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सत्यमेव जयते

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FOTULA TUNNEL
TECHNICAL SPECIFICATIONS-(TUNNEL-CIVIL)
VOLUME-4A

Prepared by:

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1 TECHNICAL SPECIFICATIONS

These Technical Specifications define the technical and quality standards specifically for NATM tunnel construction works in all ground condition.

The construction works shall be executed by the Contractor according to the quality requirements defined in the Specification and to the satisfaction of the Employer's Representative. Any item of work arising from the execution of the works, not covered by the Technical Specification, shall be according to a Standard as agreed with the Employer's Representative and the Contractor.

It is the intent of this Specification to define standards for the tendering process as well as for the planning and execution of the work by the Contractor. This includes the definition of quality standards which have to be followed and will be checked during construction by the Employer's Representative. Deviations from the Specification must be submitted in writing in the tender.

This Technical Specification is based on the "Specification for Tunnelling, Third Edition", British Tunnelling Society, Institution of Civil Engineers, 2010 and latest version of "MORTH Specification for Road and Bridge Works", Ministry of Road Transport and Highways. 2010.

1.1 Definition

Behavior Type (BT) means general categories describing similar ground behaviors with respect to failure modes and displacement characteristics.

Contractor means the person(s) named as contractor in the Letter of Tender accepted by the Employer and the legal successors in title to this person(s).

Contractor's Representative means the person named by the Contractor in the Contract or appointed from time to time by the Contractor who acts on behalf of the Contractor.

Cost means all expenditure reasonably incurred (or to be incurred) by the Contractor, whether on or off the Site, including overhead and similar charges, but does not include profit.

Day means a calendar day.

Design drawing, final drawing, construction drawing, fit-for-constriction drawing means drawing of detailed design prepared by the Contractor and approved by Employer's Representative.

Employer means the person named as employer in Contract Data and the legal successor in title to this person.

Employer's Representative and Engineer means the person appointed by the Employer to act as Employer's Representative for the purposes of the Contract and named as such in the Contract Data, or other person appointed from time to time by the Employer and notified as such to the Contractor.

Framework plan means the summary of the Geotechnical Design, including relevant parameters used in the design, and application criteria for the assignment of excavation and support methods.

Ground behavior means reaction of the ground to the excavation of the full profile without consideration of sequential excavation and support.

Ground Type (GT) means ground, soil or rock, with similar properties.

(Design) Line of excavation means the line of excavation within which no unexcavated ground material shall remain at any time. If due to additional displacements of the ground unexcavated material extend into the line of excavation the Employer's Representative may order to excavate this material at no additional costs.

Materials means things of all kinds (other than Plant) whether on the Site or otherwise allocated to the Contract and intended to form or forming part of the Works, including the supply-only Materials (if any) to be supplied by the Contractor under the Contract.

Over-break means the excavation beyond the line of excavation (payline).

Geological Over-break Overbreak can be further defined as geological overbreak if considered due to geological condition and meeting certain requirements of geological overbreak.

Over-break Line means the line to which over break is allowed without any remedial work required.

Plant means the apparatus, machinery and vehicles intended to form or forming part of the Permanent Works.

Site means the places where the Permanent Works are to be executed and to which Plant and Materials are to be delivered, and where the Operation Service is to be provided, and any other places as may be specified in the Contract as forming part of the Site.

System Behavior (ST) means behavior resulting from the interaction between ground, excavation profile and support, separated in system behaviour in the respective excavation section, system behavior in the supported section and system behavior in the final state.

Working Day mean a day, on which working is performed.

Works means the Permanent Works and Temporary Works or either of them as appropriate and the facility to be operated by the Contractor during the Operation Service Period.

1.2 Work during Extreme Weather Conditions

All works have to be continued during any weather condition. Difficulties due to snow fall and sub-zero temperature or heavy rainfall or any other weather adversary are compensated with the quoted unit prices, as well as all provisions for cold-weather concreting. No extension of construction time is derived.

1.3 Submittals

The Contractor shall provide description of all works prior to commencement of any work to the Employer's Representative for approval. The Contractor shall submit the documents in a way that sufficient time is left for approval of the submittals but latest 2 working weeks before start of the relevant works if not specified herein differently or directed by the Employer's Representative.

The description shall include but not limited to procedure, sequence, materials, equipment, laboratory etc. The Employer's Representative may request additional data and supplementation of the submittals at any time.

1.4 Standards and Units

Materials, equipment and methods shall comply with the Standards and Codes of Practice indicated using the versions that are current at the date for submission of tenders. All work shall be done following the codes and guidelines in the following order of preference unless defined otherwise in this specification

1. Indian Standards
2. Indian Road Congress (IRC)
3. Indian Railway Standards (IRS)
4. European Standards (EN, BS, ÖNORM etc.)
5. American Standards (AASHTO)
6. Any international code with approval of engineer in charge.

The Contractor may propose the adoption of alternative standards and shall provide explanations with any proposals. The use of such standards shall be subject to the agreement of the Employer's Representative.

Some Indian, European and British Standards and Guidelines are listed in section 1.4. The list is provided for information only and does not illustrate all relevant Standards for the Works. All Work shall be in compliance with these Standards and Guidelines. First and fore-most the compliance of Indian Standards is required unless defined otherwise in this Specification. International (in the first step European) Standards and Guidelines shall be accessed to when no Indian Standards/Guidelines are available for the specific matter.

References to sources for Standards, Guidelines and Recommendations cited in the contractual documents are provided in Table 1.1 for information only.

Table 1.1: References to sources of Standards, Guidelines and Recommendation

Abbreviation	Name
ASTM	American Society for Testing and Materials, 100 Bar Harbor Dive West, Conshohocken PA 19429 – 2595, U.S.A.
BSI (BS)	British Standards Institute, 389 Chiswick High Road, London, W4 4AL
DIN	Deutsches Institut für Normung e.V. Beuth Verlag GmbH, Burggrafenstrasse 6 D-10787, Berlin, Germany.

EFNARC	European Federation of Producers and Applicators of Special Building Products, Association House, 235 Ash Road, Aldershot, Hampshire, GU12 4DD, United Kingdom.
EN, ENV	European Committee for Standardisation, Central Secretariat, Rue de Stassart 36 B-1050, Brussels.
IRC	The Indian Road Congress, Jamnagar House, Shahjahan Road, New Delhi- 110011.
IS	Bureau of Indian Standards, Manak Bhavan, 9 Bahdur Shah Zafar Marg, New Delhi – 110002.
ISO	International Organization for Standardisation 1, rue de Varembé CP 56, CH- 1211 Genéve 20, Switzerland.
ÖNORM:	Austrian Standard Institute, Heinestraße 38, 1020 Wien, Austria
RVS (Austrian Code for Road Construction)	Austrian Association on Road, Rail and Transport (FSV), Karlsgasse 5, 1040 Wien, Austria
ÖGG	Austrian Society for Geomechanics, Bayerhamerstrasse 14, 5020 Salzburg, Austria
ÖBV	Österreichische Bautechnik Vereinigung (Austrian Association for Construction Technology, formerly Austrian Concrete Society), Karlsgasse 5, 1040 Vienna, Austria

The units applied are those of SI-System according to ISO 1000. A full stop (.) is used as decimal delimiter. Additionally in the schedule of prices the following abbreviations are applied:

D : calendar day

each : each

ls : lump sum

wd : working day

1.4.1 Listing of Standards

The list is provided for information only.

Indian Standards

ID of Standard	Description
IS 10262-2009 (Sec. Rev-2019)	Guidelines for concrete mix design proportioning
IS 1077-1992(Reaffirmed -2021)	Common Burnt Clay Building Bricks
IS 11171-1985(Reaffirmed -2016)	Dry-Type Power Transformers
IS 1199-1959(Reaffirmed -2018)	Methods of sampling and analysis of concrete
IS 12330-1988(Reaffirmed -2019)	Specification for sulphate resisting Portland cement
IS 1248-2021	Direct Acting Indicating Analogue Electrical Measuring Instruments and their Accessories
IS 1278-1972(Reaffirmed-2019)	Filler rods and wires for gas welding
IS 1343-1980(Reaffirmed-2017)	Code of Practice for Prestressed Concrete
IS 1542-1992	Sand for plaster
IS 1554-1988	(Part 1): PVC insulated (heavy duty) electric cables: Part 1 For working voltages up to and including 1100 V
IS 1566-1982	hard-drawn steel wire fabric for concrete reinforcement
IS 1885-1993	Electrotechnical Vocabulary: Part 32 Electric cables
IS 1651-1991(Fourth Rev-2013)	Stationary cells and batteries, lead-acid type (with tubular positive plates)

ID of Standard	Description
IS 8130-1984	Conductors for insulated electric cables and flexible cords
IS 1786-2008	High strength deformed steel bars and wires for concrete reinforcement-
IS 1791-1985 (Third Rev.-2013)	General Requirements for Batch Type Concrete Mixers
IS 1905-1987	Code of practice for structural safety of buildings; masonry
IS 2062-2011	Hot Rolled Medium and High Tensile Structural Steel
IS 2116-1980	Sand for masonry mortars
IS/IEC 60947-1-2007	Low-voltage Switchgear and Control gear :Part 1 General
IS 2180-1988	heavy duty burnt clay building bricks
IS 2309-1989	Code of practice for the protection of buildings and allied structures against lightning
IS 2386-1963	(Part 1 & 8): methods of tests for aggregates for concrete
IS 2502-1963	Code of Practice for Bending and Fixing of Bars for Concrete Reinforcement
IS 2505-1992	Concrete vibrators - Immersion type - General requirements
IS 2514-1963	Concrete vibrating tables
IS/IEC 60947-2-2003	Low-Voltage Switchgear and Control gear - Part 2 : Circuit Breakers
IS 13118-1991	High-Voltage Alternating-Current Circuit-Breakers
IS/IEC 60947-3-1999	Low-voltage switchgear and control gear : Part 3 Switches, disconnectors, switch-disconnectors and fuse
IS 269-2015	Ordinary Portland cement
IS 2705-1992	Current transformers
IS 2750-1964	Steel Scaffoldings
IS 2751-1979	Code of Practice for Welding of Mild Steel Plain and Deformed Bars for Reinforced Concrete Construction
IS 280-2006	Mild Steel Wire for General Engineering Purposes
IS 13925-1-2012	Shunt capacitors for ac power systems having a rated voltage above 1000 V Part 1:General
IS 2961-1973	Chrome retan finished upper leather
IS 8130-1984 (Sec. Rev.-2013)	Conductors for insulated electric cables and flexible cords
IS 3043-1987 (Sec. Rev.-2018)	Code of practices for earthing
IS 3085-1965	Method of Test for Permeability of Cement Mortar and Concrete
IS 3156-1992	Voltage transformers
IS 3231-1986	Electrical relays for power systems protection
IS 3427-1997	A.C. Metal Enclosed Switchgear and Control gear for Rated Voltages Above 1 kV and Up to and Including 52
IS 3443-1980	Crane rail sections
IS 3558-1983	Code of practice for use of immersion vibrators for consolidating concrete
IS 3597-1998	Concrete pipes - Methods of test
IS 5578-1984	Guide for marking of insulated conductors

ID of Standard	Description
IS 11353-1985	Guide for Uniform System of Marking and Identification of Conductors and Apparatus Terminals
IS 3764-1992	Code of safety for excavation work
IS 383-1970 (Third. Rev.-2016)	Coarse and Fine Aggregates from Natural Sources For Concrete
IS 3954-1991	Hot Rolled Steel Channel Sections for General Engineering Purposes - Dimensions
IS 4031-1989 (Sec. Rev.-1996)	Methods of physical tests for hydraulic cement
IS 4032-1985	Method of chemical analysis of hydraulic cement
IS 4081-1986 (Sec. Rev.-2013)	Safety code for blasting and related drilling operations
IS 4138-1977	Safety code for working in compressed air
IS 432-1982	Mild Steel and Medium Tensile Steel Bars and Hard-Drawn Steel Wire for Concrete Reinforcement
IS 456-2000(reaffirmed -2005)	Plain and Reinforced Concrete - Code of Practice
IS 457-1957	Code of Practice for General Construction of Plain and Reinforced Concrete for Dams and Other Massive Structures
IS 458-2003 (Fifth. Rev.-2021)	Precast Concrete Pipes (with and without Reinforcement)
IS 4756-1978	Safety code for tunnelling work
IS 4880 (Part 1-7) (First. Rev.-2014)	Code of practice for design of tunnels conveying water
IS 4925-2004	Concrete Batching and Mixing Plant
IS 4988-1968	(Part 1-5): Glossary of terms and classification of earth moving machinery
IS 5082-1998	Wrought aluminium and aluminium alloy bars, rods, tubes and sections for electrical purposes
IS 516-1959 (Part-1,sec-1-2021)	Method of Tests for Strength of Concrete
IS 5525-1969	Recommendation for detailing of reinforcement in RCC
IS 5640-1970	Method of test for determining aggregate impact value of soft coarse aggregates
IS 5819-1970	Recommended Short-circuit Ratings of High Voltage PVC Cables
IS 5831-1984	PVC insulation and sheath of electric cables
IS 5878-1971	(Part 1-7): Code of Practice for Construction of Tunnels
IS 5892-2004	Concrete transit mixers & agitators
IS 6430-1985	Mobile air compressor for construction purposes
IS 6461-1972	Glossary of terms relating to cement concrete: Part I Concrete aggregates
IS 6461-1972	Glossary of Terms Relating to Cement Concrete - Part III : Concrete Reinforcement

ID of Standard	Description
IS 650-1991	Standard Sand for Testing of Cement
IS 694-2010	POLYVINYL CHLORIDE INSULATED UNSHEATHED AND SHEATHED CABLES/CORDS WITH RIGID AND FLEXIBLE CONDUCTOR FOR RATED VOLTAGES UP TO AND INCLUDING 450/750 V
IS 7098-1988	Crosslinked polyethylene insulated PVC sheathed cables: Part 1 For working voltage upto and including 1 100 V
IS 7245-1974	Concrete payers
IS 7251-1974	Concrete finishers
IS 7293-1974	Safety code for working with construction machinery
IS 7319-1974	perforated concrete pipes
IS 783-1985	Code of Practice for Laying of Concrete Pipes
IS 7861-1981	(Part 2): Code of practice for extreme weather concreting: Part II Recommended practice for cold weather concreting
IS 7861-1981	(Part 1): Code of practice for extreme weather concreting Part 1 Recommended practice for hot weather concreting
IS 800-2007	General Construction In Steel - Code of Practice
IS 8041-1990	Specification for rapid hardening Portland cement (2nd revision)
IS 814-2004	Covered Electrodes for Manual Metal Arc Welding of Carbon and Carbon Manganese Steel
IS 816-1969	Code of practice for use of metal arc welding for general construction in mild steel
IS 817-1992	(Part 1): Training of Welders - Code of Practice: Part 1 Manual metal arc welding
IS 818-1968	Code of Practice for Safety and Health Requirements in Electric and Gas Welding and Cutting Operations
IS 2062-2011	Hot Rolled Medium and High Tensile Structural Steel
IS 8623-1993	Low-Voltage Switchgear and Control gear Assemblies
IS/IEC 60898 -2002	Electrical accessories - Circuit-breakers for overcurrent protection for household and similar installations : Part 1
IS 9012-1978	Recommended practice for shotcreting
IS 9103-1999	Concrete Admixtures
IS 9284-1979	Method of test for abrasion resistance of concrete
IS 9417-1989 (Sec. Rev.-2018)	Recommendations for welding cold worked bars for reinforced concrete construction
IS 11309-1985	Method of conducting pull out test on anchor bars and Rock bolt

European Standards

Eurocode 1	Basis of design and actions on structures
Eurocode 2	Design of concrete structures
Eurocode 3	Design of steel structures
Eurocode 5	Design of timber structures
Eurocode 7	Geotechnical design
Eurocode 8	Design of structures for earthquake resistance
BS EN ISO 62:2008	Plastics. Determination of water absorption
BS EN 196:2005	Methods of testing cement
BS EN 197-1:2011	Cement. Composition, specifications and conformity criteria for common cements
BS EN 197-1:2004	Cement – Part 1: Composition, specifications and conformity criteria for common cements
BS EN 206-1:2001	Specification, performance, production and conformity
BS EN 295-7:1996	Requirements for vitrified clay pipes and joints for pipe jacking
BS EN 338:2010	Structural timber. Strength classes
BS EN 450-1:2005	Fly ash for concrete – Part 1: Definitions, specifications and conformity criteria A1:2007
BS EN 471:2004	High-visibility warning clothing for professional use - Test methods and requirements
BS EN 480:2006	Admixtures for concrete, mortar and grout. Test methods
BS EN ISO 527-3:1996	Plastics. Determination of tensile properties. Test conditions for films and sheets
BS EN 681-2:2000	Elastomeric seals. Material requirements for pipe joint seals used in water and drainage applications. Thermoplastic elastomers
BS EN 771-3:2011	Specification for masonry units. Aggregate concrete masonry units (dense and light-weight aggregates)
BS EN 772-2:1998	Methods of test for masonry units. Determination of percentage area of voids in masonry units (by paper indentation)
BS EN 791:1996	Drill rigs – safety
BS EN 815:1997	Safety of unshielded tunnelling boring machines and rodless shaft boring machines for rock
BS EN 932-6:1999	Tests for general properties of aggregates. Definitions of repeatability and reproducibility
BS EN 933-1:2012	Tests for geometrical properties of aggregates. Determination of particle size distribution. Sieving method
BS EN 934-2:2009	Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions and requirements, conformity, marking and labelling
BS EN 1008:2002	Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete
BS EN 1011-1:2009	Welding - Recommendations for welding of metallic materials - General guidance for arc welding
BS EN 1011-2:2001	Welding. Recommendations for welding of metallic materials. Arc welding of ferritic steels
BS EN 1062-7:2004	Paints and varnishes. Coating materials and coating systems for exterior masonry and concrete. Determination of crack bridging properties
BS EN 1090-2:2008	Execution of steel structures and aluminium structures. Technical requirements for steel structures
BS EN 1097	Tests for mechanical and physical properties of aggregates

BS EN 1367	Tests for thermal and weathering properties of aggregates
BS EN ISO 1461:2009	Hot dip galvanized coatings on fabricated iron and steel articles. Specifications and test methods
BS EN 1537:2000	Execution of special geotechnical work – rock anchors
BS EN 1542:1999	Products and systems for the protection and repair of concrete structures. Test
BS EN 1562:2012	Founding. Malleable cast irons
BS EN 1563:2012	Founding. Spheroidal graphite cast iron
BS EN 1744	Tests for chemical properties of aggregates
BS EN 1849-2:2010	Flexible sheets for waterproofing. Determination of thickness and mass per unit area. Plastic and rubber sheets
BS EN 1928:2000	Flexible sheets for waterproofing. Bitumen, plastic and rubber sheets for roof waterproofing. Determination of water tightness
BS EN ISO 3506-2: 2009	Mechanical properties of corrosion-resistant stainless-steel fasteners - Nuts
BS EN ISO 4624:20016	Paints and varnishes. Pull-off test for adhesion
BS EN ISO 9001:2015	Quality management systems. Requirements
BS EN 10025:2004	Hot rolled products of structural steels
BS EN 10080:2005	Steel for the reinforcement of concrete. Weldable reinforcing steel. General
BS EN 10164:2004	Steel products with improved deformation properties perpendicular to the surface of the product – technical delivery
BS EN 10226-1:2004	Pipe threads where pressure tight joints are made on the threads. Taper external threads and parallel internal threads. Dimensions, tolerances and designation
BS EN ISO 11925-2:2011	Reaction to fire tests. Ignitability of products subjected to direct impingement of flame. Single-flame source test
BS EN 12110:2002	Tunneling machines – Air locks – Safety requirements
BS EN 12111:2002	Tunneling machines – Road headers, continuous miners and impact rippers – Safety requirements
BS EN 12310-2:2000	Flexible sheets for waterproofing. Determination of resistance to tearing (nail shank). Plastic and rubber sheets for roof waterproofing
BS EN 12317-2:2010	Flexible sheets for waterproofing. Determination of shear resistance of joints. Plastic and rubber sheets for roof waterproofing
BS EN 12336:2005	Tunneling machines - Shield machines, thrust boring machines, auger boring machines, lining erection equipment - Safety requirements
BS EN 12350	Testing fresh concrete
BS EN 12390	Testing hardened concrete
BS EN 12504-1	Testing concrete in structures – Part 1: Cored specimens – Taking, examining and testing in compression
BS EN 12588:2007	Lead and lead alloys. Rolled lead sheet for building purposes
BS EN 12620:2002	Aggregates for concrete
BS EN 12878:2005	Pigments for the colouring of building materials based on cement and/or lime. Specifications and methods of test
BS EN 12889:2000	Trenchless construction and testing of drains and sewers
BS EN 13055-1:2002	Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout
BS EN 13139:2002	Aggregates for mortar
BS EN 13263-1:2005	Silica fume for concrete – Part 1: Definitions, requirements and conformity criteria

BS EN 13492:2004 (E)	Geosynthetic barriers - Characteristics required for use in the construction of liquid waste disposal sites, transfer stations or secondary containment
DIN EN 13670-	Execution of concrete structures
BS EN 13791:2007	Assessment of in-situ compressive strength in structures and pre-cast concrete components
BS EN 14487-	Sprayed concrete – Part 1: Definitions, specifications and conformity
BS EN 14487-	Sprayed concrete – Part 2: Execution
BS EN 14488-1:2005	Testing sprayed concrete – Part 1: Sampling fresh and hardened concrete
BS EN 14488-2:2006	Testing sprayed concrete – Part 2: Compressive strength of young sprayed concrete
BS EN 14488-3:2006	Testing sprayed concrete – Part 3: Flexural strengths (first peak, ultimate and residual) of fibre reinforced beam specimens
BS EN 14488-4:2005	Testing sprayed concrete – Part 4: Bond strength of cores by direct tension
BS EN 14488-5:2006	Testing sprayed concrete – Part 5: Determination of energy absorption capacity of fibre reinforced slab specimens
BS EN 14488-7:2006	Testing sprayed concrete – Part 7: Fibre content of fibre reinforced concrete
BS EN 14889-1:2006	Fibres for concrete – Part 1: Steel fibres. Definitions, specifications and conformity
BS EN 14889-2:2006	Fibres for concrete – Part 2: Polymer fibres. Definitions, specifications and conformity
BS EN 15167-1:2006	Ground granulated blast furnace slag for use in concrete, mortar and grout – definitions, specifications and conformity criteria
BS EN 60204	Safety of machinery. Electrical equipment of machines
BS EN 61672-	Electroacoustics. Sound level meters. Specifications
DD CEN/TS 14416:2005	Geosynthetic barriers. Test method for determining the resistance to roots
PD CLC/TR 50426:2006	Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio-frequency radiation. Guide.

British Standards

BS 143 and 1256:2000	Threaded pipe fittings in malleable cast iron and cast copper alloy
BS 1134:2010	Assessment of surface texture. Guidance and general information
BS 4190:2001	ISO metric black hexagon bolts, screws and nuts. Specification
BS 4449:2005	Steel for the reinforcement of concrete – Weldable reinforcing steel – and decoiled product Bar, coil
BS 4482:2005	Steel wire for the reinforcement of concrete products. Specification
BS 4483:2005	Steel fabric for the reinforcement of concrete

BS 4921:1988	Specification for sherardized coatings on iron or steel
BS 5228-1:2009	Code of practice for noise and vibration control on construction and open sites. Noise
BS 5228-2:2009	Code of practice for noise and vibration control on construction and open sites. Vibration
BS 5607:1998	Code of practice for the safe use of explosives in the construction
BS 5911-1	Concrete pipes and ancillary concrete products. Specification for unreinforced and reinforced concrete pipes (including jacking pipes) and fittings with flexible joints (complementary to BS EN 1916:2002)
BS 5975:2008	Code of practice for temporary works procedures and the permissible stress design of false work
BS 6100	Building and civil engineering. Vocabulary. (various dates)
BS 6164:2011	Code of practice for health and safety in tunneling in the construction
BS 6319	Testing of resin and polymer cement compositions for use in construction (various dates)
BS 6472:2008	Guide to evaluation of human exposure to vibration in buildings (1–80
BS ISO 4866:2010	Mechanical vibration and shock. Vibration of fixed structures. Guidelines for the measurement of vibrations and evaluation of their
BS 7385-2:1993	Evaluation and measurement for vibration in buildings. Guide to damage levels from ground borne vibration (Part 2)
BS 7668:2004	Weldable structural steels. Hot finished structural hollow sections in weather resistant steels. Specification
BS 7671:2011	Requirements for electrical installations
BS 7973-1:2001	Spacers and chairs for steel reinforcement and their Specification. Product performance requirements
BS 7973-2:2001	Spacers and chairs for steel reinforcement and their Specification. Fixing and application of spacers and chairs and tying of
BS 7979:2001	Specification for limestone fines for use with Portland cement
BS 8102:2009	Code of practice for protection of below ground structures against water from the ground
BS 8500-1:2006	Concrete – Complementary British Standard to BS EN 206-1. Method of specifying and guidance for the specifier
BS 8500-2:2006	Concrete. Complementary British Standard to BS EN 206-1. Specification for constituent materials and concrete
BS 8666:2005	Scheduling, dimensioning, bending and cutting of steel reinforcement for concrete. Specification

Other International Standards and Guidelines

ASTM D 1777-96(2019)	Standard Test Method for Thickness of Textile materials
ASTM D 3776/D3776M-	Standard Test Methods for Mass Per Unit Area (Weight) of Fabric
ASTM D 4491/D4491M-	Standard Test Method for Water permittivity
ASTM D 4751-21A	Standard Test Method for Apparent opening size of a Geotextile
ASTM D 4632/D4632M-	Standard Test Method for Grab Breaking Load and Elongation of
ASTM D 3786/ D 3786M-18	Standard Test Method for Bursting Strength of Textile Fabrics-Diaphragm Bursting Strength Tester Method
ASTM D 4833/D 4833M-07(2020)	Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products
ASTM D 4533/D	Standard Test Method for Trapezoid Tearing Strength of Geotextiles
ASTM D 4632/D	Standard Test Method for Grab Breaking Load and Elongation of

ASTM D 4355/D 4355M-21	Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus
ASTM D 3787-16(2020)	Standard Test Method for Bursting Strength of Textiles-Constant-Rate-of- Traverse (CRT) Ball Burst Test
ASTM D 4157-13(2017)	Standard Test Method for Abrasion Resistance of Textile Fabrics (Oscillatory Cylinder Method)
EFNARC-1996	European Specification for Sprayed Concrete
ASTM C-39/C39M-21	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C-78/C78M-22	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-94/C	Standard Specification for Ready-Mixed Concrete
ASTM C-172/C-172M-	Standard Practice for Sampling Freshly Mixed Concrete
ASTM C-685/C-685M-17	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
EFNARC Three Point Bending Test on Square Panel with Notch 2011	Testing Sprayed Concrete - Flexural tensile strength of fibre concrete on sprayed test specimen.
ÖBV publications	Guideline on sprayed concrete and testing methods
ÖBV publications	Inner lining concrete
JSCE -2004	Recommendation for design and construction of steel fibre reinforced concrete, Publications of Japan society of civil
DIN 67524 (Part 1/02)	Lighting of street tunnels and underpasses
DIN 67524-2008	Tunnel illumination
DIN 5035	Artificial lighting
RABT (2006)	Guidelines for equipment and operation of road tunnels

1.4.2 Materials

All materials supplied to the Works shall conform to all of the following:

- This specification.
- The appropriate Indian Standard, if no Indian Regulation is available the corresponding European or British Standard shall be adopted.
- Where an industry certification scheme is available, material shall be supplied in accordance with that scheme.
- Materials shall be supplied from a quality assured source, operating a Quality Assurance system in compliance with the relevant part of BS EN ISO 9001.

Where required in the particular specification or where stated on the drawings, samples should be supplied and the subsequent material shall conform to the samples.

Materials used on site shall be used in accordance with the manufacturer's recommendations and instructions.

All materials should be handled and stored in a way to maintain their integrity and to avoid damage and degradation.

Details of the level of inspection and testing to be adopted in respect of supplied materials shall be agreed with the Employer's Representative prior to commencement of work. Individual submissions are then restricted to those required by the Quality System.

1.4.3 Quality Management and Records

The project shall be administered using an accredited Quality Management System conforming to ISO 9001. The individual requirements for agreement by the Employer's Representative of materials and workmanship throughout this Specification shall be incorporated into agreed self-certification procedures.

The agreed Quality Control arrangements, including hold points and submission of records for the Employer's Representative's acceptance, shall be set out in agreed Inspection and Test Plans.

References to the agreement of materials, workmanship, methods etc. throughout this specification shall be interpreted as requirement of agreement of the Employer's Representative.

The Contractor shall maintain all records necessary under this specification , including quality records as appropriate.

Electronic records shall be maintained and backed up on a daily basis to prevent loss of data in the event of failure of electronic data storage.

Copies of all site records shall be available to the Employer's Representative.

The Contractor shall supply the Employer's Representative with all information necessary for the Health and Safety file including as-built drawings and records, maintenance schedules, operation and maintenance manuals, within the time specified in the Contract. Information shall be provided in the agreed format. The Health and Safety File shall be prepared by the party identified in the Contract.

2 SITE INSTALLATION

2.1 General

The Contractor shall be responsible for providing all necessary provisions for the execution of the construction works under this Contract. This includes plants, equipment, materials and laboratories.

The Contractor shall design, furnish, install, maintain and operate at the project area all temporary works and equipment such as Contractor's camp, offices, stores, workshops, warehouses, assembly areas, machinery, vehicles, material yards, health, safety and environment friendly measures, electric power, telecommunications, illumination, water supply system, concrete and aggregate processing plants, material testing laboratory, temporary construction roads etc. All site installation and facilities shall be design and constructed to consider cold weather condition and high altitude and should enable round the year working with stoppage as minimum as possible.

56 days prior to commencement of any works the Contractor shall submit layout plans at adequate scale showing the temporary construction facilities of the Contractor to the Employer's Representative and they shall include:

- The Contractor's camp, offices, parking space, workshop, warehouses and storage areas including explosive magazines
- Water supply, electric power supply including illumination and communication system
- Sewerage, sewage treatment and disposal
- Construction of temporary roads
- Concrete and material processing plant, cement and aggregate storage
- Material testing laboratory
- Temporary tunnel ventilation system
- Survey plan
- Security and safety arrangement plan, medical care services.
- Cold weather arrangements to maintain the work progress during winter

2.2 Contractor's Camp

The Contractor shall design, furnish, install, maintain and operate the Contractor's camp at the location and within the designated lines defined by the local Authorities or the Employer's Representative. The Contractor's camp shall provide the housing, feeding and recreation of the Contractor's employees and those of his subcontractors. The Contractor's camp shall be designed for the maximum number of employees on the site.

All facilities shall be in compliance with the Indian Construction Workers Act 1996 on permanent and temporary housing of employees. Prior to any camp construction the Contractor's drawings and Specifications shall be approved by the Employer's Representative.

The Contractor shall provide additional adequate housings for the Employer's Representative staff.

2.3 Site Office, Stores

The Contractor shall design, furnish, install, maintain and operate all required offices, stores, warehouses and testing laboratories at the location and within the designated lines defined by the local Authorities or the Employer's Representative.

The Contractor shall provide and maintain a fully equipped site office for the Employer's Representative staff on each construction site on each portal (i.e. West Portal and East Portal).

2.4 Lighting & Ventilation during Construction

Lighting and ventilation during construction shall be in compliance with relevant section 5.5 in this Specification.

2.5 Electrical Power Supply

2.5.1 General

The Contractor shall be responsible for obtaining an adequate electrical supply for all his Site operations during the whole construction period.

Installations shall comply with IEC 60204 Safety of machinery, electrical equipment of machines and IEC 60364 Electrical installations of buildings.

If so required by the Employer's Representative, the Contractor shall make a copy of all certificates prepared upon completion of electrical installations and prepared for all required periodic checks available.

The Contractor shall appoint a competent person to be solely responsible for ensuring the safety of all temporary electrical equipment on site.

The Contractor is to comply at all times with the Electricity at Work Regulations.

The Contractor shall furnish, install and keep operational throughout the duration of the Works standby generating facilities of such capacity as to be able to maintain minimum services such as illumination, ventilation, water supply, dewatering etc. necessary for the Project Area safety and security during a failure of the primary power source.

Oil filled transformers are not permitted in subsurface usage. Transformers shall be air-cooled and dry type.

Electrical heaters or radiators having exposed coils or elements shall not be permitted underground.

The lighting circuits shall be separated from the other sub-circuits. An independent surge protection and UPS enabled sub-circuit shall be implemented for all critical instrument for office running like IT peripherals etc.

The Contractor shall furnish, operate and maintain 100% standby diesel-driven generators or alternative source of power supply at each working portal. The generators or alternative supply shall be capable of operating the lighting system and the pumps required to flooding of the underground works besides operating all other systems so to allow the work function smoothly in event of main power system failure. The generators shall be tested by the Contractor weekly to ensure the full working capability.

Drawings showing the design of the electrical power distribution system within each area shall be submitted to the Employer's Representative for approval at least 28 days prior to installation. This shall at least include a single line diagram for the distribution systems within each area, protection schemes for the systems and description of the operation concept. The installation of the electrical distribution systems shall not be started unless the Employer's Representative has approved the submitted documents.

The client or representative of the client shall be allowed to access always all facilities of the construction site.

2.5.2 Earthing

All light fittings, electrical equipment and appliances shall be earthed electrically, and the Contractor's specialised personnel shall periodically check the effectiveness of such earthing. The earthing shall meet the requirements for plant and equipment given by Indian Standard 3043.

2.5.3 Cables

All exposed electrical cables installed within the tunnel shall comply with the following requirements:

- Flame retarding properties to IEEE 383,
- Toxicity level Acid evolution when burned 7%
- Flame propagation Oxygen index value 30% minimum
- Smoke density rating: 35% maximum

Supply cables at 3.3 kV or below shall be 3-core with the armouring used as the earth return in conditions where the cable is not subject to continues movement after installation or where the supply is to be a fixed point.

For supply to mobile or transportable equipment, where operation of the equipment subjects the cable to flexure, cables shall be sheathed in flame retardant LSFH.

2.6 Site Communication

The Contractor shall provide a suitable system for communication between the underground work site and workstations outside the tunnel, and maintain such system in working order at

all times. An underground station (including telephone socket with bell and indicator) shall always be within 50 m of the point where major work is being carried out and at 200 m intervals along the driven tunnel.

2.7 Water Supply

The Contractor shall provide water that is adequate for year-round use in his camps as well as for general construction use.

The Contractor shall furnish, install, operate and maintain all necessary equipment including pumps, piping, fittings, valves, storage tanks and disinfectants for the water supply and distribution systems.

Special measures during low temperature periods shall be taken such as heating or thermal insulation of pipes to avoid freezing of water.

2.8 Concrete and Material Processing Plant

At each construction site the Contractor shall install and erect all required materials processing plants of sufficient capacity to meet his planned peak requirements during construction. The plants shall be subject to approval by the Employer's Representative. All control and measuring shall be regularly serviced and calibrated.

The following plants shall be installed but not limited to:

- concrete aggregates processing plant (crushing and screening);
- concrete plant (batching and mixing)
- grouting plant

Plants shall be operational regardless of climate. Contractor shall take suitable measures to provide round the year working with continue with as minimum stoppage as practically possible.

2.9 Testing Laboratory

The Contractor shall install, equip and maintain an adequate field laboratory for the sampling and testing of materials such as concrete, earth or any other materials as specified herein.

The laboratory shall be adequately lit, supplied with sufficient electrical power, water and heating. Adequate space for testing devices and storage areas shall be provided.

The equipment to be supplied and the methods of testing shall be in accordance with the referenced Standards in these specifications. The proposed type and number of items of laboratory equipment shall be presented to the Employer's Representative and approved prior to purchase.

All facilities and services shall be available to the Employer's Representative as required. All sampling and testing to be undertaken shall be subject to the supervision of the Employer's Representative. The laboratory shall be run by Contractor's personnel experienced in sampling and testing of materials, and be subject to quality control.

Specialized testing which may be required and which cannot be performed in the Contractor's laboratory due to lack of time or equipment shall be assigned by the Contractor to an independent organization approved by the Employer's Representative. The Contractor shall accept all test results and all instructions or restrictions stipulated by the Employer's Representative based on such tests.

3 WORKING ENVIRONMENT

3.1 Health, Safety, Environment and Welfare

The Contractor shall adopt safe systems of work which minimize the risk to health, safety and Environment. All persons working on the site shall be competent to carry out their tasks and duties safely and in a manner that will endanger neither their own health nor the health of others. Persons, who are employed on the site for the first time, shall be subject to appropriate pre-employment occupational health checks, instructed on the hazards inherent in the site, precautions to be taken, the form of construction, and emergency procedures and fire safety. Such instructions shall be given whenever there is a material change in the working arrangements. The Contractor shall maintain a record of all persons instructed and each person shall be required to sign such record confirming that instruction has been received. No person shall be permitted on site without being inducted as set out above. The Contractor shall prepare a written statement of Safe Systems of Working which shall be issued to all persons at site.

All parties shall comply with the requirements and recommendations of BS 6164, BS EN 815, BS EN 12336, BS EN 12110, BS EN 12111 and BS 7671/ IEC 60364.

The Contractor shall also comply with the requirements of the Employer's codes of practice for safe working and those of any authority or body where their services or property are affected by the works. Contractor is responsible to have regular updates from the local authority on new policies or amendments related to working environment (health, safety, environment and welfare) and same shall be complied without any delay.

A person responsible for Safety shall be appointed by the Contractor and this person shall be conversant with corporate policy, management operational instructions, regulations, legislation and current best practice and how these relate to health, safety, environment and welfare. Compliance with health, safety and environment requirements is the responsibility of managers and individuals at each and every level.

The Contractor shall establish on site:

- Welfare and first aid facilities with appropriately trained personnel, both on the surface and underground, as required by the scale of the Works. Welfare facilities shall include toilet and washing facilities. Where water washing facilities cannot be provided, appropriate alternative means of hand cleaning shall be provided. Barrier creams etc. for skin protection shall also be provided.
- Occupational health facilities on the surface, staffed by appropriate occupational health professionals as required by the nature and scale of the Works.
- Equipment for the rescue and evacuation of persons underground with persons instructed in its use.
- All necessary equipment, safety barriers, notices and the like for the protection of persons.
- Procedures to ensure that all plant and equipment underground is fitted with on-board fixed fire-extinguishing equipment covering fluid tanks, motors or engine compartments and tyres along with the use of reduced flammability (HFDU) hydraulic fluid.

- Comprehensive fire detection and fire-fighting facilities.
- Sufficient chemical or compressed oxygen self-rescuer sets for all persons underground in accordance with HSE guidance.
- A competent safety officer shall be appointed by the Contractor who shall be conversant with the hazards associated with the form of construction to be undertaken and who shall be responsible for ensuring compliance with all management directives, rules and regulations concerning occupational health and safety.
- Subject to any legal requirement or requirement of the Employer and the size and nature of the Works, the Contractor may appoint a visiting competent safety officer under item above. He shall visit the site at the start of operations and for changes in methods of working, but in any event his visits shall not be at greater intervals than one month.

3.2 Medical Facilities

- Basic medical facilities are available at Karu and Tangtse.
- In addition to above, the CONTRACTOR shall construct, equip and maintain on the Site the following medical facilities:
    - One clinic with ambulance and driver at his main camp.
    - One first aid station at each work site.
- The CONTRACTOR shall comply with laws and health standards presently in force in the project area. In the event of an epidemic breaking out, the CONTRACTOR shall carry out and comply with all orders, arrangements or regulations which may be issued by the Government of India.
- These facilities shall be fully equipped and staffed to meet the requirements of the maximum anticipated work load and labour force, taking into consideration the nature of the Works, its occupational hazards, location and accessibility. These establishments shall be available and fully operational within 60 days after the date of issue of the Letter of Acceptance.
- Medical services in the clinics shall be under the direction of a qualified physician surgeon on a 24 hours basis throughout the duration of the construction and shall be available free of charge to all persons engaged in the Works and their families or dependents living on the Site.
- Treatment facilities and care of seriously ill or injured persons shall be on an emergency basis until their transfer to an established hospital. Rescue by helicopter shall be taken into account.

3.3 Removal

The Contractor's Camp shall be dismantled and removed subsequently on completion of the Works by the Contractor, unless otherwise specified or directed by the Employer's Representative.

All temporary installations must be completely removed after finalization of the relevant works. Rubbish, waste, debris and material must be removed.

Any disturbed area that will not be taken over for permanent use shall be restored at the completion of the Works to the original appearance as far as possible.

3.4 Noise & Vibration

3.4.1 General

The Contractor shall minimise occupational exposure to noise and vibration, the amount of noise emitted to the environment and the environmental vibration levels generated by his work activity.

The Contractor shall select and utilize methods of working and items of plant and control in his works so as to minimise noise and vibration levels, including occupational noise and vibration exposure of the workforce, and not to exceed maximum permitted noise and vibration levels specified in the Contract or defined by local Authorities.

The adherence to any vibration levels specified in the Contract does not relieve the Contractor of his obligations with respect to structural or other property damage.

3.4.2 Temporary Fencing and Barriers

Where required the Contractor shall erect and maintain throughout the construction period temporary fencing of appropriate height taking account of the need for this fencing to act as a noise barrier around all working areas. The fencing shall be dismantled and re-erected as the progress of the Works requires.

The line of the fencing shall be uniform and the exterior face of the fencing shall be treated with a durable finish. Where required, in order to prevent reflection of noise, the Contractor shall line the inside of fencing with sound-absorbent material with accepted acoustic absorption properties. The material shall be fire and water resistant.

Local fencing barriers or shelters shall be erected as necessary to shield particular activities, such as those involving the use of pneumatic or hydraulic techniques, and all stationary plant.

3.4.3 Plant & Equipment

The Contractor shall select and use plant, equipment and working practices which minimise occupational exposure to noise and vibration and minimise emissions of noise and vibration to the environment.

All plant shall be properly maintained, and relevant service records completed. All plant shall be provided with effective silencers and vibration-dampening devices and shall be operated according to the manufacturer's recommendations in such a manner as to avoid causing any excessive noise emission or vibration. The noise emitted by an item of plant shall not exceed the relevant values quoted in the Contract or defined by local Authorities.

3.4.4 Noise & Vibration Monitoring

Where monitoring is required the Contractor shall provide, calibrate, and operate according to the manufacturer's recommendations appropriate equipment for monitoring construction noise and vibration throughout the construction period.

The Contractor shall arrange for adequate standby equipment.

The Contractor shall notify the Employer's Representative immediately whenever the specified noise or vibration limit has been exceeded and agree measures to avoid repetition.

Any items of plant causing excessive noise or vibration levels shall be removed from the site and substituted by alternative compliant equipment.

The Employer's Representative may instruct the Contractor to devise and use an alternative process if a construction method is causing unnecessary disturbance.

3.5 Access & Egress

The Contractor shall make all arrangements and assume full responsibility for transportation to the Site of all construction plant, materials and supplies needed for the proper execution of the Works.

The contractor shall maintain the access routes to the west and east portals.

Where designated access routes are indicated in the Contract, the Contractor shall use no other without the agreement of the Employer's Representative.

3.5.1 Maintenance of Routes

All public and private highways and roads which are being used by the Contractor's, Subcontractors' or Suppliers' vehicles for the construction of the Works shall be kept clean and free of dirt and mud arising from the Works. The Contractor, unless otherwise provided for in the Contract, shall provide, maintain and use as necessary suitable equipment including mechanical road sweepers, throughout the course of the Works where and as agreed with the highway authority.

The Contractor shall provide, maintain and use mechanical wheel washers and high-pressure hosing facilities at work sites and at such additional locations as required under the Contract.

The Contractor shall be responsible for all maintenance in all respects of all site roads.

Any area of public highway which is closed because of the Works shall not be reopened until appropriate safety and traffic management measures have been completed and until the Employer's Representative confirms that it is in a suitable condition for use by the public.

The Contractor shall protect the public from the Works by secure fencing and gates and shall control access through the gates as required under the Contract.

Contractor shall be responsible for snow removal as needed for his own operations and for necessary maintenance and snow remove of all construction roads, camp and work sites pertinent to his activities, regardless of the use of these roads by other parties.

3.5.2 Access for Others

The Contractor shall at all times meet the full requirements for access for fire, ambulance and other emergency services and maintain liaison with them in that respect.

The Contractor shall at all times maintain access for the authorized representatives of utility providers and allow emergency operations to be carried out on any utility or service facilities within the Site.

The Contractor shall not use public or private rights of way for depositing or storing plant or materials. The Contractor shall maintain those parts of the public or private rights of way not temporarily occupied by the Works in a clean, passable and safe condition at all times.

The Contractor shall execute the works in such a manner that safe pedestrian access, including disabled person access, to all properties is maintained at all times.

Unless otherwise provided in the Contract, methods of construction and programming of the works shall be such that vehicular access to properties affected by the Works is not restricted.

3.5.3 Traffic Safety and Management

Where work is carried out on or adjacent to a trafficked highway the Contractor shall ensure that personnel shall, at all times, wear high-visibility fluorescent garments which shall comply with BS EN 471.

All proposals, details, execution, maintenance, removal and necessary reinstatement associated with traffic safety and management and temporary decking and other temporary structures on, or subways beneath, the highway shall be subject to the approval of the appropriate authorities. The Contractor shall supply all information required, for consultation with the appropriate authorities including the local authority, police and other authorities with jurisdiction or interest.

The Contractor shall agree a traffic management plan with the Employer's Representative based on consultation and agreement with highway authorities. This shall show the scheme of traffic safety and management measures including the provision of safety zones and traffic signing. The plan shall include the requirements of emergency services for access into and through the site.

Fenced storage areas, gantries, loading bays, skips and other temporary structures on the public highway shall be provided and maintained to the conditions of a license issued by the local authority.

All traffic safety and management measures necessitated by the Works shall be fully operational before the Contractor commences any work which affects the public highway.

The Contractor shall devise and put into effect traffic management procedures, including appropriate speed limits, within the site including on haul roads and temporary access roads, which are to an equivalent standard to those for a public highway unless directed otherwise by the Employer's Representative.

3.5.4 Signing, Signaling & Lighting

The Contractor shall provide suitable entry and exit signs, at the points of access to and from the site, for vehicles and plant engaged on the works. As far as possible, vehicles and plant shall enter and exit the site in a forwards direction.

Unless otherwise specified, the Contractor shall make all necessary arrangements including notices to relevant authorities for the provision, erection, maintenance, repositioning, covering and uncovering and final removal of all traffic signs as the progress of the works requires.

The Contractor shall devise and put into operation traffic management arrangements to separate pedestrian and vehicular traffic. Pedestrian access shall be clearly signed and provided with barriers of adequate strength.

The temporary traffic Contractor shall be responsible for the design, provision and maintenance of all signals and associated equipment unless otherwise given in the Contract.

Where required during the execution of the Works, the Contractor shall provide and maintain temporary lighting for the highways. Temporary lighting shall provide the same level of illumination as that of the existing street lighting, which it replaces. Temporary lighting shall be provided and approved prior to the removal of any existing street lighting.

3.5.5 Survey & Reinstatement

Prior to commencing the works the Contractor shall carry out a condition survey of all roads, rails and footways adjacent to the site. The survey record shall be available to the Contractor.

Unless stated otherwise, the Contractor shall reinstate all roads and footways affected by the works to the extent, lines and levels that existed prior to the commencement of the works and to standards that are at least equivalent to those that existed prior to the commencement of the Works.

Unless stated otherwise, the Contractor shall reinstate all surface water drainage systems (including but not restricted to gullies, channels, catch-pits, pipe-runs, manholes and covers as applicable and the like) affected by the Works. The Standard of reinstatement shall be at least equivalent to that existing prior to the Contract commencing.

3.5.6 Access within Works

The Contractor shall provide safe access in and about the site and underground workings.

All shafts, if any, shall have a ladder access in addition to any mechanical means.

The Contractor shall provide a safe designated pedestrian access in the tunnel and throughout the site area at all times. This shall have a firm level, slip-resistant and continuous surface and shall be suitable for use in emergencies when lighting may be unavailable.

The Contractor shall segregate pedestrian and vehicular access routes.

The Contractor shall maintain a clear means of egress from each tunnel face at all times. Such means of egress through or past equipment, trains and similar obstructions shall meet the minimum dimensions in BS EN 12336.

The Contractor shall establish, maintain and operate a system whereby the presence of personnel underground is recorded, together with their location where appropriate.

3.6 Disposal of Spoil & Water

The Contractor shall prepare a Site Waste Management Plan (SWMP), which sets out in detail how spoil and all waste is to be categorized, disposed of and monitored, the program for disposal and how legislation is to be complied with. This plan will address all waste matters at the site and have specific documented mechanisms for adopting a 'reduce, reuse, and recycle' approach to waste minimization for dealing with all wastes. The SWMP shall be prepared to suit the climatic condition including the cold weather of the project site. The SWMP will be reviewed by the Employer's Representative and accepted or approved as required by the Contract.

3.6.1 Solid Waste Disposal

The Contractor shall remove all excavated material, spoil, surplus materials and rubbish from whatever source on site and shall, except where otherwise specified in the Contract, make his own arrangements for their disposal and provide all the necessary facilities to achieve this. The Contractor shall also comply with any legal or local authority requirements applying to the handling and disposal of any contaminated spoil.

The Contractor shall set up a system to control and monitor the transport of spoil from site to the tip site, in accordance with the current legislation and requirements of the local Authorities. The system shall be agreed with the Employer's Representative and will provide evidence that each load has been deposited at a licensed tip site.

The Contractor shall retain auditable records of waste removed from site. Waste Transfer Notices should be collated and submitted to the Employer's Representative. Transfer and Consignment notes shall be kept in the site file.

The Contractor shall comply with all statutes and statutory instruments relating to spoil disposal.

3.6.2 Liquid Waste Disposal

Before discharging any surplus water, the Contractor shall obtain the prior approval of the owner of the sewer or water-course and of the Environment Agency.

The Contractor shall ensure that the condition of any discharged water complies with permitted limits. The parameters to be monitored include pH values, temperature and suspended solids.

3.7 Surveying

3.7.1 Scope of Work

The CONTRACTOR shall render all services for topographical surveys and measurements required for the performance of the Work.

These services cover in general the establishment of axis centrelines, alignments of project structures and features; the setting out for construction thereof; the accompanying control surveys for correct locations, dimensions and elevations as well as the necessary surveys for measurement to permit quantity calculations for Invoicing. Such surveys shall be based on the control points, centre line, bench marks already established in the project area.

It shall be the CONTRACTOR´s responsibility to check the nets and their compatibility over the whole project area and to perform the tunnel survey so that the tunnel alignment remains within the specified accuracy.

The CONTRACTOR shall specify all his equipment for surveying works in his Method Statement.

The CONTRACTOR shall have the overall responsibility for all surveying works.

3.7.2 Materials and Instruments

The CONTRACTOR shall provide, maintain and operate suitable and appropriate equipment, instruments, materials and auxiliary equipment, commensurate with various tasks and precision requirements of the survey works.

Type and accuracy of the survey equipment to be used by the CONTRACTOR shall correspond to the nature of the construction, erection works and the construction technique.

All equipment, instruments, materials and auxiliary equipment shall be in perfect operating condition. Prior to the start of survey activities, equipment, instruments, etc., shall be checked as to their proper functioning and accuracy duly accompanied with “Fit to use” and “Permanent adjustment carried out” certificate by the manufacturer valid at the start of works.

During the construction period the survey instruments shall be checked and, if necessary, adjusted/calibrated at regular time intervals.

Instruments and equipment which have suffered from use, damage or accidents to the extent that they are unfit for further use at the site, shall be removed from the site and replaced immediately.

The number of sets of instruments shall be sufficient to meet the requirements of the construction time schedule. Delay of start of construction or construction progress caused by insufficient quantity and quality of survey equipment including provision of professional staff shall be at the CONTRACTOR's responsibility.

3.7.3 Execution

For the execution of the survey/ setting out for work the CONTRACTOR shall employ and provide experienced professionals and auxiliary staff. All survey and measurement work shall be recorded in ink and filed thoroughly.

The CONTRACTOR shall provide, maintain, adjust when necessary and operate the required survey and auxiliary equipment for the performance of the Work.

All survey and measurement activities shall be recorded in maps and field books as directed/approved by the ENGINEER. Where required, the production of drawings and maps shall be deemed to be part of the Work.

The ENGINEER shall have the right to check work performance, accuracy, stations, etc., and all survey results, measurements and calculations as well as conformity with plans and drawings.

The CONTRACTOR shall keep and maintain professional records of all field surveys and measurements, the related computations and calculations, manuscripts, plans, drawings and maps, and shall make them available to the ENGINEER whenever requested.

If, in the opinion of the ENGINEER, deficiencies and/or inaccuracies in field and office work have been found, such work shall be repeated and made good to the satisfaction of the ENGINEER at the CONTRACTOR's expense. The CONTRACTOR shall be solely responsible for accuracy of Survey maps and drawings prepared out of the surveys.

3.7.4 Preparatory Works

Prior to starting survey works, the CONTRACTOR shall inform his surveyors of the general construction procedure, survey requirements and time limits. The surveyors shall make adequate terrain investigations with respect to sightings, vegetation to be removed, placement of monuments, taking into consideration future construction work which may affect the survey: points, monuments and benchmarks. Based on these investigations, a survey plan shall be developed comprising existing basic data, the survey grid to be developed, the equipment required for the particular survey task, staff and time requirements arrangement in a way to warrant smooth progress of construction works.

All survey / setting out works shall be done with greatest care and precision.

3.7.5 Survey of Ground Profiles

3.7.5.1 Original Ground Profiles

The CONTRACTOR shall inform the ENGINEER in writing, at least 14 days before commencing such work, of his intentions to perform any work which will result in a change to the topography of the existing site for the permanent works and/or for temporary works. Thereupon, before commencing any work, the CONTRACTOR shall survey the original topography with the approval of the ENGINEER over the entire area to be occupied or disturbed. Such survey may again be required after removal of vegetation, topsoil or other overburden. The information so obtained shall be recorded by the CONTRACTOR and the ENGINEER. The CONTRACTOR shall then provide the ENGINEER with a non shrinkable

and reproducible copy of each drawing (on RTF) to serve as a permanent record of the purpose of determining the quantities of excavation or earthworks carried out in the construction of the permanent structures, and the extent to which Temporary works shall be removed or temporary excavations shall be refilled upon completion of the works.

The CONTRACTOR shall survey all excavated and final surfaces for the purpose of recording as constructed details, and for the measurement of quantities.

- on completions of excavation and prior to placing concrete or other work
- on completion of works

3.7.6 Setting Out of Works

The CONTRACTOR shall perform all setting out and check surveying of the Works in accordance with methods approved by the ENGINEER. The methods and programme of checking shall be such as to ensure the construction of every part of the Work to be in correct line and level. The ENGINEER may at any time ask the CONTRACTOR to submit proof that his own setting out has been satisfactorily checked.

The number of points required for setting out as well as between these points shall be determined by the CONTRACTOR in accordance with the type of work. The ENGINEER may require that some or all of the given points and datum levels be clearly marked during construction in such a way that the marks can be retained after completion of construction.

For the tunnel, this setting out includes for each profile the installation of reference marks located in the axis and on the edge of the platform. These reference marks are materialised by stakes and will be referenced to the Works grid as defined in the drawings;

For the tunnel portals, the setting out includes the installation of three close reference marks per portal, the staking of the boundaries, of the earthworks and of the profiles.

3.7.7 Tunnel Alignment and Gradients

The CONTRACTOR shall establish and maintain at suitable distances from tunnel portal at least two (2) reference monuments and benchmarks on the extended tunnel axis/alignment, to warrant that control surveys during "tunnel construction can always be referred to such reference monuments. They shall be secured by auxiliary fixed points permitting the location control of the reference monuments in case these have suffered during tunnel excavation periods.

Establishing and control surveys of the tunnel alignment and the gradient shall always be referred to such reference monuments.

Underground alignment and level survey and control thereof shall be performed by the use of suitable precision instruments preferably of the pulsed laser type of equivalent instruments, and auxiliary equipment. Underground survey equipment and methodology shall be subject to the approval of the ENGINEER.

3.7.8 Accuracies and Tolerances

3.7.8.1 Accuracies

Accuracy of survey works shall be within the following tolerances:

Triangulation:	
Allowable error of closure	
- Average not to exceed	5 Seconds
- Maximum not to exceed	10 Seconds
Traversing:	
Allowable error of closure	1/3,000
Allowable error of distance	1/5,000
Leveling:	
Allowable error for each 1 km measured Forward and backward	10 mm
Allowable error of closure	$10\sqrt{S}$ mm

(Where S is the total distance of leveling expressed in Km)

3.7.8.2 Tolerances

a) The tolerance given below shall be the maximum permissible deviations from the specified dimensions, levels, alignments, positions, etc as shown on the Drawings of the structures of structural elements

b) In addition at the interfaces with mechanical components, concrete surface be finished flush and shall also meet any additional tolerances required by the mechanical designs or works, respectively.

c) Determinations of center lines for alignment of tunnels shall meet the following criteria:

1. 10 mm / km horizontal and vertical offset of the tunnel axis
2. max. 60 mm horizontal and vertical offset of the tunnel axis at the break- through points of the headings
3. Slopes and slope displacements shall be measured with an accuracy of 5 mm.

-Slope protection

Benchmarks and subsidiary monuments intended to observe slope movements shall be placed with tolerances not exceeding $\pm$ 15 mm

- Rock bolts and prestressed anchors

Positions	$\pm$ 150 mm
Deviation from direction	$\pm 5^0$

3.7.9 Subsidiary Monuments and Benchmarks

The CONTRACTOR shall erect and establish all necessary additional survey monuments fix points, benchmarks, etc. required for setting out of the works and construction control including determination of coordinates and elevations.

3.7.10 Handing-Over of Basic Survey Data

3.7.10.1 General Requirements

Prior to the commencement of the survey work, the ENGINEER shall hand over to the CONTRACTOR all information and data of the survey, benchmarks and control points to which the CONTRACTOR's survey work shall refer. Upon handing-over, the CONTRACTOR shall review this information and data and shall verify the existence and accuracy of the datum points and benchmarks by field checks. Further more, the CONTRACTOR shall take responsibility for maintenance and protection of these basic datum points and benchmarks.

Should field checks reveal that points and benchmarks have been damaged, displaced or destroyed, the CONTRACTOR shall inform the ENGINEER of this fact, and the ENGINEER shall give instructions regarding the re- establishment of such datum points and benchmarks.

Should it become necessary that basic datum points and benchmarks be removed because of foreseeable construction works, the CONTRACTOR shall inform the ENGINEER of the need thereof and obtain approval and instruction for the establishment of new basic datum points and benchmarks and/or auxiliary points.

If, upon handing over, inconsistencies within the datum points, benchmarks and control points are detected by the CONTRACTOR, he shall inform the ENGINEER immediately thereof and produce the evidence. The ENGINEER shall subsequently inform and instruct the CONTRACTOR on remedial measures to be taken. Any survey work, setting out or measurement already taken or performed prior to the detection of such inconsistency shall be rechecked and corrected by the CONTRACTOR.

Additional basic datum points and benchmarks established by the CONTRACTOR for the convenience of this work shall have at least the same quality and durability as those or the existing points, and meet the accuracy requirements.

3.7.10.2 Data and Documents Available

Existing topographical maps issued by BRO, covering the area of the works can be made available to the CONTRACTOR upon request to the ENGINEER.

Topo mapping of areas for temporary facilities like the CONTRACTOR's camp, constructional buildings, construction plant, etc., shall be prepared by the CONTRACTOR prior to the construction of such facilities. Surveys works for his construction roads also shall be performed by the CONTRACTOR including preparation of maps.

3.7.10.3 Survey Records and Documentation

The CONTRACTOR shall keep records of all survey activities such as sketches, field-books, calculations, etc., for the duration of the entire construction period. The CONTRACTOR shall upon request of the ENGINEER put at his disposal all records and documentation or provide copies thereof.

3.8 Dewatering Arrangement

3.8.1 General

The Contractor shall design, furnish, maintain and remove temporary works for protecting the Works under construction against flood flows in rivers and nallahs, and design, furnish, operate, maintain and dismantle the temporary dewatering facilities required to remove water from construction activities and from natural surface flow or groundwater seepage from working areas on the surface as well as in the tunnel.

The Contractor's working methods and systems shall be designed to control ground and surface water to permit the construction of shafts, tunnels, breakouts and portal structures.

Where dewatering operations are used they shall be kept to the minimum necessary for the execution of the Works. If, at any time, during construction, the inflow of water increases more than the installed pumping capacity, the Contractor shall be required to install additional pumping facilities and perform additional sealing as required by the Employer's Representative. The dewatering system shall include a system for identifying ingress of soil material during the dewatering operation; contractors shall take immediate measure to stop ingress of soil with water during dewatering.

In planning temporary pumping systems, the Contractor shall take due consideration of water quality, pressure, quantity and variations in water levels.

Settlement ponds and other measures shall be provided so as to ensure that potentially contaminated or polluted matter from the execution of the Works is nowhere released into creeks, rivers or the ground.

The Contractor will be held responsible for all damage caused by his dewatering procedures or the lack of such, and he shall reinstate or repair disturbed ground or structures to their original condition or as otherwise approved.

Plant shall be delivered to site and maintained in good working order. Plant and pipe work shall be fitted with appropriate valves, controls and gauges. Each dewatering well shall be capable of individual adjustment and being shut down and isolated from the rest of the system. Appropriate standby equipment and spares shall be maintained on site at all times.

3.8.2 Construction Site

The Contractor shall perform all works necessary to drain the surface construction sites of rain, groundwater and service water. The work shall include, but not be limited to the following:

- design and construction of drainage, ditches, pits, pump sumps and settlement ponds with oil separators
- design, furnish, operate and maintain dewatering equipment and conduits
- relocation of dewatering facilities required for the performance of other works
- diversion of nallahs where required by construction of any permanent or
- temporary structure, including spoil and stockpile areas

- all auxiliary work required for the safe and continuous dewatering of the surface construction sites
- The Contractor shall perform all work necessary to collect and drain construction water and infiltrating groundwater, convey it to main conduits and convey it out from tunnel work to discharge points. The work shall include, but not be limited to, the following:
- design and construct pits, trenches and drainage measures along the tunnel invert
- design, furnish, operate and maintain dewatering equipment (including pumps and power supply) and conduits
- relocate dewatering facilities as required for the unhindered performance of the tunnel work
- design, construct and operate settlement ponds, with oil separators, at the portals or elsewhere, with discharge into creeks and rivers, as approved
- all auxiliary-work required for the safe and continuous dewatering of the underground working areas

The Contractor shall design and install complete facilities for the drainage of the temporary and permanent portal areas and the muck disposal areas.

Drainage ditches shall be excavated along the top of excavated slopes and on the berms. Such ditches shall be kept well back from the excavation edges. In loose materials the ditches shall be lined with concrete or with rock paving set in mortar immediately after completion of excavation. The ditches shall be regularly cleaned out of accumulated silt and other matter so that water may flow freely at all times.

Rivers, nallahs and intermittent streams in the vicinity of temporary or permanent works shall be diverted into culverts of lined ditches. Erosion must be prevented. Sediment laden water must be diverted through settling ponds or basins according to the environmental regulations.

3.8.3 Tunnel

The Contractor shall perform all necessary works to collect and drain construction and ground water in all tunnels at all headings. All required drainage measures including collection and pumping of any ground water must be included in the given prices. The water shall be drained out of the tunnel with minimum impact on ground stability and construction works. This includes, but is not limited to:

- pits, trenches and drainage along the tunnel floor dewatering equipment including pumps
- pipes along tunnel side wall
- collecting local inflows directly from tunnel perimeter before and after installation of primary support
- collect inflowing water with dimpled sheets along the tunnel perimeter

- settlement ponds or basins with oil separators before discharge into rivers, creeks or nallahs (*receiving waters*).

Mountain water due to tunnel construction shall be collected and drained. Excavation areas shall be drained of all construction water and ground water. Water appearing at the face shall be drained to the longitudinal drainage system as soon as possible.

Dewatering arrangement has to be considered for falling and rising gradient of the excavation, a softening and damaging of the bench shall be avoided. The water drainage length shall be kept at a minimum. In case of falling gradient temporary pump sumps must be max 5m behind the excavation face (top heading, bench, temporary and permanent invert).

The Contractor shall provide adequate pumping capacity where required, including a sufficient number of standby pumping units and standby power, to handle all water entering any portion of the tunnel works. These units shall be connected to the power supply and dewatering systems in such a way that proper and uninterrupted drainage will be ensured throughout the construction period.

Heavy mountain water inflow may occur, and therefore additional drainage system to the longitudinal drainage system may be required. In such zones systematic drainage drillings ahead of the tunnel face may be required and ordered by the Employer's Representative, and as necessary, measures to reduce the permeability / conductivity of the ground (e.g. systematic grouting) may be required and ordered by the Employer's Representative.

If required, drainage drillings (placement, direction and length according to local conditions) shall be constructed with no delay. Instrumentation, for measuring the pore pressure, may be required by the Employer's Representative.

In tunnel sections with ground material sensitive to water (softening or swelling ground condition) particular care has to be taken concerning water drainage. The inflowing water shall be collected as soon as possible and conveyed in pipes to not allow contact to the tunnel floor. Construction water must be reduced to a minimum and collected and pumped immediately into pipes.

Water entering a working face from another part of the tunnel must be deviated not to affect construction works such as bench/invert excavation or concreting.

Unless otherwise specified all water emanating from the tunnel excavation shall be discharged into settlement ponds, designed so as to meet the requirements of the prevailing Indian regulations. The outflow from each settlement pond shall be arranged in a way to prevent any oil from leaving the pond irrespective of the volume of water entering the pond.

Dimpled sheet membrane shall be of HDPE with a sheet thickness of 1.0 mm. The drainage capacity shall be 8 l/s/m @1m hydraulic gradient. The compressive strength shall be 150 kN/m².

Strip drains shall consist of dimpled sheet membrane as defined above, wrapped in a nonwoven het bonded geotextile. The geotextile shall comply with Clause 8.2.

3.8.3.1 Measurement and Monitoring

The Contractor shall install, operate, maintain and relocate the necessary devices for flow measurements. These measuring devices shall be checked and approved by the Employer's Representative before usage.

Gauging stations shall be installed and measurement of the total discharge shall be made as follows:

- *Heading Zone:* Measurement shall be performed during excavation and supporting work at a point not less than 50 m and not more than 100 m behind the heading face. Transfer of the measuring station in drill and blast advances shall be done in 100 m steps or as approved by the Employer's Representative.
- *Rear Zone:* Flow measurements at the portal or at the outlet of installed pump lines shall be performed, during the entire excavation and supporting work.

Measurement of water flow shall be performed once a day jointly by the Employer's Representative and the Contractor or as otherwise agreed upon.

All pumping rates must be recorded and the Contractor shall keep full and detailed records of all monitoring carried out. Copies of such records shall be available to the Employer's Representative.

The Contractor shall monitor all springs and wells which may be influenced by the lowering of the ground and mountain water table due to the tunnel construction. The zero readings must be done prior to any excavation.

3.8.3.2 Final Tunnel Dewatering Arrangement

3.8.3.2.1 Ground Water

A minimum gradient of 0.5% of the drainage pipes shall be provided in each tunnel cross section.

If not otherwise specified by the detailed design drawings or the Employer's Representative, the following ground water drainage pipes with the given diameters shall be installed at the lines will be given in the detailed design drawings.

- Side wall drainage: $\Phi \geq 200$ mm
- Sub-base drainage: $\Phi \geq 150$ mm
- Ground water collecting pipe: $\Phi \geq 800$ mm

Perforated pipes shall be made of slotted Polypropylene (PP) or polyvinyl chloride (PVC) or any other equivalent material in agreement with the Employer's Representative. The upper section of the pipe shall be slotted with the bottom section closed. The width of slots shall not exceed 1.0 mm. The total area of the slots for water intake shall exceed 50 cm^2 per meter length of pipe.

The bedding shall consist of dry lean concrete in compliance with Clause 6.6. The pipe shall be embedded in no-fines concrete in compliance with Clause 6.7.

3.8.3.2.2 Carriageway Water

The carriageway water shall be collected and drained in a separate drainage system. The collection shall be continuous by a slot channel or punctual with a maximum interval of 65m. Slot channels shall be made of water impermeable concrete with plastic fiber reinforcement.

The slot channel diameter shall be minimum 250 mm. A minimum longitudinal gradient of 0.5% shall be provided.

4 OPEN EXCAVATION

4.1 General

In these Specifications the following works are covered:

- surface excavation in soil or rock (Cut) for the temporary and permanent tunnel portals, the tunnel portal structures, cut & fill sections, control building, muck dump areas, ditches, drains,
- surface fill (Fill) with soil and rock material for the platform of the tunnel portal structures and buildings, if any, muck dump areas or roads,
- erosion protection of embankment slopes with gabions, mattresses, rip-rap, etc.
- sub surface drainage
- backfill of structures
- water proofing of structures before refill

The existing ground surface area below which open excavation is required shall be cleared of trees, brushes, shrubs, embedded logs, fallen timber and surface litter and shall be grubbed of vegetation, roots and stumps. Cleared and grubbed material shall be disposed of in the designated spoil disposal areas.

No unexcavated material is permitted inside the design lines of the excavation.

14 days prior to commencement of any surface excavation the Contractor shall submit all detailed drawings and/or descriptions of his proposed excavation methods, sequences and equipment to the Employer's Representative for approval.

28 days prior to dumping of any spoil, the Contractor shall submit all detailed drawings and/or descriptions of his proposed method for laying, compacting and protection against erosion of the muck dump material including information of dumping sequences and equipment. The muck dump areas shall be within the areas so designated by the Local Authorities or the Employer's Representative and in compliance with Clause 3.6.1.

At least 28 days prior to placing of any fill material, the Contractor shall submit detailed drawing and/or descriptions of the construction procedure, mixing, treatment and compaction procedures, top-soiling, slope stabilization and surface erosion protection, and other completion works for approval, for construction of embankments. All data of working methods, equipment and provisions for the stability of the construction as well as temporary and permanent drainage of these areas shall be included. Details of volumes, material types, heights and grades shall be provided.

The Contractor shall forward information of the progress of surface excavation including information on excavated volumes, ground type, ground support installed, water inflows and difficulties encountered to the Employer's Representative at an interval in agreement with the Employer's Representative.

4.1.1 Standards

Open excavation works shall be in compliance with the following Standards and Guidelines unless otherwise defined in these Specifications.

- Specification for Road and Bridge Works (Fourth Revision) August 2001 reprinted in April 2005 issued by MoRT&H and published by IRC.
- IS 2720: Methods of test for soils — applicable parts
- IS 4532: Method of test for stabilized soils
- ASTM D3282: Classification of soils and soil-aggregates mixtures for highway construction purposes
- Eurocode 7: Geotechnical design

4.2 Cut

The excavation requirements and limits shown on the drawings have been established on the basis of the results of subsurface exploration by the Designer. The Employer's Representative will examine the conditions exposed at the actual excavated surfaces and, if the conditions are deemed unacceptable for the intended purpose, will relocate the excavation design lines locally outside of the excavation design lines shown on the Drawings.

If, in the opinion of the Employer's Representative, the necessity for excavation outside of the excavation design lines has been caused by negligence on the part of the Contractor or by ineffective executed excavating or blasting operations by the Contractor, the volume of additional excavation shall be backfilled with concrete or other material as required by the Employer's Representative. Such additional excavation and backfilling shall be done at no additional cost to the Employer.

Unclassified material and rock excavated outside of the excavation design lines for the Contractor's own purposes shall be replaced with concrete or other material as required by the Employer's Representative. Such additional excavation and backfilling shall be done at no additional cost to the Employer.

All initial support measures will be given in the detailed design drawings or directed by the Employer's Representative e.g. sprayed concrete, pre-stressed anchors, wire mesh etc. shall be in compliance with Clause 5.7.4 of this Specification.

The Contractor shall draw his own conclusions from site inspection, from the logs of rock cores, test pits, test trenches, test tunnels, test chambers and surface exposures and from other site investigation data made available to the Contractor, as to the excavation method that will be best suited for the satisfactory removal of materials to be excavated and as to the behavior of unclassified material and rock in situ, during and after excavation.

Excavation shall include all items of work, equipment, facilities and material with respect to the proper excavation as specified, including mucking, dumping and transport of excavated materials in stockpile or disposal areas approved by the Local Authorities.

The Contractor shall apply, as approved by the Employer's Representative, excavating, drilling and blasting techniques, which will produce a smooth final profile, i.e. smooth blasting resulting in minimum over break as well as minimum detrimental effect beyond the design lines for excavation in compliance with Clause 5.2.3.3. Explosives and detonating systems shall be used by the Contractor to produce a smooth final excavated surface.

The Contractor shall adopt excavation procedures such that the stability of surfaces in open excavations is not impaired. The Contractor shall be responsible for the stability and safety of all excavations until final acceptance of the Works and shall install such instrumentation in the excavations, in addition to the instrumentation required by the Employer's Representative, that the Contractor considers necessary to measure deformation and to establish that unstable conditions do not develop. The Contractor shall execute all remedial work required in excavations to ensure that the excavated surfaces are maintained in a sound and stable condition. The Contractor shall submit to the Employer's Representative all readings taken the instruments he installs not more than 1 working day after taking the readings.

During excavation, and at any time during the Work, all material which is unsafe or appears to endanger persons, the Works or the property of others, shall be immediately scaled and removed from the excavations. The fact that such scaling and removal may enlarge the excavation beyond the excavation pay lines shall not relieve the Contractor from the necessity of doing such scaling and removal of such materials. If it is not possible to remove loose rock by normal barring and wedging, then rock support, sprayed concrete or chain link mesh or any combinations of each, shall be applied to secure and prevent the loose rock from falling or becoming unstable.

Notwithstanding the provisions specified herein, the Employer's Representative may require the Contractor to take such action as the Employer's Representative deems necessary to assure the safety of the excavations and the Contractor shall immediately comply with such requirements. Nothing in these Specifications shall be construed to relieve the Contractor from the sole responsibility for safety.

If drilling and blasting operations is required, these shall be carried out in such way that they do not interfere with the work of others nor cause any damage to adjacent structures.

If slides occur in excavated slopes, all materials affected shall be excavated and removed to the designated spoil disposal areas. The slopes shall be stabilized and then further excavated to a safe, stable and neat condition or to the lines, slopes, dimensions and elevations required by the Employer's Representative. If, in the opinion of the Employer's Representative, any slide was caused by negligence on the part of the Contractor, all remedial work shall be done at no additional cost to the Employer.

The Contractor's excavation operations and schedule shall allow for interruption while the geological conditions exposed at the excavated rock surfaces are mapped and assessed by the Employer's Representative. Local areas shall be cleaned off where required by the Employer's Representative to expose a fresh undisturbed surface. Such interruption and assistance shall be at no additional cost to the Employer.

Construction traffic shall only be routed over suitably protected parts of the excavated surfaces.

4.2.1 Excavation Classification

Surface excavation shall be classified according to the excavation method as:

- Loose excavation
- Rock excavation

Loose excavation means all excavation which may be performed without continuous and systematic drilling and blasting. Clearing and grabbing of trees, shrubs and plants, stockpiling of topsoil layer, digging, ripping and occasional blasting may be required.

Rock excavation means excavation which requires continuous and systematic drilling and blasting for loosening, including measures for smooth blasting methods. The Contractor shall solely adapt blasting whole diameters, distance, charging and detonating delay of holes to form a smooth, sound surface along the excavation design lines. The distance between blasting holes shall not exceed 10 times of the blasting whole diameter.

4.2.2 Excavation Material Disposal

The disposal of excavation material shall be in accordance to Clause 3.6.1 of this Specification.

Excavation material suitable to be utilized in the Works shall be stockpiled separately from materials to be disposed. The use of excavation material in the Works shall be in agreement with the Employer's Representative.

Suitable materials shall, wherever possible, be transported directly from the required excavation to the various designated final locations.

Excavated materials, not suitable for or in excess of the construction requirements, shall be disposed of in spoil areas designated by the Local Authorities, Forest Departments or the Employer's Representative. Unless otherwise provided for, spoil areas shall be built up in layers, with a maximum layer thickness of 0.6 m, and evenly compacted by the traffic of the construction equipment, aimed at minimizing future differential settlement. Final sloping and shaping of surfaces shall be as indicated on the Drawings. Other details of the work such as stabilization and drainage measures are shown on the Drawings.

All activity by the Contractor at spoils areas shall be confined to the limits designated by the Local Authorities, Forest Department or the Employer's Representative. The limits shall be clearly marked and, where directed barricaded to prevent traffic in areas outside the limits.

4.2.3 Fill and Embankment

The Contractor shall construct all compacted earth fill or rock fill embankment will be as shown on the Drawings or as otherwise directed by the Employer's Representative. This work shall include such work as selection of suitable material, transporting, spreading, adjusting moisture content, compacting to specified minimum dry density and completion in all respects, all in accordance with this specification.

The embankment shall extend to the design lines as given in the drawings.

All permanent and long- term temporary slopes shall generally be stabilized and erosion protected by planting of vegetation and greens similar to the typical local vegetation of the area. Additional measures such as bolts, anchors, sprayed concrete for cut slopes or gabions, rip-rap, geo-textile for embankment slopes must be applied as designed or ordered by the Employer's Representative.

The Contractor shall construct all sub-surface drainage measures in cuts or embankments as shown on the Drawings or as otherwise directed by the Employer's Representative. This work shall include such work as excavation, selection of suitable material, transporting, placing, and completion in all respects, all in accordance with this Specification.

The material beneath the road sub-base shall have CBR values. The testing procedure shall be in accordance to AASHTO T193 and fulfil the requirements shown in the detailed design drawings and Indian Standards.

Trees, shrubs, grass; humus/topsoil shall be removed from the existing ground surface and stockpiled for later reinstatement if required by the Employer's Representative prior to any placing of embankment.

The prepared surface shall be benched in vertical and horizontal cuts to provide a shear key with the embankment material.

The material of the embankment shall be placed and compacted layers with a thickness not exceeding 300 mm loose before compaction.

The moisture content of the material to be compacted shall be as wet or just wetter than optimum moisture content determined by laboratory testing.

All embankment material shall be compacted to a dry density not less than 95 per cent of the maximum laboratory dry density in accordance with IS 2720, Part 8.

4.2.4 Back Fill

Backfill shall be placed to the specified type of the lines, grades and dimensions in the locations shown on the detailed design drawings by the Contractor or directed by the Employer's Representative.

All material proposed by the Contractor to be used as backfill shall be approved by the Employer's Representative prior to any placing of backfill material. The material to be used as backfill shall be as far as possible obtained from required excavation for Underground Excavation Works.

Backfill material shall be homogeneous without layers, pockets and lenses and may not consist of any organic component. Each load of material shall be distributed well and operation of equipment shall be restricted in the area near permanent structures to avoid any kind of damage. The Employer's Representative may reject full loads of backfill material that contain unacceptable percentage of organic component.

Backfilling may not be done before reaching full load capacity of adjacent structures and only after approval of Employer's Representative. The placing of the backfill shall be done

simultaneously and with similar method, procedure and material at the different sides of a structure to avoid differential earth pressure.

Backfill material shall consist of well graded granular material containing 35% or less by weight passing a 0.075 mm sieve, as specified in ASTM D3282 and with a maximum particle size of 300mm.

Back fill material shall be placed and compacted layers with a thickness not exceeding 300 mm loose before compaction and shall be compacted to a dry density not less than 95 per cent of the maximum laboratory dry density in accordance with IS 2720, Part 8.

The moisture content of the material to be compacted shall be as wet or just wetter than optimum moisture content determined by laboratory testing.

Backfill material shall be tested every 300 m^3 or 600 m^2 or 1 test per shift, whichever is less, or as directed by the Employer's Representative. Proctor test procedures shall be done in random backfill and impervious backfill; whereas the relative density testing of IS: 2720 shall be done for free-draining backfill.

4.2.5 Gabions

The foundation for each gabion and mattress shall be prepared by the Contractor to the satisfaction of the Engineer. Irregularities in the foundation shall be excavated or tightly filled with gravel to produce a surface which has no protrusions or cavities in excess of 100 mm and the surface shall be covered with a geotextile fabric.

Gabions and mattresses shall consist of double twisted woven mesh gabions with coated, polymer sheathed wires or equivalent in agreement with the Employer's Representative.

The construction working procedures of gabions and mattresses shall be in compliance with the manufacturer's recommendations and instructions.

4.2.6 Rip-Rap Layers

Rip-rap layers shall be furnished and placed by the Contractor on permanent embankments as erosion protection layer as shown on the detailed design drawings of as directed by the Employer's Representative.

Prior to any placing of rip-rap layers the source of the material shall be approved by the Employer's Representative. Rip-rap material shall consist of hard, dense and durable rock. Material from Underground Excavation Works may be used.

The minimum rock size shall not be less than 500 mm and shall not be greater than that which can be encompassed in the specified layer thickness.

Rip-rap layers shall not be placed on earth, gravel or weathered rock foundation when not agreed with the Employer's Representative. Rip-rap shall be embedded in concrete in agreement with the Employer's Representative.

4.2.7 Water Proofing Membrane

The water proofing membrane shall cover all backfilled structures from water and moisture and is similar to the tunnel water proofing membrane as specified in clause 8.

4.3 Underground Excavation

4.3.1 General

The Contractor shall be responsible for the safety and security of excavations at all times during the execution of the Contract.

The geological/geotechnical information presented in the tender documents represents the state of knowledge of the geological/geotechnical conditions along the tunnel alignment based on available information at this stage.

Tunnel works to be executed are based on the New Austrian Tunneling Method, hereafter referred to as NATM, with observance of all principles related to the application of this method.

Mechanised techniques for excavation shall be used wherever practicable to eliminate or reduce health and safety risks.

The excavation material shall be classified in compliance with Clause 5 of this Specification. Different and adequate excavation methods shall be considered for rock excavation and loose excavation by the Contractor to keep the disturbance of the rockmass (ground) at a minimum level.

A detailed description, defined by the Contractor, of all excavation methods including equipment, location of headings, benches and pilot tunnels, drilling and blasting, controlled perimeter blasting, ripping, mucking, loading, hauling, temporary support systems, scaling, ventilation, lighting, pumping, safety measures, schedules, excavation cycles, simultaneous working of faces and sequence of operations he plans to follow in each excavation area to complete the work shall be included in the offer or submitted to the Employer's Representative prior to commencement for review. Additionally details concerning installation of pumping, ventilation and lighting systems shall be forwarded to the Employer's Representative for review. The Employer's Representative shall be provided with all submissions in sufficient time ahead of the construction works or at such dates as mutually agreed upon. No excavation shall be started in any excavation area until permission has been received in writing from the Employer's Representative.

The approval given by the Employer's Representative to the Contractor's methods and equipment does not relieve the Contractor of his full responsibility for proper and safe execution of tunnel excavations, or of liability for injuries to persons or fatal accidents, or any obligations under this Contract.

Manufacturer's certificates of compliance shall be submitted certifying that the materials and equipment proposed to be used meet Specification requirements.

During excavation, and at any time during the work, all ground material which is unsafe or appears to endanger persons, the Works or the property of others, shall be immediately scaled and removed from the excavations. The fact that such scaling and removal may enlarge the excavation beyond the line of excavation (Payline) shall not relieve the Contractor from the necessity of doing such scaling and removal of such materials. If it is not possible to remove loose rock by normal barring and wedging, then rock support, sprayed concrete or steel mesh or any combinations of each, shall be applied to secure and prevent the loose rock from falling or becoming unstable.

Excavation shall be carried out in a uniform and controlled manner and over-cutting shall be kept to a minimum consistent with the need to maintain the necessary clearance for construction of the Works.

Drilling and blasting operations shall be carried out in such way that they do not interfere with the work of others nor cause any damage to adjacent structures.

The Contractor's excavation operations and schedule shall allow for interruption while the geological conditions exposed at the excavated rock surfaces are mapped and assessed by the Employer’s Representative. Local areas shall be cleaned off where required by the Employer’s Representative to expose a fresh undisturbed surface. Such interruption and assistance shall be at no additional cost to the Employer.

The excavation invert shall not be damaged due to construction works. Hence the invert of the tunnel shall be protected against damage and deterioration which may be caused by construction traffic. Any other surfaces which deteriorate or are damaged shall be made good to a standard agreed with the Employer’s Representative.

Excavation shall be carried out in sections limited to such lengths, depths and widths as may be safely executed having regard to all the circumstances and as appropriate to the ground conditions and the equipment and method of construction being used.

In water-bearing strata the Contractor shall use such methods and take such steps as are necessary to control flows and maintain the stability of the excavation.

Additional excavation, not shown on the drawings, but the Contractor considers being required for his own purpose such as cross passages, mucking pits, niches or spaces for site installation may only be carried out in agreement with the Employer’s Representative. Such excavations are done at no additional cost for the Employer and shall be backfilled to the excavation line.

4.3.2 Overbreak

The paylineis defined with 30cm for tunnel sections with drill and blast excavation and 20 cm for tunnel sections with excavation by mechanical means such as excavator or road header.

Overbreak shall be secured with determined measures in agreement with the Employer’s Representative and according to the local conditions. Loose rock mass shall be removed. Any voids formed during the excavation process by overbreak and temporary works shall be backfilled completely with grout, concrete, sprayed concrete or other approved durable material.

- Accepted geological overbreak in tunnel excavation is defined as a local overbreak which occurs while the following four conditions are simultaneously fulfilled:
- Overbreak extends beyond the “overbreak”-line;
- The overbreak occurs above the tunnel invert;
- The Employer’s Representative is immediately notified and given the opportunity for inspection, while both the cause and the extent of the overbreak are clearly visible; and
- Appropriate working methods were used and adequate rock reinforcement and support was installed in due time, and properly applied by the Contractor.

The Contractor shall survey and plot cross sections at sufficient intervals to allow for a reasonably accurate estimate of the volume of overbreak which he claims to be due to geological conditions.

Voids created by overbreak extending beyond the “overbreak”-line in tunnel excavations shall, as directed, be backfilled up to the “overbreak”-line as required by the Employer’s Representative.

In the event of excessive geological overbreak/ instabilities, support shall be installed immediately as required to stabilize the ground. The Employer’s Representative shall be informed immediately of such conditions. Remedial works shall be in agreement with the Employer’s Representative. The design of the remedial works shall be done by the Contractor and approved by the Employer’s Representative. Remedial works shall be executed before further advance of the face unless otherwise directed by the Employer’s Representative.

The void formed by the geological overbreak shall be measured in-situ. Individual voids of less than 1 m^3 shall be discarded for measurement purposes. The materials required to complete the repair shall be quantified and approved by the Employer’s Representative and certified for payment.

Where forepoling is required no separate remuneration for the additional overbreak will be made in the crown area. i.e. the additional overbreak shall be included in the excavation costs. This is with the assumption that forepoling if effective should arrest any overbreak beyond the payline.

5 TUNNEL EXCAVATION

5.1 General

Tunnel excavation in any kind of ground shall be performed in accordance with modern blasting and excavating practice, using methods and techniques that will reduce overbreak to a minimum outside of the line of theoretical excavation, and which will preserve, in the soundest possible condition, the structural integrity of the rockmass (ground) beyond the excavation.

Excavations shall not be advanced until the pattern ground support for the previous round has been installed and the profile of the previous round has been checked and all rock remaining inside the line of theoretical excavation has been removed. The Employer's Representative may stop the work for removal of undercuts at any time if undercutting is observed.

Tunnel excavation shall not be started until the exposed rock faces in its portal excavation have been stabilized with rock support and sprayed concrete and drainage measures have been installed as given in the drawings.

The Contractor shall maintain accurate records of all blasting and excavation operations and at the end of each shift he shall provide the Employer's Representative with two copies of the records, together with such additional data as the Employer's Representative may request. The forms shall bear the signatures of the Contractor's and the Employer's Representative certifying that records are accurate and complete and include but not limited to the following:

- Length of tunnel excavated and theoretical volume of solid material excavated
- Quantity of any rock support installation
- Occurred rock falls, zones of instability and logs of pilot holes
- Water inflow at the head and rate of discharge at the tunnel portal
- Unusual occurrences and all delays with reasons for these.

Drilling of holes in swelling ground shall be conducted without water.

5.1.1 Definition of Excavation Profile

The theoretical excavation line includes the required space for the inner lining, the waterproofing system (protective felt and waterproofing membrane), the smoothening sprayed concrete and the sprayed concrete lining. It also include the deformation tolerances and construction tolerances. No rock materials will be permitted to remain protruding the theoretical excavation line under any circumstances.

An additional allowance of 300 mm over and above the line of theoretical excavation is provided for construction tolerances and excavation undulations. This line is the pay line.

The CONTRACTOR shall make all reasonable effort to maintain the excavation profile as given in the Figure by exercising careful control of drilling and by varying the various elements of smooth blasting.

The CONTRACTOR shall accommodate his construction tolerance for excavation and support installation within the given value.

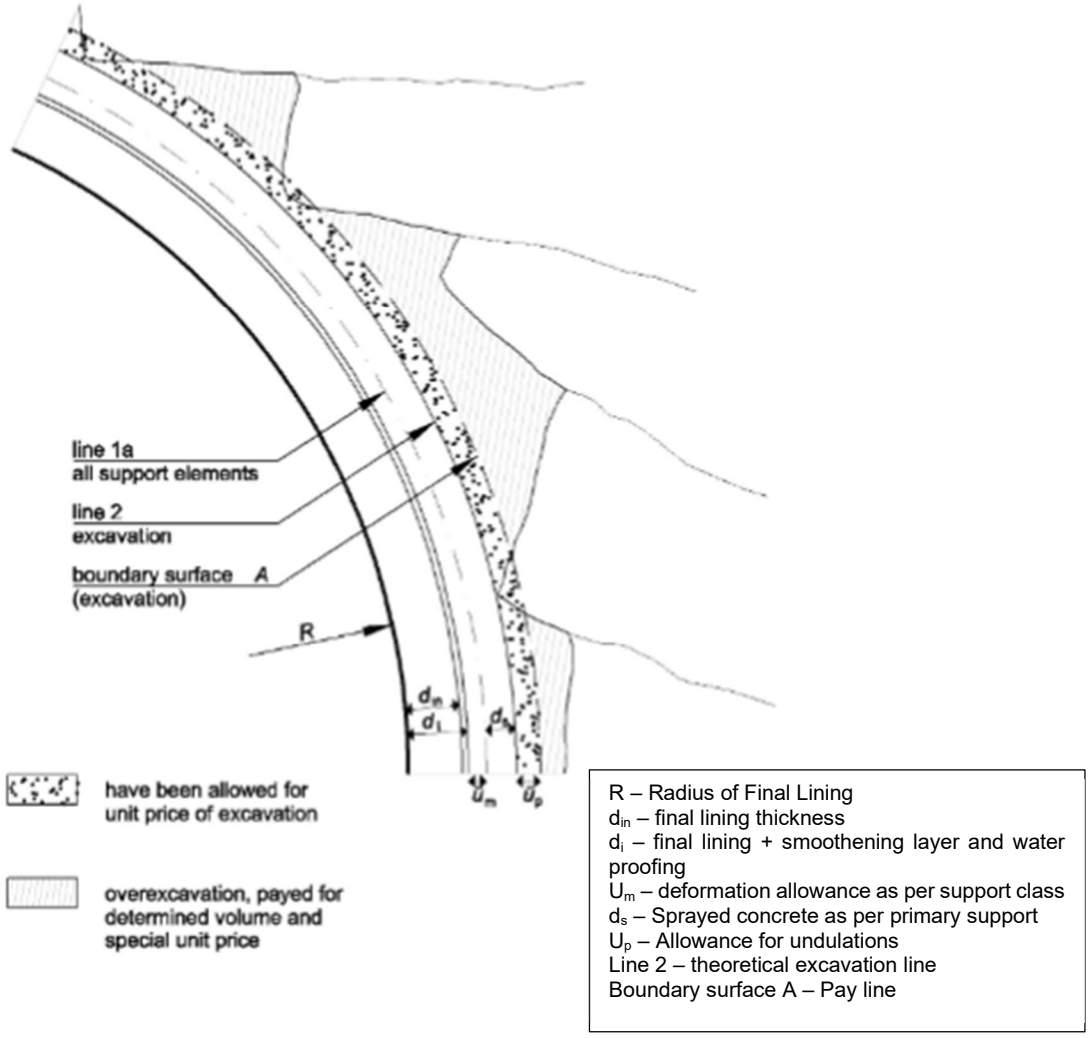


Figure 6.1: Definition of Payment Lines for Excavation and Sprayed concrete

5.1.2 .Overbreak

Overbreak is the space created when the ground breaks beyond the pay line for the various rock classes. Occurring overbreak may be caused by improper workmanship and careless working technique (avoidable overbreak) and/or by reasons which cannot be influenced by the CONTRACTOR (unavoidable overbreak). Unavoidable overbreak is overbreak caused by unfavourable geological conditions.

The Overbreak is whether avoidable or unavoidable shall be decided by the ENGINEER and his decision in this regard shall be final and binding on the CONTRACTOR. The quantity for the Overbreak in case decided by the ENGINEER as unavoidable shall be measured beyond Boundary Surface “A” (pay line as defined earlier) as shown in Figure 6.

In the event of excessive overbreak, support shall be installed immediately as required to stabilize the ground. The CLIENT/ENGINEER shall be informed immediately. Remedial works shall be discussed and agreed between the CONTRACTOR and the ENGINEER. The detail design for the repair works shall be done by the CONTRACTOR and shall be approved by the CLIENT/ENGINEER. Remedial works shall be executed before further advance of the face unless approved or directed otherwise by the CLIENT/ENGINEER.

5.1.3 Excavation Requirements

Rock excavation shall be performed by either using modern blasting methods (controlled blasting) or roadheader or excavator as per the prevailing rock conditions as encountered.

Drilling and blasting shall be done in such a manner as to ensure that the rock will break along the desired lines. Controlled blasting methods such as "smooth blasting" shall be used to limit the overbreak and to prevent shattering of the rock surfaces. This may require sufficient number of delays as well as charging of the peripheral holes with detonating cords (80 g/m) or special charging. Respective methods shall be proposed in the blasting pattern.

The diameter and the spacing of the blast holes shall be adapted to the actual rock conditions on site. The CONTRACTOR shall develop and continuously improve the blasting techniques as the works progress to obtain the best possible excavation surface after blasting.

Open up a new round of excavation shall only follow the installation of support elements of the previous round as instructed by the ENGINEER. The new round shall not exceed the maximum length of unsupported excavation indicated in the corresponding drawings for the respective rock class. The spacing of the steel ribs or lattice girders and the length of round shall be reduced if ground conditions and the actual stand-up time encountered or achieved by pre-support means so dictate.

In general the primary support must be completed two rounds from the face prior to the opening of the next round.

Additional subdivision of excavation areas and face stabilization by means of face bolting and sprayed concrete with wire mesh or by means of a face stabilization wedge and sprayed concrete shall be applied wherever ground conditions require doing so.

A flash sprayed concrete layer shall be applied immediately after excavation where required to seal and protect material from deterioration and initial loosening. Sprayed concrete lining shall be installed in a timely manner so as to maintain the inherent strength of the ground.

The excavation of niches in tunnel side walls shall in general be carried out after installation of the primary support. Sprayed concrete and lattice girders (if any) in the tunnel side wall shall be carefully cut along the profile of the niche and excavation shall be carried out in such a manner that the remaining tunnel support will not suffer any damage.

5.1.3.1 Backfilling and Support of Fault Zones

a) Fault zones intersected by tunnel excavation

If cavities form in the fault zone that are intersected during excavation of the tunnel, all voids / cavities shall be filled with grout, sprayed concrete or filling concrete according to stability requirements as instructed by the ENGINEER.

Cavities below the tunnel invert shall be backfilled with backfill material, backfilling concrete or sprayed concrete as applicable according to condition of the cavity (size, shape) and as instructed by the ENGINEER.

Large cavities shall be adequately supported by sprayed concrete, wire mesh and rock bolts as required for stability and as instructed by the ENGINEER.

b) Fault zones encountered by drilling

If fault zones are encountered by exploratory drilling only, size and location have to be investigated closer and have to be backfilled by grouting as required for stability and as instructed by the ENGINEER.

c) Backfill Material and Filling Concrete

Backfill material for backfilling cavities below the tunnel invert shall consist of free-draining material like gravel or boulders as approved by the ENGINEER. Filling concrete shall be concrete grade M10 according to IS456.

5.2 Geotechnical Design

The procedure of ground characterization during construction sequence is based on the Austrian “Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation” by the Austrian Society for Geomechanics.

Rock mass classes are determined based on the rock at the excavation face of the tunnel before the commencement of the respective excavation sequence.

5.2.1 General

A continuous updating of the geotechnical model and an adjustment of excavation and support to the actual ground conditions during construction is required.

The rock mass characterization shall be determined according to the following steps, which are summarized and presented in Figure 5.1.

- Step 1: Determination of the encountered Ground Type (GT) and prediction of ground characteristics
- Step 2: Assessment of system behavior in excavation area
- Step 3: Determination of excavation and support measures and prediction of System Behavior in supported section
- Step 4: Verification of system behavior

Step 1: The geological conditions during construction shall be monitored as defined in Section 5.4 to collect and record the relevant parameters specified in the design. Based on the geological conditions the Ground Type (GT)/ Rock Mass Types (RMT) shall be determined. Additional observations, like indications of overstressing, deformation and failure mechanisms as well as results from probing ahead and the evaluation of the geotechnical monitoring shall be used to update the ground model and predict the conditions ahead of the face.

Step 2: Based on the predicted ground conditions the system behavior in the section ahead shall be assessed under consideration of the influencing factors, and compared to the framework plan. Particular attention has to be paid on potential failure modes.

Step 3: To determine the appropriate excavation class and support category the criteria laid out in the framework plan have to be followed. Consequently, it has to be checked if the actual ground conditions (Ground Type/ Rock Mass Type, system behavior) comply with the prediction. The additional data obtained during construction form the basis for the determination of the applied excavation and support methods.

The system behavior has to be predicted for the next excavation section, considering ground conditions and the chosen construction measures. This process is to be done during the daily review meeting as per Clause 5.6.4. Records of this meeting shall be kept and signed of all attended parties in compliance with Clause 5.6.4.

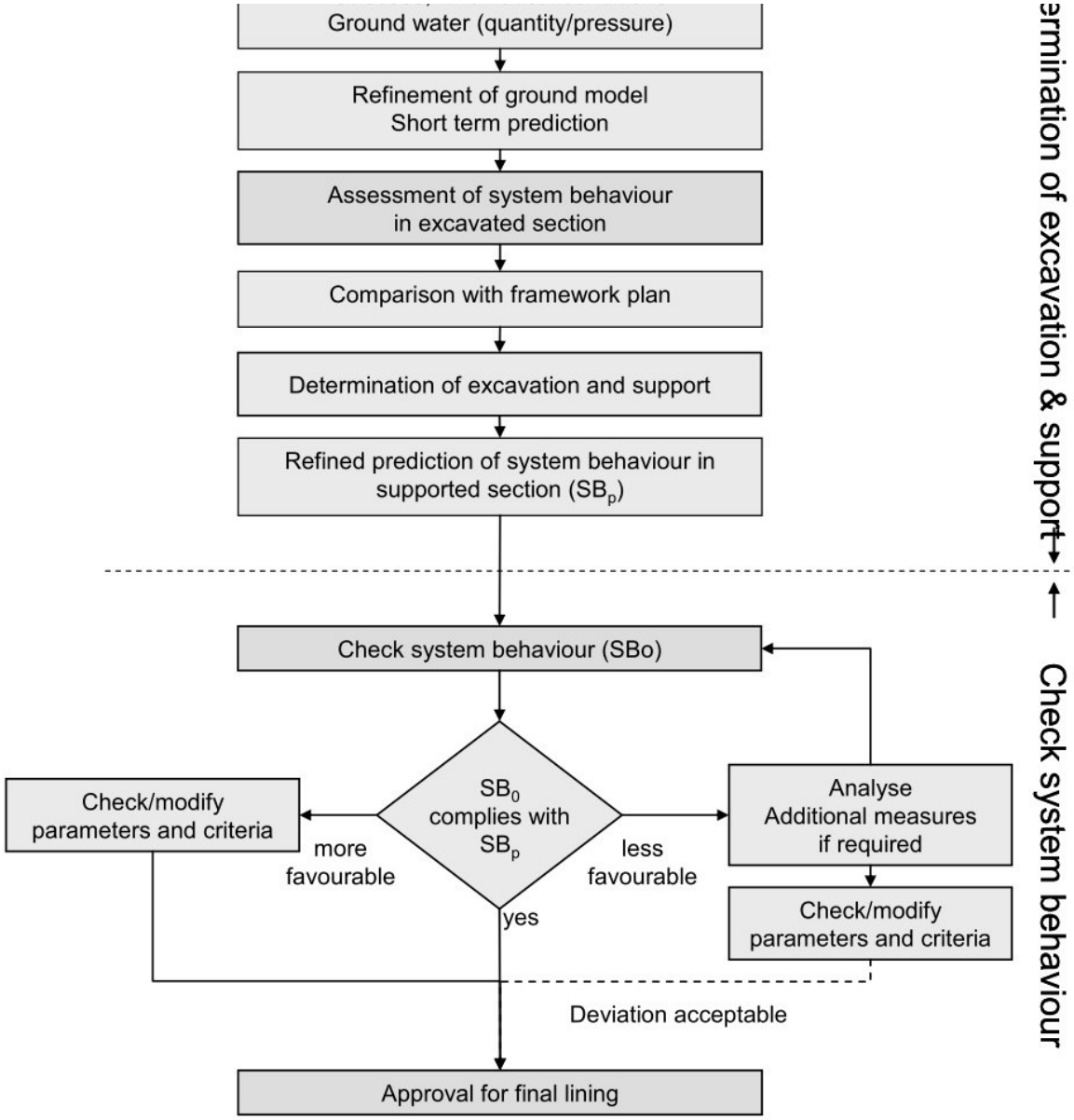


Figure 5.1: Basic procedure of determination of construction measures and check of system behavior during construction (SB_p = predicted system behavior, SB_0 = observed system behavior) from Austrian “Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation” by the Austrian Society for Geomechanics

Step 4: The system behavior shall be monitored (visually and by measurements) in compliance with Clause 5.6 of this Specification and the criteria defined in the geotechnical safety management plan. When differences between the observed and predicted behavior occur, the parameters and criteria used during excavation for the determination of the Ground Type and the excavation and support have to be reviewed. When the displacements or support utilization are higher than predicted, a detailed investigation into the reasons for the different system behavior has to be conducted, and if required mitigation measures (like increase of support) ordered. In case the system behavior is more favorable than expected, the reasons have to be analyzed as well and the used parameters modified, if appropriate. This allows for a continuous improvement and refinement of the method for assignment of excavation and support methods.

5.2.2 Determination of Actual Ground Type

Key parameters shall be defined in agreement with the Employer's Representative for the identification of each Ground Type, considering that those can be recorded during construction. If directed by the Employer's Representative, additional parameters shall be monitored, which the Employer's Representative deems necessary for determination of the system behavior.

Each of the key parameters shall be categorized. Whenever feasible, numerical values shall be used preferably than descriptive data, like spacing, joint opening, strength, etc. Due to practical reasons some of the required parameters can only be described qualitatively.

Using predefined criteria the parameters are weighted and combined, allowing the appropriate Ground Types to be identified. A correlation matrix shall be used.

Data collection on site shall be concentrated on collecting relevant geological and geotechnical data and on observing and recording the ground structure. The collected data are recorded in prepared forms. With the criteria defined during the design the Ground Type is determined. In heterogeneous ground conditions, the ground shall be divided into several sections, and the appropriate key parameters shall be collected for each section separately.

The geological and geotechnical data collected and evaluated on site are the basis for the extrapolation and prediction of the ground conditions. The geological work is not limited to recording the face conditions, but also shall involve prediction of the conditions in the volume of rock that controls the ground response.

5.2.3 Assessment of System Behavior in the Excavation Area

In addition to the parameters required to determine the Ground/ Rock Mass Type(s), influencing factors, like ground water conditions, ground structure, estimated stress situation and kinematical conditions as well as observations of the system behavior in the excavation area shall be recorded by the Contractor.

The reaction of the ground to the excavation and support are observed by the Contractor using an appropriate monitoring system in compliance with Clause 5.6 of this Specification.

The predicted ground structure in combination with the on-site observations and monitoring results shall be used for prediction of the ground behavior for the sections to be excavated subsequently.

5.2.3.1 Determination of Excavation and Support and Prediction of System Behavior

For the final determination of the excavation and support method, it must be checked if the ground conditions and system behavior observed on site conform to the design assumptions. When the observed conditions conform to the predicted ones, stipulations in the framework plan have to be followed when determining the construction measures.

In case of a deviation exceeding the specified tolerance in the framework plan, the designer has to be informed to allow for an adaptation of the prediction, based on new findings. The designer shall agree with the required additional measures in due time and update the framework plan accordingly.

The final decisions on the applied construction measures are based on the design and additional information gained during construction and shall be done during the daily review meeting as per Clause 5.6.4 of this Specification. The goal is a safe and economical construction. The decisions have to be coherently explained and documented, for example in an appendix to the required excavation and support sheet (RESS) in compliance with Clause 5.6.4.2 of this Specification.

The prediction of the system behavior shall contain the following but is not limited to:

- Expected magnitude and orientation of the tunnel displacements, and the surface (if applicable), including the displacements spatial and time dependent development
- Expected utilization factor of the support

5.2.3.2 Check of System Behavior

The actual system behavior in the supported area and in the final stage shall be compared to the predicted system behavior, and checked, whether the behavior is within the specified limits of the warning criteria. Additional measurements or evaluations may be required on direction by the Employer's Representative to determine for example the utilization of the lining.

Deviations between the expected and the observed behaviors have to be analysed and documented by the Contractor and discussed with the Employer's Representative in the daily review meeting as per Clause 5.6.4.

The reasons for the deviation in behavior have to be analysed. In case the assumptions regarding the influencing factors are inappropriate, the parameters have to be modified. The modifications have to be supported by appropriate data and analyses and documented in an updated framework plan.

In case the ground quality is better than predicted, the geotechnical model has to be revised. In case of a significant deviation, the criteria for the determination of excavation and support have to be modified.

In case the ground quality is worse than predicted and warning levels exceeded, contingency measures according to the safety management plan have to be implemented, and excavation and support shall be adjusted accordingly. This can be done for example by additional bolting, installation of a temporary invert, etc. In some cases the installation of a stronger support in the following rounds may be sufficient to achieve the target. All additional support measures are defined in the daily review meeting and presented in the RESS in agreement with the Employer's Representative.

In case of significant deviations, the geotechnical model has to be revised and the criteria for the determination of excavation and support have to be modified. This generally requires that the framework plan is updated.

5.2.3.3 Updating of Design

Based on the information available during design, a number of assumptions and simplified models have to be used to arrive at a design, which is the basis for the framework plan and the tender documents.

A continuously update of the geotechnical design with the increasing level of information shall be done. This applies to the determination of the Ground/ Rock Mass Types, the assignment and calibration of key parameters and criteria as well as for the determination of the system behavior. The refinement of parameter categories, the introduction of additional criteria, etc. help in improving the geotechnical model.

The tunnel engineer on site has to report to the designer in case of significant deviations of the actual geological/geotechnical situation or system behavior from the predicted ones, as outlined in the framework plan. A detailed report, containing all relevant information and coordinated with the site geologist and the Employer's Representative and the Contractor, has to be prepared and submitted. After consideration of the facts the designer has to update the framework plan. This has to be documented in a supplement to the geotechnical report.

5.3 Blasting

5.3.1 General

Not less than 40 days prior to commencement of rock excavation in each area, the Contractor shall submit, for review by the Employer's Representative, details of the drilling and blasting methods which he intends to use in that area. If, at any time in a specific area, a plan which has been previously adopted does not produce conditions at the excavated rock face that conform to the requirements of these Specifications, the Contractor shall submit a revised plan to the Employer's Representative before continuing excavation in adjacent areas.

The Contractor shall use/ deploy controlled blasting techniques, which will satisfy the excavation requirements specified herein. In each different type of rock conditions the Contractor's initial blasts shall be performed as trials, and the burden, drill hole pattern and depth, explosive type and quantity, blasting sequence and drill delay pattern shall be modified to achieve the requirements specified herein.

Blasting means have to follow the licensing requirements and orders as well as the manufacturer's instructions.

Blasting operations shall be carried out only under the direction of an experienced operator. The Contractor shall appoint one competent person to be responsible for the security of explosives.

Blasting shall be carried out carefully so as to avoid loosening or shattering rock beyond the required line of excavation, and loose or shattered rock (where it does not contribute to stability of the excavation) shall be removed by scaling down or other means before personnel will be permitted to restart operations after blasting.

Notices of blasting operations shall be posted on site. Before each firing, the Contractor shall give audible warning, clear the area and shall take positive measures to prevent personnel from entering the danger area.

The Contractor shall monitor the results of blasting closely and, where it is proper to do so, shall propose changes to his blasting operation for the agreement of the Employer's Representative.

Under no circumstances shall any holes be charged until completion of all drilling operations at the face.

After each blasting operation the tunnel drive shall be sufficiently ventilated to remove any nitrous gases and the atmospheric conditions shall be constantly checked prior to personnel accessing the excavated face in compliance with Clause 5.5.

No person shall be allowed to approach the face and no face operation shall commence until the Contractor's authorized person in charge of the operation has given permission after blasting round.

As soon as practicable after blasting and without undue delay the Contractor shall erect such support as may be necessary to safeguard the excavation and personnel.

The shot-firer must keep a record of the number of shots fired, their time of firing, type and weights of explosives used and the type and number of detonators used, together with a record of the post-blast situation for each and every location. A copy of the record shall be available to the Employer's Representative at the end of every shift on which shots are fired.

5.3.2 Controlled perimeter blasting

Controlled perimeter blasting techniques shall be used to produce rock faces conforming to the required excavation lines, slopes, elevations and dimensions shown on the drawings with a minimum of disturbance to the rock at, or outside of, the excavation pay lines.

Drill holes for controlled perimeter blasting shall not be less than 42 millimeters in diameter and shall be a single row of closely spaced holes drilled to a maximum depth of one round length along the excavation pay lines and a spacing of 0.4 to 0.6 m depending on the ground

condition. The spacing of the perimeter holes may be modified on the basis of results obtained and in agreement with the Employer's Representative.

All blast holes within a distance of 5 meters normal to the excavation pay lines shall be less than 75 millimetres in diameter and shall be loaded in a manner and detonated in a sequence to ensure that a minimum of damage will result to the face when the main charge is fired.

5.3.3 Explosives

The Contractor shall use explosives only in circumstances where it is safe to do so having due regard to the safety of persons, third-party property and the safety of the Works. Explosives shall not be used without the agreement of the Employer's Representative.

The Contractor shall obtain all necessary licenses and consents and shall provide secure storage facilities for all explosives and equipment in accordance with Indian or International Standards Code of practice for the safe use of explosives in the construction industry and the requirements of the local Authorities and the Employer's Representative.

Explosives shall be handled and used only by the Contractor's duly authorised personnel. The names and qualifications of such personnel shall be submitted to the Employer's Representative in writing in advance of any possible use of explosives.

At an early stage, in advance of the proposed use of explosives, the Contractor shall notify the Employer's Representative, third parties, statutory authorities and services which have an interest in or are likely to be affected by blasting operations, of the general nature of the operation. The Contractor shall subsequently give a minimum of 14 days' notice to the Employer's Representative and others described above of the proposed use of explosives. With this notification the Contractor shall submit to the Employer's Representative a detailed method statement on all aspects of the proposed use of explosives, including the treatment of misfires.

The Contractor shall comply with the following documents in respect of the use of explosives:

- Indian Explosives Act 1884
- Indian Explosive Rules 1983
- The Manufacture and Storage of Explosives Regulations 2005
- BS 5607:1998 Code of practice for the safe use of explosives in the construction industry
- Control of Explosives Regulations 1991
- Carriage of Explosives by Road. Road Traffic (Carriage of Explosives) Regulations 1996
- PD CLC/TR 50426:2004 Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio- frequency radiation. Guide Quarries (Explosives) Regulations 1988, as far as it is relevant to tunnel works.

5.3.4 Blasting Vibrations

For structures and railway tracks in the proximity of blasting, the peak particle velocity shall be measured at the locations immediately adjacent to the structure nearest to the face being blasted or any other location where it is necessary to limit vibration.

Vibration monitoring proposals shall be submitted to the Employer's Representative for his agreement.

The measurement of peak particle velocity shall be obtained from instruments capable of measuring along three orthogonal axes, one of them shall be aligned parallel to the centre line of the excavation and another shall be vertical. The Contractor has to provide supports for the measuring instrument if so required by the manufacturer's instructions.

The measurements of the particle velocities shall be the responsibility of the Contractor. Copies of the readings in an agreed form shall be supplied to the Employer's Representative.

Prior to the commencement of blasting in any location, the Contractor shall demonstrate by the use of test firings, or by other means, that neither the peak particle velocities given in the particular Standards and Specifications will be exceeded.

The maximum allowable blasting vibrations shall be defined by the Contractor for every influenced structure with reference to the applicable Standards and Specifications for the relevant structure. The allowable blasting vibrations shall be approved by the Employer's Representative prior to any blasting operations.

5.4 Geological Mapping

Geological mapping shall be performed by the Contractor's qualified geologist to provide a documentation of rock and rock mass condition encountered during excavation. Additionally all exposed rock surfaces of the open and underground excavations shall be washed down by the Contractor for inspection and geological mapping by the Employer's Representative if he deems to do so. Exposed rock surfaces at the required excavation pay lines shall be mapped after preparation but before sprayed concrete application. Tunnel and other underground faces shall be mapped just before the start of drilling. The Contractor shall allow in his construction procedure and schedule for the geological mapping of each tunnel face not less than 30 minutes.

The geological mapping shall include, but not limited to the following information:

Excavation face:-

- Tunnel meter
- geological unit
- intact rock:
  - rock type and lithology description
  - weathering and alteration degree
  - uniaxial and unconfined compressive strength (from point load tests)
- rock mass:
  - jointing degree
  - geometry, orientation (Dip direction and amount) and properties of discontinuities
  - face condition (homogeneous or heterogeneous)
  - water inflow at excavated round
  - overbreaks (separated in geological and non-geological)
  - ground response
  - suspected pervious zone
- the GSI value and the Ground Type
- groundwater influx into tunnel measured at regular intervals of excavated tunnel length.

The Contractor shall provide lights, ladders, platforms and free access and shall assist the Employer's Representative to carry out inspection and geological mapping.

In case of sudden and unexpected changes of the geological conditions the Employer's Representative shall be informed immediately by the Contractor.

5.4.1 Exploratory Drillings

Long exploratory drillings with full core recovery shall be carried out when deemed necessary and required by the Employer's Representative. Based on the geological mapping and the exploratory drillings the Employer's Representative may require rock mechanic laboratory tests.

5.5 Temporary Ventilation System

5.5.1 General

Pits and tunnels shall at all times be kept ventilated to maintain an atmosphere fit for respiration and free from oxygen deficiency, potentially explosive or noxious gases and dust, whether present naturally or otherwise. Ventilation shall also be used to maintain a safe working temperature.

Underground works shall be ventilated in accordance with all applicable regulations. Details of the proposed ventilation system shall be submitted to the Employer's Representative, for review, not less than 40 days prior to the start of commencement. Where more than one pollutant is present any adverse interaction between them shall be identified and mitigated.

All diesel engines used in the underground works shall be provided with means, which shall be maintained in efficient order, of cooling exhaust gases and reducing the concentration of toxic gases to acceptable levels, filtering particulates and preventing emission of flames or sparks. In underground workings and in confined spaces the air breathed by persons shall contain not less than 19% of oxygen by volume, and shall not contain concentration of gases, vapors or dust greater than is safe for the health or workmen, having regard to the effects of time, temperature, humidity and the combined effects contaminants. Smoking is forbidden in tunnels, pits and all confined spaces. In rock excavation all drill holes shall be wet drilled unless otherwise specified in this Specification in compliance with special ground condition.

5.5.2 Ventilation

The Contractor shall agree ventilation proposals with the Employer's Representative. Agreement shall not relieve the Contractor of his obligations under the Contract. Proposals shall include but not be limited to the types of fan employed, size of ventilation ducts, air-locks where appropriate, the power supply and the fan performance data, together with duct characteristics.

Ventilation shall be designed and implemented following the minimum requirement of IS 4756 or similar international standard. Provision for fresh air should not fall below the following limits

1. Air Velocity in the full cross section : between 0.3 and 2.0m/s
2. Fresh air concentration:
    i. 2m3/min/BHP of diesel engine
    ii. 4.25m3/min/man working at the face

In forcing systems, fans shall normally be placed on the surface. The inlet to any surface forcing fan shall have unobstructed access to fresh air. It shall not be in the vicinity of a storage site for oil, chemical or diesel drums. The fan shall also be sited so that it cannot draw in internal combustion engine fumes or gas from charging batteries. Blasting fumes shall be discharged from the underground works into a filter system or diverted adequately to ensure that concentrations of noxious or other harmful gases or dust are kept to the minimum limit as stated in the applicable laws/ Standards or the limits specified in the contract of lower.

If booster fans are to be employed by in-line staging, they shall be of an approved flame proof (FLP) construction and a monitoring system shall be installed so that the status and condition of such fans can be monitored at all times. Provision shall be made for the fan to be run continuously whether persons are within the underground works or not. After tunnel break-through the ventilating system shall be kept in operation in order to maintain the fresh air-volume requirements stated hereinafter.

If a ventilation system ceases to function for any reason for a period exceeding 30 minutes, all work in areas being ventilated by that ventilation system shall immediately cease and all workers shall immediately leave the areas. Where a fan has been stopped and restarted, the condition of the air shall be tested before personnel enter the tunnel. If only forcing surface-mounted fans are employed, the ventilation system should be restarted and run continuously ensuring that any plugs of oxygen-deficient, flammable or noxious mixtures of gas are flushed out. Care should be taken that workmen do not encounter any plugs of these gases on re-entry to the tunnel. The Contractor should take into account that air residence time in long drives can be several hours and that layered gases of different densities are difficult to disperse, especially where the gradient of the tunnel changes. All equipment and ventilation duct shall be maintained in sound working order at all times. Any damage to ventilation duct shall be repaired within 12 hours of the damage.

The outlet of the duct shall be kept as close to the face as is practicable, designed to avoid turbulence and creation of dust and not more than 10 m away. Where dust is being produced by the tunneling system, exhaust ventilation shall be used to extract such dust from the working area. Tunneling shall not continue more than 10 m from the portal or pit unless positive ventilation has been established. The fresh air supply for underground works shall not be less than two cubic meters per minute at the face for each man underground and four cubic meters per minute per kW power for all diesel units operating underground. These fresh air volumes shall be cumulative and the Contractor shall allow in his design calculations for the maximum number of persons and diesel powered equipment deployed in the Works at any one time. Any estimated losses, e.g. due to the leaks in the ducts, shall be considered. The fresh air supply shall also be adequate to produce a linear velocity of minimum 0.3 meters per second throughout the underground works. Testing devices shall be provided for measuring carbon monoxide, methane, oxides of nitrogen and aldehydes in underground works during the operation of internal combustion engines. Readings of carbon monoxide content shall be taken by the Contractor at least once during each shift. Readings of oxides of nitrogen content and of aldehydes content shall be taken frequently to ensure safety of the workers. A record of all taken readings shall be kept by the Contractor and submitted to the Employer's Representative daily. Ventilation ducts shall be firmly fixed to the vaults in such position that a minimum clearance of 20cm remains between the duct and the extremities of vehicular traffic employed in the Underground Works.

5.5.3 Monitoring

Atmospheric monitoring equipment shall be positioned at each working face and also within 20m of the tunnel entrance when the tunnel has advanced 250m or more. Monitors shall also be provided every 500m along the tunnel. Monitoring equipment shall be capable of continuously monitoring the levels of potentially explosive gases, toxic gases and radioactive gases as appropriate and the oxygen content. The equipment shall give both visual and audible warning of the presence of potentially explosive, radioactive or toxic gases and where the

oxygen content falls below safe working levels defined in Table 5.1 below. An immediate and effective means of communicating warnings to the surface shall be installed. The atmospheric monitoring system shall be a fixed system supplemented by portable monitoring equipment as necessary, except in small tunnels where the use of portable equipment only shall be permitted at the discretion of the Employer's Representative.

Table 5.1: Admissible maximum concentrations of pollution gases in underground works

Pollution gas	Max. concentration
H_2S	10 ppm
SO_2	2 ppm
CO	50 ppm
NO_2	5 ppm
CO_2	5000 ppm
CH_4	1000 ppm
Silica dust	8 mg/m³

The full length of all tunnels shall be monitored continuously for the presence of explosive or noxious gases or lack of oxygen. Records shall be kept of monitoring results. If concentrations of noxious gases or other inflammable gases exceed the permissible limits stated in Table 5.1 above, BS 6164 or HSE guidance document EH40, or oxygen content below the level set out in BS 6164, all operation's shall be interrupted immediately and personnel shall be removed to a safe area. All sources of ignition shall be extinguished or removed. All equipment with the exception of ventilation equipment shall be shut down.

When any explosive gas concentration of 1.25% is present, all persons other than those essential for safety shall be withdrawn from all parts of the tunnel. The use of explosives and locomotives or any other electrically powered equipment. shall be prohibited and all electrical equipment not intrinsically safe shall be disconnected. All persons shall be withdrawn when the explosive gas concentration exceeds 2.0%.

The required measures will be mutually determined and agreed to by the Employer's Representative and the Contractor. If required by the Employer's Representative, the Contractor shall consult the services of an independent consultant experienced in gaseous tunnelling. Re-entry and resuming of the Work shall be prohibited until the Employer's Representative has authorized re-entry.

If the ventilation system is for any reason not in operation for a period greater than 2 hours, a start-up procedure shall be invoked. This requires that the tunnel shall not be re-entered until one complete air change in the tunnel has taken place and the tunnel atmosphere is shown, by monitoring, to be safe.

Persons re-entering after shutdown must carry instruments to detect the presence of dangerous gases and the sufficiency of oxygen, and these must be used continuously during re-entry.

5.5.3.1 Checking & Inspection

During each shift, the following checks shall be made:

- The fan or fans shall be checked for heat, unusual noise and vibration. The results shall be reported and remedial action shall be taken if required.
- The ventilation ducting shall be checked for damage and the joints checked for integrity. The results shall be reported and remedial action shall be taken if required.
- The atmospheric monitoring system shall be checked at both local and remote stations and the results shall be recorded.

The air flow quantities shall be checked at both the face on a weekly basis. These figures shall be recorded and compared with the calculated flows. Any shortfall shall be made good.

The ventilation records shall be maintained and be made available for inspection by the Employer's Representative.

5.5.3.2 Control of Dust Silica and Noxious Gases

To reduce the amount of dust, only wet drilling will be allowed and during mucking, muck piles shall be kept constantly damp by sprinkling with water. The use of high pressure water jets for this purpose is not permitted.

Air Samples for this purpose shall be taken within 10 days of commencing underground excavation, at 30 days intervals thereafter and within 20 days following major changes in tunnel excavation operation or whenever required by the Employer's Representative. Samples shall be taken from actual working areas. The sampling and testing shall be performed by a qualified person or laboratory to be proposed by the Contractor and approved by the Employer's Representative. A copy of the test results shall be submitted to the Employer's Representative within 2 weeks of the sampling date.

In general, the concentration of fine dust (diameter less than 0.005 mm) may not exceed the value of 8.0 mg/cum of air and in relation to the silicon dioxide SiO_2 content in the rock this value is lowered in compliance with Table 5.2.

Table 5.2: Maximum admissible fine dust concentration with respect of SiO_2 content in the rock

per cent per weight	mg/m³ air
1-15%	8.0
15-20%	6.0
20-30%	4.0
30-60%	2.0
60-80%	1.5
80-100%	1.3

The Contractor shall take necessary measures and install appropriate equipment in agreement with the Employer's Representative if the concentration of fine dust exceeds the limits stated in Table 5.2 above.

Use of internal combustion engines, other than approved mobile diesel powered equipment will not be permitted in underground construction Sites.

5.5.3.3 Lighting

Floodlighting on the site surface shall be adequate for the safe operation of the site. It shall be shrouded where necessary to ensure the light is directed to areas within the site, and to avoid nuisance.

Lighting in the tunnel shall extend the full length and not be less than that required for safe working and access. Lamps shall be located with an interval of 25m.

An alternative source of power and emergency lighting system shall be provided to allow emergency securing operations and evacuation safely in the event of a primary power failure as specified in Clause 2.5.1. An adequate number of hand lamps shall be located at key points underground.

The Contractor shall also provide suitable movable lamps to illuminate any area in Underground Works including areas for instrumentation and where the Engineer may wish to carry out inspection and rock mechanics tests or instrumentation.

Lighting illumination by flame is strictly not permitted in the underground Works.

5.6 Monitoring

5.6.1 General

The Contractor shall submit to the Employer's Representative for agreement a detailed method statement for instrumentation and monitoring, including instrumentation layout, trigger, design and allowable values and the procedures for evaluating the monitored data.

The Contractor shall appoint within his site team an experienced Monitoring Employer's Representative who shall lead the Contractor's monitoring team. The Monitoring Employer's Representative shall present the results of the previous day's monitoring in the daily monitoring meeting as per 5.6.4 with the Employer's Representative where they shall be presented to the Employer's Representative by the Monitoring Employer's Representative.

The frequency of such review meeting may be increased if requested by the Employer's Representative. The Contractor's Site Manager shall attend monitoring review meetings if requested by the Employer's Representative.

The accuracy and precision of the required measurement will depend on the purpose of the monitoring.

Assessments shall be carried out to establish the zone of influence due to tunnelling works and to determine the likely damage that will occur to existing above-ground and subsurface infrastructure.

The outcome of the assessments shall determine the type and amount of monitoring that will be required.

Instrumentation and monitoring for the tunnel and appurtenant structures shall be carried out with the following instruments but not limited to:

- Theodolites/ Total station and reflectors
- borehole extensometers (multiple-point) and strain gauges
- load cells
- radial pressure cells tangential pressure cells
- temperature gauges
- tape extensometer and convergence pins (may be carried out)

All instrumentation operating on electrical, mechanical or hydraulic systems shall be accompanied by individual test certificates, and shall be tested in the presence of the Employer's Representative prior to installation, unless specifically stated otherwise.

The installation of instruments may interfere with the overall construction progress. The Contractor shall make provision for such interferences in his construction schedule. He will not be entitled to any compensation or extension of the Time for Completion by reason of any such delays, including repair and replacement of damaged instruments if the damage is due to construction procedure of Contractor.

No material shall be installed prior to the Employer's Representative's approval. However, approval by the Employer's Representative of the Contractor's proposals and drawings or data shall not relieve the Contractor from his sole responsibility to meet all the requirements.

5.6.2 Ground Movement Monitoring

Unless otherwise provided in the Contract, the Contractor shall monitor the effects of tunnel construction at the surface, including all ground movements and the effects on all structures, including the Works. Where specifically requested, the subsurface effects, including movements of the water table, shall also be monitored.

Monitoring shall be referenced to stable survey stations located outside the zone of influence of the Works and not subject to ground movement. Such benchmarks and coordinated stations shall be established and agreed with the Employer's Representative before any ground is excavated and before any ground treatment or dewatering takes place. They shall be checked at intervals during the duration of the Works.

The Contractor shall observe record and analyse the readings to establish trends in movement and reconcile movements measured with those predicted. He shall provide a copy of all

recorded results to the Employer's Representative. He shall make available results to the Employer's Representative in accordance with an agreed program. However, movements greater than predicted shall be reported to the Employer's Representative immediately.

Prior to construction Works commencing, a defect survey shall be carried out of all structures within the zone of influence and a schedule of defects shall be prepared. This schedule shall be agreed by the Contractor and the owner of the structure, or his representative, prior to the start of construction. Existing pipelines, tunnels and services shall be regarded as structures.

During the execution of the Works, defects which have been scheduled shall be inspected and monitored as necessary. Defects which arise during the course of the Works shall be recorded. The Contractor shall keep records of such inspections and a copy shall be available to the Employer's Representative.

Monitoring of settlement, scheduled defects and defects arising during the course of the Works shall continue at agreed intervals for a period of at least 6 months after completion.

5.6.3 Tunnel Excavation Monitoring

The Contractor shall survey, monitor and record tunnel and shaft construction as it proceeds to form a record of the Work. Monitoring shall generally be per unit of advance and include line, level, cross-sectional accuracy, shift advance and total advance.

Where grouting is carried out, the type, volume and pressure of grout shall be recorded, together with the grout hole location inclination & depth.

All information recorded by the Contractor shall be provided to the Employer's Representative on a daily basis unless another interval has been agreed.

3-dimensional deformations of the tunnel lining shall be monitored by means of optical methods. The points to be observed are marked by targets or reflectors mounted on standard convergence bolts.

Where the Contractor considers that any corrective action he may take will exceed the tolerances in the Contract, he shall so inform the Employer's Representative and obtains his agreement. Measurements shall be carried out by free station method with the help of highly precise Total station (Min angular accuracy 1" and dist accuracy 1mm+1.5ppm, R500) as laid down in Clause 5.6.2. The flow of data shall be fully automatic. The software shall allow determination of displacements in an absolute coordinate system with an accuracy of ± 1.0 mm.

The Contractor shall determine the elevation of tunnel crown or any other point as directed by the Employer's Representative during tunnel excavation to monitor vertical settlements and bottom heaves and to be able to interpret and figure the absolute amount of displacements together with convergency readings out. Pins or bolts shall comply with Clause 5.7.2. The method of performing the level measurements shall be such as to ensure an accuracy of ±1 mm.

Necessary conclusions shall be drawn from the geotechnical measurements, from their magnitude, alterations and tendencies about stability of the primary lining and surrounding rock, performance of the initial support applied and utilization of the supporting elements.

The locations and spacing between geotechnical measurement sections depends on geological conditions, frequency of geological alterations, rock mechanical behavior, length of tunnels, primary stress conditions and size of tunnels. The location of designed measurement sections shall be modified during tunnelling according to the local geological conditions and the experience gained during tunnel driving and as required and approved by the Employer's Representative.

The strata exposed in the tunnel face shall be mapped and recorded where possible, and the nature of the excavated material shall be noted in all cases. The Clause 5.4 applies accordingly. The Contractor shall keep copies of all recent face records at the workface for the information of supervisory personnel.

All significant groundwater ingress shall be recorded and monitored.

All atmospheric testing shall be recorded and monitoring for all gases carried out in compliance with Clause 5.5.3.

5.6.4 Daily Review Meeting

The monitoring instrumentation shall be read on a regular basis – as per drawings and monitoring plan – and the results shall be made available for a daily review meeting (DRM) attended by the senior members of the Contractor's and the Employer's Representative's staff. Input into the meeting shall also include current geotechnical investigations, face logs and any recent non-conformance reports relating to the tunnel construction.

This DRM shall be held daily during the excavation of the tunnels at the site unless otherwise agreed by the Contractor and the Employer's Representative.

The minimum team attending the meeting shall include the following persons:

- Monitoring Contractor's Representative
- Monitoring Employer's Representative
- Contractor's Representative
- Employer's Representative

At the meeting the Contractor shall present the current results of all monitoring equipment of the tunnels and adjacent structures respectively together with trends in these results and comparison with the deformations predicted by the calculations. Additionally the Contractor shall present the installed support measures and results from the geological mapping including information as defined in Clause 5.4.

The purpose of the daily review meeting is to assess the behavior of the ground in order to:

- Confirm the design assumptions
- Confirm that the construction methods are appropriate for the ground conditions
- Provide early warning of potentially unpredicted behavior determine the likely cause of adverse behavior
- Confirm the safety of the applied construction method

The outcome of the meeting shall be a report, the Required Excavation and Support Sheet (RESS) as per Clause 5.6.4.2, agreed by the Contractor and the Employer's Representative, which states that tunnelling may continue as proposed, or gives the requirements for modifications to the tunnelling (e.g. support measures, shorter advances, smaller headings etc.).

The Contractor shall keep minutes and records of the monitoring meetings. The minutes of the construction monitoring meetings shall be signed by the attendees. Monitoring results shall be attached to the minutes and recorded on site. All records from these meetings including face logging and monitoring results shall be kept and be available for inspection until the termination of the Contract.

5.6.4.1 Key Performance Indicators

A key performance indicator (KPI) system shall be developed for monitoring movements so that actions can be taken in a timely manner, thereby ensuring that damage to existing structures and subsurface infrastructure is within calculated predictions.

The KPIs to be used to guide construction shall relate to specific monitoring activities as follows:

- in-tunnel convergence monitoring
- ground movement monitoring
- monitoring of adjacent and overlying structures
- geological mapping

The KPI values specified in the design documentation shall be used to indicate whether there is cause for concern during tunnel construction or not. To ensure that the response is appropriate for any specific concern, certain procedures shall be implemented when a KPI is exceeded. These are summarized below.

- A full review of the lining performance shall be conducted for the relevant tunnel section and checked against the KPI values. This includes checks on the ground/soil conditions, the quality of construction and the monitoring results provided by the Contractor.
- A comprehensive review of the trends for monitoring data specific to the area of concern shall be carried out by the Contractor and the Employer's Representative.
- The Contractor shall assess the extent to which the deformations comply with the primary support serviceability and extreme limit conditions.
- Together with the Employer's Representative, the Contractor shall decide whether changes in the excavation and support system are required. This is an interactive process that will determine whether it is safe to proceed with construction or if there is reasonable cause for concern, the extent to which it is necessary to implement additional measures or emergency procedures. These measures will be included in a new RESS.

- The Contractor and Employer's Representative shall implement the Action Plan, the emergency response to implement contingency measures. If there is reasonable cause for concern, it is emphasized that the response must be rapid.
- The performance of the tunnel is kept under continuous review until the monitoring data indicate that KPI trends show a stable condition.

5.6.4.2 Required Excavation and Support Sheet (RESS)

Based on the design and the evaluation of the results of monitoring, a RESS will be issued as the outcome of the Daily Review Meeting (DRM) as per Clause 5.6.4. In the absence of any approved changes, the RESS will reflect exactly what is shown on the relevant design drawings.

The RESS shall be prepared and endorsed by the Contractor's Site Manager, Who is responsible for the tunnelling works, the designer and the Employer's Representative on site. Unless all the three signatures are obtained, the proposals indicated on the RESS shall not be implemented.

The RESS shall address, but not necessary be limited to, the following matters:

The tunnel section (chainages) to which the RESS is applicable

- the support to be installed the excavation sequence
- the method of working related to ground support including staging of application of sprayed-concrete layers and lapping of reinforcement
- monitoring to be installed in the tunnel section in question measures to be taken during stoppage of works
- other instructions relevant to the tunnel section in question reference to relevant design drawings
- ground conditioning

A copy of the RESS will be given to the foreman in charge of the work in the tunnel and shall be kept at the working face.

A RESS is required for every advance per round of the tunnel excavation.

If, for any reason, the approved design method of working is changed, then this will be reviewed prior to the DRM and, subject to acceptance by the Employer's Representative, a new RESS will be issued.

5.6.4.3 Contingency Measures and Emergency Procedures

The Contractor shall determine contingency measures to deal with potential hazards that may affect the Works. The Contractor shall submit for approval to the Employer's Representative an Action Plan which shall detail the actions, procedures and contingency measures to be followed in the event that the monitoring system shows unacceptable levels of deformation/movement if potential hazards occur.

Hazards to be addressed include:

- changing ground conditions
- excessive movement of the linings

- excessive ground movement
- excessive settlement of the existing structures
- unplanned stoppages
- mechanical excavation plant failure
- insufficient labour resources
- Failure of services to underground works (air, light, power, etc.)
- Incidents within underground works
- delay in supply of sprayed concrete

In underground construction works, changes tend to be progressive with evidence of structure or ground behavior becoming apparent before failure occurs. For this situation a system of hierarchical trigger levels will be appropriate. This allows proportionate response to adverse indications from monitoring.

Trigger levels will be based on the results of assessments of at-risk infrastructure. If the assessment indicates that the at-risk infrastructure is unlikely to be able to tolerate the change due to the Works, then triggers will be set based on the levels of change that will be tolerable.

There may be some situations where change is less progressive and monitoring may simply be required to give a yes/no response. In these cases reporting is simple and systems of triggers are not appropriate.

5.6.4.4 Probing Ahead

Where required the Contractor shall be responsible for probing ahead of the tunnel face in order to prove or investigate the ground. The selection of plant for probing shall be agreed with the Employer's Representative and shall take the probable nature of the ground ahead and its water-bearing capacity into account. Probing shall be carried out in such way to allow modification of the excavation and support according to the encountered ground conditions. The number of probes, the diameter of drilling, their positions in the face and angles with respect to the tunnel drive shall be governed by the actual ground conditions and the machinery in use. The maximum probed distance ahead of the face shall be governed by the ground conditions and the degree of uncertainty with distance. The diameter of probe holes shall be not less than 38 mm. The used flush shall be suitable for the type of ground conditions anticipated and the machinery in use. An accurate and systematic record of probe hole positions (positions in the face and angles with respect to tunnel drives), drill penetration rate, drill parameters (percussion, torque, thrust), flush (colour, percentage return), drilling sounds (loud, quiet, intermittent), water strikes and interpretation of the nature of the ground ahead shall be noted at the time the holes are bored and a copy provided to the Employer's Representative. Full facilities shall be provided for the Employer's Representative to inspect probing work in progress.

5.7 Primary Support Measures

5.7.1 General

Generally the primary support measures are installed immediately after the performed blasting round and a break of work prior to support construction is not permitted. The type and amount of tunnel support is directly related to the Behaviour type (BT) as established based on ground

condition. The primary support system and excavation sequence initial support associated with different behaviour types is shown on the Employer's design drawings. The Contractor may design his own tunnel support. However, as a consequence of variations from the anticipated rock conditions the support systems as shown on the Contractor's design drawings for each Excavation Class may require modifications and adjustment during construction as directed by the Employer's Representative.

The Contractor shall ensure that support elements will be installed or applied in such a manner and sequence as to prevent disintegration and loosening of the rock mass surrounding the excavated tunnel.

Comprehensive records, containing all particulars of the tunnel support actually installed and its performance in the course of the works shall be prepared and maintained by the Contractor and made available to the Employer's Representative on a daily basis. These records shall include type, quantity and location of installed support elements, the clearance profile after installation of support, deviations from the designed support systems, observations of excessive deformations, sprayed concrete cracking, etc. Observations of excessive deformations, sprayed concrete cracking, etc. shall be reported immediately to the Employer's Representative.

The Contractor shall keep a record of the chainage of each face position and shall keep this record updated as the face progresses. This record shall be available for consultation at any time at a convenient location close to the relevant face.

The Contractor shall record the results of all tests performed on the rock bolts prior to, during and after their installation, and submit these documents to the Employer's Representative.

The records as defined above in this Technical Specification will be submitted daily to the Employer's Representative for review and approval. The Contractor has to check the rock mass support measures by on-going visual inspection. Surfaces of water sensitive rock mass shall be sealed immediately with adequate measures. The Contractor shall apply sprayed concrete on rock masses which tend to local overbreak immediately.

Structural support consisting of wood is only permitted temporarily. It is not permitted to leave wooden support in the sprayed concrete or concrete layer.

Damaged rock mass support system due to re-profiling shall be reconstructed subsequently (see also 5.8).

The Contractor has to provide an adequate amount of rock mass support systems and required equipment on the site; hence no delays of excavation shall occur. Prior to the beginning of excavation the required rock supports shall be provided by the Contractor on the site.

Blasting round lengths, time schedules, construction sequences, quantity and location of installed support elements shall be constructed as per drawings. Deviations from the designed support systems shall be reported immediately to the Employer's Representative and shall be approved.

The Contractor shall in case of emergency be obliged to undertake independently such support measures as he deems necessary without the prior consent of the Employer's Representative. In such cases the Contractor shall inform the Employer's Representative immediately.

Rock mass support is defined as follows:

- Primary support: is defined as the support which is installed systematically within the heading, bench and invert zone in order to ensure the short term integrity of the underground excavation and safety of personnel during excavation. The installation of primary support is an essential element of the excavation cycle.
- Final lining: is defined as support which is installed subsequent to the primary and supplementary support and which does not form part of the normal excavation cycle. It serves as the permanent lining of the tunnel and shall be a cast in situ concrete lining plain or reinforced according to structural requirements.

The final lining may be installed in any section of the tunnel, with the Employer's Representative's approval, at any time after convergence measurements show that movement in the rock in the immediate vicinity has stabilised.

5.7.2 Rock Bolts

5.7.2.1 General

Unless otherwise defined herein, rock bolts shall comply with the following Indian Standards or their equivalent International Standards:

- IS: 1786:2008 Specifications for high strength deformed-steel bars and wires for concrete reinforcement
- IS: 2062 Steel for general structural purposes

Rock bolts are untensioned steel bars threaded at one end and provided with a face plate, shim plates and a conical seated washer and nut or split or deformed steel tubes. Steel bars shall be grade 500 N/mm², high strength deformed bars complying with IS 1786.. Threaded parts of bars, nuts and seatings shall comply with the requirements of IS 1364. Face plates shall be of a dish shape in steel to the appropriate standard and shall have a hemispherical seating with centralised slot to suit dimensions of the rock dowels.

Where required, the bar and components shall have corrosion protection and the threaded end shall be sealed by an end cap.

Rock bolts shall be installed according to the length, direction, placement and number as per approved design drawings for each relevant Excavation Class unless otherwise determined by the Employer's Representative. Rock bolt length, direction, placement and number shall be adjusted to the Ground Type.

Comprehensive records about details of the installation of rock bolts during drives, such as reference number, grout consistency, drilling depth, length, inclination and type of rock bolts, deviations from the theoretical position, type and time of grouting, time of tightening, special

observations, details of tests carried out, geological ground condition, etc. shall be kept for each rock bolt and round by the Contractor and countersigned by the Employer's supervisory personnel. Copies of these records should be submitted to the Employer's Representative.

The trademark of rock bolts and anchors to be installed shall be approved by the Employer's Representative. A quality assessment is required, unless common anchor steel and anchor plates were used. The Contractor's construction execution shall comply with the manufacturer's specifications and recommendations regarding drilling, installing, testing and maintenance of rock bolts.

The characteristic bearing capacity of the anchor plate and the connection between the anchor and anchor plate shall be equal to the characteristic bearing capacity (P_{tk} according to BS EN 1537) of the anchor steel.

The diameter of the drillings and the drilling technique shall be adjusted to the anchor type and Ground Type. Holes for the installation of bolts shall be drilled straight and with an accuracy of ±10°.

The drilling hole shall be flushed and cleaned with compressed air or water immediately prior to the installation of the bolt. The used technique shall be adjusted on the Ground Type (e.g. for bore holes drilled in swelling ground no water flushing is permitted).

The water pressure during drilling may have an inadequate impact on the surrounding ground (e.g. decrease of mechanical strength properties) due to this the water pressure may be reduced or dry drilling may be conducted as directed by the Employer's Representative.

Unless instructed otherwise, rock bolts shall be installed and tightened prior to the excavation of the next bench or round excavation. The tension force shall be determined by the Employer's Representative after completion of the initial testing program.

The Contractor shall provide torque wrenches of a type acceptable to Employer's Representative. All impact and torque wrenches shall be calibrated once every month.

5.7.2.2 Bearing Plates

Rock bolts shall have face plates which shall be of a dish shape in steel to the appropriate standard and shall have a hemispherical seating with centralized slot to suit the dimensions of the rock bolts.

Bearing plates shall be flat or dished steel plate of minimum dimensions of 150 x150 x 10 mm conforming to IS: 2062, or as otherwise recommended by the manufacturer and approved by the Employer's Representative. Beveled or hemispherical washers shall be used and nuts shall be heavy hexagonal type. For rock bolts that are permanently exposed, the bearing plates shall be coated before installation with an anti-corrosion protective coating compound. Any defects in the coating shall be adequately recoated after installation. The outer ends of the rock bolts, nuts and washers shall also be coated with anti-corrosion compound after installation and tensioning. The remaining portions of all rock bolts shall be clean and free of all deleterious materials.

Anchor plates, directed by the Employer's Representative to be checked, shall be held free until the check for the section is completed.

5.7.2.3 Grouted Bolts

5.7.2.3.1 Specifications

Grouted rock bolts (SN-bolts) shall consist of deformed reinforcing steel bars with a corrugated surface and one end shall be fitted with a suitable thread which is to receive an anchor plate and a fixing nut.

High quality cement shall be used for the grouting. The anchor shall reach 40 % of the characteristic bearing capacity (=Pt_k according to BS EN 1537) after 6 hours and 100 % of the characteristic bearing capacity after 12 hours.

Bolts shall have a minimum load capacity as defined in the design drawings. The load capacity shall also apply to the thread, nut, anchor plate and coupling, if any.

Washers and nuts shall allow the secure transfer from the anchor force to the anchor plate.

Where required, the bar and components shall have corrosion protection and the threaded end shall be sealed by an end cap.

5.7.2.3.2 Installation

Boreholes for all rock bolts shall be drilled to the depths as required by the lengths of rock bolts specified for the respective Excavation Class and at diameters which ensure best workability for grouting, coupling and installation. The minimum diameter of the boreholes shall be 10 mm larger than the diameter of the installed rock bolts/couplings. Holes shall be drilled to produce straight holes of the required length and with an accuracy of ±10°.

The boreholes shall be cleaned out by flushing with compressed air or with clean water to remove all drill cuttings, sludge and debris prior to fixing the rock bolt. The amount of water flushing shall be kept to an absolute minimum. The installation of rock bolts shall follow the drilling and preparation of the borehole within 3 hours.

Prior to the installation of the rock bolt, the entire borehole shall be completely filled with grout. This shall be done by filling the drilled hole from the bottom of the hole and withdrawing the grout hose slowly, always maintaining the hose embedded in the grout. A regular surface shall be provided to seat the face plate by trimming rock surfaces or forming pads of quick-setting mortar. Where mortar pads are required they shall be of adequate thickness and extend beyond the face plate by 25 mm all round at that thickness before being chamfered at 45°. Care shall be taken to ensure that the mortar does not interfere with the installed bolt.

The bolts are inserted in the drilling hole after filling with cement grout and therefore fully bonded with the surrounding rock. The outer end shall be fitted with a suitable thread to receive an anchor plate, a washer and a fixing nut to allow the secure transfer of the anchor force to

the anchor plate. The anchor plate is fixed on the bearing surface within 2 rounds behind the face or at least 6 hours with the anchor nut to achieve an approximate force of 20kN. This force shall be applied by a calibrated torque wrench.

In case of confined working space and/or great length of rock bolts, coupling shall be permitted. The number of coupled parts shall be kept to a minimum. However, the load capacity of such coupled rock bolts shall not be less than that of a standard integral rock bolt. Special attention shall be paid to the grouting procedure in order to ensure full embedment of the bolt by grout.

5.7.2.4 Frictional Bolts

5.7.2.4.1 Specifications

Frictional bolts (e.g. Swellex or similar) are mechanically folded steel tubes with immediate bearing capacity after installation in the pre-drilled borehole as high water pressure (~300 bar) inflate the tube and adapt its shape to the irregularities of the borehole (split set bolt, expandable bolt or similar).

Steel anchor plates with a minimum size of 150x150 mm (thickness as required) allow the transfer of the anchor force at the anchor head to the sprayed concrete or rock surface. The frictional bolts shall have a minimum breaking load of 150 kN or higher as defined in the design drawings.

5.7.2.4.2 Installation

Boreholes for the rock bolts shall be drilled to the depths as required. The boreholes shall be cleaned of all drill cuttings, sludge and debris.

The installation of rock bolts shall be done not later than two hours after drilling of the borehole.

For inflation of bolts, equipment as recommended by the manufacturer of the bolts shall be used. After applying the water pressure, the water shall be drained into the excavation.

5.7.2.5 Self-Drilling Bolts

Self-drilling bolts are a combined system of a rock bolt and a drill rod; the rockbolt act also as a drill rod

The system enables the installation of rock bolts in case of collapsing boreholes. Grouting of the bolt is conducted through the internal grouting canal of rock bolt.

The installation of self-drilling bolts shall be in accordance to the manufacturer’s instructions and requirements.

5.7.2.5.1 Grout

Grout constituents shall comply with Clause 5.7.9.4 and Clause 6.4 of this Specification. Cementations grouting material shall be injected through the hollow part of SDA bolt starting from the furthest point, grout . Grout shall not be used after a period equivalent to its initial setting time.

5.7.3 Sprayed Concrete

Sprayed Concrete shall be mixed, charged, applied, cured and tested according to given Specifications which are based on “Guideline for Sprayed Concrete”, Austrian Society for Concrete- and Construction Technology, 2013, Austria..

5.7.3.1 General

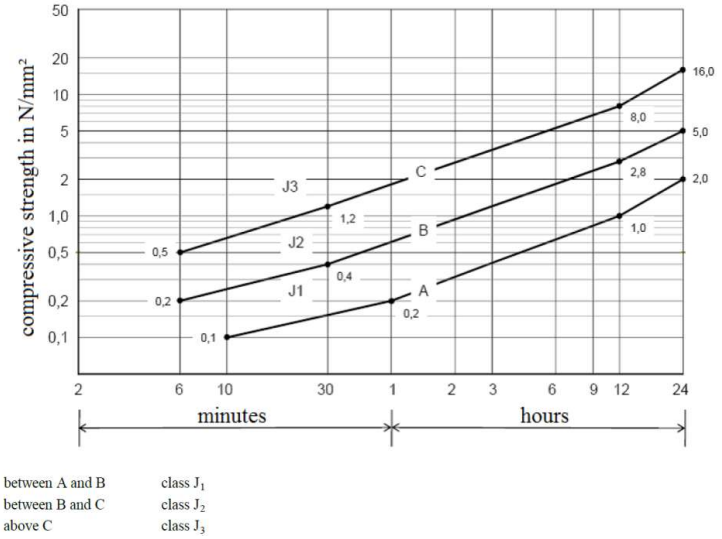
70 days prior to any sprayed concrete application the Contractor shall submit detailed description of sprayed concrete to the Employer’s Representative for review and approval such as:

- Number and type of equipment used for mixing, batching and applying sprayed concrete
- Manufacturer's certificates detailing any proposed admixture, inter alia, accelerator admixture and the Contractor's proposals for the use of such admixtures
- Mix design

The Contractor shall, 45 days prior to commencement of the actual work of spraying concrete or as otherwise approved, submit results of preconstruction tests of sprayed concrete with the actual materials, inclusive of admixtures, mixed in the proportions proposed for the Works for approval. The Contractor shall make available testing, production and application records daily to the Employer’s Representative when concrete is applied. The application records shall contain information on when, where and how much sprayed concrete was applied in each operation. The sprayed concrete shall comply with the BS EN 14487-1 Sprayed concrete, except as noted otherwise below. The requirements listed below generally refer to high-quality temporary or permanent sprayed concrete.

This specification is primarily for the use of wet-mix sprayed concrete but in certain circumstances dry-mix sprayed concrete may be suitable. Sprayed concrete shall be applied by either the wet or dry process as appropriate to the circumstances. All aspects of the application of sprayed concrete shall be subject to the agreement of the Employer’s Representative. Particular emphasis shall be placed on the provision of adequate ventilation.

The compressive strength of sprayed concrete in-situ (taken from the tunnel lining or from panels sprayed in the tunnel) shall develop progressively to a final strength according to the minimum requirements specified as per the J2 class shown in the Figure 5.2 below [As per Austrian Guidelines]. Uniaxial compressive strength tests shall be done in accordance with the provisions stipulated in Clause 5.7.10.5. The strength development due to suitability tests must exceed the specified in-situ strength by a factor of 1/0.85 (=1.18) .The sprayed concrete mix design shall, unless otherwise stated, comply with the characteristic strengths specified by the detailed design for early-age and long-term loading. The 28-day-strength (cube) of sprayed concrete shall be minimum 25 N/mm². The strength development of sprayed concrete shall be such to meet 2 N/mm2 after 4 hours.



between A and B class J_1
between B and C class J_2
above C class J_3

Figure 5.2 : Early strength development of sprayed concrete

5.7.3.2 Mixing

The Contractor shall develop a sprayed concrete mix and a plan for its production and application. Constituent materials shall comply with those listed within this Section.

The mix for sprayed concrete shall be designed by laboratory tests and field trials as indicated in Clause 5.7.10.5 of this Specification to meet the requirements for strength development and final strength.

Batching and mixing shall be carried out by equipment capable of properly mixing materials in sufficient quantity to maintain the continuous application of sprayed concrete and to the accuracy defined in BS EN 14487-2.

All measuring equipment shall be maintained in a clean serviceable condition and shall be zeroed daily and calibrated once in a month.

If required according to the support category additional fibres shall be at a stage in the mixing suitable for the sprayed concreting equipment. Fibres shall be added and mixed in a manner to avoid clumping and bending of fibres. Any fibre clumps in the mix shall be diverted and removed by means of a screen placed over the sprayed concrete hopper. Fibres shall be uniformly distributed throughout the mortar matrix without isolated concentrations.

5.7.3.3 Aggregates

Aggregates for sprayed concrete shall comply with BS EN 12620 and the Section 6.4 of this Specification.

The aggregates shall be clean, strong, durable, suitably graded and shall not contain detrimental amounts of dust, mud, clay or organic impurities. The aggregate shall be checked for chemical reactions, such as alkali-aggregate reaction, with latent hydraulic binders and admixtures, especially accelerators.

The grading and moisture content of the individual fractions of the aggregate shall be checked and recorded daily. The total chloride content shall not exceed 0.35 %. The coarse aggregates shall not contain a large quantity of long stone pieces. The maximum size of the aggregates shall not exceed 16 mm for the dry-mix process and 12 mm for the wet-mix process unless otherwise agreed with the Employer's Representative. The grading shall lie within the grading range in compliance with the Austrian Guideline on Sprayed Concrete given in Table 5.3 below.

Table 5.3: Range of the grain size distribution for grain sizes 0/8 and 8/11

Maximum grain size [mm]	passing the screen in [m%]
11	95-100
8	85-95
4	65-75
2	45-55
1	30-40
0,5	18-25
0,25	8-12
0,063	2-6

Frozen aggregates shall not be used. Minimum temperature of the aggregates shall be 5° Celsius.

During rainy and cold weather periods the aggregates shall be stored under cover for at least 48 hours before being used, in order to reduce the water content.

5.7.3.4 Admixtures

Admixtures may be used in sprayed concrete. Admixtures shall be compatible with each other and the mix. Details of the mix design and technical data demonstrating compliance with BS EN 206-1 and BS 8500 shall be submitted to the Employer's Representative for approval.

Accelerating admixtures shall be compatible with the cement used. The compatibility shall be tested in the laboratory and in field trials to achieve the required properties for setting and strength development as specified in Clause 5.7.10.5 of this Specification.

Admixtures shall be free of chlorides such that the percentage of chlorides shall not exceed 0.1% by weight.

The required characteristic values and consistency of delivery to the site shall be agreed in writing with the manufacturer of each admixture before commencement of concrete spraying. Storage conditions and usage of admixtures shall comply with the manufacturer's recommendations.

Written confirmation of the stability of admixtures with the mix water shall be provided prior to commencement of site trials.

The content of SO_3 shall not exceed 4.8% by weight of total binder content.

Only liquid alkali-free accelerators (pH value between 3.0 and 8.0 and having alkali content less than 1% by weight Na_2O equivalent) shall be used unless pre-bagged dry mix is used where powdered accelerator has already been mixed in. Only the minimum quantity of accelerator necessary shall be permitted in normal concrete spraying operations. At no stage in the strength development should the strength of the accelerated mix drop below 0.7 times the strength of the unaccelerated concrete mix. The dosage rate to be used is evaluated following the suitability tests carried out in compliance with the characteristic compressive strength requirements of Clause 5.7.10.5 of this Specification. Compliance with this Clause shall be demonstrated by site trials. Any addition to this dosage rate shall not exceed 1% of the cement content of the mix design by weight. The dosage rate may be reduced if required for down hand and vertical spraying positions. Automatically device shall be used to add the accelerating admixture. Actual dosage shall be decided by laboratory tests. At least one set of tests shall be performed each month.

Testing of accelerators and the base mix with respect to acceleration of setting, early strength and decrease of strength at a later age (28 days), shall take place in due time before commencement of concrete spraying.

Setting time of the Portland cement and accelerator shall be determined in accordance with BS EN 196-1 and 196-3. The results should be:

- initial set <3 min
- final set <10 min

Additives for the improvement of performance, workability etc. may be added with the approval of the Employer's Representative.

Additives intended to be used shall be included in the tests as described in Clause 5.7.10.5 of this Specification. Accelerating admixtures shall be used to meet the requirements for setting and strength development of sprayed concrete applied in-situ. Laboratory testing of the selected type(s) of accelerator shall be carried out at dosages as recommended by the manufacturer, to establish the variability of the above properties with dosage. Accelerators showing excessive variability with dosage will not be permitted. Accelerators delivered to site shall be tested at least once every two months for their reaction with the Portland cement used, with particular reference to the setting behavior and strength decrease after 28 days. The stability of accelerators during storage shall be visually inspected at similar intervals. Storage times and working temperature ranges shall be in accordance with the manufacturer's recommendations. The manufacturer's safety instructions shall be observed.

Plasticisers and retarders complying with BS EN 934-2 may be used to reduce the quantity of the mixing water and to improve the pumpability of the concrete. The effects and optimum dosages of plasticisers and retarders shall be determined by site trials.

The influence of the plasticisers and retarders within the concrete mix shall be checked regularly for setting time, water reduction and development of strength. These values shall be compared with the results from the pre-commencement trials.

Compatibility of plasticisers and retarders with Portland cements, latent hydraulic binders and accelerators shall be verified by observation and site trials.

Hydration control admixtures may be used to control the hydration of the mix as appropriate to expedite construction of the Works. The effects and optimum dosages of hydration control admixtures shall be determined by site trials.

Compatibility of hydration control admixtures with Portland cements, latent hydraulic binders and accelerators shall be verified by observation and site trials. Hydration control admixtures shall be used in accordance with the manufacturer's instructions.

Dosing of admixtures by hand shall not be permitted.

5.7.3.5 Cement & Additions

Portland cement shall conform to the requirements of BS EN 197-1 or National Standards and must be suitable for sprayed concrete application. The cement content shall be designed to meet the strength requirements of sprayed concrete applied in the field. As a minimum, Portland cement shall be CEM I, strength class 42.5; class N and R are both appropriate. The Portland cement fineness shall not be less than 350m^2/kg and C3A content not less than 5%. The minimum Portland cement content shall be 360kg/m^3. The minimum total binder content shall be 400 kg/m^3. In order to determine a suitable dosage rate of accelerating admixtures, suitability tests shall be carried out

Table 5.4: Maximum level of additions (in percentage of binder)

Cementitous Material	Maximum Addition
Silica fume (solids)	15% of Portland cement
Pulverised fuel ash	30% of Portland cement
GGBS	30% of Portland cement

Pulverised fuel ash and ground granulated blast furnace slag shall conform to BS EN 450-1 and BS EN 15167 respectively and may also be included in the mix provided.

Silica fume shall be in the form of water slurry and shall comply with BS EN 13263- 1.

Silica fume (microsilica) shall comply with the following requirements:

- The content of SiO_2 by weight of dry mass shall be not less than 85%.
- The silica fume shall not contain more than 0.4% elemental silica (by weight of dry mass) or any deleterious materials such as quartz, rust and/or cellulose fibres.
- The specific surface area shall not be less than 15000 m^2/kg.
- The carbon content shall not exceed 2% and the total alkali content as Na_2O equivalent shall not exceed 2%.
- SO_3 content (by weight of dry mass) shall be less than 2%.
- pH value shall be between 5.5 and 1.0.

- The viscosity shall be 20 seconds with a 4 mm viscosity cup in accordance with British Board of Agreement Certificate 85/1568 and the relative density shall be between 1.3 and 1.4.
- The activity index shall be at least 100% after 28 days.

Testing to establish compliance with items above shall be carried out on a monthly basis.

Silica fume shall be regularly agitated by circulation pumps prior to use.

The compatibility of silica fume and liquid admixtures shall be established by carrying out appropriate accelerated testing procedures agreed with the Employer's Representative.

The optimum content of silica fume shall be determined during site trials.

5.7.3.6 Water

Water shall comply with the Clause 6.4 in this Specification.

For the dry-mix sprayed concrete, the water content shall be controlled by the nozzleman to suit the conditions of the shotcreting surface and location of application. An indication that the water/cement ratio is in the correct range will be, that the sprayed concrete will seem to have a slightly shining appearance immediately following application.

For the wet-mix sprayed concrete, field trials shall be carried out to determine and establish the suitable water/cement ratio.

Due to aggressive mountain water, admixtures shall be defined in agreement with Employer's Representative.

The water/cement ratio range for permanent sprayed concrete shall be not more than 0.50.

5.7.3.7 Application

5.7.3.7.1 General

Details of all equipment to be used shall be made available to the Employer's Representative prior to commencement of site trials. The sprayed concrete nozzle and ancillary equipment shall be of an adequate capacity for the volumes to be applied.

The equipment selected and approved by the Employer's Representative will be capable of maintaining the ratio of concrete and accelerator as selected from the trials and approved by the Employer's Representative. The actual ratio of accelerator to selected concrete shall be identified at the nozzle, and take into account the filling efficiency of the equipment and the efficiency of the accelerator dosage equipment to overcome the air and concrete pressure at the nozzle while spraying at typical outputs and air flows.

Equipment shall be thoroughly cleaned at least once per shift. The spray nozzle shall be checked for wear and where necessary replaced. Transport pipes consisting of hoses and pipes shall be designed to convey the concrete efficiently and without leakage or blockage. The transport pipes shall have uniform diameter appropriate to the mix characteristics determined by site trials and be free of any dents or kinks between the sprayed concrete machine and the nozzle.

Working area for sprayed concreting shall be well illuminated and ventilated. Dust pollution shall be minimized by choice of appropriate equipment and by means of additional ventilation, water sprays and by maintaining equipment in good order. Protective clothing and dust masks shall be provided for and used by all persons present during spraying.

The equipment shall allow for air and water in any combination to be available for preparation of surfaces and/or cleaning of finished work.

The Contractor shall enable the Employer's Representative access to the sprayed concrete Works at all times, and shall allow the Employer's Representative access to inspect the excavated ground surface prior to spraying if requested.

5.7.3.7.2 Proficiency of Nozzlemen

Nozzlemen shall hold relevant certificates of competence issued by the Contractor or written evidence of previous satisfactory work indicating compliance with EFNARC Nozzleman Certification Scheme, ACI 506R-03 (USA) or similar National Standards to the approval of the Employer's Representative. Each crew shall demonstrate acceptable proficiency in the application of sprayed concrete to trial areas before being employed on the Works to the agreement of the Employer's Representative.

Subject to the Employer's Representative's agreement, tests for proficiency may be combined with trial mix tests.

Tests for proficiency shall use the equipment selected for use in the Works where practicable.

5.7.3.7.3 Applying

Rock or previously applied sprayed concrete surfaces to be sprayed shall be carefully cleaned of all loose material, scale and other contaminations. It may be necessary to use compressed air and a water jet.

Where groundwater flow could interfere with the application of sprayed concrete or cause reduction in the quality of sprayed concrete, the Contractor shall take all action necessary to control groundwater. Such action shall include the channelling of water by means of pipes etc.

In order to prevent the build-up of water pressure behind fresh sprayed concrete, apparent water shall be drained through the concrete, either with appropriate drainage holes or by other approved methods, e.g. by installing a perforated drainpipe or drainage channel covered with filter fabric and extending as approved from the leakage area to the drainage system. Such drains must be secured to the rock surface.

Drainage holes shall be drilled in the sprayed concrete lining where the build-up of water pressure may occur, and where drainage was not installed prior to the placement of sprayed concrete. The diameter and spacing of such holes shall be as directed by the Employer's Representative.

The optimum distance between nozzle and surface of application is 1.0 to 1.3 meter. The nozzle shall be positioned at right angles to the surface of application.

The sprayed concrete shall emerge from the nozzle in a steady uninterrupted flow. Should the flow become intermittent for any cause, the nozzle-man shall direct it away from the work until it becomes constant again.

For vertical and near-vertical surfaces application shall commence at the bottom and the leading edge of the work shall be maintained at a slope. Downward spraying shall be avoided where possible. The nozzle may be inclined sufficiently to ensure reinforcement is properly embedded.

The projected sprayed concrete thickness (d_S) shall be equal to the summation of thicknesses of each sprayed concrete layer. The Contractor shall determine the thickness of the sprayed concrete layers. The maximum sprayed concrete layer thickness is 20 cm, thicker layers shall be constructed with sub-sequences. Subsequent layer(s) must not be applied before the previous layer has developed sufficient strength to support the additional layer(s). These additional layers shall be completed within a period not exceeding three days.

Lattice girder, roof ties, wire mesh and other reinforcement shall be embedded in sprayed concrete as shown on the tunnel design drawings. The minimum cover of wire mesh and re-bars applied at the inner side of a sprayed concrete lining shall be 4.0 cm. Voids behind reinforcement must be avoided.

The sprayed concrete lining shall be constructed in a way that all bolts and anchors are fully covered with sprayed concrete of the primary lining. The surface of the primary lining must be smooth enough for the application of the water proofing system according to the specification of the water proofing system.

If more than one layer of reinforcement is installed, the second layer shall not be positioned before the first one is embedded and covered completely with sprayed concrete.

No rebound shall be covered with sprayed concrete to avoid structural weaknesses in the lining. Rebound shall be removed immediately after finishing of each sprayed concrete application. The rebound shall be removed, in particular at horizontal sprayed concrete connections due to separate excavation sequences and at all construction joints, if necessary by pneumatic hammers, prior to further application of sprayed concrete.

All joints in the sprayed concrete lining shall be as specified in the Design.

The surface to receive sprayed concrete shall be damp but shall not exhibit free water.

The temperature of the mix before placing shall not be below 5°C and shall not exceed 35°C unless special provisions are made. Spraying shall not be undertaken when ambient

temperature is below 5°C unless special measures can be taken to provide protection against frost until the sprayed concrete has developed a compressive strength of at least 5 MPa.

The surface of the sprayed concrete lining can follow the rounded surface of the rock mass including corners and edges. The minimum thickness of the sprayed concrete lining as given in the design drawings must be reached in every point of the lining.

Cracks in the sprayed concrete induced by shear failure shall be removed and a clean connecting face shall be constructed prior to further application of sprayed concrete.

The base mix concrete may be used up to 2 hours after the addition of water to the cement provided that the sprayed concrete can be applied satisfactorily. Any unused material after this time shall be discarded. This period may be extended by the use of hydration control admixtures, subject to the approval of the Employer's Representative.

5.7.4 Reinforcement – Wire Mesh

5.7.4.1 General

The reinforcement for primary support measures shall be in compliance with Clause 6.8 of this Specification.

Cutting of reinforcement for better placing due to edges is permitted; hence additional reinforcement in these sections is required.

Welded wire mesh fabric shall be installed in surface excavations in conjunction with sprayed concrete, as shown on the drawings, or as directed by the Employer's Representative. Chain link fabric may be used for surface applications only if previously approved by the Employer's Representative.

In general steel fibre reinforcement is preferable over wire mesh.

5.7.4.2 Specification

Welded wire mesh fabric shall conform to the requirements of IS: 4948 and shall have a mesh size of 150 x 150 x 6 mm as shown on the drawings, or as required by the Employer's Representative.

The diameter of additional steel bars shall be limited to 14 mm according to Austrian Guideline "Sprayed Concrete". The characteristic yield strength of the welded wire mesh shall be 500 N/mm².

5.7.4.3 Installation

Welded wire fabrics shall be installed in such way so that it follows as close as possible the irregularities of the excavation surface or previous layers of sprayed concrete. It shall be firmly fixed to prevent vibration and change of position during spraying of sprayed concrete. The use of wooden pegs or pins for attaching the wire mesh to the rock surface shall not be permitted.

Welded wire fabrics shall be installed in the longest practical length. The overlap for welded wire fabrics applied in the sprayed concrete lining shall be at least twice the pitch distance in circumferential direction. In longitudinal direction, the overlap shall be at least one pitch distance for the first layer of fabric and at least twice the pitch distance for the second layer of fabric.

A minimum concrete cover at the tunnel side of 4.0 cm of all wire mesh layers shall be provided.

5.7.5 Steel Fibre

Steel fibre shall have an average length of 30mm, Length / diameter ratio of 55 to 65 unless otherwise approved. In this context, the diameter is either that of a circular section or that of a circle with an area equal to the cross sectional area of the fibre.

The content of steel fibres shall be based on the types of fibres used and shall be determined to achieve the required performance criteria as set out in mix design. The minimum fibre content shall be not less than 25kg/ m^3 or as otherwise approved.

5.7.6 Lattice Girder

5.7.6.1 General

Lattice girders shall be installed to maintain the designed shape of the opening and if necessary, provide an immediate support at the working face over the length of the last excavation completed. If necessary, the installation of lattice girders together with other immediate measures shall also prevent ground loss and shall improve load distribution.

5.7.6.2 Specification

Lattice girders consist usually of three primary bars, connected by stiffening elements to the manufacturer's design or as shown on the drawings. They shall be designed so as to:

- facilitate sprayed concrete penetration into and behind the girder, thereby minimising the creation of projection shadows and/or voids
- provide good-quality bonding between the steel and sprayed concrete, to form a composite structure acting as a continuous reinforced concrete lining
- make allowance for the specified tolerances

Stiffening Elements: A minimum of 5% of the total moment of inertia shall be provided by the stiffening elements. This percentage is calculated as an average along the repeatable lengths of the lattice girder. To ensure stability against buckling, the maximum spacing between the stiffening elements shall be less than three times the cross-sectional height of the girder.

Dimensions and tolerances: The lattice girders shall be fabricated to meet minimum clearances and tolerances shown under consideration of accuracy of placement during construction, manufacturing tolerances and of lining deflection following installation. Prior to installation, each girder shall be inspected as specified below and all measurements taken shall be

recorded along with any comments. Any changes in the inspection frequency must be authorized by the Employer's Representative following a review of previous inspection results.

Each girder inspection shall check the following criteria:

- That the girder is fully identified with the girder type and the unique traceability reference.
- That the girder links and sinusoidals are in the correct positions and are adequately welded.
- That the reinforcement and plate types and sizes are as specified on the drawings.

When inspecting weld quality, the following criteria shall be used:

- The reinforcement shall be free from undercut in excess of 1 mm.
- The weld metal deposition shall be even and blend smoothly with the bars.
- The weld metal shall be free from cracks and porosity.

The chord length shall be checked by measuring the distance from the outer edge of the connection plate to the corresponding point on the connection plate at the other end of the girder. The measurement shall be taken to the nearest millimetre.

The chord height shall be checked by placing a tight cord across the centreline of the girder between the outer edges of the end plates then measuring the height from the chord to the inside edge of the lower main bar. The measurement shall be taken to the nearest millimetre. Where the girder consists of a double radius the chord lines shall be taken along the outer edge of the connection plates to the point at which the radius changes.

Lattice girders shall also comply with the following tolerances:

- The erected lattice girders shall not deviate from the design shape and position by more than -0 mm and +50 mm.
- Lattice girders shall be fabricated to include an allowance for 10 mm of convergence.

Fabrication: Each of the primary bars of the lattice girder segment shall be composed of only one piece of high-yield steel (minimum grade 500 N/mm² characteristic yielding strength). Secondary bars are either plain round profile or deformed high yield steel (minimum grade 500 N/mm² characteristic yielding strength).

The connection elements at the end of the girder segments shall be constructed of flat or angle steel to BS EN 10025:2004, grade S275JR. Connections between lattice girder segments shall be bolted as shown on the drawings. Welded connections between segments shall not be permitted. Nuts and bolts supplied are to be grade 8.8 or higher. The connections shall transfer the maximum tension load of the steel bars.

All welding shall be carried out in accordance with BS EN 1011-1:2009.

5.7.6.3 Installation

The single steel bar is situated at the inner side of the excavation profile. The lattice girder is usually separated in five elements. Three elements form the top heading arch and two elements are placed as bench segments. The arch elements are connected with bolts through the head plates which are welded onto the main steel bars. The connection has to ensure safe installation and transfer the loads between the elements of the lattice girder. The lattice girders have to be embedded entirely in sprayed concrete.

A minimum 50 mm thick sprayed concrete layer must be in place before the installation of the lattice girders. Under no circumstance lattice girders shall be installed under unsupported ground.

Lattice girder segments shall be secured by use of steel wedges, concrete spacers, mortar sacks and/or other appropriate means to maintain position during application of sprayed concrete. The means of support shall be subject to the approval of the Employer's Representative. No wood blocking shall be used.

Lattice girders (complete) shall be firmly fixed in their final position against the excavation prior to application of sprayed concrete. Lattice girders shall be sufficiently clear of the final internal profile of the structure to accommodate the required sprayed concrete cover.

Lattice girder segments shall have butt plates and the method of installation shall ensure tight connection of all elements.

Immediately prior to concreting, casting or spraying, the lattice girder shall be rendered clean and free from deleterious matter.

5.7.7 Forepoling

5.7.7.1 General

To support the excavation roof (tunnel crown) forepoling elements are installed if required at the upper part of the tunnel excavation face. Forepoling shall be applied in rock and soil conditions which tend to produce overbreak, collapses or material inflows immediately following excavation. Forepoling shall be applied locally or systematically, as the circumstances require for the safety of the works and for preventing overbreak. The installation of forepoling is usually connected to the erection of a lattice girder. They shall be driven from the supporting frame in a slightly upwardly inclined direction at the crown of the heading and should penetrate at least half a set beyond the next excavation cycle.

Forepoling shall be applied as shown on the approved detail design drawings by the Contractor or as instructed by the Tunnel Designer's Representative and/or the Employer's Representative.

Spacing between consecutive forepoling pipes or bars around the crown of the excavation profile shall not exceed the maximum distance specified on the approved design drawings, and shall be reduced if the actually prevailing geological conditions at the tunnel face require to do so.

Great care shall be taken to prevent the disturbance of face and supports in general during the forepoling cycle.

5.7.8 Lining Stress Controllers (LSC)

5.7.8.1 General

Lining Stress Controllers (LSC) are support elements which are applied in the sprayed concrete lining of rock class VI (squeezing rock conditions) as shown on the respective support drawing. The LSC shall increase the deformability of the sprayed concrete lining in a controlled manner by yielding of the deformation elements and thus prevent damages due to high lining stresses resulting from large rock deformations.

5.7.8.1.1 General Requirements

LSC shall be effective as primary support element in the sprayed concrete lining and act as deformation elements to limit sprayed concrete lining stresses due to large rock deformations.The LSC shall be manufactured to meet the geometrical requirements as shown on the drawings and as instructed by the ENGINEER on site during construction.

The deformation elements used for the LSC will have to be optimised in shape and dimension prior to construction. Adjustments in layout will be made on site by the ENGINEER according to the actual displacements and according to the type of deformation elements used for the LSC.

The LSC are manufactured of steel plates and/or steel tubes and reinforcement bars in compliance with the required geometry as instructed by the ENGINEER. The LSC shall consist of 2 steel plates (top and bottom) for load transmission and connection to the sprayed concrete lining. Top and bottom steel plates are connected by deforming elements.

To achieve satisfactory connection to the sprayed concrete lining, reinforcing steel bars shall be welded to the top and bottom steel plate of the LSC as shown on the drawings.

In case of fabrication on site, the CONTRACTOR shall submit a detailed method statement for approval to the ENGINEER.

The CONTRACTOR shall submit related detailed drawings of the LSC, to be approved by the ENGINEER.

The working line (load vs displacement relation) of the LSC elements shall be either given by the manufacturer or determined through testing. Attention is to be turned to get the full curve which requires considerable displacements when the full element is tested.

5.7.9 Grouting

Grouting operation is defined as follows:

- contact or cavity grouting, to fill voids between final concrete lining and primary sprayed concrete lining, or between the primary lining and rock

- consolidation grouting or strata grouting, of the rock surrounding the excavated space, which shall commence after completion of contact grouting, where applied
- consolidation grouting or strata grouting in the heading zone, in zones of sheared and disturbed material or of high water inflow
- final grouting of temporary drainage holes

5.7.9.1 General

The Contractor shall prepare a detailed grouting Specification to suit best the actual conditions encountered. This grouting specification shall be submitted to the Employer's Representative for approval unless otherwise agreed or directed by the Employer's Representative. The Tunnel Designer's Representative shall specify the maximum pressures to be used for grout injection at each location. The pressures specified are subject to approval by the Employer's Representative.

Records of all details of grouting works such as location, inclination, diameter of boreholes, drilling time, equipment used, results of water pressure tests, mix, quantity, pressure of grouting, development and special events during grouting operation etc. shall be kept by the Contractor, countersigned on site by the Employer's supervising personnel and submitted to the Employer's Representative. Grouting through steel pipes or SDA shall be avoided.

Where necessary due to the nature of the ground conditions or where adverse water conditions are anticipated, the requirements for the use of special grouts shall be stated in the Contract.

Special grouts supplied by proprietary manufacturers may be used subject to agreement with the Employer's Representative.

Preconstruction grout trials shall be undertaken to demonstrate that the required setting times and strength gains will achieved. Details of the trials and results shall be submitted to the Employer's Representative.

Quality control of grout mortar shall be in compliance with Clause 5.7.10.4 of this Specification as directed by the Employer's Representative, water pressure tests shall be carried out.

5.7.9.2 Drilling

Grout holes shall be drilled either with percussion type or rotary type drilling equipment, depending on Ground Type.

The diameter at the bottom of the grout holes shall not be less than 35 mm. For percussion drill holes the diameter of the drilling bit shall be at least 8 mm larger than the diameter of the couplings used for the drill rods.

Only water shall be used for flushing during drilling unless directed otherwise by the Employer's Representative. All holes shall be thoroughly cleaned immediately after drilling using water and/or

air under pressure. After washing, downward holes shall be kept plugged until the commencement of grouting operation.

5.7.9.3 Mixing

All grout mixes shall be prepared using high speed, high shearing action mixers to produce a grout of uniform consistency.

General-purpose cement grout shall be mixed in accordance with the proportions given in Table 5.5. The water content shall be kept to the minimum required to ensure a smooth, fluid mix.

Table 5.5: Mix proportions for cement grout

Class	Proportion by mass		
	Cement	Sand	Pulverised Fuel Ash (PFA)
G1	1	-	-
G2	1	3	-
G3	1	10	-
G4	1	-	10
G5	1	-	4
G6	1	-	0,5

When, prior to pumping, mixed grout is to be stored for short periods, purpose made agitator tanks shall be used. Grout shall be used within 1 hour of mixing.

When clay or bentonite additives are used, separate mixing tanks shall be provided for mixing and agitation.

Grouts containing polymer additives shall only be mixed in a colloidal-type mixer.

Water meters shall be provided for accurate measurement of water used for mixing. Pressure gauges, safety valves, by-pass valves etc. shall be provided where required on mixers, agitators, pumps and injection hoses.

Special grouts from proprietary manufacturers shall be mixed and used in accordance with the manufacturers' instructions.

5.7.9.4 Materials

The following types of grout mixes may be used:

- Neat cement grout, possibly with admixture
- Cement-sand grout, possibly with admixture
- Cement (with silica fume) grout with or without sand
- Micro-cement grout

- Chemical grouts (polyurethane urea silicates and epoxy)

General the constituents of the grout (cement, water, sand and admixtures) shall comply with the requirements given in Clause 6.4 unless specified otherwise hereinafter.

5.7.9.5 Cement

Cement for grouting purposes shall in general be rapid Portland type in accordance to ENV 197.

Micro-cement for grout shall be milled from pure Portland cement clinker and shall have a minimum blaine specific area of 900 m2/kg with 95% of all particles < 10μm and with a maximum particle size of30μm

5.7.9.6 Sand

If sand is required in the grout mix design, it shall comply to the following gradation (Table 5.6).

Table 5.6: Sand gradation used for grout mix

Sieve size in mm	Percentage passing by weight
2.00	100
1.00	90 – 100
0.50	50 – 80
0.25	18 – 48
0.125	7 – 25
0.063	0 – 3

5.7.9.7 Additives

Silica fume for grout shall be micro fine powder with an average particle size less than 0.5 μm. Pulverised fuel ash (PFA) shall not be used as a constituent of grouts which contain sulphate-resistant cement.

5.7.9.8 Admixtures

Only admixtures tested prior to the start of grouting work and approved by the Employer's Representative may be used. The approval and Manufacturer's certificates or guarantees will not be accepted as relieving the Contractor of his responsibility for the suitability of any admixture.

If admixtures or chemicals are proposed for use in grout, the Contractor shall transmit all relevant manufactures certificates (including toxicity, health, safety and environmental certification) to the Employer's Representative for review prior to any grouting measures.

Details of accelerating and retarding agents for proposed inclusion within the grout mix shall be submitted to the Employer's Representative for agreement. Any such proposal shall be submitted in conjunction with a statement which outlines the Contractor's interpretation of ground behavior during tunnel construction.

5.7.9.9 Grouting

All hoses and piping should be of a small diameter to ensure a high velocity flow without segregation.

Grouting operation shall be performed without major interruptions. In case of an interruption before completion of grouting (plant breakdown), the hole shall be washed with clean water.

Grouting in the tunnel shall be performed in a manner that pressures are equally distributed and do not overstress the initial tunnel lining.

In case of any grout communicating between holes, grouting shall be done simultaneously or holes where grout issues shall be plugged.

Grouting is completed, when the required pressure can be kept constant over a period of 10 minutes.

5.7.9.10 Cavity Grouting of In-situ Lining

The Contractor shall grout all cavities, voids and spaces remaining unfilled outside the in-situ concrete lining. Grouting of a section of lining will not be allowed until that section has achieved its design strength.

Procedures for cavity grouting of in-situ lining to tunnels with a waterproof membrane shall be subject to agreement with the Employer's Representative.

Grout for cavity grouting shall be in compliance with this Specification, except where otherwise agreed by the Employer's Representative, who may direct that large voids be filled with other materials. The grout consistency shall be sufficiently fluid, but not more as, to ensure that the grout flows freely under low (<100 kN/m²) pressure into all parts of the space to be filled via grout pipes or grout holes provided for the purpose.

The injection points shall be provided and used for cavity grouting at an average of at least one per 2.5 linear meters of tunnel and more frequently in any areas of excessive over-break. Vent pipes shall be provided extending to the highest points of cavities. The injection points for cavity grouting in arched roofs shall be located within 500 mm of the crown unless otherwise agreed by the Employer's Representative.

The Contractor's proposals for the installation of grout pipes shall be submitted to the Employer's Representative for agreement. Grout pipes and grout holes for cavity grouting shall be at least 40 mm internal diameter.

Grouting shall be carried out by equipment similar to that used for segmental tunnel grouting. Grouting pressures shall be such as not to damage the Works or any other property.

Grout pipes shall not remain within 25 mm of a finished concrete internal surface, and when no longer required all injection holes in concrete linings shall be filled with dry pack mortar to within 25 mm of the finished concrete surface and finally made good.

Control grouting, to verify that voids have been completely filled with grout, shall be carried out where directed by the Employer's Representative.

5.7.9.11 Consolidation or strata grouting

Consolidation grouting of the rock shall be carried out in sections of the Tunnel structures as shown on the drawings or as directed. Additionally, consolidation grouting may be required during the excavation works, in order to consolidate the heading face or seal off inflow of groundwater.

Strata grouting shall start with neat cement grout. Depending on the grout consumption the water/cement ratio may be reduced subsequently. In case of large grout consumption, injections shall be continued with cement mortar grout. Final injections shall be done with neat cement grout again.

Grouting of a hole will be considered as complete when the rate of grout consumption at the maximum grouting pressure is less than an amount set by the Employer's Representative, or otherwise directed.

Upon completion of grouting, the packer shall remain in the hole and the pressure maintained until the grout has attained its initial set.

5.7.10 Testing

5.7.10.1 Rock Bolts

The required bearing capacity of rock bolts is to be ensured by pull out test procedures, in agreement with the Employer's Representative. The pull out tests shall be conducted with a hydraulic press, in appearance of the Employer's Representative. The test results shall be recorded and forwarded to the Employer's Representative for review.

The equipment for pull out test procedures shall be provided and maintained by the Contractor during the whole construction phase.

5.7.10.2 Suitability Test

A detailed suitability test program elaborated by the Contractor set up on basis of BS EN 1537 shall be approved by the Employer‘s Representative prior to all testing work. Deviations from the European Standard shall be approved by the Employer‘s Representative.

Suitability tests in different ground types and with all types of bolts shall be conducted prior to the commencement of tunneling. The tests shall be performed in similar geological ground conditions as expected during tunnel excavation. The location of the bolts to be tested shall be selected by the Employer‘s Representative.

A minimum of five bolts of each type shall be tested. Depending on the testing procedure and the test results the Employer‘s Representative may require further bolts to be tested.

Adequate testing equipment shall be provided to record bolt elongation, movement of the bolts and tension forces.

The bolts shall be installed in the designed manner and the external anchor resistance (R_a according to BS EN 1537) shall be determined. The anchor shall be stressed to the external anchor resistance R_a or to the proof load P_p. The proof load P_p is defined to 0.8 P_{tk} (= characteristic bearing capacity according to BS EN 1537).

For each type of rock bolt information of type, testing equipment, location and installation records, applied testing loads and records of deformation shall be forwarded to the Employer‘s Representative. For failed pull-out tests, the evaluation and interpretation of test results as specified in BS EN 1537 and proposed action shall be submitted to the Employer‘s Representative.

Based on the suitability tests and considering the economical respects the Constructor shall define the rock bolt types in agreement with the Employer‘s Representative.

With specific order of the Employer's Representative rock bolts with a smaller proof load P_p (according to BS EN 1537), due to smaller shaft friction may be installed. The characteristic anchor resistance R_{ak} of the rock bolt is therefore determined with the factor R_a (according to BS EN 1537) based on the suitability tests. Further quality testing is based on the characteristic anchor resistance R_{ak}.

5.7.10.3 Quality tests during tunnel excavation

The Employer‘s Representative will select 5 % of all rock bolts, which shall be tested. The test quantity can be reduced to 3 % of all rock bolts, in case of on-going positive test results and in agreement with the Employer‘s Representative. The Employer‘s Representative may order additional quality tests in case of a high failure rate of the rock bolts with no additional costs for the Employer. The quality tests shall be conducted in attendance of the Employer‘s Representative and only with hydraulic presses. The test results shall be documented and forwarded to the Employer‘s Representative for review.

The bearing capacity of rock bolts shall be ensured by pull out tests. The testing stress is 80 % of the critical strength (= characteristic bearing capacity P_{tk} according to BS EN 1537) of the bolt system.

Bolts which fail the tests or which are pulled out shall be replaced. For each failure, the Employer‘s Representative shall require further bolts to be tested in the vicinity.

5.7.10.4 Grout Mortar

Prior to acceptance tests of rock bolts, tests with available cements and sands shall be carried out to determine an appropriate mix design to achieve the specified strength and a proper workability in association with the grouting equipment used.

Additives may be used to improve workability. The influence of the additive on the strength development shall be followed by tests. The grout mortar shall be tested on cubes 5 x 5 x 5 cm. The cubes shall be cured in water. Five numbers of cubes shall be prepared for each compressive strength test. The resultant strength is the average evaluated from the three remaining values after elimination of the highest and the lowest value.

During construction, cube sample shall be taken weekly from the grouting hose at the nozzle. Preparation and evaluation shall follow the procedure as described above.

5.7.10.5 Sprayed Concrete

The testing procedure and quantity of tests shall be in accordance to “Guideline for Sprayed Concrete”, Austrian Society for Concrete- and Construction Technology, 2013, Austria.

An Employer’s Representative shall be on site at all times to check the consistency of materials and workmanship with the design intent, and to ensure that ground and groundwater conditions are in accordance with design assumptions. The Contractor shall establish a procedure to respond effectively to changes in ground and groundwater conditions from the design assumptions.

The Contractor shall establish and maintain the instrumentation and monitoring required by the design. The Contractor shall establish a procedure that will enable prompt and regular review and effective response to the results from the instrumentation and monitoring. The sprayed concrete lining designer shall be included in the monitoring review procedure.

5.7.10.6 Strength

The compressive strength of sprayed concrete after 28 days shall be in accordance with BS EN 206-1, with minimum concrete strength class M30. According to BS EN 13791 a reduction factor of 0.85 can be applied for cores from in-situ concrete. The early-strength development shall conform to

Figure 5.3 below, unless otherwise specified in the detailed design.

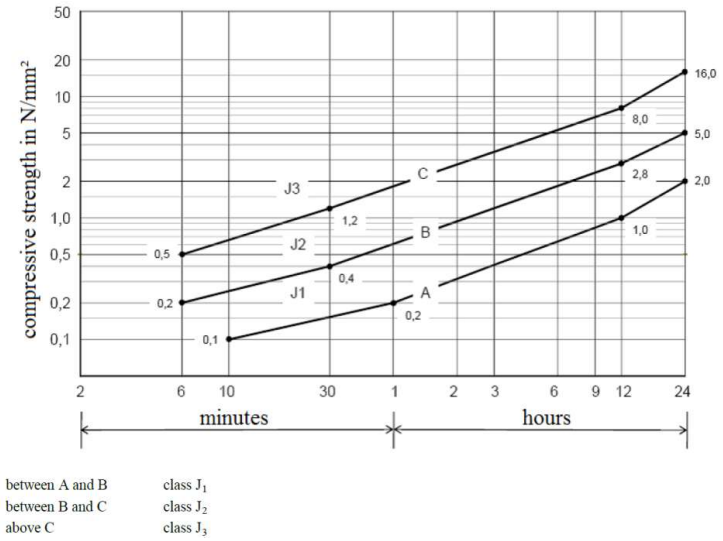


Figure 5.3: Sprayed concrete early strength development for a C25 mix,

The concrete shall not show any decrease in strength with time.

5.7.10.7 Field suitability tests – preconstruction tests

Prior to first application of sprayed concrete mixture in the tunnel the field suitability tests under construction conditions using concrete components intended for executing the construction job shall be performed and approved by the Employer's Representative. Field suitability tests determine the early and final strength of the intended sprayed concrete mixture. If the conditions or the mixture of the sprayed concrete vary to the tested ones, the field suitability test has to be repeated.

The equipment proposed for the application of concrete in the Works shall be used for the trial. The trial will establish whether the selected equipment is capable of efficiently mixing concrete, accelerator and air at the nozzle, and is capable of positioning the nozzle at a suitable distance and orientation to the surface geometry of the structure to which the concrete is to be applied.

For each mix design a trial mix shall be sprayed into test panels (3 Nos. per trial mix). Different dosages of the accelerating admixture shall be tested following the recommendation of the accelerator manufacturer.

If a particular quality of finish is required other than as sprayed, the trials will evaluate the methods and tools to be used to achieve the required finish and the Employer's Representative will approve the method and quality of finish achieved.

The compressive strength development up to 1.2 N/mm^2 shall be determined indirectly by the Penetrometer using a plunger of 3 mm diameter according to ÖNORM B-2203-01 - 2011.

The compressive strength development in the range between 2 and 16 N/mm^2 shall be determined using the bolt-driving method according to ÖNORM B-2203-01 – 2011.

The compressive strength above 10 N/mm^2 shall be determined by crushing of cylindrical sprayed concrete specimens. After spraying, the test panels shall be covered and not be moved for 18 hours after spraying. Cores for strength testing shall be obtained from the panels between 18 hours and 1 day. The cores for determination of final strength shall be stored in water until 3 days before testing. The specimens shall have a diameter of 100 mm and be cut to a height of 100 mm. The average value of five test results shall exceed the strength specified in Clause 5.7.3.1 by 5 N/mm^2.

If required by the Employer's Representative, the trial shall include the construction of the proposed joints including layer joints and advance joints.

Should any mix fail to produce satisfactory sprayed concrete, the Contractor shall repeat the construction of test panels and test the same mix, plant and labour or make such adjustments as he considers as necessary.

5.7.10.8 Quality control tests

The performance requirements shall be set by the Designer.

The strength class of the sprayed concrete shall be ensured by the quality tests. If the strength class of the tested sprayed concrete is smaller than the required one, adequate measures shall be performed to secure the sprayed concrete strength. The Employer's Representative shall, in the event of repeated failure in Quality Control, require the Contractor to adjust the mix to achieve the required strength. A new quality test shall be performed if differences in the mixture of the sprayed concrete will be taken.

In sections where the strength class can't be ensured, the thickness of the sprayed concrete layer may be increased, by order from the Employer's Representative, based on following equation:

$$d1 = \{(F/M)-1\}*d$$

F is the required compression strength in N/mm², M is the measured compression strength in N/mm², d is the required theoretical sprayed concrete thickness in cm and d_1 is the additional required sprayed concrete thickness in cm.

The Contractor shall keep a record, in a form to be agreed with the Employer's Representative, of all tests on sprayed concrete, which shall be kept on site identifying the tests with the section of work to which they relate.

The testing procedure and quantity of tests is according to the Austrian Guideline “Sprayed Concrete”. A summarize is given by following clauses.

Site-specific calibration is required for the strength tests of young sprayed concrete as per BS EN 14488-2.

Every 500 m³ of sprayed concrete delivered to the site, the early strength of sprayed concrete up to 30 minutes and at 1 day shall be tested. The test results shall comply with the requirements for early strength given in Clause 5.7.3.

Every 500 m³ of sprayed concrete delivered to the site, the in-situ final strength of sprayed concrete shall be tested. The specimens shall be prepared by means of core drilling at random places from the tunnel lining after 1 to 3 days but as close as possible to 24 hours after placing. The specimens shall have a diameter of 100 mm and be cut to a height of 100 mm and water stored until 3 days before testing. The average 28 days strength of five cores shall exceed the strength specified in Clause 5.7.3.

Where the nominal required sprayed concrete thickness is less than 100 mm, the cores for the compressive strength testing shall be taken from areas where the actual thickness is greater than 100 mm. alternatively additional sprayed concrete thicknesses shall be applied in selected areas agreed by the Employer’s Representative for subsequent coring of test specimens.

All required drillings for the testing procedure shall be filled with concrete subsequent.

5.7.10.9 Measures on strength failures

Failure of 1 day compressive strength tests: 1) Inform the Tunnel Designer’s Representative and the Employer’s Representative, 2) Immediate examination of tunnel lining in suspect area, 3) Immediate examination of elements concerned in making, transporting and placing of sprayed concrete, 4) Assess the results of the geotechnical monitoring program to determine any correlation between non- conformance and tunnel deformation behavior, 5) Prepare to take further tests at three days, 6) Take further compression tests as soon as possible, 7) The Contractor may propose measures for strengthening of the area for approval of the Employer’s Representative

Failure of final strength: 1) Inform the Tunnel Designer’s Representative and the Employer’s Representative, 2) Further cores shall be taken from the tunnel lining in the vicinity of the failed specimen to establish the area of non-conformance, 3)Assess the results of the geotechnical monitoring program to determine any correlation between non-conformance and tunnel deformation behavior, 4) The Contractor shall propose measures - if any - for strengthening of the area for the approval of the Employer’s Representative

5.7.10.10 Thickness of sprayed concrete

Measures to establish the total thickness of sprayed concrete shall be set up by the Contractor and approved by the Employer’s Representative. These may include visual guides installed prior to spraying or holes drilled after completion of spraying.

All required drillings for the testing procedure shall be filled with concrete subsequently.

The thickness of sprayed concrete is defined as a minimum thickness; consequently the sprayed concrete shall not be less than nominal design thickness at any place. 5 independent tests shall be done per every 500 m³ of applied sprayed concrete per construction element (e.g. tunnel lining, slope support…).

5.8 Cross Section Check of Primary Lining

5.8.1 Tolerances

No reduction of the theoretical thickness of the inner concrete lining is permitted unless it is approved by the Employer's Representative. To achieve this requirement, no support elements such as sprayed concrete, anchor heads, lattice girder etc. may protrude into the theoretical inner concrete lining, as shown on the drawings.

In the area of the invert and the foundation beams no rock parts or rock peaks may protrude into the theoretical excavation line.

For tunnel sections with no concreted invert arch the Contractor shall excavate the bottom level of the invert with an accuracy of +0 to -100 mm related to the theoretical excavation line of the invert.

If the bottom excavation level, after the clearing of all detritus material, is more than 100 mm below the designed theoretical excavation line, the Contractor shall backfill such areas up to the designed, theoretical level by means of sub-base material or as directed and approved by the Employer's Representative.

For tunnel sections with a concrete invert arch no reduction of the designed, theoretical thickness of the concrete structure is permitted. Over excavation must be compensated with structural concrete for the invert arch as specified or as directed by the Employer's Representative. The inside face of the invert arch may deviate not more than +/- 50 mm in elevation from the theoretical cross section.

5.8.2 Profile Control

The final geometry of the primary lining shall be checked solely and systematically by the Contractor in order to accommodate the designed nominal thickness of the inner concrete lining. After incremental displacements are smaller than the permitted displacement velocity and prior to the water sealing construction, the Contractor shall measure the excavated profile by electronic means, or another method approved by the Employer's Representative.

Provision is made for the final concrete lining to be cast using a rail mounted shutter running on footing beams constructed to the designed longitudinal alignment levels and cross falls at each side of the tunnel.

It is the Contractor's responsibility to ensure that the minimum clearance for the final lining, as shown on the drawings, is provided. In order to establish deviations from the theoretical profile

the Contractor shall provide a gantry furnished with a template set to show the minimum profile required to give the nominal thickness of the final concrete lining. The gantry shall be designed to move along the rail tracks to be used for the movement of the tunnel shutter and is to provide access for the marking out of the areas of the initial lining which protrude into the minimum clearance zone.

The Contractor shall submit full details of the design of the gantry with its template for the approval of the Employer's Representative. On approval the Employer's Representative will issue instructions with regard to the systematic checking of the geometry of the template during profiling operations.

The Contractor may prefer to use advance surveying techniques and data processing to establish the final clearance profile. The Contractor shall define a method of marling out areas of deviation from the theoretical profile to be approved by the Employer's Representative.

The clearance checking of the primary lining shall not commence until the rate of convergence at any of the adjacent monitoring stations is more than 2 mm per month.

Any deviations from the theoretical clearance profile shall be made good, either by providing extra sprayed concrete or inner lining concrete in the case of excess clearance, or by re-profiling any parts of the tunnel support protruding into the clearance profile. Contractor is responsible for these Works without any extra payments. The remedial works shall be in agreement with the Employer's Representative. No re-profiling shall be carried out without approval by the Employer's Representative. If the thickness of the re-profiling layer is more than 1/3 of the primary lining thickness or if an area is larger than 5 m² detailed procedures including structural stability proof shall be elaborated and shall be reported in a written document to the Employer's Representative prior to commencement for approval. The Structural safety of the tunnel shall not be endangered due to re-profiling and is secured by geotechnical measurements prior, in between and afterwards. Measurement equipment in the re- profiling area shall be replaced in adequate vicinity.

Records shall be kept for each stage the remedial measures executed.

The final clearance profile shall be recorded at intervals in longitudinal direction and points along the periphery of the tunnel as proposed by the Contractor in agreement with the Employer's Representative.

The final checking of the clearance profile after completion of re-profiling and surface shall be done in presence of the Employer's Representative.

6 CONCRETE WORK

6.1 Concrete

Concrete shall be mixed, charged, applied, cured and tested according to given Specifications which are based on “Specification for tunneling” by BTS and the Indian Standards. For the tunnel inner lining and where these Specifications do not cover all aspect the Addendum 1 - “Guideline for Inner Shell Concrete”, Austrian Society for Concrete- and Construction Technology, 2006, Austria shall be applied.

6.2 General

All structural elements must be designed for fire load if required based on according to the above mentioned standards and guidelines.

The final lining cross section geometry shall be checked and the tolerances shall be in accordance with these Specifications.

If squeezing ground conditions are observed during primary lining construction, stress gauges and pressure cells shall be installed in the final lining to monitor the actual stress-strain condition of the final lining. Minimum three stress gauges and pressure cells shall be installed in cross sections where squeezing ground conditions are encountered or as directed by the Employer’s Representative. Records shall be kept available at site and submitted to the Employer’s Representative for review.

Concrete and concrete constituents and all materials and operations relating to concrete shall meet the requirements of the Indian Standards Code of Practice for Plain and Reinforced Concrete IS 456 unless otherwise specified herein and as required by the Employer’s Representative.

Where concrete is to be placed in aggressive ground, appropriate ground investigation shall be undertaken to identify the nature of the chemical composition of groundwater and ground.

The grade and properties of the concrete used in each part of the work shall be as stated on the drawings or in the Specification.

No material shall be added to ready-mixed concrete at the site unless approved by the Employer’s Representative. Full responsibility shall be taken for ensuring that any materials added to ready-mixed concrete on site not causes the concrete to fail the quality control testing requirements of this Specification. Items made from such concrete which fail the quality control testing shall be rectified. Concrete is not permitted to contact to aluminum during mixing, conveying and placing.

Concrete Requirements

Concrete mixed by the Contractor or any other Sub-Contractor shall comply with the exposition classes and strength classes as defined in the approved detailed design drawings and BS EN 206-1.

The maximum chloride content of concrete shall be in accordance with IS 456-2000.

Chloride content class for concrete containing steel reinforcement shall be Cl. 0.20 (maximum Cl. content by mass of cement 0.20%) and for concrete containing pre- stressed steel reinforcement Cl. 0.10 (maximum Cl. content by mass of cement 0.10%), unless otherwise directed by the Employer's Representative.

Consistence of concrete mix, other than concrete mix used for tunnel lining, shall be in compliance with IS: 456-2000.

6.3 Concreting in cold weather

Concreting in cold weather shall be caorreid out in accordance with IS7861 Pt.2. concrete placement shall not commence without approved special provisions if ambient temperature below 4° C is expected. Such provisions include

a. Surface adjacent to the concrete lift to be placed shall be heated to at least 4° C prior to pouring of concrete

b. Forms shall be adequately insulated to keep concrete temperature above 4° C, taking into account the shape of the concrete member and the expected heat generation in the concrete.

The concrete may be heated during batching and mixing. The following criteria shall not be exceeded

a. The maximum temperature of fresh concrete shall not exceed 25° C during mixing, transporting and placing

b. Mixing water shall not be heated above 60° C, unless it is mixed with the aggregates before cement is added; care must be taken that neither quick set nor flash set occurs.

c. The aggregates shall be heated uniformly and carefully; all frozen lumps, ice and snow shall be eliminated before entering the concrete mix; average aggregate temperature shall not exceed 60° C and maximum spot temperature shall be below 100° C.

6.4 Concrete Composition

6.4.1 Aggregates

Aggregates shall be supplied only from sources approved by the Employer's Representative. The Contractor shall demonstrate compliance with laboratory tests that shall be made at regular intervals to confirm the suitability of aggregate. Approval of a source shall not be constructed as constituting acceptance of all materials from that source.

The quality of all aggregates used in the work, including processing such as washing, classifying, screening, rescreening crushing and blending, necessary to meet the required Specifications, shall all be subjected to acceptance of the Employer's Representative.

Aggregate shall be free from earth, clay, loam and soft, clayey, shaley or decomposed stone, organic matter and other impurities and shall be hard and dense.

Aggregates shall not contain any other matter likely to affect the long-term durability of the concrete. Reference is to be made to the BRE Digest 330 for guidance in reducing the risk of deleterious alkali–silica reaction to the absolute minimum.

Mineral aggregates shall comply with IS: 383 and BS EN 12620 respectively.

Tests shall be carried out in accordance with International Standards, as appropriate, and the results shall comply with the limits given therein, or as otherwise specified. Testing will be carried out to BS EN 932, BS EN 933, BS EN 1097 and BS EN 1744 as appropriate.

If necessary, fine aggregate shall be washed to remove excess fines.

Coarse aggregate shall be washed at the aggregate source. However, further washing at the batch plant may be required if the aggregate is found to be unacceptable to the Employer's Representative.

Coarse aggregate shall be tested for drying shrinkage characteristics in accordance with BS EN 1367-4. The drying shrinkage shall not exceed 0.075%.

Coarse aggregate delivered to the batching plant shall have uniform and stable moisture content.

The acid-soluble sulphate (SO_3) level shall not exceed the values specified in BS EN 12620.

The alkali reactivity of aggregates in combination with the proposed cement shall be tested in accordance with IS 383 and IS 2386.

Flakiness & Elongation of aggregates shall be comply with IS 2386(Part-1).

Aggregate Impact value shall be comply with IS 2386 (Part-4).

Specific Gravity and absorption shall be comply as per IS 2386(Part-3)

The maximum permitted level of equivalent acid-soluble chloride ions (Cl^-) for any single constituent or combination of the constituents of the concrete in the hardened mix shall not exceed the limits given in BS EN 206-1.

Total estimated sulphate content (SO_3) shall comply with the limits given in BS EN 206-1.

The water-soluble chloride ion content of the sand and coarse aggregate, combined in the proportions intended for a particular mix, shall not exceed the values given in IS-2386; Methods of test for aggregates for concrete.

Hardness and abrasion characteristics of the aggregate will comply with BS EN 12620.

Water absorption shall not exceed the permitted value in BS EN 12620.

Where specific thermal characteristics of the mix are required, the aggregate will be appropriately selected and tested in accordance with BS EN 1367.

Each size of aggregate shall be stored separately in drained concrete-based bins or on stages to prevent intermixing and the inclusion of foreign materials.

The size of aggregates shall be in accordance with IS 456-2000 such as to establish the required properties of the concrete best. The grading of aggregates shall conform to IS: 383-2016.

6.4.2 Cement

The Contractor shall submit cement and cementitious material manufacturers' certificates in accordance with the relevant Standard. Details of all cements and cementitious materials shall be supplied including any alternative sources that might be used. The Contractor shall show that the quantity and quality required can be attained and maintained throughout the construction period. Any cement type proposed for usage in the Works shall be approved by the Employer's Representative.

Cement shall comply with the requirements as per:

- IS 269 Ordinary Portland Cement, 43/53 Grade
- IS 8041 Rapid Hardening Portland Cement

Requirements to be met by cement (heat build-up, water segregation, fineness, C_3A content, cement temperature) shall comply with BS EN 197.

Where Sulphate resistance is required, the selected cement will be appropriate to the required Design Chemical (DC) class.

Where specified or appropriate to use, blast furnace cements, Portland slag cements and blended ground granulated blast furnace slag (ggbs) cements will comply with the blending proportions specified in BS 8500-2.

Where specified or appropriate to use, Portland limestone cements and blended limestone cements will comply with the blending proportions specified in BS 8500-2.

Cementitious materials shall have a reactive alkali content not exceeding a value of 0.6% by mass and/or the total mass of reactive alkali in the mix shall be calculated and controlled to satisfy the requirements of BS 8500-2 and the British Research Establishment (BRE) Digest 330. Certification will be supplied by the producer to demonstrate compliance with BRE Digest 330.

Cementitious materials shall be supplied in bulk, unless such cementitious materials are to be used for mortar finishing, patching or grouting. Bulk cementitious materials shall be delivered to the Site in bulk carriers which shall be clean and dry prior to loading. All carriers for bulk or bagged cement shall be equipped with watertight closures for all openings.

Immediately upon delivering to the site, cementitious materials shall be stored in dry, watertight, ventilated structures. Cement bags shall be stored and stacked as per IS 4082-1992(Reaffiremed-2003)

Different types of cements shall be stacked and stored separately as per IS 4082-1992(Reaffirmed-2003)

Cements which have exceeded the manufacturer's designated shelf life will not be used and appropriate measures shall be taken for its safe disposal or return to the manufacturer.

6.4.3 Admixtures

No admixtures shall be permitted without written acceptance of the Employer's Representative.

All admixtures shall be obtained from the same manufacturer to ensure compatibility between the admixtures. Technical details including data of all admixtures proposed to be used shall be forwarded to the Employer's Representative for review. The Contractor shall carry out tests and trial mixes to determine that the admixtures are compatible with the other mix ingredients.

Unless otherwise specified by the Employer's Representative, all admixtures shall be of a liquid type.

Handling and storing of admixtures shall be in accordance with the manufacturer's recommendations. Admixtures shall be stored in weatherproof buildings at a temperature not higher than 35 degree Celsius. Mechanical agitators shall be used for those admixture solutions required by the admixture manufacturer to be agitated prior to and during use.

Admixtures shall be in compliance with IS: 9103.

Water-reducing admixtures in liquid form shall comply with BS EN 206 and BS EN 934.

Admixtures shall not be mixed together prior to introduction to the mix. The use of set-retarding and water-reducing admixtures shall be in agreement with the Employer's Representative, unless otherwise specified in the Contract. Admixtures not covered by International Standards shall not be used. Concrete containing fly ash shall not be air entrained, unless the Contractor supplies proof (from tests on trial mixes or previous production) that the amount of air entrained can be controlled within specified limits and that the compressive strength of the concrete will be satisfactory.

6.4.4 Additions

General suitability as a Type II addition is established for the following:

- fly ash conforming to BS EN 450-1
- silica fume conforming to BS EN 13263-1
- ggbs(Ground Granulated Blastfurnace Slag) conforming to BS EN 15167-1
- meta-kaolin with an appropriate agreement certificate

General suitability as a Type I addition is established for the following:

- filler aggregate conforming to BS EN 12620 or BS EN 13055-1
- pigments conforming to BS EN 12878

6.4.5 Water

Water for concrete mixing and curing shall be clean and free from injurious amounts of oil, silt, salt, organic matter, acid, alkali, sediment or other deleterious substances and shall conform IS 456-2000 and BS EN 206 respectively. Recycled water may be used provided controls are in place to demonstrate compliance with BS EN 206. The Contractor shall supply, install, operate and maintain a system for water supply for concrete, mortar, sprayed concrete and grout manufacture. Not less than 40 days prior to the start of concrete production, sprayed concrete placement, or grout injection whichever occurs first, the Contractor shall submit to the Employer's Representative details of the method by which the Contractor proposes to ensure a clean and adequate supply of water. Alternative water storage facilities shall be provided to ensure that concreting, shotcreting and grouting operations will not be hindered by a temporary breakdown in the main water supply system. The permissible limits for solids when tested in compliance with IS 3025 shall be as given in Table 6.1 below.

Table 6.1: Limits of deleterious material in water for concrete mixing

deleterious material	max. permissible limit
organic	200 mg/lit
inorganic	3000 mg/l
sulphates (SO4)	500 mg/lit
chloride (Cl)	500 mg/lit
suspended matter	2000 mg/lit

The pH value of the water shall not be less than 6.

6.4.6 Fibre

6.4.6.1 General

Fibres are generally accepted for use in concrete conforming to BS EN 206-1 and BS 8500 if the fibre conforms to BS EN 14889, a European Technical Approval.

Fibre-reinforced concrete will be trialled and tested to ensure it meets the designers' requirements before inclusion in the works. Historical data of the same fibre and dosage will be accepted in place of trials provided the data are deemed appropriate.

6.4.6.2 Steel Fibre

Steel fibre can be used in permanent lining of tunnel and concrete structure as per detailed design. The fibre shall be multi hooked ends type with diameter ratio of 60 to 80 (aspect ratio) unless otherwise approved. In this context, the diameter is either that of a circular section or that of a circle with an area equal to the cross-sectional area of the fibre. Tensile strength of fibres shall be minimum 2000N/mm^2.

The content of steel fibres shall be based on the types of fibres used and shall be determined to achieve the required performance criteria as set out in mix design. The minimum fibre content shall be not less than 35kg/ m^3 or as otherwise approved.

6.4.6.3 Polymer Fibre

Polymer micro fibres shall be used in permanent lining of tunnel to improve its performance in fire case. The fibers used shall be of 100% virgin polymers with a melting point of 160°C. the length of fibre in blend form should range in 13 to 19mm and fibre count of 160 – 180 million/kg.

The content of polymer micro fibres shall be based on the types of fibres used and shall be determined to achieve the required performance criteria as set out in mix design. The minimum fibre content shall be not less than 1kg/ m^3 or as otherwise approved.

6.4.7 Temperature

Every effort shall be made to maintain the temperature of concrete during manufacture, placement and curing as per IS 7861 (Part I & II) unless otherwise specified herein.

The concrete temperature at the time of placing shall not exceed 27°C nor be less than 4°C. Fresh concrete temperatures of 13°C to 18°C are most favorable. Concrete and concrete constituents may be heated to reach the preferable concrete temperature. Heating of concrete or concrete constituents shall under no circumstances increase the concrete temperature above 27°C.

Aggregates shall be heated uniformly and carefully; all frozen lumps, ice and snow shall be eliminated before entering the concrete mix; average aggregate temperature shall not exceed 60 °C and maximum spot temperature shall be below 100 °C. Frozen aggregates shall not be used.

Mixing water shall not be heated exceeding 60°C.

To avoid surface cracking caused by heat generated during setting of concrete, the temperature difference between a measuring point at the surface and a measuring point in the centre of a concrete body, or 1000 mm inside the surface if the body is more than 2 m thick, shall be less than 20°C, if not otherwise approved by the Employer's Representative. The location of the measuring point at the surface plane shall be defined as 10 mm inside the surface on a perpendicular projection of the structure member's centre point to the surface plane.

Temperature difference across construction joints shall be less than 15 °C at the time of concrete placement.

The maximum temperature during setting of concrete shall not exceed 40 °C except it is approved by the Employer's Representative.

6.4.8 Mix Design

The selection design and quality control of mixes shall be carried out by the Contractor or on his behalf by the manufacturer.

The Contractor shall design concrete mixes for each class of concrete. The concrete mixes shall be designed to produce a workable plastic mixture with the lowest slump that will suit the specified condition at the time of placement and will produce concrete of uniform consistency that conforms to the requirements specified for the various parts of the works.

In order to minimize thermal cracking, the cement content of all classes of concrete shall be the minimum necessary to produce the specified strength, permeability, freeze-thaw resistance and temperature rise requirements.

6.5 Mixing and Batching

6.5.1 General

The Contractor shall provide at the site, modern and dependable, automatically or semi-automatically controlled batching and mixing plant or plants, in an "as new" condition, capable of supplying concrete in accordance with the Specifications and at a continuous rate adequate to meet the requirements of his schedule for concrete placement. Each plant shall have not less than two concrete mixers, each with a separate power and drive system with a standby generator and other equipment to ensure a continuous supply of concrete during concrete placement operations. Site infrastructure shall be equipped for meeting the requirement of concreting in cold weather as explained in IS 7861 part 2.

6.5.2 Batching

The Contractor shall provide, operate and maintain all necessary equipment and plant required to determine accurately and to control the amount of each separate ingredient entering the concrete mix. The actual amount of fine aggregate, each size of coarse aggregate, cement, fly ash, admixtures, ice and water entering each batch of concrete shall be determined by automatic weighing of each ingredient separately and not cumulatively. All constituents shall be weighed or metered in compliance with the limits prescribed in BS EN 206.

Proportioning of concrete mixes shall be in accordance with IS 456-2000 and IS 4925.

Admixtures shall only be introduced using purpose-made equipment accurately calibrated. Where such equipment is unavailable, and where agreed with the Employer’s Representative, alternative dosing methods to the manufacturer’s recommendations may be adopted.

Water shall not be added to concrete after it has left the mixer unless controlled, recorded and agreed with the Employer’s Representative.

Where fibre reinforcement is added to the concrete mix, this shall only be introduced using purpose-made equipment.

All necessary measures shall be taken to prevent charging the batching plant with frozen aggregates. Aggregates in bins at the batching plant shall be kept above zero degrees Celsius at all times. Heating and cooling equipment shall be provided with sufficient capacity to heat or cool the water and aggregates to a uniform temperature so that the concrete will meet the placement temperature requirements. During winters mixing water shall be headed under control

environment to avoid fluctuation of temperature between batches. The heated aggregate/ water shall be mixed first so that high temperature of one or other is reduced before cement is added. Water upto boiling point may be used provided the aggregate is cold enough to reduce the temperature of mix appreciable below 40 degree Celsius.

Free access for testing and inspection of the cementations materials shall be provided. The batchers shall be arranged that the loading cycle cannot start again as long as materials remain in the batchers.

A thermometer shall be installed in the cement day bin such that the operator can see readily the temperature of the cement at the time of batching.

The plant shall be equipped with a batching recorder which shall print the mass or volume for each material in each batch, identify the concrete mix being batched, the size of each batch in cubic meters, and the time and date of batching. The records shall be submitted to the Employer's Representative at the end of each shift and shall become the property of the Employer's Representative.

The accuracy of the measuring and weighing equipment shall be maintained so that the indicated mass does not vary by more than 0.6 per cent from the true mass throughout the range of use.

The measuring and weighing equipment shall be capable of being operated to control the delivery of materials so that the combined inaccuracies in feeding and measuring do not exceed the limits in Table 6.2.

The Contractor shall provide standard certified test weights and any other auxiliary equipment required for checking the operating performance of each measuring and weighing device. Unless otherwise required by the Employer's Representative, check tests of equipment used for measuring water, cement and the admixtures shall be made at intervals not exceeding one month. Check tests of measuring and weighing equipment used for measuring fine and coarse aggregate shall be made at intervals not exceeding two months. The tests shall be made in the presence of the Employer's Representative and the Contractor shall make such adjustments, repairs or replacements as the Employer's Representative may deem necessary to secure satisfactory performance before further use of the measuring or weighing equipment will be allowed.

All aspects of the batching and mixing operation including quantities of aggregates, cement, fly ash, admixtures and water shall be automatically recorded.

Table 6.2: Batching tolerances

cement	20 % per weight
fine aggregates	3,0 % per weight
coarse aggregates	3,0 % per weight
admixtures	2,0 % per weight
water	1,5 % per weight

6.5.3 Mixing

The mixing plant shall combine fine aggregates, each size of coarse aggregates, cement, fly ash, admixtures, ice and water into a uniform mass and shall discharge the mixture without segregation.

The batching and mixing plant shall have capacity of batching and mixing concrete at a rate in excess of the Contractor's peak placing requirements. A standby mixer with a capacity of not less than 40% of the peak placing requirements shall be available at all times for use during critical concreting operations.

A mixer timer with an automatic lock which will not release the discharging mechanism until the completion of a pre-set mixing time shall be provided on all mixers.

Separation of coarse aggregate from the mortar shall be avoided by arranging the discharge mechanism so that the concrete will fall vertically into the receiving container or hopper.

Mixers shall be examined by the Contractor at regular intervals to ensure that wear on the blades and liners does not allow dead spots or agglomerations of mortar around the sides of the mixer. Mixers shall be cleaned of any hardened materials which have built up on the insides. Should a mixer at any time produce unsatisfactory results, in the opinion of the Employer's Representative, its use shall be discontinued until it is repaired or replaced.

Mixer performance tests shall be performed on all mixers, as soon as the equipment is in operating condition at the start of the Work, at least once every 30 days during the course of the Work and at any time the Employer's Representative suspects any type of operating difficulties with the machinery. At the end of the mixing period prescribed by the Employer's Representative for the test, two samples of concrete shall be taken.

When necessary mixing times shall be increased until the required uniformity and consistency of the concrete is adequate. Mixers shall not be used if they produce unsatisfactory concrete.

6.5.4 Conveying

Concrete shall be conveyed from the mixer to the place of final deposit without segregation, contamination, loss of ingredients, loss of entrained air, loss of slump or damage from exposure. Trucks, buckets, belt conveyors, pumps, chutes and drop pipes may be used for conveying concrete and shall be of such size, design and condition as to ensure a continuous and even supply of concrete at the point of delivery. Alternative methods will be required to prove their success in conveying concrete rapidly, without segregation and the loss of materials. All conveying equipment shall be supported independently of the forms.

Concrete conveying equipment shall be checked by means of site trials prior to general use for its ability to deliver uniform concrete as per Clause 6.5.14. Slump tests shall be made on samples of concrete taken from the first and last one-tenth of a batch of mixed concrete. If these slumps differ by more than 25 mm, the equipment shall not be approved for use until the condition causing the inconsistency is corrected. Concrete conveying equipment used shall be examined

daily for accumulations of hardened concrete or mortar, or for wear of the blades. Where necessary, the uniformity test may be repeated.

The time elapsed between completion of the mixing of the concrete at the plant and its discharge at the forms shall not exceed 45 minutes for concrete agitated while in transit and 30 minutes for non-agitated concrete. These basic limits apply in the case of non-set-retarded concrete. For set-retarded concrete the limits may be increased. Open conveyances shall be covered against the weather when required by the Employer's Representative.

Dispatch tickets or a record direct from the batching plant recorder shall be furnished to the Employer's Representative with each batch of concrete recording the serial number of ticket, date, batch number, truck number, amount and class of concrete, location of placement, and time of mixing. At the end of each day or shift, the Contractor shall supply the Employer's Representative with a written report concerning the quantity of each class of concrete and the number of batches produced.

The concrete shall be delivered to the point of placing at not less than 5 degree Celsius. During cold weather, it is necessary to place the concrete quickly and cover the top of the concrete with an insulating material.

Equipment to be used to convey the concrete shall not contain hardened concrete or foreign materials.

In general, the use of chutes to convey concrete will not be permitted, except that chutes less than 3 m in total length may be used with acceptance of the Employer's Representative. The delivery end of the chute shall be as close as possible to the point of deposit. The chute shall be thoroughly flushed with fresh clean water before and after each run, the water used for this purpose being discharged outside the form.

Concrete in the walls and arches of tunnel linings shall be placed by a displacement type pump or by other approved methods by the Employer's Representative. The equipment used in placing the concrete, and the method of its operations, shall be in a way to permit introduction of the concrete into its final location without high- velocity discharge and resultant segregation.

Concrete pumps shall have a variable speed control and shall be capable of pumping concrete containing 20 mm aggregate through delivery lines not less than 75 mm diameter and for a distance required for placement within the works to meet requirements of this specification.

6.5.5 Placing

General

The Contractor shall develop a detailed plan of concrete lifts for each structure which shall show the location of all construction joints and all concrete lifts in the structure and shall take reinforcing steel bars, embedded parts and water stops into account. The submission shall include calculations supported by laboratory and full scale test data showing how the temperature control requirements will be achieved. The plan for each structure, which shall include detailed drawings, shall be submitted to the Employer's Representative not less than 80 days prior to the start of concrete placement in that structure and not less than 20 days prior to the submission

of reinforcing steel bar placement drawings, bar bending schedules and bar lists for that structure. The Employer's Representative shall have the right to require the Contractor to move the location of any construction joint if the location proposed by the Contractor will have an adverse effect on the design and performance of the structure.

The construction joints shown on the drawings shall not be moved unless the Contractor can satisfy the Employer's Representative that there is justification for the relocation and that there will be no adverse effect on the performance of the structure.

After the Contractor's plan for construction joints and concrete lifts has been approved by the Employer's Representative no additional joints shall be incorporated into the Works unless approved by the Employer's Representative. Details of proposed additional joints shall be submitted to the Employer's Representative not less than 60 days prior to concrete placement at the location of the proposed additional joints.

Concrete shall not be placed in any part of the Works until the foundations, previously placed concrete, formwork, reinforcing steel bars, embedded parts and water-stops in that area have been inspected by the Employer's Representative and permission has been given by the Employer's Representative for concrete placing to proceed. Concrete shall be placed only in the presence of the Employer's Representative.

All surfaces to be in contact with the in-situ concrete lining shall be thoroughly cleaned and scaled of all loose or defective material.

The surfaces of water-proofing membranes shall be thoroughly cleaned to remove any loose and foreign materials. They shall be cleaned by washing with a stream of air and water, but care shall be taken not to displace the membrane or its fixing and seals.

Concrete shall not be placed in still or running water and shall not be subjected to the action of running water until the concrete has set.

During cold weather, all concrete surfaces shall be covered as soon as the concrete has been placed in order to keep the heat in and to help prevent freezing.

All formwork shall be true to form, securely made and supported, and joints shall be sealed to prevent the loss of cement from the mix. Where required, grout pipes shall be incorporated for pressure relief and subsequent grouting.

Concreting shall not commence until the formwork has been inspected and agreed with the Employer's Representative.

The build-up of water pressure behind uncured linings shall be prevented. Concrete shall be placed continuously in each length of formwork. Concrete shall be protected from rain during placement.

The time between batching and complete discharge shall be less than 90 minutes and shall be such that the concrete can be placed and consolidated without the addition of extra water.

The time between batching and complete discharge shall be reduced to a maximum of 60 minutes when the air temperature exceeds 25 degrees Celsius.

In order to reduce bleeding, slump shall not be higher than necessary to achieve proper placement and consolidation.

The depth of concrete placed in each lift shall be as shown on the Contractor's drawings. All concrete shall be deposited in approximately horizontal layers 50 centimeters in thickness at such a rate that the formation of cold joints will be prevented. Each new lift of concrete shall be placed on the oldest exposed lift.

Hardened or stiff concrete shall not accumulate on reinforcing steel or formwork.

Partially hardened concrete shall not be re-tempered with or without additional aggregate, cement or water.

Once concrete placing has started it shall be carried on as a continuous operation until the placing of the lift is completed. The rate of placing shall be such that each successive layer can be vibrated and bonded into the previous layer.

When concrete is placed on an inclined surface, the placing operation shall begin at the lower end of the slope and shall progress upward.

The sequence of work within the tunnels or shafts shall be arranged as that no damage occurs to permanent linings. The proposed sequences and methods of operations shall be agreed with the Employer’s Representative.

Before any concrete is placed for tunnel linings the Contractor shall demonstrate to the Employer’s Representative that his concrete mix, equipment and working methods are capable of producing fully compacted concrete to the required surface finish. If required by the Employer’s Representative, this shall take the form of a trial length.

6.5.6 Preparation

Excavated rock surfaces against which concrete will be placed shall be scaled and cleaned to remove unclassified material, loose, broken and detached rock fragments and unsound, slaked, deteriorated and closely fractured rock which remain in the excavated surface of the rock. Where required by the Employer’s Representative, scaling and cleaning shall be followed by dental excavation to remove the unclassified material remaining in open and debris filled joints, cracks, fissures, seams, crevices, faults, shear zones and other relatively narrow openings. The purpose of scaling, cleaning and dental excavation is to produce a sound, intact, tightly anchored rock surface.

Scaling, cleaning and dental excavation will require the use of manual labour, with hand held pneumatic tools, shovels, bars, trowels, compressed air jets, high pressure water jets, brooms, brushes and other hand held tools. High pressure water jets shall not be used.

Foundation surface of the rock, concrete and sprayed concrete shall be protected against weathering and the deleterious effects of frost action, rain, ground-water seepage and construction equipment until concrete placement commences.

Sprayed concrete in underground works shall be cut back so that no sprayed concrete protrudes inside the concrete pay line (see 5 and 5.8).

Rock, sprayed concrete and concrete surfaces against which concrete is to be placed shall be kept continuously damp for a period of not less than 24 hours immediately prior to concrete placement.

Surfaces of reinforcing bars, forms and embedded parts shall be cleaned of all dried mortar, grout, oil and all other coatings except epoxy coating and galvanizing.

Immediately before concrete is placed, forms shall be inspected to ensure that the forms are accurately placed to the specified tolerances and are sufficiently rigid and braced to prevent movement during concrete placement and that all reinforcing bars are in the correct position and secured against movement during the placing operation. Chemicals shall not be used to remove ice or hardened concrete from the forms.

In hot weather or concreting on surfaces which are highly water absorbent, the surfaces against which concrete is to be placed, including reinforcement and formwork, shall be lightly sprayed with water to prevent excessive absorption of water from the fresh concrete. Pre-wetted surfaces shall be free from excessive water before concreting.

6.5.7 Placing

The concrete shall not be placed until the rate of convergence at any of the adjacent monitoring stations is less than 4 mm per month, unless otherwise approved by the Employer's Representative.

Concrete shall be placed while still sufficiently plastic for adequate compaction and shall be carefully worked around all reinforcement and embedded fixture and corners of the formwork.

Concrete shall be inspected at the point of placing.

There shall be no vertical drop greater than 1.5 m except where equipment such as tremie pipes and chutes satisfactory to the Employer's Representative to use to confine and control the falling concrete. Horizontally movement of concrete exceeding 1.0 m by the use of vibrators is not permitted.

Concrete shall be placed as close as possible to its final position, in continuous near level layers not exceeding 500 mm. Each layer shall be compacted before succeeding layers are placed. The depositing of large quantities of concrete at any one point and running or working it along the forms will not be allowed.

Placing equipment shall be operated by experienced operators only. In general, the concrete placing shall continue uninterrupted until the structure is filled over the entire length of the

formwork. In the event of equipment breakdown or if for any other unavoidable reason placing is interrupted, the Contractor shall thoroughly compact the concrete to a reasonable level or flat slope while the concrete is plastic. The concrete at the surface of such cold joints shall be cleaned with a high-pressure air water jet before the concrete achieves a primary set, to provide an irregular clean surface free from laitance. Prior to restarting concreting, the surface shall be wetted. The work shall be carried out in a way that a sound dense homogeneous structural element is produced. The concrete which forms the openings to caverns and niches or other recesses shall be placed concurrently with the concrete in the parent tunnel at the same cross section. Concrete shall not be subjected to disturbance between 4 hours and 24 hours after placing.

6.5.8 Consolidation

As concrete is being placed, it shall be compacted thoroughly and uniformly by means of vibrators, supplemented by hand spading, ramming, and tamping to produce dense, homogeneous concrete, that is at its maximum density, that is in complete contact with forms, that is effectively bonded to the reinforcing steel bars and the embedded parts and that has smooth formed surfaces, free of air pockets and blemishes.

Concrete shall be consolidated with the aid of approved immersion type mechanical vibrators complying with IS 2505. Immersion vibrators shall be a minimum of 40 mm in diameter and shall be capable of transmitting vibration to the concrete at frequencies in excess of 150Hz or 4000 rpm and shall visibly affect the concrete at a radius of 300 mm. At least one vibrator in working order shall be held in reserve for emergency use. Concrete vibrators shall not be used for moving concrete. Vibrators shall be operated as nearly as practicable in a vertical position. The vibrating head shall be allowed to penetrate under its own weight until it can re-vibrate the top 5 centimeters of the underlying concrete layer. The vibrator shall be withdrawn slowly to avoid the formation of voids and shall be carefully positioned to avoid contact of the vibrating head with the formwork. Vibrators shall be inserted at uniform spacing over the entire area of placement. The distance between insertions shall be approximately 1.5 times the radius of action of the vibrator. Vibrators shall be held stationary until the concrete is consolidated and then withdrawn slowly. The concrete ingredients shall not be allowed to segregate and no laitance shall be allowed to appear on the surface. Vibrators shall not come in contact with nor disturb embedded parts, water stops, reinforcing steel bars and formwork.

Particular care shall be taken with the compaction of concrete surrounding water bars to avoid honeycombing and to prevent the displacement of the water bar. Care shall also be taken to avoid displacement of pre-fixed pipes, block-outs, thermocouples and the like.

Where placing concrete for tunnel linings formwork vibrators shall be used for compacting concrete in the tunnel arch above the highest openings in the formwork. They shall be operated at intervals of not more than 1.2 m behind the advancing slope of the concrete in the shoulders and crown of the arch. The location and operation of the vibrators shall be carefully coordinated with the withdrawal of the discharge line so as to avoid settlement and flow of the concrete from the filled crown.

6.5.9 Finishing

The surface of formed and unformed concrete shall be within the specified allowable deviations from the lines, slopes, elevations and dimensions shown on the drawings and shall be smooth and uniform in texture and free from streaks, discoloration and surface irregularities to the extent specified herein. Any damage to finished concrete resulting from the action of removing from work or any other cause shall be repaired to the satisfaction of the Employer's Representative.

Formed Surfaces:

Table 6.3: Formed concrete finishes

F1	No specific requirement
F2	The irregularities in the finish shall be no greater than those obtained from the use of wrought thickness square-edged boards arranged in a uniform pattern. Fins shall be removed and imperfections shall be made good.
F3	The resulting finish shall be smooth and of uniform texture and appearance. The formwork lining shall leave no stain on the concrete and shall be so joined and fixed to its backing that it imparts no blemishes. It shall be of the same type and obtained from only one source throughout any one structure. The Contractor shall make good any imperfections in the finish. Internal ties and embedded metal parts shall not be used

All formwork joints for F2 and F3 finish shall form a regular pattern.

Unformed Surfaces:

Table 6.4: Unformed concrete finishes

U1: Screened finish	The concrete shall be levelled and screeded. No further work shall be applied to the surface unless it is a first stage for a wood float or steel trowel finish.
U2: Wood float	A pre-screeded finish shall be floated with light finish pressure using a wooden float to eliminate surface irregularities
U3: Steel trowel finish	A steel trowelled finish shall be first wood-floated and then trowelled under firm pressure with a steel float to produce a dense, smooth, uniform surface. The final surface shall be free from trowel marks.

When required by the Employer's Representative and before commencing concreting the Contractor shall prepare a trial panel to demonstrate that the required surface finish can be achieved by the equipment and methods proposed. The panel shall be filled with the proposed concrete compacted by the method to be used in the work. When agreed with the Employer's Representative the trial panel shall be retained and will form the benchmark against which all Works concrete shall be prepared. Where the concrete surface is to receive waterproofing it shall be in accordance with the waterproofing system manufacturer's recommendations. Permanently exposed concrete surfaces shall be protected from rust marks and all kinds of stains. After removal of the formwork no treatment, other than that approved for curing, shall be applied to the concrete until its surfaces have been inspected by the Employer's Representative. Where any surface fails to comply with the Specification in respect of finish, dimensional tolerance, or in any other way, the Contractor shall rectify the work as agreed with the Employer's Representative. The Contractor shall be responsible for preventing any damage to the finished concrete surfaces, and shall adopt any necessary protective measures to prevent subsequent staining from any cause.

6.5.10 Curing

The concrete shall be protected from damage due to load overstress, heavy shocks, excessive vibrations and the effects of rain and running water particularly during the curing period. Curing and protection of concrete in cold weather shall be carried out in compliance with IS 7861 Part 2. All concrete should be allowed to cure by methods which will ensure the production of concrete of the specified quality. Curing materials and methods shall be compatible with any subsequent waterproofing. In general, concrete shall not be placed when the temperature at the location of the Work is below, or likely to fall below, 5°C before the section of work can be completed except in emergencies. Concrete shall be continuously moist cured from the time that the concrete has hardened sufficiently to prevent damage to the surface finish and shall be continued for not less than 14 days for concrete not containing fly ash and 21 days for concrete containing fly ash or until fresh concrete has been placed on or against the concrete surface or until a membrane curing compound has been applied. All material and equipment required for adequate curing and protection shall be on hand before concrete placement begins. Concrete shall be protected from exposure to rain for 12 hours, from exposure to the sun for 72 hours and from exposure to flowing water for 14 days. For concrete surface temperature below 5°C, the duration of curing shall be extended for the number of days the temperature has been below 5°C. Concrete shall be moist cured by maintaining the surfaces continuously wet for the duration of the specified curing period. During the curing period concrete shall not be intermittently wetted and allowed to dry. Curing water temperature shall not exceed 25 grade Celsius or above the expected minimum ambient temperature of the curing period. At least 14 days prior to the use of curing compound, full details of the proposed compound shall be submitted to the Employer's Representative for review. Such details shall be accompanied by test certificated to show that the compound will give satisfactory results for the proposed application. Curing compound shall be wax-based compounds and shall be approved by the Employer's Representative. The compound shall be applied in strict accordance with the manufacturer's Specifications and shall be applied as soon as the surface water has disappeared. Curing compounds shall be delivered to the Site in suitably labelled containers to enable identification of the batch number and date of manufacture. Curing compounds shall comply with the requirements of ASTM C309. For each curing compound proposed for use in the Works, the Contractor shall obtain a Certificate of Compliance from the supplier, supported by test certificates from a laboratory with appropriate registration, certifying that the curing compound complies with this Specification. The curing compound shall be applied by a pressurised sprayer to give a uniform cover. The sprayer shall incorporate a device for continuous agitation and mixing of the compound in its container during spraying. The curing compound shall be applied using a fine spray at a rate of 0.2 litres/m² and per coat or otherwise directed by the Employer's Representative. The application rate shall be checked by calculating the amount of curing compound falling on felt mats, each approximately 0.25 m^2 in area, placed on the concrete surface. Two coats shall be applied at the full rate. The curing compound shall be applied to unformed surfaces immediately after completion of all finishing operations, and to formed surfaces within half an hour of the removal of formwork from the section.

6.5.11 Joints

Joints in concrete are either movement (deflection, expansion or contraction) joints or construction joints. All construction joints shall comply with IS 11817. Joints shall be formed on horizontal or vertical planes except for joints in tunnel linings which shall be formed on radial planes. Joints in horizontal planes, which intersect with exposed surfaces making an angle of

45° or more with the horizontal, shall be truly horizontal. Joints in horizontal planes, which intersect with exposed surfaces making an angle of less than 45° with the horizontal, shall be formed to provide at least 75 mm of surface normal to the slope of the surface. Construction joints shall be positioned only where agreed with the Employer's Representative. The Contractor's proposal on constructions joints shall be given on lift drawings submitted to the Employer's Representative for review. Formed construction joints shall be formed using purpose-made stop ends. Expanded metal stop ends shall not be used. Unformed construction joints shall be formed using a grout check or similar so that the exposed edge is a crisp true line. The joint surface shall be either: brushed using water to remove laitance and expose the aggregate without disturbing it, treated with retarder and then water-jetted to remove laitance and expose the aggregate to a depth of not less than 3 mm without disturbing it, or lightly roughened by light chipping or needle-gunning of set concrete. Hacking of set concrete shall not be permitted. Construction joints shall be clean and damp, with no standing water, immediately before wet concrete is placed against them. At horizontal construction joints on exposed surfaces forms shall be constructed with strips to produce a straight joint at the exposed surface, unless otherwise directed. Movement joints shall be constructed as shown on the drawings. The Contractor shall provide the various joint components and install these in accordance with the drawings and the manufacturer's recommendations, or as directed or approved by the Employer's Representative. Any material used for expansion joint filler shall be approved by the Employer's Representative. Sealing compound is applied as surface sealant for movement joints or other boundaries of construction elements. The compound shall be polyurethane-rubber type or other type approved by the Employer's Representative. 56 days prior of any sealing compound is applied, the Contractor shall submit a sample of the proposed sealing compound together with the manufacturer's technical data and the details of the recommended method of application for approval.

6.5.12 Water Stops

Water stops shall be installed as shown on the drawings or as directed by the Employer's Representative. Detailed information on all water stops, their properties, installation and standard support, shall be submitted to the Employer's Representative for approval. Only approved water stops shall be used in the Works and the manufacturer's regulations and instructions shall be followed. All joints of sealing strips shall be welded by the appropriate device to the tensile strength at least 80% of the initial material. Prior to any concrete work the water stops shall be placed as given in the drawings and adequate measures shall be made to prevent a dislocation of water stop due to concreting works. Thermoplastic sunken sealing strips for construction joints shall be in compliance with DIN 18541.

6.5.13 Quality Check & Tolerances

The Contractor shall keep logs on all his concrete activities, i.e. production, placing, supervision and production control, inspection and testing. These logs shall be available to the Employer's Representative for examination at any time. The Contractor shall supervise and inspect the concrete works so as to fulfill the provisions of this Specification. This applies to the inspection of materials and products, of concreting execution, of false work and form-work, of reinforcement, of concreting operations and of pre-cast concrete elements. The Employer's Representative may at any time, unless critical concrete work is done, inspect and test any Contractor's equipment intended for batching, mixing, transporting, placing and testing concrete.

6.5.14 Trial Mix Testing

In conjunction with the design of concrete mixes, the Contractor shall complete a laboratory trial mix program for each class of concrete. The trial mix program will be used to confirm to the satisfaction of the Employer's Representative, that the proposed concrete mix designs will produce concrete having the properties required by the Specification with minimum cement content.

Unless otherwise agreed with the Employer's Representative, field trial mixes shall be prepared under full-scale site conditions at least 35 days before the commencement of concreting and tested in accordance with IS 10262, BS EN 12350 and BS EN 12390. For each concrete plant proposed by the Contractor the field trial mixes shall be tested separately. The field trial mixes shall be tested to determine compliance under statistical evaluation where required by BS EN 206. An acceptable value for the limits of the required properties shall be established during the trials which shall thereafter be used to monitor the Quality Control of the mixes and set the standard of compliance. In the event quality control tests indicate that concrete below the specified standards is being produced, the Employer's Representative may order such adjustment of mix design, additional quality control, or other measures as it may deem necessary to raise quality to specified standards. If, at any time during the Work, the Contractor proposes to change or modify the source, type or quality of any concrete material or materials for the selected concrete mix designs, the laboratory testing program shall be repeated for each class of concrete affected by the proposed change.

Detailed test results on the concrete mix designs with changed or modified materials shall be submitted to the Employer's Representative not more than three days after the completion of each test. The 28 day compressive strength test results and details of the changes or modifications to the concrete mix designs proposed by the Contractor shall be provided to the Employer's Representative before the changed or modified concrete mix designs are used to produce concrete for the works.

The following minimum values of samples shall be taken for trial mix testing:

- nine compression test cylinders (3 for each of 3, 7 and 28 days)
- six shrinkage test prisms
- three test cubes (200 mm) or slabs (200 mm x 200 mm x 120 mm) for water permeability testing according to DIN 1048 Part 5
- one specimen for sulphate and chloride testing

6.5.15 Conformity Control of Concrete

In the event the specified strength criteria are not met, the Employer's Representative may, if he deems it necessary, require that the unacceptable concrete be cut out and replaced. The conformity control of strength parameters required shall be demonstrated in accordance with BS EN 206-1. Specimens tested to demonstrate compliance will be cubes, cylinders or prisms appropriate to the testing standards and BS EN 206-1.Test samples shall be made, cured, stored, transported and tested according to BS EN 12350 and BS EN 12390. Spot samples will not be used to evaluate strength parameters. Concrete cube test results will be acceptable if statistical analysis of the results meets the requirements of BS EN 206-1.Concrete shall be tested

for durability properties by means of absorption and capillary suction (sorptivity) tests where appropriate. An appropriate test method will be agreed by all parties before testing is undertaken.

Compaction factor, slump, Vebe, flow table or other workability tests shall be carried out as required during concreting of permanent works to control workability at the batching plant and at the site of the pour. The degree of workability shall be as specified or as determined during the trial mixes. Permitted tolerances shall be in accordance with BS EN 206. Samples tested will be either spot samples or composite samples taken in accordance with BS EN 12350-1 and the appropriate tolerances for compliance will be applied in each case.

Where inspection reveals non-conformity, appropriate measures shall be taken in accordance to EN206-1 and in agreement with the Employer's Representative.

6.5.16 Production Control of Concrete

All concrete shall be subject to production control by the Contractor in accordance to EN 206. All data of production control shall be recorded by the Contractor and made available to the Employer's Representative at any time.

6.5.17 Tolerances

Surface finishes shall generally conform to the types and tolerances indicated in

Table **6.5**, unless otherwise specified herein, as shown on the drawings or as required by the Employer's Representative. The Contractor shall carry out a cover meter survey over all reinforced concrete surfaces within 24 hours of removal of formwork. The cover survey shall be undertaken on a 500 mm grid over the whole structure. Access for the Employer's Representative to verify cover meter surveys shall be provided. The deviation of the inner face of the concrete lining according to the theoretical cross section may in general not exceed 50 mm to the inner side. At the lower side wall (walkway level/cable duct) the deviation of the inner face is limited to the inner side in order to maintain minimum dimensions of the cable ducts. Pre-cast concrete cover plates for the cable ducts shall be fabricated based on the as-built survey results. No tolerance will be permitted inside of the specified clearance profile for vehicles or pedestrians.

In any case and for all specified deviations permitted, the specified theoretical thickness for the inner concrete lining as well as the specified clearance profile for the roadway and the walkways shall be maintained.

Niches, recesses and similar structures are to be constructed with a tolerance of +/- 50 mm related to the designed stationing.

Pre-cast elements and other structural elements are to be constructed and placed with a tolerance of +/-15 mm, related to the theoretical tunnel cross section.

Table 6.5: Types and tolerances for finishing of concrete surfaces

Type of finishing	General areas of application and method of forming	Tolerances in mm
F1	Formed surfaces of construction joints and other surfaces which will not be permanently exposed, including surface upon or against which backfill or concrete is to be placed. Minor blemishes caused by entrapped air or water will be accepted. In general the surface will require no treatment after form removal, other than repair of defective concrete and specified curing, or treatment as specified for construction joints.	+10
F2	All permanently exposed formed surfaces for which type F3 finish is not specified. For which sheating or lining shall be placed so that joint marks on the concrete surface will be in general alignment, both horizontally and vertically, and conform to a standard pattern. Immediately on the removal of forms, all unsightly ridges or fines shall be removed, all holes left by removal of ends of form rods shall be neatly filled with mortar and surfaces treated to meet the required tolerances by tooling and rubbing. In general, not more than 50 air voids of 5-15 mm diameter per m' will be accepted. Air voids exceeding 15 mm in diameter shall be repaired. When filling holes and repairing defective areas of permanently exposed surfaces, effort shall be made to match the colour of the concrete. The use of release agents which may permanently stain or discolour the finished surface will not be permitted.	+5 -5
F3	Formed surfaces which will be exposed to flowing water. These surfaces shall be hard, smooth and dense, free from offsets, pits, voids, air holes and irregularities and shall be chipped, ground and thoroughly cleaned as necessary to conform to the required tolerances.	+3 -3
U1	Unformed, screeded surface which will be covered by fill materials, static water or concrete. Type U1 finish shall be used as the first stage. Types U2 and U3 as finishes. Finishing shall consist of sufficient leveling and screeded to produce an even, uniform surface meeting the required tolerance.	+10 -10
U2	Unformed surfaces not permanently concealed by fill or concrete or not required to receive Type U3 finish. Floating by means of hand or power driven equipment shall be started as soon as the screeded surfaces has stiffened sufficiently, and shall be the minimum necessary to produce a surfaces that is free from screed marks and that is uniform in texture. If type U3 finish is to be applied floating shall be continued until a small amount of mortar without excess water is brought to the surfaces so as to permit effective trawling.	+5 -5

Type of finishing	General areas of application and method of forming	Tolerances in mm
U3	Unformed, screeded surfaces which will be exposed to flowing water. This finish shall be applied by steel trawling after the concrete has hardened enough to prevent excess of fine materials and water from blemishes, ripples and trowel marks. After the surface has nearly hardened, it shall be trowelled once more until the surface is hard and glossy in appearance.	+3 -3

6.5.18 Repair of Damage

All irregularities on concrete surfaces shall be repaired to produce smooth, uniform surfaces that conform to the tolerances specified herein for the finishes shown on the drawings.

The Contractor shall notify the Employer's Representative not less than 24 hours prior to the start of any concrete repairs.

Surface irregularities shall not be repaired until they have been inspected by the Employer's Representative. The Employer's Representative will inspect the surface irregularities and determine whether the surface irregularities shall be repaired by cutting out the concrete to a depth of 75 millimeters beyond the reinforcing bars and filling the cavity with cement mortar or concrete, or whether the concrete shall be cut out to a shallower depth and the cavity filled or patched with cement mortar or saran latex dry pack mortar or epoxy sand mortar, or an alternative mortar approved by the Employer's Representative. The Employer's Representative will also determine the extent to which concrete shall be cut out, the shape of the resulting cavity, the material that is to be used for the repairs and whether the filling shall be secured with keys, dovetails or anchors. Reinforcing steel bars shall not be cut.

Should the concrete exhibit any form of cracking at 28 days, in excess of 0.l5mm width, it shall be brought to the attention of the Employer's Representative. The Employer's Representative may, at his discretion and based on the particular crack location, require that the crack be repaired. Where so instructed, the concrete shall be repaired using an epoxy injection system or other approved method of permanent crack repair. Repairs using an epoxy injection system shall not be performed for at least 56 days from the original date of concrete placement.

Repairs shall be performed only in the presence or on direction of the Employer's Representative.

The Contractor shall repair all leakage spots in concrete joints or elsewhere in agreement with the Employer's Representative.

6.6 Lean Concrete

The strength class C15 shall be applied for wet lean concrete. With the following constituents:

- Cement shall be in accordance with Clause 7.4.2.1

- Water/cement ratio shall be in accordance with Clause 7.4.2.2
- Aggregates shall be in accordance with Clause 7.4.2.4
- Consistence shall comply with Clause 7.4.3.1.

Wet lean concrete shall be spread uniformly, without segregation and without varying degrees of pre-compaction. The concrete shall be struck off to a level so that the surcharge is sufficient to ensure that after compaction the surface is at the required level.

The spread wet lean concrete shall be compacted using internal or external vibration, or a combination of both to meet the required density. At transverse and longitudinal construction joints between two separately constructed slabs, the previously laid slab end or edge shall present a vertical face before construction of subsequent slabs. Longitudinal joints in wet lean concrete shall be staggered by at least 300 mm from the position of longitudinal joints in any superimposed concrete slab, and by 1m for transverse joints. Curing of wet lean concrete shall comply BS EN 12390-2 as appropriate. The density shall be determined as in Clause 7.4.3.2 and sampling shall be as specified therein.

The surface of the wet lean concrete after compaction and finishing and before overlaying shall be free from ridges, loose material, pot holes, ruts or other defects. The surface of wet-laid concrete bases shall be roughened before the application of any curing compound by brushing with a wire brush or stiff broom.

Trial concrete mixes shall conform with BS 8500-2 for designed concretes for strength class 15 and above, unless recent data relating entirely to the proposed concrete, satisfies the requirements of the Specification.

At least 10 days before the start of the main wet lean concrete works a trial length of at least 400 m² for mechanised construction and 30 m² for hand-guided methods shall be constructed. The trial length shall be laid to assess the suitability of the proposed material, plant, equipment and construction methods to meet the requirements of the Specification. The main construction in the Permanent Works shall not start unless the trial length complies with the Specification. If any trial length does not conform to the Specification another trial length shall be constructed. Trial lengths not complying shall be removed unless they can be rectified to comply with the Specification. After satisfactory completion of the trial, the material, plant, equipment and construction methods shall not be changed unless the Contractor lays a further trial length to assess the suitability of the proposed changes or agrees the changes with the Employer's Representatives.

6.7 No-Fines Concrete

No-fines porous concrete shall be used for the surround of ground water drainage pipes in tunnels at locations indicated on the drawings. No-fines porous concrete shall be composed of ordinary Portland Cement and 37.5 mm single size aggregate complying with Clause 6.4.1.

The ratio of aggregate to cement shall be 8:1 by volume or 10:1 by mass. The concrete shall be mixed by machine or by hand to a uniform colour and consistency before placing. The quantity

of water used shall not exceed that required to coat all of the aggregate particles without forming excess grout. No fines concrete shall be compacted by hand.

6.8 Reinforcement

6.8.1 General

The items of work falling within the scope of work under this section shall be in accordance with the Indian and European Standards Specification (Latest edition) given under:

- IS:280-1978: Specifications for mild steel wire for General Engineering purposes
- IS:432-1966/82: Specifications for mild steel and medium tensile steel bars and hard drawn steel wire for concrete reinforcement
- IS:432 (Part I): Mild steel and medium tensile bars
- IS:432 (Part II): Hard drawn steel wire
- IS:456-1978: Code of practice for plain and reinforced concrete
- IS:814-1974: Specifications for covered electrodes for metal arc welding of structural steel
- IS:814 (Part I): For welding products other than sheets
- IS:814 (Part II): For welding sheets
- IS:1139-1966: Hot rolled mild steel medium tensile steel and high yield strength deformed bar for concrete reinforcement
- IS:1786-1979: Specifications for cold worked steel high yield strength deformed bars for concrete reinforcement
- IS:2502-1963: Code for practice for bending and fixing of bar for concrete reinforcement
- IS:5525-1979: Recommendations for detailing of reinforcement in reinforced concrete constructions
- IS:9417-1979: Recommendations for welding cold-worked bars for reinforcement concrete constructions
- BS EN 10080: Steel for the reinforcement of concrete. Weldable reinforcing steel. General
- BS 4449: Steel for the reinforcement of concrete – Weldable reinforcing steel Bar, coil and decoiled product
- BS 4482: Steel wire for the reinforcement of concrete products. Specification BS 4483: Steel fabric for the reinforcement of concrete

The Contractor may adjust the position of lap joints to fit in with available stock lengths, or construction joints, subject to the Employer's Representative's agreement to the altered positions. The Contractor shall amend the bending schedules, as necessary, to allow for such alterations. Reinforcement shall be obtained from a Certificated Authority for Reinforcing Steels Quality Assurance approved supplier and the Contractor shall provide copies of the manufacturer's certificates of test results relating to the steel reinforcement to be supplied.

Reinforcing steel bars and welded steel wire fabric may be stored outside in an approved manner provided that they do not rust and are placed on sleepers which will prevent the steel from coming into contact with the ground and a protection against contact with aggressive elements is provided.

Reinforcing steel bars shall be free from dirt, oil, flaky rust, loose mill scale and any other coating that would destroy or reduce the bond with the concrete.

Tying wire shall be 1.6 mm diameter soft annealed mild steel, and when fixed shall not project into the concrete cover. Where the Contract so requires, the Contractor shall produce bending schedules.

6.8.2 Placing and fastening

Placing and fastening of reinforcement shall comply with IS 456 unless specified otherwise herein. All reinforcement shall be accurately placed, securely fixed and adequately maintained in the positions shown on the drawings. The reinforcement shall be fixed so that the cover specified on the drawings is achieved, subject to the tolerances specified therein. Reinforcing steel bars shall be installed as shown on the drawings and shall be solidly attached to the formwork. Reinforcing steel bars shall be tied together with wire ties to form a rigid grid which shall be supported in its required position, on chairs and with spacers and hangers. The wire ties shall be used in a staggered pattern at a spacing not exceeding 60 centimeters. Reinforcing steel bars shall be accurately placed within the specified tolerances and shall be secure against displacement during concrete placement. Reinforcement shall not be re-bent on site unless agreed with the Employer's Representative. The minimum clear distance between parallel reinforcing steel bars shall be the nominal diameter of the reinforcing steel bars or 1.25 times the maximum size of the coarse aggregate, whichever is the greater, provided that the minimum clear distance between parallel reinforcing steel bars in beams shall not be less than 30 millimeters and in columns shall not be less than 50 millimeters. Spacer blocks shall be of comparable strength, durability and appearance to the surrounding concrete and shall be factory produced. Site-produced concrete or mortar cover blocks shall not be used. Spacers and chairs shall ensure that the reinforcement is correctly positioned, be as small as possible consistent with their purpose, and designed so that they will not overturn or be displaced when the concrete is placed. Wire cast in the block for the purpose of tying it to the reinforcement shall be as specified below.

Prior to placing reinforcement on rock or gravel foundation, the foundation shall be covered with at least 50 mm thick layer of concrete. Cover as per the approved drawing shall be maintained, in no case it should be less than 40mm on the rockmass (ground) measured from the prepared foundation. Tying wires shall be 1.6 mm soft annealed iron wire unless drawings require the use of stainless steel tying wire. Where stainless steel tying wire is required it shall be1.2 mm diameter stainless steel wire throughout the structure. Projecting ends of ties or clips shall not encroach into the concrete cover.

Overlap between adjacent sheets of welded wire fabric shall be a minimum of 2 squares.

Concreting shall not commence until the reinforcement has been inspected in accordance with the Inspection and Test Plan.

6.8.3 Splicing

Joints or splices in reinforcing bars shall generally be made at the positions shown on the drawings, but the contractor would be permitted to make joints or splices at positions other than those shown on the drawings, providing that such positions are approved by the Employer's Representative-in-Charge and that joints and splices in adjacent bars are staggered if directed by the Employer's Representative-in-Charge. Approval of such additional splices will generally be restricted to splices not closer than 8 m in horizontal bars or 4 m in vertical bars measured between mid-points of laps. The number of splices shall be kept to a minimum. If the Contractor proposes to use mechanical couplings for reinforcing bars, he shall submit samples of the proposed coupling to the Employer's Representative for approval not less than 60 days prior to their proposed use.

6.9 Formwork

6.9.1 General

Material and workmanship shall comply with IS 456 and IS 14687.

The supply of all labour, supervisors, Contractor's equipment and materials and the execution of all work necessary to design, supply, fabricate, erect, treat, support, brace, use, remove and dispose of formwork for retaining and forming concrete structures as specified herein and as shown on the drawings shall be provided by the Contractor.

Not less than 60 days prior to the start of fabrication of formwork and false work for each structure or part of a structure, the Contractor shall submit to the Employer's Representative design calculations and erection drawings showing the formwork and false work for that structure or part of the structure. The general method and system proposed shall be submitted in detailed drawings of the formwork to the Employer's Representative for agreement.

The erection drawings shall indicate the method and schedule of construction, member sizes and type, grade and quality of materials, the arrangement of joints, splices, liners and locations of temporary openings and embedded parts. Details of mechanical equipment that will operate or be supported on the false work shall be submitted with the erection drawings. Design assumptions, loads and allowable stresses shall be indicated on the erection drawings.

All formwork shall be dimensioned, constructed and securely braced as to prevent displacement.

All joints in the formwork and between the formwork and previous work shall be sufficiently tight to prevent loss of liquid from the concrete. Formers for all chases, grooves, recesses, etc. shall be securely fixed as part of the formwork. No part of the concrete shall be cut away for any such item, or for any other reason, without the Employer's Representative's agreement The face of the formwork shall be clean and applied with non-staining release agent. The agent shall not touch reinforcement, or items to be embedded, and shall not be allowed to collect in the bottom of the formwork, or flow onto previously placed concrete. Before any concrete is placed, the Contractor shall examine and clean out the formwork and ensure that the specified reinforcement cover is attained. Where cyclical casting, e.g. in-situ concrete tunnel lining, striking

times may be agreed with the Employer's Representative following criteria determined from trial lengths.

6.9.2 Material Requirements

The surface of steel plate formwork and steel faced lumber formwork shall be smooth and free from dents, buckles and other surface irregularities. The sheathing for steel formwork shall be steel plate not less than three millimeters thick. All bolts and rivet heads shall be countersunk. Means shall be provided to ensure a snug fit of steel plate sheathing and steel faced sheathing against previously hardened concrete so as to provide smooth joints.

Lumber used for formwork shall be free from warp, loose knots and decay and shall be sawn straight and dressed smooth.

Plywood shall be non-warping and non-wrinkling and shall be manufactured with waterproof glue. Only plywood sheets with identical length and width shall be used.

Fillers for repairing and reconditioning formwork shall be subject to approval by the Employer's Representative. All filler material shall be sanded flush and sealed with an approved sealer to prevent adhesion to the concrete.

6.9.3 Tunnel Formwork

Formwork for tunnel lining shall be constructed in such lengths that each concrete placement can be completed without cold joints.

Concrete pads, pedestals and other means to support tunnel formwork shall be subject to approval by the Employer's Representative on the basis of the effects of such supports on the structural properties of the tunnel section and on the finish of the lining.

Formwork for tunnel lining above the invert shall be provided with rows of openings along each side. The bottom row shall be located with the centerline of the openings above the longitudinal construction joint at the invert. Successive rows shall be located on two meters centres above the next lower row. The rows of openings shall be staggered. Openings shall permit access for inspection and vibration of concrete being placed behind the formwork. Each row of openings shall be provided with a platform for access to the openings. Openings shall be located at a minimum spacing of 2.5 meters along the tunnel centerline and up the tunnel walls. Openings shall be not smaller than 45 by 60 centimeters, with the long dimension parallel to the centerline of the tunnel.

6.9.4 Execution

6.9.4.1 Preparation

Formwork shall be constructed in strict accordance with the erection drawings after they have been reviewed by the Employer's Representative and shall produce concrete conforming to the lines, slopes, elevations and dimensions and with the surface finishes shown on the drawings. Joints between formwork sections shall be sufficiently tight to prevent loss of mortar from

concrete. Formwork shall be securely tied and anchored to maintain shape and position and to avoid warping and bulging. Formwork for curved surfaces shall be constructed so as to conform accurately to the required curvatures of the surfaces within the allowable tolerances specified. Formwork joints shall fit together without gaps greater than two millimeters at any point. The joint marks on the concrete surface in the water passages shall follow in general the line of water flow. Forms shall be placed so that the joint marks on concrete surfaces will be in alignment both horizontally and vertically and the joint marks between surfaces shall be smooth.

6.9.4.2 Installation

Formwork shall be braced to maintain its position and shape. Formwork and false work shall be arranged for ease of dismantling and stripping to ensure that its removal will not damage the concrete. Formwork blocking and supports to be left permanently in the concrete shall be fabricated of steel.

The interior surfaces of formwork shall be covered with colourless mineral form oil or other bond breaking compound approved by the Employer's Representative. The bond breaking compound shall be applied before reinforcing steel bars are placed. Form oil or bond breaking compounds shall not come in contact with reinforcing steel bars or with concrete surfaces on which additional concrete, epoxy mortar or any bonded coating is to be placed.

6.9.4.3 Tolerances

Formwork and false work shall be constructed, located, supported and braced in such a manner that the finished surfaces of concrete structures are within the allowable construction tolerances as defined in Clause 6.5.17 of this Specification.

6.9.4.4 Concrete Placement

Temporary openings shall be provided in the formwork at any place where necessary to facilitate concrete placement, insertion of vibrators, cleaning and inspection. The temporary openings shall be closed with removable panels that are flush with the formwork surface on the inside. Immediately before concrete is placed, formwork shall be inspected to ensure that it is accurately placed, rigid, tight, clean and free from foreign matter. Inspection of formwork by the Employer's Representative and approval to proceed with concrete placement shall not relieve the Contractor of his responsibility for safety and accuracy of the Work. Any repairs of concrete due to faulty or inaccurate formwork shall be done by the Contractor at no additional cost to the Employer.

6.9.4.5 Quality Control

The alignment and position of formwork shall be checked frequently during concrete placement. Any misalignment shall be corrected by wedging and shoring. Formwork and false work may be reused, provided that the material is undamaged and the surface in contact with concrete is cleaned and is capable of producing the required surface finish. Timber and plywood formwork shall not be repaired with metal patches.

6.9.4.6 Removal

Formwork shall be removed in such a manner as to prevent concrete spalling and to produce sharp and clean joints. Formwork shall be eased, struck or removed in such a manner that the structure is not distorted, damaged or overloaded. Except where otherwise agreed with the Employer's Representative, formwork shall not be eased or struck until:

- the concrete has attained sufficient strength to support itself in the position cast without deformation or
- a minimum period in line with Section 11 of IS 456.
- vertical forms and formwork for tunnel crown lining may be removed when the concrete has attained a compressive strength of min 6 MPa, deduced from the strength development of comparable test specimens cured under similar conditions
- 10 hours after concrete placing unless measures are taken to prevent excessive cooling and drying. These measures shall be agreed with the Employer's Representative

6.9.5 Design and Installation Criteria

Formwork and false work shall be designed to withstand, safely and without distortion, all loads that will be applied before, during and after concrete placement. The design loads shall include wind, concrete, equipment and personnel. Formwork shall be designed to permit the concrete to be deposited as nearly as practicable directly in its final position and shall have access facilities that will allow inspection, checking and clean-up of the surface of the preceding concrete placement and inspection and vibration of the concrete.

7 PAVEMENT

7.1 General

The Contractor shall furnish all materials, equipment and labour necessary for permanent roadwork as shown on the drawings or as directed. The design for the permanent roadwork will be provided by the Employer. The Contractor shall design and furnish all materials, equipment and labour necessary for construction roads or tracks to other work sites, to spoil areas, to installation areas and to camps to the extent that he considers necessary for his activities. These roads shall be constructed at the minimum standard necessary for the Contractor to safely execute the Works. The layout and design for all temporary roadwork shall be provided by the Contractor and approved by the Employer before the work commences.

The Contractor shall place compacted and treated, if necessary, selected backfill, either from required excavations or approved borrow areas, to completed structures as shown on the drawings or as directed. The Clause 4.2.4for backfill material shall be applied accordingly.

All permanent road work, materials, workmanship, quality, construction tolerances, testing and etc. shall be carried out in accordance with the “Specifications for Road and Bridge Works” by Ministry of Road Transport and Highways (MoRTH 2000), unless otherwise spec ified in the drawings or as directed by the Employer’s Representative. This requirement applies to both the road outside the tunnel or portal buildings/structures as well as that inside these. The main Clauses of the “Specifications for Road and Bridge Works” (MoRTH 2000) which shall be applied are summarized in this Specification.

7.2 Tolerances

The design levels of pavement courses shall be calculated from the vertical profile, cross falls and the pavement course thicknesses as described in relevant drawings. The level of any point on the constructed surface of the pavement courses shall be the design level subject to the appropriate tolerances stated in Table 7.1.

Table 7.1: Tolerances in surface levels of pavement courses

Pavement course	Tolerances
General Adjacent to a surface water channel1	± 6 mm + 0-10 mm
Base under concrete pavement surface slabs laid full thickness in one operation by machines with surface compaction	± 10 mm
Unbound sub-base layer	+ 10-30 mm

Where a surface water channel is laid before the adjacent road pavement layer the top of that layer, measured from the top of the adjacent edge of the surface water channel, shall be to the given tolerances.

Notwithstanding the tolerances permitted in surface levels of pavement courses, the cumulative tolerance shall not result in a reduction in thickness of the pavement, excluding the sub-base and filter layer, by more than 15 mm neither from the specified thickness nor a reduction in the thickness of the bituminous surface course by more than 5 mm from that specified. For checking compliance with this Clause, measurements of the surface levels of all courses shall be taken on a grid pattern in agreement with the Employer's Representative. The longitudinal regularity of the surfaces of surface courses, binder courses and concrete slabs shall be such that the number of surface irregularities is within the relevant limits stated in Table 7.2. An irregularity is a variation of not less than 4 mm or not less 7 mm of the profile of the road surface as measured by the rolling straight-edge set at 4 mm or 7 mm as appropriate or equivalent apparatus capable of measuring irregularities within the same magnitudes over a 3 m length. No irregularity exceeding 10 mm shall be permitted. Prior to checking any final road surface it shall be cleaned of loose or extraneous materials. These operations shall be carried out without damaging the surface of the pavement as soon as possible and within 3 days of construction of the pavement. Compliance with Table 7.2 shall be checked by the rolling straight-edge along any line or lines parallel to the edge of pavement on sections of 300 m at regular intervals in agreement with the Employer's Representative, whether or not it is constructed in shorter lengths. Sections shorter than 300 m forming part of a longer pavement shall be assessed using the number of irregularities for a 300 m length pro - rata to the nearest whole number. Pavements shall be measured transversely for irregularities at regular intervals in agreement with the Employer's Representative, by a 3 m long straight-edge placed at right angles to the centre line of the road. The maximum allowable difference between the pavement surface and the straight-edge shall be 3 mm. A 3metres long straight-edge shall be used to check longitudinal surface regularity for all lengths of base layers under concrete pavement slabs laid full thickness in one operation by machine with surface compaction.

The maximum allowable difference between the surface and the underside of the straight-edge, when placed parallel with or at right angles to the centre line of the road, shall be:

- 3 mm for pavement surfaces
- 10mm for bases under concrete pavements

Table 7.2: Maximum permitted number of surface irregularities

	Surfaces of each lane of carriageway, each hard strip and each hard shoulder for each irregularity limit				Surfaces of lay-bys, service areas for each irregularity limit			
Irregularity limits	4 mm		7 mm		4 mm		7 mm	
Length [m]	300	75	300	75	30	75	300	75
Number of	40	18	4	2	60	27	6	3

7.3 Rectification

Where any pavement area does not comply with the Specification for regularity, surface tolerance, thickness, macro-texture depth, material properties or compaction, the full extent of the area

which does not comply with the Specification shall be made good and the surface of the pavement course shall be rectified in the manner described below:

- *Unbound base layer:* The top 75 mm shall be scarified, reshaped with material added or removed as necessary, and re-compacted. The area treated shall be not less than 30 m long and 2 m wide or such area as necessary to obtain compliance with the Specification.
- *Bituminous bases:* With coated macadam or asphalt bases, the full depth of the top layer as laid shall be removed and replaced with fresh material laid and compacted in accordance with the Specification. Any area so treated shall be at least 5 m long and the full width of the paving laid in one operation. Alternatively for low areas in bituminous bases, the Contractor may make up the level with additional binder course material.
- *Concrete slabs:* Concrete slabs shall be rectified by planing, grinding or bump cutting. Large depressions, which cannot be dealt in this way, shall be rectified by cutting out the surface and replacing by a thin bonded surface repair. Where the slab cannot be rectified as above, the full depth of slab shall be removed and replaced with a slab constructed in compliance with these

Specifications: Remedial works involving the placing of fresh concrete shall be completed in sufficient time for the concrete strength which has to be developed as specified before that section of pavement is opened to traffic.

7.4 Concrete Pavement

7.4.1 General

The work shall consist of construction of unreinforced, dowel jointed, plain cement concrete pavement in accordance with the requirements of IRC 15: 2017 and these specifications and in conformity with the lines, grades and cross sections shown on the drawings. The work shall include furnishing of all plant and equipment, materials and labour and performing all operations in connection with the Work, as approved by the Employer's Representative. Concrete in rigid or rigid composite pavements shall be of the class C32/40 XF4 and shall confirm to the Clauses of Chapter 7 given otherwise below. Prior to commencement of any concrete works the base layer shall be checked of adequate bearing capacity and elevation the tolerances are given in Clause 7.2. The check has to be in appropriate time prior to commencement hence measures shall be taken contemporary and no time delay may occur.

If the thickness of the base layer is not in the range of the tolerances the base layer shall be corrected. If this is not possible, the base layer shall be fully replaced. The base layer shall be clean and free of deleterious material. The concrete slab shall be laid in two layers. The surface layer shall be laid monolithically with the lower layer. The surface layer shall be not less than 50 mm thick.

7.4.2 Concrete Composition

The concrete composition shall comply with Clause 6.4 unless given otherwise below.

7.4.2.1 Cement

The cement content shall be in accordance to Table 7.3 and means any of the following materials or combinations below:

- Ordinary Portland Cement IS:269 (43 Grade and 53 Grade) including 5% performance Improver (Mineral admixture etc. as per IS:269)
- Portland-Pozzolana Cement IS:1489 (Part 1)
- Portland Slag Cement, IS:455
- Composite Cement (blended with granulated slag & fly ash), IS:16415

Table 7.3: Minimum cement or combination contents with 40 mm maximum aggregates

Min. cement content (for all types of cement and composite content [kg/m³]	360
Max. cement content (not including mineral admixtures) [kg/m³]	450
Maximum proportion of Flyash in [%]/ Min cement content (OPC)	25/ 310
Maximum proportion of Flyash in [%]/ Min cement content (OPC)	50/250
Maximum proportion of Silica Fume in [%] of cement content (OPC)	10

If the concrete layer shall be laid in two layers, the cement of the surface layer shall be limited to Class 42.5N/42.5R Portland cement CEM I in accordance to BS EN 197-1. The minimum cement content of the concrete shall be 375 kg/m³.

7.4.2.2 Water

Water from a water company supply may be used without testing. Water from other sources may be used if it conforms to IS 456. The water content shall be the minimum required to provide the specified consistence for full compaction of the concrete to the required density, as determined by trial concrete mixes or other means. The maximum free water/cement ratio shall be 0.45 for strength classes C32/40 and C25/30 and 0.60 for strength classes C16/20 and C12/15.

If the concrete layer shall be laid in two layers, the free water/cement ratio of the surface layer shall be max. 0.40 for strength classes C32/40 and C25/30.

7.4.2.3 Admixtures

Concrete for pavement slab shall incorporate an air-entraining admixture complying with BS EN 934-2 in at least the top 50 mm of surface slabs. Plasticisers or water reducing admixtures shall comply with BS EN 934-2. Admixtures containing calcium chloride shall not be used.

7.4.2.4 Aggregates

Aggregates for all pavement concrete, including wet lean, shall comply with IS:383 and BS EN 12620 respectively. The aggregates shall be free from chert, flint, chalcedony or other silica in a form that can react with the alkalies in the cement. In addition, the total chlorides content expressed as chloride ion content shall not exceed 0.06 per cent by weight and the total sulphate content expressed as sulphuric anhydride (S03) shall not exceed 0.25 per cent by weight.

No aggregate which has water absorption more than 2 per cent shall be used in the concrete mix.

If the concrete layer shall be laid in two layers, the surface layer shall comply with following requirements:

- For 6.3/10 mm coarse aggregate or 4/8 mm coarse aggregate the amount of aggregate retained on the 10 mm sieve and 8 mm sieve respectively shall not exceed 3% by mass. The aggregate passing the 6.3 mm sieve and 4 mm sieve respectively shall not exceed 10% by mass.
- The fine aggregate grading shall comply with the 0/2 (FP) or 0/1 (FP) grading in BS EN 12620 except that not less than 99% of the mass of the material shall pass the 2 mm sieve.
- The coarse aggregate shall comprise at least 60% by mass of the oven dry constituents of the concrete.
- The polished stone value (PSV) and the aggregate abrasion value (AAV) of the coarse aggregate determined in accordance with BS EN 1097-8 shall be PSV_{50} and AAV_{15}. The Category of flakiness index of the aggregate is FI_{15}. The resistance to fragmentation of the coarse aggregate shall be of class LA_{20}. The resistance to freezing and thawing shall be of class F_1 for the coarse and fine aggregates.

7.4.3 Concrete Requirements

7.4.3.1 Consistence (Workability)

The consistence shall be determined by the Degree of Compatibility (Compaction Index) test in accordance with BS EN 12350-4, or the Vebe test in accordance with BS EN 12350-3. Alternatively for concrete class C16/20 or below, consistence may be determined by the slump test in accordance with BS EN 12350-2. The sampling for all concrete classes shall be undertaken in accordance with BS EN 12350-1 and the rate of testing in accordance with Table 12 of BS EN 206-1. Consistence shall be carried out at the point of placing, in conjunction with tests for strength and any tests for air content. The consistence shall be maintained at the optimum within the limits specified in BS EN 206-1.

If any determination of consistence gives a result outside the tolerance, a further test shall be made immediately on the next available load of concrete. The average of the two consecutive results and the difference between them shall be calculated. If the average is not within the tolerance or the difference is greater than 0.1 for CI or 20 mm for slump or 6 seconds for Vebe, subsequent samples shall be taken from the delivery vehicles, which shall not be allowed to discharge into the Works until compliance with the Specification has been established.

Air content

The concrete shall meet the requirement for exposure class XF4 in BS EN 206-1. This shall be achieved by the use of an air-entraining agent. The minimum quantity of air in air-entrained concrete as a percentage of the volume of the concrete shall be as in Table 7.4.

Table 7.4: Minimum air content with respect to max. aggregate size

max. aggregate size in [mm]	min. air content in [%]
20	3.5
40	3

The air content shall be determined at the point of delivery to the paving plant by the pressure gauge method in accordance with BS EN 12350-7, at the rate of one determination per 300 m² of slab or at least 6 times per day, whichever is the greater, in conjunction with tests for consistence and strength. For areas less than 300 m² the rate shall be at least one determination to each 20 m length of slab or less constructed at any one time or at least 3 times per day. If the air content is outside the specified limits in BS EN 206-1, the Contractor shall remove the concrete from the Works.

The air-entraining agent shall be added at the mixer by an apparatus capable of dispensing the correct dose within the tolerance for admixtures given in Table 6.2, to ensure uniform distribution of the agent throughout the batch during mixing.

7.4.3.2 Density (Manual of Contract Documents for Highway Works)

The density of a saturated core cut from the full depth of the concrete pavement shall not be less than 95% of the average density of at least six fully compacted saturated moulded specimens made from the same concrete and tested at the same age.

The density of the concrete pavement shall be determined in accordance with BS EN 13877-2. The density of a saturated core cut from the full depth of the concrete pavement shall be determined in accordance with BS EN 12390-7. The determination of the saturated density of the fully compacted moulded specimens shall be in accordance with BS EN 12350-1, BS EN 12390-1 and BS EN 12390-2.

The core shall have an average diameter of at least four times the nominal maximum aggregate size, and in any case at least 100 mm diameter. Where different concrete mixes are used in separate layers, the density of each layer shall be separately determined by splitting or cutting the cores between the layers.

If the density of any core is below the minimum required, the concrete across the whole width of the slab constructed at the time relating to that core shall be removed. In unreinforced concrete the whole slab length between joints shall be removed. For reinforced slabs, in order to determine the limit of the defective area of concrete which shall be removed, additional cores shall be taken at 5 m intervals on each side of any defective core until concrete of satisfactory density

is found. Defective areas shall be made good with new material in accordance with the Specification. In calculating the density, allowance shall be made for any steel in the cores. Core holes shall be reinstated with compacted concrete with mix proportions of 1 part of Portland cement CEM I: 2 parts of sand: 2 parts of 10 mm single sized coarse aggregate by mass.

7.4.3.3 Pavement concrete strength

Sampling and testing for and compliance with the specified characteristic core strength of designed concretes shall be undertaken by compressive strength testing in accordance with BS EN 13877-2 on cores cut from the full depth of the slab. No correction for maturity shall be applied to the 7 day or 28 day strength.

Concrete cores of the appropriate size shall be taken, cured and tested in accordance with BS EN 12504-1 with the exception that the core shall be cured under water at 20°C ±2°C as soon as practically possible. The sampling rate shall be as designated in BS EN 13877-2 for Category 2, three cores shall be taken from areas of concrete of up to 3000 m² and one additional core for every further 1000 m² of concrete laid. An exception to the above sampling rate is that in the trial slab at least six cores shall be taken, three to be tested at 7 days and three at 28 days. The end preparation of the core shall be by grinding and the height/diameter (h/d) ratio of the tested specimen shall be between 1 and 2.

If during the construction of the trial length the average corrected core compressive strength, from the three cores, falls below the 7 day corrected core compressive strength given in Table 7.5, then either the cement content of the concrete shall be increased by 5% by mass, or a further trial slab shall be constructed using an improved compaction technique and/or an increased cement content. The increased cement content shall be maintained at least until the three corresponding 28-day core strength tests have been assessed. If the cement content is increased, the concrete shall be adjusted to maintain the required consistence.

Table 7.5: 7 day corrected core compressive strength

Concrete Class	7 day corrected compressive strength for CEM I concrete in [N/mm²]	7 day corrected compressive strength for CEM I with pfa or ggbs concrete in [N/mm²]
C32/40	32	26.8
C25/30	25	20
C16/20	16.5	13
C12/15	12	10
C8/10	7.5	6.5
C6/8	5	4

Overlapping groups of four consecutive 28 day corrected core strengths shall be used for assessing the pavement for compliance with the criteria in Table A.1 of BS EN 13877-2. The pavement shall be accepted if the criteria in Table A.1 are satisfied for four results derived from strength tests on cores taken from the constructed pavement. Conformity control of the concrete will be the responsibility of Contractor.

7.4.3.4 Finished Surface Requirements

The finished surface of the pavement shall comply with the requirements of Clause 7.2. Where a pavement area does not comply with the Specification in any respect, the full extent of the surface which does not comply shall be rectified in accordance with Clause 7.3

After the final regulation of the surface of the slab and before the application of the curing membrane, the surface of concrete slabs to be used as running surfaces shall be brush-macrotextured in a direction at right angles to the longitudinal axis of the carriageway. The macrotexture shall be applied evenly across the slab in one direction by a brush not less than 450 mm wide. The macrotexture shall be uniform both along and across the slab.

The macrotexture depth shall be determined by the volumetric patch technique as described in BS EN 13036-1. Tests shall be taken within 100 m of commencement of paving and thereafter at least once for each day's paving at the times after construction as given below and in the following manner: 10 individual measurements of the macrotexture depth shall be taken at least 2 m apart anywhere along a diagonal line across a lane width between points 50 m apart along the pavement. No measurement shall be taken within 300 mm of the longitudinal edges of a concrete slab constructed in one pass.

Macrotexture depths shall be as required in Table 7.6.

Where the required macrotexture depth is found to be deficient the Contractor shall make good the texture across the full lane width over lengths necessary to comply with the requirements of Table 7.6, by retexturing the hardened concrete surface as described in Clause 7.4.16.

Table 7.6: Required macrotexture depth and tolerances

Time of test		Required macrotexture depth in	
		Specified value	Tolerance
between 24 hours and 7 days after the construction of the slab or until the slab is first used by vehicle	an average of 10 measurements	1.0	±0.25
not later than 6 weeks before road is opened to public traffic	an average of 10 measurements	1.0	+0.25 -0.35

7.4.4 Transverse Joints

7.4.4.1 General

Transverse joints shall be provided in unreinforced and jointed reinforced concrete slabs and shall be contraction, expansion or warping joints at spacing of 25 times the plate thickness and with a maximum of 5.0 m, such that for unreinforced concrete slabs the length/width ratio shall be not greater than 1.5.Joints in the surface slab and sub-base shall be staggered so that they are not coincident vertically and are at least 1 m apart. Transverse joints shall be straight within the

following tolerances along the intended line of the joint, which is the straight line transverse to the longitudinal axis of the carriageway.

- deviations of the filler board or bottom crack inducer from the intended line of the joint shall be not greater than ± 10 mm;
- the best fit straight line through the joint groove as constructed shall be not more than 25 mm from the intended line of the joint;
- deviations of the joint groove from the best fit straight line of the joint shall be not greater than 10 mm.

Transverse joints on each side of a longitudinal joint shall be in line with each other and of the same type and width.

Concrete pavement layers shall be isolated from fixed structures by expansion joints, or earthworks or a granular layer over the structure, or by bridge-type expansion joints, or by lengths of fully flexible pavement construction. End of pavement surface slabs shall have a transition bay leading into the fully flexible construction.

Transverse joints shall have a sealing groove which shall be sealed in compliance with Clause 7.4.11.

Contraction Joints
Contraction joints shall consist of:

- a sawn joint groove complying with Clause 7.4.9
- dowel bars complying with Clause 7.4.7,
- a sealing groove complying with Clause 7.4.11.

Expansion Joints
Expansion joints shall consist of:

- a joint filler board complying with Clause 7.4.10
- dowel bars complying with Clause 7.4.9
- a sealing groove complying with Clause 7.4.11.

The filler board shall be positioned vertically within the prefabricated joint assemblies along the line of the joint within the tolerances of Clause 7.4.4.1, and at such depth below the surface as will not impede the passage of the finishing beams on the paving machines. The joint filler board together with the sealing groove shall provide a complete separation of adjacent slabs and any spaces around dowel bars and between the sub-base and the filler board shall be packed with a suitable compressible material after fixing the joint assembly.

Warping Joints
Warping joints shall consist of:

- a sawn joint groove complying with Clause 7.4.9,
- tie bars complying with Clause 7.4.8

- a sealing groove complying with Clause 7.4.11.

7.4.5 Construction joints

Construction joints made at the end of a working day in unreinforced concrete slabs and jointed reinforced concrete slabs shall be contraction joints. In the event of mechanical breakdown of the concreting machinery, or at the onset of adverse weather, emergency joints may be formed. Emergency joints in unreinforced concrete slabs shall be contraction joints not less than 2.5 m from the preceding or succeeding joint position. The stop end formwork shall be sufficiently rigid to ensure that dowel bars and tie bars will be held in position in compliance with these Specifications.

7.4.6 Longitudinal Joints

7.4.6.1 General

Sawn or wet-formed longitudinal joints shall be provided in surface slabs between or at the centre of traffic lanes within the allowable positions as shown on the drawings, so that bay widths are not greater than 4.2 m. Joints in the surface slab, base or sub-base shall be staggered so that they are not coincident vertically and are at least 300 mm apart.

Wet-formed longitudinal joints shall consist of:

- wet-formed joint grooves complying with Clause 7.4.9,
- a bottom crack inducer,
- tie bars complying with Clause 7.4.8.

Longitudinal joints shall be constructed within the following tolerances:

- deviations of the bottom crack inducer from the intended line of the joint, parallel to the axis of the road shall be not greater than ± 13 mm;
- the joint groove shall be located vertically above the bottom crack inducers within a horizontal tolerance of ± 25 mm;
- the best fit line along the constructed joint groove shall be not more than 25 mm from the intended line of the joint;
- deviations of the joint groove from the best fit line of the joint shall be not greater than 10 mm.

Sawn longitudinal joints shall consist of joint grooves complying with Clause 7.4.9

7.4.6.2 Longitudinal Construction Joints

Longitudinal construction joints between separate slabs shall have tie bars as in Clause 7.4.8 with a joint groove as in Clause 7.4.9.

7.4.7 Dowel Bars

The dowel bars shall conform to IS:432 of Grade I, shall be free from oil, dirt, loose rust and scale. They shall be straight, free of burrs and other irregularities and the sliding ends sawn or cropped cleanly with no protrusions outside the normal diameter of the bar.

Dowel bars shall be supported on cradles in prefabricated joint assemblies positioned prior to construction of the slab. For contraction joints, as an alternative to prefabricated assemblies, dowel bars may be mechanically inserted with vibration into the concrete by a method which ensures full recompaction of the concrete around the dowel bars and the surface finished by a diagonal finishing beam, or a longitudinal oscillating float travelling across the slab. Dowel bars shall be positioned at mid-depth from the surface level of the slab± 20 mm and centred equally about intended lines of the joint within a tolerance of± 25 mm. They shall be aligned parallel to the finished surface of the slab to the centre line of the carriageway and to each other within the following tolerances:

- for bars supported on cradles prior to construction of the slab and for inserted bars in two layer construction prior to placing the top layer:

- all bars in a joint shall be within ± 3 mm per 300 mm length of bar;
- two thirds of the bars shall be within ± 2 mm per 300 mm length of bar;
- no bar shall differ in alignment from an adjoining bar by more than 3 mm per 300 mm length of bar in either the horizontal or vertical plane;

- for all bars, after construction of the slab:

- twice the tolerances for alignment as above
- equally positioned about the intended line of the joint within a tolerance of 25 mm.

Dowel bars shall be covered by a flexible polymeric corrosion resistant coating. The coating shall be smooth and free of indentations. During coating, the bar shall be supported at each end. Minimum thickness shall be 0.3 mm. The coating shall also be able to withstand 250 hours immersion in a salt fog cabinet complying with BS EN ISO 7253, without showing any visible crazing or corrosion of the protected bar. The coated bar shall comply with the following pull out test: Four bars shall be taken at random from stock and shall be coated as required in this Clause without any special preparation. The dowel bars which have been coated shall be cast centrally into concrete specimens 150 x 150 x 450 mm, made of the same concrete mix proportions to be used in the pavement, but with amaximum aggregate size of 20 mm and cured in accordance with BS EN 12390-2. At 7 days a tensile load shall be applied to achieve a movement of the bar of at least 0.25 mm. The average bond stress to achieve this movement shall be not greater than 0.14 N/mm².For expansion joints, a 100 mm long closely fitting cap consisting of waterproofed cardboard or an approved synthetic material like PVC or GI pipe shall be placed over the sheathed end of each dowel bar. An expansion space at least equal in length to the thickness of the joint filler board shall be formed between the end of the cap and the end of the dowel bar by using compressible sponge. To block the entry of cement slurry between dowel and cap it may be taped.

7.4.8 Tie Bars

Tie bars shall be Thermo- Mechanically Treated (TMT) bars conforming to IS:1786 and grade of Fe 500.Tie bars for use across joints shall have corrosion protection in the form of a flexible polymeric corrosion resistant coating, bonded centrally onto 150 mm of the previously cleaned centre section of the bars. Where tie bars are to be cranked for construction joints and later straightened, the coating shall be shown to be capable of being straightened through 90 degrees without cracking.

Tie bars in warping joints and wet-formed longitudinal joints shall be made up into rigid assemblies with adequate supports and fixings to remain firmly in position during the construction of the slab. Alternatively, tie bars at longitudinal joints may be mechanically inserted by vibration from above using a method which ensures recompaction of the concrete around the tie bars. Tie bars in warping joints shall be positioned from the top surface of the slab within +20, -10 mm of the mid depth of the slab. Tie bars shall be positioned and remain within the middle third of the slab depth, approximately parallel to the surface and approximately perpendicular to the line of the joint, with the centre of each bar on the intended line of the joints within a tolerance of ± 50 mm, and with a minimum cover of 30 mm below any top crack inducer of joint groove for slabs 200 mm thick or more, or 20 mm for slabs up to 200 mm thick.

7.4.9 Joint Grooves

Transverse contraction or warping joint grooves shall be sawn in the hardened concrete.

Transverse joint grooves which are initially constructed less than the full width of the slab shall be completed by sawing through to the edge of the slab and across longitudinal joints as soon as any forms have been removed and before an induced crack develops at the joint. *Sawn transverse and longitudinal joint grooves*: Sawing shall be undertaken as soon as possible after the concrete has hardened sufficiently to enable a sharp edged groove to be produced without disrupting the concrete and before random cracks develop in the slab. The grooves shall be between 1/4 and 1/3 of the specified depth of the slab and of any convenient width not less than 3 mm. The sealing groove may be sawn to the required width later. Expansion joint sealing grooves shall be sealed as soon as practical after sawing. *Wet formed longitudinal joint grooves:* When slabs are constructed in more than one lane width in one operation, a joint groove shall be formed by inserting a groove former ahead of the finishing beams from dispenser. The concrete so displaced shall be re-compacted by a vibrating compactor or similar device, at least 300 mm wide operating symmetrically along the line of the joint. After finishing the concrete, the groove forming strip shall be in the correct position and alignment, within 10° of the vertical, and to sufficient depth below the surface to allow for the passage of the finishing beam within the range 0-3 mm below the finished level of the slab. Groove forming strips in wet-formed longitudinal joint grooves shall be left in place. *Construction joint grooves in surface slabs:* The grooves shall be formed by fixing a groove-former or strip or cork seal along the top edge of the slab already constructed, before concreting the adjacent slab. Where the edge of the concrete is damaged, it shall be ground or made good before fixing the groove forming strip. Alternatively the subsequent slab may be placed adjacent to the first and a sealing groove sawn later in the hardened concrete to the minimum of 1/4 to 1/3 of the specified slab depth or to the manufacturer's instructions if greater, and to sufficient width to eliminate minor spalling of the joint arris, up to a maximum of 25 mm for longitudinal joints and 40 mm for transverse joints. The joint shall be sealed in compliance with Clause 7.4.11.

7.4.10 Joint Filler Board

Joint filler board for expansion joints and manhole and gully slab joints shall be 25 mm thick unless otherwise shown in the drawings, within a tolerance of ± 1.5 mm. It shall be a self-expanding cork seal or a firm compressible material or a bonded combination of compressible and rigid materials of sufficient rigidity to resist deformation during the passage of the concrete paving plant.

7.4.11 Sealing of Joint Groover

Sealing shall be carried out continuously along the full length of joint in any one rip, except for remedial areas. When hot or cold applied sealants are used the sealant shall be applied within the minimum and maximum drying times of the primer recommended by the manufacturer. Priming and sealing with applied sealants shall not be carried out when the naturally occurring temperature in the joint groove to be sealed is below 10°C except between 8°C and 10°C it may be carried out when the temperature is rising.

7.4.12 Inspection of Dowel Bars

Compliance with tolerances for the position and alignment of dowel bars as per Clause 7.4.7 at contraction and expansion joints shall be checked

When the slab has been constructed, the position and alignment of dowel bars and any filler board shall be measured after exposing them carefully across the whole width of the slab. When the joint is an expansion joint, the top of the filler board shall first be exposed sufficiently in the plastic concrete to permit measurement of any lateral or vertical displacement of the board. During the course of normal working these measurements shall be carried out at a rate of one joint per 1500 m length of slab or one per 5 days whichever occurs the sooner. For small areas the rate shall be one joint for up to each 100 joints.

If the position or alignment of the bars in a single joint in the slab is unsatisfactory, then the next two joints shall be inspected. If only the one joint of the three is defective, the rate of checking shall be increased to one joint per day until compliance is being achieved. In the event of non-compliance in two or more successive joints, the Contractor shall revert to the construction of trial lengths and make any necessary alterations to the concrete mix, paving plant or methods until the dowel bar position and alignment is satisfactory.

After the dowel bars have been examined, the remainder of the concrete shall be removed 500 mm on each side of the line of the joint, and reinstated to the requirements of the Specification. Alternatively, if the dowels are examined in the penultimate joint of a day's work, that joint shall be made a construction joint for the next day's work and the remainder of the concrete in the last slab may be discarded.

7.4.13 Curing

Immediately after the surface treatment described in Clause 7.4.3.4, the surface and exposed edges of surface slabs shall be cured for a minimum period of 7 days, by the application of an approved resin based aluminised curing compound, or polythene sheeting or an approved

sprayed plastic film which hardens into a peelable plastic sheet and which shall be removed before road marking and opening to traffic. Resin based aluminised curing compound shall contain sufficient flake aluminium in finely divided dispersion to produce a complete coverage of the sprayed surface with a metallic finish. The compound shall become stable and impervious to evaporation of water from the concrete surface within 60 minutes. The curing compound shall not react chemically with the concrete to be cured and shall not crack, peel or disintegrate within three weeks after application. Prior to application, the contents of any containers shall be thoroughly agitated. The curing compound shall be mechanically applied using a fine spray on to the surface at a rate of at least 0.22 l/m². For the sides of slip-formed slabs or when the side forms are removed within 24 hours and for small areas where mechanical application cannot be used, the compound shall be sprayed by hand lance at a rate of at least 0.27 l/m². The rate of spread shall be checked during construction of each trial length and for each 1000 m² of treated slab.

7.4.14 Exposed Aggregate Concrete Surface

In order to obtain a suitable exposed aggregate surface the main requirement shall be the removal of the surface mortar from the top of the slab to produce an exposed aggregate finish. This objective may be achieved by the application of suitable cement set retarder which is sprayed on the surface of the fresh concrete immediately after it has been levelled and finished. Retarded mortar shall be removed by wet or dry brushing generally not sooner than when the surface concrete has reached a maturity of 16 hours at 20°C or after a suitable interval determined by trial. The finished surface of the pavement concrete after application of retarder shall be protected against precipitation, moisture loss, contamination and dispersal of the retarder by air movements. This protection shall be applied immediately after the application of the retarder. Where waterproof sheeting is used; it shall be laid onto the surface of the concrete immediately after the retarder has been sprayed. It shall be retained in position until immediately prior to exposing of the aggregate. The protection system shall not adversely affect either, the finish, the line or the level of the concrete surface or the even distribution of the retarder in any way. Where sheeting is used, any air bubbling or blistering shall be prevented. Brushing equipment shall be used to expose the concrete surface aggregate. Where the brushing equipment runs on the slab, the concrete shall have gained sufficient strength to avoid any damage to the concrete. Removal of the protection system shall take place as brushing proceeds. If waterproof sheeting is used as protection system, it shall be maintained in position until immediately in advance of the brushing operation. The Contractor shall complete the process of exposing the aggregate before the retarder becomes ineffective. Failure to do so shall entail the remedial measures. Sufficient brushing capability shall always be maintained on site to complete the exposure of the aggregate before the retarder becomes ineffective. An adequate back-up brushing facility shall be available on the site at all times for use in case of a breakdown of the brushing equipment. Brushing shall be used to produce an even macro texture on the surface of the slab and shall be carried out in the longitudinal direction of the concrete slab. The wheels of any brushing equipment which may run on the slab shall be fitted with tyres with a shallow tread pattern and a low inflation pressure and be sufficiently wide to avoid damage to the concrete. Within one hour of completing exposure of the aggregate the surface shall be dampened with water. A curing compound shall be applied to the entire exposed aggregate surface of the slab. In wet weather the curing compound shall be applied as soon as practicable after the rain stops. The surface may, alternatively, be covered by hessian provided it is maintained in a wet condition at all times during the curing period of the concrete. During brushing, initial interim spot check measurements of the surface macro texture depth shall be made as soon as it is considered

that the required texture depth has been reached. This shall continue until the specified macro texture depth has been achieved. In the event that it is not possible to achieve the specified minimum macro texture depth by further exposure, the Contractor shall treat the surface in accordance with Clause 7.4.16 to achieve the specified macro texture depth. This treatment shall not be applied until the concrete has reached an age of 28 days. Failure to achieve a satisfactory minimum macro texture depth by mechanical means shall result in removal of the full thickness of the slab to the extent required to permit reconstruction of the slab in accordance with the Specification. Where the maximum macro texture depth is exceeded suitable remedial measures shall be employed

7.4.15 Trial Tests

The Contractor shall demonstrate the constituent materials, concrete proportions, plant, equipment and methods of construction that are proposed for concrete paving, by first constructing a trial length of slab, at least 150 m but not more than 300 m long for mechanised construction, and at least 30 m long for hand guided methods. The concrete proportions decided by trial concrete mixes may be adjusted during the trial but shall not be changed once the trial length has been satisfactorily completed unless the Contractor lays a further trial area to assess the suitability of the proposed changes. The trial length shall be constructed in two parts over a period comprising at least part of two separate working days, with a minimum of 75 m constructed each day when mechanised paving plant is used and a minimum of 15 m on each day for hand guided methods. The trial length shall be constructed at a similar rate to that which is proposed for the main construction in the Permanent Works. Preliminary trial panels shall be constructed off-line incorporating a top surface of exposed aggregate concrete similar to that specified for the permanent Works. These panels shall be 20 m long and not less than 100 mm deep and the maximum intended paving width. They shall be used to enable the Contractor to determine the required application rate of the retarder and the amount of brushing required achieving the specified macro texture depth. The trial panels may alternatively be constructed on-site, but in this case, they may only form part of the permanent Works if they meet all the requirements of the Specification, otherwise they shall be removed after they have served their purpose. The surface macro texture depth shall be determined by volumetric patch technique at approximately 2m spacing along a diagonal line across each trial panel, and shall follow the procedure described in BS EN 13036-1.The average value of each set of 10 individual measurements shall be taken as the resulting macro texture depth which shall be assessed against the Specification. At least two transverse joints and one longitudinal joint of each type that are proposed for unreinforced concrete slabs and jointed reinforced concrete slabs in the main construction in the Permanent Works shall be constructed and assessed in the trial length. If in the trial length expansion joints are not demonstrated, the first 2 expansion joints and at least the first 150 m of longitudinal construction joint for mechanised paving, or 30 m for hand guided method of construction laid in the main construction in the Permanent Works, shall be considered the trial length for these joints. The trial length shall comply for strength and density with the Specification in all respects, with the following additions and exceptions:

- In checking for compliance with Table the levels shall be taken at intervals of not more than 2.5 m along any line or lines parallel to the longitudinal centre line of the trial length.
- The maximum number of permitted irregularities of pavement surfaces shall comply with the requirements of Table for 300 m lengths. Shorter trial lengths shall be assessed pro-rata based on values for a 300 m length.

- At least 3 cores of minimum diameter 100 mm shall be taken from the slab at joints to check the lateral and vertical location of joint grooves and bottom crack inducers.
- Alignment of dowel bars shall be inspected as described in Clause 7.4.12 in any two consecutive transverse joints. If the position or alignment of the dowel bars at one of these joints does not comply with Clause 7.4.7, but if that joint remains the only one that does not comply after the next 3 consecutive joints of the same type have been inspected, then the method of placing dowels shall be deemed to be satisfactory. In order to check sufficient joints for dowel bar alignment without extending the trial length unduly, the Contractor may construct joints at more frequent joint intervals than the normal spacing required.
- If there are deficiencies in the first expansion joint that is constructed as a trial, the next expansion joint shall be a trial joint. Should this also be deficient, further trial expansion joints shall be made as part of a trial length. Deficient expansion joints shall not form part of the Permanent Works.
- Compliance with Clause 7.4.8 for the position and alignment of tie bars shall be checked by drilling additional cores from the slab unless they can be determined from cores taken for density assessment.

The Contractor shall not proceed with normal working unless the trial length complies with the Specification and any earlier defective trial lengths have been removed, unless they can be remedied to comply with the Specification. After satisfactory completion of the trial length, the constituent materials, concrete proportions, plant, equipment and construction methods shall not thereafter be changed, except for normal adjustments and maintenance of plant, unless the Contractor lays a further trial length as described in this Clause to demonstrate that the changes will not adversely affect the Permanent Works or in agreement of the changes with the Employer's Representative.

7.4.16 Texturing of Hardened Concrete

Worn, rain damaged or inadequately textured surface slabs shall be macro-textured by sawing grooves in the hardened concrete surface at right angles to the longitudinal axis of the pavement with machines using diamond or other abrasive cutting discs. Grooves shall be irregularly spaced and shall be not less than 2 mm and not more than 5 mm wide. The sequence of distances between groove centres in mm shall be: 40, 45, 35, 45, 35, 50, 30, 55, 35, 30, 50, 30, 45, 50, 30, 55, 50, 40, 35, 45, 50, 40, 55, 30, 40, 55, 35, 55. A tolerance of ± 3 mm shall be allowed on each of the spacing's. The minimum width of grooving head shall be 500 mm and a head not providing a complete sequence of spacing's shall use the number of spacing's appropriate to its width commencing at the start of the sequence.

Groove depths shall be measured using a tyre tread depth gauge and measurements shall be taken as follows:

- At 10 locations at least 2 m apart along a diagonal line across a lane width between points 50 m apart longitudinally. No measurement shall be taken within 300 mm of the longitudinal edge of a slab. Where a grooved area is less than 50 m in length the locations where measurements are taken shall be as proportional to the requirements for 50 m.
- At each of the 10 locations the depth of 10 adjacent grooves shall be measured.

- The average of each set of 10 measurements shall be not less than 3 mm nor greater than 7 mm.

Slurry from the sawing process shall be prevented from flowing into joints, drains or into lanes being used by traffic and all resultant debris from the grooving shall be removed.

7.4.17 Weather Conditions

Road pavement materials in a frozen condition shall not be incorporated in the Works but may be used, if acceptable, when thawed. Road pavement materials shall not be laid on any surface which is frozen or covered with ice. The temperature of concrete in any pavement layer shall not be less than 5ºC at the point of delivery. These materials shall not be laid when the air temperature falls below 3ºC and laying shall not be resumed until the rising air temperature reach 3ºC unless all surfaces of the concrete slabs are protected by thermal insulation blankets laid immediately after placing and finishing the concrete. The insulation shall be placed before the temperature of the concrete surface has dropped below 2ºC and shall be retained for a minimum of 3 days or until the concrete is assessed to have reached 50% of the specified characteristic compressive strength provided the air temperature is above 0ºC and rising at that time. Thermal insulation blankets shall be closed cell polyethylene foam sheets, minimum 10 mm thick with a 'U' value of 4 watts/mC (or K value of 0.04 watts/m Kelvin) or suitable material with an equivalent or lower thermal conductivity. They shall be sufficiently robust and capable of being held in place against variations in wind and weather conditions for the necessary curing time.

7.4.18 Construction Traffic

Construction plant and traffic used on pavements under construction shall be suitable in relation to the material, condition and thickness of the courses it traverses so that damage is not caused to the sub-grade or the pavement courses already constructed. The wheels or tracks of plant moving over the various pavement courses shall be kept free from deleterious materials.

Concrete slabs may be used by traffic when the cube compressive strength is assessed to have reached 25 N/mm². In the absence of test data establishing compliance, no vehicle with an axle loading greater than 2 tones shall run on concrete slabs within a period of 14 days after placing the concrete. Vehicles with rubber tyres with an axle loading less than 2 tons, or wheels or tracks of concreting plant, shall not use any part of a newly constructed pavement within 7 days. The above periods before traffic may run on the pavement shall be increased if the 7 day cube strength is below that what is required in the Specification. These periods shall be extended by one day for each night on which the temperature of the layer falls to 0ºC or below.

8 WATER PROOFING SYSTEM

8.1 General

Sheet water-proofing membrane systems for the tunnel shall comprise of a geotextile fleece fixed to the primary lining substrate in combination with a sheet water-proofing membrane fastened to this; see Section 8.5 for details of installation. Waterproofing shall be applied to crown and sidewalls above footing or invert arch level. The waterproofing membrane shall always be located between primary support and final concrete lining. As the underground structures referred to be not immersed below a distinct groundwater table no membrane waterproofing will be provided for tunnel inverts. Where the water-proofing system is to be divided into sectors, the water stops should be formed of material that can be welded to the sheet waterproofing membrane. Additional drainage capacity can be provided by studded drainage membrane made from thermoplastic material (dimpled sheet) attached prior to installation of the geotextile fleece.

Waterproof membranes shall not be stored in direct sunlight prior to use. Waterproof membranes shall be protected from damage at all times especially during installation of reinforcement.

8.2 Geotextile Fleece

The purpose of the geotextile fleece is to protect the sheet membrane against mechanical puncture and to provide a drainage path for any ground water along the rock side of water proofing system around the tunnel structure. The geotextile, used in combination with dimpled sheet as strip drain is to protect the dimpled sheet and allows the inflow of ground water into the dimpled sheet drainage area. The geotextile fleece shall be a non-woven fleece and shall provide a minimum weight of 500 g/m² in tunnel vault and 900 g/m² in tunnel invert if required and in c&c tunnels, in accordance to the Specification set forth in Table 8.1.

Table 8.1: Requirements on geotextile fleece

Description	Standard	Requirement	
		500 g/m²	900 g/m²
Mass per unit area	BS EN ISO 9864	≥ 500 g/m²	≥ 900 g/m²
Nominal weight	BS EN ISO 9864	≥ 556 g/m²	≥1000 g/m²
DSC analysis	BS EN ISO 11357-1 & -3	Tolerance of melting temperature ≤±10%	
Thickness under normal pressure	BS EN ISO 9863-1	Within the tolerances of the manufacturer	
2 kPa			
200 kPa		≥1.7 mm	≥3.4 mm
Tensile strength in Longitudinal and transversal direction to the direction of production	BS EN ISO 10319	≥30 kN/m	≥50 kN/m

Elongation at break in longitudinal and transversal direction to the direction of production	BS EN ISO 10319	Within the tolerances of the manufacturer	
Elongation at maximum Tensile force	BS EN ISO 10319	≥50%	
Static puncture	BS EN ISO 12236	≥3kN	≥7kN
Cone drop test	BS EN ISO 13433	≤13mm	≤7mm
Behavior during oxidation	BS EN ISO 13438	Design life of minimum 25 years in compliance with BS EN 13256	
Behavior in basic Environment (pH≥9)	BS EN 14030 and BS EN ISO 10319	Decrease of tensile strength and elongation at break during design life of 25 years: ≤20%	
Behavior during fire	BS EN ISO 11925-2 and BS EN 13501-1	Class E	
Permeability in flow direction with 200 kPa	BS EN ISO 12958	≥7l/(m*h)	
Protection	BS EN 14574	≤0.1 mm	

The geotextile is to provide adequate protection from chemical aggression caused in the cur ing processes of concrete. Water transmissivity of the geotextile fleece should be designed to suit expected volume of water ingress.

8.3 Fixing Element

The geotextile is fixed onto the substrate with non-projecting disks. The disks are secured through the geotextile and into the substrate with shot-fired nails. The disks should be made of a compound that allows the sheet waterproofing membrane to be fully welded to the surface. In order to prevent stresses being transferred from the secondary lining to the sheet water-proofing membrane, the resistance to failure in shear of the nails and disks must be less than the shear resistance of the sheet membrane itself.

8.4 Waterproof Membrane

The waterproof membrane shall consist of a continuous impermeable heat-welded sheet of one of the following materials:

- soft polyvinyl chloride (PVC) unreinforced
- flexible polyolefin (FPO/TPO) unreinforced
- high-density polyethylene (HDPE) in accordance with DIN 16776 Parts 1 and 2
- ethylene copolymerical bitumen (ECB).

The membrane as supplied shall be of such dimensions and shape as will result in the minimum of on-site seam welds.

Unless otherwise stated in the Contract, the membrane shall conform to performance requirements and have properties shown in Table 8.2.

Table 8.2: Performance requirements of sheet waterproof membranes

Thickness	BS EN 1849-2	2,0 mm ±10%
Tensile Strength	BS EN ISO 527-3	16 MPa
Elongation at break	BS EN ISO 527-3	Not less than 300% (-
Resistance under water pressure	BS EN 1928 method B	5 bars at 1 hour
Root resistance	DD CEN/TS 14416	No penetration
Tear resistance	BS EN 12310-2	80 N/mm
Tensile strength of welded seam	BS EN 12317-2	Cracks occur next to the seam
Water absorption	BS EN ISO 62	<4,0%
Fire rating	BS EN ISO 11925-2	Self-extinguishing
Smoke class	BS EN ISO 11925	E

Further guidance on test methods and requirements for mechanical properties and durability can be found in BS EN 13492:2004 (E): “Geosynthetic barriers – Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures”.

Where reinforced concrete is to be placed against the sheet waterproofing membrane, a signaling layer, to give a visual indication of any mechanical damage, shall be provided on the exposed surface of the waterproofing membrane. The signaling layer shall be such that it does not adversely affect the seam welds.

8.5 Installation

The manufacturer's instructions for installation of felt backing and waterproofing membrane, including procedures for preparation, fixing, welding and splicing, flashing shall be followed solely by the Contractor.

Prior to application of the geotextile fleece layer the primary lining shall be surveyed to confirm that it does not encroach into the designed extrados of the secondary lining. Any proposals to rectify areas of the primary lining shall be agreed with the Employer’s Representative.

The sprayed concrete lining shall be constructed in a way that all bolts and anchors are fully covered with sprayed concrete of the primary lining. The surface shall be prepared in accordance with the manufacturer’s instructions. Except where indicated on the drawings, all fixtures shall be removed from the primary lining prior to application of the geotextile fleece layer. All core holes shall be backfilled with mortar to be flush with the surface of the primary lining.

For sheet waterproof membranes, the profile of the substrate (tunnel surface) shall not have any irregularities that exceed a ratio of length to depth of 5:1 and its minimum radius shall be 200 mm. Transitions and intersections of tunnel profiles shall be rounded off with a minimum radius of 500 mm. The substrate surface shall be free from protrusions or sharp edges which may lead to membrane puncture. Crushed aggregates of a grain size greater than 8 mm shall not be used.

Groundwater penetrating through the primary tunnel lining shall be collected and drained by appropriate measures. This drainage shall be maintained throughout the membrane placing process, and shall be so arranged that excess water pressure behind the membrane cannot develop. All sprayed concrete surface shall finally be smoothened with fine-graded sprayed concrete (rounded aggregates, grain size 0 - 8 mm), applied in a layer of 30 mm minimum thickness. A layer of protective geotextile shall be attached to the substrate by suitable non-projecting fastenings installed directly through the geotextile fleece. When fixing the geotextile fleece overhead, sufficient fixings shall be installed to ensure the fleece is in close contact with the substrate and is self-supporting. The sheets shall overlap by at least 200 mm. When placing the sheet waterproof membrane, no other Works shall be carried out in the vicinity which may cause personnel or equipment to come into contact with the sheet waterproof membrane before it has been protected. If it is likely that excessive dust may be generated in the vicinity of the Works (vehicle movements etc.), then dust suppression measures shall be put in place. The amount of membrane stored in the tunnel shall not exceed one day's production to minimise the fire load stored underground. The sheet waterproof membrane shall be fixed to the tunnel structure by means of fastening devices which preserve the integrity of the sheet waterproof membrane. Sufficient fixings shall be installed to ensure the fleece is in close contact with the substrate and is self-supporting. No perforation of the membrane shall be allowed for installation purposes. The waterproofing membrane shall be laid with the signal layer towards the inside and with sufficient slack to prevent overstressing during concreting. All sheet waterproof membrane overlaps shall be welded in accordance with the membrane manufacturer's instructions. Where waterproof membrane has been installed in the tunnel invert, it shall be protected from any damage as soon as possible after testing. Radial joints between sheets of sheet waterproof membrane shall be welded using flat-faced fillet welds. Two lines of weld shall be used on each joint forming a double seam of at least 15 mm wide, with the minimum sheet waterproof membrane overlap 80 mm for manual welding and 100 mm for automatic welding. If protrusions through the membrane are required, they shall be fitted with collars to maintain the water tightness of the system. Star or cross joints shall be avoided. The length of material roll shall be procured to enable a complete extrados to be installed as a continuous length. Longitudinal joints shall be avoided. The placing of inner lining concrete sequence and processes shall be such that they do not displace or damage the geotextile fleece or sheet waterproofing membrane.

8.6 Checking

8.6.1 Field Trials

Field trials shall be made to demonstrate the capability of the equipment, workmanship, materials and application methods under field conditions. The testing program shall be started sufficiently early prior to installing the membrane to ensure that the required water-tightness can be achieved and allow repetition of the trials should the initial results prove unsatisfactory. All trials and acceptance tests shall be completed satisfactorily by the time installation commences. Prior to construction, trials shall be carried out in order to establish the speed and temperature

of joint welding required achieving welds which are acceptable to the Employer's Representative. If hand-welded joints are proposed at junctions, then this type of weld shall be pre-tested and agreed with the Employer's Representative.

8.6.2 Construction Testing

A visual inspection of the sheet waterproof membrane shall be carried out as specified in Table 8.3. Areas where the sheet waterproof membrane is damaged shall be marked up; repairs carried out and tested in accordance with the manufacturer's instructions. All welded joints shall be tested in accordance with Table 8.3. Any joints that fail the test and require repair shall be marked with a permanent marker, at the time of the test. Repairs and hand-welded joints shall be tested by hand-held vacuum chamber in accordance with Table 20.

Table 8.3: Construction testing for sheet waterproof membrane

Parameter	Test Method	Frequency	Pass Criteria
Coverage	Visual	A visual inspection to be carried out continuously while the membrane is applied	100% coverage
Double welded seam joints	DIN 16726	Every joint	Pressure drop not to be greater than 20% when a 2 bar pressure is applied for 10 minutes
Hand welding and repairs	ASTM D5641-94 (2006)	Every hand-weld and repair	Pressure drop not to be greater than 20% when a 0.3 bar pressure is applied for 10 minutes

A visual inspection of the fleece shall be carried out. Areas in which the substrate is still visible, or where the fleece is damaged, shall be marked up and an additional layer of fleece applied with a minimum lap of 200 mm around the area.

8.6.3 Failure Measures

Where tears, rips or defective joints in the geotextile fleece are noted, these shall be repaired with a minimum overlap of 200 mm.

Where tears, rips or defective joints in the sheet waterproof membrane are noted, these shall be repaired in accordance with manufacturer's recommendations. These shall be tested by hand-held vacuum chamber in accordance with Table 8.3.

Any sheet waterproof membrane not meeting specified requirements shall be removed and replaced including any associated water management measures or smoothing layer. The cause of the problem shall be rectified before placing any further sheet waterproof membrane.

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