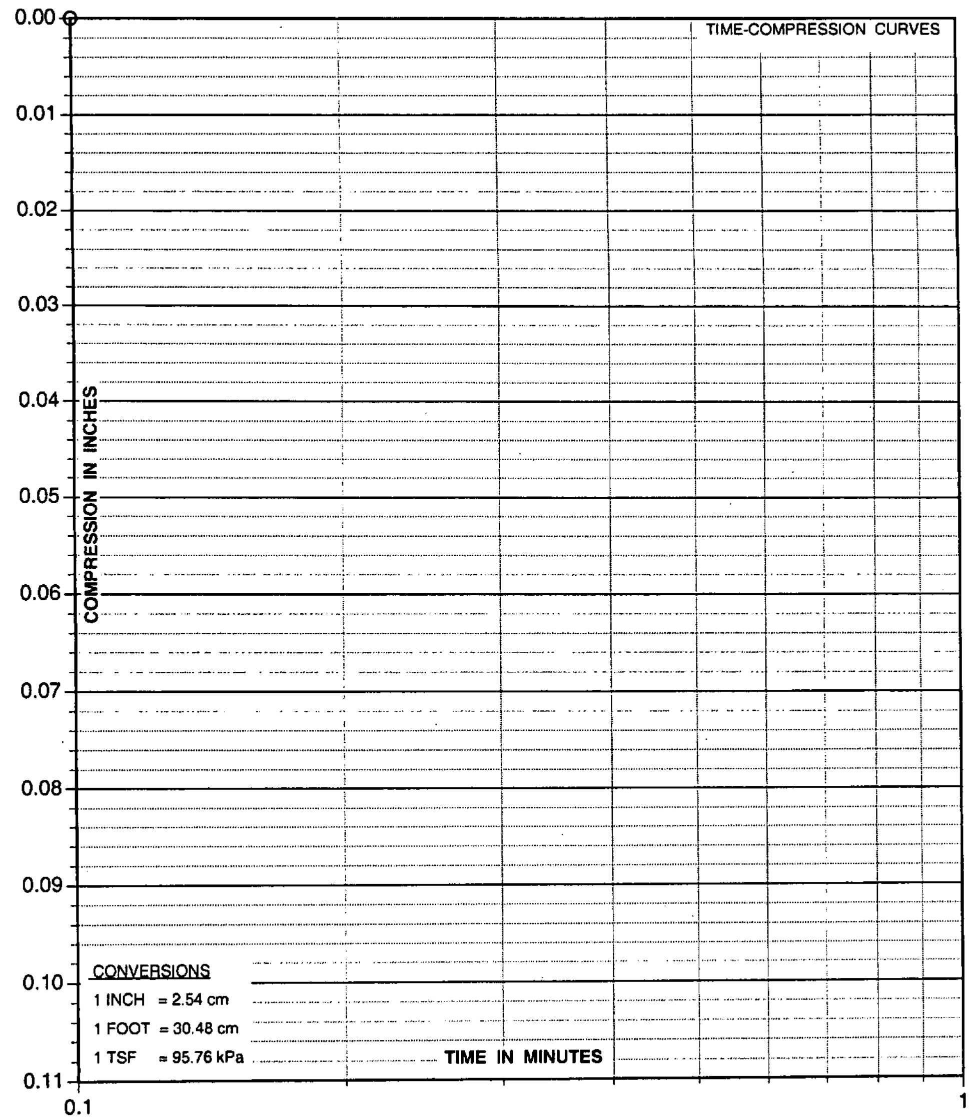
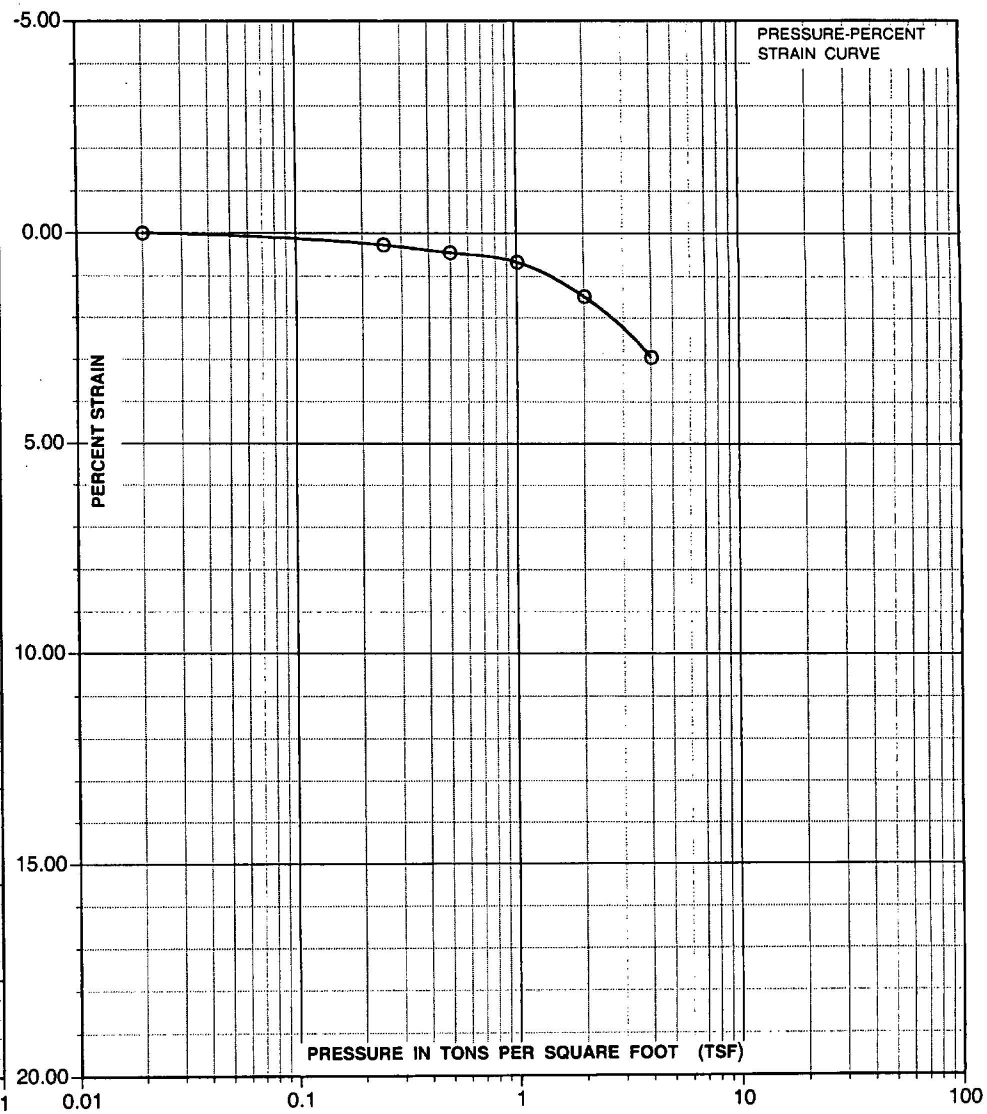
CH'KD BY: AA DATE: 6-6-02
FILE NO. 9726B

**CONSOLIDATION TEST**
BORING NO. B-22 SAMPLE NO. 21
PLATE NO. 36




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
| ① | | |
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| ⑧ | | |

PLATE NO. 37

SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT , $w_L$ =
PLASTIC LIMIT , $w_P$ =
PLASTICITY INDEX , $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY , $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 78
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

— — — INITIAL VOID RATIO , $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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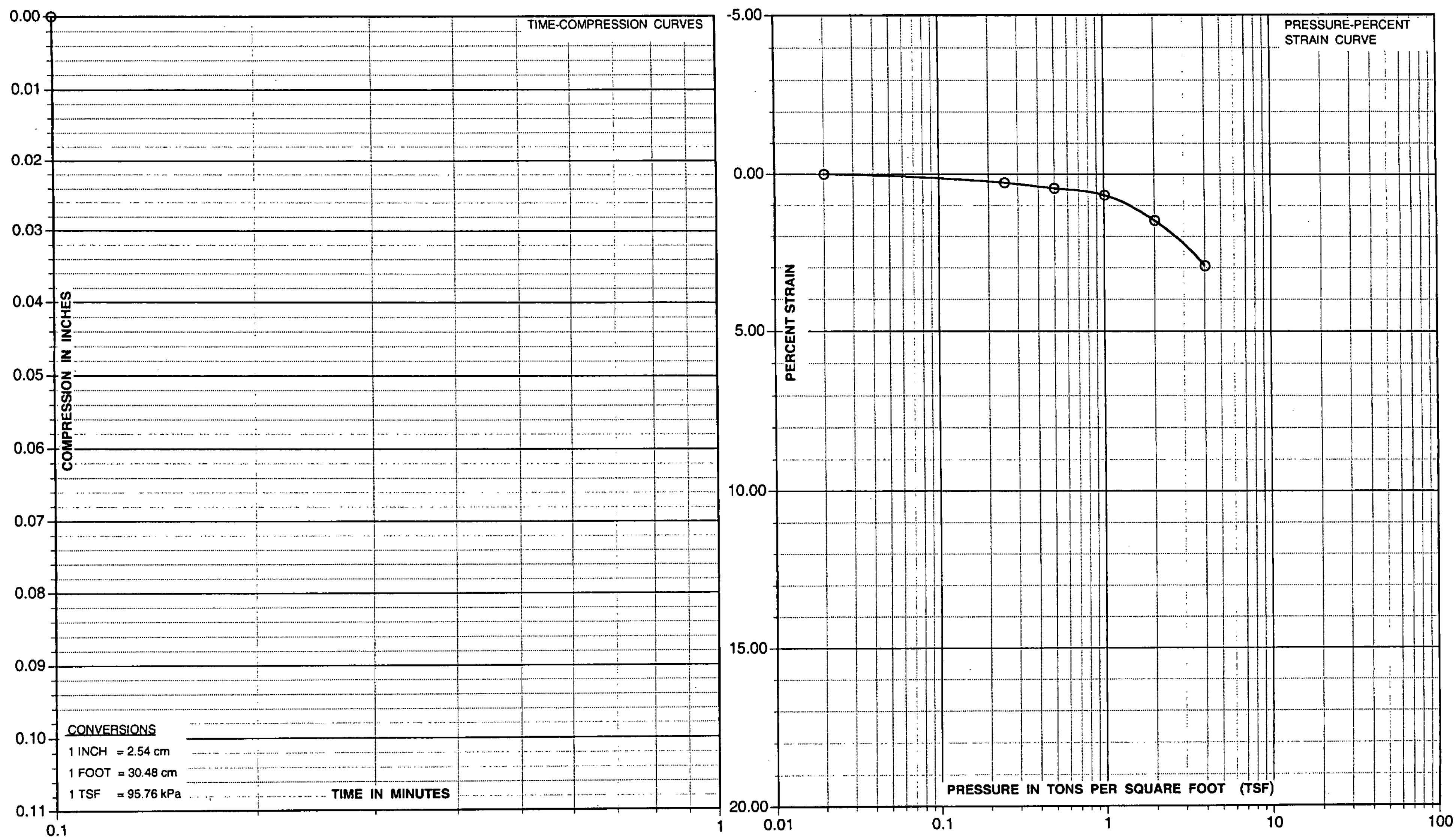
| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |
| **CONSOLIDATION TEST** | | PLATE NO. |
| BORING NO. B-23 | SAMPLE NO. 20 | 37 |




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
| ① | | |
| ② | | |
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| ⑧ | | |

SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, lb/ft$^3$ =

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 78
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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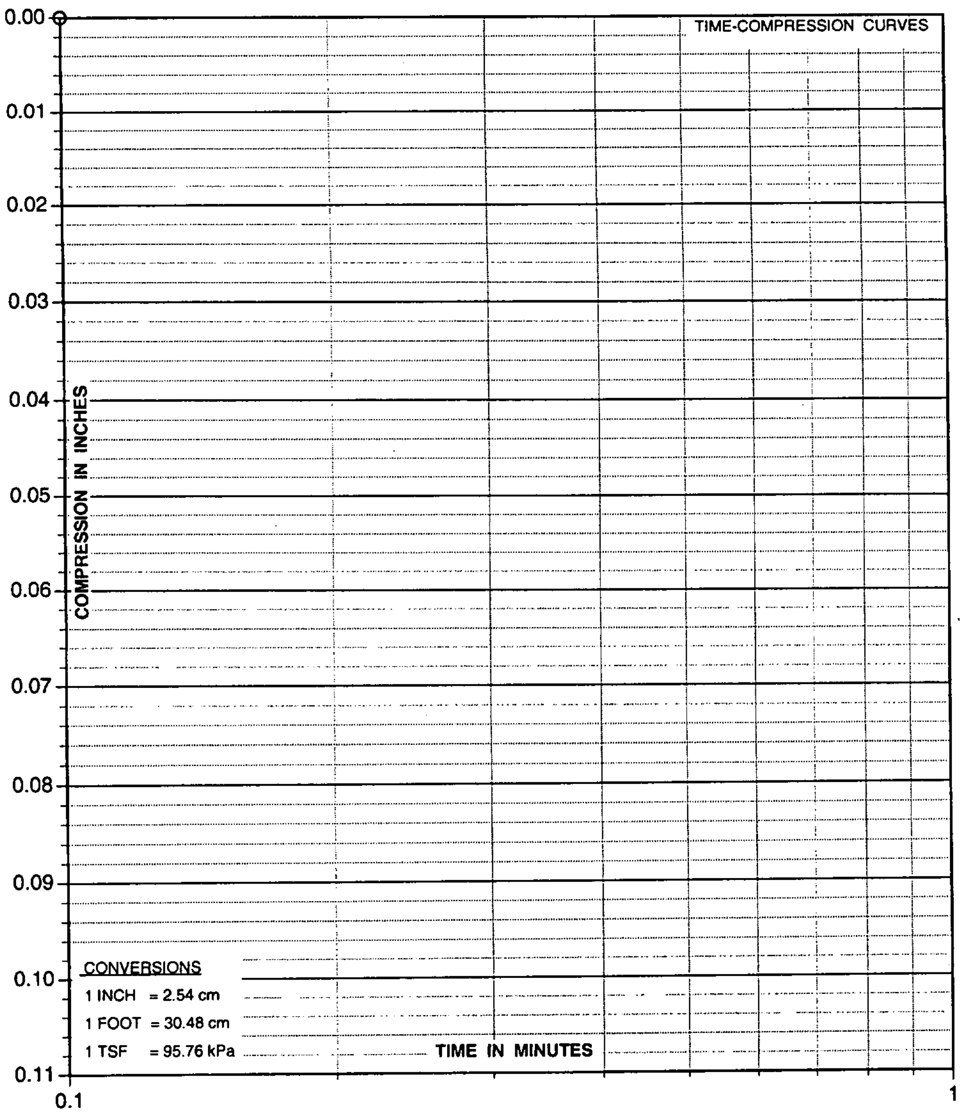
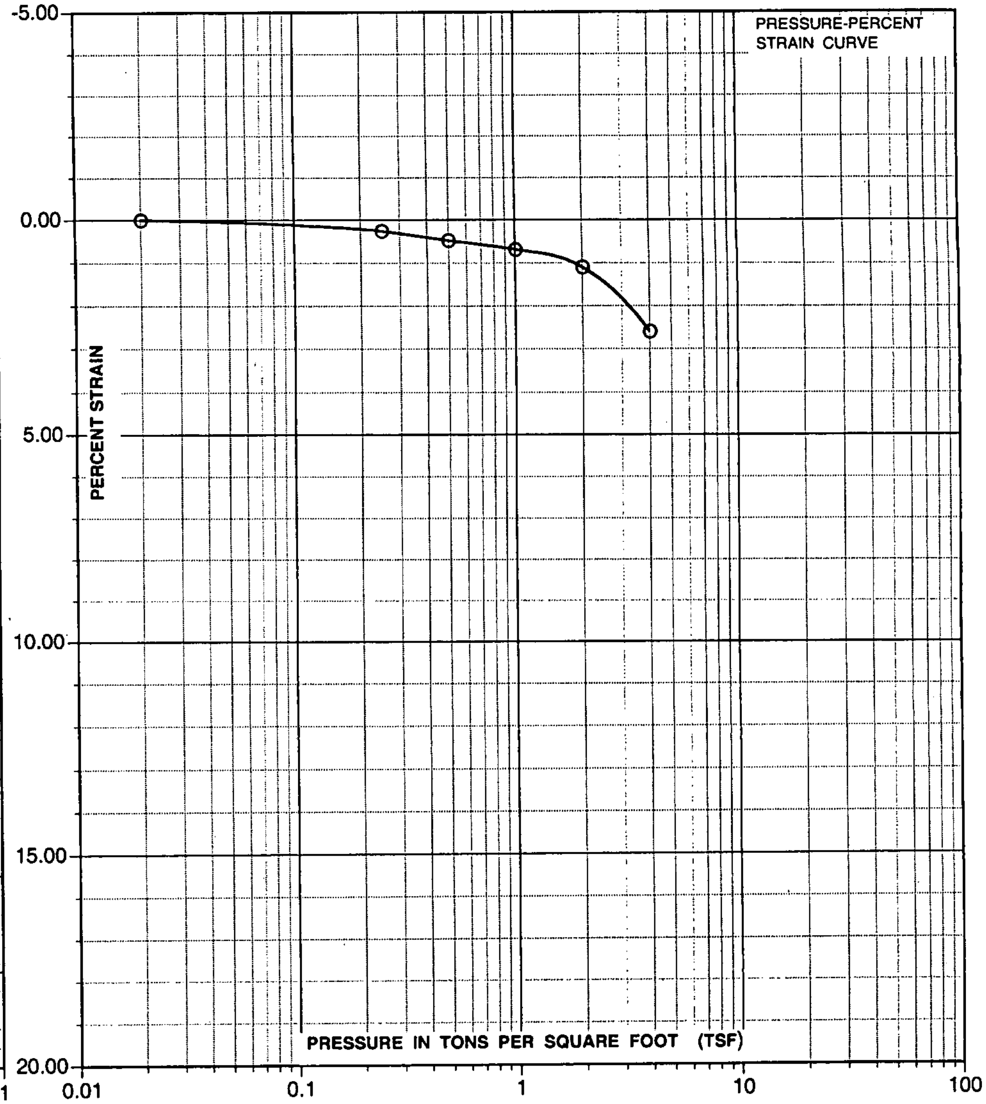
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | |
| **CONSOLIDATION TEST** | | PLATE NO. 37 |
| BORING NO. B-23 | SAMPLE NO. 20 | |




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
| ① | | |
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SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 97
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

**FROM 1962 DATA BY EDWARD S. BARBER**

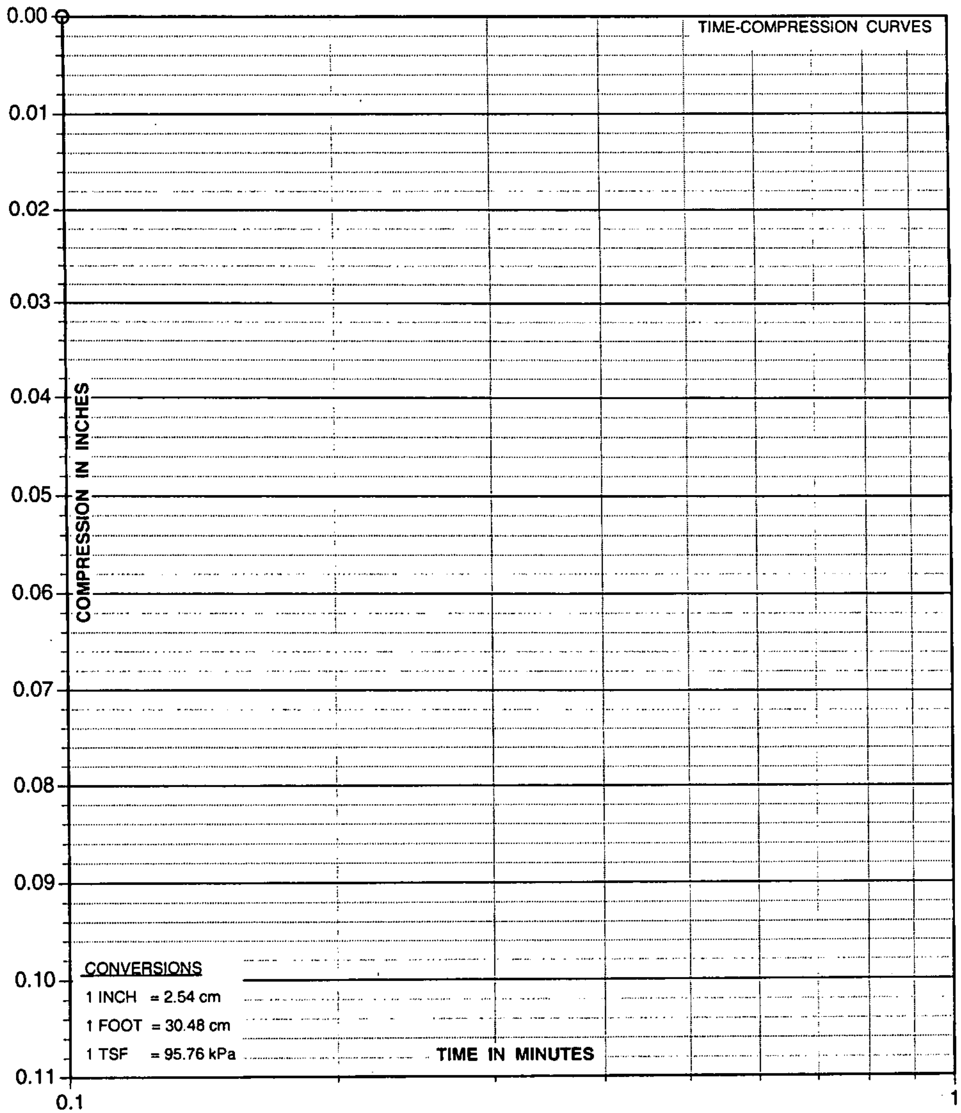
WASHINGTON MONUMENT

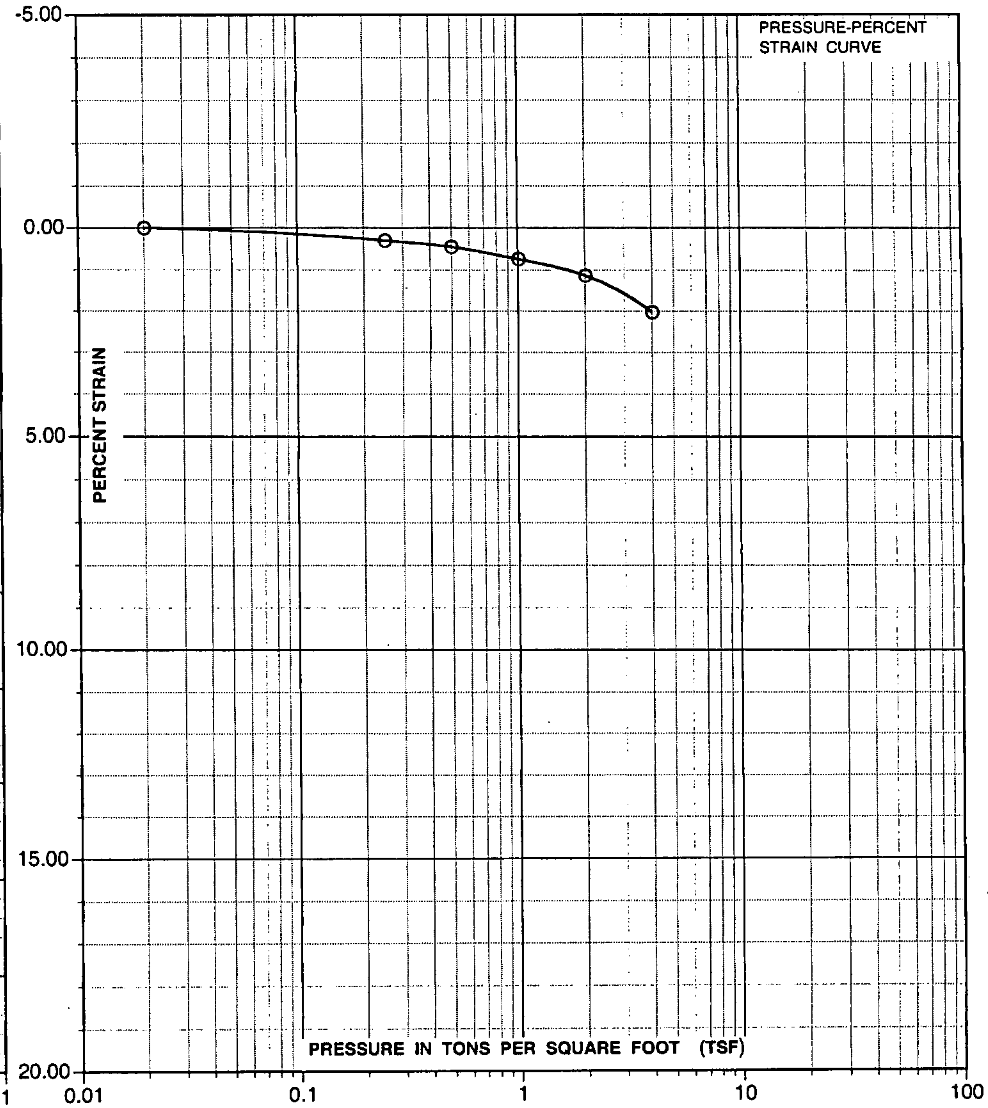
WASHINGTON D.C.

**MUESER RUTLEDGE CONSULTING ENGINEERS**
225 WEST 34TH STREET, NEW YORK, N.Y. 10122

MADE BY: MM DATE: 5-23-02 FILE NO. 9726B
CH'KD BY: AA DATE: 6-6-02

**CONSOLIDATION TEST**
BORING NO. B-23 SAMPLE NO. 28 PLATE NO. 38




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
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PLATE NO. 39

SPECIMEN DESCRIPTION:

STRATUM

PROPERTIES OF PLASTICITY LIMIT SPECIMEN

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

PROPERTIES OF CONSOLIDATION SPECIMEN

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 95
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

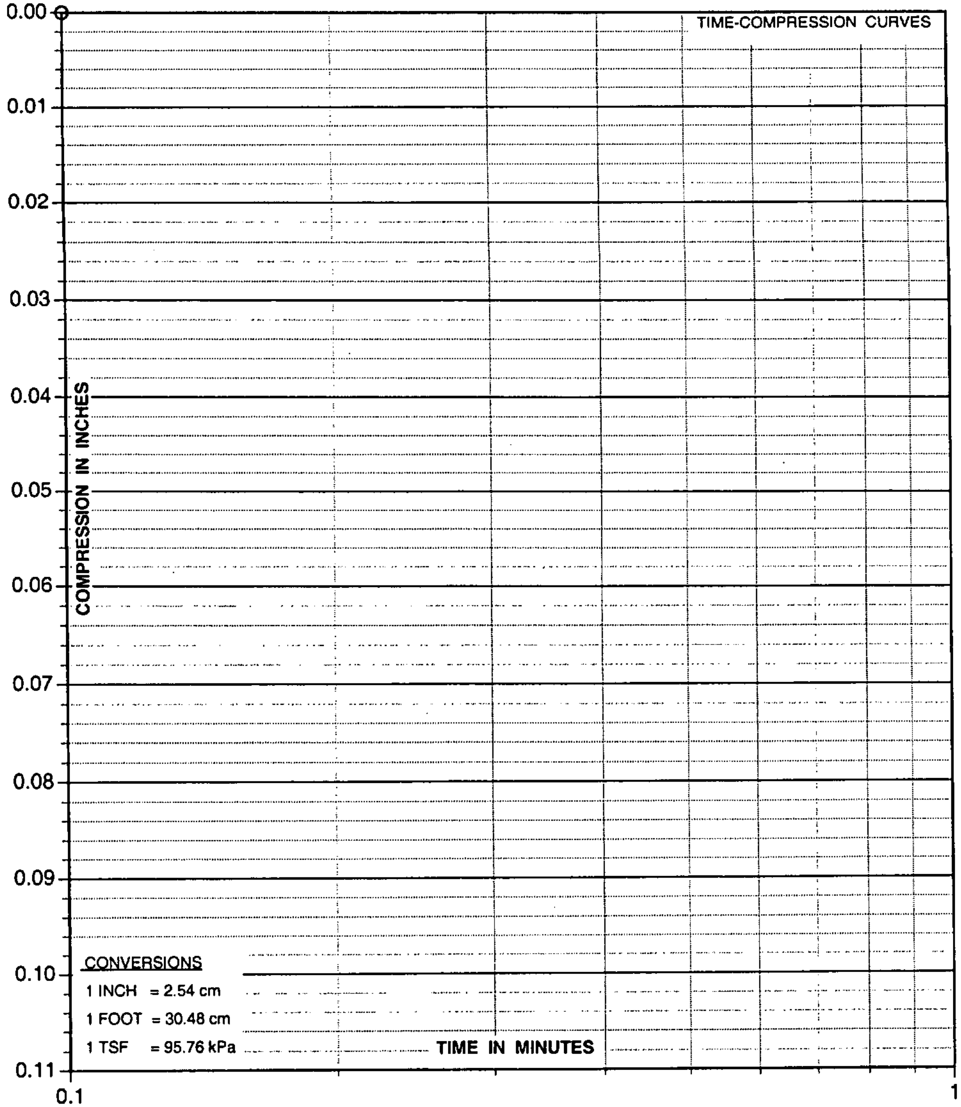
**FROM 1962 DATA BY EDWARD S. BARBER**

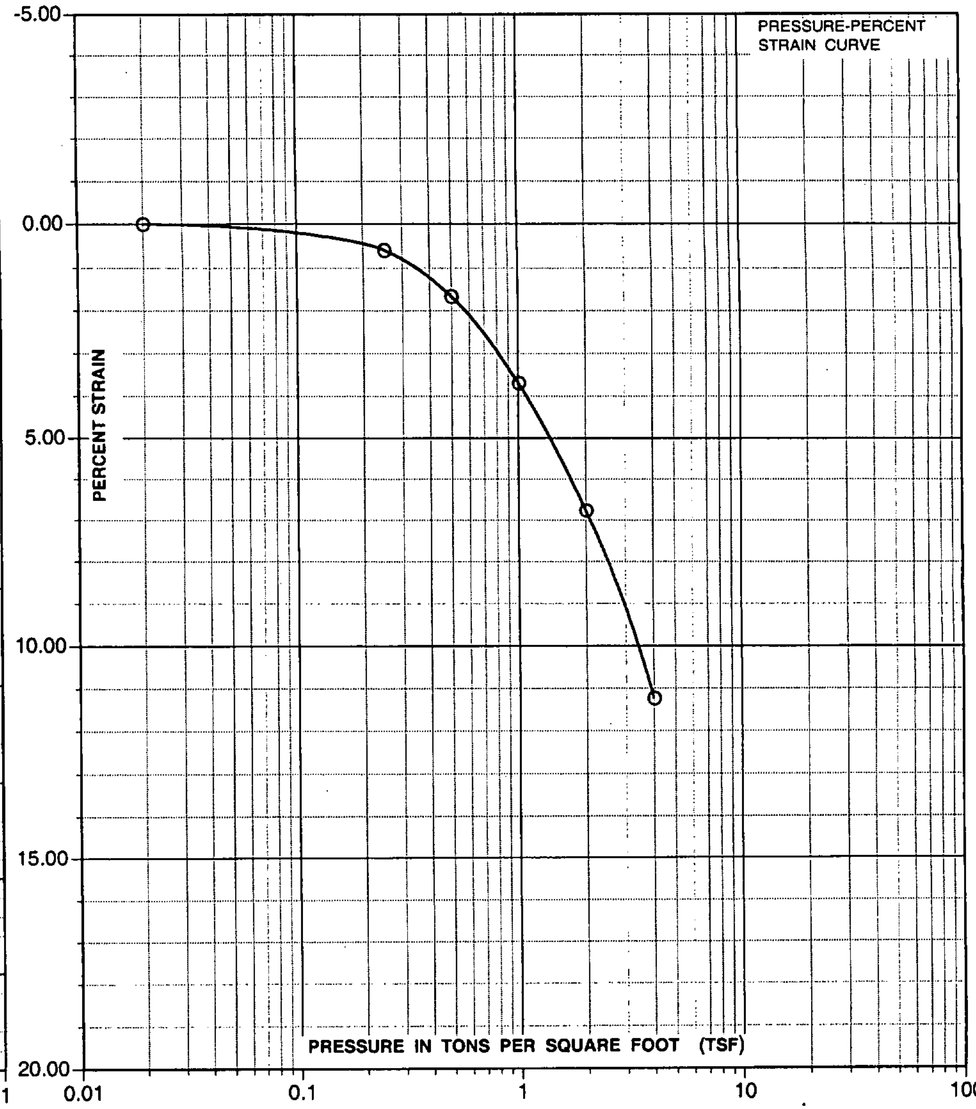
WASHINGTON MONUMENT

WASHINGTON D.C.

**MUESER RUTLEDGE CONSULTING ENGINEERS**
225 WEST 34TH STREET, NEW YORK, N.Y. 10122

| MADE BY: MM | DATE: 5-23-02 | FILE NO. 9726B |
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | |
| **CONSOLIDATION TEST** | | PLATE NO. 39 |
| BORING NO. B-24 | SAMPLE NO. 20 | |




| CURVE NO. | INCREMENT FROM (TSF) | TO (TSF) |
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PLATE NO. 40

**SPECIMEN DESCRIPTION:**

PROPERTIES OF PLASTICITY LIMIT SPECIMEN

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

PROPERTIES OF CONSOLIDATION SPECIMEN

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 44
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

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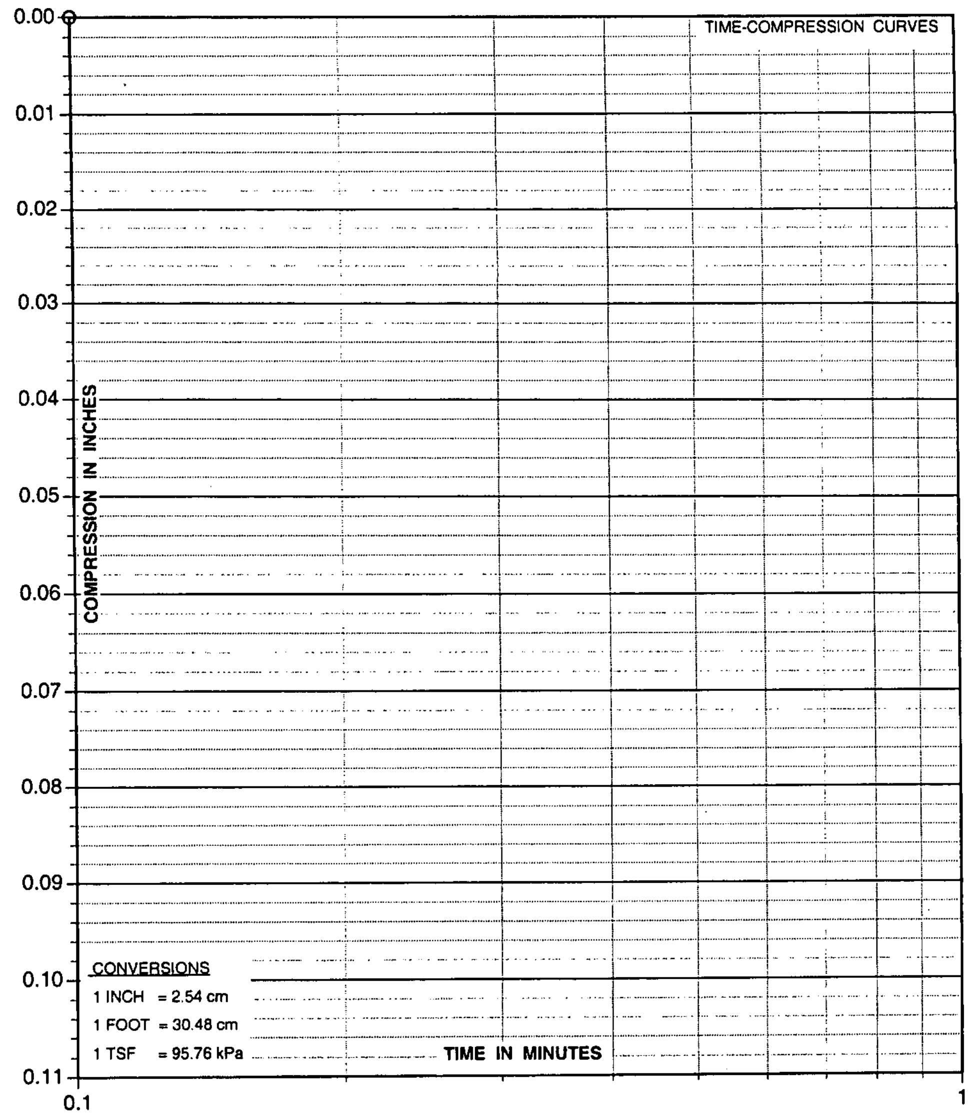
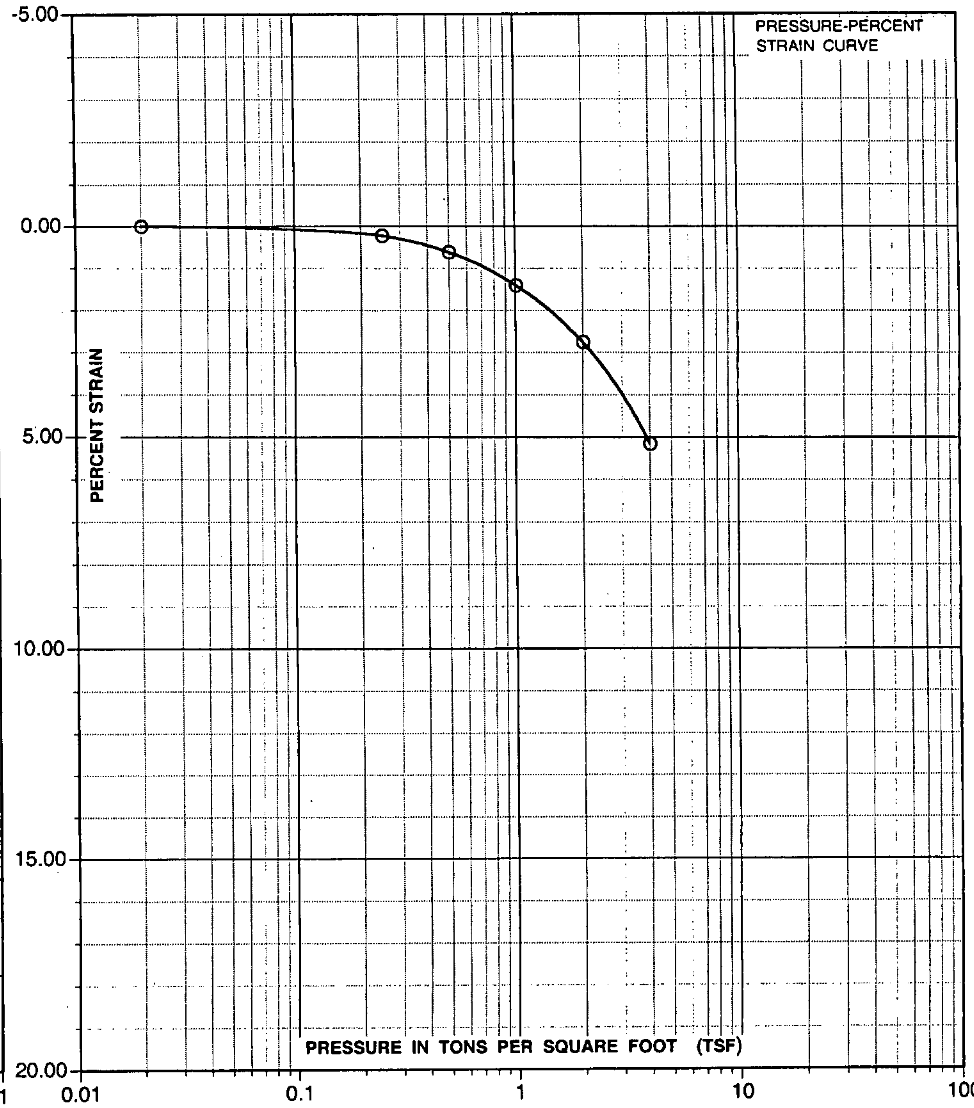
WASHINGTON MONUMENT

WASHINGTON D.C.

**MUESER RUTLEDGE CONSULTING ENGINEERS**
225 WEST 34TH STREET, NEW YORK, N.Y. 10122

| | | |
|---|---|---|
| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |
| **CONSOLIDATION TEST** | | PLATE NO. |
| BORING NO. B-26 | SAMPLE NO. 14 | 40 |

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SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 67
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

— — — INITIAL VOID RATIO, $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

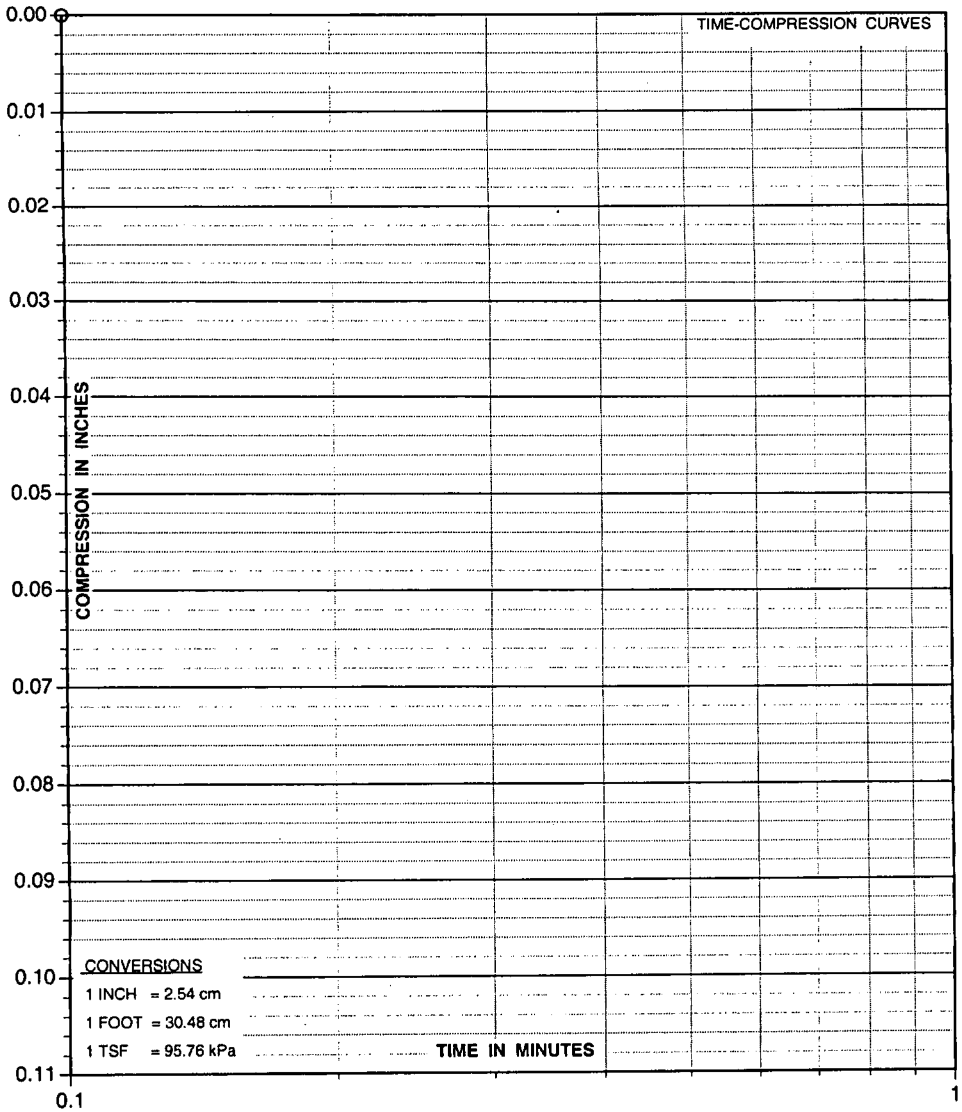
**FROM 1962 DATA BY EDWARD S. BARBER**

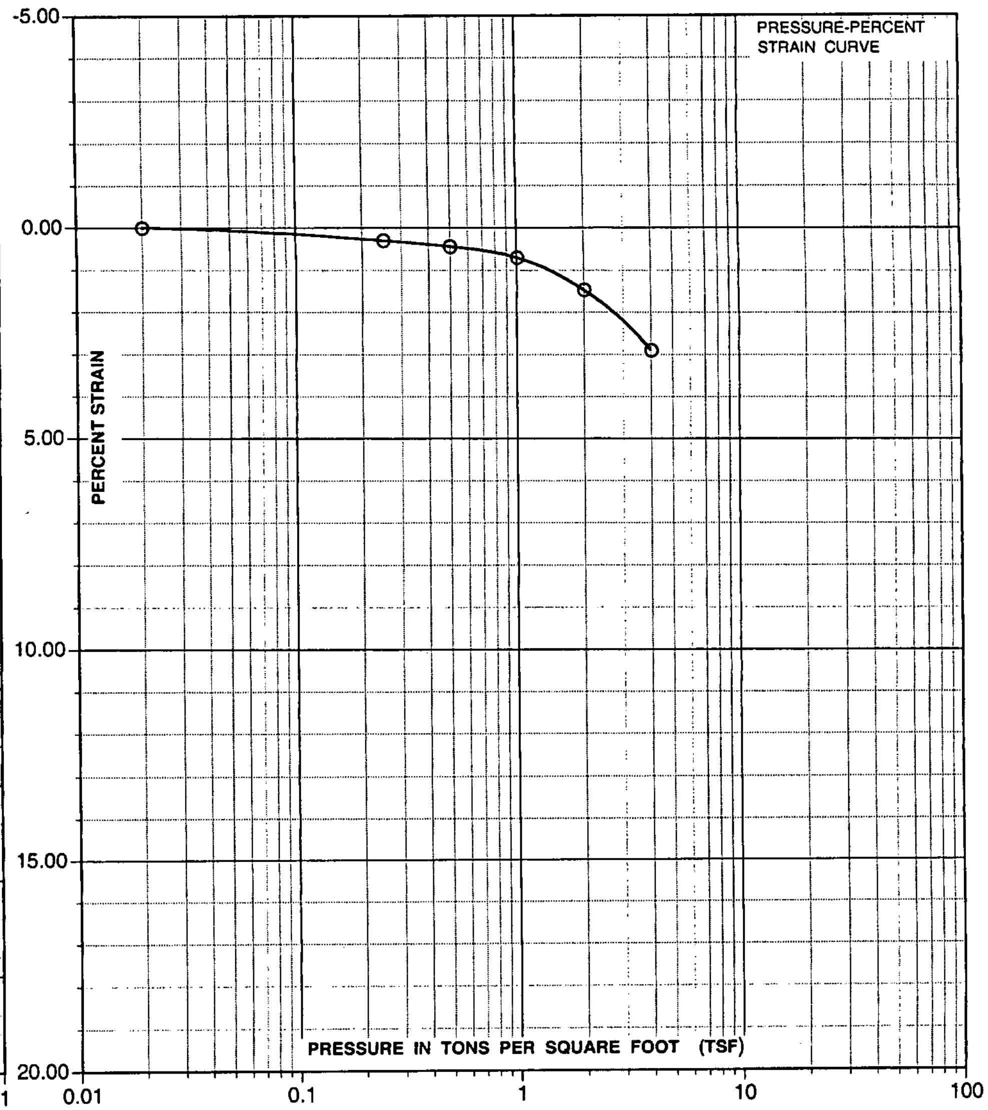
WASHINGTON MONUMENT

WASHINGTON D.C.

**MUESER RUTLEDGE CONSULTING ENGINEERS**
225 WEST 34TH STREET, NEW YORK, N.Y. 10122

| | | |
|---|---|---|
| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |
| **CONSOLIDATION TEST** | | PLATE NO. |
| BORING NO. B-27 | SAMPLE NO. 23 | 41 |




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
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SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 76
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

**FROM 1962 DATA BY EDWARD S. BARBER**

WASHINGTON MONUMENT

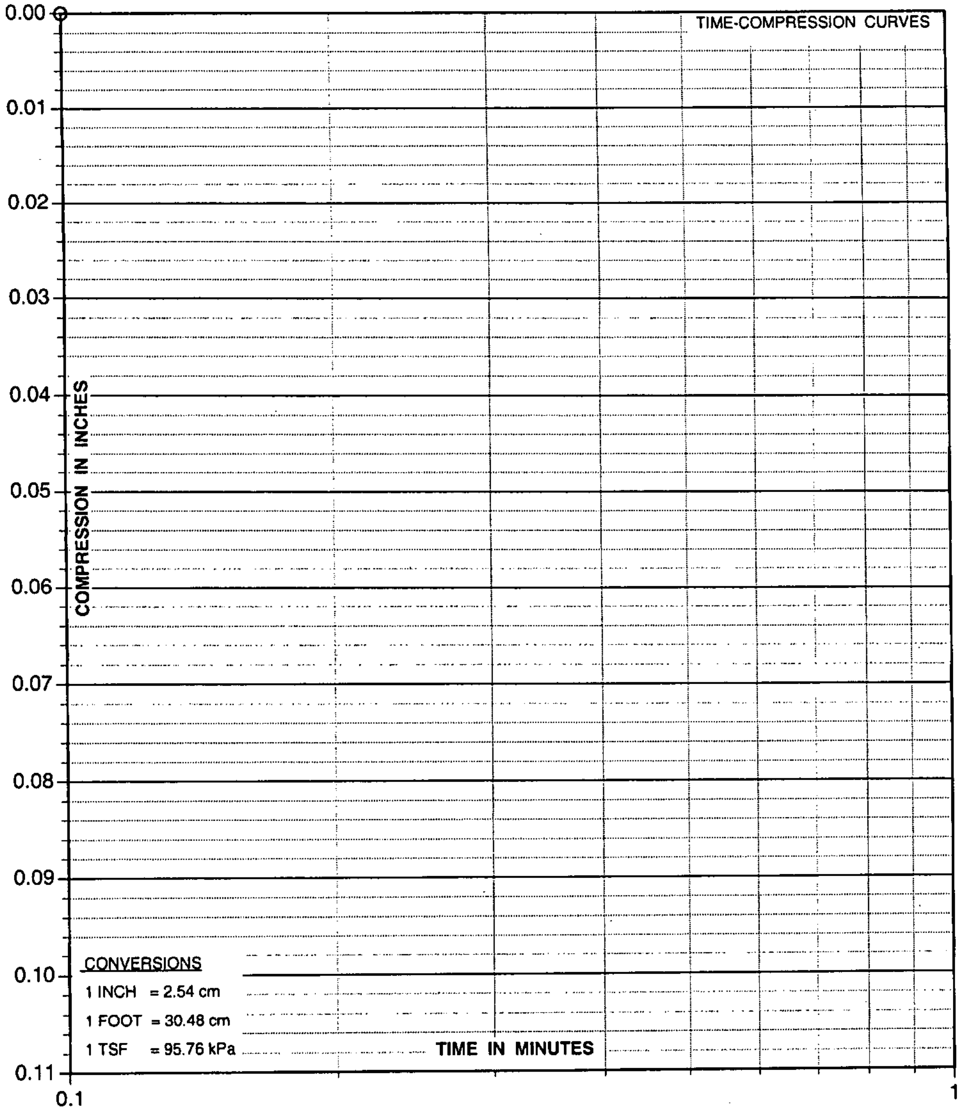
WASHINGTON D.C.

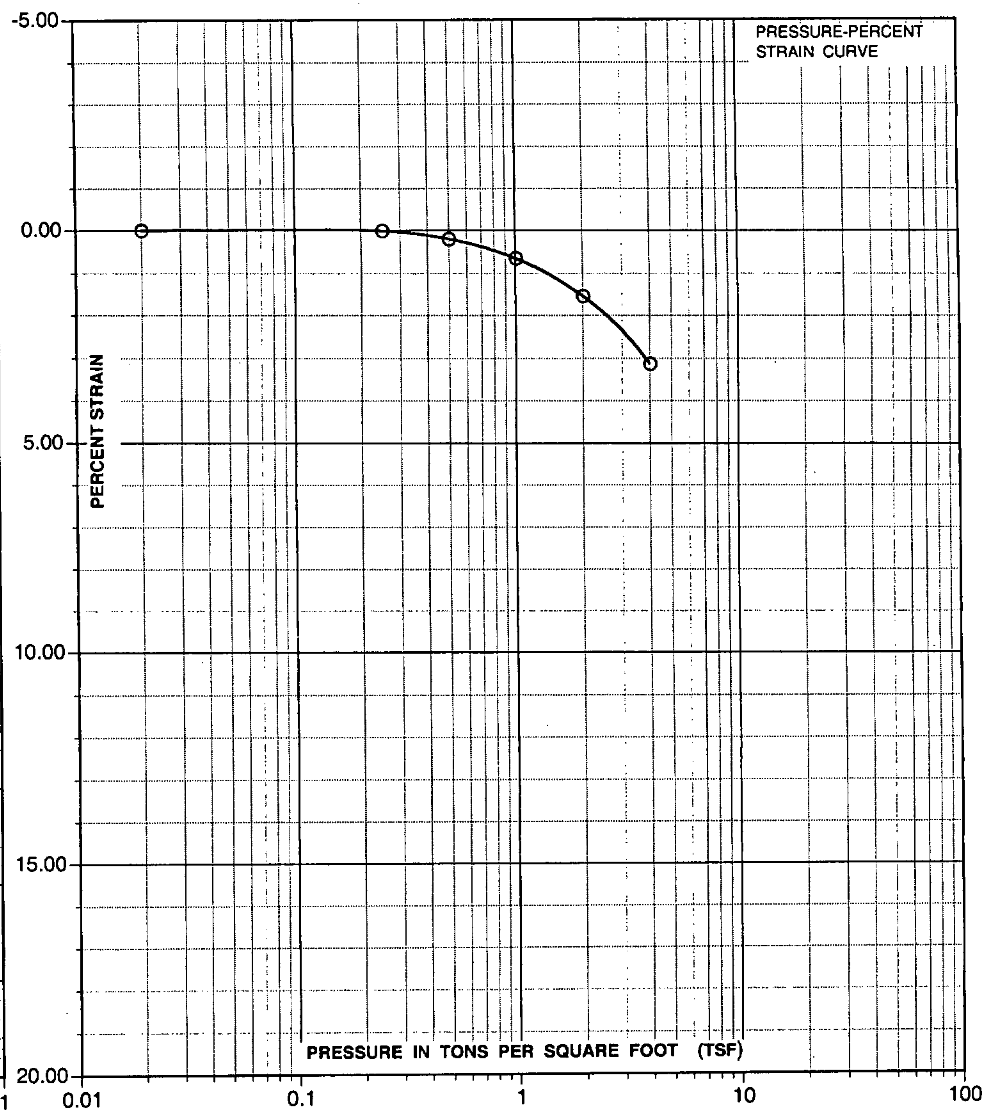
**MUESER RUTLEDGE CONSULTING ENGINEERS**
225 WEST 34TH STREET, NEW YORK, N.Y. 10122

| MADE BY: MM | DATE: 5-23-02 | FILE NO. |
|---|---|---|
| CH'KD BY: AA | DATE: 6-6-02 | 9726B |

**CONSOLIDATION TEST**

BORING NO. B-27 SAMPLE NO. 27 | PLATE NO. 42




| CURVE NO. | INCREMENT FROM (TSF) | INCREMENT TO (TSF) |
|---|---|---|
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SPECIMEN DESCRIPTION:

**PROPERTIES OF PLASTICITY LIMIT SPECIMEN**

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =
INITIAL DENSITY, $lb/ft^3$ =

**PROPERTIES OF CONSOLIDATION SPECIMEN**

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 67
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

— — — INITIAL VOID RATIO, $e_o$ =
- - - - - FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

**FROM 1962 DATA BY EDWARD S. BARBER**

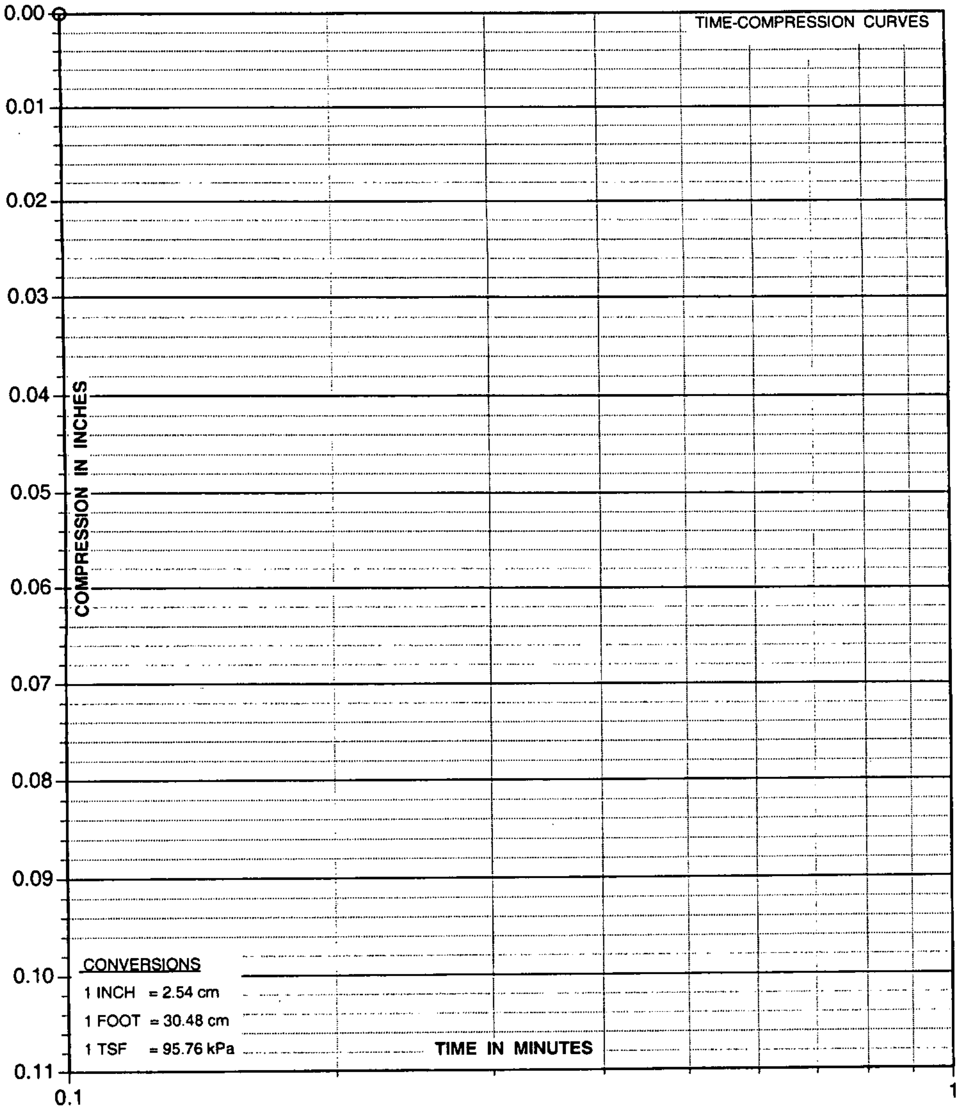
WASHINGTON MONUMENT

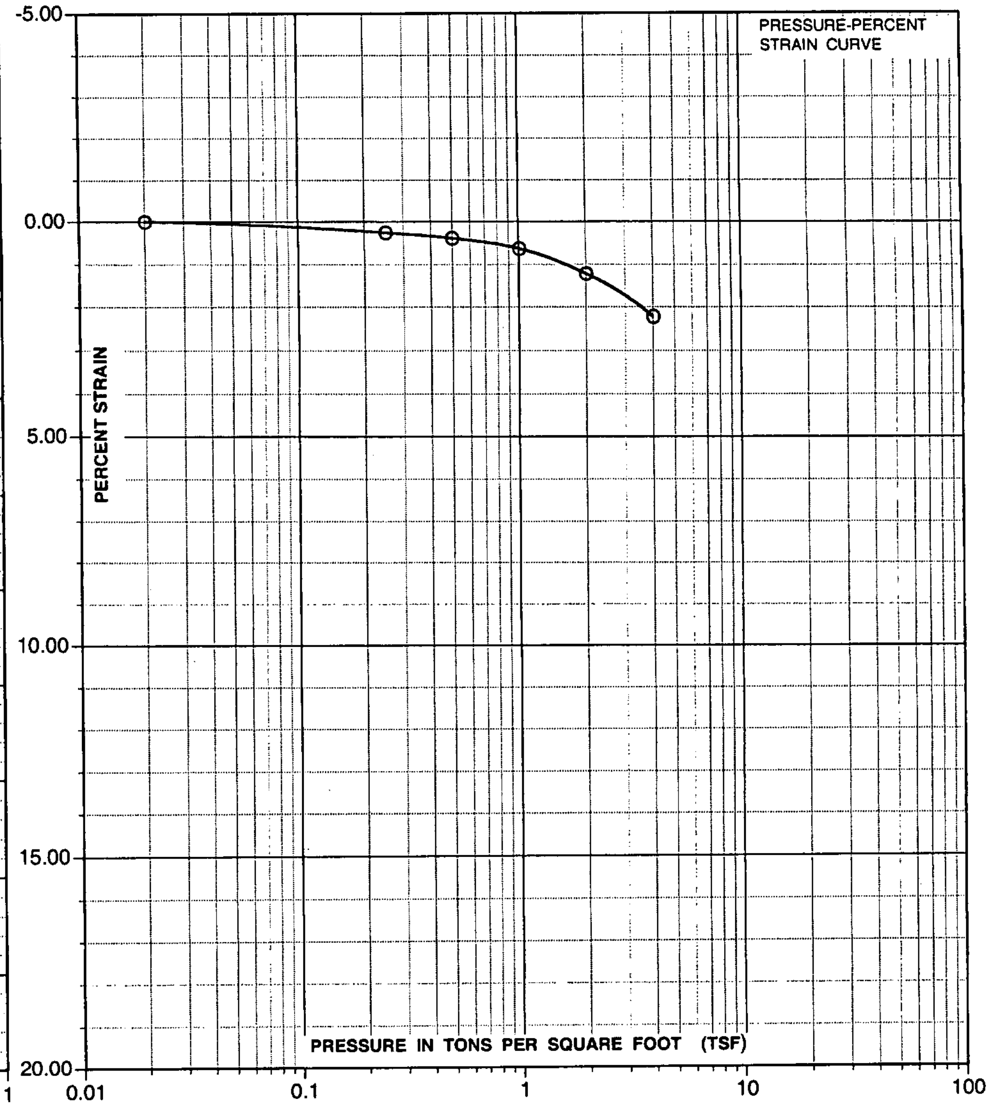
WASHINGTON D.C.

**MUESER RUTLEDGE CONSULTING ENGINEERS**
225 WEST 34TH STREET, NEW YORK, N.Y. 10122

MADE BY: MM DATE: 5-23-02 FILE NO. 9726B
CH'KD BY: AA DATE: 6-6-02

**CONSOLIDATION TEST**
BORING NO. B-28 SAMPLE NO. 18 PLATE NO. 43




| CURVE NO. | INCREMENT FROM (TSF) | TO (TSF) |
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PLATE NO. 44

SPECIMEN DESCRIPTION:

PROPERTIES OF PLASTICITY LIMIT SPECIMEN

UNIFIED SOILS CLASSIFICATION -
LIQUID LIMIT, $w_L$ =
PLASTIC LIMIT, $w_P$ =
PLASTICITY INDEX, $I_P$ =
NATURAL WATER CONT. %, w =
LIQUIDITY INDEX, $(w-w_p)/I_p$ =
SPECIFIC GRAVITY, $G_s$ =

PROPERTIES OF CONSOLIDATION SPECIMEN

ELEVATION OF SPECIMEN =
DEPTH OF SPECIMEN (FT) = 66
DIAMETER OF SPECIMEN (IN) = 2.50
INITIAL THICKNESS OF SPECIMEN (IN) = 1.00
INITIAL WATER CONTENT, % =
FINAL WATER CONTENT, % =
INITIAL DEGREE SATURATION, % =
FINAL DEGREE SATURATION, % =

STRATUM

INITIAL VOID RATIO, $e_o$ =
FINAL VOID RATIO, $e_f$ =
ESTIMATED PRECONSOLIDATION STRESS (TSF), $P_c$ =
EXISTING OVERBURDEN STRESS (TSF), $P_o$ =
COMPRESSION INDEX, $C_c$ =
SWELLING INDEX, $C_s$ = , REBOUND FROM e =

**FROM 1962 DATA BY EDWARD S. BARBER**

WASHINGTON MONUMENT

WASHINGTON D.C.

**MUESER RUTLEDGE CONSULTING ENGINEERS**
225 WEST 34TH STREET, NEW YORK, N.Y. 10122

MADE BY: MM DATE: 5-23-02
CH'KD BY: AA DATE: 6-6-02
FILE NO. 9726B

**CONSOLIDATION TEST**
BORING NO. B-29 SAMPLE NO. 16
PLATE NO. 44

# APPENDIX D

# SETTLEMENT ANALYSIS FOR WASHINGTON MONUMENT GROUNDS IMPROVEMENT NPS: D18 (NCR-NACC) (XF54)

National Park Service
National Capitol Parks - Central
900 Ohio Drive, Southwest
Washington, D.C. 20242

Mueser, Rutledge, Johnston & DeSimone
Consulting Engineers
708 Third Avenue
New York, New York 10017

February 13, 1984

MUESER-RUTLEDGE-JOHNSTON-&-DESIMONE
*Consulting Engineers*

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JAMES P. GOULD
ELMER A. RICHARDS
EDMUND M. BURKE
DOMINIC A. ZARRELLA
GEORGE J. TAMARO
WARREN H. ANDERSON
*Partners*

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NICHOLAS W. KOZIAKIN
*Consultants*

708 THIRD AVENUE
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212-490-7110
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JAMES L. KAUFMAN
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SERGIO L. TELLO
TONY FENNIMORE
ARTHUR M. MAYES
JOEL MOSKOWITZ
*Associates*

MICHAEL SICILIANO
*Controller*

February 13, 1984

U.S. National Park Service
National Capitol Parks- Central
900 Ohio Drive, Southwest
Washington D.C 20242

Att: Mr. William F. Ruback, Superintendent

Re: Settlement Analysis for
Washington Monument Grounds Improvement
NPS: D18 (NCR-NACC) (XF54)
MRJD File #5841

Gentlemen:

Pursuant to your request of October 4, 1983 and our confirmation of October 28, 1983, we have completed a study of your plans for placing fill in a grading operation on the grounds of the Washington Monument. Your Mr. Robert Humphreys provided us with a copy of the pertinent plans and specifications. The work consists of fill placement and regrading on the west side of the Monument for installation of new sidewalks to 17th Street, the parking lot and the Survey Lodge. You have requested that we evaluate the possible effects of this fill on the Monument's settlement and stability.

## References

We have referred to the following previous studies for the Washington Monument:

1. Subsurface Investigation and Foundation Study for Interpetive Facility at the Washington Monument, prepared by Mueser, Rutledge, Wentworth & Johnston, September 14, 1973.

2. Loading Limitations, Washington Monument Grounds, Subsoil Study, prepared by Edward S. Barber, December 31, 1962.

## Exhibits

The following exhibits are attached for illustrative purposes:

| | | |
|---|---|---|
| 1. | Drawing No. B-1 | Distribution of Principal Strata. |
| 2. | Drawing No. GS-1 | North-south Geological Section |
| 3. | Drawing No. GS-2 | East-west Geological Section |

4. Drawing No. GS-3 — Cross Sections of Site of Washington Monument
5. Plate No. 1 — Observed Settlement
6. Appendix — Settlement Analysis Calculations

Exhibits 1 through 4 were reproduced from our September 14, 1973 report for the Interpetive Facility.

Subsurface Conditions

The subsurface stratification in the vicinity of the Monument is described in detail in Reference 1, which contains boring data from investigations made in 1930, 1962 & 1973. The Monument is underlain by stream terrace deposits of Pleistocene times, directly over bedrock. The Pleistocene materials range from a medium plastic and slightly to moderately organic clay, to a very compact mixture of sand and gravel with some boulders. It is the presence of a layer of this clay, designated Stratum T-1 (D), which has occasioned concern about stability of the Monument and the effect of grading operations around the Monument. As shown in the right panel of Drawing No. B-1 this layer thickens from 5 feet southwest of the Monument to a maximum of about 35 feet northeast of the structure. Thicknesses are roughly uniform on line in a northwest-southeast direction.

Analysis of Probable Settlement and Tilt of Monument

We have transferred the contour data from your grading plans onto the profiles on Drawing No. GS-3. The dashed lines added to this drawing represent the planed final ground surface after regrading is completed. The increment of added fill between the present and final profiles has been colored red for emphasis. The maximum thickness of the new fill is approximately seven feet positioned at a distance of 320 feet north-west of the center of the Monument.

We estimate the increase in stress below the center of the monument at the mid- depth of the clay layer, due to fill placement, will be about 10 lbs per sq. foot, which is less than 1/10 of 1 percent of the present stress due to the load of the Monument and overburden soil. Using much more conservative values for stress increase, we estimated the settlement taking place along a diagonal line through the Monument from the northwest to the southeast, using typical compression parameters of the subsoils that were determined from previous investigations. Estimated settlements are 0.015 inches at the southeast corner and 0.06 inches at the northwest corner, resulting in an estimated differential settlement of 0.045 inches across the Monument. Taking into account the height of the Monument and assuming a "rigid body" tilt, this magnitude of differential settlement would result in a lateral deflection at the top of the Monument of one-third of an inch, equivalent to angular rotation of three one-thousandths of a degree.

This orientation was chosen for an analysis of the settlement profile because it was judged that this was the direction along which a maximum tilt would take place directed toward the northwest. To complete the record, our settlement computations are attached following the exhibits of this report.

## Observed Settlement

Plate No. 1 is a plot of observed settlement of the Monument reported by published sources, supplemented by observations recorded by the US Coast & Geodetic Survey. It should be noted that the apparent discrepancy in settlement reported by the ASCE Special Committee on Earth and Foundations and N. H. Darton is probably due to the use of different survey datums for the two sets of observations. The District of Columbia Engineers datum is 0.7 feet above the USC&GS mean sea level datum. This is approximately equal to the difference in magnitude of settlement reported by the two sources.

The magnitude of settlement that has occurred between 1898 and the late 1960's is consistent with an appropriate theoretical rate of secondary compression of the underlying soil strata. The increased rate of settlement that has occurred since the late 1960's is very probably due to an effective increase in overburden stress as a result of lowering of the ground water level in the general area by construction activity. Following extensive development in the Mall, involving deep basement excavation and depressed roadways, there has been a widespread drawdown of groundwater in the range of ten to 15 feet. The Mall area between 12th Street and the Monument has been dewatered to an appreciable extent by the construction along 12th Street. Evidence of this groundwater lowering can be seen on Drawings Nos. GS-1 and GS-2 by comparing the water levels observed in the 1962 and 1973 borings. In 1962, groundwater beneath the monument was at about Elev..0, whereas in 1973 it had been drawn down to about Elev. -10. The increased settlement has not resulted in visible distress to the Monument. The settlement rate should gradually return to the previously observed semi-log straight line rate of settlement, once final ground water levels have stabilized.

## Conclusion

On the basis of data developed in our 1973 report and the history of Monument performance, we conclude that the planed filling operation on the Monument grounds will not adversely influence the Monument's stability and will not cause displacements of engineering significance which could be observed by ordinary measuring methods. We suggest that before earthwork commences the Coast and Geodetic survey, or other organizations which have been maintaining precise measurements on the Monument, be requested to go through a cycle of observations. These should be repeated after the filling operation is complete for the purpose of demonstrating, for future planning purposes, the response of the Monument to this modest filling operation. Previous observations and investigations have indicated that there is no significant differential settlement or tilting of the monument and the rate of settlement is small and completely explainable in terms of normal physical phenomena in the underlying soils. Our evaluation has demonstrated that no detrimental effects to the Monument's foundation performance are to be anticipated.

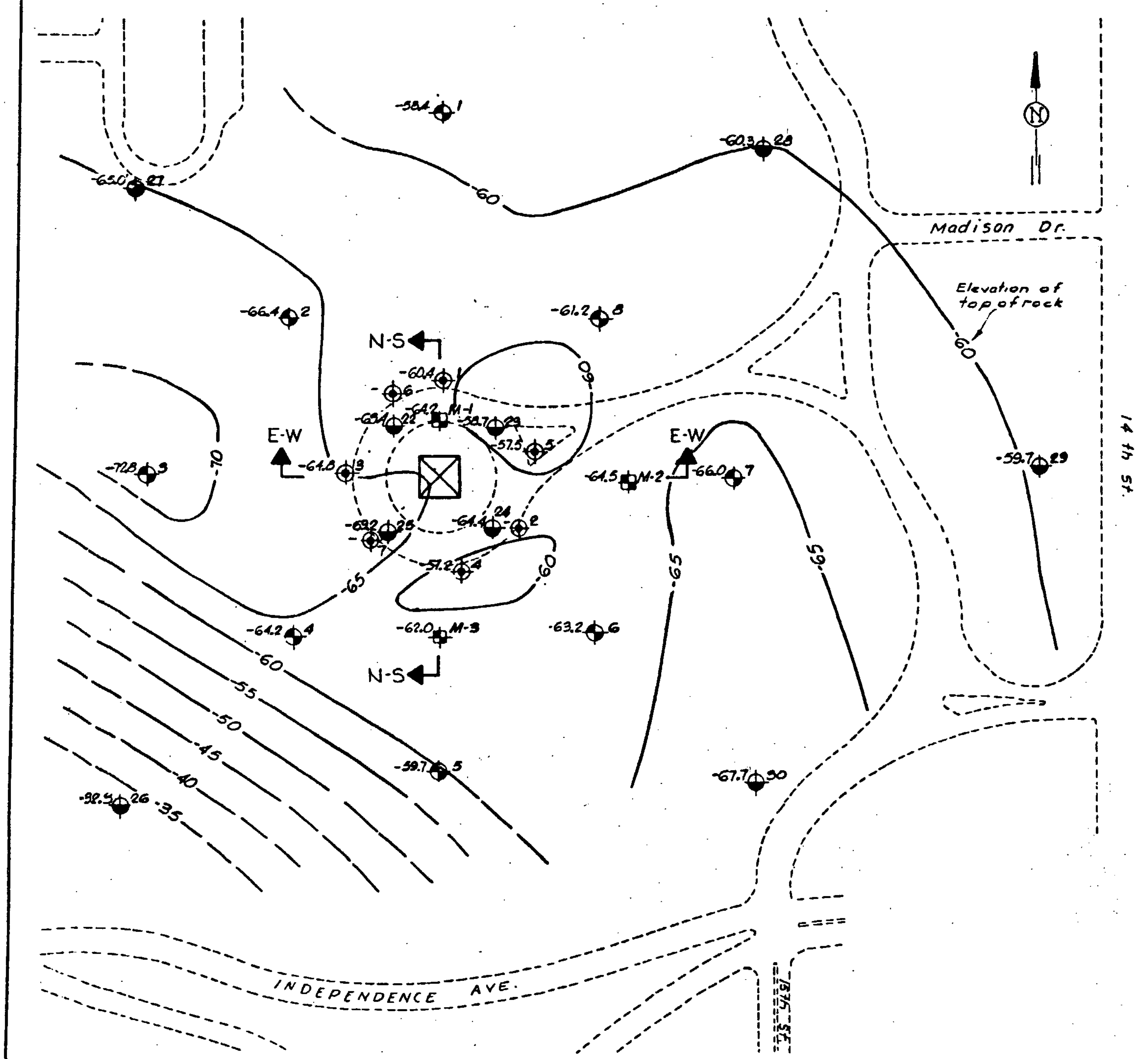
We are pleased to be able to contribute these services to the Grounds Improvement program. As compensation, we request that observations made during the filling operations be transmitted to us so that we may complete our long-term records of the Monument performance. If questions have been generated by this report or arise during the field work, please do not hesitate to call on us.

Very truly yours,

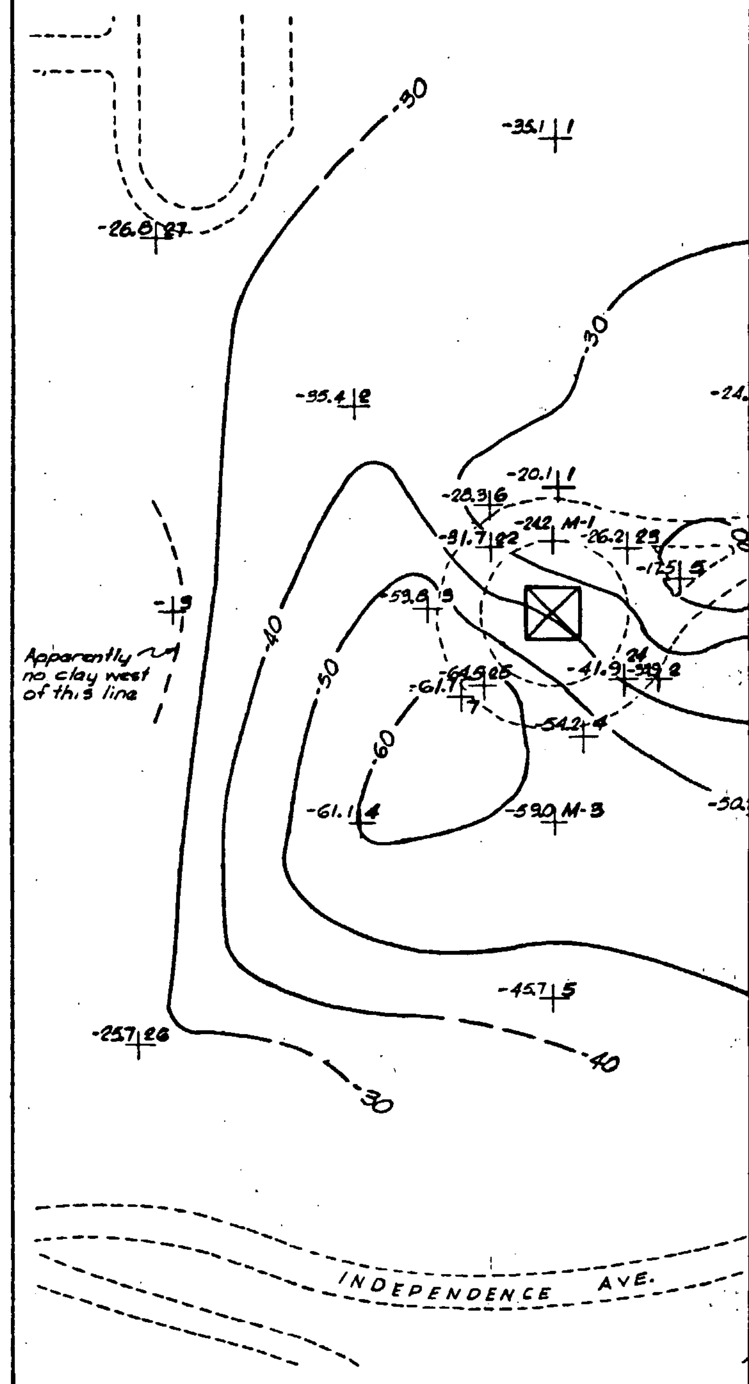
MUESER, RUTLEDGE, JOHNSTON & DESIMONE

By James P. Gould
James P. Gould

JFQ/JPG/sbd




CONTOURS OF TOP OF ROCK




CONTOURS OF TOP

## GENERAL NOTES:

1. - Borings made in 1973
   - Borings made in 1962
   - Borings made in 1930 (Inner Ring)
   - Borings made in 1930 (Outer Ring)
2. Elevation of top of rock contours correspond to the top of geologic rock, generally decomposed in its upper part, as indicated in the dry sample borings. This may or may not correspond to the top of solid rock.
3. Elevations refer to the Engineer Department of the District of Columbia datum which is 0.705 feet above U.S.C. & G.S. sea level standard datum 0.00 at Sandy Hook, N.J., 1929
4. Base Plan for this Drawing obtained from map of 1930 and may not agree with present features.
5. For Geologic Sections N-S and E-W see Dwgs. Nos. GS-1 and GS-2.

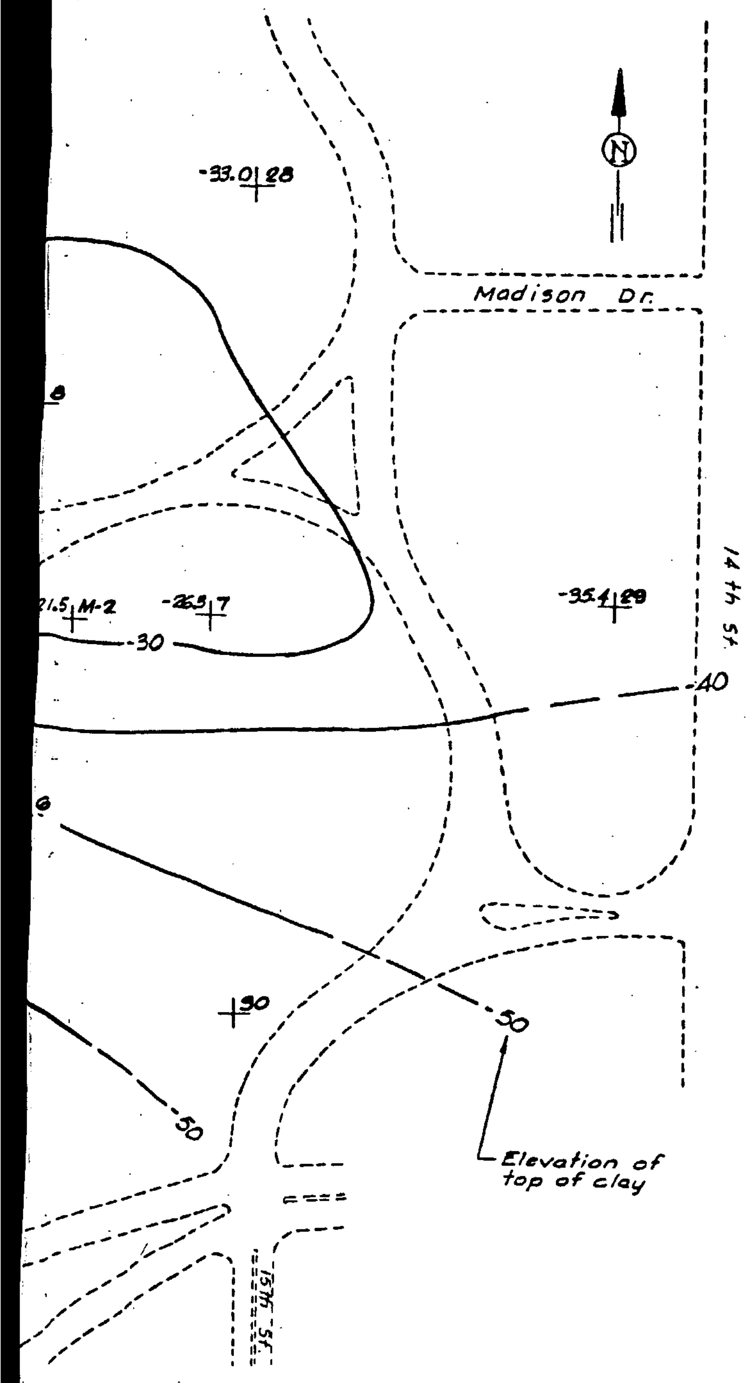
## LEGEND

B┼A - Boring locations for borings shown in detail on the Contour of Top of Rock Plan

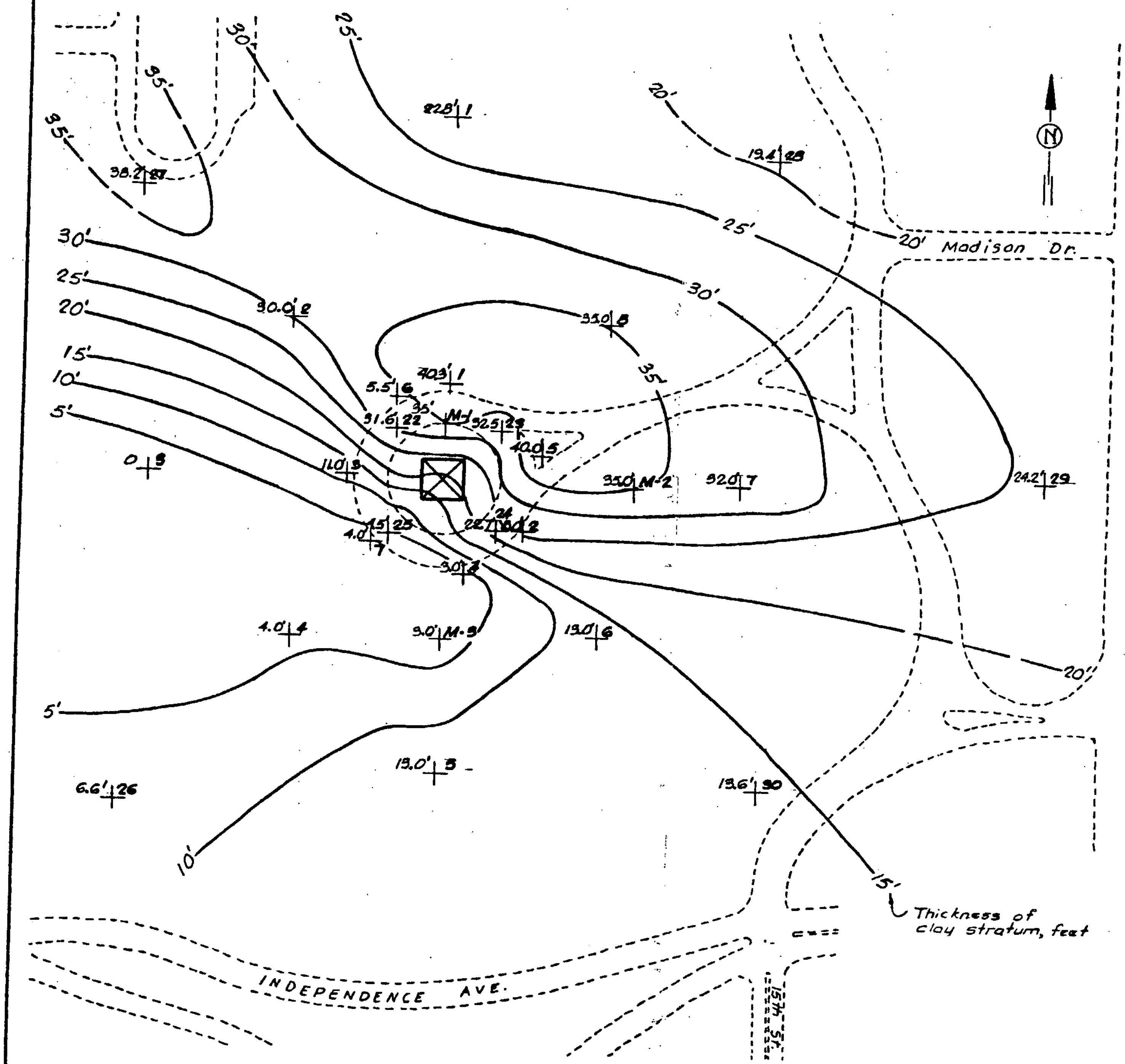
A - Boring Number

B - Elevation of top of geologic rock or clay; or thickness of clay strata in feet

⊠ - Base of Washington Monument




F CLAY STRATUM - T1(D)




CONTOURS OF THICKNESS OF CLAY STRATUM - T1(D)

GRAPHIC SCALE

100' 50' 0' 100' 200' 300'

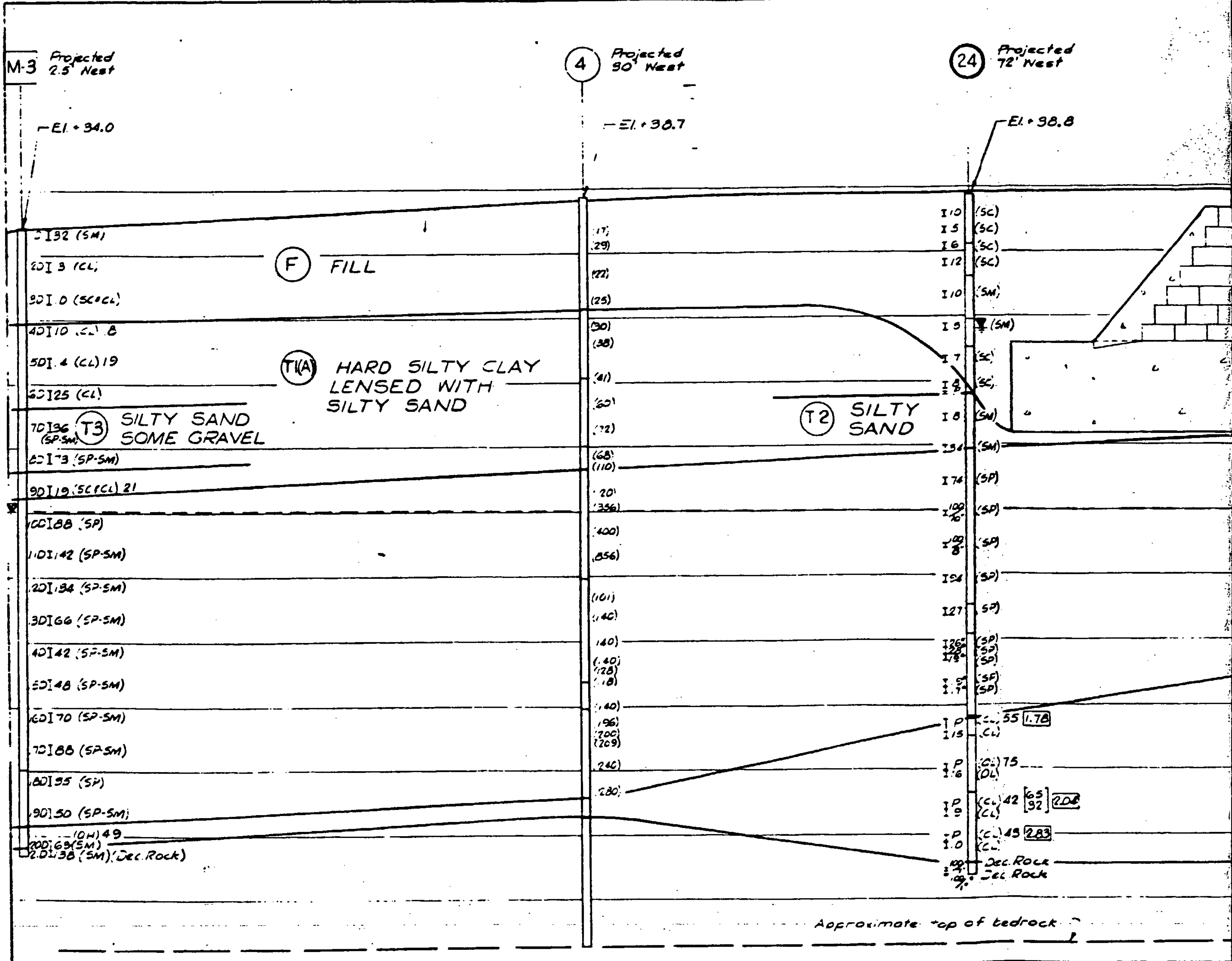
WASHINGTON MONUMENT INTERPRETIVE FACILITY

HARTMAN - COX, ARCHITECTS
JAMES MADISON CUTTS
STRUCTURAL ENGINEERS

**MUESER - RUTLEDGE - WENTWORTH & JOHNSTON**
CONSULTING ENGINEERS
415 MADISON AVE., NEW YORK, N.Y. 10017

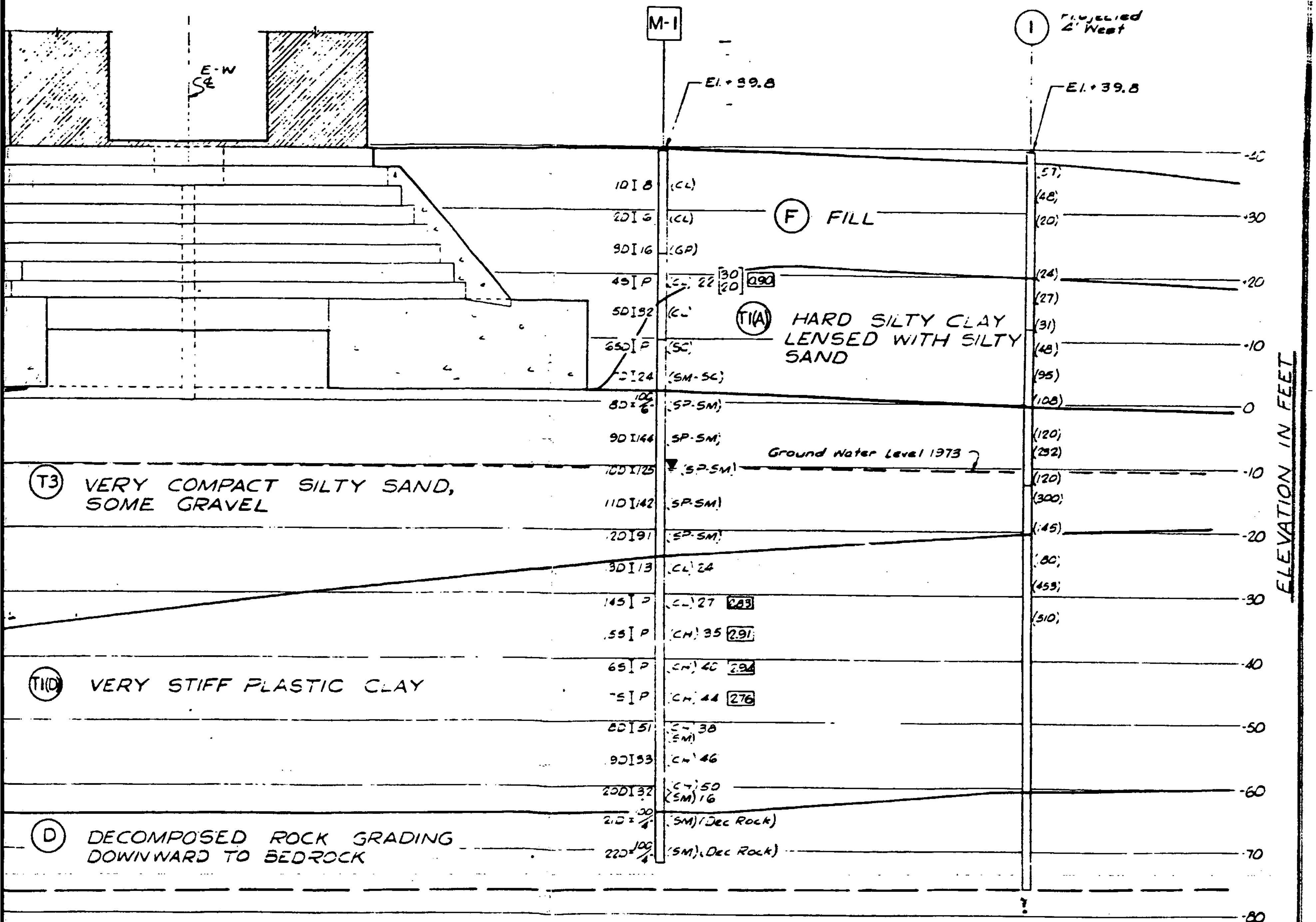
| SCALE | MADE BY WJW DATE 8-73 | FILE NO. |
|---|---|---|
| GRAPHIC | CH'KD BY J Mc DATE 9-73 | 4254 |

| DISTRIBUTION OF PRINCIPAL STRATA | DRAWING NO. B-1 |
|---|---|




## GENERAL NOTES

1. 1973 borings were made by Maryland Foundation Testing Co. between July 20, 1973 and July 31, 1973 under the inspection of Mueser, Rutledge, Wentworth & Johnston Consulting Engineers.
2. 1962 borings were made by Foundation Test Service under the supervision of Edward S. Barber Consulting Engineer.
3. 1930 borings were made under the supervision of Moran & Proctor Consulting Engineers.
4. Classifications of the 1973 soil samples were made by Mueser, Rutledge, Wentworth & Johnston and may not agree with driller's classifications.
5. Classifications of the 1962 soil samples in the Unified Soil Classification System were made by interpreting the word descriptions of the soil samples as provided by others.
6. Stratifications shown are necessary interpolations between borings and may or may not represent actual subsurface conditions.
7. Elevations refer to the Engineer Department of the District of Columbia datum which is 0.705 feet above U.S.C. & G.S. mean sea level standard datum 0.00 at Sandy Hook, N.J., 1929.
8. Locations and elevations of ground surface at borings were determined by Mueser, Rutledge, Wentworth & Johnston.
9. Lab tests for the 1973 borings were performed by Mueser, Rutledge, Wentworth & Johnston.
10. Lab test data for the 1962 borings was obtained from the subsoil study report prepared by Edward S. Barber, Consulting Engineer for the National Park Service, dated Dec. 31, 1962




## SECTION ON NORTH - SOUTH CENTERLINE LOOKING WEST

## GRAPHIC SCALE

10' 0' 10' 20' 30'

Horizontal & Vertical

## GENERAL STRATA DESCRIPTIONS

(F) *Medium stiff red brown fine sandy clay trace gravel and cinders (Fill)*

(T1A) *Hard brown silty clay lensed with silty fine sand*

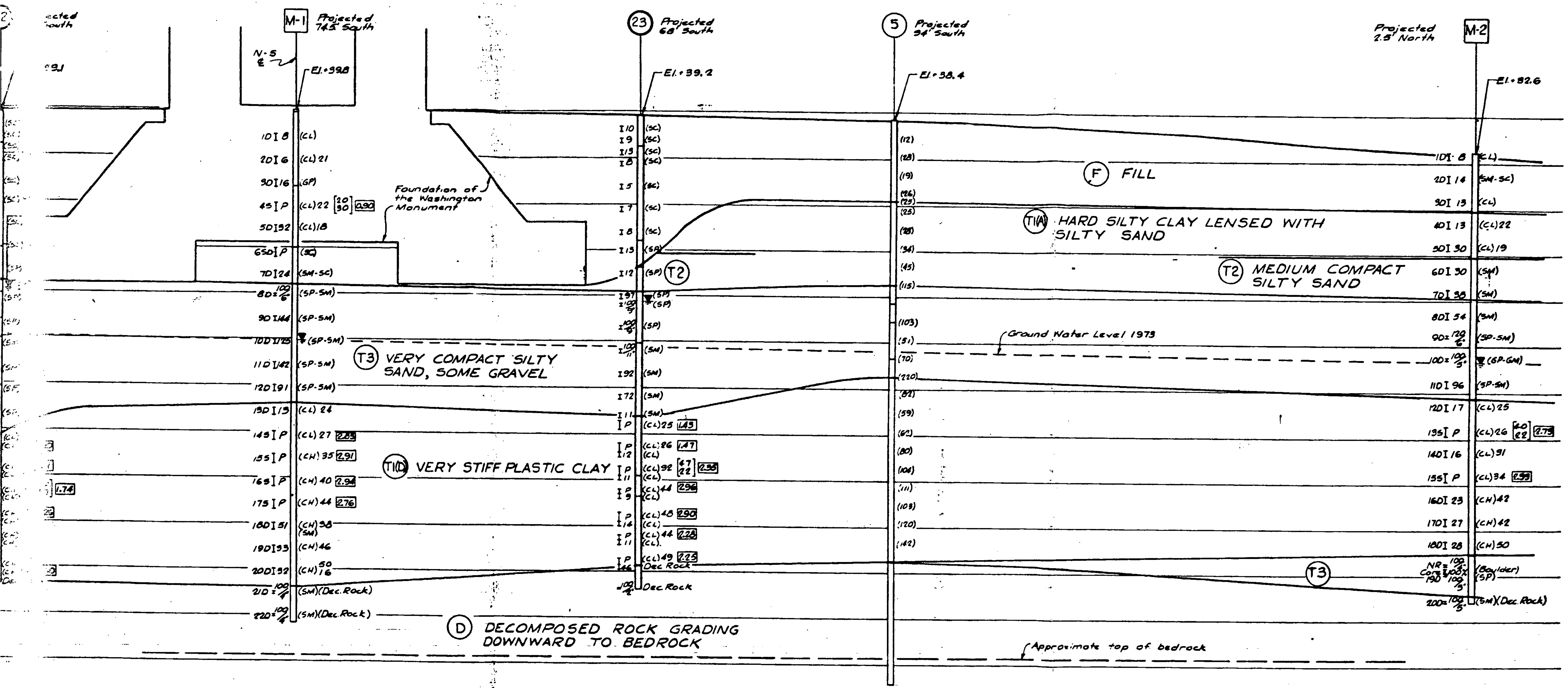
(T2) *Medium compact brown silty fine sand, occasional silty clay layers*

(T3) *Very compact brown fine to coarse sand some silt and gravel, occasional boulders*

(T1D) *Very stiff dark blue-gray plastic clay, trace fine to medium sand pockets occasional highly organic lenses*

(D) *Very dense gray-green micaceous silty fine sand (Decomposed rock grading downward to bedrock)*

| | | | |
|---|---|---|---|
| WASHINGTON MONUMENT INTERPRETIVE FACILITY | | | |
| HARTMAN - COX, ARCHITECTS<br>JAMES MADISON CUTTS STRUCTURAL ENGINEERS | | | |
| **MUESER - RUTLEDGE - WENTWORTH & JOHNSTON**<br>CONSULTING ENGINEERS<br>415 MADISON AVE., NEW YORK, N.Y. 10017 | | | |
| SCALE GRAPHIC | MADE BY W J W DATE 8 - 73 | CH'KD BY J M^c DATE 9 - 73 | FILE NO 4254 |
| NORTH - SOUTH GEOLOGICAL SECTION | | | DRAWING NO. GS-1 |




## SECTION ON EAST-WEST CENTERLINE LOOKING NORTH

### LEGEND

...cation of boring
... in 1973
... in 1962
... in 1930
...d surface at boring
... sample
...n with 2" O.D. split spoon
...elby tube sample
... of sample
...om 140 lb. hammer free falling 30" 2" O.D. split spoon sampler one foot ...d penetration is indicated.
...shed sample

(E) - Symbol for sample's soil type using the Unified Soil Classification System

F - Average natural water content of sample in per cent of dry weight

G - Liquid limit

H - Plastic limit

J - Compressive Strength in tons per sq foot obtained by means of unconfined compression test on an undisturbed sample

(K) - Penetration resistance in blows per foot for the borings made in 1930; driving method unknown

▼ - Ground water level-observed in boring

Core - Rock coring (length of run) by diamond drilling

L - Indicates length of rock recovered expressed as a per cent of the length of core run.

GRAPHIC SCALE

10' 0' 10' 20' 30'

Horizontal & Vertical

WASHINGTON MONUMENT INTERPRETIVE FACILITY

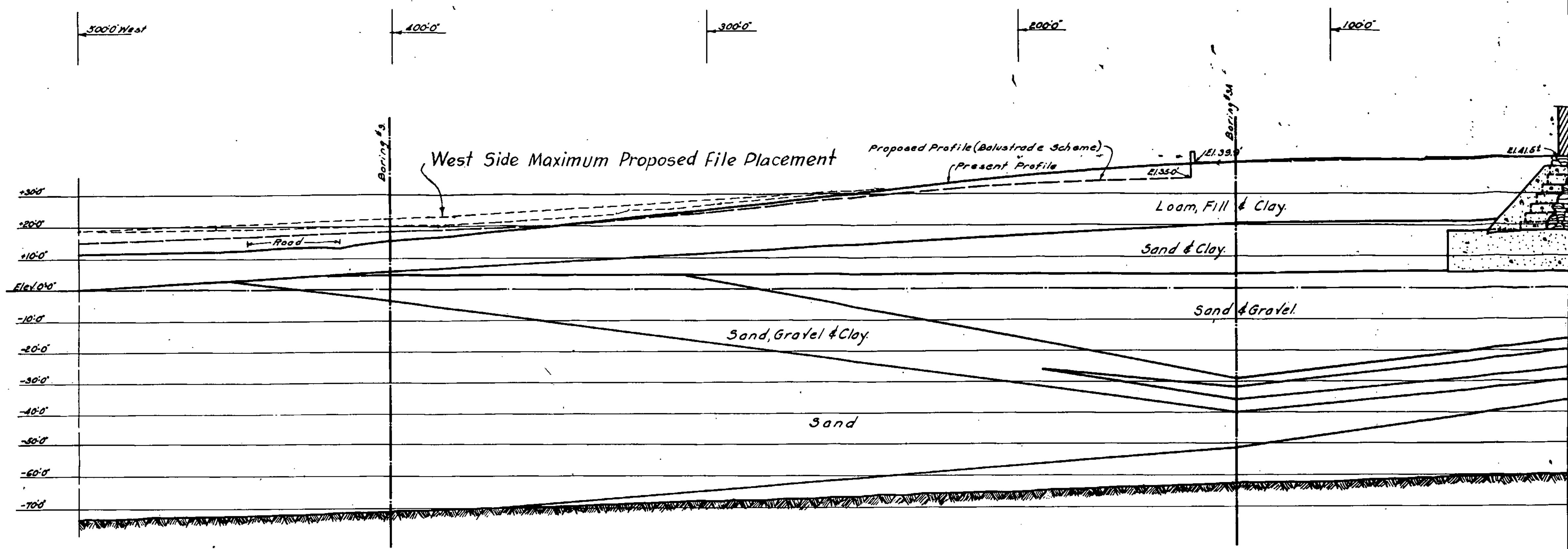
HARTMAN - COX, ARCHITECTS
JAMES MADISON CUTTS STRUCTURAL ENGINEERS

MUESER · RUTLEDGE · WENTWORTH & JOHNSTON
CONSULTING ENGINEERS
415 MADISON AVE., NEW YORK, N.Y. 10017

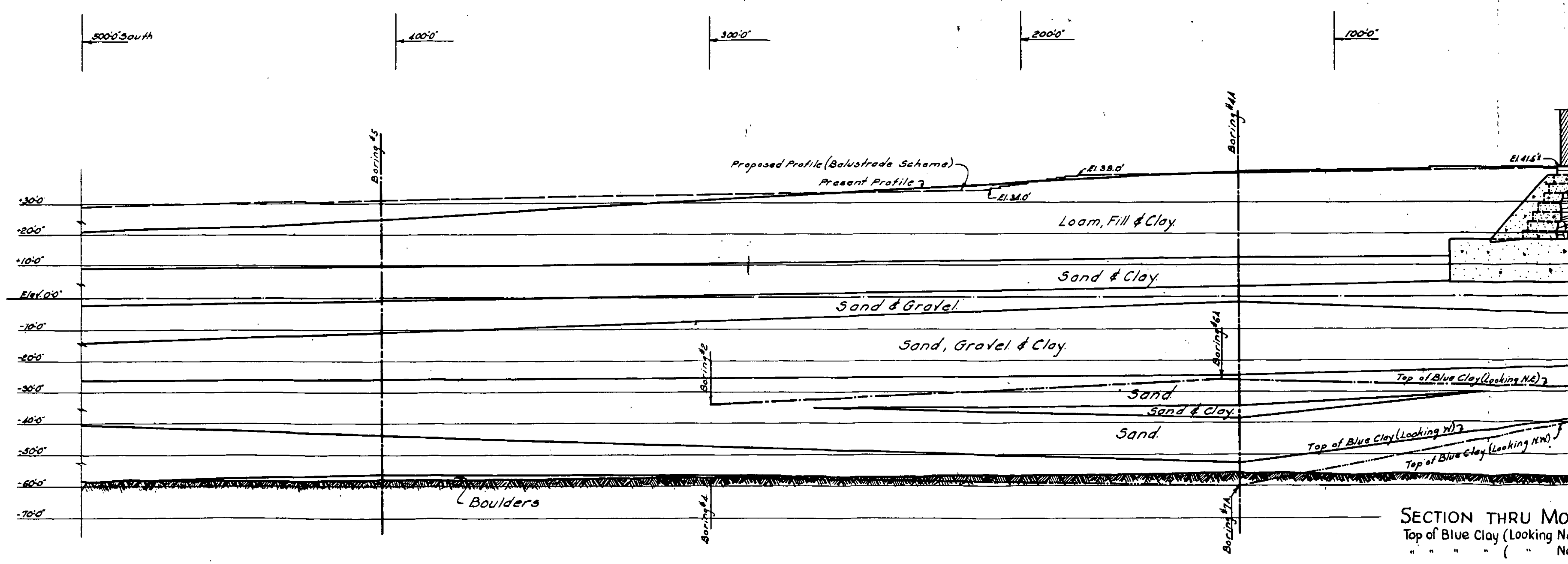
| SCALE | MADE BY | DATE | FILE NO |
|---|---|---|---|
| GRAPHIC | MADE BY WJW | DATE 8-73 | 4254 |
| | CH'KD BY JMc | DATE 9-73 | |

EAST - WEST GEOLOGICAL SECTION

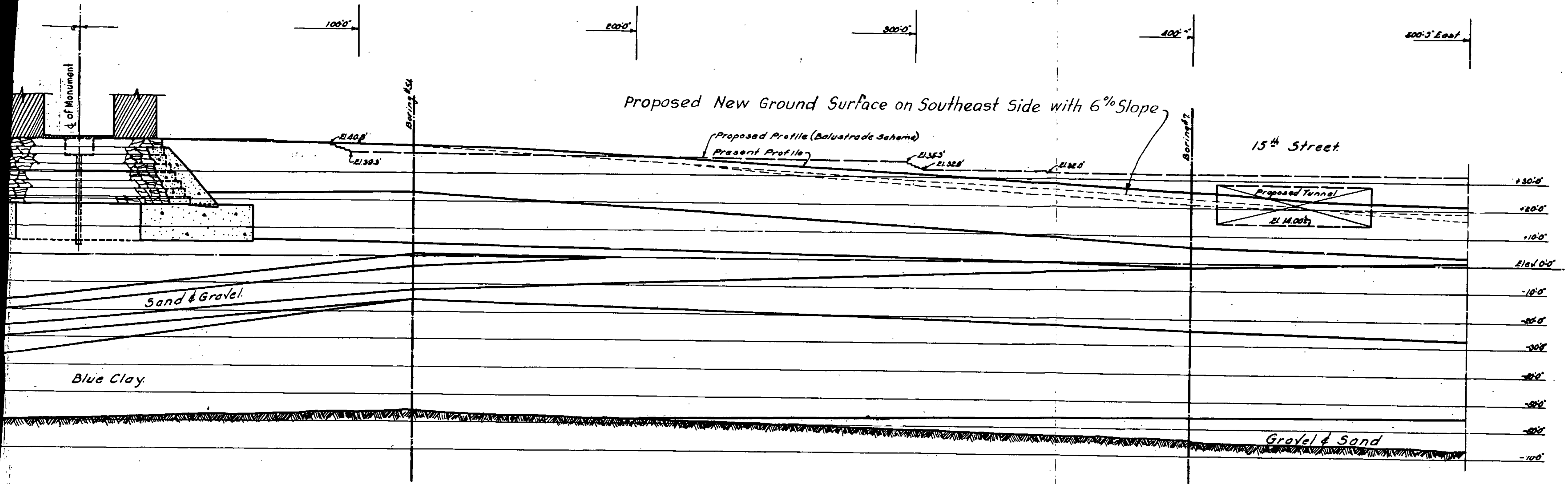
DRAWING NO. GS-2




SECTION THRU MONU




SECTION THRU MO
Top of Blue Clay (Looking N
" " " ( " N



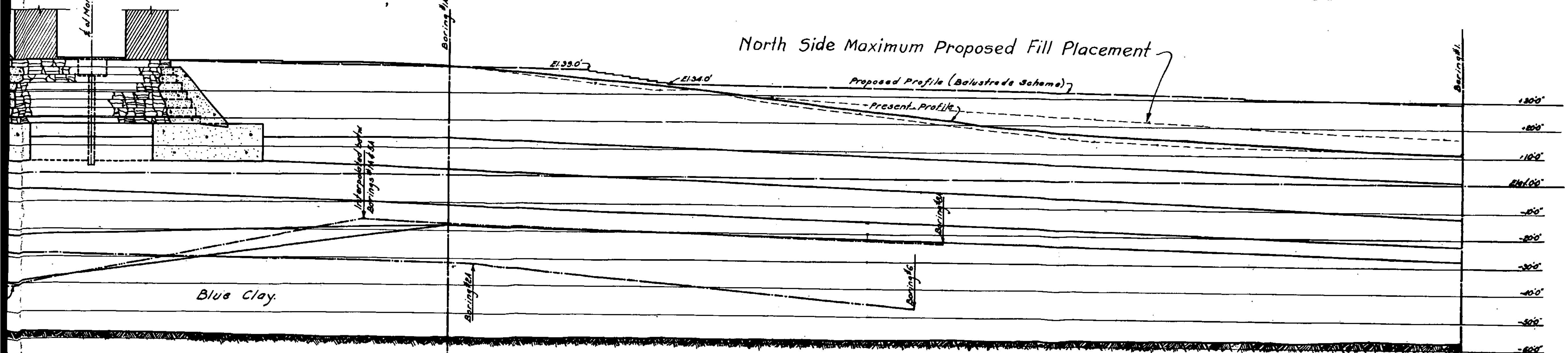

…MENT LOOKING NORTH

NOTE: New original ground surface and fill elevations were obtained from S.O.& M. drawing dated 6-5-74 and have been adjusted to correspond to the elevation datum used for this drawing.

CROSS SECTIONS OF SITE
OF
WASHINGTON MONUMENT
TO ACCOMPANY REPORT
TO
U. S. GRANT 3RD, DIRECTOR
PUBLIC BUILDINGS AND PUBLIC PARKS
OF THE NATIONAL CAPITAL

BY Daniel E. Moran CONSULTING ENGINEER
342 MADISON AVE. NEW YORK CITY

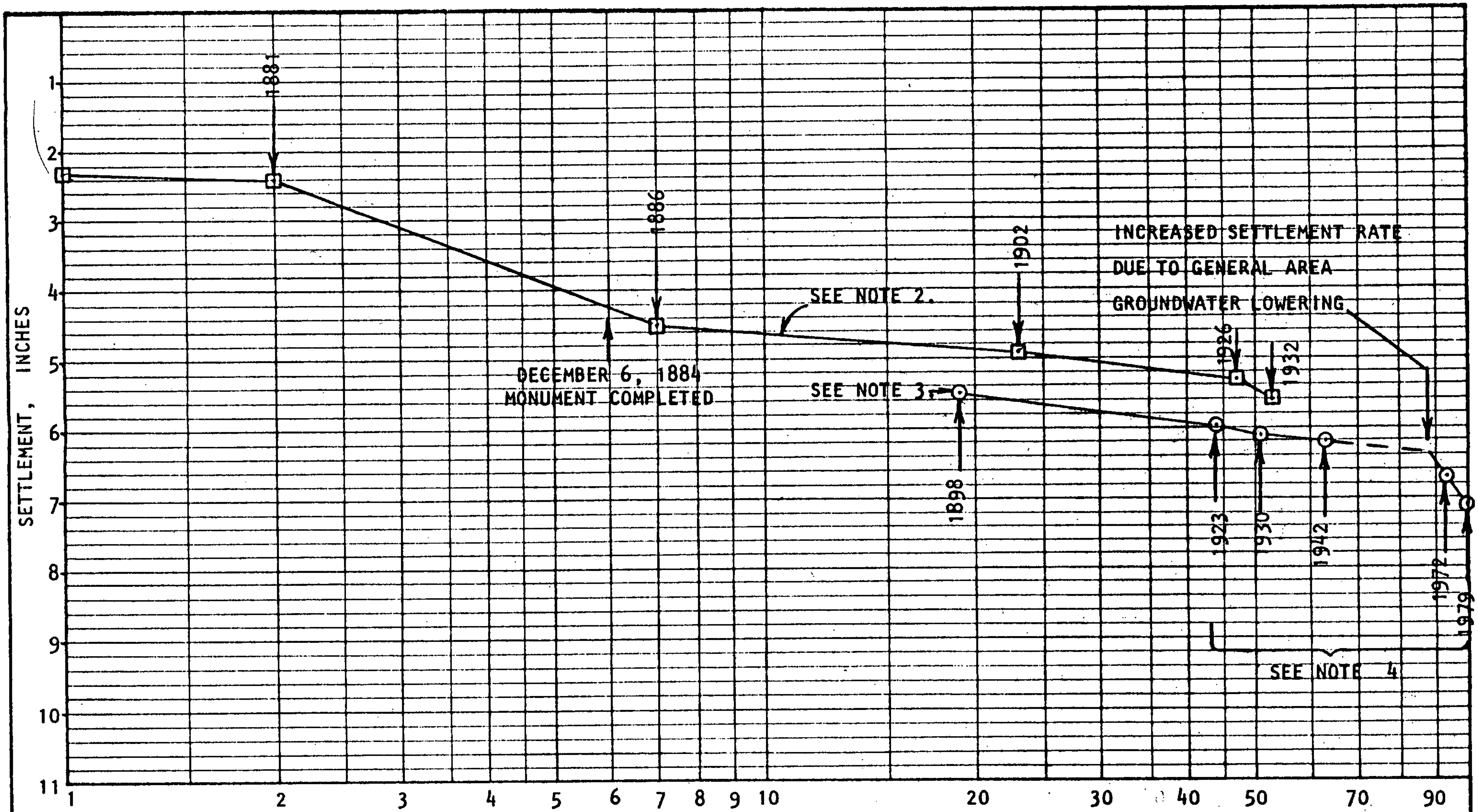
DATE 6-24-31 SCALE 1"=20'0 FILE 566




…ONUMENT LOOKING WEST
(North-West) shown thus ——·——
(North-East) " " —·—·—

Obtained from MRW&J File of Job No.566 for inclusion in report of September 1973

DRAWING NO.
GS-3




NOTES

1. YEAR 0 AT 1879
2. SETTLEMENT OBSERVATIONS REPORTED BY THE SPECIAL COMMITTEE ON EARTH AND FOUNDATIONS, A.S.C.E. PROCEEDINGS, MAY, 1933.
3. SETTLEMENT REPORTED BY N.H. DARTON, GEOLOGICAL SURVEY PROFESSIONAL PAPER 217, 1950.
4. SETTLEMENT OBSERVATIONS RECORDED BY U.S. COAST AND GEODETIC SURVEY.

**WASHINGTON MOUNMENT**

**NATIONAL PARK SERVICE**

**MUESER · RUTLEDGE · JOHNSTON & DESIMONE**
CONSULTING ENGINEERS
708 THIRD AVENUE, NEW YORK, N.Y. 10017

MADE BY: JFQ DATE 2-02-84
CH'KD BY DATE

FILE NO. 5841

OBSERVED SETTLEMENT

PLATE NO. 1

PLATE NO. 1

APPENDIX

MUESER, RUTLEDGE, JOHNSTON & DESIMONE
CONSULTING ENGINEERS
FOR Washington Monument

SUBJECT Stress Increase Below Center of Monument

Boussinesq Influence Diagram (Circular)

From Contract Dwgs. 6 & 7:

| Location | Average Thickness of New Fill | Average Existing Surface Elev. |
|---|---|---|
| N. Walkway | 3' ✓ | +30 ✓ |
| S. Walkway | 3' ✓ | +22 ✓ |
| N. Walk Tie to Parking Lot | 5' ✓ | +24 ✓ |
| S. Walk Tie to Survey Lodge | 2' ✓ | +19 ✓ |
| Average | 3' ✓ | +24 ✓ |

Approx. Limits of Significant Fill Shown in Red on Dwg. 4

From Dwg. B-1 (File 4254 – 9/14/73 Report):

Top of Clay (T1(D)) below center of monument = El. −40 ✓

Thickness of Clay " " " " = 20' ✓

Elev. of middle of clay = $-40 - \frac{20}{2}$ = El. −50 ✓

$Z = +24 - (-50) = 74'$, say 80' ✓

From "Bowles – Fdtn Analysis & Design (1st edit.)," pg. 70:

Table 2-8: Infuence Values for Boussinesq Diagram (Circular)

| $q/q_o$ | $r/z$ | $R$ |
|---|---|---|
| 0.88 | 1.7637 ✓ | 3.53" ✓ |
| 0.90 | 1.9084 ✓ | 3.82 ✓ |
| 0.92 | 2.0944 ✓ | 4.19 ✓ |
| 0.94 | 2.3506 ✓ | 4.70 ✓ |
| 0.96 | 2.7479 ✓ | 5.50 ✓ |
| 0.98 | 3.5460 ✓ | 7.09 ✓ |
| 0.99 | 4.5326 ✓ | 9.07 |
| 0.999 | 9.9500 | 19.90 |

$Z = 80'$ ✓ = 2 in ✓ on Dwg. 4

$R = 2\left(\frac{r}{z}\right)$

If circle is divided into 20 segments; I for .88 to .98 $= \frac{.02}{20} = 0.001$ ✓

I for .98 to .99 $= \frac{.01}{20} = 0.0005$ ✓

I for .99 to .999 $= \frac{.009}{20} = 0.00045$ ✓

Boussinesq Influence Diagram shown in green on Dwg. 4

$q_o = 3 \times 125 = 375$ psf ✓ (Assume $(\gamma_T)_{FILL} = 125$ Pcf)

No. of 0.001 rectangles = 18 ✓

No. of 0.0005 rectangles = 5.5 ✓

No. of 0.00045 rectangles = say 1 ✓

$q = q_o N I = 375(18 \times .001 + 5.5 \times .0005 + 1 \times .00045) = 8$ psf ✓

5' of fill: $q = 5 \times 125(0.0212) = 13$ psf ✓

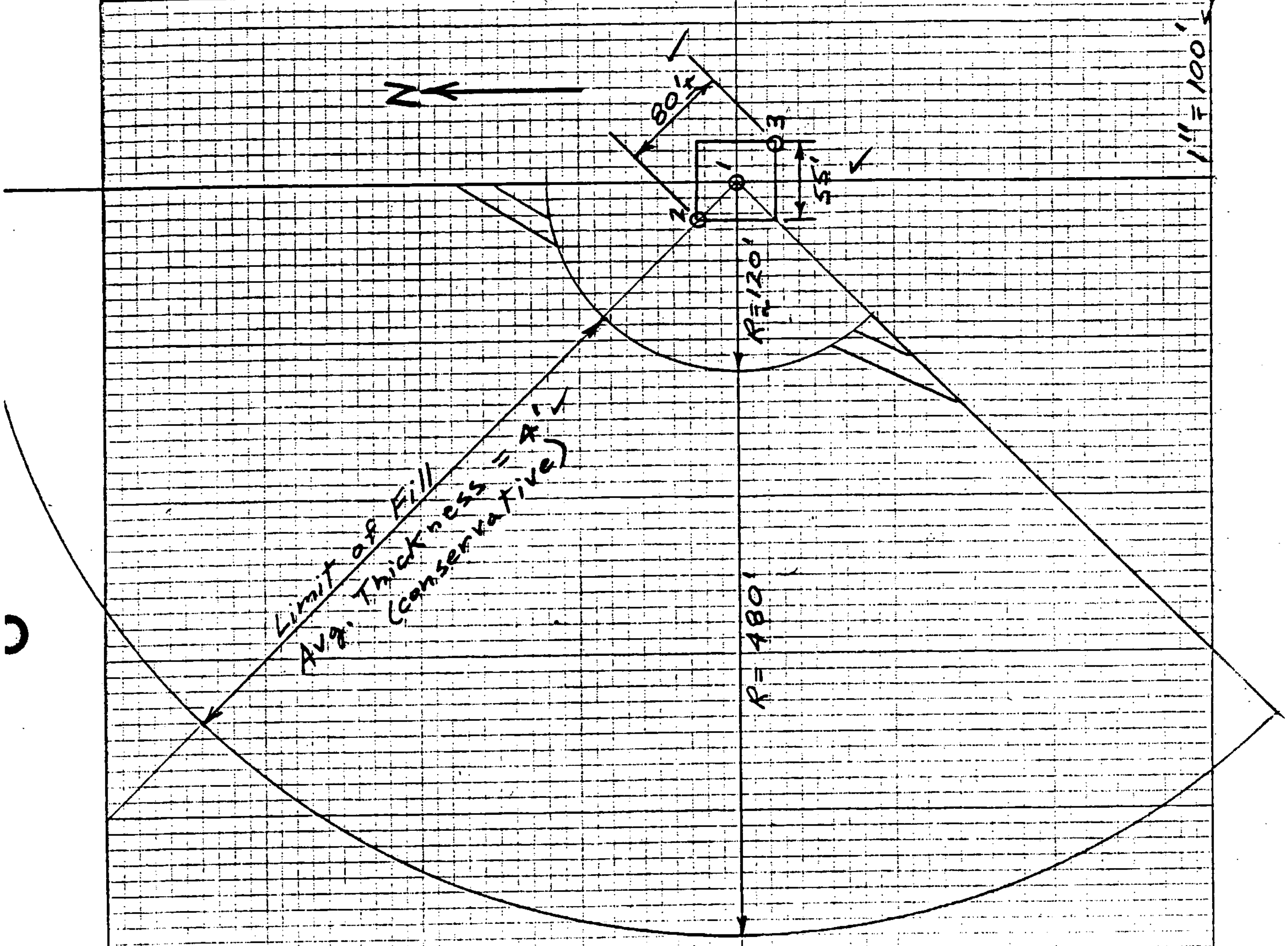
Sheet No. 2 of 5

MUESER, RUTLEDGE, JOHNSTON & DESIMONE
CONSULTING ENGINEERS

File 5841
Made By JFQ Date 1-31-84
Checked By SKJ Date 2-3-84

FOR Washington Monument

SUBJECT Settlement Analysis



SHEET No. 3 OF 5
FILE 5841
MADE BY JFQ DATE 1-31-84
CHECKED BY SKJ DATE 2-3-84

MUESER, RUTLEDGE, JOHNSTON & DESIMONE
CONSULTING ENGINEERS
FOR Washington Monument

SUBJECT Settlement Analysis

Increase in Stress below Monument at Mid. of Clay ✓

Pt. 1 – Center of Monument   20' of clay   Z = 80' ✓
Pt. 2 – Near Corner   4' fill: $q_o = 4 \times 125 = 500$ psf ✓
Pt. 3 – Far Corner

| Pt. | $R_1$ | $r_1/z$ | $(q/q_o)_1$ | $R_2$ | $r_2/z$ | $(q/q_o)_2$ | $\Delta q/q_o \times 3/8$ | | $\Delta q$ psf |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 480' ✓ | 6.0 ✓ | .995 | 120' ✓ | 1.5 ✓ | 0.83 ✓ | .165 ✓ | .062 | 31 ✓ |
| 2 | 440 ✓ | 5.5 ✓ | .994 | 80 ✓ | 1.0 ✓ | 0.65 ✓ | .344 ✓ | .129 | 65 ✓ |
| 3 | 520 ✓ | 6.5 ✓ | .996 | 160 ✓ | 2.0 ✓ | 0.91 ✓ | .086 ✓ | .032 | 16 ✓ |

Increase in Stress below Monument at Mid. of Sand, Z = 40' (40' of sand)

| Pt. | $R_1$ | $r_1/z$ | $(q/q_o)_1$ | $R_2$ | $r_2/z$ | $(q/q_o)_2$ | $\Delta q/q_o \times 3/8$ | | $\Delta q$, psf |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 480' ✓ | 12 ✓ | 1 ✓ | 120' ✓ | 3 | 0.97 ✓ | 0.03 ✓ | .011 | 6 ✓ |
| 2 | 440 ✓ | 11 ✓ | 1 ✓ | 80 ✓ | 2 | 0.91 ✓ | 0.09 ✓ | .034 | 17 ✓ |
| 3 | 520 ✓ | 13 ✓ | 1 ✓ | 160 ✓ | 4 | 0.99 ✓ | 0.01 ✓ | .004 | 2 ✓ |

Estimated Settlement of Clay, use $C_c = 0.2$ ✓, $e_o = 1.0$ ✓
Existing stress at mid. of clay = 6.8 tsf (JPG, 8-24-73, File 4254) ✓

Pt. 1: $S = \frac{0.2}{1+1} \times 20 \times 12 \times \log \frac{13,631}{13,600} = 24 \times 0.001 = 0.024''$ ✓

Pt. 2: $S = 24 \times \log \frac{13,665}{13,600} = 24 \times 0.002 = 0.048''$ ✓

Pt. 3: $S = 24 \times \log \frac{13,616}{13,600} = 24 \times 0.0005 = 0.012''$ ✓

Estimated Settlement of Sand, use $C_c = 0.1$, $e_o = 1.0$
Existing stress at top of clay = 6.4 tsf
Existing stress at mid. of sand $= 6.4 - \frac{20 \times 0.065}{2} = 5.75$ ✓ tsf

Pt. 1: $S = \frac{0.1}{1+1} \times 40 \times 12 \times \log \frac{11,506}{11,500} = 24 \times 0.0002 = 0.005''$

Pt. 2: $S = 24 \times \log \frac{11,517}{11,500} = 24 \times 0.0006 = 0.014''$ ✓

Pt. 3: $S = 24 \times \log \frac{11,502}{11,500} = 24 \times 0.0001 = 0.002''$ ✓

Summary – Total Settlement
Pt. 1: $S = 0.024 + 0.005 = 0.029''$, say 0.03'' ✓
Pt. 2: $S = 0.048 + 0.014 = 0.062''$, say 0.06'' ✓
Pt. 3: $S = 0.012 + 0.002 = 0.014$, say 0.015'' ✓

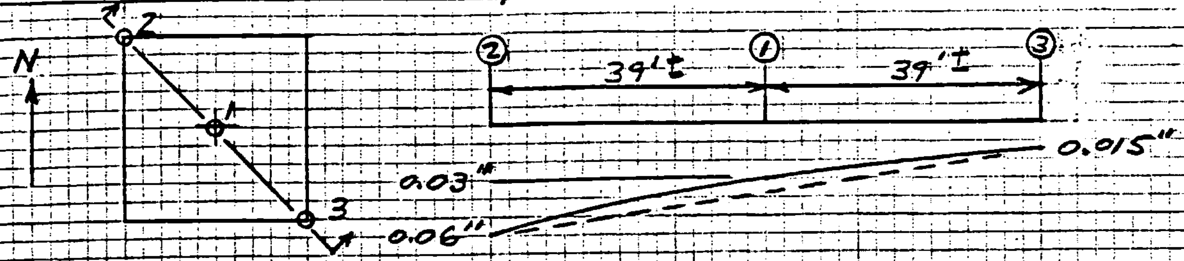
File 5841

MUESER, RUTLEDGE, JOHNSTON & DESIMONE
CONSULTING ENGINEERS

FOR Washington Monument

Made By JFQ Date 2-1-84.
Checked By SKJ Date 2-3-84

SUBJECT Settlement Analysis




Differential Settlement (Corner to Corner) = 0.045" ✓

$\frac{0.045}{78}$ = 0.00058 in/ft.

Monument is 555' high

Lateral deflection at top = 555×0.00058 = 0.32" ✓ say $\frac{1}{3}$" ✓

Angular rotation = arc tan $\frac{0.00058}{12}$

= 0.003° ✓

MUESER, RUTLEDGE, JOHNSTON & DESIMONE
CONSULTING ENGINEERS
FOR Washington Monument

SUBJECT Settlement Analysis

Estimate Secondary Compression

From Plate 1: Slope of observed settlement from 1898 to 1967 = 1.4" from year 10 to 100 (1 log-cycle)

for 20' of clay: $C_\alpha = \frac{1.4}{20 \times 12} = 0.006$ ✓

assume $C_\alpha$ for 40' of sand is ½ $C_\alpha$ for clay ✓

$1.4 = C_\alpha \times 20 \times 12 + \frac{1}{2} C_\alpha \times 40 \times 12$

$C_{\alpha\,clay} = \frac{1.4}{480} = 0.003$, ✓ $C_{\alpha\,sand} = 0.0015$ ✓

Estimate Settlement due to Groundwater Lowering

From Sheet 3: $C_c = 0.2$, $e_o = 1.0$ ✓

Existing stress at mid. of clay = 6.8 tsf = 13,600 psf ✓

For 10' lowering: $\Delta q = \frac{10 \times 0.06}{2} = 0.3$ ✓ tsf = 600 psf

For 20' lowering: $\Delta q = \frac{20 \times 0.06}{2} = 0.6$ tsf = 1200 psf ✓

10': $S = 24 \times \log \frac{7.1}{6.8} = 24 \times 0.019 = 0.46"$ ✓

20': $S = 24 \times \log \frac{7.4}{6.8} = 24 \times 0.036 = 0.86"$ ✓

Existing stress at mid. of sand = 5.75 tsf = 11,500 psf

10': $S = 24 \times \log \frac{6.05}{5.75} = 24 \times 0.022 = 0.53"$ ✓

20': $S = 24 \times \log \frac{6.35}{5.75} = 24 \times 0.043 = 1.03"$ ✓

$C_v$ clay = 0.3 ft²/day ✓ $T = \frac{C_v t}{H^2}$, t = 1967 to 1979 = 12 yrs = 4380 days ✓

$C_v$ sand = say 0.6 ft²/day ✓

clay: $T = \frac{0.3 \times 4380}{(10)^2} = 13.1$, $U = 100\%$ ✓

sand: $T = \frac{0.6 \times 4380}{(20)^2} = 6.6$, $U \cong 100\%$ ✓

Total settlement: 10' lowering = 0.46 to 0.99" ✓

20' lowering = 0.86 to 1.89" ✓

Actual Settlement (estimated from Plate 1) = 0.7" ✓

# APPENDIX E

SUBSURFACE INVESTIGATION
AND FOUNDATION STUDY FOR
INTERPRETIVE FACILITY AT THE
WASHINGTON MONUMENT
WASHINGTON, D. C.
NATIONAL CAPITAL PARKS

CONTRACT NO. CX-2000-3-0046
UNITED STATES DEPARTMENT OF THE
INTERIOR
NATIONAL PARK SERVICE

MUESER, RUTLEDGE, WENTWORTH & JOHNSTON
CONSULTING ENGINEERS
415 MADISON AVENUE
NEW YORK, NEW YORK 10017

SEPTEMBER 14, 1973

# SUBSURFACE INVESTIGATION AND FOUNDATION STUDY FOR INTERPRETIVE FACILITY AT THE WASHINGTON MONUMENT

## BASIC INFORMATION AND HISTORY

### Introduction

The National Park Service in Contract No. CX-2000-3-0046, provided for architect-engineer services for the general planning and design of an Interpretive Facility near the Washington Monument in Washington, D.C. The professional firms engaged are Hartman-Cox Architects and James Madison Cutts, Consulting Structural Engineers. A portion of this assignment included study of the advisability of building an underground structure near the Monument with recommended locations and alternative locations based on subsoil conditions. In order to provide this specialized information a proposal was submitted to the Consulting Structural Engineers on June 4, 1973, which was accepted by them on June 26, for a study of subsurface conditions and foundation problems of the interpretive facility. This report is made pursuant to that proposal by Mueser, Rutledge, Wentworth & Johnston (MRW&J) and it is intended that it be submitted in its entirety to the National Park Service in compliance with requirements of the architect-engineer contract.

Our investigation included the following items of work:

1. Study and assemble on one plan the available subsurface information in order to locate supplementary borings for the purpose of correlating the older boring data with present knowledge of Washington subsurface conditions;

2. Contract for and inspect these supplementary borings;

3. Analyze boring information and laboratory test data included in an earlier subsoil study by E.S. Barber;

4. Review and evaluate the Monument's foundation construction and observed settlement;

5. Prepare geologic sections showing subsurface materials which incorporate both the old information and that recently developed.

6. Prepare a report presenting the above information and recommendations for the type and extent of underground structures that could be placed near the Monument.

## Information Available for this Study

The Washington Monument as a focus of national interest has been the subject of a number of studies and reports in the past, many of these relating to subsurface conditions or plans for construction or modification which were strongly influenced by these subsurface conditions. A list of references both of descriptive and physical information is presented at the end of this text. The principal sources of quantitative data are borings and studies made in 1930 and 1931 for a report on improvement of the Monument grounds (Reference 3), a report of 1962 by Edward S. Barber, Consulting Engineer, relating to loading limitations on the Monument grounds (Reference 5). This latter reference is known as the "Barber Report" and is cited specifically for review in the architect-engineer contract. The other principal source of information is observations of settlement of the Monument noted in References 1, 3 and 4.

As soil consultant to the Washington Metropolitan Area Transit Authority in construction of the METRO subway, Mueser, Rutledge, Wentworth & Johnston has developed a great deal of information as to the physical properties and performance of Washington soils. These data have been made available by publication by the Department of Commerce. In order to be able to correlate that information and experiences with subsoils at the Washington Monument, three additional borings for this study were planned and contracted for. Bids were taken from five qualified boring contractors for boring work to be performed under our standard specifications and the contract was awarded to the low bidder, Maryland Foundation Company on July 19, 1973. The borings were made between July 20 and 30 under the continuous inspection of our resident engineer Mr. Sajjan K. Jain and under the general supervision of our Washington project engineer, Mr. Charles R. Heidengren. The three borings were intended primarily for conventional split-spoon sampling, but in order to ensure that a realistic impression was obtained of the underlying clays, recovery of a few 2-inch diameter thin Shelby tube samples was included. All of the samples obtained were delivered to our New York laboratory for examination, check of the field classifications and a limited amount of laboratory testing.

## History of the Monument Construction

Subsurface conditions in and around the Monument have had an important influence in several stages of its history. The site for an equestrian statue of Washington stipulated in the L'Enfant plan was to be at the intersection of the north-south line through the White House and the east-west line through the Capitol dome. In 1848 when Congress authorized the Washington National Monument Society to commence construction, the location designated by L'Enfant was occupied by low marshy ground bordering the estuary of Tiber Creek that then flowed along the north side of the Mall along the line of Constitution Avenue. Therefore the site selected was on a mound a few hundred feet to the southeast of the intersection position. Construction commenced in 1848 and by 1854 the shaft had reached a height of 152 feet above the top of its foundation. The original foundation was built in pyramidal shape with stepped sides, made of blue gneiss blocks set in a mortar of hydraulic cement, stone, lime and sand. The pyramid was 23 feet high and 80 feet square at its base.

From 1854 until 1878 little was accomplished and when the work of completing the Monument was taken over by the government in 1876 a Corps of Engineer investigating board concluded that the height of shaft would have to be reduced from 600 to 500 feet due to excessive pressures on the existing foundation. It has been stated that settlement of the original construction had been a matter of concern but its magnitude is unrecorded. A second board advised that even with this change the old blue stone foundation would have to be enlarged. Consequently, an underpinning operation was carried out between late 1879 and June 1880 which involved placing concrete pads 13.5 feet thick and required excavations over 70 per cent of the original base area of the pyramidal foundation. This concrete underpinning was extended 18 feet beyond the original base on all sides and provides a bearing area of 16,000 sq. ft. as compared to the 6,400 sq. ft. of the old foundation. Work on the shaft was then continued to completion in December 1884. The foundation and loading characteristics at various stages of construction are given in Table No. 1. The 37 ft. depth of the final foundation and its massive pyramidal construction are such that it must be completely rigid with respect to normal deformations of the supporting soils. Hence the distribution of the Monument load over the entire bearing area of the foundation, including the central area of the original foundation that was not underpinned, must be essentially uniform and it has been so assumed herein.

Proposed Improvement of the Monument Grounds of 1931

In 1901 a plan was proposed for an elaborate treatment of the Monument grounds involving extensive regrading and a number of decorative architectural features. Consideration of the threat to stability of the Monument due to extensive earthwork operations in the 1901 plan led the National Capital Park and Planning Commission to recommend a more thorough study of the site and early in 1930 a special advisory committee was organized consisting of well known engineers and architects to evaluate schemes for improvement. Test borings made in 1930 and 1931 formed part of their investigation. The report of that committee as summarized by Colonel U.S. Grant, 3rd, is contained in Reference 3. Architects of the committee recommended modifications of the 1901 plan of less grandiose scale involving filling on the east and cutting on the west of the Monument.

The engineering members of the committee maintained that even with the revision a threat still existed to stability of the Monument which they were unwilling to risk. Their particular concern was the effect of a change in loading condition in a deposit of clay overlying bedrock. The architectural members then requested additional expert engineering opinion which was obtained from H. G. Balcom and Daniel E. Moran, consulting engineers of New York City. Balcom expressed a somewhat less conservative opinion than the engineer committee members, Moran took the view that regrading involved in the modified plan was no threat to stability of the Monument and his views are explained in Appendix No. 1 to Reference 3. Because the 1930 and 1931 borings had disclosed the bed of clay below the Monument foundation which became a cause of concern among the advisory committee members, Moran evaluated all the detrimental effects of the clay stratum in his report. These included consolidation of the clay leading to increased settlements, sliding of the foundation bearing soils on the sloping upper surface of the clay, and plastic lateral squeezing of the clay. Reasoning on principles similar to those of present-day soil mechanics, he concluded that none of these possibilities constituted a hazard to the Monument and the minor changes in ground loading around the Monument would have no significant effects. The stability and very small settlements of the Monument during the forty-two years after his report confirm the accuracy of his evaluations. Moran was the founder and for many years the senior partner of the predecessor firms of Mueser, Rutledge, Wentworth & Johnston. The file of his notes and correspondence which was compiled in rendering this advisory opinion is contained in Reference 2. Faced with a disagreement in the committee opinion, Colonel Grant recommended that grading be undertaken only to modify the Monument grounds for greater convenience in traffic circulation and that larger scale changes be deferred until after additional studies could be made.

## SUBSURFACE CONDITIONS

### General Geological Setting of the Monument

The general geology of the District of Columbia with particular emphasis on bedrock conditions is described in Reference 4 which contains boring data from a large number of projects including the exploration of 1930 and 31. The part of Washington, D.C. occupied by the Monument grounds and central government buildings south of Farragut Square lies within the geological province known as the "coastal plain" wherein soils of sedimentary origin overlie crystalline bedrock. The bedrock surface is a gently undulating surface sloping gradually toward the south or southeast. In southern sections of the District bedrock is overlain by thick deposits of marine sediments of Cretaceous age which consist of hard plastic clays or very compact clayey sands. In downtown Washington the Cretaceous series is overlain by much later stream terrace deposits of Pleistocene times laid down in periods of varying sea level and abruptly changing climatic conditions by ancestors of the Potomac and Anacostia Rivers.

The Monument is underlain by a subsoil profile unusual for downtown Washington where Pleistocene terrace deposits lie directly upon bedrock without the intervening Cretaceous soils. This characteristic has been observed in a limited area at the western end of the Mall where bedrock is relatively shallow and Pleistocene streams draining the surrounding bowl of downtown Washington removed the older soils. The Pleistocene materials range from a medium plastic and slightly to moderately organic clay to a very compact mixture of sand and gravel with some boulders. It is the presence of a layer of this clay which has occasioned so much concern about stability of the Monument and the effect of nearby grading operations.

### Presentation of Boring Information

Locations of all borings of four different series are distinguished by symbol on the plan in the left panel of Drawing No. B-1. These comprise two sets made for the 1932 study, borings for the Barber report of 1962, and three borings, designated as M-1 through M-3, made for the current investigation. To illustrate subsurface conditions two orthogonal geological sections have been drawn at locations shown on the plan, a north-south section through the Monument centerline which is plotted on Drawing No. GS-1 and an east-west section on Drawing No. GS-2. Notes and Legends explaining details on these drawings accompany the two sections and general subsurface strata descriptions are listed in Drawing No. GS-1. To avoid distorting the appearance of the Monument foundation and subsurface profile, these sections are plotted at natural scale wherein the graphic scale is equal in the vertical and horizontal directions. The sections extend an average of about 150 feet outward from the Monument's center.

Datum for elevations is the zero of the District of Columbia Engineers which is 0.7 feet above USC&GS readjusted mean sea level of 1929. This D.C. Engineers zero is 2.1 feet higher than the USED mean low water which was taken as zero for the borings of 1930, 1931 and apparently also those of 1962. All of the borings on these earlier series have been plotted so as to conform to D.C. Engineers datum.

At the individual borings the data obtained in the boring and sampling operations are plotted in symbol form, including: sample number, designation and position; standard sampler penetration resistance in blows per foot; Unified Classification of samples where available; natural water contents, Atterberg plastic and liquid limits, and shear strength in kips per sq. ft. obtained from the laboratory strength tests. For the borings made in 1962 the Unified Classification symbol was interpreted from the word descriptions and test data from the Barber report have been added. For borings of 1930 and 1931 no effort has been made to translate strata descriptions to the Unified Classification but a value of penetration resistance is noted which is taken from the boring logs although the energy employed is not known. In order to supplement these two geological sections which are concentrated near the Monument, broader scale sections extending for a distance of 500 feet from the Monument are presented in Drawing No. GS-3. This is a reprint of the original sections made in our office in 1931 for the Moran report to the Monument advisory committee which is cited in Reference 3. Descriptions of strata in these older geological sections generally correspond with those shown on Dwgs. Nos. GS-1 and GS-2. For the latter we have utilized division and designation of strata which were employed in the extensive subsurface exploration program made by our office for the Washington Metropolitan Area rapid transit system. Detailed information on the geological background and physical characteristics of the principal overburden materials in the Mall can be obtained in Reference 7 which is a report made by

MRW&J for the subway crossing the Mall on 12th Street two blocks east of the Monument grounds.

Subsurface Stratification

Following the scheme used in the subway exploration program, Pleistocene stream terrace materials are grouped in a succession of strata generally identified with the prefix "T". Decomposed rock overlying solid bedrock is designated as a Stratum "D". Descriptions of subsurface strata taken in order of depth below the ground surface are as follows:

Stratum F, Fill: medium red brown fine sandy clay with trace of gravel and cinders. Directly outside of the Monument foundations the fill is 20 feet thick between the present ground at Elev. +40 and the original ground at about +20. The fill was placed to form a mound which accentuated the dominating topographic position chosen for the Monument and its thickness decreases to typically 10 feet at a distance of 500 feet. The fill is soil lacking refuse or organic material and probably was carefully selected to meet standards of the time in which it was placed. Sampler penetration resistance is erratic because of the presence of gravel and boulders but generally is in the range of about 5 to 15 blows per foot.

Stratum T1(A): hard brown silty clay, lensed with silty fine sand. This constitutes the uppermost natural soil and is a Pleistocene stream deposit in which fine sand and clay are intricately interlensed. Standard penetration resistance is medium to high in the range of about 10 to 30 blows per foot and there are contained within the clay distinct layers of silty sand of Stratum T2 or silty sand with some gravel of Stratum T3. This stratum is typically about 20 feet thick between Elev. +20 and 0 and it constituted the bearing material for the original foundations.

Stratum T2: medium compact brown silty fine sand with occasional silty clay layers. This is generally interlensed in the lower part of the clay of Stratum T1(A). The upper Pleistocene layer is a complex mingling of clay and sand constituents and the divisions portrayed in the geologic sections probably are drastic simplifications of actual conditions.

Stratum T3: very compact brown fine to coarse sand with some silt and gravel and occasional boulders. This is the coarsest

Pleistocene terrace deposit and is encountered throughout the Monument grounds between about Elev. 0 and a base typically at Elev. -30. This layer is the bearing stratum for the enlarged foundations. Standard penetration resistance is exceptionally high, ranging from about 50 to 150 blows per foot. Frequently the higher values are caused by the presence of gravel and boulders too large to enter the sampling spoon.

Stratum T1(D): very stiff blue-gray plastic clay, trace of fine to medium sand pockets, occasional highly organic lenses. Its thickness varies from a maximum of about 40 feet at a point 100 feet northeast of the Monument to zero directly west of the Monument. It apparently continues in a band to the east, and was found in borings made for the subway along the line of 12th Street shown in Reference No. 7. Because of its importance in the overall foundation evaluation, contours of the top of Stratum T1(D) clay are plotted in the center panel of Drawing No. B-1 and contours of the thickness of the layer are given in the right panel. The layer appears rather uniform in character throughout except that at about Elev. -40 to -45 it tends to become distinctly more plastic with a higher concentration of organic material which indicates a change in its deposition regime. Standard sampler penetration resistance is fairly consistent throughout, in the range of about 10 to 30 blows per foot with higher blows being at the bottom of the layer where sand is interlayered with the clay. For the most part the clay layer lies directly on the surface of decomposed rock. At some locations, for example in Boring No. M-2, a stratum is encountered beneath the clay consisting of gray sand with some gravel and boulders similar to the upper T3 material but lacking its brown and iron-stained color.

Stratum D: very dense gray-green micaceous silty fine sand, decomposed rock grading downward to bedrock. The surface of the formation that would be described geologically as rock is encountered between about Elev. -60 and -70 on the Monument grounds. This is essentially a flat-lying surface as the geological sections indicate. The uppermost 15 to 20 feet is designated as decomposed rock and much of this layer can be penetrated by ordinary soil sampling methods with very high driving resistance, typically 100 blows for several inches of penetration. This is the residual material formed by weathering and decomposition of the crystalline bedrock. Bedrock is primarily a fine to medium grained schistose gneiss with comparatively large amount of hornblende and biotite minerals with feldspar and quartz. None of the three borings in the current program extended to a depth where rock coring was necessary, as was the case in the 1962 borings. In some of the exploration of 1930 and 1931 apparently rock cores were taken but the precise depth of these cores is not clear.

### Ground Water Conditions

Mention has been made in various references of the fact that the sand and gravel of the Pleistocene terrace beneath the foundation appear to be in communication with open water in the Potomac. Reference 3 reports that the tidal cycle in the Potomac caused a corresponding fluctuation in ground water levels of about 0.25 feet. As a consequence of the permeability of the Pleistocene sands and their communication with open water the water table probably varied seasonally up to about 5 feet above sea level. Following extensive development in the Mall involving deep basement excavations and depressed roadways, there has been a widespread drawdown of ground water to 5 feet to 15 feet below mean sea level. Before subway construction on 12th Street the water table was as low as Elev. -20 between Pennsylvania Avenue and Constitution Avenue, rising gradually to the south through the Mall to between Elev. -5 and -10. The mound upon which the Monument is built is remnant of terrace deposits that occupy the Mall south of Constitution Avenue and in the recent borings made for this study the ground water appeared at Elev. -10 to -11. The Mall area between 12th Street and the Monument has been dewatered to an appreciable extent by the current subway construction on 12th Street. It is likely that the long-term water level will average several feet below sea level. Even though flood waters from the Potomac River no longer will be permitted to intrude into the Mall, the back-up of storm drainage on Constitution Avenue northeast of the Monument grounds could provide sufficient recharge to raise ground water temporarily to sea level.

## PROPERTIES OF THE UNDERLYING CLAY STRATUM

### Laboratory Testing for the Barber Report

In the 1930 and 1931 borings samples presumably were obtained by driving a pipe or spoon into soil which may have been appreciably disturbed in the boring process. Opinions of the quality of the underlying clay of Stratum T1(D) seem to have been excessively apprehensive and this may reflect the disturbed condition of the soil samples. In any case, the earliest testing was carried out for the Barber report of 1962 which contains results of tests performed on thirty six 3-inch Shelby tube samples, almost all obtained within the blue clay of Stratum T1(D). For each sample consolidation and unconfined compression tests were performed and natural water contents and selected Atterberg limits were determined. Test information from the Barber report is summarized in the form of a soil properties profile wherein the results are plotted against sample elevation in Plate No. 1.

The consolidation test simulates the stress-strain performance when a load is applied whose dimension in plan is much greater than the thickness of the compressible layer. Potential settlements are controlled to a large extent by the degree of preconsolidation of the clay, that is the magnitude of the maximum stress to which the sample has been subjected at some time in the past. Specific values of preconsolidation stress are not included in the Barber report and therefore it was necessary for us to plot compression curves for each of the consolidation tests and from these to estimate the magnitude of greatest past stress. If the structure load applied to the clay plus existing overburden pressures are less than the preconsolidation stress the resulting settlements tend to be small. If loads applied to the clay exceed the preconsolidation stress settlements become disproportionately larger. The preconsolidation also chiefly controls a clay's strength and thus it is the engineering property of chief interest in a fine grained soil. In the left panel of Plate No. 1 preconsolidation stresses estimated from the Barber testing for the Pleistocene clays have been plotted as solid circles. In the same panel are shown values of compressive strength in units of tons per sq. ft. obtained from unconfined compression tests. These are numerically equal to the shear strength in units of kips per sq. ft. In the right panel of the plate are plotted natural water contents and Atterberg limits of the 3-inch samples of the Barber study.

## Laboratory Testing for the Current Investigation

There is such a scatter of preconsolidation and strength values from the Barber tests that it was concluded it would be necessary to procure at least a few 2-inch diameter Shelby tube samples suitable for unconfined compression tests to make an independent appraisal of properties. Accordingly a total of seven of these samples were obtained, six from Stratum T1(D) clay and one from shallow material which proved to be clayey fill. Results of laboratory tests on these samples are listed in Table No. 2 and strength values for Stratum T1(D) clay are denoted by triangles in the left panel of Plate No. 1. They indicate that the clay strength is extraordinarily uniform and probably equals the maximum values obtained in the Barber study. Compressive strength of a clay ordinarily is in the range of about 0.5 to 0.6 times the preconsolidation stress and tests suggest that the highest preconsolidation values of the Barber report are the most realistic. Dashed lines in Plate No. 1 represent the most likely profiles of preconsolidation stress and strength with depth. Stratum T1(D) clay has been preconsolidated to a maximum value of about 5 tons per sq. ft. at its upper surface, increasing with depth to roughly 6 tsf at its base. Compressive strength probably averages 3 tsf, equivalent to a shear strength of 3 ksf.

It should be noted that the test samples are from borings sufficiently close to the Monument to be influenced to a small extent by pressures on the Monument foundation. However, similar properties were obtained for T1(D) clay in the Mall on 12th Street, as shown by Plate No. A205 from Reference 7 which is reproduced herein. This suggests that preconsolidation of the Pleistocene clay is the result of a greater weight of overburden soil, since removed by erosion, which affected wide areas of the deposit. While these conclusions are not supported by elaborate testing on our part for the Monument site, it is believed certain that even a much more extensive investigation program would yield essentially the same results. In fact, Barber finally reaches conclusions similar to those stated above as to the strength and preconsolidation condition of the clay. These appear to be based on his intuition and experience with Washington soils and discount a large part of the testing which gave less favorable values for the clay's properties.

## OBSERVED SETTLEMENTS AND EVALUATION

### Observations of Monument Settlement

The available record of Monument settlement is described in Reference 3. No reliable data exist for settlement of the shaft prior to underpinning but the 152-foot shaft leaned 1-3/4 inches out of plumb to the north. This would have been produced by a differential settlement of about 3/4 inches between the north and south edges of the original pyramidal foundation. During underpinning and before adding weight other than the concrete of the foundation, an average settlement of 2 inches was reported and by careful control of the underpinning operation the tilt was corrected. In completing the shaft to its final height by 1884 an additional 1-3/4 inches of settlement occurred without any significant tilt. Although the record is not entirely clear, another 3/4 inch settlement was produced by placing 20 feet of fill around the Monument and over the concrete slope and protrusion of the concrete footings. By the time all work was finished in 1886 the recorded settlement totalled 4-1/2 inches. From that year to 1923 an additional settlement of 3/4 inch occurred for an average rate of 0.02 inches per year. In 1923 the Coast and Geodetic Survey initiated vertical movement observations on the Monument and their records from that date to 1972 show further settlement of approximately 3/4 inches for an average rate of 0.015 inches per year. Long-term settlements ordinarily occur at a gradually decreasing time rate somewhat as shown by these records. It is possible that there has been some slight increase in the time rate of settlement in the last two decades due to lowering of the ground water table.

Significance of the Observations

This record of observations is extremely valuable as a large-scale field test to provide information on the character and engineering properties of the subsoils. The following general conclusions can be drawn:

1. The 2-1/2 inches of settlement that occurred upon completion of the shaft and surrounding mound of fill indicates that the underlying clay was not entirely preconsolidated to the final effective stress of 6.4 tsf applied to its upper surface. The equivalent value of the compression index for this settlement is 0.15 which is midway between the stress-strain properties for recompression and virgin compression. The corresponding "modulus of elasticity" for the entire subsoils above bedrock is about 500 to 600 tsf.

2. The abrupt slowing of the rate of settlement at the completion of construction suggests that consolidation occurred rapidly, essentially concurrent with the application of load. This is consistent with a value of the coefficient of consolidation of 0.3 $ft^2$ per day cited in the Barber report.

3. Long-term settlement of 1-1/2 inches occurring in 86 years since completion from 1886 to 1972 is entirely consistent with secondary compression to be expected of the underlying clay. This represents 0.5 per cent compression of a 25-foot thick clay layer and is equivalent to a coefficient of secondary compression of 0.003 to 0.004. No shear deformations involving lateral strains in the subsoils need be postulated to explain the long term settlements. This is a very small value for the coefficient of secondary compression commensurate with the slow time rate of the settlements.

4. Despite the fact that the settlement record can be explained

in terms of the properties of an average thickness of 25 or 30 feet of the clay, the apparent uniformity of the settlement since underpinning suggests that compressibility of the clay is not much greater than that of the overlying very compact sand and gravel of Stratum T3.

## FOUNDATION STABILITY

### Existing Stability Condition of the Monument

Under existing static loading the average bearing pressure on the base of the foundation at Elev. +2 equals 5.1 tons per sq. ft. The total effective vertical stress on top of the T1(D) clay at about Elev. -35 beneath the center of the foundation equals 6.4 tsf. If spread of the Monument load through the sand and gravel of Stratum T3 is considered, the average effective vertical stress on the top of the clay equals about 5.3 tsf. The effective vertical pressure of overburden surrounding the Monument at the top of the clay equals 3.7 tsf. The differential vertical pressure therefore is 1.6 tsf and this produces a shear stress of about 0.6 to 0.7 ksf in the clay layer compared to a shear strength of 3 ksf. Thus there is a safety factor of 4 or 5 against a shear stress at any point exceeding the strength if the clay layer were very thick. The clay layer actually is thin compared to the width of the rigid foundation and usual considerations of bearing failure are not strictly relevant but the overall safety factor is of the order of 6 to 8.

Excavation of fill completely around and adjacent to the Monument down to Elev. +20 would remove a surcharge pressure of about 1.25 tsf which now balances some of the load concentrated on the Monument foundation. Reasoning as above, the differential vertical pressure acting on the top of the clay would be 2.8 tsf and the resulting shear stress would be about 1.1 or 1.2 ksf compared to a shear strength of 3 ksf. It is believed that no greater shear stresses should be permitted even temporarily in the underlying clay layer.

The recommendations of the Barber report are much more conservative in this regard, cautioning that a zone extending 250 feet from the center of the Monument should not be unloaded. Available records and photographs indicate that as construction of the shaft was being completed in 1884 the surrounding fill had not yet been placed above the original ground. Thus, it is likely that the Monument has already experienced a loading condition equivalent to removal of the man-made fill.

## Limitations to the Addition of Load

The addition of load adjacent to the Monument seems to be the chief possibility evaluated in the Barber report. Considering a displacement of 0.1 inch at the top of the Monument permissible, this would limit the differential movement between edges of the foundation to 0.023 inch. On the basis of this stringent criterion Barber recommended that no addition of load be permitted within 250 feet of the Monument center. While we are generally in agreement with compressibility properties of the underlying clay chosen by Barber for his studies, we feel that selected limitation on tilt of the Monument is much too conservative to be realistic.

In fact an approximate 12 foot of drawdown between 1962 and 1973 increased the effective stress in the subsoils by almost 0.4 tons per sq. ft. This may have been responsible for about 1/4 inch of settlement. However, any local or asymmetrical increase of load directly adjacent to the Monument foundation must be strictly limited because of the possible differential settlement leading to tilting of the shaft. For example, if a fill 8 feet high were placed over a strip adjacent to one side of the foundation only, a settlement of the edge of the foundation of about 0.2 inches would be produced which would cause a tilt of the shaft from plumb of about 0.8 inches. While this represents an extremely small angle change, less than one part in six thousand or an angle change less than one minute of arc, and is probably less than that caused by the heat of the sun on one side of the Monument, it is suggested that this be considered the maximum tolerable tilt movement caused by any new construction.

## RECOMMENDATIONS

The Washington Monument is a highly visible feature of the nation's capitol skyline of great historical and national significance and importance. It is believed, therefore, that planning for construction of the proposed Interpretive Facility should be highly conservative in terms of possible effects on foundation performance of the Monument. The following recommendations have been made on this basis and are considered highly but not excessively conservative. It is understood that they are to include possible additions of load by above ground structures and below ground structures that may or may not decrease existing loads.

1. Restrictions must be placed on the net permanent change

in loads within a distance of several hundred feet from the center of the Monument. More severe limitations would apply to asymmetrical loads than to loads placed symmetrically on all sides of the Monument since it is the one-sided loading which will produce a tilt of the shaft. More stringent limitation should be applied to the addition of load compared to a reduction of load since an increase in stress beneath the Monument foundation will produce settlements in the range of virgin compression. A permanent net increase in loading within a distance of 150 feet from the Monument Center should generally not exceed 1,000 per sq. ft. If such an additional load were to be placed over a sector of 180° on one side of the foundation it would produce a tilt of the top of the shaft of nearly one inch and detailed studies of its specific effect would be desirable.

2. The net change in load equals the total dead load plus permanent live load applied by the structure plus any filling or backfilling minus the total weight of soil removed by excavation for the structure. For purposes of appraising the magnitude of loading, the unit weight of excavated soil can be assumed at 130 lbs. per cu. ft. If construction of an underground facility produces a net reduction of loading, the average magnitude of this reduced loading should be limited to about 1500 lbs. per sq. ft. if placed asymmetrically or 2,000 psf if it is positioned symmetrically around the Monument within a distance of 150 feet from the center. The precise effect of a specific asymmetric loading in producing tilt of the shaft would have to be evaluated in detail when a final scheme is evolved.

3. Permanent net changes in load taking place in a distance within 63 feet of the Monument center, that is, overlying the projected base of the underpinned foundation, generally should not exceed 500 lbs. per sq. ft. and should be restricted in lateral extent to the least practicable dimensions. For a structure of small dimension such as a passageway or narrow corridor, this 500 psf limit might be relaxed after specific study. The magnitude of pressures which are transmitted to soil directly beneath the Monument foundation from wall footings, column footings, slabs or other foundation units of the newly constructed facility must be strictly limited. We believe that this pressure increase should not exceed about 1 to 1.5 kips per sq. ft. The effects of a local or asymmetric increase in pressure beneath the Monument foundation would have to be evaluated in detail for the specific scheme of new construction.

4. Beyond 150 feet from the Monument Center permanent net

changes in load will have little if any effect on the foundation performance of the Monument but net changes exceeding 1,500 lbs. per sq. ft. additive load or 2000 psf net reduction in load with lateral dimensions of more than 150 feet asymmetric to the Monument should be kept beyond 200 feet from the Monument Center if possible.

5. Excavations for construction of the Interpretive Facility should be limited as follows to avoid any possible disturbance to the soils that are carrying the loads of the Monument.

(a). Within 115 feet from the Monument center no excavation for construction of the Interpretive Facility should be allowed to extend below Elev. +16, that is, the level of the base of the original stone foundation. The width of such excavations before placing of structure concrete and partial backfilling should not exceed 45 feet.

(b) Beyond 150 feet from the Monument center temporary excavations for construction can be carried down to as low as Elev. 0 provided the excavation and replacement by construction is carried out in width increments not exceeding about 100 feet.

(c) Between 115 feet and 150 feet from the Monument center the maximum depth of temporary excavation is defined by a line sloping downward from Elev. +16 with a slope of 1 vertical on 2.6 horizontal and width limitations are intermediate between those stated in (a) and (b).

(d) Excavation for a widespread structure symmetrically placed which would approach the limitation on maximum load removal must be carried out with great caution. Specifications should require a program of excavation in which load removal on opposite sides of the Monument would be reasonably well balanced at all stages of the operation.

(e) In general, it would be preferable to stabilize the sides of excavations near the Monument by cutting on sloped banks rather than by driving sheet piling or soldier piles for a cofferdam. Where vertical-wall cofferdams are absolutely necessary these could be formed by soldier piles placed in pre-augered holes.

5. Unless structures with very heavy column loads, in excess of 600 kips, are planned, it is believed that all structures of the Interpretive Facility can safely be carried on spread footings without their experiencing detrimental settlements. However, heavy column or wall loads which would apply a substantial increase in pressure on the Monument's foundation or beneath its foundation should receive special treatment. This might include the use of stiffened grade beams, grid footings, mats or the like that would serve to spread concentrated reaction pressures outward away from the Monument foundation. The following are recommended design bearing intensitites for footings bearing directly on the several soil strata shown on the sections on Drawings Nos. GS-1 and GS-2:

F-Fill, Below 3 ft. below existing ground surface: 1 ton per sq. ft.

T1(A) - Clay: 1.5 tons per sq. ft.

T2 - Silty Sand: 2 tons per sq. ft.

T3 - Very Compact Sand and Gravel: 3 tons per sq. ft.

T1(D) Stiff Plastic Clay: 2 tons per sq. ft.

Ordinarily no structural bearing should be planned below Elev. 0 because of potential ground water effects. These general recommendations should be reevaluated when the structure design concepts have been finalized. Recommended earth pressure diagrams for design of walls of below-ground structures can be provided at this stage of the planning. Structures requiring deep excavations should be so planned and designed that the net changes in load fall within the criteria stated above.

## CONCLUSIONS

In the preparation of this report and the preceding recommendations it is most fortunate that reasonably complete records of the Monument settlements have been made since completion of all work in 1886. While the load intensitites applied by the Monument to the underlying soils are large, the settlement records clearly indicate a safe and satisfactory foundation performance. There has been no differential settlement or tilting and the rate of settlement of 0.015 inches per year is small and completely explainable in terms of normal physical phenomena in the underlying soils. Hence it has been possible to make the recommendations contained herein with complete confidence that no detrimental effects to the Monument foundation performance will occur.

## REFERENCES

1. "The Washington Monument" (Second Edition), The Society of American Military Engineers, Washington, District of Columbia, 1929.

2. File of Job No. 566, Moran & Proctor, Consulting Engineers (Now Mueser, Rutledge, Wentworth & Johnston) June 1931 to January 1933. (Includes copy of original report of Daniel E. Moran to U.S. Grant, 3rd, which is incorporated in Reference 3.)

3. "Improvement of the Washington Monument Grounds", communication from the President of the United States transmitting a report on Improvement of the Washington Monument Grounds by U.S. Grant, 3rd, Director of Public Buildings and Public Parks of the National Capitol, dated January 1933.

4. "Configuration of the Bedrock Surface of the District of Columbia and Vicinity", N.H. Darton, U.S. Geological Survey Professional Paper 217, Washington, D.C. 1950.

5. "Loading Limitations, Washington Monument Grounds, Washington, D.C., Subsoil Study", report by Edward S. Barber, Consulting Engineer, Arlington, Virginia, December 31, 1962.

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7. "Final Report, Subsurface Investigation, Volume 4, Washington Metropolitan Area Rapid Transit Authorized Basic System, Benning Route and a Portion of the Pentagon Route", report by Mueser, Rutledge, Wentworth & Johnston, Consulting Engineers to WMATA, New York, July 1969. This report and its Appendix A have been reprinted and are on sale by the U.S. Department of Commerce, Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia as Publications Nos. PB185758 and PB185757.

## TABLE NO. 1
## FOUNDATION AND LOADING CHARACTERISTICS OF THE WASHINGTON MONUMENT

**Conditions at Initial Construction 1848-1854:**

Dimension of base of shaft 55.12'x55.12'
Elev. of base of shaft Elev. +39.4

Dimension of pyramidal foundation, at its base: approximately 80'x80', 6,400 sq. ft. area

Bearing level of original foundation=Elev. +16 approximately (DC Engrs. Datum)

Total weight of 152' of shaft and original pyramidal foundation=31,500 tons

Gross average bearing pressure on base of pyramidal foundation=4.9 tons per sq. ft.

Total effective vertical pressure on top of Stratum T1(D) clay at Elev. -35=7.1 tsf

**Characteristics of Underpinned Foundation of 1879-1880:**

Dimension of underpinned foundation, at its base: 126.5'x126.5', 16,000 sq. ft. area

Bearing level of underpinned foundation =Elev. +2 approximately (DC Engrs. Datum)

Total weight of 152' of shaft and underpinned foundation =59,300 tons

Gross average bearing pressure on base of underpinned foundation=3.7 tons per sq. ft.

Total effective vertical pressure on top of Stratum T1(D) clay at Elev. -35=5.0 tsf

**Characteristics of Completed Construction, 1886:**

Total added weight of shaft above 152' height =21,800 tons

Added average bearing pressure on base of underpinned foundation=1.4 tsf

Total weight of shaft, foundation and earth above foundation=81,120 tons

Gross average bearing pressure on base of underpinned foundation=5.1 tsf

Total effective vertical pressure on top of Stratum T1(D) clay at Elev. -35=6.4 tsf

# TABLE NO. 2

## SUMMARY OF LABORATORY TEST DATA

| SAMPLE IDENTIFICATION | | | | CLASSIFICATION PROPERTIES | | | | | | | | PHYSICAL PROPERTIES | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | UNIFIED CLASSIFICATION SYSTEM | | | STRENGTH | | | | | | | | CONSOLIDATION | | | | | |
| | | | | | | | | | | | | UNCONFINED COMPRESSION | | | TRIAXIAL COMPRESSION | | | | | | | | | | |
| BORING NO. | SAMPLE NO. | DEPTH FT. | STRATUM DESIGNATION | NATURAL WATER CONTENT %(W) AVERAGE OF ENTIRE SAMPLE | LIQUID LIMIT ($W_L$) | PLASTICITY INDEX ($I_p$) | NATURAL WATER CONTENT OF LIMIT SAMPLE %(W) | SPECIFIC GRAVITY OF SOLIDS (G) | SOIL TYPE | % SAND (<#4,>#200 SIEVE) | % FINES (<#200 SIEVE) | COMPRESSIVE STRENGTH TSF | WATER CONTENT AT END OF TEST % | STRAIN AT FAILURE % | TYPE OF TEST | DEVIATOR STRESS ($\sigma_1 - \sigma_3$) TSF | CONFINING PRESSURE ($\sigma_3$) TSF | NATURAL WATER CONTENT % | WATER CONTENT AT END OF TEST % | NATURAL WATER CONTENT % | EXISTING OVERBURDEN STRESS TSF | ESTIMATED PROBABLE PRECONSOLIDATION STRESS - TSF | COMPRESSION INDEX $C_c$ | SWELLING INDEX $C_s$ | VOID RATIO AT START OF SWELL, $e_r$ |
| M-1 | 4S | 21.0 | F | 22 | 30 | 10 | 22 | | CL | | | 0.90 | 22 | 2 | | | | | | | | | | | |
| | 14S | 71.0 | TI(D) | 27 | | | | | CL | | | 2.83 | 27 | 3 | | | | | | | | | | | |
| | 15S | 76.0 | TI(D) | 35 | | | | | CL | | | 2.91 | 35 | 3 | | | | | | | | | | | |
| | 16S | 81.0 | TI(D) | 40 | | | | | CH | | | 2.94 | 39 | 4 | | | | | | | | | | | |
| | 17S | 86.0 | TI(D) | 44 | | | | | CH | | | 2.76 | 44 | 3 | | | | | | | | | | | |
| M-2 | 13S | 61.0 | TI(D) | 27 | 40 | 19 | 27 | | CL | | | 2.73 | 26 | 4 | | | | | | | | | | | |
| | 15S | 71.0 | TI (D) | 34 | | | | | CL | | | 2.93 | 34 | 6 | | | | | | | | | | | |

### DESCRIPTION OF SOIL TYPES

F — Stiff brown silty clay, some fine sand

TI(D) — Very stiff dark blue-gray plastic clay, trace fine to medium sand pockets, occasional highly organic lenses

### NOTES

1. All tests summarized above were performed in the soils laboratory of Mueser, Rutledge, Wentworth & Johnston.
2. The sample depth listed above is the average depth of the sample recovered.
3. Ground surface elevations at borings are as follows:

| Boring No. | Elevation |
|---|---|
| M-1 | 39.9 |
| M-2 | 32.6 |

4. "Natural water content of entire sample" is a weighted average of all material types recovered.
5. Strength tests were performed on samples approximately 2.38 inches in diameter. The ratio of height to diameter of all strength test specimens was approximately 2.0.

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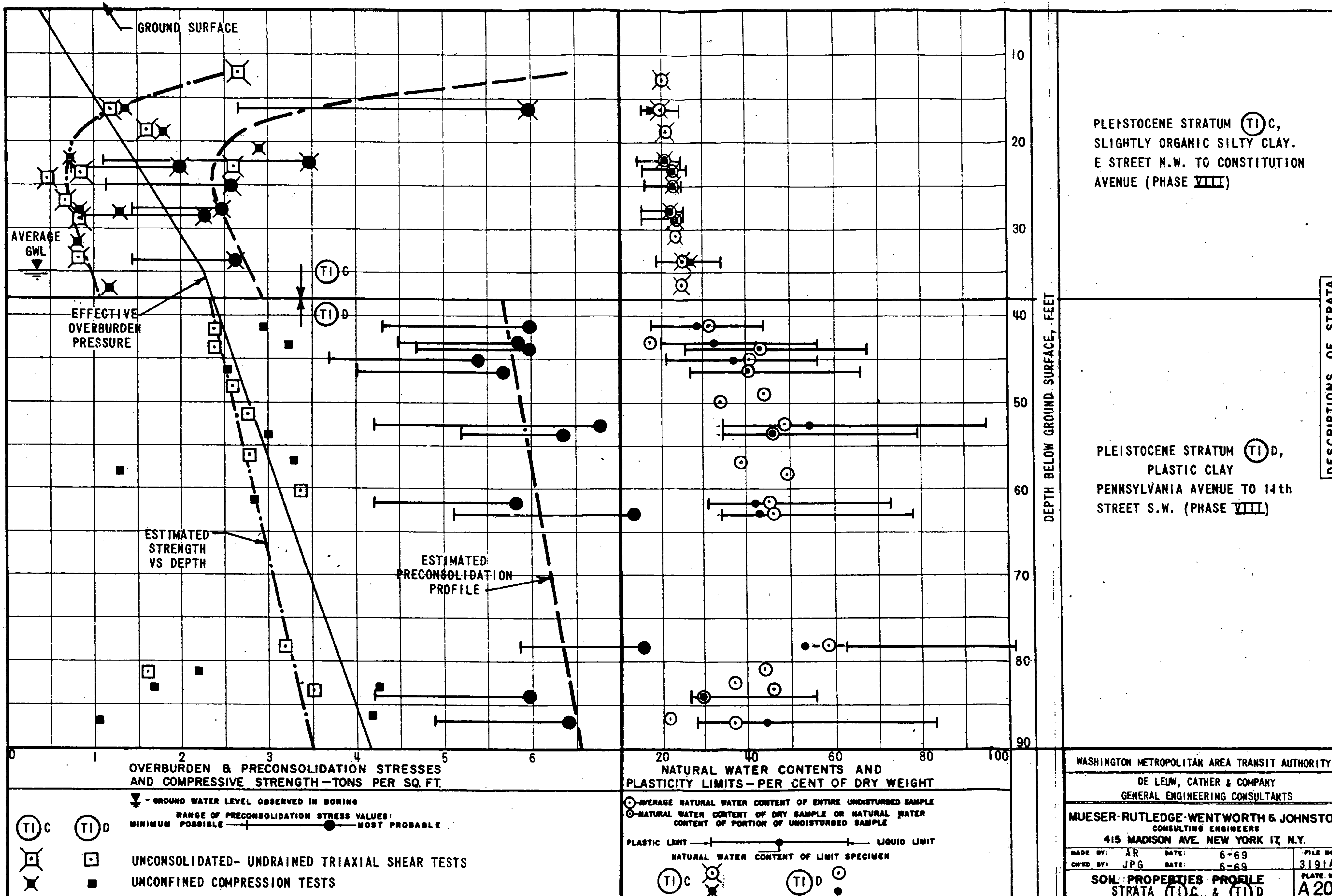
DATE August 22, 1973 — FILE NO. 4254 — SHEET NO. 1 OF 1 — TABLE NO. 2

For Drawings Nos. B-1, GS-1, GS-2, and GS-3, see MRW&J report dated February 13, 1984, included herein as Appendix D




WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

DE LEUW, CATHER & COMPANY
GENERAL ENGINEERING CONSULTANTS

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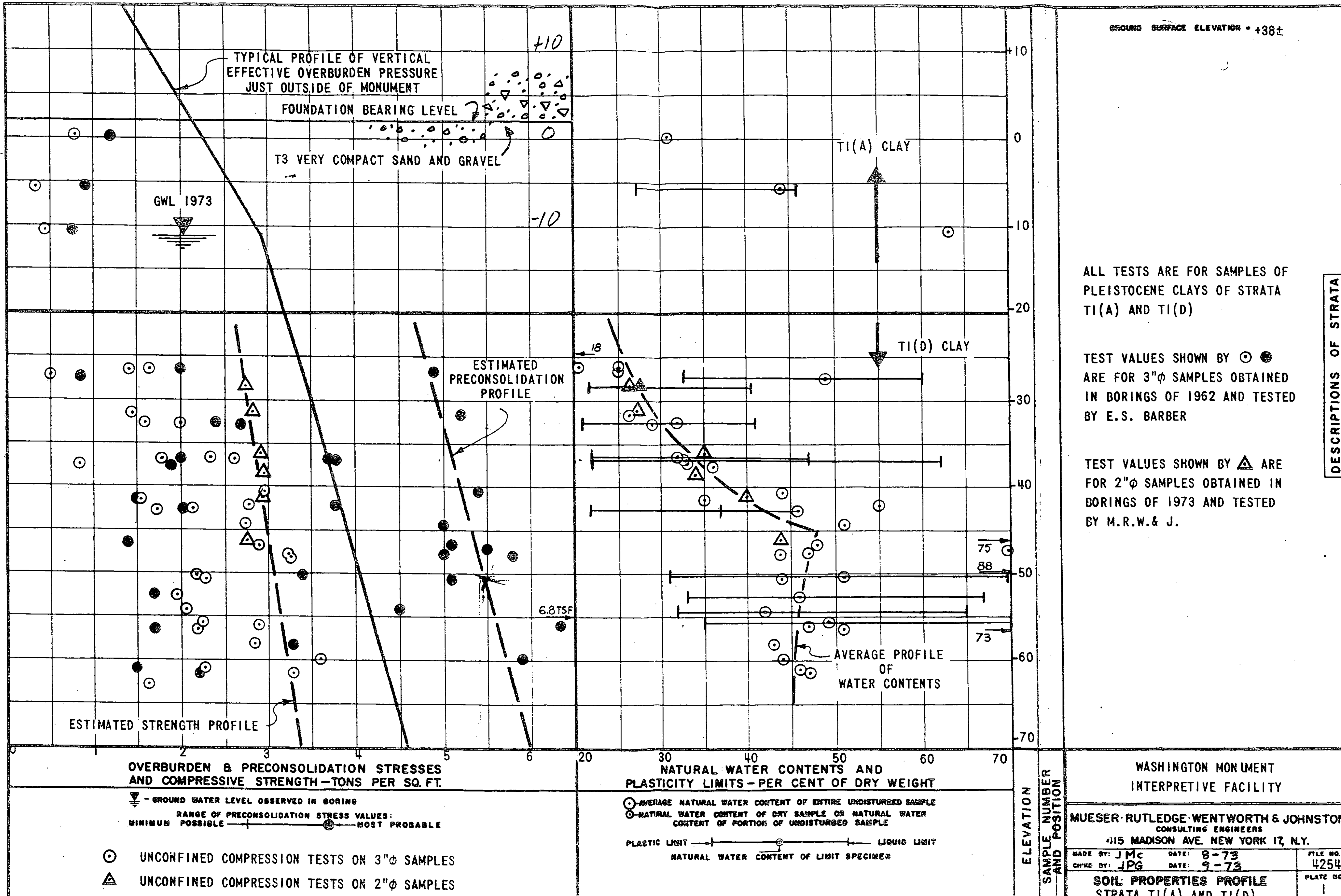
| CH'KD BY: | JPG | DATE: | 6-69 | |

SOIL PROPERTIES PROFILE
STRATA (TI) C & (TI) D

PLATE NO. A 205

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SOIL PROPERTIES PROFILE
STRATA TI(A) AND TI(D)

PLATE NO. 1