Part -II

OUTLINE DESIGN CRITERIA - GEO-TECHNICAL, FOUNDATION AND RAILWAY FORMATION WORKS

CONTRACT NO: NGNDD01

INDEX

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OUTLINE DESIGN CRITERIA

GEOTECHNICAL, FOUNDATION AND RAILWAY FORMATION WORKS

Section E1 – GENERAL, STANDARDS AND CODES

E1.1. Purpose and Scope

The purpose of this chapter of these Design Criteria is to establish the minimum requirements for geotechnical site investigations, studies, analyses, and preparation of geotechnical reports and design and construction recommendations for earthwork, foundations, structure, and substructure design for the `Noida Extension Metro Corridor'.

The Criteria in this Appendix apply to all phases of geotechnical site investigations, studies, analyses, reports and recommendations.

"Geotechnical works" shall mean foundations, earthworks, deep excavations, slopes, embankments and earth retaining structures. It shall also include dewatering, and any ground related activities in soil and rock.

The NMRC will make available to the DDC, for information only the Geotechnical Investigation Report prepared earlier. This shall be supplemented as necessary by additional boreholes as required by the DDC in consultation with NMRC under provisional sum.

E1.2 Codes, Standards, and Regulations

The principal standards listed below shall be complied with, superseded, or amended by these Criteria.

The version of the standards, codes, and regulations shall be the latest version.

Indian Standards

SP 36 (Part 1):	Compendium of Indian Standards on Soil Engineering (Laboratory Testing)
SP 36 (Part 2) :	Compendium of Indian Standards on Soil Engineering (Field Testing)
IS 1080 : 1986,	Code of Practice for Design and Construction of Shallow Foundations on Soils.
IS 1200 : (Part 1) :	1992, Methodology of measurement of Building and Civil Engineering Works.
IS 2386: (Part 1 to Part 8)	1963, Methods of Test for Aggregates for Concrete.
IS 2720:	Methods of Tests for Soils.
IS 2911: (Part 1) 1979,	Code of Practice for Design and Construction of Pile Foundations.
IS 3067 : 1988,	Code of Practice for General Design Details and Preparatory Work for Damp-Proofing and waterproofing of Buildings.

British Standards Institution

BS 812 : 1985/1988, Testing Aggregates (Parts 117 to 119).

BS 1377 : 1990, Methods of Test for Civil Engineering Purposes (Parts 1 to 9).

BS 5930 : 1981, Code of Practice for Site Investigations.

BS 6031 : 1981, Code of Practice for Earthworks.

BS 6349 : 1991, Code of Practice for Dredging and Land Reclamation.

BS 8000 : Part 4 : 1989, Code of Practice for Waterproofing.

BS 8000 : Part 5 : 1989, Code of Practice for Below Ground Drainage.

BS 8002 : 1994, Code of Practice for Earth Retaining Structures.

BS 8004 : 1986, Code of Practice for Foundations.

BS 8081 : 1989, Code of Practice for Ground Anchorages.

Standard Method of Measurement for Civil Engineering Works, Edition 1, 4/92.

Others

American Society for Testing and Materials (ASTM), Section 4 : Construction, Volume 04.08 : Soil and Rock I, and Volume 04.09 : Soil and Rock II, 1995.

International Society for Rock Mechanics (ISRM), Suggested Test Methods, (various dates).

GEOTECHNICAL DATA

E1.3 A safety factor of not less than 2.5 should be adopted as the test load for a single pile and a safety factor of not less than 2.0 shall be adopted when considering pile and pile group capacities. A safety factor of at least 1.75 for a single pile and at least 1.5 for group piles shall be adopted when the negative skin friction (which results from downward movement of adjacent soil relative to the pile caused by dewatering and/or the placement of fill) is considered.

E1.4 In his design the DDC shall take adequate measures to minimise the amount of local differential settlement of road surfaces around below ground level works.

E1.5 The slopes of all permanent cuttings and excavations shall be so designed that they are capable of supporting vegetation and shall be stabilised where necessary. In particular, soil slopes shall be hydroseeded or turfed.

E1.6 Piles and Pile Caps

Preliminary geo-technical investigations indicate that piled foundations will be required for elevated structures. Spread foundations shall also be considered if these can be justified on cost, time and geo-technical parameters. For major bridges and culverts, the type of foundation shall depend on soil and site conditions, and, where the MRTS alignment is close to the Northern Railway line, the foundation design of the adjacent structure.

Section E2 – SITE INVESTIGATIONS AND LABORATORY INVESTIGATIONS

SITE INVESTIGATIONS

E2.1 General Conditions

Subsurface Conditions

Regional engineering geology aspects for the area of the Rail alignments are generally documented by the Geological Survey of India.

Seismic Conditions

Detailed, seismic loading and ground-acceleration criteria are discussed under Structural, of these Design Criteria. Consideration of design-level seismic forces in the design of temporary structures is generally not required, except that such designs shall ensure public safety and cause no loss or damage to adjacent projects or properties.

The effects of the design seismic event on the stability of slopes and on the potential for liquefaction of soils shall be taken into account in the design.

E2.2 Investigation Requirements

Existing information shall be supplemented with project-specific site investigations (SI). The intent and objectives of the SI shall be to collect all pertinent and reliable data and information required to produce a safe and economic design and to meet tender and construction requirements.

For the purpose of these Criteria, the term SI shall be considered to include, but not be limited to, the following.

- Compiling and reviewing pertinent existing geologic data.
- Compiling and reviewing pertinent existing geotechnical data from adjacent projects.
- Compiling and reviewing pertinent existing foundation, structure, substructure, and related data from adjacent projects.
- Performing a detailed field reconnaissance.
- Performing ground investigations under provisional sum.

E2.3. Investigation Methods

E2.3.1 Geologic Studies

Geologic studies shall include, but not be limited to, a review of pertinent and existing literature, aerial photographs, and remote-sensing data; a detailed field reconnaissance of the site; and preparation of project-specific maps and cross-sections.

Project-specific geologic maps shall be prepared at about 1:5,000 scale, and geologic cross-sections shall be prepared at about 1:5,000 scale, both horizontal and vertical. Suitable base maps for geologic maps shall be utilised.

Section E3 – FOUNDATIONS

E3.1 Introduction

Foundation depth shall be governed by two factors viz. safe bearing pressure on founding soil and adequate embedment/grip for the foundation structure after allowing for deepest possible scour around the foundation.

In case of continuous structures no settlement is normally permitted. However design should cater for possible settlement as specified above or in accordance with accepted International practice for Railway bridges. Possible settlement, if any, during replacement of bearing under continuous spans also should be completed and limited to permissible limits.

E3.2 Foundation Design Loads, Forces and Stresses

E3.2.1 Ground/Structure Interaction

The effects of foundation settlements on the structures shall be allowed for in the design.

The calculated differential settlement for serviceability Limit State (SLS) between adjacent viaduct piers shall not be greater than 1/1200 times the span or as specified in Clause D5.10.

In the selection of the structural framework for elevated stations, careful consideration shall be given to the isolation or reduction of vibration transmitted from viaduct to the station structure. Complete isolation, if practical, is preferred.

E3.2.2 Earth Pressure

Substructure elements of the bridges/elevated structures, shall be designed to withstand earth pressures in accordance with provisions in IRS Code of Practice for Design of Substructures and Foundations. When Highway, Railway or MRTS system traffic can come within a distance from the top of the structure equal to one-half its height, the applicable load surcharge as specified in respective code shall be adopted. For MRTS loadings the surcharge effect of trains shall be equal to 1.18 tonne/sq.metre.

E3.2.3 Live Loads

The worst of 4 loading conditions shall be considered:

- when only one span is loaded (which would cause an eccentricity effect); or
- when both spans are fully loaded; or
- when both spans on one line loaded with no traffic on other end; or
- when only one girder on one span only is loaded.

In case of well/caisson foundations only such proportion of live load which exceeds 15% of dead load after deducting buoyancy need be considered.

E3.2.4 Buoyancy

The effect of buoyancy shall be considered in the design of substructure (including piling and wells).

E3.2.5 Stream Force

All piers and other portions of structures subject to the force of flowing water shall be designed to resist the maximum forces induced therefrom in accordance with the design flood in accordance with design codes.

E3.3. Load Combinations

All footings shall be designed to keep the soil pressures within safe bearing values and to keep the pressure as uniform as possible. In addition the footings shall be proportioned in such a way that:

Load Combination (See also Table D5.1)	Applicable Condition
Spread Foundation	
Under Combination I loading	Resultant to fall within middle third of base (in Either direction)
Under Combination II loading	Resultant to fall within 42% of base (in either Direction) and maximum Toe pressure not to Exceed 125% of Allowable Bearing Pressure
Under Combination III loading	Resultant to fall within 44% of base (in either Direction) and maximum Toe pressure not to Exceed 133% of allowable bearing pressure.
Footing on Rock –Under Combination I loading	Resultant to fall within 55% of base(in either Direction) and maximum toe Pressure not to exceed allowable bearing pressure
Pile Foundation	
Under Combination I loading	Load on any pile not to exceed its safe load capacity and Uplift force not Exceeding 5% of safe load capacity of pile.
Under Combination II Loading	Load on any pile not to exceed its safe load capacity by more than 25% and Uplift force not exceeding30% of safe Load capacity of pile
Under Combination III loading	Load on any pile not to exceed its safe load capacity by more than 33% and Uplift force not exceeding 40% of safe load capacity of pile

When footings are to be constructed on uneven and/or smooth rock surfaces, the rock surface shall be notched and benched as necessary. In case of shallow foundation, it should be checked for uplift and overturning effects and if found unstable it should be anchored by rock anchors. Shear anchors in form of old light gauge rails or end split rod dowels taken sufficiently deep (at least 0.6 m) into bed rock shall be provided.

BELOW GROUND STRUCTURES

E3.4 General Principles

The designs provided under this Clause shall also satisfy the requirements of Clause foundations to elevated structures.

E3.4.1 The DDC shall use design methods for the analysis of the below ground structures that take account of:

- The method of construction, including temporary works.
- The ground/structure interaction, including the effects of temporary works.
- Ground pressure redistribution and bending moment redistribution.
- Short and long term heave and settlement.
- Groundwater loading, backfill, temperature and other imposed loadings such as surcharge and highway loadings.

E3.4.2 For the purpose of assessing ground pressures the walls of the covered approach shall be considered as either free ended or propped cantilevers as appropriate for the proposed roof slab connection. In either case the ground pressure shall be taken as the at rest value.

E3.5 Types of Construction

E3.5.1 The method of construction for the below ground structure shall take into account the following :

- The geology along the length of the approach structure.
- The hydrogeology and ground permeabilities of the site.
- The maximum depth of construction required.
- Control over heave and instability of the base of the excavation.
- The methods by which the completed structure shall be secured against flotation.
- The method for waterproofing the completed structure.

E3.5.2 The following methods of construction may be used either individually or in combination depending upon the particular requirements of the location, size and type of structure. The list is not considered to be exhaustive.

(i) Diaphragm Walling

Particular attention shall be paid to the stability of the reinforcement cage during placing, methods for forming and locating box-outs, waterproofing of the vertical panel joints and support of the walls during excavation.

(ii) Secant Piling

Particular attention shall be paid to the formation of piles to ensure their integrity and water tightness, and to the support of the completed walls during excavation.

(iii) Soldier Piles and Lagging

Particular attention shall be paid to ensuring that the lagging is providing proper support to the ground, and that the wall is adequately supported during excavation.

(iv) Steel Sheet Piling

Particular attention shall be paid to adequately supporting the walls during excavation and to ensuring that water leakage will not be such that loss of ground or significant groundwater draw down will occur.

(v) Precast Concrete panels.

E3.5.3 In all cases the need to support existing services adequately across or near to the excavation shall be taken into account.

E3.6 Flotation

The DDC shall include in the design of the below ground structure suitable methods for countering the uplift due to displaced water.

E3.7 Base Heave/Boiling

E3.7.1 The excavation during construction for below ground structures shall be checked for base heave/boiling.

E3.7.2 The completed subways shall be checked against base heave.

E3.7.3 Differential heave and settlement shall be considered.

SHALLOW FOUNDATIONS

E3.8 Types, Applications, and General Methods of Analyses

Shallow foundations shall include spread footings for isolated columns, combined footings that support the loads from more than one structural unit, strip footings for walls, and foundation mats or rafts that support an entire structure or loaded area. Shallow foundations may be used where sufficient depth of competent bearing stratum occurs at the foundation's bearing level, and where the following statements are true.

- No highly compressible deposits are present below.
- The calculated foundation settlements are acceptable.
- Existing foundations and slopes shall not be adversely affected.

Methods for shallow-foundation analyses shall be based on recognised standard formulations. All design formulations, parameters, and assumptions shall be presented and accounted for in the analyses.

E3.9 Factors of Safety and Allowable bearing Intensities

Allowable, bearing-pressures shall be based on the calculated ultimate bearing capacities after applying a minimum factor of safety of 3.0 to the overall capacity. Increases in static load capacity of one-third may be allowed for short-term, transient-loading conditions. Requirements shall be satisfied for allowable, bearing pressures based on material type, relative compaction, strength, and other classifications addressed in applicable government publications and standards. The computation for bearing capacity shall be in accordance with IS 6403 or equivalent.

Spread foundations shall be proportioned to keep the maximum imposed soil pressure within the allowable levels and to minimise differential settlement. The design shall ensure that the resultant of the vertical, soil-pressure diagram falls within the middle one-third of either of the plan dimensions of the foundation.

E3.10 Settlements

The total or differential settlements of the chosen foundation system and the site-specific ground conditions shall be demonstrated not to have a significant influence on either the structure as a whole or on individual or groups of elements in the structure. This is particularly important for structures constructed in reclamation areas.

The design of any temporary, ground-support wall (prior to dewatering and excavation) shall include provisions to limit settlement in the adjacent structures or ground to 25mm maximum. The design shall also include provisions to limit angular distortions in adjacent structures to 1:2,000 maximum

The chosen foundation system or form of construction shall be demonstrated not to result in settlement of adjacent structures and properties exceeding the values above. In particular, such structures shall be capable of withstanding these deformations either with or without building-protection measures.

In addition, the requirements for tolerable settlements addressed in applicable government publications and standards shall be satisfied.

DEEP FOUNDATIONS

E3.11 Types and Applications

Deep foundations can generally be classified as follows: driven, displacement elements (large displacement, small displacement) and drilled, cast-in-place, replacement elements.

Driven, displacement elements includes the following.

- Precast prestressed concrete piles (solid sections, cylinder sections).
- Open- and closed-end steel pipe sections.
- Steel H-sections.
- Special sections (Franki piles, Monotube piles, step-tapered piles, PIP piles).

Drilled, cast-in-place, replacement elements includes the following.

- Machine-excavated piers.
- Hand-excavated caissons.
- Barrettes.
- Minipiles.

Deep foundation elements shall be used where bearing capacity or settlement considerations, or both, render shallow foundations unsuitable, or where it is necessary to span foundation loads over existing structures.

E3.12 General Methods of Analyses

Analytical methods include evaluations of axial and lateral capacities, including determinations based on presumptive, simplified rational methods based on total and effective stress analyses, numerical methods, and semi-empirical correlations with in-situ test results. Driveability analyses (wave equation analyses) shall also be performed for driven foundation elements.

Corrosion considerations with respect to deep foundations shall be according to IS 2911 and IS 2720.

E3.13 Factors of Safety and Allowable Capacities

Allowable capacities shall be based on the ultimate capacities after applying appropriate factors of safety. The ultimate pile capacity can be derived from shaft resistance, end bearing, or a combination of both. Capacities shall consider both the strength of the subsurface bearing materials and the allowable structural stresses in the pile materials (steel, concrete). Increases in static axial compressive capacity of one-third may be allowed for short-term intermittent-loading conditions.

For foundation elements under static, axial compressive loads, a minimum, global factor of safety of between 2.0 and 3.0 shall be applied to the ultimate pile capacity. A minimum factor of safety of between 2.0 and 2.5 shall be applied to the ultimate shaft resistance, and a minimum factor of safety of 3.0 shall be applied to the ultimate end bearing.

For foundation elements under static, axial tensile loads, a minimum factor of safety of between 2.5 and 3.0 shall be applied to the ultimate shaft resistance.

Lower-bound minimum factors of safety for axially-loaded foundation elements may be applied if validated by comprehensive load testing. However, in no cases shall minimum factors of safety for axial-loaded foundation elements be less than 2.0.

For vertical foundation elements under lateral load, load-carrying capacity will normally be governed by limiting lateral-deflection requirements, and the moment or shear capacity, or both, of the structural members.

E3.14 Settlements

See Sub-Section E3.10

E3.15 Negative Skin Friction

The design of deep foundations shall include the effects of negative skin friction or downdraw, which may result from settlement of surrounding compressible soils at built-up (fill) sites, from subsidence caused by construction dewatering, or from particular methods of foundation installation. Even with extensive pre-treatment of reclaimed areas, deep foundations and other structural elements constructed in these areas may be subject to negative skin friction loads caused by settlement of the fill and the underlying soft material should be accounted for also.

Unless otherwise accepted, negative skin friction shall be considered as a permanent load on the structural elements and shall be determined from the settlement profile of the relevant strata.

Proposals for bitumen or slip coats applied to these elements, or other appropriate methods to reduce the effects of negative skin friction or other adverse soil conditions may be submitted for acceptance.

E3.16 Group Effects

The design of deep foundations shall include group effects that may reduce the calculated single element axial and lateral capacities and increase the calculated single element deformation.

E3.17 Testing Programme for Deep Foundations

The design shall include the details of a deep foundation load-and-integrity testing programme generally in accordance with IS 2911 (Part 4). Provisions shall be made for the following tests.

Static Load Tests. Compression load tests; uplift load tests; lateral load tests, for all deep foundation types to validate design capacities. Static load testing may be expanded here to include test methods, using Osterberg-type load cells, in which the test load is applied to the base of the foundation element.

Dynamic Load Tests. Pile Driving Analyser; Case Pile Wave Analysis Program (CAPWAP) method; Statnamic-type tests, may be used to supplement, but not replace, static load tests.

Provisions for non-destructive integrity testing (seismic testing, nuclear probes) shall also be included in the testing programme. Testing methods for deep foundations shall be generally according to IS 2911 (Part 4).

For driven, displacement elements, the programme shall include the details of a preproduction, probe, pile programme to be conducted with load testing to determine driving conditions and to confirm installation methods.

Section E4 – RETAINING WALLS AND ABUTMENTS

GENERAL

E4.1 Types, Applications, and General Methods of Analyses

The Criteria set forth in this section governs the design of retaining walls, abutments, and wing walls for viaduct, bridge, and crossing structures. Retaining structures shall be designed to resist earth pressures, hydrostatic pressures, seismic loads, and lateral loads due to surcharge, such as those imposed by highway or railway traffic. Analyses shall consider foundation bearing capacity, stability against base sliding and overturning, and slope stability (resistance against both local instabilities of the back slope area and global slope instabilities that involve the entire wall structure). Settlement of the wall and backfill, and tilting shall also be considered. Retaining walls and abutments may be supported on either shallow or deep foundations.

E4.2 Definitions

Load Factors.

Typically applied to surcharge loads and to material properties, such as unit weights, base friction angles, drained and undrained shear strengths (soils), and compressive strengths (rock). For drainage considerations, an appropriate load factor is also applied to permeability values of granular filters and backfill drainage materials. Load Factors are also known as factors of safety.

Loading Conditions.

Earth pressures and lateral loads due to surcharge shall be based on soil and rock parameters determined from interpretations of ground investigation and laboratory test data and from information related to the state of stress of the backfill. The methods and sequence of backfilling and the effects of compaction shall be considered. Saturated unit weights of soils shall be used to determine earth pressures. A reduction in the saturated unit weight shall be considered only where it can clearly be demonstrated that the backfill soil/rock is and will remain well-drained.

E4.3 Methods of Support

Retaining walls, abutments, and wing walls may include the following.

- Gravity and semi-gravity walls where stability is derived from the dead weight of the structure itself.
- Counterfort and cantilever walls where stability is derived from the dead weight of the wall and of soil engaged by the geometry of the wall.
- Tieback walls where stability is derived from the tensile capacities of tiebacks/anchors.
- “Reinforced earth”-type walls (including reinforced fill structures) where stability is derived from the composite action of the wall facing and backfill, which is reinforced with closely-spaced, small reinforcing elements.
- Crib walls and gabion walls (which may be considered where maximum vertical height measured from toe of wall will not exceed 7m, and where surcharge loading is not present).

E4.4 Load Factors

The partial-load-factor method of applying different load factors (factors of safety) for loading and for material properties shall be used. Loading conditions, such as wall weights, backfill soil/rock, water, and seismic loads, are typically unfactored (load factor of 1.0). Load factors shall be recommended by the Designer.

E4.5 Drainage and Waterproofing Considerations

Retaining wall designs shall provide both effective measures to prevent saturation of backfill soil/rock and to provide effective drainage of backfill soil/rock at all times, including during design flood conditions. If possible, where the retaining structure is impermeable, drainage blankets and toe drains shall be provided to allow drainage and dissipation of water pressures.

Section E5 - SLOPES

E5.1 Typical Slopes

Typically, cut slopes in rock shall not be steeper than 3 horizontal to 10 vertical, with a minimum 4m-wide bench at least every 15m vertical interval. Typically, cut slopes in highly weathered rock of and compact alluvial deposits shall not be steeper than 1.5 horizontal to 1.0 vertical, with a minimum 1.5m-wide bench at least every 7.5m vertical interval. Typically, fill slopes shall not be steeper than 2.0 horizontal to 1.0 vertical.

The typical slopes cited above are provided as guidelines. Actual slope designs shall be based on the results of recognised, analytical methods.

E5.2 General Methods of Analyses

E5.2.1. Soil Slopes

Geometries of slopes in soils shall be determined analytically, generally using non-circular calculation methods, such as the Simplified Janbu method. Depending on soil type/composition, infinite slope, sliding block, or Bishop circular analyses may be used where more appropriate. Where high-quality subsurface data are available, or when back-analyses of a failed slope are being carried out the Rigorous Janbu, Morgenstern-Price or Sarma's methods may be appropriate.

E5.2.2. Rock Slopes

Geometries of slopes in rock, including completely to highly weathered rock with controlling remnant rock jointing or other structure, shall be determined analytically, generally using stereographic projection or vector methods. Slope geometries shall be analysed for planar sliding along individual joints, block sliding along joint set combinations, and toppling.

E5.3 Methods of Support

Typical methods of support include mechanical restraint involving walls, temporary and permanent ground anchors, soil nailing, and rock bolting. Passive methods involving internal drainage of slopes (horizontal drains or weepholes) shall be considered in design and construction to improve stability by dissipating driving water forces.

E5.4 Factors of Safety

Factors of safety for slopes shall be at least 1.5 and 1.2 for the short term and long term case respectively.

E5.5 Drainage and Erosion-protection Considerations

All slopes shall be provided with surface drainage and erosion-protection systems based on acceptable soil loss, topography and hydrology. Typically, slope drainage shall be provided by a series of interconnected channels at the top of the slope, along intermediate benches, and at the toe of the slope that intercept runoff and convey it to discharge points beyond the slope. Drainage channels shall typically be concrete-lined U-channels, or half-round channels.

Rigid surface protection such as shotcrete/gunite, with/without welded-wire fabric or fibre reinforcement shall be provided for all exposed soil slopes. Weepholes penetrating the surface protection shall be provided to prevent build-up of water pressures. Typically, 50mm diameter weepholes at 1.2m centres each way shall be provided.

Vegetative protection shall be limited to relatively flat slopes with low relief that are capable of supporting vegetation and that have adequate stability under saturated conditions.