CHAPTER 7: SERVICEABILITY LIMIT STATES

7.1 GENERAL

It shall be in accordance with JSCE Standard Specification (Design), 7.1.

7.2 CALCULATION OF STRESS AND STRAIN

It shall be in accordance with JSCE Standard Specification (Design), 7.2, with the following assumptions made regarding CFRM:
(i) CFRM is elastic body;
(ii) The Young's modulus of CFRM is determined according to **3.4.3(2)**.

7.3 STRESS LIMITATION

It shall be in accordance with JSCE Standard Specification (Design), 7.3. The limitation of tensile stress in CFRM shall be determined by testing, according to the type of reinforcing material used.

[COMMENT]:
Unlike reinforcing or prestressing steel, CFRM undergoes failure at less than their static strength when subjected to sustained stress for long periods (i.e. creep failure).

Creep failure strength is to be tested according to JSCE-E 533 "Test Method for Creep Failure of Continuous Fiber Reinforcing Materials" based on the test results up to 1000 hours, extrapolating the creep failure strength at 1 million hours. The limitation of tensile stress in CFRM may generally be derived by multiplying the characteristic value of creep failure strength f_{fck} by a reduction factor of 0.8, given that the creep failure strength varies significantly depending on the fiber type, and given also that creep testing requires long periods of time. The limit value shall be not more than 70% of the characteristic value for tensile strength.

Creep failure as a phenomenon properly belongs under investigation of ultimate limit state, although it is placed in this section on serviceability limit state owing to the nature of the loads studied. For this reason, a reduction factor is used instead of a material factor.

7.4 CRACKING

7.4.1 General

(1) It shall be examined by an appropriate method that cracking in concrete does not impair the function, durability, appearances of the structures.

(2) This clause shall be applied to the verification of cracking caused by flexural moment, shear force,

torsional moment and axial force.

(3) Where the appearances of the structure is deemed important, the crack width on the concrete surface shall generally be kept within an allowable crack width considered acceptable for aesthetic considerations. Verification of cracking may be omitted for structures with particularly short service life, temporary structures, or structures where aesthetic considerations are not important.

(4) Where watertightness is important, the verification of cracking shall be done according to JSCE Standard Specification (Design), 7.4.1(4).

[COMMENTS]:

(1) Unlike steel materials, CFRM is considered to be free from corrosion. Cracking in concrete structures, however, generally results in loss of watertightness, airtightness and other functions, deterioration of the concrete, excessive deformation, unattractive appearance etc. Cracking in concrete must therefore be examined according to appropriate methods, to ensure that the functions, appearances of the structure are not impaired.

(3), (4) Verification of serviceability limit state when the intended purpose of the structure dictate particular aesthetic requirements, watertightness and airtightness requirements shall if necessary be made on the basis of a maximum allowable crack width.

7.4.2 Allowable crack width

(1) The allowable flexural crack width w_a shall generally be determined based on the intended purpose of the structure, environmental conditions, member conditions etc.

(2) Allowable crack widths set for aesthetic considerations may generally be set to not more than 0.5 mm, depending on the ambient environment of the structure.

(3) Crack limitations and allowable crack widths set for considerations of watertightness shall be based on JSCE Standard Specification (Design), 7.4.2(3).

[COMMENTS]:

(1) Allowable crack widths must be determined based on the intended purpose of the structure - function, relative importance, service life etc., the ambient environment and loading conditions, and also on member conditions such as the effects of axial force, covering, variation in crack widths etc.

(2) As CFRM is generally considered to be non-corrosion, there is no necessity to set allowable crack widths out of consideration of corrosion. Excessive crack width, however, would impair the appearance of the structure, as well as having a negative psychological impact. Whether or not cracking is likely to occur should first be investigated, and if cracking to be allowed, an appropriate allowable cracking width should be set based on aesthetic considerations, depending on the type of structure, the distance of the structure from the eyes of the casual onlooker, etc. Generally speaking, where main reinforcement is not prestressed, if the CFRM has low rigidity, large crack width may occur even at low load levels.

Where CFRM is used in conjunction with steel reinforcement, steel corrosion must also be considered in setting the allowable crack width, and in this case the allowable crack width is based on JSCE Standard Specification (Design), 7.4.2. Where steel reinforcement is not used, the maximum allowable crack width for members in public view has been set at not more than 0.5 mm.

7.4.3 Verification of flexural cracks

(1) Verification of flexural cracks may be omitted where the tensile stress of the concrete due to flexural moment and axial forces is lower than the design tensile strength of the concrete considering size effect.

(2) In the verification of flexural cracks shall be made, in general, the crack width w obtained from Eq. (7.4.1) shall be confirmed to be less than the allowable crack width w_a.

$$w = k\{4c + 0.7(c_f - \phi)\}\left(\sigma_{fe}/E_f \left(or\,\sigma_{pe}/E_{fp}\right) + \varepsilon'_{csd}\right) \qquad (7.4.1)$$

where

k = constant expressing the effects of bond characteristics and multiple placement of reinforcing materials; generally 1.0~1.3

c = concrete cover (mm)

c_f = center-to-center distance between reinforcing materials (mm)

ϕ = diameter of reinforcing materials (mm)

ε'_{csd} = compressive strain for evaluation of increment of crack width due to shrinkage and creep of concrete

σ'_{fe} = stress increase in reinforcement

E_f = Young's modulus of reinforcement

σ_{fpe} = stress increase in tendons

E_{fp} = Young's modulus of tendons

(3) The reinforcement and tendons to be examined for flexural cracks shall generally be the tensile reinforcement nearest to the concrete surface. Stress and strain shall be obtained according to section **7.2** above.

[COMMENTS]:

(1) Design tensile strength of concrete considering the size effect shall be according to Eq. (C 7.4.1) in the JSCE Standard Specification (Design).

(2) Eq. (7.4.1) is the same as that used for calculation of crack widths in concrete members using conventional steel reinforcement. The width and spacing of flexural cracks is generally affected significantly by the bond between the reinforcement and the concrete. CFRM may be classified according to their method of manufacture and surface geometry as strand, braid, wound, machined, lattice etc., and each type is considered to have different bond characteristics. Previous studies have found that when the surface is treated to give bond characteristics similar to conventional deformed steel bars, the spacing of cracks in concrete members is almost identical to that when deformed steel bars are used. In cases such as this, crack width can be calculated according to Eq. (7.4.1). The bond properties of CFRM are generally between those of round steel bars and deformed steel bars. The value of k in Eq. (7.4.1) must therefore be determined appropriately for each CFRM type, although for CFRM which has

been confirmed to have bond characteristics similar to those of deformed steel bars, a value of k = 1.0 may be adopted.

The term ε'_{csd} in Eq. (7.4.1) expresses the effects of concrete shrinkage and creep on crack widths, and must be determined on the basis of the surface configuration of the member, ambient environment, stress levels etc. Little basic data is available regarding ε'_{csd}, and further research in this area is required, but on the basis of an overall consideration of existing crack width formulae etc., ε'_{csd} can generally be taken to be = 150×10^{-6}.

When latticed CFRM is used, the lattice spacing also affects crack spacing; this effect is allowed for by calculating crack spacing l_k, calculating the crack width according to the following eq.:

$$w = l_k (\sigma_{fe} / E_f + \varepsilon'_{csd}) \qquad \text{(C 7.4.1)}$$

The basic policy regarding control of crack widths is to keep the width of cracks on the concrete surface below the allowable crack width determined on the basis of structural conditions and the concrete cover, although for convenience of design, for normal members a limit is set on the increase of strain in the CFRM due to permanent loads, considered to have minimal effect on crack widths; this provision allows the verification of crack widths in (2) to be omitted. Generally speaking, if either the strain increase in the reinforcement due to permanent loads σ_{fp}/E_f, or the strain increase in the tendons σ_{fpp}/E_{fp}, is less than 500×10^{-6}, verification of crack width may be omitted.

(3) If CFRM is arranged in multiple layers, normally the stress used will be that of the tensile reinforcement closest to the concrete surface, although the effects on crack width of CFRM further inside the section may also be evaluated, if such effects have been determined experimentally to be present.

7.4.4 Verification of shear cracks

It shall be in accordance with JSCE Standard Specification (Design), 7.4.5.

[COMMENT]: Verification of shear cracks is normally to be done according to JSCE Standard Specification (Design), 7.4.5, although this verification may be omitted where the strain increase in the shear reinforcement due to permanent loads is less than 500×10^{-6}.

7.4.5 Verification of torsion cracks

It shall be in accordance with JSCE Standard Specification (Design), 7.4.6.

[COMMENT]: Verification of torsion cracks is normally to be done according to JSCE Standard Specification (Design), 7.4.6, although this verification may be omitted where the strain increase in the torsional reinforcement due to permanent loads is less than 500×10^{-6}.

7.4.6 Structural Details

It shall be in accordance with JSCE Standard Specification (Design), 7.4.7.

7.5 DISPLACEMENT AND DEFORMATION

7.5.1 General

It shall be in accordance with JSCE Standard Specification (Design), 7.5.1.

7.5.2 Allowable displacement and deformation

It shall be in accordance with JSCE Standard Specification (Design), 7.5.2.

7.5.3 Verification of displacement and deformation

It shall be in accordance with JSCE Standard Specification (Design), 7.5.3.

[COMMENT]: Verification of displacement and deformation is normally to be done according to JSCE Standard Specification (Design), 7.5.3, although where the Young's modulus of the CFRM is extremely low compared to the steel reinforcement, and where the quantity of reinforcement is low, the deformation will be greater than in conventional steel reinforced concrete members. The increased deformation makes shear cracking more likely, and this in turn is considered to affect the displacement and deformation of the whole structure. In cases where shear cracking occurs, it must be properly allowed for in calculating deformation levels.

7.6 VIBRATION

It shall be in accordance with JSCE Standard Specification (Design), 7.6.