5 SERVICEABILITY LIMIT STATES

5.1 GENERAL

A structure shall be designed and constructed to meet relevant serviceability criteria in clauses 5.2 to 5.4. The checking should be based on the most adverse realistic combination and arrangement of serviceability loads and the structure is assumed to behave elastically.

5.2 DEFLECTION

The deflections or deformations from all load types should not impair the strength or effective functioning of a structure, supporting elements or its components, nor cause damage to the finishes. For typical structures, the deflection limits in Table 5.1 are recommended. Precamber in an unloaded structural member may be used to reduce the calculated deflection of that member under the loading conditions.

Table 5.1 - Deflection limits

a)	*Deflection of profiled steel sheeting*	
	Vertical deflection during construction when the effects of ponding are not taken into account	Span/180 (but ≤20 mm)
	Vertical deflection during construction when the effects of ponding are taken into account	Span/130 (but ≤ 30 mm)
	Vertical deflection of roof cladding under dead and wind load	Span/90 (but ≤ 30 mm)
	Lateral deflection of wall cladding under wind load	Span/120 (but ≤ 30 mm)
b)	*Vertical deflection of composite slab*	
	Due to imposed load	Span/350 (but ≤20 mm)
	Due to the total load plus due to prop removal (if any) less due to self-weight of the slab	Span/250
c)	*Vertical deflection of beams due to imposed load*	
	Cantilevers	Length/180
	Beams carrying plaster or other brittle finish	Span/360
	Other beams (except purlins and sheeting rails)	Span/200
	Purlins and sheeting rails	To suit cladding
d)	*Horizontal deflection of columns due to imposed load and wind load*	
	Horizontal drift at topmost storey of buildings	Height/500
	Horizontal drift at top of a single storey portal not supporting human	To suit cladding
	Relative inter-storey drift	Storey height/400
	Columns in portal frame buildings	To suit cladding
	Columns supporting crane runways	To suit crane runway
e)	*Crane girders*	
	Vertical deflection due to static vertical wheel loads from overhead traveling cranes	Span/600
	Horizontal deflection (calculated on the top flange properties alone) due to horizontal crane loads	Span/500
f)	*Trusses*	
	Typical trusses not carrying brittle panels	Span/200

Note:
Exceedance of the above limit is not acceptable unless a full justification is provided.
Precamber deflection can be deduced in the deflection calculation.
Ponding should nevertheless be avoided in all cases.
Long span structures should be checked against vibration.

5.3 WIND INDUCED VIBRATION

Vibration of a structure should be limited to avoid discomfort to users and damage to contents. For special structures, including long-span bridges, large stadium roofs and chimneys, wind tunnel model tests are recommended for their wind resistant design to meet serviceability limits.

5.3.1 Wind sensitive buildings and structures

A design procedure which incorporates dynamic analysis in addition to static analysis shall be undertaken for wind sensitive buildings and structures. Structures with low natural frequency or large height-to-least dimension ratio should receive special checking. Reference should be made to the Code of Practice on Wind Effects in Hong Kong.

For slender, flexible and lightly damped tall buildings and structures, those with a long afterbody or complex geometry, and those with an eccentricity between mass and stiffness centres, aeroelastic instabilities such as lock-in, galloping and flutter may cause large amplitude crosswind responses. Specialist advice and wind tunnel model test are recommended for their wind resistant design to meet serviceability limits.

5.3.2 Serviceability limit state

The serviceability limit states on vibration, deflection and acceleration should be checked to ensure serviceable condition for the structure.

5.3.3 Dynamic structural characteristics

5.3.3.1 Natural frequencies

Structural analysis programmes should be used to determine the natural frequencies of vibration of buildings and structures to mitigate excessive horizontal and vertical vibration. Empirical formulae can also be used for approximated vibration analysis of typical and regular buildings.

5.3.3.2 Structural damping

The structural damping value for steel buildings and structures is amplitude dependent and varies greatly depending on the type of structure and the structural layout. When structural damping is required to enhance serviceability limit state, published data on damping ratio for various types of structures may be used with justification. Clauses below cover common structural forms while special structures should be referred to specialist literature.

5.3.4 Serviceability criteria for tall buildings

Generally the maximum wind load and deflection occurs along an axis in the along-wind direction although the cross-wind response may dominate in the case of certain tall and slender structures. For such tall and slender structures (typically with an aspect ratio of 5:1 or greater), occupant discomfort due to building motion may be an issue during severe typhoons. Torsional effects and eccentricity between centres of building mass and stiffness can affect building response to wind.

Excessive deflection may cause cracking of masonry, partitions and other interior finishes and building façade. Whilst the maximum lateral deflection shall not exceed the values given in Table 5.1, (Topmost storey deflection limited to Height / 500 and inter storey drift limited to Storey height / 400) the design and detailing of cladding, curtain walling, partitions and finishes should take into account the effects of deflection, inter storey drift and movement.

Alternatively, a dynamic serviceability analysis and design may be carried out to justify compliance with serviceability limit for tall buildings. In such a case:

a) It should be recognised that excessive deflection may cause cracking of masonry, partitions and other interior finishes and the design and detailing of cladding, curtain walling, partitions and finishes should take into account the effects of deflection, inter-storey drift and movement.

b) A dynamic analysis to study building motion, frequency of vibration and acceleration should be carried out. Acceptable levels of occupant comfort will be considered to have been achieved in compliance with the Code if the following building acceleration limits during the worst 10 consecutive minutes of an extreme wind event with a return period of 10 years are met:

Type of Use of Building	Peak acceleration (milli-g)
Residential	15
Office building, Hotel	25

The ***10-year*** return period of ***10-minute*** wind speed may be determined from suitable analysis of Hong Kong wind climate data, numerical typhoon modelling or derived from the wind speed used for strength design.

It should be noted that for some buildings, a higher degree of occupant comfort may be desirable. The above only represents an acceptable minimum standard for most buildings. Local researchers and published standards, e.g. ISO 6897 indicates that peak acceleration as comfort criteria is frequency dependent.

c) Occupant tolerance of motion is influenced by many factors including experience, expectation, frequency of building motion, frequency of exposure, and visual and audio cues. As an alternative to the above guidelines in (b) performance based assessments may be carried out to justify the design. Such a performance-based approach would normally include comprehensive wind tunnel testing.

Excessive acceleration under wind loads should always be avoided. Limiting deflection at the topmost storey of a building to H / 500 under the design wind load specified in the HKWC will usually provide an acceptable environment for occupants in most typical buildings without the need for a dynamic analysis. However, the Responsible Engineer should always consider each building on its merits.

For other types of structures, specialist advice should be sought.

5.3.5 Serviceability criteria for communication and broadcasting towers

Communication and broadcasting services demand minimal disruption to transmission. The serviceability limits for communication and broadcasting towers are selected to meet the performance specifications of antennae and other transmission devices to be mounted on those towers. Excessive vibration of towers should be avoided. For design, reference should be made to specialist literature.

5.3.6 Reduction of wind induced dynamic response

If the calculated deflection or acceleration exceeds the serviceability limits, mitigation methods including but not limited to (a) increasing mass (i.e. frequency dependent mitigation method), (b) increasing stiffness, (c) increasing damping and (d) altering the aerodynamic shape may be used. Specialist advice should be sought when changing mass, stiffness, damping and/or aerodynamic shape is needed for reducing wind-induced response.

5.4 HUMAN INDUCED FLOOR VIBRATION

When the deflection limit for beams and floors are exceeded, it may be necessary to check the vibration of the members for human comfort. For light weight and long span structures as well as vibration suspected occupancies (such as dancing hall, aerobics, and factory, etc.), where excessive vibration is anticipated, floor vibration assessment may be necessary. Reference should be made to relevant Code of Practices and specialist literature as given in Annex A2.5.

5.5 DURABILITY

5.5.1 General

Steelwork can be subjected to many different degrees of environmental exposure. This section provides general guidance for steelwork in building and some other structures subjected to more commonly occurring exposure conditions.

The following factors should be taken into account in design of protective systems for steelwork in order to ensure the durability of the structure under conditions relevant both to its intended use and to its design working life.

a) The environment of the structure, whether bimetallic corrosion is possible and the degree of exposure of the structure.

b) Accessibility of structure for inspection and maintenance, (i.e. easy, difficult or impossible). Access, safety and the shape of the members and structural detailing are relevant.

c) The relationship of the corrosion protection and fire protection systems.

The purpose of this section is to provide general guidance on corrosion protection. It is not an attempt to prescribe particular solutions in detail. Detailed guidance on corrosion protection can be found in specialist literature.

Refer to clause 13.8 for guidance on maintenance.

5.5.1.1 Typical exposure conditions

Typical examples of commonly occurring exposure conditions are given below.

Table 5.2 - Exposure conditions

Exposure Class	Type of Exposure	Examples
1	Non corrosive	Steelwork in an internal controlled (i.e. dry) environment. Steel piles driven into undisturbed and non-corrosive ground.
2	Mild (typically internal)	Steelwork in an internal humid environment.
3	Moderate (internal or external)	Steelwork built into perimeter cladding. External steelwork in a dry climate.
4	Severe	External steelwork exposed to rain and humidity. Internal steelwork over a swimming pool, kitchen or water tank.
5	Extreme	External steelwork in a marine environment. Steel piles driven into corrosive ground. Steelwork exposed to salt water.

5.5.1.2 Maintenance regime

The degree of maintenance to be carried out to the protective system depends not only on the client's requirements for initial cost versus ongoing maintenance cost but also on the accessibility of the steelwork for carrying out the maintenance.

Three classes for accessibility of maintenance are defined here:

Class A: Good access i.e. easily accessible and / or will be regularly maintained.

Class B: Poor access i.e. difficult to access and will be infrequently maintained.

Class C: Extremely difficult or impossible access for maintenance.

5.5.2 Types of protection against corrosion

Systems for various levels of corrosion protection are described in this section. A guide to

their applicability is given in Table 5.3 below. All relevant information including the proposed maintenance regime shall be considered before selecting an appropriate system. Refer to clause 14.6 for protective treatment workmanship.

Table 5.3 - Types of protective system and typical application guide

Type of protection system	Exposure class	Minimum recommended class for accessibility of maintenance
None, i.e. bare steel,	1	Not applicable
Use of paint systems as protective coatings.	2, 3, 4	B
Paint and cementitious or sprayed fibre fire protection	1, 2	B
Encasement in concrete. (also provides structural composite action)	1, 2, 3, 4, possibly 5	C
Use of galvanized or metal sprayed protective coatings.	3, 4	C
Use of a corrosion resistant alloy e.g. stainless steel or weathering steel	3, 4, 5	C
Use of a sacrificial corrosion allowance	4, 5	C
Use of Cathodic Protection (CP)	5	B

5.5.2.1 *Galvanizing*

Hot dip galvanizing should comply with the requirements of the applicable standards and be at least 85 microns thick.

The high temperature of the galvanizing process can lead to distortions as locked-in stresses are relieved.

Bolts of ISO Grade 10.9 or higher grade or equivalent should not be galvanized, but should be sheradized and coated with zinc-rich or appropriate protective paint.

Hollow sections should be vented if they are to be galvanized.

Some high strength steels with yield strength greater than 460 N/mm^2 may be sensitive to cracking during galvanization and therefore special care should be taken. Hence, suitable venting should be provided while special dipping procedures shall be executed in order to alleviate the risk of cracking and distortion.

BS EN ISO 14713-2 has provided further guidance, including information on the influence of various factors, including steel chemical composition, on the coating formation.

5.5.2.2 *Concrete casing*

Concrete casing shall be reinforced with wrapping fabric e.g. D49 as a minimum. Cover shall be as required for fire protection but should not be less than 50 mm for practical reasons of compaction. Small sized aggregate may be required.

If the casing is required to act compositely with the steel to transfer significant shear stresses (over 0.1 N/mm^2), then the steel shall be blast cleaned to remove mill scale before casing.

5.5.2.3 *Paint systems*

A suitable paint system should be selected using one of the references given or manufacturer's guidance. Regular maintenance of paint protection systems shall be carried out.

5.5.2.4 *Minimum thickness of permanent steelworks without special protection against corrosion*

Steel plates and rolled sections used in an external environment exposed to the weather i.e. exposure classes 3, 4 and 5, shall not be less than 8 mm thick. Steel used in an internal

environment, i.e. exposure classes 1 and 2, shall not be less than 6 mm thick. (Except packing plates which may be thinner.)

Sealed hollow sections in exposure classes 3, 4 and 5 shall not be less than 4 mm thick and for exposure classes 1 and 2 shall not be less than 3 mm thick.

These minimum thicknesses may not apply to particular proprietary products and in such a case, the Responsible Engineer shall provide justification that the corrosion resistance of the product is suitable for its application. Under all circumstances, the minimum thickness for all structural members shall not be less than 3 mm.

Cold formed steel protected by a factory applied barrier against corrosion shall not be less than 0.5 mm thick.

5.5.2.5 Sacrificial corrosion allowances for steel

Where other forms of protection are not practical, a sacrificial corrosion allowance may be made for steelwork in exposure classes 4 and 5. In such cases, the sacrificial allowance for corrosion shall be made in addition to the minimum thickness obtained from calculations for structural strength and stability.

The sacrificial thickness shall be determined from the particular corrosion regime and required life of the structural element under consideration. As a guide, an allowance of 0.25 mm to 0.5 mm per year may be considered.

5.5.3 Corrosion from residual stresses

Corrosion normally occurs severely at locations where there are significant residual stresses inherent in the steel during fabrication (cold working) and welding, for example from cambering, curving and straightening. Corrosion protection by painting or galvanizing, adoption of sacrificial thickness philosophy or other effective measures can be taken to improve the corrosion resistance of the material.

To relieve residual stresses, post-weld heat treatment with 600°C to 650°C of heat applied to a region between 150 mm to 300 mm around the subject location may be considered when applicable.