# 1 DESIGN ASPECTS

## 1.1 BASIC DESIGN PARAMETERS

### 1.1.1 General

1 The works shall be designed in accordance with the standards specified by the Employer's Requirements.

2 If no local standard exists or the applicable standard is not specified otherwise, the appropriate and compatible internationally recognised standard or code of practice shall be adopted.

3 A consistent set of standards that specifically apply to the design of civil and structural elements shall be adopted.

4 The hierarchy of standards is as follows:

(a) Qatar Construction Specifications;

(b) Euro Norms (EN);

(c) National European Standards; and

(d) International Standards and Codes of Practice.

5 The purpose of QCS is to provide as a general technical guide for acceptable construction work practices in the State of Qatar, considering this; any addition for technology, material, specification, standard that are not mentioned in this section or their modification, shall be subject to approval as stated in the introduction of QCS (00-02).



### 1.1.2 Design Philosophies

1 The design shall ensure and demonstrate throughout the Works that the requirements of future operation and maintenance (O&M) activities have been considered and incorporated to produce a design that is based on a whole-life approach that optimises both capital and operating cost. Evidence of this approach shall be incorporated into the Contractor's project plans and, particularly, in the design documentation.

2 The design shall ensure and demonstrate throughout the Works that construction and O&M safety requirements have been included and incorporated into the design. Evidence of these considerations shall be included in the Contractor's project plans.

3 The design shall ensure that both the serviceability and ultimate limit states have been checked in accordance with the standards and codes as specified herein.

4 The design shall take full account of the prevailing soil and groundwater conditions and those predicted to occur at the site within the design life of the Works.

### 1.1.3 Deflection Criteria

1 Deflection Limits

(a) The deflection of a structure or part thereof shall not adversely affect the appearance, functionality, durability or efficiency of the structure, or associated finishes or partitions.

(b) The deflection of a structure shall comply with the applicable design codes and standards as specified herein.

(c) The final deflection due to all loads including the effects of temperature, creep and shrinkage shall be measured from the as-cast level of the supports of floors, roofs and all other horizontal members and should not exceed the ratio of (span)/500.

### 1.1.4 Durability Requirements

1 Durability requirements shall be addressed throughout the design, construction, operation and maintenance of all assets and shall be reflected in the Contractor's project plans and O&M manuals.

2 The design shall consider the highly aggressive nature of the geological conditions in Qatar with regards to soluble sulphate, chloride and salt concentrations. This shall be taken into account for durability purposes when designing the underground structures.

3 In designing structures and selecting materials for durability, reliance shall not be placed solely on the recommendations of codes and standards, but due account shall be taken of the environment in which the structures are situated and to the monitoring and maintenance works required to maximise the life of the structures.

4 The primary approach to designing concrete elements for durability shall be based on the need to achieve a high quality and relatively impermeable concrete, paying particular attention to structural detailing. Construction joints in underground conditions are vulnerable to deterioration by aggressive agents and shall be designed to incorporate details that provide two lines of defence against leakage.

5 The presence of highly aggressive groundwater requires careful design of resistant concrete mixes, increased cover to reinforcing steel, close control of flexural cracking and very careful detailing of gaskets, water bars and hydrophilic water stops to ensure water tight, durable structures.

6 Particular attention shall be given to the detailing and appropriate selection of durable tunnel lining materials. Lining materials (concrete and reinforcement) and lining components (gasket seals and fixings) are to be designed and specified to satisfy the durability requirements.

7 Particular attention shall be given to the deterioration of those elements which cannot be easily accessed for maintenance or repair during the design life, such as reinforcement within the inaccessible faces of structures. In such a case the design shall ensure that the durability of the element can be achieved without maintenance.

8 Where the structure interfaces with, or is in close proximity to other light rail or metro facilities, provisions to reduce and control stray current shall be adopted to mitigate associated corrosion problems.

9 Where particularly aggressive conditions are found, a detailed assessment shall be carried out to determine if the installation of a full cathodic protection system and/or a corrosion monitoring system is needed in order to achieve the design life of the structure.

10 Cathodic protection shall be considered for all underground reinforced concrete structures. Connection points and other necessary devices shall be provided to enable the future installation of a cathodic protection system or electro chemical chloride extraction using electrical techniques in retaining walls and concrete reinforcement cage continuity. For diaphragm wall construction, connection points and other necessary devices shall be provided at each panel.

11 The Design shall include analysis of thermal strains and stresses to mitigate early-age cracking.

12 The Design shall address all physical or chemical factors such as corrosion, chloride penetration, carbonation, sulphate cracking and corrosion of the steel reinforcement, steel spacer, steel accessories, embedded items and similar components that adversely affect the durability of the Works shall be identified and taken into account in the design to ensure the specified design life is achieved.

### 1.1.5 Fire Resistance Period

1 All structures shall be designed for fire protection as specified by the Qatar Ministry of the Interior General Directorate of Civil Defence and as otherwise specified by the Contract. Materials specified for the Works shall be non-combustible and shall not emit toxic fumes when subject to heat or fire. In all cases where there are significant fire risks the materials shall be self-extinguishing, low flammability, low smoke and low toxicity.

### 1.1.6 Crack Width

1 All structural concrete elements shall be designed to prevent excessive cracking due to flexure, early age thermal phenomena and shrinkage. The maximum crack widths shall be as specified in Table 1.1.

### 1.1.7 Flexural Cracking

1 Flexural crack width shall be checked in accordance with the applicable design codes and standards as specified herein. The limits specified in the table below shall apply irrespective of whether any additional protection, such as a waterproofing membrane, is applied to the elements of the structure.

### 1.1.8 Early Age Thermal and Shrinkage Cracking

1 Suitable reinforcement shall be designed to prevent early-age thermal and shrinkage cracking for walls and slabs of more than 250 millimetres in thickness if they are subjected to internal and external restraint during construction. Thermal and shrinkage strains due to early-age temperature differences and shrinkage shall be accounted for in the design of reinforcement for cracking.

2 The preferred method for control of early age thermal and shrinkage cracks is to use small diameter reinforcing bars placed at close intervals. The limits specified in table below shall be imposed. CIRIA Report C660 on Early Age Thermal Control of Concrete Shall be followed

3 For massive structural elements additional considerations shall be taken into account, including the duration of hydration and the related concrete strength.

Table 1.1
Crack width limits

| Element | Exposure Condition | Max. Crack Width [mm] |
|---|---|---|
| Concrete surface In direct contact with the ground/blinding with or without a waterproofing membrane | Very severe | 0.15 |
| Above ground, external concrete surfaces | Severe | 0.20 |
| All other concrete surfaces | Moderate | 0.30 |

### 1.1.9 References

1 The following standards are approved and/ or referred to in this Section:

CIRIA Report C660 ....Early-age thermal crack control in concrete(CIRIA Report (C766) Control of cracking caused by restrained deformation in concrete)

EN 1991 .....Eurocode 1: Actions on structures:

EN 1991-2 .....Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges

EN 1992 .....Eurocode 2: Design of concrete structures:

EN 1993 .....Eurocode 3: Design of steel structures:

EN 1997 .....Eurocode 7 - Geotechnical design:

EN 1998 .....Eurocode 8: Design of structures for earthquake resistance:

## 1.2 LOADS AND LOAD REQUIREMENTS

### 1.2.1 General

1 Unless specified otherwise the design of concrete and steel elements shall conform to the following:

(a) Qatar Construction Specifications, QCS;

(b) Euronorms (EN)

### 1.2.2 Nominal Loads

1 As a minimum, for the purpose of computing stresses and deformations, the following load types and consequential effects shall be taken into account as applicable.

Table 1.2

Loading Types

| Loading Type | Acronym |
|---|---|
| Dead loads (including notional loads) | DL |
| Superimposed Dead loads | SIDL |
| Imposed (Live) loads | LL |
| Railway loads | RL |
| Fatigue | GG |
| Dynamic | DY |
| Derailment | DR |
| Wind Loads | WL |
| Temperature loads | TE |
| Seismic Loads | EQ |
| Construction/Erection | ER |
| Shrinkage | SH |
| Creep | CP |
| Movement/ Distortion | MD |
| Earth Pressure | EP |
| Surcharge | SR |
| Hydrostatic | WP |
| Accidental | AC |
| Redundancy | R |



### 1.2.3 Design Loads

1 Design loads shall include:

(a) The weight of the load carrying structures themselves ('self-weight') and the loads imposed on to them, dead, live and accidental (including seismic, impact, fire and explosion) loads;

(b) The deformations imposed on to the structures by temperature variations, concrete shrinkage and creep and other similar factors; and

(c) Any loading, caused by any source of vibrations and other similar factors.

### 1.2.4 Dead Loads

1 Self-weight of the materials shall be calculated in accordance with the relevant codes as specified herein.

### 1.2.5 Superimposed Dead Loads and Imposed (Live) Load

1 Superimposed dead loads include the weights of all the permanent elements of the structures (except the load bearing elements), such as floor and roof finishes, cables, trackwork and other similar installations, to the dimensions in the Contractor's design.

2 The self-weights of the elements in (a) above shall be assessed according to the relevant codes and standards, by other valid sources, or by substantiated and controllable manufacturer's information, or by experimental measurements.

3 For live loads on all underground structures beneath green areas (such as squares, parks, open-air recreation areas) a minimum distributed load of 10 kN/m$^2$ on the entire surface of the roof of the structure, at ground level, shall be assumed.

4 For all stations the minimum distributed and concentrated loads shall be in accordance with the table below.

Table 1.3

Superimposed Dead Loads (SIDL) & Imposed (Live) Load

| Area Description | Superimposed Dead Load #1 | | Imposed Load #1 | |
|---|---|---|---|---|
| | Finishes [kN/m²] | Ceiling & Services [kN/m²] | Uniform Distributed Load [kN/m²] | Concentrated Load #2 [kN] |
| Public Area | 5.0 | 1.0 | 5.0 | 5.0 |
| Non-public Area #3 | 5.0 | 1.0 | 3.5 | 5.0 |
| Under platform | 2.5 | 1.0 | 10.0 | 10.0 |
| Stairs and Landings | 2.5 | 1.0 | 5.0 | 5.0 |
| Equipment Rooms | 2.5 | 1.0 | 10.0 | 10.0 |
| Surcharge Load on Roof Slabs | | | 10.0 | 100.0 |
| Elevated and at grade stations and entrance shelters – roof cladding | 2.0 | 2.0 or 0.7 #4 | | |

*#1 this is a minimum requirement. If higher loads apply due to architectural, MEP or any other circumstances, these shall be used.*

*#2 concentrated load distributed on an area 300 x 300 mm.*

*#3 Areas like offices, staff rooms, toilets etc. (not equipment rooms).*

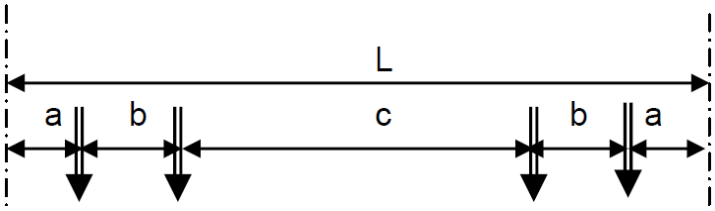
*#4 At the location where the cladding to the underside of the roof changes from an exterior finish to an interior ceiling finish, the ceiling and services load can be reduced from 2 kN/m² to 0.7kN/m²*

### 1.2.6 Railway Loads

1 Vertical Train Live Loads

(a) Each component of the structure shall be designed / checked for all possible combinations of these loads and forces. They shall resist the effect of all combinations:

Figure 1.1
Vertical Train Live Loads




Axle loads = 16 tons

Maximum number of successive cars = 6 car or 2 units

L = max 20 m (Length of a car)

a = 2.65m for the external cars of a 3 car set and 2.35m for the internal car of a 3 car set (Overhang)

b = 2.10m (Wheel base in a bogie)

c = 10.50m (Distance between Axle-2 and Axle-3 in the car)

(b) The maximum number of axles will be applied to the structure to arrive at the maximum vertical force, maximum shear and maximum bending. The structure shall be suitable for both single-track and (double) 2-tracks load conditions.

2 Horizontal Train Live Loads

(a) The braking loads shall be assumed to be 30% of the vertical loads. The traction loads shall also be assumed to be 30% of the vertical loads. Where the structure carries two tracks, both tracks shall be considered to be occupied simultaneously. Traction forces shall be considered as acting on one track and braking forces acting on the other, with both forces acting in the same direction simultaneously to produce the worst loading condition in the rails and supporting elements. Provision shall be made in supporting elements for the effects of horizontal and vertical forces transferred to rails.

(b) Centrifugal Force shall be considered, taking into account a design speed for various radii of curvature as stipulated in the alignment design specification.

(c) Hunting/noising forces shall be considered in accordance with EN 1991.

### 1.2.7 Fatigue

1 The nominal loadings on the structures for the purposes of the Contractor's fatigue assessment shall comprise trains as advised by the Engineer.

2 Fatigue load histories shall be evaluated to provide valid and representative design spectra, with stress histories analysed by the rain-flow counting algorithm or equivalent method, both in conjunction with the projected annual tonnages of rail traffic per track. The provisions of BS 5400 Part 10 Clause 9.3.3 or other relevant methods may be used as a rigorous method of evaluation of compliance with fatigue criteria.

### 1.2.8 Dynamic Effects

1 Dynamic effects resulting from the operation of the metro system shall be considered in accordance with EN 1991 and EN 1998.

### 1.2.9 Derailment

1 The impact loads on adjacent structures due to derailment shall be considered at all locations.

2 The adjacent structures are to be protected by direct means (e.g., strengthening) or indirect means (e.g., repositioning of rail alignments or providing barriers) to ensure these structures are still functional after an impact occurs.

3 Where indirect measures are employed in the design these can be considered when calculating the impact loads.

### 1.2.10 Temperature

1 The effects of temperature shall be considered in the design of the Works using the external temperatures as stated in the Qatar Rail Development Program Definition Document.

### 1.2.11 Wind

1 Wind loading will affect the surface elements such as vent-shafts, cooling towers, pedestrian bridges and entrances/exits. It is also a factor on temporary structures during construction. As per EN 1991, fundemental wind speed of 160 km/h shall be applied to determine the appropriate design wind loads.

2 Applied wind loads on bridges and other above ground structures shall be in accordance with EN 1991.

### 1.2.12 Seismic Loads

1 Seismic effects shall be considered on all permanent structures.

2 The effects of load changes and deformation as a result of soil behaviour (eg, liquefaction) shall be allowed for in the design.

3 The design of the tunnels final linings shall be made for static loadings and shall be checked against the seismic loadings, by any simplified method similar or comparable to the method developed for the San Francisco Metro (‘Earthquake Design Criteria for Subways’, ASCE, Volume 95, No ST6, June 1969, pp 1213-1231).

4 The seismic design of all structures shall comply with the requirements of EN 1998 and the clauses of EN 1992 and EN 1993 where relevant.

5 The Works shall be designed to withstand a seismic peak ground acceleration (horizontal) of 0.07g.

### 1.2.13 Groundwater and Uplift Loads

1 Loads due to water pressure shall be calculated using a unit weight of 10 kN/m³ for fresh water and a unit weight of 10.3 kN/m³ for brackish-water. Should liquefaction of soils be a potential risk, then the design water table level for permanent structures shall include layers affected by liquefaction if this is above the design groundwater levels. The effects of temporary drawdown, seepage and base heave effects shall be considered in the design of the temporary works, and catered for in the permanent works if there is a 'locked-in' effect from transferred forces. The extent of the temporary walls shall be sufficient to mitigate the effects of such loads during construction.

2 Groundwater level for design of the permanent structure shall be assumed at ground level unless long-term (i.e. over 10 years) groundwater data is available and sufficient to accurately predict the groundwater level over the design life of the structure, the Contractor may propose a revised design ground water level based on the maximum groundwater level plus an additional 2m. The revised design ground water level will be subject to independent verification prior to submission to the Engineer for ~~a~~ approval. For Temporary Works, the design groundwater level shall not be lower than 500 mm above the maximum present groundwater level.

3 The effects of floatation loads shall be considered in the design of both the Temporary and Permanent Works. The Contractor shall check the structure's stability for resistance to buoyancy and shall design the structure such that adequate factors of safety against buoyancy are provided. For this check overburden height less 2m for the possible excavation for utilities in the future shall be considered. A study showing different possible scenarios for future excavation above the stations shall be considered in the buoyancy check and submitted to the Engineer for approval.

4 Protection against buoyancy shall comply with EN 1997.

5 Suitable measures from those listed below to counteract buoyancy forces for the Permanent Works shall be incorporated in the Contractor's design. The measure(s) chosen shall suit the particular conditions and the method of construction:

(a) Toe-in of the base slab into the surrounding ground; and

(b) Increasing the dead weight of the structure.

6 Where the base slab has toe-in to the surrounding ground, a partial safety factor of 2.0 shall be applied to the shear resistance of the ground above the toe and the adhesion factor shall not apply. The value of the weight of ground above the toe shall be calculated as for the backfill material.

7 If tension piles are used to counteract buoyancy forces, special precautions shall be made to preserve the integrity of the waterproofing system and the durability of the tension pile. These precautions shall be submitted to the Engineer for a SONO.

8 The proposed structures (primarily the stations) may act as obstructions to groundwater movement. The Contractor shall design and subsequently allow for unobstructed movement of the groundwater through and around these structures so that there are no changes to the groundwater level that exceeds normal expected diurnal fluctuations.

### 1.2.14 Highway Loading

1 Highway loading shall not be less than that specified in EN 1991-2, LM 1.

2 Loads shall be applied for the worst-case combinations and shall be multiplied by the specified impact coefficients. No dynamic allowance shall be added for underground structures with an overburden greater than 1 m.

3 For underground structures beneath existing or planned public roads with a minimum ground cover thickness equal to or greater than 2.0 m a minimum uniform live load of 20 kN/$m^2$ shall be applied at any position and configuration to give the worst-case loading. Whenever the minimum cover thickness is less than 2.0 m, the live load shall be determined precisely.

### 1.2.15 Loading Combinations

1 The load factors and load combinations shall comply with EN 1991 and EN 1997.

## 1.3 SUBMISSIONS

### 1.3.1 General

1 For all submissions to the Engineer for his review, the Engineer will allocate a status of:

(a) Statement of No Objection (SONO)

(b) No Objection With comments (NOWC)

(c) Fail

END OF PART