CHAPTER 4

DESIGN STANDARDS AND SPECIFICATIONS

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4.1 Bridges

4.1.1 General Description

The Detailed Design of the proposed facilities will be basically carried out in accordance with the "Highway Design Manual (Sultanate of Oman)" (hereinafter referred to as "Omani Design Manual") as the prime design standards. The Omani Design Manual is largely based on design standards established by the American Association of State Highway and Transportation Officials (hereinafter referred to as "AASHTO"). The actual design works for the proposed facilities are to be carried out in Japan. Although the principal design concept is in accordance with the Omani Design Manual and AASHTO standards, various detailed calculation method will be based on Japanese specification as listed in 4.1.2 below.

STRUCTURAL CALCULATION METHOD

The structural calculation method for the detailed design will basically follow the "Allowable Stress Design (service load design) Method" in accordance with "Specifications for Highway Bridge" practiced in Japan. However, prestressed concrete structures will be so designed as to ensure their safety in the ultimate loading condition prescribed in these specifications.

4.1.2 Authorized Design Standards to be Applied

The following Standards will be applied for this detailed design study.

【Sultanate of Oman】

- Highway Design Manual
  - Volume I (February, 1994)
  - Volume II (January , 1994)
- General Specifications for Roads (April, 1994)

【U.S.A】

[American Association of State Highway and Transportation Officials]

- A Policy on Geometric Design of Highways and Streets (1990)
- Standard Specifications for Highway Bridges (Fifteenth Edition 1992)
- Standard Specifications for Transportation Materials and Methods of Sampling and Testing
  - Part I
  - Part II

[American Society for Testing and Materials]

(hereinafter referred to as "ASTM")

- Annual Book 1995

- Section-1 Iron and Steel Products
- Section-4 Construction

[American Concrete Institute]
(hereinafter referred to as "ACI")
• Building Code Requirements for Reinforced Concrete (ACI 318-83)

【Japan】

[Japan Road Association]
• Road Structure Ordinance
• Specifications for Highway Bridges (February, 1994)
- Part Ⅰ Common
- Part Ⅱ Superstructure (Steel Bridges)
- Part Ⅲ Superstructure (Concrete Bridges)
- Part Ⅳ Substructure
- Part Ⅴ Seismic Design
• Design Guideline for Concrete Highway Bridges (February, 1994)
• Construction Guideline for Concrete Highway Bridges (February, 1994)
• Guideline for Road Design and Works
- Embankment
- Retaining Wall
- Temporary Works
• Guideline for Reinforced Earth Method
• Guideline for Drainage Design of Roads

[Japan Highway Public Corporation]
• Design Standard for Highway and Bridges (February, 1994)
- Part Ⅰ
- Part Ⅱ
- Part Ⅲ
- Part Ⅳ
- Part Ⅴ

The followings are other reference documents

【 Sultanate of Oman 】
• Rehabilitation of Batinah Highway (MOC)
- Tender Drawings-Volume 4 (August, 1993)

• Aqr - Seeb Second Carriageway (MOC)
- As Built Drawings- Plan and Longitudinal Section (1984)
- As Built Drawings- Details (1984)

- Rusayl - Nizwa Road Dualization (Muscat Municipality)
  - Tender Drawings- Part III

- Rehabilitation of Batinah Highway (MOC)
  - Al Bidayah Pedestrian Underpass- Design Drawings (July, 1993)

- Roads in the Southern Region Mughsayl to Dhalgut Road
  - Proposal to use "COB" units and "WEBSOL" walls

- Qurm-Rusayl Highway (MOC)
  - Roundabout and Flyover at Ghala- Volume 2 of 2 (1984 /85)

【 Japan 】

- All Japan Construction Technology Association
  - Standard Design for Civil Structures (Established by Ministry of Construction)

4.1.3 Design Standards and Specifications

a) Design Loads

1. Type of Loads

Structures will be designed to carry the loads and forces shown in the following table.

Classification	Types of loads
Principal load (P)	1. Dead Load (D) 2. Live Load (L) 3. Impact (I) 4. Prestressing Force (PS) 5. Effect of Creep of Concrete (CR) 6. Effect of Shrinkage of Concrete (SH) 7. Earth Pressure (E) 8. Hydraulic Pressure (HP) 9. Buoyancy or Uplift (B)
Subsidiary load (S)	10. Wind Load (W) 11. Thermal Effect (T) 12. Earthquake (EQ)
Particular loads to be regarded as Principal loads (PP)	13. Effect of Ground Movement (GD) 14. Effect of Displacement of Supports (SD) 15. Centrifugal Force (CF)
Particular loads (PA)	16. Longitudinal Force (LF) 17. Temporary Load during Erection (ER)

2. Dead Load (D)

The following unit weights of materials are to be used in computing the dead load.

Types of Dead Load	Unit Weight (kgf/m^3)	Types of Dead Load	Unit Weight (kgf/m^3)
Steel or cast steel	7850	Asphalt pavement	2300
Cast iron	7250	Bituminous material	1100
Aluminum alloys	2800	Compacted sand, earth and gravel	1900
Timber(treated or untreated)	800	Loose sand, earth, and gravel	1800
Concrete(plain)	2350	Underground water	1000
Concrete(reinforced or prestressed)	2500		
Cement mortar	2150		

3. Live Load (L)

The following live load will be considered for this detailed design.

Truck loading types:

1) Special truck type A
2) Special truck type B1
3) Special truck type B2
4) AASHTO Standards HS20-44 truck increased by 100%

Lane loading:

5) AASHTO HS20-44 loading increased by 100%

4. Impact (I)

Application :

Highway Live Loads will be increased for those structural elements in Group A, below, to allow for dynamic, vibratory and impact effects. Impact allowances will not be applied to items in Group B. It is intended that impact be included as part of the loads transferred from superstructure, but will not be included in loads transferred to footings nor to those parts of piles or columns that are below ground.

Group A - Impact will be included.

(1) Superstructure, including legs of rigid frames.

(2) Piers, (with or without bearings regardless of type) excluding footings and those portions below the groundline.

(3) The portions above the groundline of concrete or steel piles that support the superstructure.

Group B - Impact will not be included.

(1) Special Truck Type B1 and B2.

(2) Abutments, retaining walls, piles except as specified in the above (3).

(3) Foundation pressures and footings.

(4) Timber Structures.

(5) Sidewalk loads.
(6) Culverts and structures having 1.0m or more ground cover.

Impact Formula ;

$$I = \frac{15}{L+38}$$

in which
I = impact fraction (maximum 40 percent);
L = length in meter of the portion of the span that is loaded to produce the maximum stress in the structure member.

For uniformity of application, the loaded length ' L' in the above formula will be taken as:

(a) For roadway floors : the design span length.
(b) For transverse members, such as floor beams : the span length of member from center to center of supports.
(c) For computing truck load moments : the span length, or for cantilever arms the length from the moment center to the furthermost axle.
(d) For shear due to truck loads : the length of the loaded portion of span from the point under consideration to the far reaction; except, for cantilever arms, use a 40 percent impact factor.
(e) For continuous spans: the length of span under consideration for positive moment, and the average of two adjacent loaded spans for negative moment.

5. Longitudinal Forces (LF)

Provision will be made for the effect of a longitudinal force of 5% of the live load (a minimum longitudinal force of 46 tf will be considered.) in all lanes carrying traffic heading in the same direction. All lanes will be loaded for bridges, if they are likely to become one directional in the future. The load used, without impact, will be the lane load plus the concentrated load for moment specified in 4.1.3 a).3, with reduction for multiple-loaded lanes as specified in 4.1.3 a).8. The center of gravity of the longitudinal force will be assumed to be located 1.83m above the floor slab and to be transmitted to the substructure through the superstructure.

6. Centrifugal Forces (CF)

Structures on curves will be designed for a horizontal radial force equal to the following percentage of the live load, without impact, in all traffic lanes:

$$C = 0.00303S^2D = \frac{56.76S^2}{R}$$

where
C = the centrifugal force in percent of the live load, without impact;
S = the design speed in kilometer per hour;
D = the degree of curve;
R = the radius of the curve in meter

The centrifugal force will be applied 1.83m above the roadway surface, measured along the centerline of the roadway. The design speed will be determined with regard to the amount of superelevation provided in the roadway. The traffic lanes will be loaded in accordance with 4.1.3 a).3. with one standard truck on each design traffic lane placed in position for maximum loading.

Lane loads will not be used in the computation of centrifugal forces. When a reinforced concrete floor slab or a steel grid deck is keyed to or attached to its supporting member, it may be assumed that the deck resists, within its plane, and the shear results from the centrifugal forces acting on the live load.

7. Application of Live Load

Loading for Maximum Stress :
The type of loading, whether Special Truck Type A, B1, B2, Standard Truck Load or Lane Load, to be used will be the loading which produces the maximum stress for each design calculation of structures or members.

Traffic Lane Unit :
In computing stresses, each one-lane-width lane load or single standard truck will be considered as a unit. And only one special truck will be applied to a bridge at once in accordance with Omani Design Manual.

Lane Loads on Continuous Spans :
For the determination of maximum negative moment in the design of continuous spans, the lane load described in 4.1.3 a).3. will be modified by the addition of a second, equal weight concentrated load placed in one other span in the series in such a position as to produce the maximum effect. For maximum positive moment, only one concentrated load will be used per lane, combined with as many spans loaded uniformly as are required to produce the maximum moment.

8. Reduction in Load Intensity

Where maximum stresses are produced in any member by simultaneously loading a number of traffic lanes, the following percentage of the live loads will be used in view of the improbability of coincidental maximum loading:

	Percent
One or two lanes	100
Three lanes	90
Four lanes or more	75

The reduction in intensity of loads on transverse members such as floor beams will be determined as in the case of main trusses or girders, using the number of traffic lanes across the width of roadway that must be loaded to produce maximum stresses in the floor beams.

9. Sidewalk Loading

Sidewalk floors, stringers and their immediate supports will be designed for a live load of 500 kgf/m^2 of sidewalk area. Girders, trusses, arches, and other members will be designed for the following sidewalk live loads :

Span length (m)	L≦80	80<L≦130	L>130
Uniform load (kgf/cm^2)	350	430−L	300

10. Wind Loads (W)

Wind load will consist of uniformly distributed moving loads applied to the exposed area of the structure. The exposed area will be the sum of the areas of all members, including floor system and railing , as seen in elevation at 90 degrees to the longitudinal axis of the structure.

Superstructure Design :
For superstructures, a wind load of the following intensity will be applied horizontally at right angles to the longitudinal axis of the structure:

Shape of cross section	Wind load (kgf/m)
1≦B/D<8	[400−20(B/D)]D≧600
8≦B/D	240 D≧600

Where

B = the entire width of the superstructure
D = the entire height of the superstructure

Substructure Design :
For substructures, the forces to be applied directly to the members will be horizontal forces in perpendicular or parallel direction to the longitudinal axis of the bridge. However, the wind load will not act simultaneously in both directions.

The intensity of the wind load for the effective exposed substructure area against the wind direction will be as follows:

Shape of cross section of substructure body		Wind load (kgf/m^2)
Circular or Oval shape	with live load	75
	without live load	150
Square shape	with live load	150
	without live load	300

11. Thermal Effect (T)

i) The base temperature for the design calculation will be as follows:

	Temperature
Base temperature in the Sultanate of Oman --------------------------	+30℃

This value is based on the annual average temperature for past 8 years reported in the 1994 Statistical Yearbook.

ii) Range of Temperature for Structural Design

The range of temperature for structural design will generally be as follows:

	Change in Temperature
Range of temperature in the Sultanate of Oman ---------------	±0℃~+52℃

Rise and fall in temperature of the structures will be considered as a change between the base temperature and the range of temperature.

For Concrete Structures

	Temperature Rise	Temperature Fall
General concrete structures ----------------------	+15 ℃	−15 ℃
Structures with the minimum section size ------- of not less than 70 cm	+10 ℃	−10 ℃

The sectional force due to the difference of temperature between deck slab and other members will be calculated with assumption that the temperature distribution in deck slab and other members is respectively uniform and the relative difference of temperature between them is 5 ℃.

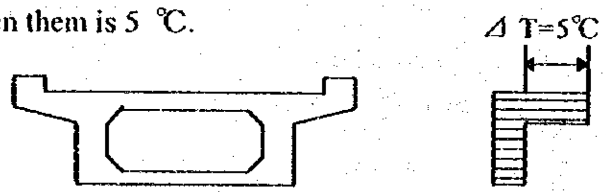


Figure 4.1:Assumed temperature distribution

iii) Coefficients of Thermal Expansion

The coefficients of thermal expansion will be as follows:

Classification	Coefficient of Thermal Expansion
Steel of Steel Structure	12×10^{-6} /℃
Reinforcing Bar and Concrete of Concrete Structure	10×10^{-6} /℃
Steel and Concrete of Composite Girder	12×10^{-6} /℃

iv) For the calculation of the amount of movement at movable bearing supports.

In the Sultanate of Oman, the range of temperature for the calculation of the amount of movement at movable bearing supports will be given as follows:

Type of Bridges	Range of Temperature
Prestressed or reinforced concrete bridge	±0℃～+52℃

v) The thermal effect for underwater or underground structures will not be considered.

12. Earthquake (EQ)

In regions where earthquake is anticipated, structures will be designed to resist earthquake motions by considering the seismic response of the soils at the site in accordance with Specifications for Highway Bridges - Part V Seismic Design (Japan). However, the acceleration coefficient for seismic loads will be taken as 0 in Dhofar Region, 0.2g in Musandam, and 0.1g elsewhere in accordance with Highway Design Manual in the Sultanate of Oman.

13. Earth Pressure (E)

The earth pressure will be taken as the distributed load acting on the wall surface, and the pressure as given by Coulomb's formula will be adopted. Therefore the intensity of load will be calculated by the following considerations:

Earth Pressure at Ordinary Time:

i) The earth pressure acting on movable wall will be calculated in accordance with following formulae:

For sandy soil

$$Pa = K_A \cdot \gamma \cdot x + K_A \cdot q$$

$$Pp = K_p \cdot \gamma \cdot x + K_p \cdot q$$

For cohesive soil

$$Pa = K_A \cdot \gamma \cdot x - 2 \cdot c \cdot \sqrt{K_A} + K_A \cdot q \quad \text{where } Pa \geqq 0$$

$$Pp = K_p \cdot \gamma \cdot x + 2 \cdot c \cdot \sqrt{K_p} + K_p \cdot q$$

in which

$$K_A = \frac{\cos^2(\phi - \theta)}{\cos^2\theta \cos(\theta + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi - \alpha)}{\cos(\theta + \delta)\cos(\theta - \alpha)}}\right]^2}$$

$$K_p = \frac{\cos^2(\phi + \theta)}{\cos^2\theta \cos(\theta + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi - \delta)\sin(\phi + \alpha)}{\cos(\theta + \delta)\cos(\theta - \alpha)}}\right]^2}$$

in case $\phi \pm \alpha < 0$, $\sin(\phi \pm \alpha) = 0$ will be used

ii) The earth pressure acting on fixed walls will be computed by using the following formula:

$Ps = K_S \cdot \gamma \cdot x + K_S \cdot q$

where

γ = unit weight of soil (tf/m³)

Pa= active earth pressure at depth x m (tf/m²)

Pp= passive earth pressure at depth x m (tf/m²)

Ps= earth pressure at rest at depth x m (tf/m²)

K_A= coefficient of active earth pressure as given by Coulomb's theory

K_p= coefficient of passive earth pressure as given by Coulomb's theory

K_s= coefficient of earth pressure at rest

x = depth of earth pressure Pa, Pp, Ps acting on the wall surface

c = cohesion of soil (tf/m²)

q = surcharge at ordinary time (tf/m²)

ϕ = shear resistance angle of soil (degree)

α = angle of ground surface to horizontal plane (degree)

θ = angle of wall rear surface to vertical plane (degree)

δ = wall surface friction angle between rear wall surface and earth (degree)

Angles used herein will be positive when they are measured counterclockwise.

Earth Pressure during an Earthquake:

The earth pressure during an earthquake will be treated as distributed load, and its intensity will be calculated as follows:

Intensity of active earth pressure

$P_{Ea} = \gamma \cdot x \cdot K_{EA} - 2c \cdot \sqrt{K_{EA}} + q' \cdot K_{EA}$

$$K_{EA} = \frac{\cos^2(\phi - \theta_0 - \theta)}{\cos\theta_0 \cdot \cos^2\theta \cos(\theta + \theta_0 + \delta_E)\left[1 + \sqrt{\frac{\sin(\phi + \delta_E)\sin(\phi - \alpha - \theta_0)}{\cos(\theta + \theta_0 + \delta_E)\cos(\theta - \alpha)}}\right]^2}$$

Intensity of passive earth pressure

$P_{Ep} = \gamma \cdot x \cdot K_{EP} + 2c \cdot \sqrt{K_{EP}} + q' \cdot K_{EP}$

$$K_{EP} = \frac{\cos^2(\phi - \theta_0 - \theta)}{\cos\theta_0 \cdot \cos^2\theta \cos(\theta - \theta_0 + \delta_E)\left[1 - \sqrt{\frac{\sin(\phi - \delta_E)\sin(\phi + \alpha - \theta_0)}{\cos(\theta - \theta_0 + \delta_E)\cos(\theta - \alpha)}}\right]^2}$$

where

P_{EA}= intensity of active earth pressure during an earthquake at depth x (tf/m²)

P_{EP}= intensity of passive earth pressure during an earthquake at depth x (tf/m²)

K_{EA}= coefficient of active earth pressure during an earthquake

K_{EP}= coefficient of passive earth pressure during an earthquake
x = depth at which earth pressures P_{Ea} and P_{Ep} act on wall surface
q' = surcharge during an earthquake (tf/m^2)
δ_E= wall surface friction angle between rear wall surface and earth (degree)
$\theta_0 = \tan^{-1} kh$
kh = design horizontal seismic coefficient.

However, $\sin(\phi \pm \alpha - \theta_0)=0$ when $\phi \pm \alpha - \theta_0 < 0$. The term q' will only be loads which certainly act during an earthquake, but not including live load.

13. Effect of Creep (CR) and Shrinkage (SH) of Concrete

The effect of creep and shrinkage of concrete to be considered in designing concrete members will be as follows:

i) The strain due to creep of concrete will be calculated by the following formula:

$$\varepsilon_{cc} = \frac{\sigma_c}{E_c}\phi$$

where

ε_{cc} = strain due to creep of concrete;
σ_c = stress of concrete due to sustained load (kgf/cm^2);
E_c = Young's modulus of concrete (kgf/cm^2);
ϕ = creep coefficient of concrete.

ii) For the calculation of the prestress loss and the statically indeterminate force, the creep coefficient of concrete given in the following table will be used as standard value :

Age of concrete when sustained load is applied. (days)		4～7	14	28	90	365
Creep coefficient	For using high-early-strength Portland cement	2.6	2.3	2.0	1.7	1.2
	For using normal Portland cement	2.8	2.5	2.2	1.9	1.4

iii) When the prestress loss is calculated, the shrinkage strain of concrete will be as given in the table below:

Age of concrete when prestress is introduced (days)	4～7	28	90	365
Shrinkage strain	20×10^{-5}	18×10^{-5}	16×10^{-5}	12×10^{-5}

iv) When the condition is different with above mentioned (2) and (3), the creep coefficient or the shrinkage strain of concrete will alternately be determined with consideration of the ambient relative humidity, geometric dimension of cross section of concrete, the age of concrete at loading, etc.

v) The statically indeterminate force due to the effect of creep and shrinkage of concrete will be calculated in accordance with the followings:

a. In cases where structural system does not change

When the structural system does not change between the construction stage and completion stage as in such cases where the whole structure is constructed by full support at a time, the creep effect of concrete will not be considered. In calculating the statically indeterminate force due to the shrinkage of concrete, the shrinkage strain will be taken as 15×10^{-5}. However, in the case where the amount of longitudinal reinforcement is less than 0.5% of the area of the cross section of the member, the shrinkage strain will be 20×10^{-5}.

b. In cases where structural system changes

When the structural system does change between the construction stage and completion stage as in such cases where the entire structure is not constructed by full support at a time, the statically indeterminate force due to the creep effect of concrete will be calculated in accordance with section 4.1.3 a).13 ii) or iv) above. The sustained load to be considered in this case will be the dead loads, the prestressing force and the effect of shrinkage of concrete. The statically indeterminate force due to the shrinkage of concrete will be calculated in accordance with section 13 iv).

14. Buoyancy or Uplift (B)

Buoyancy will be considered where it may affect the design of either substructure, including piling, or the superstructure. Provision will be made for adequate attachment of the superstructure by ensuring that the calculated uplift at any support is resisted by tension members engaging a mass of masonry equal to the largest force obtained.

15. Temporary load and Force during Erection (ER)

For any stage of construction, the study on the effects of the weight of members and equipment, wind and earthquake will be carried out with consideration on the construction method and the structural conditions during construction.

b) Materials and Physical Constants to be used in Design Calculations

Materials to be considered in this design calculation will generally be in accordance with the "General Specifications for Roads in the Sultanate of Oman". Although application of

AASHTO or BS is actually provided in these specifications, the AASHTO standards will be applied to this detailed design. However, JIS (Japanese Industrial Standards) will be applied to part of this detailed design calculation. In such a case, the AASHTO's equivalent to JIS adopted in this design calculation will be applied to the actual construction works.

1. Materials

i) Reinforcing Bars

Reinforcing bars will be deformed bars according to AASHTO M31/M31M (ASTM A615/A615M), Standard Specifications for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, except where shown on the drawings.

Table 4.1: Tensile Requirements

	Grade 40[A] (300)[C]	Grade 60 (400)[C]	Grade 75[B] (500)[C]
Tensile strength, min, kgf/cm^2	4921	6327	7030
Yield strength, min, kgf/cm^2	2812	4218	5273
Elongation in 203 mm, min, %:			
Bar Designation No.			
3	11	9	-
4,5	12	9	-
6	12	9	7
7,8	-	8	7
9,10,11	-	7	6
14,18	-	7	6

[A] Grade 40(300) bars are furnished only in sizes 3 through 6.

[B] Grade 75(500) bars are furnished only in sizes 6 through 18.

[C] Number in brackets shows SI units.

Table 4.2: Bend Test Requirements

Bar Destination No.	Pin Diameter for Bend Test[A]		
	Grade 40(300)	Grade 60(400)	Grade 75(500)
3,4,5	$3^1/_2$d[B]	$3^1/_2$d	-
6	5d	5d	5d
7,8	-	5d	5d
9,10,11	-	7d	7d
14,18 (90°)	-	9d	9d

[A] Test bends 180° unless noted otherwise.

[B] d = nominal diameter of specimen.

Table 4.3: Deformed Bar Designation Numbers, Nominal Weights, Nominal Dimensions, and Deformation Requirements

Bar Designation No.[B]	Nominal Weight, kgf/m	Nominal Dimensions[A]			Deformation Requirements, mm		
		Diameter mm	Cross-Sectional Area, cm^2	Perimeter mm	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal perimeter
3	0.560	9.525	0.707	29.921	6.655	0.381	3.632
4	0.994	12.700	1.290	39.903	8.890	0.508	4.851
5	1.552	15.875	2.000	49.860	11.100	0.711	6.071
6	2.235	19.050	2.839	59.842	13.335	0.965	7.264
7	3.042	22.225	3.871	69.825	15.545	1.118	8.484
8	3.973	25.400	5.097	79.807	17.780	1.270	9.728
9	5.059	28.651	6.452	90.018	20.066	1.422	10.947
10	6.403	32.258	8.194	101.346	22.581	1.626	12.370
11	7.906	35.814	10.064	112.522	25.070	1.803	13.716
14	11.383	43.002	14.516	135.128	30.099	2.159	16.459
18	20.237	57.328	25.806	180.086	40.132	2.591	21.946

[A] The nominal dimensions of a defomed bar are equivalent to those of a plain round bar having the same weight per foot as deformed bar.

[B] Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars.

ii) Tendons

In this design calculation of prestressed concrete, Freyssinet method will be adopted as a prestressing system. However, the prestressing system in the actual construction may be changed by the contractors in accordance with their own license. In this case, prestressing wire or strand will comply with the requirements of AASHTO M203 (ASTM A416) or M204 (A421), or BS 5896, and high tensile alloy steel bars will comply with AASHTO M275 (ASTM A722) or BS4486 in accordance with "General Specifications for Roads in the Sultanate of Oman."

Table 4.4: Tendons for Freyssinet Method

(Standard Specification for Freyssinet Method by Japan Society of Civil Engineering)

Diameter & Composition of Tendons	Area	Unit Weight	Ultimate Strength (σ_{pu}) & Ultimate Load		Yield Strength (σ_{py}) & Yield Load		Allowable Tensile Stress (σ_{pa}): Initial Prestressing, $\sigma_{pa} \leq 0.80\,\sigma_{pu}$ or $\leq 0.90\,\sigma_{py}$		Immediately after Prestressing, $\sigma_{pa} \leq 0.70\,\sigma_{pu}$ or $\leq 0.85\,\sigma_{py}$		At Service Load, $\sigma_{pa} \leq 0.60\,\sigma_{pu}$ or $\leq 0.75\,\sigma_{py}$		Designation of Materials
mm	mm²	Kgf/m	kgf/mm²	kgf	kgf/mm²	kgf	kgf/mm²	kgf	kgf/mm²	kgf	kgf/mm²	kgf	
φ 5	19.64	0.154	175	3450	155	3050	140	2745	123	2415	105	2070	SWPR1
12 φ 5	235.68	1.848		41400		36600		32940		28980		24840	SWPR1
φ 7	38.48	0.302	165	6350	145	5600	131	5040	116	4445	99	3810	SWPR1
12 φ 7	461.76	3.624		76200		67200		60480		53340		45720	SWPR1
φ 8	50.27	0.395	160	8050	140	7050	126	6345	112	5635	96	4830	SWPR1
12 φ 8	603.24	4.740		96600		84600		76140		67620		57960	SWPR1
T12.4	92.90	0.729	175	16300	150	13900	135	12510	123	11410	105	9780	SWPR7A
12T12.4	1114.80	8.748		195600		166800		150120		136920		117360	SWPR7A
T12.7	98.71	0.774	190	18700	160	15900	144	14310	133	13090	114	11220	SWPR7B
12T12.7	1184.52	9.288		224400		190800		171720		157080		134640	SWPR7B
T15.2	138.70	1.101	190	26600	160	22600	144	20340	133	18620	114	15960	SWPR7B
12T15.2	1664.40	13.212		319200		271200		244080		223440		191520	SWPR7B
1T12.7	98.71	0.774	190	18700	160	15900	144	14310	133	13090	114	11220	SWPR7B
1T15.2	138.70	1.101	190	26600	160	22600	144	20340	133	18620	114	15960	SWPR7B
1T15.2	138.70	1.101	175	24500	150	20800	135	18720	123	17150	105	14700	SWPR7A
1T17.8	208.40	1.652	190	39500	160	33600	144	30240	133	27650	114	23700	SWPR19
1T19.3	243.70	1.931	190	46000	160	39500	144	35550	133	32200	114	27600	SWPR19
1T20.3	270.90	2.149	185	50500	160	43000	144	38700	130	35350	111	30300	SWPR19
1T21.8	312.90	2.482	185	58400	160	50500	144	45450	130	40880	111	35040	SWPR19

Table 4.5: Mechanical Properties, Nominal Area of Cross-Section and Unit Mass of PC Wire and PC strand

(JIS G 3536)

Designation	Detail	Tensile Test			Rate of Relaxation (%)	Nominal Area of Cross Section (mm²)	Unit Mass (kg/m)
		Load at 0.2% Permanent Extension (kgf)	Tensile Load (kgf)	Elongation (%)			
SWPR1 & SWPD1	5mm	2850 or more (145 or more)	3250 or more	4.0 or more	3.0 or less	19.64	0.154
	7mm	5200 or more (135 or more)	5950 or more (155 or more)	4.5 or more	3.0 or less	38.48	0.302
	8mm	6550 or more (130 or more)	7550 or more (150 or more)	4.5 or more	3.0 or less	50.27	0.395
	9mm	7950 or more (125 or more)	9200 or more (145 or more)	4.5 or more	3.0 or less	63.62	0.499
SWPR2	2.9mm Two-Wire	2300 or more (175 or more)	2600 or more (195 or more)	3.5 or more	3.0 or less	13.21	0.104
SWPR7A	9.3mm Seven-Wire	7700 or more (150 or more)	9050 or more (175 or more)	3.5 or more	3.0 or less	51.61	0.405
	10.8mm Seven-Wire	10400 or more (150 or more)	12200 or more (175 or more)	3.5 or more	3.0 or less	69.68	0.546
	12.4mm Seven-Wire	13900 or more (150 or more)	16300 or more (175 or more)	3.5 or more	3.0 or less	92.90	0.729
	15.2mm Seven-Wire	20800 or more (150 or more)	24500 or more (175 or more)	3.5 or more	3.0 or less	138.7	1.101
SWPR7B	9.5mm Seven-Wire	8850 or more (160 or more)	10400 or more (190 or more)	3.5 or more	3.0 or less	54.84	0.432
	11.1mm Seven-Wire	12000 or more (160 or more)	14100 or more (190 or more)	3.5 or more	3.0 or less	74.19	0.580
	12.7mm Seven-Wire	15900 or more (160 or more)	18700 or more (190 or more)	3.5 or more	3.0 or less	98.71	0.774
	15.2mm Seven-Wire	22600 or more (160 or more)	26600 or more (190 or more)	3.5 or more	3.0 or less	138.7	1.101
SWPR19	17.8mm Seven-Wire	33600 or more (160 or more)	39500 or more (190 or more)	3.5 or more	3.0 or less	208.4	1.652
	19.3mm Seven-Wire	39500 or more (160 or more)	46000 or more (190 or more)	3.5 or more	3.0 or less	243.7	1.931
	21.8mm Seven-Wire	50500 or more (160 or more)	58400 or more (185 or more)	3.5 or more	3.0 or less	312.9	2.482

Note: The values in bracket of tensile load and load at 0.2% permanent extension are values from load divided by nominal area.

iii) Concrete

a. Materials

Cement will be Portland cement , originating from manufacturers and will, as shown on the Drawings, be either:

- Ordinary Portland Cement to AASHTO M85 (ASTM C-150) Type I.
- Sulphate Resisting Portland Cement to AASHTO M85 (ASTM C-150) Type II or Type V.

b. Concrete Class

Class of concrete is also prescribed in General Specification for Roads in the Sultanate of Oman. However, allowable stresses of materials to be used will be based on Japanese Specifications of Highway Bridges in this design work, so that specified compressive strength of concrete in this design will be as given in Table 4.6.

Table 4.6: Concrete Classes and General Application

Class of Concrete	Specified Compressive Strength (28days) (kgf/cm²)	Characteristic Strength at 28 days				Application
		Cylinders		Cubes		
		(N/mm²)	(kgf/cm²)	(N/mm²)	(kgf/cm²)	
12	120	12	122	15	153	
16	160	16	163	20	204	Blinding(leveling), Stone masonry
20	200	20	204	25	255	
24	240	24	245	30	306	Substructure, Retaining wall, Box culvert
28	280	28	286	35	357	
32	320	32	326	40	408	Floor slab, Cross beam Felloe guard & parapet (precast) Cast-in-place concrete pile
36	360	36	367	45	459	
40[A]	400	40	408	50	510	Prestressed concrete girder

[A] Concrete class 40 is not prescribed in General Specification for Roads in the Sultanate of Oman, however, it is necessary for prestressed concrete girder.

Table 4.7 : Concrete Classes

Class of concrete	Maximum water/cement ratio	Nominal maximum size of aggregate (mm)	Minimum cement content (kg/m^3)
12	0.55	20	250
16			300
20			310
24			325
28	0.45	20	350
32			375
36			400

Table 4.8 Requirements for Reinforced Concrete and Prestressed Concrete

Exposed condition	Minimum cement content (kg/m^3)	Maximum water/cement ratio	Cement type	Minimum cover (mm)	External protection
Superstructure and piers above the capillary rise zone	320	0.42	OPC^A	45	
Permanently below sea or ground water	350	0.42	ASTM Type II^B	50	Tacking with thick membrane
Underground but above the influence of capillary rise	350	0.42	ASTM Type II^B	50	Two coats bituminous paint
Within ground water capillary rise zone	370 with entrained air	0.42	ASTM Type II^B	75	Tacking with thick membrane
	420	0.38	ASTM Type II^B	100	Two coats bituminous paint
Intertidal and splash zone. Subject to wetting and drying with saline water	400 with entrained air	0.40	ASTM Type II^B	100	Surface coating. Preferable to design in mass concrete

^{A} OPC is abbreviation of Ordinary Portland Cement

^{B} ASTM Type II - For general use, and more specifically when moderate sulfate resistance or moderate heat of hydration is desired.

2. Physical Constants to be used in Design Calculations

Values of physical constants to be used in design calculations will be as follows:

STEEL :
Physical constants of steel materials to be used in design calculations are given in the following table:

Classification	Constant Value
Young's modulus of steel and cast steel	2.1×10^6 kgf/cm²
Young's modulus of wire, steel strand and steel bar for prestressed concrete	2.0×10^6 kgf/cm²
Young's modulus of cast iron	1.0×10^6 kgf/cm²
Shear modulus of steel	8.1×10^5 kgf/cm²
Poisson's ratio of steel and cast steel	0.30
Poisson's ratio of cast iron	0.25

For calculating the amount of loss of prestressing forces, nominal relaxation rates of prestressing tendons will be used as given in the following table:

Prestressing tendons	Relaxation rate (%)
Wire and steel strand for prestressed concrete	5
Steel bar for prestressed concrete	3

However, for the prestressing tendons affected by high temperature, nominal relaxation rates of prestressing tendons will be 2% higher than the values listed in the table above.

CONCRETE :

i) Young's modulus of concrete will be provided as follows:

The values of Young's modulus to be used for the calculation of the statically indeterminate force or the elastic deformation of the reinforced concrete structures and the general design calculation of prestressed concrete will be as listed below:

Specified compressive strength (kgf/cm²)	210	240	270	300	400	500
Young's modulus	2.35×10^5	2.5×10^5	2.65×10^5	2.8×10^5	3.1×10^5	3.3×10^5

The ratio of Young's modulus 'n' to be used in the calculation of stresses of reinforced concrete members will be 15.

ii) Shear modulus of concrete will be calculated from the following formula:

$Gc = Ec / 2.3$

where
Gc = shear modulus of concrete (kgf/cm^2)
Ec = Young's modulus of concrete (kgf/cm^2)

c) Combinations of Loads and Allowable Stresses

1. Combinations of Loads

SERVICE LOAD DESIGN

The following table represents various combinations of loads and forces to which a structure may be subjected. Each component of the structure, or the foundation on which it rests, will be proportioned to withstand safely all loading combinations of these forces that are applicable to the particular site or type.

However, subsidiary loads and particular loads to be regarded as principal loads are taken into account, basic allowable stresses specified in 3.1.3 c) 2. of this section will be increased by multiplying the rates given in the following table:

Application	Combinations of loads	Rate of increase
For Superstructures	1. P+PP	1.00
	2. P+PP+T	1.15
	3. P+PP+W	1.25
	4. P+PP+T+W	1.35
	5. P+PP+LF	1.25
	6. P(without live loads and impact)+EQ	1.50
	7. W	1.20
	8. In case considering ER	1.25
For Substructures	1. P+PP	1.00
	2. P+PP+T	1.15
	3. P+PP+W	1.25
	4. P+PP+T+W	1.35
	5. P+PP+LF	1.25
	6. P(without live loads and impact)+EQ	1.50
	7. In case considering ER	1.25

where
P = Principal load
PP = Particular load to be regards as principal load
T = Thermal Force
W = Wind load
LF = Longitudinal force
EQ = Earthquake
ER = Temporary load during erection

ULTIMATE LOAD DESIGN

Prestressed concrete structures will be so designed as to hold in ultimate loading condition added to service loading condition. Loading combinations to consider ultimate loading are shown below. Furthermore, the method of ultimate load design will be that in which the calculated ultimate resistant bending moment is not less than the bending moment calculated in the ultimate loading condition and, for shear force, mean shear stress of concrete calculated in the ultimate loading is not more than the upper limits of mean shear stress of concrete prescribed in Table 4.9.

Loading Combination of ultimate load
a) $1.3 \times D + 2.5 \times (L + I)$
b) $1.0 \times D + 2.5 \times (L + I)$
c) $1.7 \times (D + L + I)$
d) $1.3 \times (D + EQ)$
e) $1.0 \times D + 1.3 \times EQ$
where
D = Dead load
L = Live load
I = Impact
EQ = Earthquake

Table 4.9: Upper Limits of Mean Shear Stress of Concrete

Concrete Designation	210	240	270	300	400
Upper Limits of Mean Shear Stress of Concrete (kgf/cm^2)	28	32	36	40	53

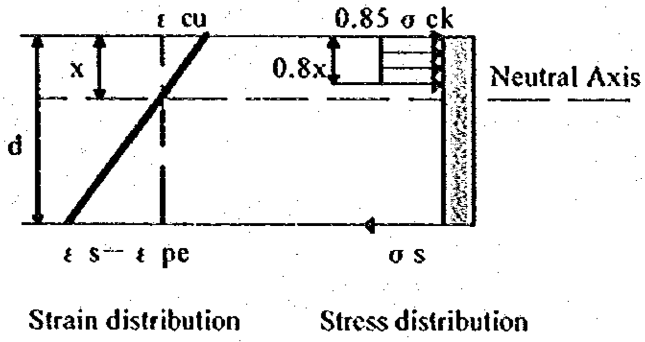
Ultimate Resisting Bending Moments at the section of Concrete Members

The ultimate resisting bending moment at the section of concrete members will be calculated in accordance with the following assumptions.

1) Strain is directly proportional to the distance from the neutral axis.
2) Tensile strength of concrete is not considered.
3) The distribution of compressive stresses of concrete is shown in Fig. 4.2.

However, the concrete compressive stress of a member with peculiar shaped cross section will be calculated in accordance with the stress-strain curve shown in Fig. 4.3.

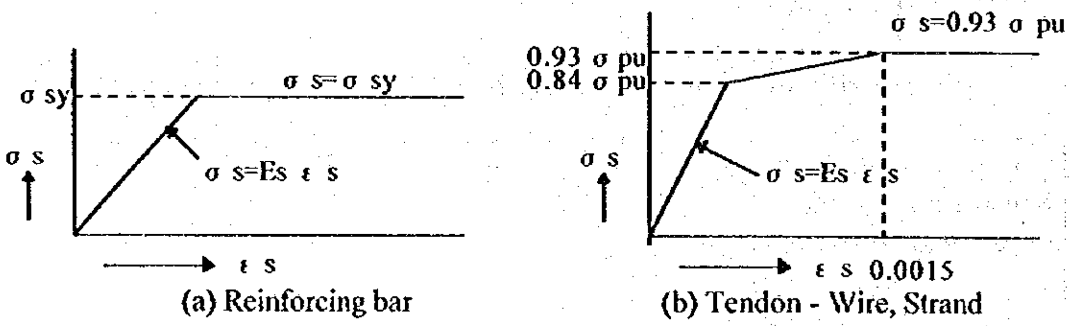
4) Stress-strain curve of reinforcing steel is as given in Fig. 4.3.



Where

ε cu	=	ultimate strain in concrete (=0.0035)
ε s	=	strain in reinforcing steel
ε pe	=	strain in tendon due to effective prestressing force
σ ck	=	specified compressive strength of concrete (kgf/cm^2)
σ s	=	stress in reinforcing steel (kgf/cm^2)
d	=	effective height (cm)
x	=	distance from flexural compressive fiber to neutral axis (cm)

Figure 4.2: Stress-Strain Curve of Concrete to be Used in Calculation of the Ultimate Resisting Bending Moment



where

σ sy	=	specified yield stress of reinforcing bar (kgf/cm^2)
σ pu	=	specified tensile strength of PC tendon (kgf/cm^2)
σ s	=	stress of reinforcing steel (kgf/cm^2)
Es	=	Young's modulus of reinforcing steel (kgf/cm^2)
ε s	=	strain of reinforcing steel

Figure 4.3: Stress-Strain Curves of Reinforcement to be Used in Calculation of the Ultimate Resisting Bending Moment

Mean Shear Stress of Concrete

$$\tau m = \frac{S_h - S_p}{bw \cdot d}$$

where

τm = mean shear stress at the section of concrete member (kgf/cm^2)

S_h = shear force considering the influence of change in the effective height of a member (kgf)

S_p = component of prestressing force in the acting direction of the shear force (kgf)

For RC members $S_p = 0$

For PC members $S_p = A_p \cdot \sigma_{pe} \cdot \sin\alpha$

A_p = area of prestressing tendons at the section of a member (cm^2)

σ_{pe} = effective tensile stress of tendons at the section of a member (kgf/cm^2)

α = angle between tendons and longitudinal axis of a member

bw = web thickness of the section of a member (cm)

d = effective height of the section of a member (cm)

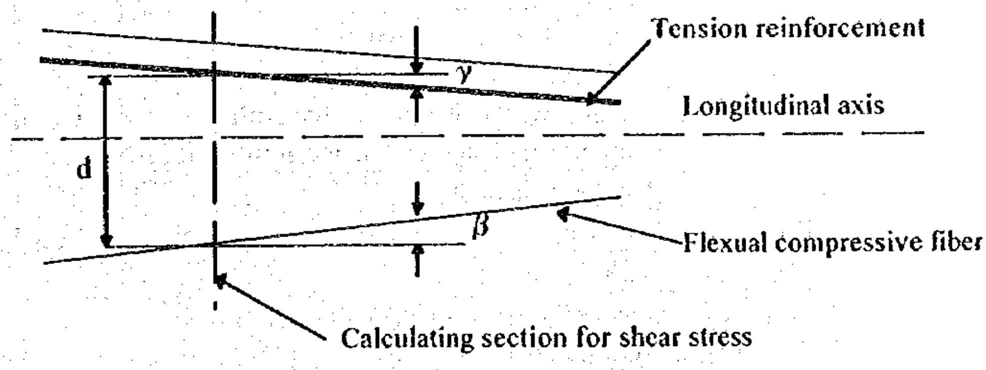
$$S_h = S - \frac{M}{d}(\tan\beta + \tan\gamma)$$

S = shear force at the section of a member (kgf)

M = bending moment at the section of a member (kgf · cm)

β = angle between the flexural compressive fiber of a member and the longitudinal axis of a member.

γ = angle between the tension reinforcement and the longitudinal axis of a member.



2. Allowable Stresses

i) Allowable Stress of Reinforcing Bars

Table 4.10: Allowable Stresses of Reinforcing Bars (unit : kgf/cm²)

Classification		Reinforcing Bars	Grade 40 (300)	Grade 60 (400)	Grade 75 (500)
Tensile Stress	Cases lacking effect of collision force or earthquake force in the combinations of loads	1)Ordinary members	1400	1800	1800
		2)Floor slab	1400	1400	1400
		3)Members underwater or below ground water level.	1400	1600	1600
	4) Basic allowable stresses in cases including effect of collision or earthquake force in the combinations of loads.		1400	1800	2000
	5) For the calculation of lap joint or anchoring length of reinforcing bars.		1400	1800	2000
6) Compressive Stress			1400	1800	2000

ii) Allowable Stresses of Reinforced Concrete

a. For members cast in dry condition

Table 4.11: Allowable Stresses of Reinforced Concrete (unit : kgf/cm²)

Types of Stress		Concrete Class* 20 (200)	24 (240)	28 (280)	32 (320)
Compressive Stress	Flexural compressive stress	65	80	90	100
	Axial compressive stress	50	65	75	85
Shear Stress	In case shearing is resisted only by concrete	3.5	3.9	4.2	4.5
	In case shearing is resisted by both concrete and diagonal tension reinforcement	15	17	18	19
	Punching shear stress	8.0	9.0	9.5	10
Bond Stress	With round bar	7.0	8.0	8.5	9.0
	With deformed bar	14	16	17	18

* The value of concrete class is equivalent to specified compressive strength at the age of 28 days in N/mm² and in kgf/cm² in bracket.

The allowable bearing stress of reinforced concrete will be as follows:

$$\sigma_{ba} = \left(0.25+0.05\frac{Ac}{Ab}\right)\sigma_{ck}$$

where

σ_{ba} = Allowable bearing stress of reinforced concrete (kgf/cm^2) ($\leqq 0.5\ \sigma ck$)
Ac = Total area of reinforced concrete in case of local loading (cm^2)
Ab = Locally loaded area (cm^2)
σck = Specified compressive strength of reinforced concrete (kgf/cm^2)

b. For cast-in-place concrete piles constructed underwater

Table 4.12: Allowable Stresses of Cast-in-place Concrete Piles Constructed Underwater

(unit : kgf/cm^2)

	Designation compressive strength of concrete	32 N/mm^2 (320)
	Specified compressive strength of underwater concrete	24 N/mm^2 (240)
Compressive Stress	Flexural stress	80
	Axial compressive stress	65
Shear Stress	In case shearing is resisted only by concrete	3.9
	In case shearing is resisted by both concrete and diagonal tension reinforcement	17
Bond Stress	With deformed bar	12

Note: unit of strength is kgf/cm^2 except those values given with unit N/mm^2.

iii) Allowable Stresses of Plain Concrete

Table 4.13: Allowable Stresses of Plain Concrete

Type of Stress	Allowable Stress
Compressive stress	$\frac{\sigma ck}{4} \leqq 55$
Flexural tensile stress	$\frac{\sigma tk}{7} \leqq 3$
Bearing stress	$0.3\ \sigma ck \leqq 60$

Where

σck = Specified compressive strength of concrete
σtk = Specified tensile strength of concrete prescribed in JIS A 1113

iv) Allowable Stresses of Prestressed Concrete

a. Allowable Compressive Stresses of Prestressed Concrete

Table 4.14: Allowable Compressive Stress of Prestressed Concrete (unit : kgf/cm^2)

			32 N/mm² (320)	40 N/mm² (400)
Immediately after prestressing	Flexural compressive stress	(1) Rectangular section	150	190
		(2) T shaped or Box section	140	180
	(3) Axial compressive stress		110	145
Other Conditions	Flexural compressive stress	(4) Rectangular section	120	150
		(5) T shaped or Box section	110	140
	(6) Axial compressive stress		85	110

b. Allowable Tensile Stresses of Prestressed Concrete

Table 4.15: Allowable Tensile Stress of Prestressed Concrete

Type of Stress \ Concrete Class			32 N/mm² (320)	40 N/mm² (400)
Flexural Tensile Stress	(1) For Immediately after prestressing		12	15
	(2) For the loading principal loads except live load and impact		0	0
	Principal load or Particular load to be regarded as principal load	(4) For floor slab	0	0
		(5) For other conditions	12	15
(6) Axial tensile stress			0	0

c. Allowable Diagonal Tensile Stresses of Prestressed Concrete

Table 4.16: Allowable Diagonal Tensile Stress of Prestressed Concrete

Conditions \ Concrete class	32 N/mm² (320)	40 N/mm² (400)
(1) With consideration for only shear force or only torsional moment	8	10
(2) With consideration for both shear force and torsional moment	11	13

d) Allowable Bond Stresses of Prestressed Concrete

Table4.17:Allowable Bond Stresses of Prestressed Concrete

Conditions \ Concrete class	32 N/mm² (320)	40 N/mm² (400)
(1) With round bar	9	10
(2) With deformed bar	18	20

e) Allowable Stresses of Tendons

Allowable stresses of tendons for Freyssinet Prestressing Method authorized by Japan Society of Civil Engineering are shown in Article 3.2.5.5B (Materials).

d) Structural Details

1. Waterproofing

All concrete surface in contact with soil should have fibre-reinforced bitumen membrane protection. The bitumen membrane should be protected by 5mm-thick hard board when back filled.

All exposed concrete surfaces should have a five (5) coats (one primer/sealer, two high build and two gloss) approved polyurethene paint system. (Color "Butter Milk" code 10 B 15 or similar).

2. Construction Joint

Construction joints should be constructed at intervals of 10m each or less depending on the construction sequence. Considering the reuse of form work of the box tunnel, it is desirable that the construction joints be constructed at a constant interval. In particular, construction joints under the median of highway should be decided giving attention to the traffic during full closure of one carrigeway.

PVC waterstop with 190mm wide should be provided at the center of the internal area of the construction joint.

3. Haunch

Haunch with 150mm in height and 300mm in width should be designed at the internal upper corners of the box tunnel section.

4. Minimum and Maximum Area of Reinforcing Steel

Superstructure (For Canopy Design)

i) In any reinforced concrete section, bonded steel of 0.15% or more of the area of the concrete member should generally be applied.

ii) The area of main axial tension bar or main axial bar to be designed in the reinforced concrete members will be given as follows :

a. Girder -- $Ast \geqq 0.005bw \cdot d$

b. Column -- $As \geqq 0.008bw \cdot A'$

c. For members in which diagonal tension bar cannot be designed due to the slimness of the member in the direction of loaded shear force -- $Ast \geqq 0.01 bw \cdot d$

where

Ast = area of main axial tension bars (cm^2)
As = area of main axial bars (cm^2)
bw = web thickness of girder (cm)
d = effective height of the member (cm)
A' = required area of the column (cm^2)

$A' = \max(A1', A2')$

$A1' = Na/(0.008\ \sigma sa + \sigma ca)$

$A2' = Nu/(0.008\ \sigma sy + \sigma ck)$

where Na = axial force at service load (kgf)
Nu = axial force at ultimate load (kgf)
σsa = allowable stress of reinforcing bars (kgf/cm^2)
σca = allowable axial compressive stress of concrete (kgf/cm^2)
σsy = yield stress of reinforcing bars (kgf/cm^2)
σck = specified compressive strength (kgf/cm^2)

iii) The minimum reinforcement content of the diagonal tension bar to be designed in the member of the girder will be as follows :

Using deformed bar------------------------------ $Aw \geqq 0.002 bw \cdot a \cdot \sin\theta$
Using round bar-------------------------------- $Aw \geqq 0.003 bw \cdot a \cdot \sin\theta$

where

Aw = area of the diagonal tensile bars arranged at interval of 'a' and angle 'θ'.
bw = web thickness of the girder
a = interval of diagonal tension bars in direction of the longitudinal axis of the member.
θ = angle between diagonal tension bars and longitudinal axis of the member.

Substructure

The area of the main axial tensile bar in the beam members and axial bar in the column members should be in the following ranges:

a. Beam -------------------------------- $0.002b \cdot d \leqq Ast \leqq 0.02b \cdot d$
b. Column ---------------------------- $0.0015A(0.008A') \leqq As \leqq 0.06A$

and the footing (foundation slab) should be calculated as a beam member.
where
  Ast = area of main axial tension bars
  As = area of axial bars
  d = effective height of the member
  A' = required area of the column
  A = total cross-section area of the column

However, the above provision may not be applied to beam members in the following case:
  $4/3 \cdot Mdn \leqq Mc$
where Mdn = design flexural moment (kgf・cm)
  Mc = cracking moment (kgf・cm)
  $Mc = Zc(\sigma'ck + N/Ac)$
  Zc = section modulus of concrete members (cm^3)
  σ'ck = flexural compressive strength of concrete (kgf/cm^2)
  $\sigma'ck = 0.9 \cdot \sigma ck^{2/3}$
  σ ck = specified compressive strength of concrete (kgf/cm^2)
  N = axial forces (kgf)
  Ac = area of concrete members (cm^2)

5. Arrangement of Reinforcing Steel

Cover

The minimum concrete cover for reinforcing steel, under various conditions as given in the following table will apply, while the concrete for reinforcing bar will not be less than the diameter of the bar:

Expose condition	Superstructure and piers above the capillary rise zone	Permanently below sea or ground water	Underground but above the influence of capillary rise	Within ground water capillary rise zone	Intertidal and splash zone, Subject to wetting and drying with saline water
Minimum cover	45mm	70mm	70mm	100mm	100mm

Spacing

Spacing of main reinforcing bars and prestressing tendons, including sheaths, and that between the main reinforcements and prestressing tendons, including sheaths, should not be less than 4 cm and not less than 4/3 times the maximum size of course aggregate. The spacing of main reinforcing bars should not be less than 1.5 times the diameter of bars.

Splice(Joint)

The length of lap joint for tensile reinforcing bars should not be less than the value calculated by the following formula or 20 times the diameter of reinforcing bars :

$$la = \frac{\sigma\ sa}{4\ \tau\ oa} \cdot \phi$$

where

la = length of lap joint determined by bond stress (cm)

σ sa = allowable tensile stress of reinforcing bar (kgf/cm^2)

τ oa = allowable bond stress of concrete (kgf/cm^2)

ϕ = diameter of reinforcing bar

The lap joint will be reinforced by two or more reinforcing bars arranged perpendicular to the lap joint.

Anchoring

i) The ends of reinforcing bars should be anchored sufficiently in concrete by any method specified below. However, round bar used as tension reinforcements should be anchored by hooks.

Method 1 - the reinforcing bars are buried in concrete and anchored by bond between the reinforcing bar and concrete.
Method 2- the reinforcing bars are buried in concrete and anchored with hooks.
Method 3- the reinforcing bars are mechanically anchored using anchor plates.

ii) The length of anchoring by bond between reinforcing bar and concrete should not be less than the length of lap joint determined by bond stress (la) as prescribed in *Splice (Joint).*

iii) The length of anchoring with hook of tensile bars should not be less than 2/3 times the length of that prescribed in ii) above. The length of anchoring with hook of compressive bars should not be less than the length as prescribed in ii) above, and the effect of the hook should not be considered.

4.2 Pedestrian Underpasses

4.2.1 General Description

As mentioned in section 4.1.1, this Detailed Design Study will be carried out in accordance with the "Highway Design Manual (Sultanate of Oman)" (hereinafter referred to as "Omani Design Manual") as the main design standards. The Omani Design Manual is based on design standards established by the American Association of State Highway and Transportation Officials (hereinafter referred to as "AASHTO"). The actual design works for this detailed design of pedestrian underpasses will also be executed in Japan. Although the principal design concept will follow that as specified in the Omani Design Manual and AASHTO, detailed calculation method will be based on Japanese specification as listed in section 4.2.2 below.

STRUCTURAL CALCULATION METHOD

Structural calculation method for this detailed design will basically follow the "Allowable Stress Design (service load design) Method" in accordance with "Specifications for Highway Bridge" authorized in Japan.

4.2.2 Authorized Design Standards to be Applied

The following standards will be applied for this detailed design study.

【Sultanate of Oman】

- Highway Design Manual
  - Volume I (February, 1994)
  - Volume II (January , 1994)
- General Specifications for Roads (April, 1994)

【U.S.A】

[American Association of State Highway and Transportation Officials]

- Standard Specifications for Highway Bridges (Fifteenth Edition 1992)
- Standard Specifications for Transportation Materials and Methods of Sampling and Testing
  - Part I
  - Part II

[American Society for Testing and Materials]
(hereinafter referred to as "ASTM")

- Annual Book 1995
  - Section-1 Iron and Steel Products
  - Section-4 Construction

[American Concrete Institute]
(hereinafter referred to as "ACI")
• Building Code Requirements for Reinforced Concrete (ACI 318-83)

【Japan】
[Japan Road Association]
• Specifications for Highway Bridges (February, 1994)
- Part Ⅰ Common
- Part Ⅱ Superstructure (Steel Bridges)
- Part Ⅲ Superstructure (Concrete Bridges)
- Part Ⅳ Substructure
- Part Ⅴ Seismic Design
• Standard Specifications for Pedestrian Road Crossing
• Guideline for Road Design and Works
- Culverts
• Guideline for Drainage Design of Roads

The followings are other reference documents

【 Sultanate of Oman 】
• Rehabilitation of Batinah Highway (MOC)
- Al Bidayah Pedestrian Underpass- Design Drawings (July, 1993)

【 Japan 】
• All Japan Construction Technology Association
- Standard Design for Civil Structures (Established by Ministry of Construction)
*Pedestrian Road Crossing Structures

4.2.3 Design Standards and Specifications

a) Design Loads

1. Types of Loads

Structures of the pedestrian underpasses will be designed to carry the following loads and forces.

Classification	Types of loads
Principal load (P)	1. Dead Load (D) 2. Live Load (L) 3. Impact (I) 4. Effect of Creep of Concrete (CR) 5. Effect of Shrinkage of Concrete (SH) 6. Earth Pressure (E) 7. Hydraulic Pressure (HP) 8. Buoyancy (B)
Subsidiary load (S)	9. Wind Load (W) 10. Thermal Effect (T) 11. Earthquake (EQ)
Particular loads (PA)	12. Temporary Load during Erection (ER)

2. Dead Load (D)

The following weights are to be used in computing the dead load.

Types of Dead Load	Unit Weight (kgf/m^3)	Types of Dead Load	Unit Weight (kgf/m^3)
Steel or cast steel	7850	Asphalt pavement	2300
Cast iron	7250	Bituminous material	1100
Aluminum alloys	2800	Compacted sand, earth and gravel	1900
Timber(treated or untreated)	800	Loose sand, earth, and gravel	1800
Concrete(plain)	2350	Under ground water	1000
Concrete(reinforced or prestressed)	2500		
Cement mortar	2150		

3. Live Load (L)

The following live load will be considered for this detailed design.

As truck loading,

1) Special truck type A
2) Special truck type B1
3) Special truck type B2
4) AASHTO Standard HS20-44 truck increased by 100%

As lane loading,

5) AASHTO HS20-44 loading increased by 100%

Sidewalk Loading

Box tunnel and stairs of pedestrian underpass will be designed for a live load of 500 kgf/m^2 of internal walking area.

4. Impact (I)

Application:

Highway Live Loads will be increased for those structural elements in Group A, below, to allow for dynamic, vibratory and impact effects. Impact allowances will not be applied to items in Group B. It is intended that impact be included as part of the loads transferred from superstructure, but will not be included in loads transferred to footings nor to those parts of piles or columns that are below ground.

Group A - Impact will be included.

1) Superstructure, including legs of rigid frames.
2) Piers, (with or without bearings, regardless of type) excluding footings and those portions below the groundline.
3) The portions above the groundline of concrete or steel piles that support the superstructure.

Group B - Impact will not be included.

1) Special Truck Type B1 and B2.
2) Abutments, retaining walls, piles except as specified in the Group A 3) above.
3) Foundation pressures and footings.
4) Timber Structures.
5) Sidewalk loads.
6) Culverts and structures having cover 1.0m or more. See details below:

For culverts with cover (h) :

$0.000\text{ m} \leqq h \leqq 0.305\text{ m}$	Impact = 30%
$0.305\text{ m} < h \leqq 0.610\text{ m}$	Impact = 20%
$0.610\text{ m} < h < 1.000\text{ m}$	Impact = 10%
$1.000\text{ m} < h$	Impact = 0%

5. Application of Live Load

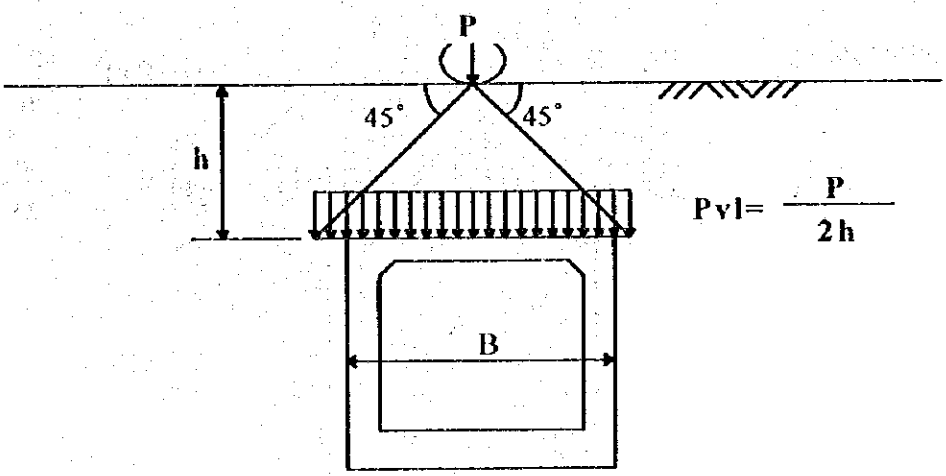
***Loading for Maximum Stress* :**

The type of loading, whether Special Truck Type A, B1, B2, Standard Truck Load or Lane Load, to be used will be the loading which produces the maximum stress for each design calculation of structures or members. However, for the design of pedestrian underpass, the influence of truck loading will be superior to that of lane loading. Therefore, load intensity by live load for the design of box tunnel will be as follows:

i) Case of Live Load Being Within The Width Of Box Tunnel

In cases with loading of Special Truck Type A, B and Standard Truck HS20-44, their wheel load will be considered as uniformly distributed at 45° (degree) in cross-sectional direction of box tunnel. However, in these cases, truck loading will be independent of the number of actual traffic lane in longitudinal direction of the box tunnel.

a. AASHTO Standard Truck HS20-44



where P = load intensity including impact by wheel load per linear meter in longitudinal direction of pedestrian underpass (tf/m)

$$P = \frac{\text{Total of rear wheel load per axle}}{\text{Occupying width of truck}} \times (1+i)$$

i = impact coefficient

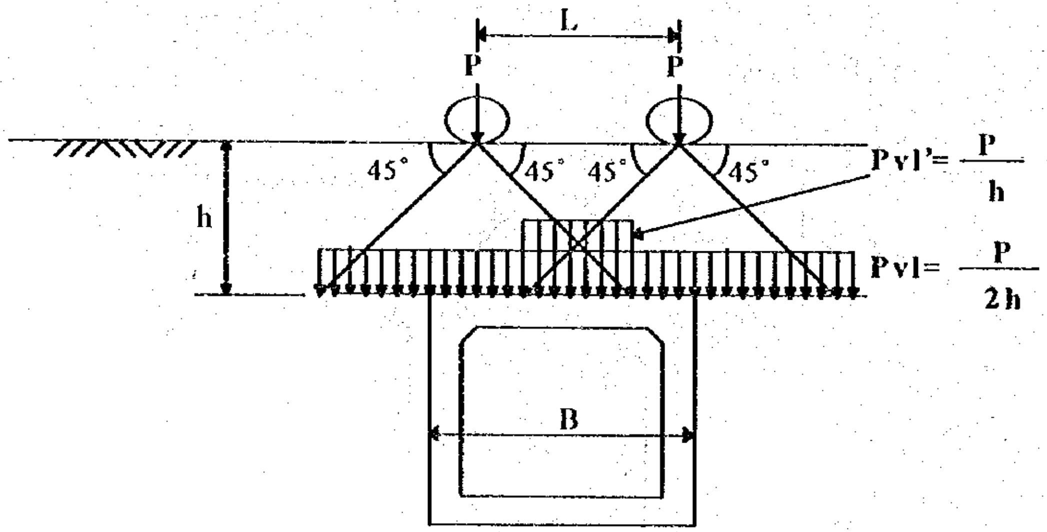
Pvl = vertical load intensity by live load acting on the upper slab of box tunnel (tf/m^2)

Table 4.18: Load Intensity by Wheel load (excluding Impact)

Standard	Name of Load	Axle Load (tf)	Occupying Width W(m)	P (tf/m)	Pvl (tf/m²)
AASHTO	Standard Truck HS20-44 increased 100%	29.00	3.05	9.508	$Pvl = \frac{9.508}{2h}$

In AASHTO Standard Truck HS20-44 design the loading is considered as one axle rear wheel load, but in the case of Omani Truck Loading (Special Truck Type A, B1 and B2) , wheel loads by two or more axles will be considered due to the closeness of the rear axles.

b. Special Truck Type A



where L = distance between axles (m)

Table 4.19: Intensity by Wheel load (excluding Impact)

Standard	Name of Load	Axle Load (tf)	Occupying Width W(m)	P (tf/m)	Distance between axles (m)
Highway Design Manual	Special Truck Type A	22.00	3.00	7.333	1.50

For Special Truck A Loading, load intensity on the upper slab, Pvl, will be given by the following formula according to the depth of cover (h).

i. $0 \leqq h \leqq 0.75$ m

$$Pvl = \frac{7.333}{2h} \quad (tf/m^2)$$

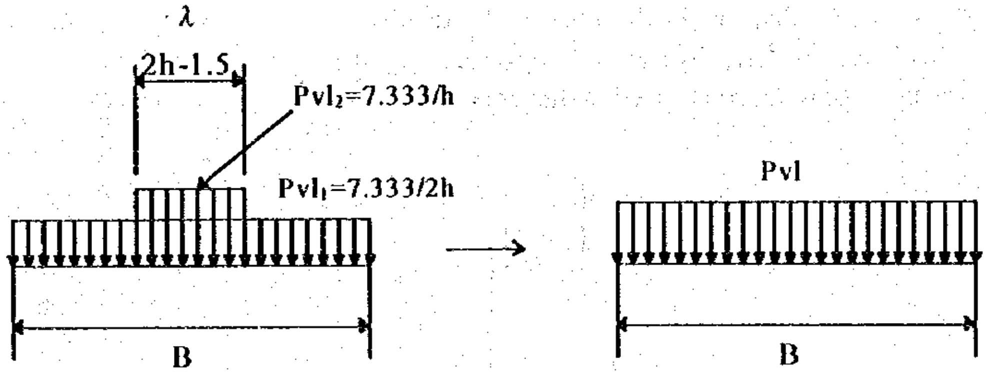
ii. $0.75 < h \leqq 2.75$ m

$$Pvl = 5.0415 - 0.9165h + \frac{0.401}{h} \quad (tf/m^2)$$

iii. $2.75 \text{ m} \leqq h$

$$Pvl = \frac{7.333}{h} \quad (tf/m^2)$$

Formula for ii . is given as follows:



(a) (b)

For special truck A loading , load intensity changes due to the influence of two axles (See above (a)). Therefore, the equivalent uniform load, Pvl, will be used to facilitate design calculation.

First, width of Pvl_2; λ , is given as a function of cover ;h.

$$\lambda = 2h-1.5$$

Generally, the maximum flexural moment of condition (a) will be as follows:

$$Mmax(a) = \frac{wB^2}{8} + \frac{wB\lambda}{4} - \frac{w\lambda^2}{8}$$

where $w = Pvl_1 = 0.5 * Pvl_2$

And the maximum flexural moment of condition (b) will be as follows:

$$Mmax(b) = \frac{Pvl \cdot B^2}{8}$$

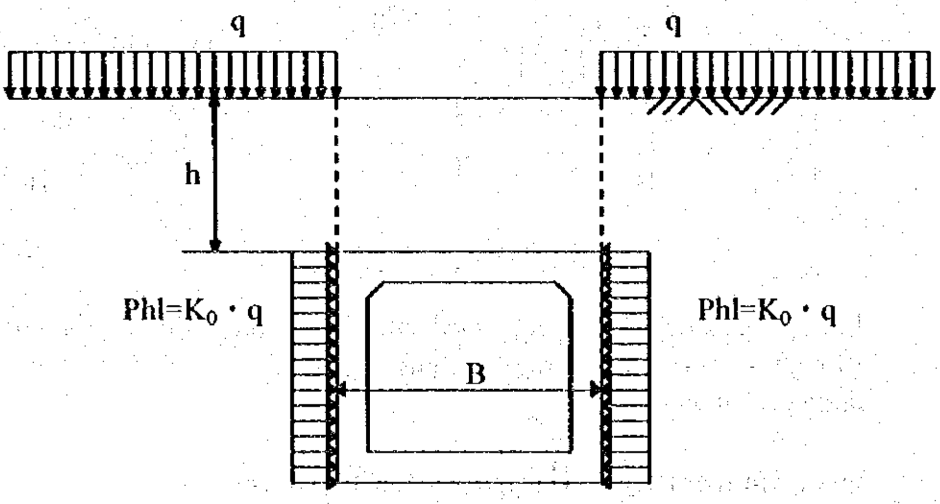
Pvl will be determined as Mmax (b) and should be equal to Mmax (a).
In this design criteria, Pvl was calculated with the assumption that B will be 4.0m since the internal width of the box tunnel is 3.6 m.

c. Special Truck Type B1 and B2

Load intensity of Special Truck B1 or B2 will be calculated as a continuous load due to closeness of the axles. For the design calculation, an equivalent uniform load for continuous axle load will be calculated. Any reduction of such will be considered according to the thickness of cover over the upper slab of box tunnel.

ii) Case of Live Load Being Outside The Width Of Box Tunnel

In the case that live load is outside the width of the box tunnel, the influence of live load will be considered as horizontal pressure by surcharge. Load intensities by live load as surcharge to be considered in this detailed design are as listed in the following table.



where

q	=	surcharge by live load (tf/m^2)
Phl	=	horizontal load intensity by surcharge live load (tf/m^2)
K_0	=	coefficient of earth pressure at rest (= 0.5)

Table 4.20: Load Intensity as Surcharge

Standard	Name of Load		Total Weight (tf)	Length L(m)	Width B(m)	Load Intensity (tf/m2)
AASHTO	Lane load incresed 100%		–	–	–	1.90
	Truck load increased 100%		65.20	8.53	3.05	2.51
Highway Design Manual in Oman	Special Truck Type A		100.00	11.00	3.00	3.03
	Special Type B1	tractor	46.60	6.00	2.70	2.88
		trailer	200.00	8.00	2.94	8.50
	Special Type B2	tractor	24.00	7.75	2.70	1.15
		trailer	260.00	10.57	2.94	8.37

6. Earth Pressure (E)

The earth pressure acting on a box culvert will be calculated by Coulom's theory as well as bridge structures (Refer to 4.1.3 - a) - 13.).

Earth and Water Pressure on Box Tunnel of Pedestrian Underpass

a. Vertical Earth Pressure

The vertical earth pressure on the upper slab of box tunnel will be as follows:

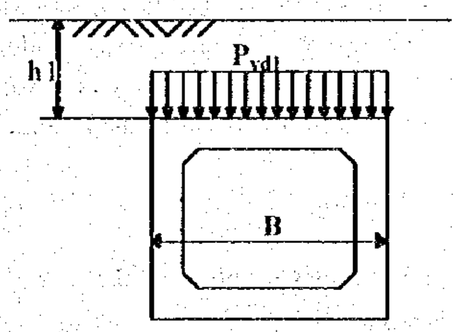
$$P_{vd1} = \gamma_t \cdot h_1$$

where

P_{vd1} = earth pressure on the upper slab (tf/m^2)

γ_t = unit weight of soil (tf/m^3)

h_1 = cover (m)



b. Horizontal Earth Pressure and Water Pressure

The total horizontal pressure of horizontal earth pressure and water pressure, depending on the elevation of underground water, will be calculated by the following formula :

i. Portion above underground water

$$P_{hd} = K_0 \cdot \gamma_t \cdot z$$

where

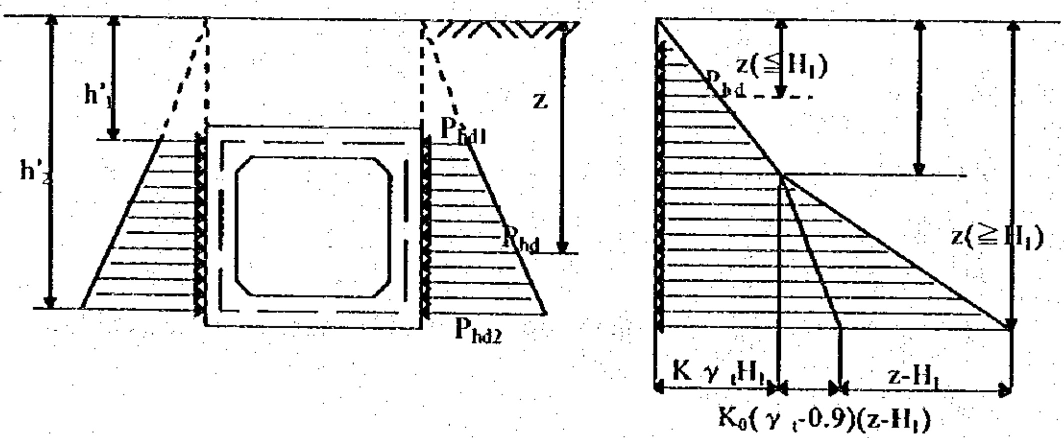
P_{hd} = total horizontal pressure of earth and water pressure (tf/m^2)
K_0 = coefficient of earth pressure at rest (=0.5)
z = depth from the ground level to the calculated point below the ground (m)

ii. Portion within ground water

$$P_{hd} = K_0 \{\gamma_t H_1 + (\gamma_t - 0.9)(z - H_1)\} + (z - H_1)$$

where

H_1 = depth from ground level to underground water elevation



7. Buoyancy (B)

Buoyancy will be considered where it affects the design of either substructure, including piling, or the superstructure. In the design of the pedestrian underpass, it is possible for the box tunnel under the ground level to be lifted by the buoyancy force. Therefore, the stability against the buoyancy must be examined in the design calculation for the box tunnel.

8. Wind Loads (W) (For Canopy Design)

The wind load to consider in the design will be taken as the moving and uniformly distributed loads applied on the exposed area of the structure. The exposed area will be the sum of the areas of all members, including handrail and screen , as seen in elevation at 90 degrees to the longitudinal axis of the canopy structure.
The forces to be applied directly to the canopy will be a horizontal force which is applied in a perpendicular or parallel direction to the longitudinal axis of the canopy. However, the wind load will not act simultaneously in both directions.

The intensity of the wind load for the effective exposed canopy area against wind direction will be as follows:

Shape of cross section of canopy member	Wind load (kgf/m^2)
Circular or Oval shape	150
Square shape	300

9. Thermal Effect (T)

i) The base temperature for the design calculation will be as follows:

Temperature

Base temperature in the sultanate of Oman -------------------------- +30℃

This value is based on the annual average temperature for past eight years.

ii) Range of Temperature for Structural Design

The range of temperature for structural design will generally be as follows:

Change in Temperature

Range of temperature in the Sultanate of Oman -------------------- ±0℃～+52℃

The rise and fall in temperature of the structures will be considered as a change between the base temperature and the range of temperature.

For Concrete Structures

	Temperature Rise	Temperature Fall
General concrete structure --------------------	+15 ℃	−15 ℃
Structure with the minimum section size ------- of not less than 70 cm	+10 ℃	−10 ℃

iii) Coefficients of Thermal Expansion

The coefficients of thermal expansion will be taken as follows:

Classification	Coefficient of Thermal Expansion
Steel of Steel Structure	12×10^{-6} /℃
Reinforcing Bar and Concrete of Concrete Structure	10×10^{-6} /℃
Steel and Concrete of Composite Girder	12×10^{-6} /℃

iv) The thermal effect for underwater or underground structures will not be considered.

10. Earthquake (EQ) (For Canopy Design)

In regions where earthquake may be anticipated, structures will be designed to resist earthquake motions by considering the seismic response of the soils at the site in accordance with Specifications for Highway Bridges - Part V Seismic Design (Japan). However, the acceleration coefficient for seismic loads will be taken as 0 in Dhofar Region, 0.2g in Musandam, and 0.1g elsewhere in accordance with the Highway Design Manual in the Sultanate of Oman.

11. Effect of Creep (CR) and Shrinkage (SH) of Concrete (For Canopy Design)

The statically indeterminate force due to the effect of creep and shrinkage of concrete will be calculated in accordance with the followings:

When the structural system does not change between the construction stage and completion stage since the entire structure is constructed by full support at a time, the creep effect of concrete will not be considered. For the calculation of statically indeterminate force due to the shrinkage of concrete, the shrinkage strain will be taken as 15×10^{-5}. However, in the case of the amount of the longitudinal reinforcement is less than 0.5% of the area of the cross section of the member, the shrinkage strain will be taken to be 20×10^{-5}.

b) Materials and Physical Constants to be used in Design Calculations

Materials to be considered in this design calculation of pedestrian underpasses will generally be the same kind as the bridge design. Therefore, details of material and its physical constants will be refereed to the section 4.1.3 - b).

c) Combinations of Loads

Combinations of loads and allowable stresses for the design of pedestrian underpasses will also be refereed to the section 4.1.3 - c).

d) Structural Details

1. Water Proof

All concrete surface in contact with soil should have fiber reinforced bitumen membrane protection. The bitumen membrane should be protected by 5mm thick hard board when back filled.

All exposed concrete surfaces should have a five (5) coats (one primer/sealer, two high build and two gloss) approved polyurethane paint system. (Color "Butter Milk" code 10 B 15 or similar).

2. Construction Joint

Construction joints should be constructed at intervals of 10m each or less depending on the construction sequence. Considering the reuse of form work of the box tunnel, it is desirable that the construction joints be constructed at a constant interval. In particular, construction joints under the median of highway should be decided giving attention to the traffic during full closure of one carriageway.

PVC waterstop with 190mm wide should be provided at the center of the internal area of the construction joint.

3. Haunch

Haunch with 150mm in height and 300mm in width should be designed at the internal upper corners of the box tunnel section.