National Highways & Infrastructure Development Corporation Ltd.

Consultancy Services for preparation of Feasibility Study and Detailed Project Report for Up gradation to 2-lane with paved shoulder Chenani-Sudhmahadev-Goha-Khellani-Kishtwar-Sinthan Pass-Khanabal section of NH-244 (Old NH-1B).
Part-1 of ***Phase-I: Chenani-Sudhmahdev***

Geotechnical Report

SubmittedBy: -

M/s Wadia Techno Engg. Ltd In Association with **M/s Zoma Engineers**

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1.0 INTRODUCTION

1.1 Project Description

The National Highways & Infrastructure Development Corporation Ltd. (*NHIDCL*) is planning the up-gradation (two laning with paved shoulder) of Chenani – Sudhmahadev – Goha – Khellani - Sinthan Pass - Khanabal section of NH-244 (Old-NH1B) in the state of Jammu and Kashmir. The tentative design length of the Package is about 274 km.

Wadia Techno-Engineering Services Ltd (*Wadia*) in association with Zoma Consulting Services Pvt. Ltd (*Zoma*) has been retained by NHIDCL for carrying out the Feasibility Study, Preparation of Detailed Project Report and providing pre-construction services in respect of up-gradation of the designated corridor on EPC mode.

As part of the consultancy services, geotechnical investigation has been carried out to investigate the stratigraphy and to develop geotechnical recommendations for the foundation design and construction of the structures planned along the proposed alignment.

S. No.	Chainage, km	Structure	Span Arrangment	Borehole drilled at each Structure
1	0+928	Major Bridge	1x22.5+1x30+1x22.5	4
2	4+200	Culvert	1x6	1
3	2+575	Major Bridge	3x83.33	4
4	7+500	Culvert	1x6	1
5	8+730	Culvert	1x6	1
6	8+950	Culvert	1x6	1
7	9+334	Minor Bridge	1x60	2
8	13+270	Culvert	1x6	1
9	14+500	Culvert	1x6	1
10	14+840	Culvert	1x6	1
Total Structures : **Ten (10)**				Total Boreholes : **Seventeen (17)**

This final report presents our engineering analysis and recommendations for structures planned between Chainage 0+928 km. to 14+840 km.

1.2 Purposes of Study

The overall purposes of this study are to investigate the stratigraphy at the site and to develop geotechnical recommendations for the foundation design and construction of the structures planned along the proposed alignment.

To accomplish these purposes, the study was conducted in the following phases:

a) drilling seventeen (17) boreholes at ten (10) proposed structure locations to the specified depths, in order to evaluate the stratigraphy, and to collect soil/rock and groundwater samples for laboratory testing;

b) testing selected samples in our laboratory to determine pertinent index and engineering properties of the soils encountered at the site; and

c) analyzing all field and laboratory data to develop geotechnical recommendations for foundation design and construction.

1.3 Scope of Work included in this Report

Details of the exploratory boreholes drilled along the alignment are tabulated below:

S. No.	Chainage, km	Structure	Easting	Northing	Borehole Designation	Ground Level, m	Final Explored Depth, m
1	0+928	Major Bridge	526106	3656357	BH-A1	1200	30
					BH-P1	1198	30
					BH-P2	1190	30
					BH-A2	1195	30
2	4+200	Culvert	527700	3654749	BH-1	-	20
3	2+575	Major Bridge	527253	3655972	BH-A1	1147	30
					BH-P1	1115	30
					BH-P2	1100	30
					BH-A2	1119	30
4	7+500	Culvert	529078	3656446	BH-1	-	20
5	8+730	Culvert	529941	3657198	BH-1	-	20
6	8+950	Culvert	530157	3657217	BH-1	-	20
7	9+334	Minor Bridge	530513	3657242	BH-A1	1413.6	30
					BH-A2	1416.35	30
8	13+270	Culvert	531702	3654956	BH-1	-	20
9	14+500	Culvert	532611	3655610	BH-1	-	20
10	14+840	Culvert	532893	3655787	BH-1	-	20

2.0 FIELD INVESTIGATIONS

2.1 Rock Drilling

Core drilling through rock formation was performed using a hydraulic rotary drill rig. The drilling rig has a hydraulic feed and is driven by a bevel gear system run by a 28 HP Perkins engine. The drill chuck has four jaws to accommodate NW size drill rod.

Drilling and sampling of the rock was performed using an NX size double tube core barrel. A TC/32–carat diamond impregnated bit was used to drill through rock strata. The bit was attached to the end of a core barrel, which is connected to the machine by a string of NW drill rods and rotated by the drilling machine.

Water was circulated through the drill rods to the bottom of the hole. The water serves the purpose of lubrication, cooling and protection of the diamond drill bit in addition to flushing the cuttings out of the hole. A reciprocating pump was used to circulate the water. While drilling through soft rock that is likely to collapse, NX size casing was installed. The casing has a TC shoe bit to assist it to advance.

The percent core recovery and Rock Quality Designation (RQD) was measured for each core run. The percent core recovery is defined as the percent ratio of the cumulative length of core sample recovered to the total length of the core run. The Rock Quality Designation (RQD) is defined as the ratio of the cumulative length of core pieces 10 cm or longer to the total length of the core run, expressed as percentage. The Rock mass Rating (RMR), an engineering parameter that assists in assessing the rock quality and behavior is also presented on the individual rock profiles. Standard Penetration Tests (SPT) was conducted in the boulder strata encountered.

Details of rock samples collected and their respective core recovery / RQD values are presented on the rock profiles at various depths. The color of return water and the extent of water loss while drilling the borehole recorded on the boring logs may be used for an assessment of the nature of rock, water-tightness of joints and possible presence of interconnected channels / cavities.

2.2 Groundwater

Groundwater level was measured in the boreholes after drilling and sampling was completed. The measured water levels are recorded on the individual soil profiles.

3.0 LABORATORY TESTS

Laboratory tests were conducted on selected rock and groundwater samples to determine their physical and engineering properties. The testing procedures were in accordance with current applicable IS specifications.

The following tests were conducted on selected rock samples recovered from the boreholes:

Laboratory Test	IS Code Referred
Natural Density	IS : 13030-1991, RA-2006
Specific Gravity	IS : 2720 (Part-3)-1980
Point Load Strength Index	IS : 8764-1998, RA-2008
Unconfined Compressive Strength	IS : 9143-1979, RA-2006

4.0 GENERAL SITE CONDITIONS

4.1 Regional Geology

Geologically, the area can be explained as the northern hilly area underlain by the Siwalik rocks and the southern outer plain area underlain by the sediments of Recent Sub-Recent times laid down by the present day stream area.

Following geological succession occurs in the area[1].

	Geological Horizon Lithology Age	Geological Horizon Lithology Age	Geological Horizon Lithology Age
	Alluvium, fan, terrace deposits	Heterogeneous Clastic sediments	Sub-Recent to Recent
	(Kandi and Sirowals)		
Upper Siwaliks	Boulder bed stage	Conglomerates sandstones with intercalations of red clays	Lower to Middle Pleistocene.
	Pinjor Stage	Coarse sandstone, sand rock and massive sandstone beds.	Lower Pleistocene
	Tatrot Stage	Sandstone drab clays alternative beds.	Upper Pleistocene
Middle Siwaliks	Dhokpathan Stage	Sandstone & shale with isolated sand nodules	Lower Pleistocene
	Nagri Stage	Sandstones & Shale, Hard & compact	Upper Miocene
Lower Siwaliks	Chingi Stage	Bright red shale and sandstones	Middle Miocene
	Kamlial Stage	Hard red sandstones & shale with pseudo conglomerates	Middle to lower Miocene

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[1] N. R. Bhagat (Scientist-D), "*Ground Water Information Booklet, Jammu District, Jammu & Kashmir*", Central Ground Water Board, Ministry of Water Resources, North Western Himalayan Region, Jammu 2013.

4.2 Site Stratigraphy

The overburden soil along the stretch consists of clayey soil intermixed with gravels. The depth of overburden soil varies from 0.5m to 1.5m below EGL along the captioned alignment.

The overburden of clayey soil is underlain by boulder formation (boulder / cobbles / pebbles of various sizes) is encountered to about 5.0 to 9.0 m depth. The boulder strata are weak to moderately weak.

The bouldary strata are underlain by weak to moderately strong, grey sandstone to the final explored depth of 30.0 m depth below EGL.

4.3 Groundwater

The water table encountered along the alignment ranges from 0.5 to 12.4 m depth during the period of our field investigations.

Please note that fluctuations may occur in the measured water table due to seasonal variation in rainfall and surface evaporation rates.

5.0 FOUNDATION ANALYSIS AND RECOMMENDATIONS

5.1 General

For designing the foundation system, the following parameters are required:

a) Suitable type of foundation on which the proposed super-structure can be supported.

b) Depth of these foundations, and

c) Allowable bearing pressure at the founding level corresponding to various footing sizes.

A suitable foundation for any structure should have an adequate factor of safety against exceeding the bearing capacity of the supporting soils. Also the vertical movements due to compression of the soils should be within tolerable limits for the structure. We consider that foundation designed in accordance with the recommendations given herein will satisfy these criteria.

5.2 Liquefaction Susceptibility Assessment

Liquefaction is defined as the transformation of a granular material from a solid to a liquefied state as a consequence of increased pore-water pressure and reduced effective stress (Marcuson, 1978)[(2)]. Increased pore pressure may be induced by the tendency of granular materials to compact when subjected to cyclic shear deformation, such as in the event of an earthquake.

As per IS: 1893-2016, liquefaction is likely to occur in loose fine sand below water table.

Generally, Boulders / Rock (Sandstone) is encountered along the project alignment. As per our assessment of the limited borehole data, we are of the opinion that liquefaction is not likely to occur at the project site in the event of an earthquake.

According to Fig.1 of IS: 1893 (Part-1) - 2016 showing seismic zones, the project site falls under Zone-IV. The design for seismic forces should be done considering the project site in Zone-IV.

[(2)]Marcuson, W.F. (III) (1978), “Definition of terms related to liquefaction”, J. GeotechEngg. Div,, SCE, 104(9), 1197-1200.

5.3 Foundation Type and Depth

Type of foundation to be adopted for a particular structure depends upon the loading intensity at the foundation level and the configuration of loading points.

Reviewing the stratigraphy of the site on the basis of limited borehole data, SPT values & laboratory test results, we are of opinion that open foundations are feasible foundation scheme to support the structural load of the proposed structures. Our suggested net allowable bearing pressures for the proposed structures are provided in Section 5.6.

5.4 Concept of Analysis

5.4.1 Open Foundations on Rock

Analysis for allowable bearing capacity on rock has been done by following methods.

(i) Presumptive values as published in IS: 12070.
(ii) Based on rock mass rating (RMR values) as per IS: 12070.
(iii) "*Foundation on Rock*" by Duncan C.Wyllie (1992).

Presumptive Values: The classification of rock mass for assessing safe bearing pressure based on rock type is as follows:

Material	**q_{ns} (T/m^2)**
Bedded limestone in sound condition	400
Sedimentary rock, including hard shales and sandstones	250
Soft or broken bed rock (excluding shale), and soft limestone	100
Soft shale	30

Reduction factors are to be applied on the above presumptive values for saturation and orientation of joints.

Rock Mass Rating (RMR): Analysis has been carried out using the RMR also known as Geo-mechanics classification(3) by considering classification parameters and their ratings. Depending upon the quality of rock as assessed from the RMR values, the net safe allowable bearing pressures are specified in IS: 12070. RMR values are not reported in the borehole logs provided to us. RMR value has been assessed by us based on available borehole data for the calculation purpose.

Foundation on Rock (Duncan C. Wyllie)[4]: Based on our evaluation of rock characteristics, parameters may be selected for foundation analysis by using following equation:

$$q_{ult} = c\, N_c C_c + 0.5\, B \Upsilon\, N_{\Upsilon} C_{\Upsilon} + \Upsilon D\, N_q$$

where:

c	=	cohesion intercept
ϕ	=	angle of internal friction of the rock mass
B	=	width of foundation
D	=	depth of foundation
Υ	=	effective unit weight of rock

(3) Bieniawski, Z.T (1989). **"*Engineering Rock Mass Classifications*"**, A Complete Manual for Engineers and Geologists in Mining, Civil & Petroleum Engineering, John Wiley Publication, New York.

(4) Duncan C.Wyllie (1992) **"Foundation on Rock"** by E&FN SPON(An imprint of Chapman & Hall) pp.114

C_c, C_γ	=	correction factors for foundation shape
C_c	=	1.20 for circular foundation
	=	1.25 for square foundation
C_γ	=	0.70 for circular foundation
	=	0.85 for square foundation
N_c, N_q, N_γ	=	bearing capacity factors which are a function of ϕ.

The bearing capacity factors may be calculated using the following equations:

$$N_c = 2 N_\phi^{0.5} (N_\phi + 1)$$
$$N_\Upsilon = N_\phi^{0.5} (N_\phi^2 - 1)$$
$$Nq = N_\phi^2$$
$$N_\phi = \tan^2(45 + \phi/2)$$

The net safe bearing capacity may be worked out using the following equation:

$$q_{ns} = \frac{1}{F} [q_{ult} - \Upsilon D]$$

where :

q_{ns}	=	net safe bearing capacity
F	=	factor of safety.

Heavily fractured / disintegrated rock may be treated as soil / dense gravelly material for the purpose of analysis[5].

5.4.2 Open Foundations on Boulders

Bearing capacity analysis for open / raft foundations has been done in general accordance with IS: 6403-1981.

The bearing capacity equation used is as follows:

$$q_{net\ safe} = \frac{1}{F} [cN_c\zeta_c d_c + q(N_q-1) \zeta_q d_q + 0.5 B \Upsilon N_\gamma \zeta_\gamma d_\gamma R_w]$$

Where:

$q_{net\ safe}$	=	safe net bearing capacity of soil based on the shear failure criterion.
q	=	overburden pressure
R_w	=	water table correction factor
F	=	Factor of safety, taken as equal to 2.5 in accordance with IS:1904-1986.
$\zeta_c, \zeta_q, \zeta_\gamma$	=	Shape factors. For Strip footings, $\zeta_c = \zeta_q = \zeta_\gamma = 1$
		For Square footing, $\zeta_c = 1.3$, $\zeta_q = 1.2$, $\zeta_\gamma = 0.6$
d_c, d_q, d_γ	=	Depth factors
		For $\phi \leq 10$, $d_c = 1 + 0.2 \tan(45 + \phi / 2)$ D / B, $d_q = d_\gamma = 1$
		For $\phi > 10$, $d_q = d_\gamma = 1 + 0.1 \tan(45 + \phi / 2)$ D / B

Appropriate values have been substituted into the bearing capacity equation given above to compute the safe net bearing capacity. The values have been checked to determine the settlement of the foundation under the safe bearing pressure. The allowable bearing pressure has been taken as the lower of the two values computed from the bearing capacity shear failure criterion as well as that computed from the tolerable settlement criterion.

Settlement analysis for open foundations has been done based on the SPT values in accordance with Clause 9.1.4 of IS 8009 (Part 1)-1976 Fig.9.

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(5) Tomlinson ML (1986): ***Foundation Design and Construction***, English Language Book Society, Longman, UK

5.5 Behavior of Bouldary /Gravelly Deposits Under Load

IS: 10042-1981 states that "*the performance of bouldary deposits under load is a matter of intelligent guess*". The behavior of boulder deposits under high loads depends upon the size and quantity of gravel-boulder and also the nature and amount of the filler.

As per our assessment, the boulders / cobbles size range from 200 mm to more than 1000 mm. The proportion of the boulders/cobbles/gravels may range from 60-80 percent. Therefore, the behavior of soil-gravel matrix will be governed by the boulders / cobbles.

When the quantum of filler material is less, the load carrying capacity is high and the compressibility is low. If the gravel lies in the matrix of the filler material, the behavior is governed by the nature of filler material and it is likely to reduce the compressibility.

The boulder-soil matrix, unlike ordinary soil, shows certain peculiar characteristics when the boulder proportion is large (>30 percent); the deposit shows an initial rapid compression followed by a stage where the compression decreases considerably as the boulders take over the load carrying function.

5.6 Recommended Net Allowable Bearing Pressures

The following table presents our suggested values of net allowable bearing pressures for open foundations at various depths for various structures:

<table>
<tr><th>Chainage, km</th><th>Structure</th><th>Boreholes</th><th>Reduced Level (RL), m</th><th>Foundation Depth below EGL, m</th><th>Foundation Level (RL), m</th><th>Net Bearing Presure, T/m²</th><th>Suggested Modulus of Subgrade Reaction (k), kN/m³</th></tr>
<tr><td rowspan="8">0+928</td><td rowspan="8">Major Bridge</td><td rowspan="2">BH-A1</td><td rowspan="2">1200</td><td>3</td><td>1197</td><td>40</td><td>16000</td></tr>
<tr><td>4</td><td>1196</td><td>45</td><td>18000</td></tr>
<tr><td rowspan="2">BH-P1</td><td rowspan="2">1198</td><td>4</td><td>1194</td><td>35</td><td>14000</td></tr>
<tr><td>5</td><td>1193</td><td>40</td><td>16000</td></tr>
<tr><td rowspan="2">BH-P2</td><td rowspan="2">1190</td><td>4</td><td>1186</td><td>35</td><td>14000</td></tr>
<tr><td>5</td><td>1185</td><td>40</td><td>16000</td></tr>
<tr><td rowspan="2">BH-A2</td><td rowspan="2">1195</td><td>3</td><td>1192</td><td>40</td><td>16000</td></tr>
<tr><td>4</td><td>1191</td><td>45</td><td>18000</td></tr>
<tr><td rowspan="2">4+200</td><td rowspan="2">Culvert</td><td rowspan="2">BH-1</td><td rowspan="2">-</td><td>2</td><td>2</td><td>35</td><td>14000</td></tr>
<tr><td>3</td><td>3</td><td>40</td><td>16000</td></tr>
<tr><td rowspan="8">2+575</td><td rowspan="8">Major Bridge</td><td rowspan="2">BH-A1</td><td rowspan="2">1147</td><td>3</td><td>1144</td><td>50</td><td>20000</td></tr>
<tr><td>4</td><td>1143</td><td>55</td><td>22000</td></tr>
<tr><td rowspan="2">BH-P1</td><td rowspan="2">1115</td><td>4</td><td>1111</td><td>45</td><td>18000</td></tr>
<tr><td>5</td><td>1110</td><td>50</td><td>20000</td></tr>
<tr><td rowspan="2">BH-P2</td><td rowspan="2">1100</td><td>4</td><td>1096</td><td>45</td><td>18000</td></tr>
<tr><td>5</td><td>1095</td><td>50</td><td>20000</td></tr>
<tr><td rowspan="2">BH-A2</td><td rowspan="2">1119</td><td>3</td><td>1116</td><td>50</td><td>20000</td></tr>
<tr><td>4</td><td>1115</td><td>55</td><td>22000</td></tr>
<tr><td rowspan="2">7+500</td><td rowspan="2">Culvert</td><td rowspan="2">BH-1</td><td rowspan="2">-</td><td>2</td><td>2</td><td>30</td><td>12000</td></tr>
<tr><td>3</td><td>3</td><td>35</td><td>14000</td></tr>
<tr><td rowspan="2">8+730</td><td rowspan="2">Culvert</td><td rowspan="2">BH-1</td><td rowspan="2">-</td><td>2</td><td>2</td><td>28</td><td>11200</td></tr>
<tr><td>3</td><td>3</td><td>33</td><td>13200</td></tr>
<tr><td rowspan="2">8+950</td><td rowspan="2">Culvert</td><td rowspan="2">BH-1</td><td rowspan="2">-</td><td>2</td><td>2</td><td>30</td><td>12000</td></tr>
<tr><td>3</td><td>3</td><td>35</td><td>14000</td></tr>
</table>

Chainage, km	Structure	Boreholes	Reduced Level (RL), m	Foundation Depth below EGL, m	Foundation Level (RL), m	Net Bearing Presure, T/m^2	Suggested Modulus of Subgrade Reaction (k), kN/m^3
9+334	Minor Bridge	BH-A1	1413.6	2	1411.6	40	16000
				3	1410.6	45	18000
		BH-A2	1416.4	2	1414.4	40	16000
				3	1413.4	45	18000
13+270	Culvert	BH-1	-	2	2	35	14000
				3	3	40	16000
14+500	Culvert	BH-1	-	2	2	30	12000
				3	3	35	14000
14+840	Culvert	BH-1	-	2	2	35	14000
				3	3	40	16000

1. The above values include a bearing capacity safety factor of 2.5 for foundations bearing on boulders /cobbles with silty sand and 3.0 for foundations bearing on rock.

2. The settlement of the rock under the design load is expected to be small. For the purpose of analysis, the settlement of foundation bearing on rock, designed for the above recommended bearing pressures, may be considered as less than 12 mm.

3. Total settlement of foundations bearing on boulders/cobbles with silty sand is expected of less than 25 mm.

4. The appropriate values of net bearing pressure may be selected as per the permissible settlement criterion. Net bearing pressures for foundations of at intermediate depths may be interpolated linearly between the values given above.

5. The change in SBC for different foundation sizes is insignificant for foundations bearing on rock formation. Therefore, the recommended values may be considered applicable for all sizes of foundations including raft foundation.

6. For foundations bearing on rock, a seating of at least 0.5 m into the natural rock formation should be ensured.

7. All loose, weathered or fragmented rock should be removed so that foundation may bear on the firm rock.

8. The suggested modulus of sub-grade reaction (k) has been computed based on the net bearing pressure considering a corresponding foundation settlement of 25 mm. For a better estimate of foundation deformation characteristics, full scale footing load tests may be carried out on site.

5.7 Definition of Net Bearing Pressure

For the purposes of this report, the net allowable bearing pressure should be calculated as the difference between total load on the foundation and the weight of the soil overlying the foundation divided by the effective area of the foundation.

The following equations may be used –

$$q_{net} = [(P_s + W_f + W_s) / A_f] - S_v$$
$$q_{gross} = q_{net} + S_v = (P_s + W_f + W_s) / A_f$$

where:

q_{net}	=	*net allowable bearing pressure*
q_{gross}	=	*gross bearing pressure*
P_s	=	*superimposed static load on foundation*
W_f	=	*weight of foundation*
W_s	=	*weight of soil overlying foundation*
A_f	=	*effective area of foundation*
S_v	=	*overburden pressure at foundation level prior to excavation for foundation.*

It may please be noted that safe bearing pressures recommended in this report refer to “net values”. Where filling is done, it should be treated as a surcharge over the foundation.

6.0 VARIABILITY IN SUBSURFACE CONDITIONS

Subsurface conditions encountered during construction may vary somewhat from the conditions encountered during the site investigation. In case significant variations are encountered during construction, we request to be notified so that our engineers may review the recommendations in this report in light of these variations.