CHAPTER 10: GENERAL STRUCTURAL DETAILS

10.1 GENERAL

It shall be in accordance with JSCE Standard Specification (Design), 9.1, where "steel" shall be taken to signify "steel or CFRM".

10.2 CONCRETE COVER

(1) Concrete cover shall be determined taking into consideration the quality of concrete, bar diameters, environmental conditions, errors in construction, and the importance of the structure.

(2) The minimum concrete cover shall be obtained from Eq. (10.2.1), and shall be not less than the bar diameter.

$$c_{\min} = \alpha \cdot c_0 \tag{10.2.1}$$

where

c_{min} = minimum cover

α = cover factor dependent on design strength of concrete f'_{ck}, as follows:

$f'_{ck} \le 18$ N/mm^2: $\alpha = 1.2$

18 N/mm^2 < $f'_{ck} \le 34$ N/mm^2: $\alpha = 1.0$

34 N/mm^2 < f'_{ck}: $\alpha = 0.8$

c_0 = basic concrete cover, dependent on member as shown in **Table 10.2.1**

Table 10.2.1: Values of c_0 (basic concrete cover; mm)

Member	*Slab*	*Beam*	*Column*
c_0	25	30	35

(3) Concrete placed directly in the earth for footings or important members of structures, concrete cover should be not less than 75 mm.

(4) Concrete cover for concrete placed under water should be not less than 75 mm.

(5) Where concrete is vulnerable to abrasion by running water or similar, concrete cover should be increased as appropriate.

(6) Members placed in an acid river or subjected to severe chemical action shall be appropriately protected.

(7) Concrete cover in structures requiring special fire protection shall be determined taking into consideration the heat resistance of the CFRM, fire temperature and duration, aggregate characteristics etc.

[COMMENTS]:

(1) Adequate concrete cover of CFRM is necessary to realize full bond strength with the CFRM, to prevent deterioration of the CFRM, and to protect the CFRM in fires. Concrete cover should therefore be determined based on the designer's experience, taking into account the quality of the concrete, the characteristics and diameter of the CFRM, the effects of harmful substances acting on the concrete surface, the dimensions of the member, construction errors, the importance of the structure and so forth.

(2) Eq. (10.2.1) gives the minimum concrete cover. CFRM is generally highly resistant to corrosion, therefore there is no need to make special allowance for environmental conditions in **table 10.2.1**. Where CFRM is arranged in bundles, the diameter of the reinforcement shall be deemed to be that of a single rod of cross-sectional area equivalent to the sum of the cross-sectional areas of the individual strands in the bundle.

(3) This value may be reduced by a further 25 mm, provided the quality of cover is adequately assured by, for example, the use of high fluidity concrete.

(4) Concrete placed under water cannot be adequately compacted, the concrete sometimes does not adequately fill narrow spaces between the CFRM and the formwork, and the quality of underwater concrete is hard to determine, therefore a safe minimum of 75 mm has been set. For cast-in-place concrete piles etc., cover should be around 125 mm to allow for the presence of casings, irregularity of the inner face of drilled earth, installation of cages etc. All of these values are reduced by 25 mm from those given for steel reinforcement, in consideration of the superior corrosion resistance of CFRM which allows underwater environments to be treated as standard environments.

(5) Where concrete is vulnerable to abrasion, for instance on the upper side of a slab without effective protection, concrete cover should be increased by at least 10 mm, giving a section larger than the minimum required according to bearing capacity calculations.

(6) Members placed in acid rivers or exposed to strong chemical action should be provided with extra corrosion protection, as deterioration of the concrete cover cannot be prevented.

(7) A "structure requiring special fire protection" refers here to a structure showing little or no damage or weakness during a fire. Tests have found that the fire resistance of CFRM varies greatly from type to type, and the fire resistance of the proposed CFRM must be allowed for in determining concrete cover. If necessary the sue of additional fire-proofing layers etc. should be considered.

10.3 CLEAR DISTANCE

It shall be in accordance with JSCE Standard Specification (Design), 9.3, where "steel" shall be taken to signify "steel or CFRM".

10.4 BENT CONFIGURATIONS OF REINFORCEMENT

10.4.1 General

(1) CFRM may be placed bent within their elastic limit. The effects of elastic bending stress shall be allowed for in design.

(2) When bent CFRM is used, the design strength of the bent section shall be allowed for.

[COMMENT]: (2) The design strength of bent sections of CFRM is obtained from **3.4.1(3)** or **(4)**.

10.4.2 Stirrups, ties and hoops

(1) CFRM may be bent in closed, spiral, grid or solid configurations for use as stirrups, ties or hoops.

(2) The standard inside radius of bent sections of stirrups and hoops shall be 2ø, where ø = bar diameter.

[COMMENTS]:
(1) Ties and hoops serve to prevent buckling of axial reinforcement while constraining the inner concrete. They must therefore be closely spaced to ensure adequate effectiveness, and the ties and hoops themselves must be properly anchored. For this reason, the use of closed configurations is advised. Whichever configuration is used, the strength of bent sections and the panel points must be allowed for.

(2) The inside radius of bent sections of stirrups and hoops should be small as possible, from the practical point of view of containing the reinforcement, but making the inside radius too small could result in significant loss of strength.

10.4.3 Other reinforcement

(1) The inside radius of bends in reinforcement along the outer side of a corner in a frame structure shall be not less than 10 times the reinforcement diameter.

(2) Reinforcement along the inner sides of corners in a haunch or rigid frame shall not be bent reinforcement carrying tension of slabs or beams.

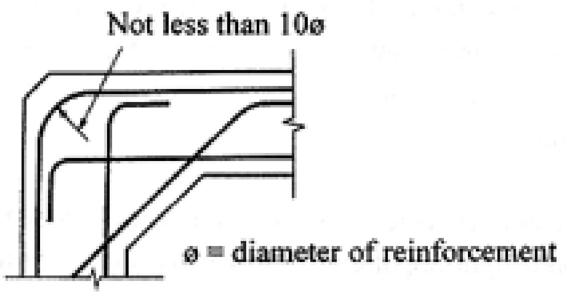

Fig. 10.4.1: Inside radius of bend in reinforcement along outer side of corner in frame structure

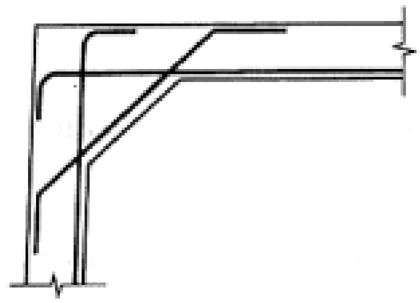

Fig. 10.4.2: Reinforcement along inner side of corner in haunch or frame structure

10.5 ANCHORAGES

10.5.1 General

(1) Reinforcement ends shall be embedded sufficiently in concrete, and anchoring shall be achieved either by the bonding force between the reinforcement and concrete, or by mechanical anchoring.

(2) At least 1/3 of the positive moment reinforcement in slabs or beams shall be anchored beyond the support, without being bent.

(3) At least 1/3 of the negative moment reinforcement in slabs or beams shall extend beyond the inflection point and anchored in the compression zone, or shall be connected to the next negative moment reinforcement.

(4) Stirrups shall enclose positive or negative moment reinforcement, and their ends shall be either closed or anchored in the concrete on the compression side.

(5) Spiral reinforcement shall be anchored in concrete enclosed by spiral reinforcement wound an extra one and a half turns.

(6) When the end of reinforcement is anchored by bonding between concrete and reinforcement, anchoring shall be done following the development length given in **10.5.2**.

[COMMENTS]:

In CFRM reinforced concrete, the CFRM and concrete must act in concord against external forces. Thus, when there is an external force acting against concrete members, the anchoring of the reinforcement is extremely important, and must be developed free from defects. If the anchoring of the reinforcement ends is adequate, the effects of local bond may be ignored, thus in this section only development of bar ends is covered.

(1) CFRM may be categorized as follows according to their bond property.
[1] Bond failure by bond splitting of concrete: This is equivalent to the failure mode of deformed steel bars, and in general, this is the mode of failure observed when the surface of the CFRM is treated to resemble a deformed steel bar.

[2] Bond failure by pull-out of reinforcement: This mode of failure is generally observed where indentations on the surface of the CFRM are small, or where abrasive grains or threads are bonded onto the CFRM surface, but the bond strength is low.
[3] No bond strength: CFRM with smooth surfaces generally has lower bonding action with concrete than conventional round steel bars, giving almost no bond strength at all. In these cases mechanical anchoring is required.
[4] Anchoring by resistance from intersecting lateral reinforcement: In lattice and solid configurations, anchoring is generally achieved by the resistance of intersecting lateral reinforcement.

In order to achieve full strength of reinforcement, depending on the bond characteristics of the CFRM used, either an adequate development length should be allowed or a mechanical anchorage fitted to embed the reinforcement securely within the concrete, in order to ensure the CFRM does not pull out from the concrete. Given that CFRM looses strength in bent sections, and that their flexural rigidity is inadequate, unlike the case with steel reinforcement no anchoring effect is expected from hooks.

Where bond between the reinforcement and the concrete is relied on for anchoring, reinforcement must also be arranged perpendicularly, to ensure adequate anchoring. For tensile reinforcement at the fixed ends of members, both ends of tensile reinforcement in footings, tensile reinforcement at the free ends of cantilever beams and so forth, anchorages should be fitted to prevent reinforcement pulling out even if major cracking appears.

(4) When a diagonal crack occurs in a beam, the two parts of the beam on either side of the crack will tend to part from one another. Stirrups are place to prevent these two parts from separating, performing the function of a vertical tensile member of a Howe truss. The stirrup must therefore either be closed, or bent so that its end is hooked around reinforcement in the compression zone, to ensure that its end is properly anchored. The purpose of enclosing compression reinforcement with stirrups is to anchor the stirrup properly, and to prevent the compression reinforcement from buckling.

10.5.2 Development length of reinforcement

(1) The development length for CFRM l_0 shall be not less than the basic development length l_d. Where the quantity of reinforcement placed A_f is greater than the quantity required by calculation A_{fc}, development length l_0 may be reduced in accordance with Eq. (10.5.1)

$$l_0 \geq l_d \cdot (A_{fc} / A_f) \qquad (10.5.1)$$

where

$l_0 \geq l_d/3$, $l_0 \geq 10ø$

ø = diameter of reinforcement

(2) The development length of reinforcement where the anchorage is bent shall be as follows:

(i) When the inside radius of the bend is not less than 10 times the reinforcement diameter, the entire length of reinforcement including the bent part shall be effective.

(ii) When the inside radius of the bend is less than 10 times the reinforcement diameter and the straight part beyond the bend is extended more than 10 times the reinforcement diameter, only the straight part beyond the bend shall be effective.

(iii) The length of the straight part *l′* shall be not less than the length necessary for the stress acting on the reinforcement in the bent part not to exceed the tensile strength of the bent part.

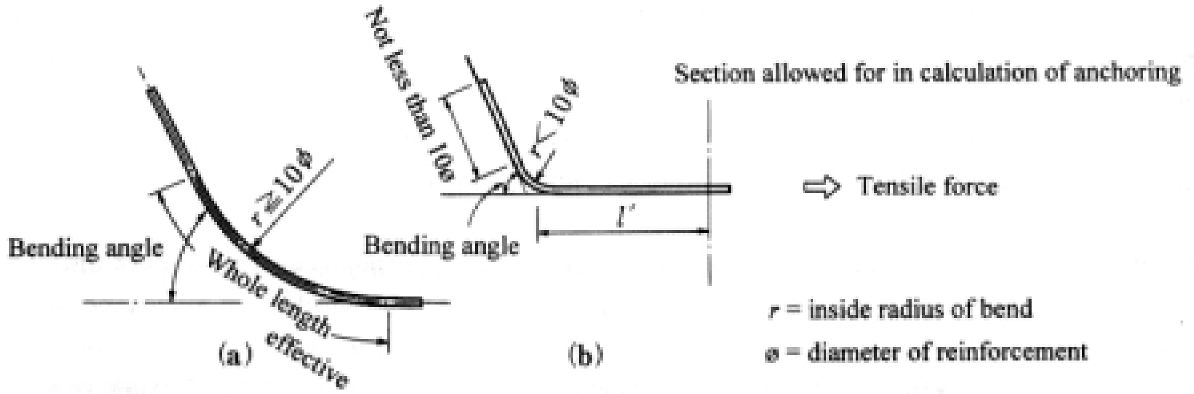

Fig. 10.5.1: Determination of development length of reinforcement in bent anchorages

(3) Tensile reinforcement shall generally be anchored in concrete not subject to tensile stress. If either of the conditions (i) or (ii) below is satisfied, tensile reinforcement may be anchored in concrete subject to tensile stress. In this case, the anchorage of the tensile reinforcement shall be extended by ($l_d + l_s$) from the section where the reinforcement is no longer required to resist calculated flexure, where l_d is the basic development length and l_s may in general be the effective depth of the member section.

(i) The design shear strength shall be not less than 1.5 times the design shear force between the point of reinforcement cutoff and the section where the reinforcement is no longer required to resist calculated flexure.

(ii) The design flexural capacity shall be not less than 2 times the design moment at a point where adjacent reinforcement terminates, and design shear capacity shall be not less that 4/3 times the design shear force between the point of reinforcement cutoff and the section where the reinforcement is no longer required to resist calculated flexure.

(4) Where positive moment reinforcement in a slab or beam is anchored beyond the support at the end, the development length of the reinforcement shall be not less than l_0 for stress in reinforcement at a section which is at a distance of l_s from the center of the support and shall be extended to the end of the member.

[COMMENTS]:

(1) The development length is calculated from the basic development length l_d, determined by the type and arrangement of the reinforcement, and by the strength of the concrete, modified according to the usage conditions.

Where the quantity of reinforcement placed is in excess of that quantity required according to calculation, the basic development length may be reduced proportionally. A minimum value for l_0 has been given, as the safety level with regard to additional forces is reduced.

(2) (iii) As the tensile strength of bent sections of CFRM is generally less than that of straight sections, it is necessary to reduce the tensile force acting on the bent section by the bonding at the straight length *l′*. Where the quantity of reinforcement placed is in excess of that quantity required according to calculation, length *l′* may be reduced following section (1) above.

10.5.3 Basic development length

(1) The basic development length of CFRM shall generally be determined on the basis of appropriate testing.

(2) The basic development length of tensile reinforcement types which undergo bond splitting failure may be calculated according following Eq. (10.5.2), provided that ld > 20ø.

$$l_d = \alpha_1 \frac{f_d}{4 f_{bod}} \phi \qquad (10.5.2)$$

where

ø = diameter of main reinforcement

f_d = design tensile strength of CFRM

f_{bod} = design bond strength of concrete according to Eq. (10.5.3), where $\gamma_c = 1.3$

$$f_{bod} = 0.28\alpha_2 f'_{ck}{}^{2/3}/\gamma_c \ \text{(N/mm}^2\text{)} \qquad (10.5.3)$$

where

$f_{bod} \leq 3.2$ N/mm^2

α_2 = modification factor for bond strength of CFRM; $\alpha_2 = 1.0$ where bond strength is equal to or greater than that of deformed steel bars; otherwise α_2 shall be reduced according to test results.

f'_{ck} = characteristic compressive strength of concrete

$\alpha_1 = 1.0$ (where $k_c \leq 1.0$)
= 0.9 (where $1.0 < k_c \leq 1.5$)
= 0.8 (where $1.5 < k_c \leq 2.0$)
= 0.7 (where $2.0 < k_c \leq 2.5$)
= 0.6 (where $2.5 < k_c$)

where

$$k_c = \frac{c}{\phi} + \frac{15A_t}{s\phi} \cdot \frac{E_t}{E_0} \qquad (10.5.4)$$

c = downward cover of main reinforcement or half of the space between the anchored reinforcement, whichever is the smaller

A_t = area of transverse reinforcement which is vertically arranged to the assumed splitting failure surface

s = distance between the centers of the transverse reinforcement

E_t = Young's modulus of transverse reinforcement

E_0 = standard Young's modulus (= 200 kN/mm^2)

(3) Where the reinforcement to be anchored is located at a height of more than 30 cm from the final concrete surface during concrete placement and at an angle of less than 45° from the horizontal, the basic development length shall be 1.3 times the value of l_d obtained from the application of section (2).

(4) The basic development length of compression reinforcement shall be 0.8 times the values of l_d obtained from the application of sections (1), (2) and (3).

[COMMENTS]:

(1) The development length of CFRM varies with the reinforcement type, concrete strength, concrete cover and transverse reinforcement. These factors must be adequately allowed for in testing. For this reason, the test method(s) used to determine the development length of a CFRM should be methods which reflect the actual bond characteristics within the member, such as methods using test beams or lap jointed test specimens.

JSCE-E 539 "Test Method for Bond Strength of Continuous Fiber Reinforcing Materials by Pull-Out Testing" does not reflect the actual bond characteristics within the member, and thus will generally over-estimate bond strength. Calculation of basic development length substituting bond strengths obtained from this test for f_{bod} should thus be avoided.

(2) In the JSCE Standard Specification (Design), the required development length for steel reinforcement with transverse reinforcement is given as Eq. (C 10.5.1)

$$l_0 = \frac{\left(\dfrac{f_{yd}}{1.25\sqrt{f'_{cd}}} - 13.3\right)\phi}{0.318 + 0.795\left(\dfrac{c}{\phi} + \dfrac{15A_t}{s\phi}\right)} \qquad \text{(C 10.5.1)}$$

where

f_{yd} = design tensile yield strength of steel reinforcement (N/mm^2)
f'_{cd} = design compressive strength of concrete (N/mm^2)
$c/\phi \leq 2.5$

This equation is further simplified by factoring in a factor α, given in the present recommendation.

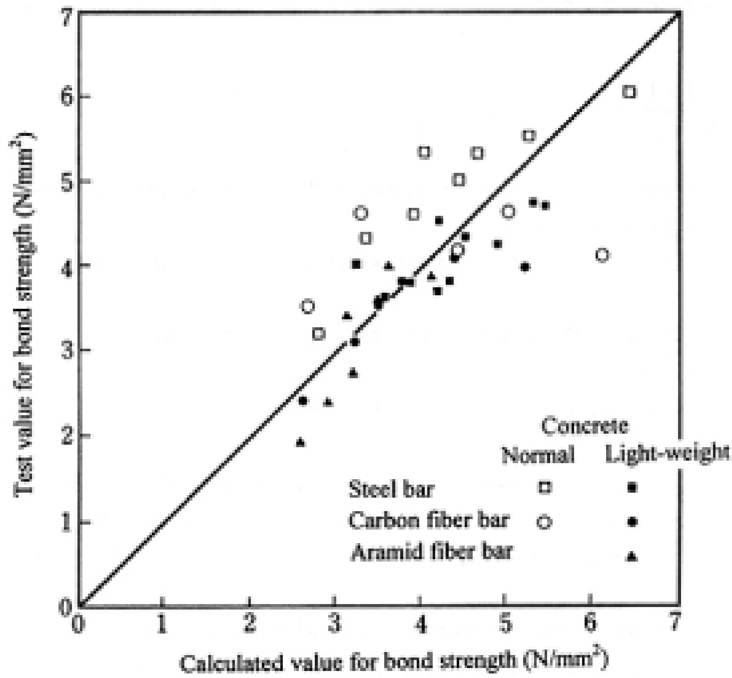

Fig. C 10.5.2 Comparison of bond strength Eq. (C 10.5.2) with test results

For CFRM with deformed surfaces which fail by bond splitting, comparison of the bond strength obtained from testing of this bond splitting and the bond strength calculated according to the formula below, derived allowing for the ratio of the Young’s modulus of the CFRM used as transverse reinforcement E_t (=E_f) to the standard Young’s modulus E_0 (=E_s) yields the following formula:

$$f_{bod} = \frac{0.318 + 0.795\left(\dfrac{c}{\phi} + \dfrac{15A_t}{s\phi}\cdot\dfrac{E_t}{E_0}\right)}{\dfrac{3.2}{\sqrt{f'_c}} - \dfrac{53.2}{f_y}} \qquad \text{(C 10.5.2)}$$

Based on Eq. (**C 10.5.2**), evaluation of the basic development length according to the method used for deformed steel bar has been allowed for any CFRM that fails by bond splitting. For CFRM that fail by bond splitting but show bond strength that is not equal to or greater than that of deformed steel bars, if the design bond strength is estimated following Eq. (10.5.3), a modification factor α_2 ($\leq$1.0) shall be factored in. Where the data available is inadequate or where significant variation is found, the basic development length shall generally be determined by appropriate testing.

The basic development length of reinforcement where the bond failure mode is by pull-out may be determined by appropriate testing.

10.6 SPLICES

10.6.1 General

It shall be in accordance with JSCE Standard Specification (Design), 9.6.1, where "steel" shall be taken to signify "steel or CFRM".

10.6.2 Lap splices

Lap splices for longitudinal reinforcement shall follow the JSCE Standard Specification (Design), 9.6.2, where "steel" shall be taken to signify "steel or CFRM".

[COMMENT]: Where the quantity of reinforcement place A_f is greater than the calculated requirement A_{fc}, the length of lap splices may be reduced by factoring in A_{fc}/A_f, determined as specified in the present recommendation (above). Where $A_{fc}/A_f > 350/f_d$, $A_{fc}/A_f = 350/f_d$, where f_d = design tensile strength of CFRM (N/mm^2).