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GEOTECHNICAL SITE INVESTIGATION

BORING 1 THROUGH 4

PROPOSED COMMERCIAL BUILDING SITE

NO. 112, OLD MAHABALIPURAM ROAD

KANDHANCAVADI, CHENNAI 600 096, TN.

Report to

M/s. SRH Ventures Pvt. Ltd.
No. 112, Old Mahabalipuram Road
Kandhanchavadi, Chennai 600 096, TN.

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Report No. 067/GI/18-19.
June 27, 2018.

M/s. SRH Ventures Pvt. Ltd.
No. 112, Old Mahabalipuram Road
Kandhanchavadi, Chennai 600 096, TN.

Attention: Mr. Sreejit Kesavan
Director

Geotechnical Site Investigation
Boring 1 through 4
Proposed Commercial Building Site
No. 112, Old Mahabalipuram Road
Kandhanchavadi, Chennai 600 096, TN.

The Prasad Armstrong Yen GEC (P) Ltd., Chennai is pleased to submit this report on our geotechnical site investigation conducted at the above location. This work was authorized by your confirmation letter No. Nil dated June 1, 2018.

Estimated capacities of the recommended foundation for the proposed building are presented here in final form together with a summary of laboratory and field data.

We appreciate the opportunity to be of service to you on this project. Please call us if you have any questions or when we can be of further assistance.

Sincerely,

PRASAD ARMSTRONG YEN GEC (P) Ltd.

B. Ram Prasad ME, PhD (Texas A&M)
Managing Director

(067brpt)
Copies Submitted: (3)

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SUMMARY

Prasad Armstrong Yen GEC (P) Ltd. performed a geotechnical site investigation at the Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai 600 096, TN. Primary purpose of the investigation was to obtain data to develop to identify variability in soil and rock stratification of the site, select suitable foundation, and estimate load carrying capacities of the considered foundation. Typical maximum column load will be about 1,250 tons for the proposed building type with large column spans and spacing. In case of combined raft foundation the expected maximum bearing pressure will be about 30 tons/M^2. These details were used only for estimating the preliminary foundation size and type of foundation.

The field investigation was performed June 14 through 22, 2018. Number and location of the borings was selected to cover four corner of the proposed building. Boring 1 through 4 were drilled to 18-, 17-, 17-, and 17-M penetration below the Existing Ground Level (EGL), respectively. All the borings were terminated after drilling into **hard granite rock formation**. NX TC bit and diamond bit drilling was used for drilling through the rock formation. In the last 2- to 3-M of drilling rock core recovery (CR) was more than 75% and above with RQD in the range of 50% and 100%. Tests were conducted to determine the pertinent index and engineering properties of the soils and rock encountered. We then performed engineering analyses to develop the required design data.

Natural topography of the site reflects a relatively flat terrain. Site had Old Mahabalipuram Road (OMR) along the eastern boundary and Cheran Chenguttuvan Street along the western boundary. A Stilt + 9 floors residential apartments building was present in the adjacent north side plot. A Stilt + 4 floors residential apartments building was present in the adjacent south side plot. Present site's EGL was about 0.3-M above the Existing Road Level (ERL) of OMR in front of the site, and 0.4-M below ERL of Cheran Chenguttuvan Street behind the site. No significant vegetation was present in the site. Some old construction equipment was present in the site during this investigation. Proposed construction will be first major construction of this magnitude to cover the site. Site soil stratigraphy at the borings can be typically summarized as below:

Typical Soil Profile of the Site:

	Penetration, M		
Stratum	From	To	Description
I	0	2.5-8.0	Silty Sand and Sand Soils
II	2.5-8.0	10.0-14.5	Weathered Rock
III	10.0-14.5	14.5-16.0	Highly Jointed Granite Rock
IV	14.5-16.0	16.0-18.0+	Hard Granite Rock

Data from the borings indicate similar profiles with some variations in depth to hard granite rock. Hard strata (SPT "N" $\geq$ 75) weathered rock started from 3.5- to 8-M below EGL. Depth to coreable hard granite rock formation with good CR varied from 14.5- to 16-M below EGL. This site has high potential for groundwater at EGL itself as groundwater was at about 0.4-M below EGL in the borings with high recuperation capacity. As per the client's drawing for the proposed building expected bottom of the lowest basement floor or raft foundation will be about 10-M below EGL.

Therefore, for the proposed building, and expected column loads it was **recommended** to provide **"Combined Raft" foundation at about 10-M below EGL**. The combined raft should be designed for at least 10 tons/M^2 uplift hydraulic pressure. For this site it was recommended to provide rock anchors at regular intervals to provide better uplift resistance, and resistance to bending. A typical raft size of about 20- by 60-M at 10-M below EGL was considered in the analysis. For the considered foundation the **estimated ultimate and recommended allowable capacities were 1,195 and 50 tons**, respectively. Estimated total settlements for expected bearing pressure of 30 tons/M^2 was 3 mm, less than 75 mm, IS: 1904 - 2006 code limiting settlement for raft foundations on granular soils.

Groundwater was at about 0.4-M below EGL in Boring 1 through 3. There was no known groundwater source in the site. Hence, groundwater sample was collected from Boring 1 after flushing the boring a few times for construction suitability tests. Test results indicate groundwater from **Boring 1** was **not suitable** for construction purposes as per IS: 456 - 2000 guidelines due to high alkalinity as inferred by the methyl orange titration test, and high chlorides. However, the collected water had very strong odour inferring possible contamination by raw sewage from outside the site. Groundwater quality from the site should be checked during construction period at regular intervals to confirm groundwater construction suitability. All the structural elements upto EGL of the site should be provided with **steel and cement used upto stilt floor roof slab resistant to marine conditions** like ports and harbors.

Site soil profiles infer presence of weathered rock and jointed with N_{avg} > 100 from 5- / 6-M below EGL with more than 300 at deeper depths with hard granite rock with N_{avg} >> 100 beyond 14.5-M in the borings. Actual "Sub-Grade Modulus" value is influenced by thickness of soil in the influence zone, size and rigidity of foundation. Since it is not possible to estimate the same with variable strata, as a general guideline following sub-grade modulus values as per IS: 2950 - 1998 were presented. As per IS code in case of granular material with SPT "N_{avg}" > 30 and above in **saturated condition** **Sub-Grade Modulus** "**K_s**" was **2.9 to 10.8 kg/cm^3** (**2,900 to 10,800 tons/M^3**.) For the proposed raft design **Sub-Grade Modulus** "**K_s**" of **9.00 kg/cm^3** (**9,000 tons/M^3**) can be adopted.

We do expect construction problems at this site due to site's soil and very high groundwater conditions. Therefore, it will be necessary to provide a high capacity dewatering system to maintained dry working condition at 10-M depth below EGL. The typical average co-efficient of permeability "k" of top 5-M sand soils will be about 10^{-2} cms/sec range due to presence of layers of clean sands with 3% to 25% silt content. A trial pump-out test should be performed to ascertain the yield of the bore wells / wells to plan for the suitable capacity dewatering program for this site.

At 10-M final depth exposed weathered rock surface should be cleaned of thin layer of loose material accumulated due to softening by possible groundwater upward movement. Site's EGL was at about 0.3-M above ERL of OMR and 0.4-M below ERL of Cheran Chenguthavan Street behind the site. In order to avoid future site flooding from road runoff it was recommended to raise site's Finished Ground Level (FGL) by **at least 0.9-M above ERL** of OMR in front of the site, and the Finished Floor Level (FFL) of ground floor should be at least 0.35-M above FGL of the site. This will minimize rainwater flooding into site and building from rainwater and water from road due to rise in road level by regular relaying. The lowest basement floor slab should be designed to counter uplift pressure of 10 tons/M^2 due to possible high groundwater level. At present about six months after rainy season groundwater was at 0.4-M below EGL in the site. Excavated soils and weathered rock can be used for site filling purposes.

For the encountered sand soils in top 8-M, and high groundwater conditions 10-M deep excavation, properly designed earth retaining structure will be required to maintain deep excavation. For this site soil and groundwater conditions it was recommended to provide "**Diaphragm Wall**" along the periphery of the planned excavation. The wall should be designed for both soil and water pressure with provision of rock anchor tie-backs due to presence of hard rock at relatively shallow depth. Alternatively, any other type of suitably designed soil retaining structure can be provided for the excavation. However, it should be made sure the retaining structure should be continuous without any gaps to minimize or avoid seepage of groundwater into the excavation. To avoid future dampness problems it was recommended to grout bentonite solution outside the Diaphragm Wall from EGL to bottom rock level to reduce the co-efficient of permeability "k" of the soil adjacent to Diaphragm Wall which in turn reduces the groundwater seepage quantity.

All structures have to be designed for higher seismic forces (**Zone III**) due to increased seismic activity in peninsular India in the last decade and half. Seismic events of 7.9 magnitude on April 25, 2015, 6.0 magnitude on May 21, 2014, 8.4 magnitude on April 11, 2012, 7.2 magnitude on June 13, 2010, and 7.6 magnitude on August 11, 2009 with epicenters in Himalayas, Bay of Bengal, and near Andaman Islands were felt at Chennai. It is recommended to provide rigid plinth beams in ground level, shear walls in the structure, and continuous lintels in each floor. Lintels must be integrated into columns of the structure. Plinth beams must be designed to be rigid to allow redistribution of loads in case of differential settlements. The site soil profile infers **"No"** seismic susceptibility. For overall soil profile under a seismic event of **6.5 Richter scale**, and peak ground acceleration of **0.08g** the total estimated vertical settlement was 8.34 cms and total horizontal displacement was about 92.12 cms with main contribution from soil in the top 5-M. For the same Iwasaki liquefaction potential was 4.40 inferring "**Liquefaction Not Probable**." **However, for the proposed building resting on hard strata weathered rock there will be no significant vertical or horizontal movements.** Also, for the same Iwasaki liquefaction potential was 0.0 inferring "**No Liquefaction**." As per IS code for **Zone III** design horizontal acceleration was **0.08g** only. Hence, in the analysis peak ground acceleration of **0.08g** was used.

INTRODUCTION

Purpose and Scope

Prasad Armstrong Yen GEC (P) Ltd. performed a geotechnical site investigation at the Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai 600 096, TN. Primary purpose of the investigation was to obtain data to develop to identify variability in soil and rock stratification of the site, select suitable foundation, and estimate load carrying capacities of the considered foundation. Typical maximum column load will be about 1,250 tons for the proposed building type with large column spans and spacing. In case of combined raft foundation the expected maximum bearing pressure will be about 30 tons/M^2. These details were used only for estimating the preliminary foundation size and type of foundation. To accomplish these purposes, the following tasks were performed:

(1) Boring 1 through 4 were drilled to 18-, 17-, 17-, and 17-M below EGL of excavated area to explore the subsurface stratigraphy and obtain soil and rock samples for lab testing;

(2) Field and laboratory tests were conducted to evaluate the pertinent index and engineering properties of the foundation materials; and

(3) Engineering analyses were performed to develop foundation design information for the proposed building.

Report Format

The initial sections of this report contain brief descriptions of the field and laboratory phases of our study. A general soils description is then presented, followed by discussions of foundation design recommendations followed by a brief on construction considerations for this project.

FIELD AND LABORATORY INVESTIGATIONS

Exploratory Borings

Soil conditions at the site were explored by Boring 1 through 4. Boring location details are presented on Plate 1. Number and location of the borings was selected to cover four corner of the proposed building. Boring 1 through 4 were drilled to 18-, 17-, 17-, and 17-M penetration below EGL, respectively. All the borings were terminated after drilling into **hard granite rock formation**. NX TC bit and diamond bit drilling was used for drilling through the rock formation. In the last 2- to 3-M of drilling rock core recovery (CR) was more than 75% and above with RQD in the range of 50% and 100%. Tests were conducted to determine the pertinent index and engineering properties of the soils and rock encountered. Groundwater was at about 0.4-M below EGL in the boring 1 through 3. Log of Boring are presented on Plate 2 thorough 5.

Field and Laboratory Tests

Borings were drilled using Calyx drilling unit. In the borings SPT was performed at 0.75-M interval upto 7-M, at 1-M interval upto 10-M, and at 1.5-M interval beyond 10-M from EGL, and soil and rock samples for laboratory tests were collected. SPT consists of driving a standard split spoon sampler, 50.8-mm outside diameter and 35-mm inside diameter into soil under the blows of a drop

hammer of 63.5 kg falling weight freely through 75-cm. The number of blows required for 30-cm of penetration of sampler in soil is designated as N value and it is termed as the SPT blow count. Detailed information regarding SPT can be found in the IS: 2131 code of practice.

The soil-testing program was designed to evaluate pertinent index and engineering properties of the encountered foundation soil and rock samples. During the field operations soil and rock samples were collected at 1-M interval either disturbed or undisturbed as the case may be. All soil and rock samples were shipped to our Chennai laboratory where pertinent index properties - grain size analyses, natural water content Atterberg limit tests were performed on collected soil samples. Point load tests were performed on rock core samples to estimate the rock strength. All the test results were tabulated on the Summary of Test Results on Plate 6. Grain size distribution curves of tested samples were presented on Plate 7. Summary of water test results are presented on Plate 8.

GENERAL SOIL CONDITIONS

Topography

Natural topography of the site reflects a relatively flat terrain. Site had Old Mahabalipuram Road (OMR) along the eastern boundary and Cheran Chenguttuvan Street along the western boundary. A Stilt + 9 floors residential apartments building was present in the adjacent north side plot. A Stilt + 4 floors residential apartments building was present in the adjacent south side plot. Present site's EGL was about 0.3-M above ERL of OMR in front of the site, and 0.4-M below ERL of Cheran Chenguttuvan Street behind the site. No significant vegetation was present in the site. Some old construction equipment was present in the site during this investigation. Proposed construction will be first major construction of this magnitude to cover the site.

Soil Stratigraphy

Soil stratigraphy disclosed by our field and laboratory investigations of the borings is presented on the log of borings on Plate 2 through 5. The soil stratigraphy is based on classification of soil samples recovered from the boring, and our observations during drilling operations. A generalized summary of the major soil strata is tabulated below:

Boring – 1:

Stratum	Penetration, M From	To	Description
I	0	1.0	Brown Fine to Medium Sand with Silt and Rubbish
II	1.0	2.25	Gray Brown Silty Fine to Medium Sand
III	2.25	5.0	Gray Brown Fine to Medium Sand with Silt
IV	5.0	6.0	Brown Gray Green Silty Fine to Medium Sand
V	6.0	10.0	Brown Green White Weathered Rock
VI	10.0	16.0	Brown Blue Highly Jointed Rock
VII	16.0	18.0+	Brown Blue Granite

Boring – 2:

Stratum	Penetration, M From	To	Description
I	0	1.75	Brown Silty Fine to Medium Sand with Rubbish
II	1.75	4.0	Gray Brown Silty Fine Sand
III	4.0	4.75	Gray Fine to Medium Sand with Silt and Shell Fragments
IV	4.75	8.0	White Brown Green Silty Fine to Coarse Sand with Weathered Rock
V	8.0	14.5	Blue White Brown Weathered Rock
VI	14.5	17.0+	Brown Green Blue Granite

Boring – 3:

Stratum	Penetration, M From	To	Description
I	0	1.0	Brown Fine to Medium Sand with Silt and Rubbish
II	1.0	2.5	Gray Brown Silty Fine to Medium Sand
III	2.5	14.5	White Gray Brown Weathered Rock
IV	14.5	17.0+	Brown Blue Granite

Boring – 4:

Stratum	Penetration, M From	To	Description
I	0	1.0	Brown Silty Fine to Medium Sand with Rubbish
II	1.0	2.5	Gray Brown Silty Fine to Medium Sand
III	2.5	3.25	Gray Brown Red Gravely Silty Fine to Coarse Sand
IV	3.25	11.5	White Gray Brown Weathered Rock
V	11.5	16.0	Brown Blue Highly Jointed Rock
VI	16.0	17.0+	Green Blue Granite

Detailed soil descriptions that include textural variations and inclusions are noted on the log of boring, presented on Plate 2 through 5.

Interpretation of Soil and Rock Properties

Shear strength parameters for cohesionless soils were selected based on the SPT, and grain size distribution analyses. Shear strength parameters for cohesive soils were selected based on the SPT results. The unit weight (soil density) profiles of the soils in the borings were developed from estimated values based on correlations of unit weight with particle size gradation and field test results (Bowles, 1982.) Point load test data on rock core samples infer very wide variation in rock core uniaxial compressive strength due to presence or absence of joints or facture planes in the rock core sample. Due to presence of large number of joints in a highly random distribution the rock mass was treated as very dense gravely formation for foundation design.

Foundation recommendations presented herein were based on the soil properties encountered in the Boring 2. There may be a need to drill additional borings to investigate soil variability after more

specific building location details are finalized. Based on the field and laboratory test results the following are the properties for soils encountered in the borings.

Boring – 1:

Stratum	Penetration, M From	To	Properties
I	0	1.0	γ_{sat} = 1.55 tons/M^3
II	1.0	2.25	$\phi = 27^o$; γ_{sat} = 1.55 tons/M^3
IIIa	2.25	4.0	$\phi = 25^o$; γ_{sat} = 1.45 tons/M^3
IIIb	4.0	5.0	$\phi = 29^o$; γ_{sat} = 1.65 tons/M^3
IV	5.0	6.0	$\phi = 38^o$; γ_{sat} = 2.2 tons/M^3
V	6.0	10.0	$\phi = 39^o$; γ_{sat} = 2.25 tons/M^3
VI	10.0	16.0	$\phi = 40^o$; γ_{sat} = 2.3 tons/M^3
VII	16.0	18.0+	$\phi = 42^o$; γ_{sat} = 2.35 tons/M^3

Boring – 2:

Stratum	Penetration, M From	To	Properties
Ia	0	1.0	γ_{sat} = 1.7 tons/M^3
Ib	1.0	1.75	γ_{sat} = 1.85 tons/M^3
IIa	1.0	2.5	$\phi = 27^o$; γ_{sat} = 1.55 tons/M^3
IIb	2.5	3.25	C_u = 2 tons/M^2; γ_{sat} = 1.455 tons/M^3
IIc	3.25	4.0	$\phi = 24^o$; γ_{sat} = 1.4 tons/M^3
III	4.0	4.75	$\phi = 24^o$; γ_{sat} = 1.4 tons/M^3
IVa	4.75	6.25	$\phi = 37^o$; γ_{sat} = 2.1 tons/M^3
IVb	6.25	8.0	$\phi = 38^o$; γ_{sat} = 2.2 tons/M^3
Va	8.0	9.0	$\phi = 38^o$; γ_{sat} = 2.2 tons/M^3
Vb	9.0	10.0	$\phi = 39^o$; γ_{sat} = 2.25 tons/M^3
Vc	10.0	11.5	$\phi = 37^o$; γ_{sat} = 2.1 tons/M^3
Vd	11.5	14.5	$\phi = 39^o$; γ_{sat} = 2.25 tons/M^3
VI	14.5	17.0+	$\phi = 42^o$; γ_{sat} = 2.35 tons/M^3

Boring – 3:

Stratum	Penetration, M From	To	Properties
I	0	1.0	γ_{sat} = 1.5 tons/M^3
IIa	1.0	1.75	$\phi = 26^o$; γ_{sat} = 1.55 tons/M^3
IIb	1.75	2.5	$\phi = 30^o$; γ_{sat} = 1.65 tons/M^3
IIIa	2.5	3.5	$\phi = 34^o$; γ_{sat} = 1.85 tons/M^3
IIIb	3.5	4.75	$\phi = 37^o$; γ_{sat} = 2.1 tons/M^3
IIIc	4.75	6.25	$\phi = 38^o$; γ_{sat} = 2.2 tons/M^3
IIId	6.25	9.0	$\phi = 39^o$; γ_{sat} = 2.25 tons/M^3
IIIe	9.0	14.5	$\phi = 40^o$; γ_{sat} = 2.3 tons/M^3
IV	14.5	17.0+	$\phi = 42^o$; γ_{sat} = 2.35 tons/M^3

Boring – 4:

Stratum	Penetration, M From	To	Properties
I	0	1.0	γ_{sat} = 1.55 tons/M^3
II	1.0	2.5	$\phi = 28^o$; γ_{sat} = 1.6 tons/M^3

III	2.5	3.25	$\phi = 37^o$; γ_{sat} = 2.1 tons/M^3
IVa	3.25	4.75	$\phi = 37^o$; γ_{sat} = 2.1 tons/M^3
IVb	4.75	11.5	$\phi = 39^o$; γ_{sat} = 2.25 tons/M^3
V	11.5	16.0	$\phi = 40^o$; γ_{sat} = 2.3 tons/M^3
VI	16.0	17.0+	$\phi = 42^o$; γ_{sat} = 2.35 tons/M^3

DESIGN INFORMATION

Data from the borings indicate similar profiles with some variations in depth to hard granite rock. Hard strata (SPT "N" $\geq$ 75) weathered rock started from 3.5- to 8-M below EGL. Depth to coreable hard granite rock formation with good CR varied from 14.5- to 16-M below EGL. This site has high potential for groundwater at EGL itself as groundwater was at about 0.4-M below EGL in the borings with high recuperation capacity. As per the client's drawing for the proposed building expected bottom of the lowest basement floor or raft foundation will be about 10-M below EGL. Therefore, for the proposed building, and expected column loads it was **recommended** to provide **"Combined Raft" foundation at about 10-M below EGL**. The combined raft should be designed for at least 11.5 tons/M^2 uplift hydraulic pressure. For this site it was recommended to provide rock anchors at regular intervals to provide better uplift resistance, and resistance to bending. A typical raft size of about 20- by 60-M at 10-M below EGL was considered in the analysis. The ultimate bearing capacity of the soil was estimated as per IS: 6403 Code of Practice Method using the following equation and soil parameters presented above sections:

$$q_{ult} = CN_c s_c d_c i_c + q(N_q - 1)s_q d_q i_q + 0.5B\gamma' N_\gamma s_\gamma d_\gamma i_{\gamma\delta}$$

Where

B = Width of Footing;
q_{ult} = Ultimate Bearing Capacity of the Soil;
C = Avg. Soil Undrained Shear Strength;
N_c , N_q & N_γ = Bearing Capacity Factors;
q = Eff. Vertical Pressure at Footing Level
γ' = Eff. Unit Weight of Soil;
s_c, s_q, s_γ = Shape Factors;
d_c, d_q, d_γ = Depth Factors;
i_c, i_q, i_γ = Inclination Factors; and

For the considered foundation **estimated ultimate and recommended allowable capacities were 1,195 and 50 tons**, respectively. Estimated total settlement was 3 mm, less than 75 mm, the IS: 1904 - 2006 code limiting settlement for raft foundations on granular material. Hence, raft foundation can be used for the proposed building at this site. Sample foundation capacity calculations were presented on Plate 9.

GROUNDWATER

Groundwater was at about 0.4-M below EGL in Boring 1 through 3. There was no known groundwater source in the site. Hence, groundwater sample was collected from Boring 1 after flushing the boring a few times for construction suitability tests. Test results indicate groundwater from **Boring 1** was **not suitable** for construction purposes as per IS: 456 - 2000 guidelines due to high alkalinity as inferred by the methyl orange titration test, and high chlorides. However, the collected water had very strong odour inferring possible contamination by raw sewage from outside the site. Groundwater quality from the site should be checked during construction period at regular intervals to confirm groundwater construction suitability. All the structural elements upto EGL of the site should be

provided with **steel and cement used upto stilt floor roof slab resistant to marine conditions** like ports and harbors. Summary of groundwater test results are presented on Plate 8.

SUB-GRADE MODULUS OF SOIL

Site soil profiles infer presence of weathered rock and jointed with N_{avg} > 100 from 5- / 6-M below EGL with more than 300 at deeper depths with hard granite rock with N_{avg} >> 100 beyond 14.5-M in the borings. Actual "Sub-Grade Modulus" value is influenced by thickness of soil in the influence zone, size and rigidity of foundation. Since it is not possible to estimate the same with variable strata, as a general guideline following sub-grade modulus values as per IS: 2950 - 1998 were presented. As per IS code in case of granular material with SPT "N_{avg}" > 30 and above in **saturated condition** **Sub-Grade Modulus** "**K_s**" was **2.9 to 10.8 kg/cm^3** (**2,900 to 10,800 tons/M^3**.) For the proposed raft design **Sub-Grade Modulus** "**K_s**" of **9.00 kg/cm^3** (**9,000 tons/M^3**) can be adopted.

CONSTRUCTION CONSIDERATIONS

We do expect construction problems at this site due to site's soil and very high groundwater conditions. Therefore, it will be necessary to provide a high capacity dewatering system to maintained dry working condition at 10-M depth below EGL. The typical average co-efficient of permeability "k" of top 5-M sand soils will be about 10^{-2} cms/sec range due to presence of layers of clean sands with 3% to 25% silt content. A trial pump-out test should be performed to ascertain the yield of the bore wells / wells to plan for the suitable capacity dewatering program for this site.

At 10-M final depth exposed weathered rock surface should be cleaned of thin layer of loose material accumulated due to softening by possible groundwater upward movement. Site's EGL was at about 0.3-M above ERL of OMR and 0.4-M below ERL of Cheran Chenguthavan Street behind the site. In order to avoid future site flooding from road runoff it was recommended to raise site's FGL by **at least 0.9-M above ERL** of OMR in front of the site, and FFL of ground floor should be at least 0.35-M above FGL of the site. This will minimize rainwater flooding into site and building from rainwater and water from road due to rise in road level by regular relaying. The lowest basement floor slab should be designed to counter uplift pressure of 10 tons/M^2 due to possible high groundwater level. At present about six months after rainy season groundwater was at 0.4-M below EGL in the site. Excavated soils and weathered rock can be used for site filling purposes.

For the encountered sand soils in top 8-M, and high groundwater conditions 10-M deep excavation, properly designed earth retaining structure will be required to maintain deep excavation. For this site soil and groundwater conditions it was recommended to provide "**Diaphragm Wall**" along the periphery of the planned excavation. The wall should be designed for both soil and water pressure with provision of rock anchor tie-backs due to presence of hard rock at relatively shallow depth. Alternatively, any other type of suitably designed soil retaining structure can be provided for the excavation. However, it should be made sure the retaining structure should be continuous without any gaps to minimize or avoid seepage of groundwater into the excavation. To avoid future dampness problems it was recommended to grout bentonite solution outside the Diaphragm Wall from EGL to bottom rock level to reduce the co-efficient of permeability "k" of the soil adjacent to Diaphragm Wall which in turn reduces the groundwater seepage quantity.

All structures have to be designed for higher seismic forces (**Zone III**) due to increased seismic activity in peninsular India in the last decade and half. Seismic events of 7.9 magnitude on April 25, 2015, 6.0 magnitude on May 21, 2014, 8.4 magnitude on April 11, 2012, 7.2 magnitude on June 13, 2010, and 7.6 magnitude on August 11, 2009 with epicenters in Himalayas, Bay of Bengal, and near Andaman Islands were felt at Chennai. It is recommended to provide rigid plinth beams in ground level, shear walls in the structure, and continuous lintels in each floor. Lintels must be integrated into columns of the structure. Plinth beams must be designed to be rigid to allow redistribution of loads in case of differential settlements. The site soil profile infers **"No"** seismic susceptibility. For overall soil profile under a seismic event of **6.5 Richter scale**, and peak ground acceleration of **0.08g** the total estimated vertical settlement was 8.34 cms and total horizontal displacement was about 92.12 cms with main contribution from soil in the top 5-M. For the same Iwasaki liquefaction potential was 4.40 inferring "**Liquefaction Not Probable**." **However, for the proposed building resting on hard strata weathered rock there will be no significant vertical or horizontal movements.** Also, for the same Iwasaki liquefaction potential was 0.0 inferring "**No Liquefaction**." As per IS code for **Zone III** design horizontal acceleration was **0.08g** only. Hence, in the analysis peak ground acceleration of **0.08g** was used. Liquefaction Analysis results are presented on Plate 10.

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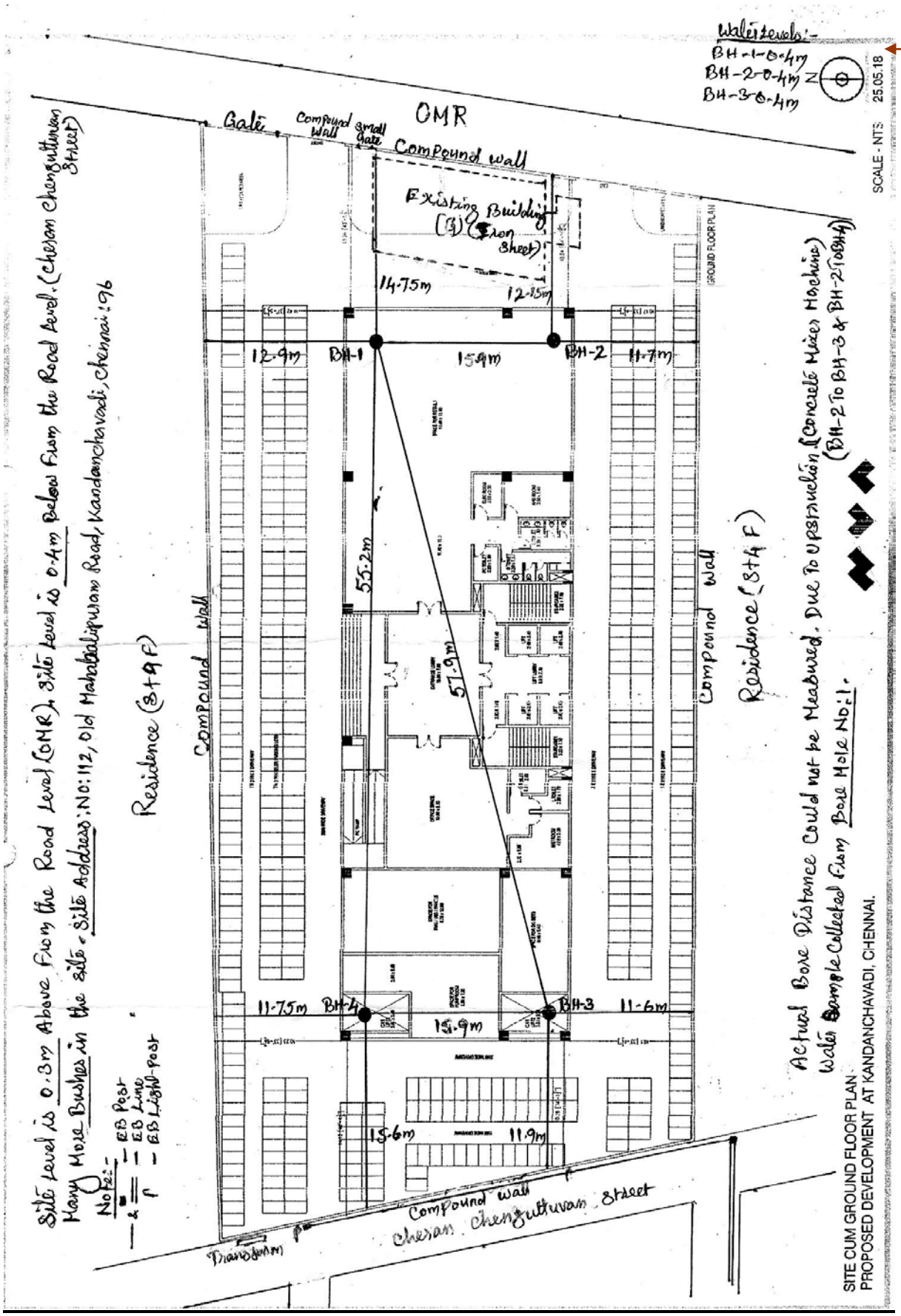
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(Not to Scale)

Site EGL = 0.3-M Above ERL of Road In Front of Site.

Site Plan With Bore Location Details.

PLATE 1

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 1 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 14-6-'18 **Ended on:** 17-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 18.0-M **Depth to G W S:** 0.4-M **Remarks:** None.

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE	SPT "N" PROFILE 10 20 30	INDEX TEST DATA 25 50 75
GWL	**BROWN FINE TO MEDIUM SAND with silt and rubbish (To 1.0-M)**	DS @ 0.25 M		
	0.0- to 1.0-m – γ_t = 1.55 tons/M^3	SPT @ 1 M		
1.0	(N_{avg} ~ 6)	3/3/4 = 7 Blows		
	GRAY BROWN SILTY FINE TO MEDIUM SAND (To 2.25-M)	SPT @ 1.75 M		
	1.0- to 2.25-m – ϕ = 27°; γ_t = 1.55 tons/M^3	3/4/7 = 11 Blows		
2.0	(N_{avg} = 7)			
		SPT @ 2.5 M		
	GRAY BROWN FINE TO MEDIUM SAND with silt (To 5.0-M)	2/1/2 = 3 Blows		
3.0	-with shell fragments, 2.25- to 4-m	SPT @ 3.25M (SNR)		
	2.25- to 4.0-m – ϕ = 25°; γ_t = 1.45 tons/M^3	0/1/1 = 2 Blows		
	(N_{avg} ~ 2.5)			
4.0		SPT @ 4 M		
		4/3/7 = 10 Blows		
	4.0- to 5.0-m – ϕ = 29°; γ_t = 1.65 tons/M^3			
	(N_{avg} = 10)	SPT @ 5 M 23/		
5.0		2 cms for 10 Blows		
	BROWN GRAY GREEN SILTY FINE TO MEDIUM SAND (To 6.0-M) (N_{avg} > 100)	(Hammer Rebound)		
	5.0- to 6.0-m – ϕ = 38°; γ_t = 2.2 tons/M^3	SPT @ 6 M		
6.0	-NX TC bit drilling from 6-m	2 cms for 10 Blows		
	BROWN GREEN WHITE WEATHERED ROCK (To 10.0-M)	1 cms for 10 Blows		
		(Hammer Rebound)		
		SPT @ 7 M (SNR)		
7.0	-drilled from 6- to 7-m in 90 minutes	2 cms for 20 Blows		
	-NX Diamond bit drilling from 7-m	(Hammer Rebound)		
		SPT @ 8 M (SNR)		
8.0	-drilled from 7- to 8-m in 20 minutes	0.5 cms for 5 Blows		
	6.0- to 10.0-m – ϕ = 39°; γ_t = 2.25 tons/M^3	0 cms for 5 Blows		
	(N_{avg} >> 100)	(Hammer Rebound)		
		SPT @ 9 M (SNR)		
9.0	-drilled from 8- to 9-m in 25 minutes	0 cms for 5 Blows		
		(Hammer Rebound)		
		SPT @ 10 M (SNR)		
10.0	-drilled from 9- to 10-m in 25 minutes	0 cms for 5 Blows		
	BROWN BLUE HIGHLY JOINTED GRANITE (To 16.0-M)	(Hammer Rebound)		
	10.0- to 16.0-m – ϕ = 40°; γ_t = 2.3 tons/M^3			
11.0	(N_{avg} >> 100)			

CONTINUED ON PLATE 2b.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 2a

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 1 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 14-6-'18 **Ended on:** 17-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 18.0-M **Depth to G W S:** 0.4-M **Remarks:** **Continued from Plate 2b.**

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE	SPT "N" PROFILE 10 20 30	INDEX TEST DATA 25 50 75
	BROWN BLUE HIGHLY JOINTED GRANITE (To 16.0-M)	SPT @ 11.5M (SNR) 0 cms for 5 Blows		
12.0	-drilled from 10- to 11.5-m in 110 minutes -37 cms core recovered drilling to 11.5-m	(Hammer Rebound)		
	-25% CR and 0% RQD 10.0- to 16.0-m – $\phi = 40^o$; $\gamma_t = 2.3$ tons/M^3 (N_{avg} >> 100)	SPT @ 13 M (SNR)		
13.0	-drilled from 11.5- to 13-m in 105 minutes	0 cms for 5 Blows		
	-9 cms core recovered drilling to 13-m -drilled from 13- to 13.65-m in 60 minutes	(Hammer Rebound) SPT@13.65M (SNR)		
14.0	-12 cms core recovered drilling to 13.65-m -18% CR and 0% RQD	0 cms for 5 Blows (Hammer Rebound)		
	-drilled from 13.65- to 14.5-m in 80 minutes	SPT @ 14.5M (SNR) 0 cms for 5 Blows		
15.0	-36 cms core recovered drilling to 14.5-m -42% CR and 0% RQD	(Hammer Rebound)		
	-drilled from 14.5- to 16-m in 75 minutes			
16.0	-29 cms core recovered drilling to 16-m -29% CR and 17% RQD	SPT @ 16 M (SNR) 0 cms for 5 Blows		
	BROWN BLUE GRANITE (Below 16.0-M) -drilled from 16- to 17-m in 750 minutes	(Hammer Rebound)		
17.0	-76.5 cms core recovered drilling to 17-m -76% CR and 46% RQD			
	16.0- to 18.0-m – $\phi = 42^o$; $\gamma_t = 2.35$ tons/M^3 (N_{avg} >> 100)			
18.0	-drilled from 17- to 18-m in 135 minutes	SPT @ 18 M (SNR) 0 cms for 5 Blows		
	-93 cms core recovered drilling to 18-m -93% CR and 57% RQD	(Hammer Rebound)		
19.0				
20.0				
21.0				
22.0				

BORE HOLE TERMINATED AT 18.0-M.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 2b

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 2 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 17-6-'18 **Ended on:** 18-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 17.0-M **Depth to G W S:** 0.4-M **Remarks:** None.

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE
GWL	**BROWN SILTY FINE TO MEDIUM SAND with rubbish (To 1.75-M)**	DS @ 0.25 M
	0.0- to 1.0-m – γ_t = 1.7 tons/M^3	SPT @ 1 M
1.0	(N_{avg} ~ 16)	8/12/14 = 26 Blows
	1.0- to 1.75-m – γ_t = 1.85 tons/M^3	
	(N_{avg} ~ 26)	SPT @ 1.75 M
		2/2/4 = 6 Blows
2.0	**GRAY BROWN SILTY FINE SAND (To 4.0-M)**	
	1.75- to 2.5-m – ϕ = 27^o; γ_t = 1.55 tons/M^3	SPT @ 2.5 M
	(N_{avg} = 6)	2/1/2 = 3 Blows
	-soft clay at 2.5-m	
3.0	2.5- to 3.25-m – C_u = 2 tons/M^2; γ_t = 1.45 tons/M^3	SPT @ 3.25M (SNR)
	(N_{avg} = 3)	1/0/1 = 1 Blows
	3.25- to 4.0-m – ϕ = 24^o; γ_t = 1.4 tons/M^3	
	(N_{avg} = 1)	SPT @ 4 M
4.0		0/0/1 = 1 Blows
	GRAY FINE TO MEDIUM SAND with silt and shell fragments (To 4.75-M) (N_{avg} = 1)	SPT @ 4.75 M 26/
	4.0- to 4.75-m – ϕ = 24^o; γ_t = 1.4 tons/M^3	8 cms for 20 Blows
5.0	**WHITE BROWN GREEN SILTY FINE TO COARSE SAND with weathered rock (To 8.0-M)**	
	4.75- to 6.25-m – ϕ = 37^o; γ_t = 2.1 tons/M^3	SPT @ 5.5 M 24/ 4 cms for 10 Blows
	(N_{avg} ~ 75)	3 cms for 10 Blows
6.0		(Hammer Rebound)
		SPT @ 6.25 M
		4 cms for 10 Blows
	-NX TC bit drilling from 7-m	2 cms for 10 Blows
7.0	6.25- to 8.0-m – ϕ = 38^o; γ_t = 2.2 tons/M^3	SPT @ 7.0 M
	(N_{avg} > 100)	3 cms for 10 Blows
		2 cms for 10 Blows
	-drilled from 7- to 8-m in 25 minutes	SPT @ 8 M
8.0	-NX Diamond bit drilling from 8-m	3 cms for 10 Blows
	BLUE WHITE BROWN WEATHERED ROCK (To 14.5-M)	2 cms for 10 Blows (Hammer Rebound)
	8.0- to 9.0-m – ϕ = 38^o; γ_t = 2.2 tons/M^3	SPT @ 9 M (SNR)
9.0	(N_{avg} > 100)	0.5 cms for 5 Blows
	-drilled from 8- to 9-m in 30 minutes	0 cms for 5 Blows
	9.0- to 10.0-m – ϕ = 39^o; γ_t = 2.25 tons/M^3	(Hammer Rebound)
	(N_{avg} >> 100)	SPT @ 10 M 18/22/
10.0	-drilled from 9- to 10-m in 20 minutes	3 cms for 10 Blows
	-white green silty fine sand and wea. rock mix at 10-m	(Hammer Rebound)
	10.0- to 11.5-m – ϕ = 37^o; γ_t = 2.1 tons/M^3	
	(N_{avg} ~ 75)	
11.0		

SPT "N" PROFILE: 10 20 30

INDEX TEST DATA: 25 50 75

CONTINUED ON PLATE 3b.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 3a

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 2 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 17-6-'18 **Ended on:** 18-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 17.0-M **Depth to G W S:** 0.4-M **Remarks:** **Continued from Plate 3b.**

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE	SPT "N" PROFILE 10 20 30	INDEX TEST DATA 25 50 75
	BLUE WHITE BROWN WEATHERED ROCK (To 14.5-M)	SPT @ 11.5M (SNR) 1.5 cms for 15 Blows		
12.0	-drilled from 10- to 11.5-m in 35 minutes	0 cms for 5 Blows (Hammer Rebound)		
13.0	-drilled from 11.5- to 13-m in 40 minutes 11.5- to 14.5-m – $\phi = 39^{o}$; $\gamma_t = 2.25$ tons/M^3 (N_{avg} >> 100)	SPT @ 13 M (SNR) 0.5 cms for 5 Blows 0 cms for 5 Blows (Hammer Rebound)		
14.0	-drilled from 13- to 14.5-m in 110 minutes -47.5 cms core recovered drilling to 14.5-m -32% CR and 24% RQD	SPT @ 14.5M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
15.0	**BROWN GREEN BLUE GRANITE (Below 14.5-M)**			
16.0	-drilled from 14.5- to 16-m in 135 minutes -129 cms core recovered drilling to 16-m -86% CR and 74% RQD 14.5- to 17.0-m – $\phi = 42^{o}$; $\gamma_t = 2.35$ tons/M^3 (N_{avg} >> 100)	SPT @ 16 M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
17.0	-drilled from 16- to 17-m in 80 minutes -100 cms core recovered drilling to 17-m -100% CR and 82% RQD	SPT @ 17 M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
18.0				
19.0				
20.0				
21.0				
22.0				

BORE HOLE TERMINATED AT 17.0-M.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 3b

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 3 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 19-6-'18 **Ended on:** 20-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 17.0-M **Depth to G W S:** 0.4-M **Remarks:** None.

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE	SPT "N" PROFILE 10 20 30	INDEX TEST DATA 25 50 75
GWL	BROWN FINE TO MEDIUM SAND with silt and rubbish (To 1.0-M)	DS @ 0.25 M		
	0.0- to 1.0-m – γ_t = 1.5 tons/M^3	SPT @ 1 M		
1.0	(N_{avg} ~ 4)	2/2/3 = 5 Blows		
	GRAY BROWN SILTY FINE TO MEDIUM (To 2.5-M) (N_{avg} = 5)	SPT @ 1.75 M		
	1.0- to 1.75-m – ϕ = 26°; γ_t = 1.55 tons/M^3	2/4/9 = 13 Blows		
2.0				
	1.75- to 2.5-m – ϕ = 30°; γ_t = 1.65 tons/M^3	SPT @ 2.5 M		
	(N_{avg} = 13)	10/15/14 = 29 Blows		
	WHITE GRAY BROWN WEATHERED ROCK			
3.0	(To 14.5-M)	SPT @ 3.25M 10/25/		
	2.5- to 3.5-m – ϕ = 34°; γ_t = 1.85 tons/M^3	5 cms for 10 Blows		
	(N_{avg} = 30)	4 cms for 10 Blows		
		SPT @ 4 M 14/		
4.0		4 cms for 10 Blows		
	3.5- to 4.75-m – ϕ = 37°; γ_t = 2.1 tons/M^3	3 cms for 10 Blows		
	(N_{avg} > 75)	SPT @ 4.75 M 28/		
		2 cms for 10 Blows		
5.0		(Hammer Rebound)		
		SPT @ 5.5 M		
	4.75- to 6.25-m – ϕ = 38°; γ_t = 2.2 tons/M^3	3 cms for 10 Blows		
	(N_{avg} > 100)	2 cms for 10 Blows		
6.0		SPT @ 6.25 M		
	-NX TC bit drilling from 6.25-m	2 cms for 10 Blows		
		1 cm for 10 Blows		
		SPT @ 7 M		
7.0	-drilled from 6.25- to 7-m in 20 minutes	1.5 cms for 10 Blows		
		1 cm for 10 Blows		
	6.25- to 9.0-m – ϕ = 39°; γ_t = 2.25 tons/M^3	(Hammer Rebound)		
	(N_{avg} >> 100)	SPT @ 8 M 27/		
8.0	-drilled from 7- to 8-m in 30 minutes	1 cm for 10 Blows		
		(Hammer Rebound)		
		SPT @ 9 M (SNR)		
9.0	-drilled from 8- to 9-m in 30 minutes	0.5 cms for 5 Blows		
	-NX Diamond bit drilling from 9-m	0 cms for 5 Blows		
		(Hammer Rebound)		
		SPT @ 10 M (SNR)		
10.0	-drilled from 9- to 10-m in 20 minutes	0 cms for 5 Blows		
	9.0- to 14.5-m – ϕ = 40°; γ_t = 2.3 tons/M^3	(Hammer Rebound)		
	(N_{avg} >> 100)			
11.0				

CONTINUED ON PLATE 4b.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 4a

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 3 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 19-6-'18 **Ended on:** 20-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 17.0-M **Depth to G W S:** 0.4-M **Remarks:** **Continued from Plate 4b.**

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE	SPT "N" PROFILE 10 20 30	INDEX TEST DATA 25 50 75
	WHITE GRAY BROWN WEATHERED ROCK (To 14.5-M)	SPT @ 11.5 M 2 cms for 15 Blows		♦■
	-drilled from 10- to 11.5-m in 25 minutes	0 cms for 5 Blows (Hammer Rebound)		
12.0				
	-drilled from 11.5- to 13-m in 40 minutes	SPT @ 13 M (SNR)		
13.0	9.0- to 14.5-m – $\phi = 40^{o}$; $\gamma_t = 2.3$ tons/M^3	0.5 cms for 5 Blows		
	(N_{avg} >> 100)	0 cms for 5 Blows (Hammer Rebound)		
14.0				
	-drilled from 13- to 14.5-m in 50 minutes	SPT @ 14.5M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
15.0	BROWN BLUE GRANITE (Below 14.5-M)			
	-drilled from 14.5- to 16-m in 140 minutes			
16.0	-131.5 cms core recovered drilling to 16-m -88% CR and 69% RQD	SPT @ 16 M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
	14.5- to 17.0-m – $\phi = 42^{o}$; $\gamma_t = 2.35$ tons/M^3 (N_{avg} >> 100)			
17.0	-drilled from 16- to 17-m in 95 minutes	SPT @ 17 M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
	-97 cms core recovered drilling to 17-m -97% CR and 83% RQD			
18.0				
19.0				
20.0				
21.0				
22.0				

BORE HOLE TERMINATED AT 17.0-M.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 4b

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 4 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 20-6-'18 **Ended on:** 22-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 17.0-M **Depth to G W S:** Not Measured **Remarks:** None.

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE	SPT "N" PROFILE 10 20 30	INDEX TEST DATA 25 50 75
	BROWN SILTY FINE TO MEDIUM SAND with rubbish (To 1.0-M)	DS @ 0.25 M		
	0.0- to 1.0-m – γ_t = 1.55 tons/M^3	SPT @ 1 M		
1.0	(N_{avg} ~ 6)	3/3/6 = 9 Blows		
	GRAY BROWN SILTY FINE TO MEDIUM SAND (To 2.5-M)	SPT @ 1.75 M		
	1.0- to 2.5-m – ϕ = 28°; γ_t = 1.6 tons/M^3	3/3/7 = 10 Blows		
2.0	(N_{avg} = 9)			
		SPT @ 2.5 M 18/		
		5 cms for 10 Blows		
	GRAY BROWN RED GRAVELY SILTY FINE	4 cms for 10 Blows		
3.0	**TO COARSE SAND (To 3.25-M)** (N_{avg} ~ 70)	SPT @ 3.25M 10/27/		
	2.5- to 3.25-m – ϕ = 37°; γ_t = 2.1 tons/M^3	4 cms for 10 Blows		
	WHITE GRAY BROWN WEATHERED ROCK	3 cms for 10 Blows		
	(To 11.5-M)	SPT @ 4 M		
4.0	3.25- to 4.75-m – ϕ = 37°; γ_t = 2.1 tons/M^3	4 cms for 10 Blows		
	(N_{avg} ~ 75)	3 cms for 10 Blows		
		SPT @ 4.75 M		
	-NX TC bit drilling from 4.75-m	1.5 cms for 10 Blows		
5.0		1 cm for 10 Blows		
		SPT @ 5.5 M (SNR)		
	-drilled from 4.75- to 5.5-m in 35 minutes	1.5 cms for 15 Blows		
	-NX Diamond bit drilling from 5.5-m	0 cms for 5 Blows		
6.0		SPT @ 6.25M (SNR)		
	-drilled from 5.5- to 6.25-m in 15 minutes	0.5 cms for 5 Blows		
		0 cms for 5 Blows		
		SPT @ 7 M (SNR)		
7.0	-drilled from 6.25- to 7-m in 25 minutes	0.5 cms for 5 Blows		
		0 cms for 5 Blows		
		(Hammer Rebound)		
	-drilled from 7- to 8-m in 20 minutes	SPT @ 8 M (SNR)		
8.0	4.75- to 11.5-m – ϕ = 39°; γ_t = 2.25 tons/M^3	0 cms for 5 Blows		
	(N_{avg} >> 100)	(Hammer Rebound)		
		SPT @ 9 M (SNR)		
9.0	-drilled from 8- to 9-m in 25 minutes	0 cms for 5 Blows		
		(Hammer Rebound)		
		SPT @ 10 M (SNR		
10.0	-drilled from 9- to 10-m in 25 minutes	0.5 cms for 5 Blows		
		0 cms for 5 Blows		
		(Hammer Rebound)		
11.0				

CONTINUED ON PLATE 5b.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 5a

LOG OF BORING

Project: Proposed Commercial Building Site, No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Bore Hole No.: 4 **Type of Boring:** Calyx Drill **Dia. of Hole:** 150 mm

Started on: 20-6-'18 **Ended on:** 22-6-'18 **Field Work In Charge:** M Munivel

Final Depth: 17.0-M **Depth to G W S:** Not Measured **Remarks:** **Continued from Plate 5b.**

DEPTH, M	SOIL DESCRIPTION	SPT / VANE & SAMPLE TYPE	SPT "N" PROFILE 10 20 30	INDEX TEST DATA 25 50 75
	WHITE GRAY BROWN WEATHERED ROCK (To 11.5-M)	SPT @ 11.5M (SNR) 0 cms for 5 Blows (Hammer Rebound)		♦
12.0	BROWN BLUE HIGHLY JOINTED GRANITE (To 16.0-M)			
	-drilled from 10- to 11.5-m in 40 minutes			
	-drilled from 11.5- to 12.5-m in 85 minutes			
13.0	-drilled from 12.5- to 13-m in 40 minutes	SPT @ 13 M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
	-45.5 cms core recovered drilling to 13-m			
	-30% CR and 16% RQD			
14.0	11.5- to 16.0-m – $\phi = 40^{o}$; $\gamma_t = 2.3$ tons/M^3			
	(N_{avg} >> 100)	SPT @ 14.5M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
	-drilled from 13- to 14.5-m in 105 minutes			
15.0	-57.5 cms core recovered drilling to 14.5-m			
	-38% CR and 17% RQD			
	-drilled from 14.5- to 16-m in 85 minutes			
16.0	-42.5 cms core recovered drilling to 16-m	SPT @ 16 M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
	-28% CR and 9% RQD			
	GREEN BLUE GRANITE (Below 16.0-M)			
	16.0- to 17.0-m – $\phi = 42^{o}$; $\gamma_t = 2.35$ tons/M^3			
	(N_{avg} >> 100)	SPT @ 17 M (SNR) 0 cms for 5 Blows (Hammer Rebound)		
17.0	-drilled from 16- to 17-m in 125 minutes			
	-10 cms core recovered drilling to 17-m			
	-100% CR and 92% RQD			
18.0				
19.0				
20.0				
21.0				
22.0				

BORE HOLE TERMINATED AT 17.0-M.

SPT=Standard Penetration Test; DS=Disturbed Sample; UDS = UnDisturbed Sample; WS=Water Sample; SNR=Sample Not Recovered; LS = Liner Sample; +----+ = Plastic and Liquid Limits; ♦ = N M C; ■ = % -75μ Size

PLATE 5b

SUMMARY OF TEST RESULTS

Boring	Depth,	w %	PL	LL	-75μ%	SAND			GRAVEL	IS
No.	M					Fine%	Medium%	Coarse%	%	CLASS.
1	0.25	6			8					
	1.0	15			16	71	13	0	0	SM
	1.75	13			17					
	2.5	20			9	73	18	0	0	SP-SM
	3.25	SNR								
	4.0	25			9	67	20	1	3	SP-SM
	5.0	12			17					
	6.0	13			16	49	24	8	3	SM
	7.0	SNR								
	8.0	SNR								
	9.0	SNR								
	10.0	SNR								
	11.5	SNR	rock	core	pieces					
	13.0	SNR	rock	core	piece					
	13.65	SNR	rock	core	pieces					
	14.5	SNR	rock	core	pieces					
	16.0	SNR	rock	core						
	17.0	SNR	rock	core						
	18.0	SNR	rock	core						
2	0.25	1			12					
	1.0	31			12					
	1.75	6			25	68	7	0	0	SM
	2.5	30								
	3.25	SNR								
	4.0	23			5	67	27	1	0	SP
	4.75	14			14					
	5.5	13			21	53	19	7	0	SM
	6.25	12			10	28	25	19	18	SP-SM
	7.0	10			14					
	8.0	8			16	33	27	9	15	SM
	9.0	SNR								
	10.0	20			25	65	10	0	0	SM
	11.5	SNR								
	13.0	SNR								
	14.5	SNR	rock	core						
	16.0	SNR	rock	core						
	17.0	SNR	rock	core						
3	0.25	16			13					
	1.0	12			15	73	12	0	0	SM
	1.75	11			7					
	2.5	10			5	35	42	15	3	SP
	3.25	16			24					
	4.0	16			27	67	6	0	0	SM
	4.75	16			24					
	5.5	12			29	62	9	0	0	SM
	6.25	11			24	70	6	0	0	SM
	7.0	8			18					
	8.0	9			28	62	10	0	0	SM
	9.0	SNR								
	10.0	SNR								
	11.5	11			19	50	21	10	0	SM
	13.0	SNR								
	14.5	SNR								
	16.0	SNR	rock	core						
	17.0	SNR	rock	core						

PLATE 6a

SUMMARY OF TEST RESULTS

Boring	Depth,	w %	PL	LL	-75μ%	SAND			GRAVEL	IS
No.	M					Fine%	Medium%	Coarse%	%	CLASS.
4	0.25	4			12					
	1.0	12			15	72	13	0	0	SM
	1.75	12			9					
	2.5	7			13	42	21	13	11	SM
	3.25	16			21					
	4.0	12			25	68	7	0	0	SM
	4.75	11			28	67	5	0	0	SM
	5.5	SNR								
	6.25	SNR								
	7.0	SNR								
	8.0	SNR								
	9.0	SNR								
	10.0	SNR	stone	pieces						
	11.5	SNR	stone	pieces						
	13.0	SNR	rock	core						
	14.5	SNR	rock	core						
	16.0	SNR	rock	core						
	17.0	SNR	rock	core						

PLATE 6b

Rock Sample Point Load Test Result Analysis

Client: M/s. SRH Ventures P. Ltd.
Site: No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai 600 096, TN.

D = Sample Diameter, mm

D_e = Effective Diameter of non-cylindrical rock sample, mm

P = Point Load, Newtons, N

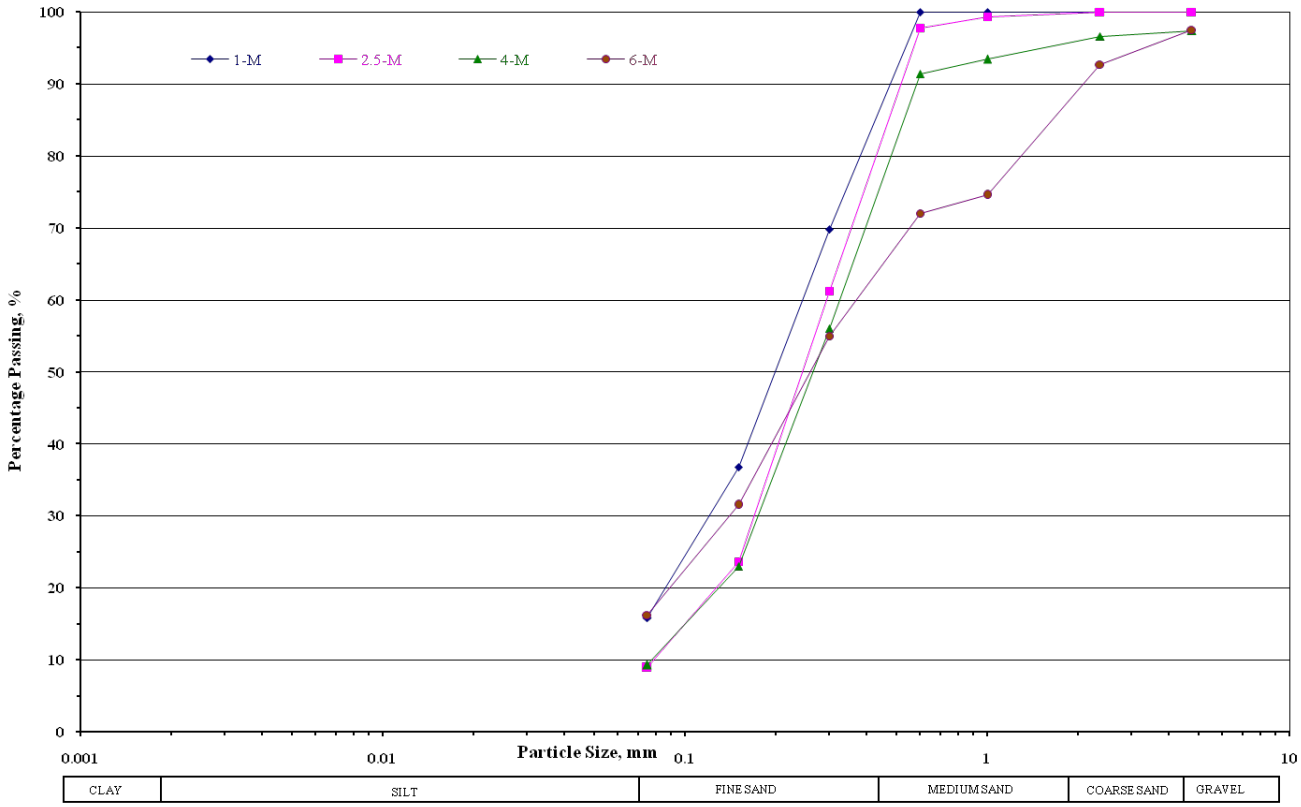
I_{L50} = Point Load Index for 50 mm Dia. Sample, N/mm^2

$$I_{L50} = \frac{P\,[D/50]^{0.45}}{D^2} \quad \text{OR} \quad I_{L50} = \frac{P\,[D_e/2500]^{0.45}}{D_e^{\,2}}$$

UCS = Unconfined Compression Str. = **20 to 24 x I_{L50}** (Use Avg. of 22)

S. No.	Bore No.	Sample Depth, M	Dia. D mm	Rock Type	"P" kN	Pt. Load Test Index, I_{L50} MN/M^2	UCS MPa	UCS Kg/cm^2
1.	1	10.0 - 11.5	52.0	Brown Blue Granite	7	2.63	58.0	579.7
2.		11.5 - 13.0	53.0	Brown Blue Granite	5	1.83	40.2	402.0
3.		13.0 - 14.5	53.0	Brown Blue Granite	25	9.14	201.0	2010.0
4.		14.5 - 16.0	54.0	Blue Granite	27	9.59	210.9	2108.8
5.		16.0 - 17.0	55.0	Blue Granite	20	6.90	151.8	1518.3
6.		17.0 - 18.0	55.0	Blue Granite	20	6.90	151.8	1518.3
7.	2	13.0 - 14.5	54.0	Blue Granite	33	11.72	257.7	2577.4
8.		14.5 - 16.0	51.0	Blue Granite	25	9.70	213.3	2133.5
9.		16.0 - 17.0	55.0	Blue Granite	27	9.32	205.0	2049.7
10.	3	14.5 - 16.0	54.0	Blue Granite	30	10.65	234.3	2343.1
11.		16.0 - 17.0	55.0	Blue Granite	28	9.66	212.6	2125.6
12.	4	11.5 - 13.0	55.0	Brown Blue Granite	3	1.04	22.8	**227.7**
13.		13.0 - 14.5	54.0	Brown Blue Granite	15	5.33	117.2	1171.6
14.		14.5 - 16.0	55.0	Brown Blue Granite	40	13.80	303.7	**3036.6**
15.		16.0 - 17.0	55.0	Brown Blue Granite	23	7.94	174.6	1746.0

Grain Size Distribution Curves
Boring 1



Grain Size Distribution Curves
Boring 2

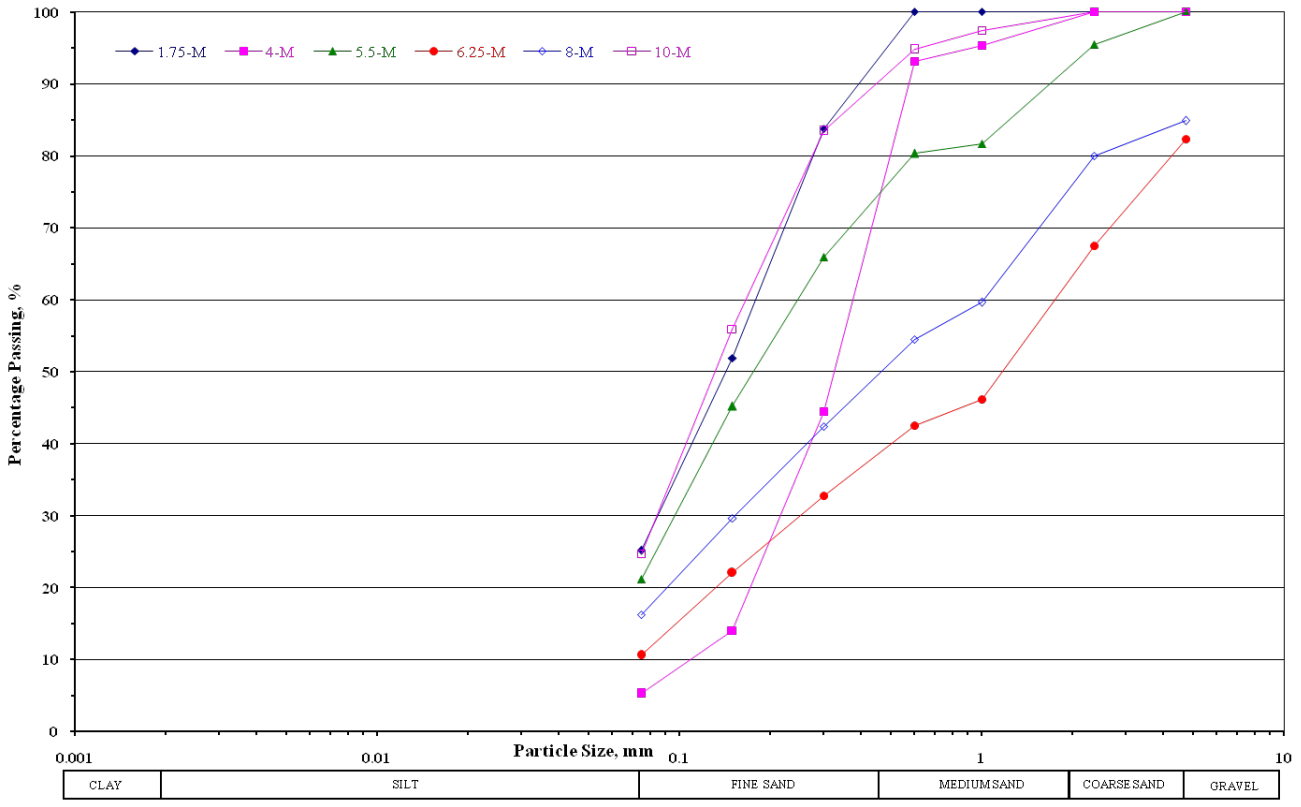
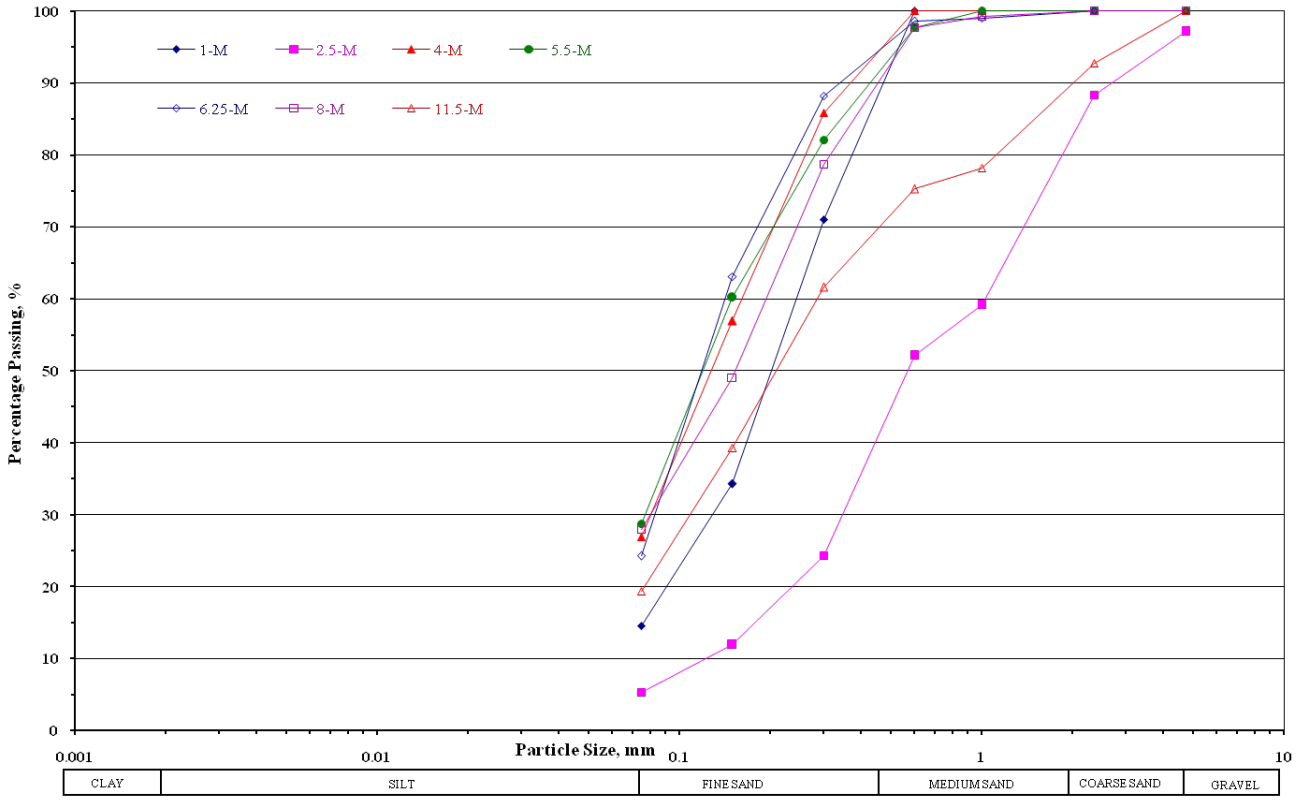


PLATE 7a

Grain Size Distribution Curves
Boring 3



Grain Size Distribution Curves
Boring 4

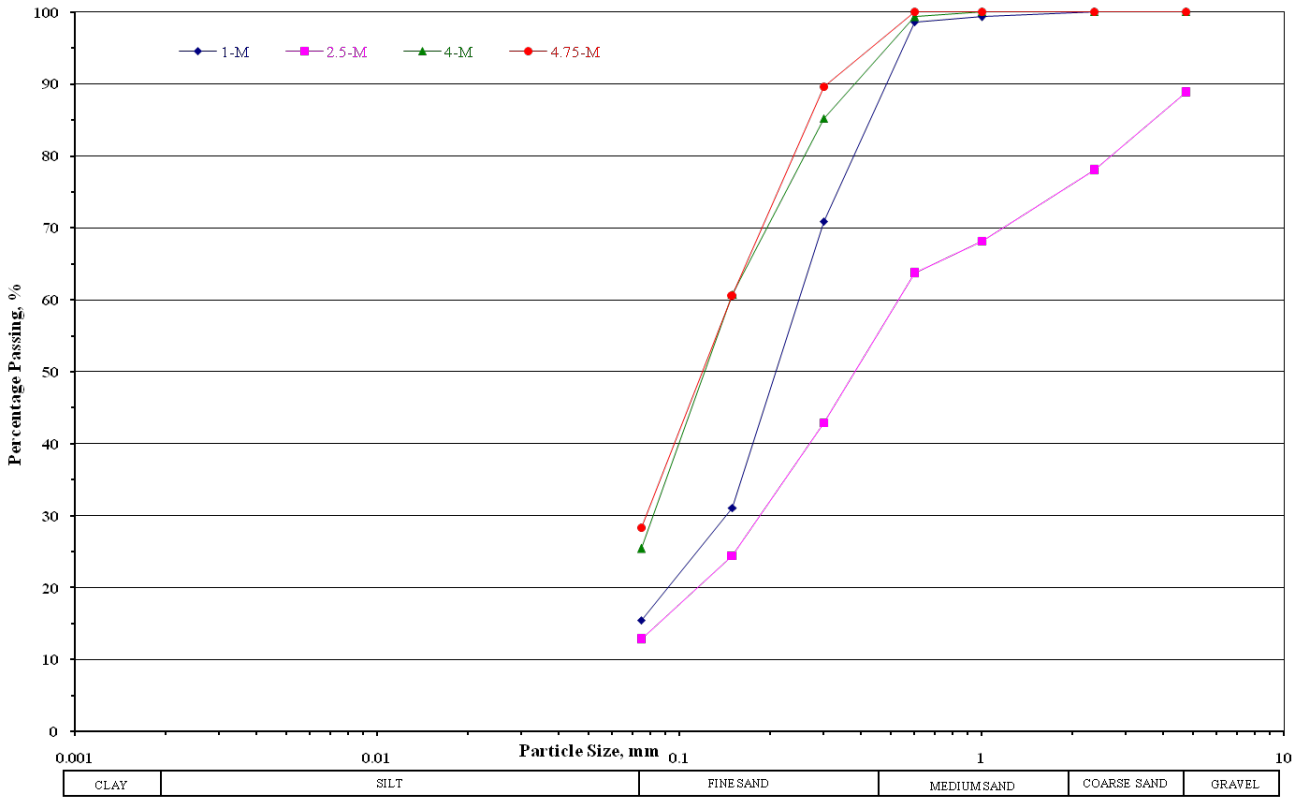


PLATE 7b

SUMMARY OF WATER TEST RESULTS

BORING 1 WATER SAMPLE

DEPTH = 18-M; WATER LEVEL ~ 0.4-M.

S. No.		Description	Results Obtained	As per IS:456 – 2000
1		To neutralize 100 cc of water using phenolphthalein as indicator	0.5 ml	Not more than 5 ml of 0.02N NaOH
2		To neutralize 100 cc of water using methyl orange as indicator	47.5 ml	Not more than 25 ml of 0.02N H_2SO_4
3	a	Organic Solids, mg/liter	48	200 Max.
	b	Inorganic Solids, mg/liter	1,984	3,000 Max.
	c	Sulphates as SO_3, mg/liter	118	400 Max.
	d	Chlorides as Cl, mg/liter	567	2,000 Max. - Plain Concrete 500 Max. RCC
	e	Suspended Solids, mg/liter	0	2,000 Max.
	f	pH	7.20	6 Min.

Remarks: Sample does not meet the requirements of above clauses 2, and 3d for use in RCC. Water cannot be used for construction purposes as per IS 456 - 2000.

Note:- Water had very strong bad smell inferring sewage contamination.

SAMPLE CALCULATIONS FOR RECOMMENDED FOUNDATION

Bearing capacity was estimated using soil properties from Boring 2. Following is a list of design assumptions:

Type of Foundation	=	Combined Raft Foundation;
Foundation Depth below EGL	=	10-M below EGL;
Worst Case Ground Water Level	=	At EGL;
Minimum Raft Size	=	20- by 60-M;
Expected Max. Column Load	=	1250 tons; and
Expected Bearing Pressure	=	30 tons/M^2.

Bearing Capacity Calculations:

Ultimate Bearing Pressure $q_{ult} = C_u*N_c*S_c*D_c + q'(N_q - 1)*S_q*d_q + 0.5*B*\gamma'*N_\gamma* S_\gamma*d_\gamma$

ϕ	=	37^o
C_u (Undrained Shear Strength)	=	0 tons/M^2
N_c (Bearing Capacity Factor)	=	N/A
N_q (Bearing Capacity Factor)	=	45.66
N_γ (Bearing Capacity Factor)	=	72.58
S_c (Shape Factor)	=	1 + 0.2*(B/L) = 1.0 + 0.2*(20.0/60.0) = 1.07;
D_c (Depth Factor)	=	1 + 0.2*D_f/B*tan (45 + ϕ/2) = 1.22
S_q (Shape Factor)	=	1 + 0.2*(B/L) = 1.0 + 0.2*(20.0/60.0) = 1.07;
d_q (Depth Factor)	=	1 + 0.1*D_f/B*tan (45 + ϕ/2) = 1.11
S_γ (Shape Factor)	=	1 - 0.4*(B/L) = 1.0 - 0.4*(20.0/60.0) = 0.87;
d_γ (Depth Factor)	=	1 + 0.1*D_f/B*tan (45 + ϕ/2) = 1.11
q'(O B @ Footing)	=	~ (1.8-1)*10.0 = 8.0 tons/M^2

Note: Ground water is assumed to rise to EGL of the site.

q_{ult} = 0 + 8.0*(45.66-1)*1.07*1.11 + 0.5*1.1*20*72.58*0.87*1.11 = 1,195.34 ~ 1,195 tons/M^2

$q_{all} = q_{ult} / 2.5 = 1195 / 2.5 =$ 478 tons/M^2 **Use and Limit q_{all} = 50 tons/M^2 > 30 tons/M^2**

Settlement Calculations:

In case of raft foundation the "Zone of Influence" will extend to "2B" depth below raft, i.e., 2*20 = 40-M below raft or upto hard stratum level, whichever is earlier. There will be only elastic (immediate) settlement and no consolidation (long term) settlements as soil profile had weathered rock and jointed granite in the zone of influence.

Elastic or Immediate Settlement:-

1. 10.0- to 16.0-M = H_1 = 6.0-M; SPT "N" >> 100 (Wea. and Jointed Granite); E_s = 20,000 tons/M^2

q_0 = 30 tons/M^2; H/B' = 6.0/20.0 = 0.30; L/B = 60.0/20.0 = 3; μ = 0.2; E_s = 20,000 tons/M^2

I_f = 0.85; I_1 = 0.012; I_2 = 0.051; I_s = 0.05;

$\Delta H_E = 4*10.0*30.0*(1-0.2^2)/20000*0.85*0.05*1000 =$ **2.45 mm**

Total Elastic Settlement ΔH_E = 2.45 mm.

Consolidation Settlement: None.

Total Consolidation Settlement ΔH_C = 0.00 mm.

Total Combined Settlement **ΔH** = $\Delta H_E + \Delta H_C$ = 2.45 + 0.00 = **2.45 ~ 3 mm**.

PLATE 9a

Estimated total settlement for a 20- by 60-M combined raft foundation at 11.5-M below EGL was about 3 mm. The estimated total settlement was less than 75 mm – allowable limits for the total settlements for raft foundations on granular material as per IS: 1904 - 2006 code. Therefore, combined raft foundations can be used for the proposed building.

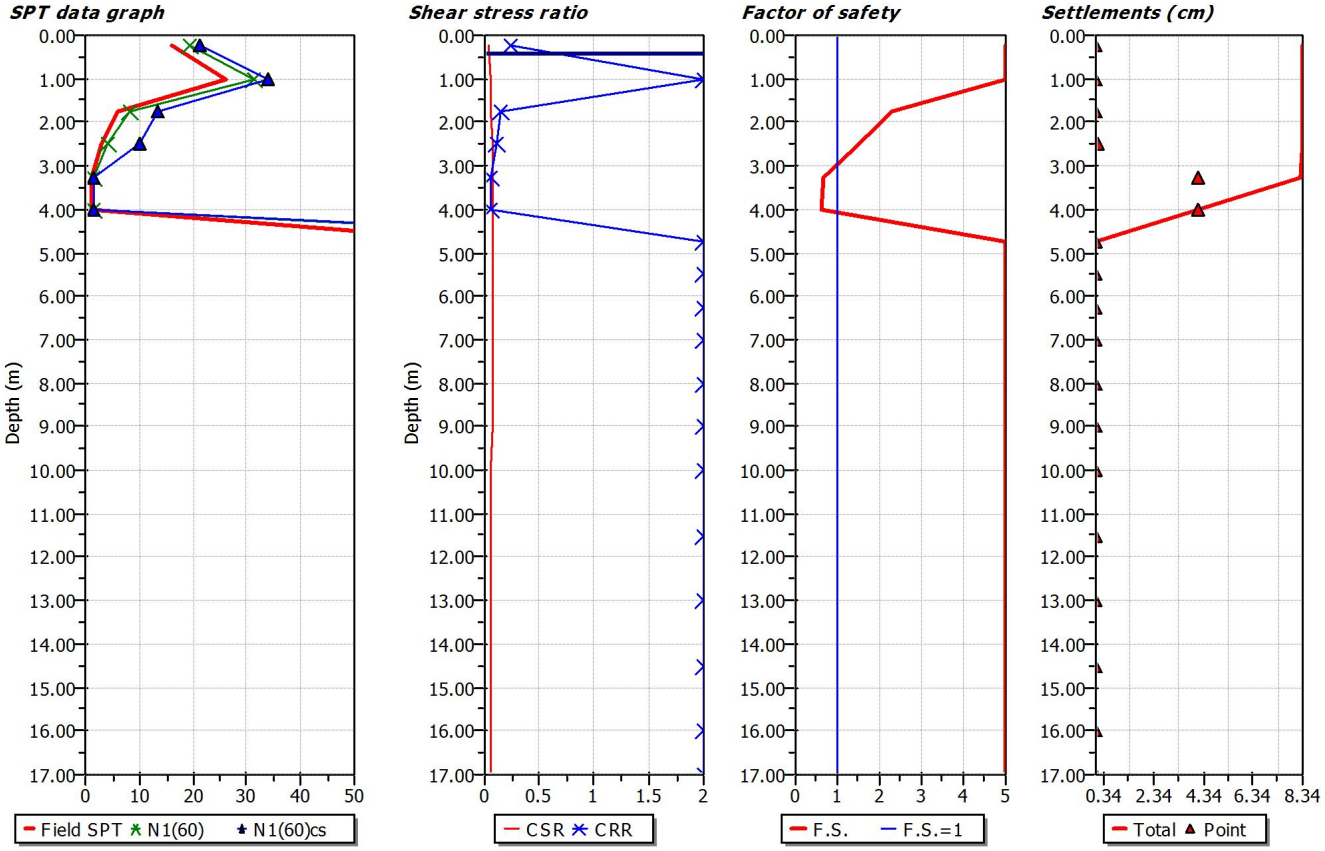
LIQUEFACTION ANALYSIS REPORT

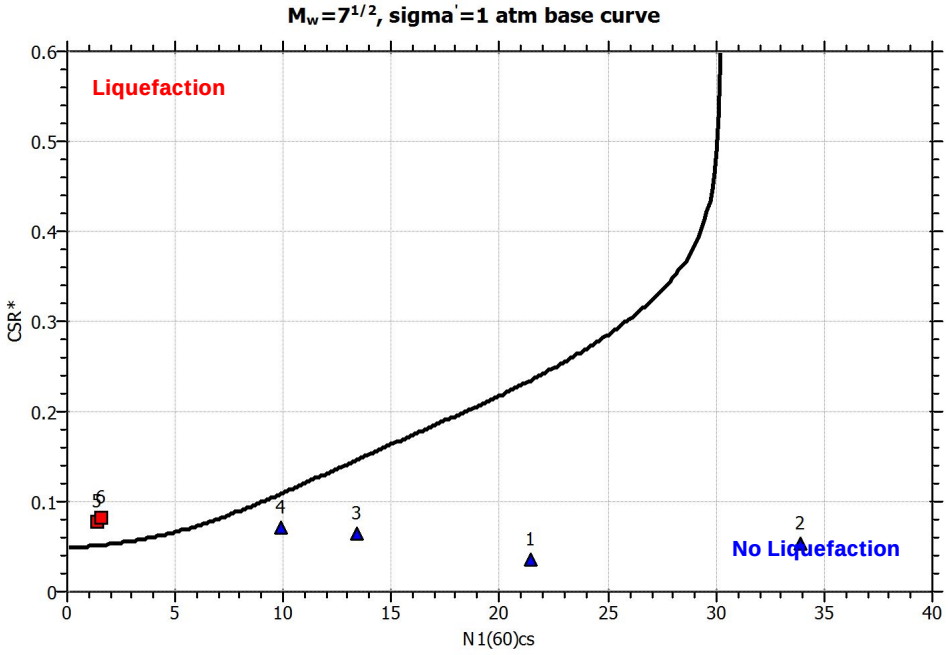
Project title : No. 112, Old Mahabalipuram Road, Kandhanchavadi, Chennai - 96.

Project subtitle : Boring 2 Soil Profile

Input parameters and analysis data

In-situ data type:	Standard Penetration Test	Depth to water table:	0.40 m
Analysis type:	Deterministic	Earthquake magnitude M_w:	6.50
Analysis method:	NCEER 1998	Peak ground accelaration:	0.08 g
Fines correction method:	Idriss & Seed	User defined F.S.:	1.00





Horizontal Acceleration, α_h = 0.08g

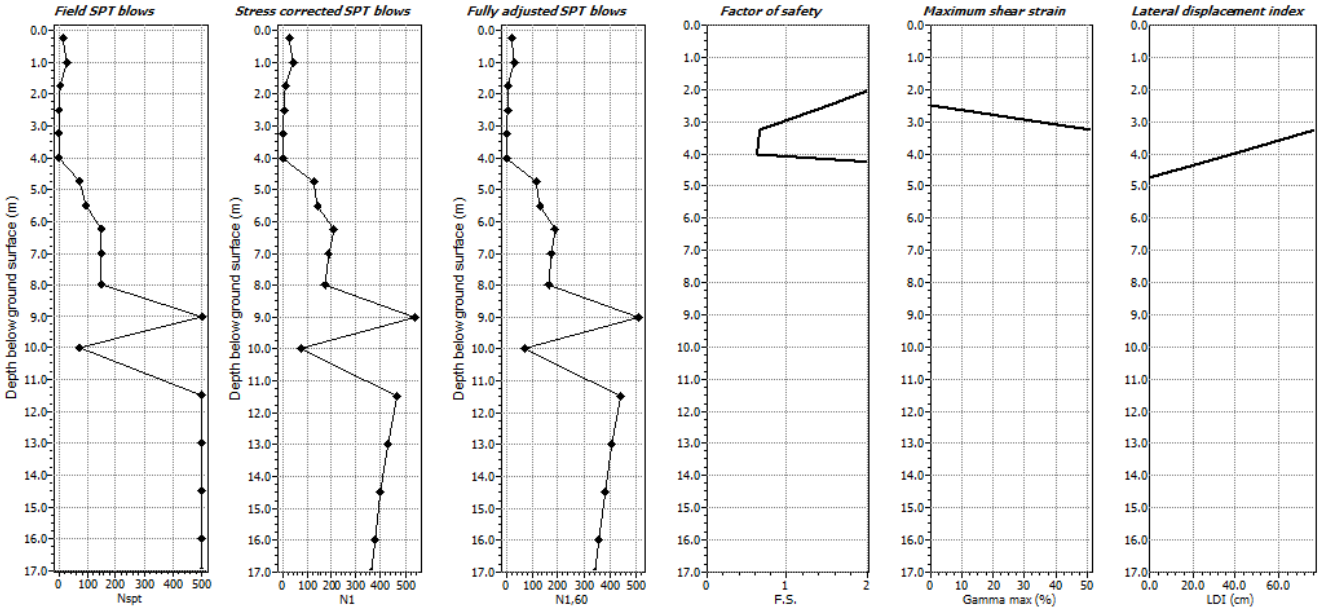
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Url : http://www.geologismiki.gr - Email : info@geologismiki.gr

LiqIT software v.4.6
Assessment of soil liquefaction potential from SPT, CPT or Vs data

LATERAL DISPLACEMENTS ESTIMATION DUE TO SOIL LIQUEFACTION[1]

Geometric parameters: Gently sloping ground without free face
Total lateral displacement estimation: 92.16 cm



N_{spt}: Measured SPT blows
N_1: Stress adjusted SPT blows
$N_{1,60}$: Fully adjusted SPT blows

F.S.: Factor of safety
Gamma max: Maximum cyclic shear strain
LDI: Lateral displacement index

[1] This method was developed using the NCEER methods (SPT and CPT) and other methods will produce slightly different results

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