Manual

for

Structural Design of

Waterworks Structures

Water Supplies Department
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1. SCOPE

This Manual sets out the design standards and technical guidelines to be adopted for the structural design of reinforced concrete (RC) waterworks structures (such as pumping stations, service reservoirs, buildings and other structural facilities within water treatment works) for migration from British Standards BS 8110 and BS 8007 to Eurocodes and their UK National Annexes. This Manual shall be read in conjunction with other WSD documents related to design and associated administrative procedures. Advice should be sought from the Design Division of WSD in case of any enquiries related to this Manual.

2. DESIGN STANDARDS

Structural design of waterworks structures shall be in accordance with the following design standards:

(i) BS EN 1990:2002+A1:2005 "Eurocode: Basis of Structural Design" and UK National Annex (NA) to BS EN 1990:2002+A1:2005.

(ii) Eurocode 1: Actions on Structures -

- BS EN 1991-1-1:2002 "Part 1-1: General Actions – Densities, Self-weight and Imposed Loads for Buildings" and UK NA to BS EN 1991-1-1:2002.
- BS EN 1991-1-5:2003 (Incorporating Corrigendum No. 1) "Part 1-5: General Actions – Thermal Actions" and UK NA to BS EN 1991-1-5:2003.
- BS EN 1991-1-6:2005 "Part 1-6: General Actions – Actions during Execution" and UK NA to BS EN 1991-1-6:2005.
- BS EN 1991-1-7:2006+A1:2014 "Part 1-7: General Actions – Accidental Actions" and UK NA to BS EN 1991-1-7:2006+A1:2014.
- BS EN 1991-3:2006 "Part 3: Actions Induced by Cranes and Machinery" and UK NA to BS EN 1991-3:2006.
- BS EN 1991-4:2006 "Part 4: Silos and Tanks" and UK NA to BS EN 1991-4:2006.

(iii) Eurocode 2: Design of Concrete Structures -

- BS EN 1992-1-1:2004+A1:2014 "Part 1-1: General – Common Rules for Building and Civil Engineering Structures" and UK NA to BS EN 1992-1-1:2004+A1:2014.
- BS EN 1992-3:2006 "Part 3: Liquid Retaining and Containment Structures" and UK NA to BS EN 1992-3:2006.

(iv) BS EN 1998 Eurocode 8: Design of Structures for Earthquake Resistance -

- BS EN 1998-1:2004+A1:2013 "Part 1: General Rules Seismic Actions and Rules for Buildings" and UK NA to BS EN 1998-1:2004+A1:2014.
- BS EN 1998-4:2006 "Part 4: Silos, Tanks and Pipelines" and UK NA to BS EN 1998-4:2006.

(v) HKSAR Standards and Codes of Practices, together with WSD design documents if the above codes and documents are not considered suitable.

3. DESIGN WORKING LIFE

Unless otherwise stated, the design working life of waterworks structures shall be 50 years, i.e. design working life category 4 as defined in Clause NA.2.1.1 of UK NA to BS EN 1990:2002+A1:2005.

4 MATERIAL PROPERTIES

4.1 Concrete

The following concrete parameters shall be adopted for structural design of waterworks structures:

Parameter	**Eurocode & UK NA** (for reference)	**Recommended Value**
Compressive strength	Design equations based on cylinder strength (f_{ck}) determined at 28 days, with its Equivalent cube strength ($f_{ck,cube}$) given in Table 3.1 of BS EN 1992-1-1:2004+A1:2014	Retain the use of cube strength, but convert to cylinder strength using conversion factors based on past test data on the relationship between compressive strengths of 100 mm cubes and 150 mm cubes and Table 3.1 of BS EN 1992-1-1:2004+A1:2014.
Exposure condition	Pumping station – XC4, but XS3 for intake structure of salt water pumping station Fresh water service reservoir – XC4 Salt water service reservoir – XS3 (*Table 4.1 of BS EN 1992-1-1:2004+A1:2014)*	Adopt Eurocode.
Concrete grade	$f_{ck,\ cube}$ = 35 MPa (for XC4) $f_{ck,\ cube}$ = 50 MPa (for XS3)	Adopt concrete grade strength 35 MPa for XC4 and grade strength 50 MPa for XS3.
Nominal concrete cover	40 mm for XC4 60 mm for XS3	Adopt 40 mm for XC4 and 60 mm for XS3.

Parameter	Eurocode & UK NA (for reference)	Recommended Value
Modulus of elasticity	Table 3.1 of BS EN 1992-1-1:2004 $E_{cm} = 22 \times ((f_{ck}+8)/10)^{0.3}$	Adopt values of E_c for general use in Table 3.2 or Equation 3.1 of Code of Practice for Structural Use of Concrete 2013, but with the material safety factor applied, i.e. $E_c = 3.46 \times (f_{ck,cube} / \gamma_m)^{0.5} + 3.21$
Stress-strain curve	Figure 3.3 of BS EN 1992-1-1:2004+A1:2014	Adopt Figure 3.8 of Code of Practice for Structural Use of Concrete 2013.
Simplified stress block at ultimate limit state	Figure 3.5 and Equations (3.19) to (3.22) of BS EN 1992-1-1:2004+A1:2014	Adopt Eurocode.
Coefficient of thermal expansion	$10 \times 10^{-6}/^{\circ}C$	Adopt Eurocode.
Drying shrinkage	Expressions 3.9 & 3.10 and Annex B.2 of BS EN 1992-1-1:2004+A1:2014	Adopt Section 3.1.8 of Code of Practice for Structural Use of Concrete 2013.
Creep	Expressions 3.6 & 3.7 and Appendix B.1 of BS EN 1992-1-1:2004+A1:2014	Adopt Section 3.1.7 of Code of Practice for Structural Use of Concrete 2013.

Note:

1. *The concrete grade and nominal concrete cover are based on concrete using CEM I cement and may need to be adjusted in accordance with BS EN 1992-1-1:2004+A1:2014 and its UK NA in case concrete with other cement and combination type is used.*

4.2 Reinforcing Steel

The following parameters for reinforcing steel shall be adopted for structural design of waterworks structures:

Parameter	Recommended Value
Yield strength	500 MPa
Modulus of elasticity	200 GPa

Reinforcing steel shall comply with the requirements of Construction Standard CS2:2012. References in the Eurocodes to reinforcing steel Class B and Class C shall be replaced by grade 500B and grade 500C of CS2:2012 respectively.

4.3 Partial Factors for Materials

The following partial factors for materials shall be adopted:

Limit State	Material	Partial Factor for Material γ_m
Ultimate limit state	Concrete	1.5
	Reinforcing Steel	1.15
Serviceability limit state	Concrete	1.0
	Reinforcing Steel	1.0

5. ACTIONS

5.1 Dead and Imposed Loads

The self-weight of reinforced concrete shall be taken as 25 kN/m^3.

The roof slabs of pumping stations and service reservoirs shall be designed to take an imposed load of 1.5 kN/m^2 and 5 kN/m^2 respectively.

Where applicable, reference should be made to *Code of Practice for Dead and Imposed Load 2011* (or its latest version) published by the Buildings Department.

5.2 Wind Action

The design wind action on waterworks structures shall follow the requirements of *Code of Practice on Wind Effect in Hong Kong 2004* (or its latest version) published by the Buildings Department.

5.3 Seismic Action

The structures for service reservoirs (SRs) shall be designed to withstand the seismic action in accordance with the requirements of Eurocode 8. The following parameters shall be adopted for seismic design:

Parameter	Eurocode & UK NA (for reference)	Recommended Value
Reference return period T_{NCR} of seismic action for the no-collapse requirement	475 years *(Clause 2.1(1)P of BS EN 1998-1:2004+A1:2013)* UK NA – 2,500 years in the absence of a project-specific assessment (*Table NA.1 of NA to BS EN 1998-1:2004+A1:2014*)	Adopt Eurocode, but not UK NA.

Parameter	Eurocode & UK NA (for reference)	Recommended Value
Reference peak ground acceleration on type A ground, a_{gR}	a_{gR} may be derived from zonation maps found in the country's National Annex. *(Clause 3.2.1(2) of BS EN 1998-1:2004+A1:2013)* UK NA – has adopted the reference peak ground acceleration for a return period T_{NCR} of 2500 years given by seismic contour map in PD 6698 *(Table NA.1 of NA to BS EN 1998-1:2004+A1:2014)*	Adopt 0.12g (based on GEO's Final Report on Overall Seismic Hazard Assessment, Jan 2012).
Importance factor γ_I for service reservoirs	Class I: $\gamma_I = 0.8$ Class II: $\gamma_I = 1$ Class III: $\gamma_I = 1.2$ Class IV: $\gamma_I = 1.6$ *(Clause 2.1.4 of BS EN 1998-4:2006)* UK NA – $\gamma_I = 1$ where a value of the reference return period T_{NCR} of 2500 years has been adopted. *(Table NA.1 of NA to BS EN 1998-4:2006)*	Adopt Eurocode, but not UK NA ($\gamma_I = 1.2$ to be adopted for service reservoirs).
Parameters S, T_B, T_C & T_D defining shape of horizontal elastic response spectra	Parameters for type 2 spectra (for a surface-wave magnitude, M_s, not greater than 5.5) *(Clauses 3.2.2.2(1)P & 3.2.2.2(2)P of BS EN 1998-1:2004+A1:2013)* UK NA – Recommended values for Type 2 earthquakes may be used in the absence of site-specific information. *(Table NA.1 of NA to BS EN 1998-1:2004+A1:2014)*	Adopt Eurocode, but not UK NA.

Note:

1. *SRs are considered as Importance Class III (or Consequences Class CC3 in BS EN 1990 Annex B) and shall be designed to withstand seismic action in accordance with BS EN 1998 Eurocode 8.*
2. *Other waterworks structures are normally considered as Importance Class I or Importance Class II (or CC1 or CC2 in BS EN 1990 Annex B) unless the project designer has identified project-specific needs.*

Checking of Structural Elements

Only waterworks structures with high consequence for loss of human life, etc. (i.e. consequence class CC3 in Annex B of BS EN1990) shall be designed to withstand seismic action. The project designer shall check structural elements of these structures in accordance with the following table :

Elements	**Action required**
Beams	Design according to EN 1992-1:2004 for bending and shear resistance and reinforcement ratio
Columns	Design according to EN 1992-1:2004 and EN 1998-1:2004 for flexural and shear resistance and normalized axial force
Beam-Column Joints	Review horizontal confinement reinforcement in joints of primary seismic beams
Foundation	Review foundation design in particular for bearing capacity and consider inclined piles and add shear keys
Seismic Joints	Design according to EN 1998-1:2004 and add seismic joints with a width of 50-100mm between adjacent structures
Anchorages and splices	Re-adjust anchorages and splices according to EN 1998-1:2004

Enhancement of Ductility Performance

For waterworks structures not designed to withstand seismic action, Technical Guide of "Practical Design Guide on Seismic Detailing for Concrete Buildings in Hong Kong" (CICR0213) shall be used as a reference to enhance the ductility performance of structural members.

5.4 Partial Factors for Actions

The following partial factors for actions at the ultimate limit state of STR (check for structural capacity of structural members) shall be adopted:

Permanent action		**Leading variable action**		**Accompanying variable actions**	
Unfavourable	**Favourable**	**Unfavourable**	**Favourable**	**Unfavourable**	**Favourable**
1.35	1.0	1.5	0	1.5 $\psi_{0,i}$	0

Notes:

1. *The ultimate limit states of "EQU", "GEO" and "UPL" are not applicable. These limit states are replaced by the local codes for the design of foundations and stability check (see Section 7 below).*
2. *The above table does not apply to seismic design situation.*

3. ψ_0 shall be based on Table A1.1 of BS EN 1990:2002+A1:2005.

The following partial factors for actions in the seismic design situation shall be adopted:

Permanent action		Leading seismic action	Accompanying variable actions
Unfavourable	**Favourable**		
1.0	1.0	1.0	$\psi_{2,i}$

Notes:

1. ψ_2 shall be based on Table A1.1 of BS EN 1990:2002+A1:2005.

2. The design seismic actions meeting the no-collapse requirement and damage limitation requirement shall both be considered.

The following partial factors for actions at the serviceability limit state shall be adopted:

Combination	Permanent action		Variable actions	
	Unfavourable	**Favourable**	**Leading**	**Others**
Characteristic	1.0	1.0	1.0	$\psi_{0,i}$
Frequent	1.0	1.0	$\psi_{1,1}$	$\psi_{2,i}$
Quasi-permanent	1.0	1.0	$\psi_{2,1}$	$\psi_{2,i}$

Note:

1. ψ_0, ψ_1 and ψ_2 shall be based on Table A1.1 of BS EN 1990:2002+A1:2005.

6. WATER RETAINING STRUCTURES

A service reservoir and the basement of a pumping station lying below the natural ground water level shall be designed as a water retaining structure with tightness class 2 in accordance with Clause 7.3.1 (111) of BS EN 1992-3:2006. The values of the design crack width w_{k1} for the water retaining structure, defined as a function of the ratio of the hydrostatic pressure, h_D to the wall thickness of the structure, h, shall be as follows in accordance with UK NA to BS EN 1992-3:2006:

- For $h_D/h \leqq 5$, $w_{k1} = 0.2$ mm
- For $h_D/h \geqq 35$, $w_{k1} = 0.05$ mm
- For intermediate values of h_D/h, linear interpolation between 0.2 mm and 0.05 mm shall be used.

7. FOUNDATIONS

The following design codes shall be adopted for foundation design:

Type	**Eurocode & UK NA** (for reference)	**Recommendation**
Shallow and deep foundations	BS EN 1990 and BS EN 1997 (limit state approach)	Adopt local codes, including Buildings Department's Code of Practice for Foundations 2004 and GEO Publication No. 1/2006 "Foundation Design and Construction" (working load and global factor of safety approach).
Pile cap / raft foundation	BS EN 1992-1	Adopt Eurocode for structural concrete design.