

CHAPTER 1: GENERAL

1.1 SCOPE

(1) This Recommendation (Construction) provides the general requirements relating specifically to the construction of concrete structures using Continuous Fiber Reinforcing Materials, hereafter called CFRM. The requirements given in this Recommendation are based on JSCE Standard Specification for Design and Construction of Concrete Structures (Construction), hereafter called JSCE Standard Specification (Construction).

(2) CFRM used in construction shall normally be materials meeting the requirements given in JSCE-E 131 "Quality Standards for Continuous Fiber Reinforcing Materials".

[COMMENT]:

CFRM may be used as tendons or as reinforcement in concrete, either singly or in conjunction with prestressing or reinforcing steel. This Recommendation (Construction) gives general requirements relating to the use of CFRM in concrete structures not specified in JSCE Standard Specification (1996). A wide range of CFRM of varying types and quality are available, but for the purposes of this Recommendation, CFRM used shall normally meet the requirement given in JSCE-E 131.

1.2 DEFINITIONS

The following terms are defined for general use in this Recommendation (Construction).

Reinforcement: Materials used to reinforce concrete. These include steel and continuous fiber reinforcing materials ("CFRM").

Continuous fiber: General term for continuous fibers used for concrete reinforcement. These include carbon fibers, aramid fibers, and glass fibers, etc.

Fiber binding materials: Binders are used to solidify continuous fibers together. These are generally plastic materials such as epoxy resin or vinyl ester resin.

Volume ratio of axial fiber: Ratio of the volume of the actual fiber and the volume of fiber arranged in the direction of strengthening of CFRM.

Continuous fiber reinforcing materials (CFRM): General term for dimensionally strengthened material for the purpose of reinforcing concrete on being formed by impregnating and hardening continuous fiber with fiber binding material, or only continuous fibers bundled or woven together.

CFRM tendons: CFRM used as prestressing materials to induce prestress in concrete mostly used in bar or strand forms.

CFRM reinforcement: CFRM other than those used as prestressing materials.

CFRM bar: CFRM in the form of bar similar to reinforcing or prestressing steel.

CFRM shape: CFRM in the form of sectional steel shape.

Continuous fiber reinforced concrete: Concrete reinforced with CFRM.

Continuous fiber prestressed concrete: Concrete reinforced by inducing prestress with CFRM.

Capacity of CFRM: Maximum load that CFRM can sustain.

Strength of CFRM: Value obtained by dividing the capacity of CFRM by the nominal cross-sectional area.

Characteristic value of capacity of CFRM: Value for the capacity of CFRM which guarantees that the probability of tested capacity being below this value is within the specified limit based on statistical interpretation of test results.

Specified value of capacity of CFRM: Value for the capacity of CFRM which is specified by other design codes or specifications, apart from the characteristic value of capacity of CFRM.

Guaranteed capacity of CFRM: Guaranteed capacity according to JSCE-E 131 "Quality Standards for Continuous Fiber Reinforcing Materials".

Design capacity of CFRM: Value obtained by dividing the characteristic value of capacity of CFRM by the material factor.

Characteristic value of ultimate strain of CFRM: Strain corresponding to the characteristic value of tensile capacity of CFRM.

Design ultimate strain of CFRM: Value obtained by dividing the characteristic value of ultimate strain of CFRM by the material coefficient.

Tensile rigidity of CFRM: Slope of the tensile force-strain curve for CFRM, when this curve is assumed to be linear.

Young's modulus of CFRM: Value obtained by dividing the tensile rigidity of CFRM by the nominal cross-sectional area.

Nominal cross-sectional area of CFRM: Value obtained by dividing the volume of CFRM by the length.

Bent section of CFRM: Section of CFRM set in a curved shaped by hardening with fiber binding material while continuous fibers are bent. May be in spiral form, stirrup form etc.

Curved placement of CFRM: Placement of straight CFRM in a curved layout.

Creep failure: Failure due to progressive loss of tensile capacity over time, when CFRM is subjected to a continuous static tensile load.

Creep failure capacity: Load-bearing capacity at time of creep failure.

Flexural compressive failure: Form of failure in members subjected to flexure, whereby the compressed section of concrete fails before CFRM for main reinforcement break.

Fiber breaking flexural failure: Form of failure in members subjected to flexure, whereby CFRM for main reinforcement break before failure of the compressed section of concrete.

Fiber breaking shear failure: Form of shear failure in members subject to shear forces, whereby CFRM for shear reinforcement break.

Tendon coating materials: Coating materials applied to tendons to prevent bonding with concrete.

Tendon protection materials: Materials used to protect tendons from physicochemical deterioration due to external forces.

[COMMENT]:

Definitions of shear reinforcement, hoop ties, spiral hoops, and tendons follow those given in JSCE Standard Specification (Design), where "steel" shall be taken to signify "CFRM". The nominal cross-sectional area of CFRM is obtained by dividing the volume of CFRM by the length. As volume generally includes elements not contributing to the strength of the reinforcement, the strength and Young's modulus of CFRM, obtained using the nominal sectional area, are generally not equal to those of the continuous fiber itself.

CHAPTER 2: MATERIALS

2.1 GENERAL

Materials to be used shall be of confirmed quality.

[COMMENT]:

CFRM are new materials with limited field experience, and for some types little data on quality are available. It is therefore necessary to confirm the quality of the materials. In order to enhance the effectiveness in service of CFRM, it is particularly important to ensure that the concrete and any reinforcing or prestressing bars, anchoring devices, couplers, covering, protective materials, sheaths, grout etc. are of confirmed quality.

2.2 CONCRETE

(1) Concrete shall have a design strength of not less than the values given in **table 2.2.1**.

Table 2.2.1 Minimum design strength of concrete

CFRM application	Minimum design strength
As substitute for reinforcing bars	21 N/mm ²
As prestressing materials	30 N/mm ²

(2) Concrete quality shall be in accordance with chapter 2 of JSCE Standard Specification (Construction).

(3) Quality of cement, water, fine aggregate, coarse aggregate, and admixtures used in concrete shall be in accordance with chapter 3 of JSCE Standard Specification (Construction).

[COMMENT]:

When using CFRM as prestressing materials, greater compressive strength of concrete is required, as with conventional prestressed concrete structures.

In structures where steel is not used and where there is no danger of corrosion of CFRM anchorages and couplers, the limitations on chloride contents in concrete given in JSCE Standard Specification (Construction) need not be applied. An excess of alkali ions such as Na⁺ and K⁺, however, will tend to accelerate alkali-aggregate reaction, and appropriate methods should be taken to prevent alkali-aggregate reaction, for instance by eliminating reactive aggregate.

2.3 CONTINUOUS FIBER REINFORCING MATERIALS

(1) CFRM used in construction shall normally be materials meeting the requirements given in JSCE-E 131 "Quality Standards for Continuous Fiber Reinforcing Materials".

(2) Where CFRM do not meet the requirements of JSCE-E 131 "Quality Standards for Continuous Fiber Reinforcing Materials" are to be used, tests must first be carried out to establish the design strength, design value of modulus of elasticity, design ultimate strain and method of use.

(3) Where CFRM are to be subjected to heat treatment or other form of processing for anchoring, jointing, processing, assembly or placement, tests shall be performed to determine the level of quality loss due to the treatment, and an appropriate design tensile strength and other design values shall be determined separately.

[COMMENTS]:

(2) Tests shall be conducted according to JSCE-E 531 "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", and guaranteed values such as the tensile strength, modulus of elasticity and ultimate strain shall be determined based on the test results. Bonding strength shall be tested according to JSCE-E 539 "Test Method for Bond Strength of Continuous Fiber Reinforcing Materials by Pull-Out Testing". Flexural tensile failure strength, creep failure strength, relaxation, fatigue strength, coefficient of thermal expansion, alkali resistance, and shear strength shall be determined using test methods meeting JSCE standards. Values determined using well-established alternative test methods, however, may also be used provided a reliable guaranteed value allowing for the effect of anchorage is obtained.

(3) See section 3.3 below for details of treatment and handling for heat treatment or other forms of processing.

2.4 REINFORCING BARS

(1) Where CFRM are to be used in conjunction with reinforcing bars, the bars shall be selected to conform to the intended purpose of the CFRM.

(2) Where CFRM are to be used to enhance the corrosion resistance of a structure, epoxy-coated reinforcing bars used in conjunction with the CFRM shall conform to JSCE-E 102 "Quality Standards for Epoxy-Coated Reinforcing Steel Bars".

(3) Where ordinary reinforcing bars without corrosion-proofing are to be used, section 3.7.1 of JSCE Standard Specification (Construction) shall be adhered to.

[COMMENTS]:

(1) CFRM are used mainly for their corrosion-resistant and non-magnetic properties, therefore reinforcing bars used in conjunction with CFRM must be selected in accordance with the intended purpose. It should be noted in this connection that non-magnetic reinforcing bars have also been developed in recent years.

(2) The material properties of CFRM tend to lead to their being used in harsh, saline environments etc., thus epoxy-coated reinforcing bars are prescribed as standard for use in conjunction with CFRM, in order to ensure corrosion protection. Galvanized reinforcing bars could also be considered, but owing to the lack of experience with this in combination with CFRM, epoxy-coated reinforcing bars have been preferred here.

(3) Where ordinary unprotected reinforcing bars are used, the prescription given in section 3.7.1 of

JSCE Standard Specification (Construction) of conformity with JIS G 3112 "Steel Bars for Concrete Reinforcement" must be adhered to.

Stainless and corrosion-proof reinforcing bars have been developed in recent years. Where these or non-magnetic reinforcing bars are to be used, they must first be confirmed to have performance equivalent to the JIS standard quoted above.

2.5 PRESTRESSING STEEL

Where prestressing steel is to be used, section 3.7.2 of JSCE Standard Specification (Construction) shall be adhered to.

[COMMENT]:

Where ordinary prestressing steel without corrosion-proofing is to be used, the requirements of section 3.7.2 of JSCE Standard Specification (Construction) are to be applied as-is; this means prestressing steel must generally conform to JIS G 3109 "Steel Bars for Prestressed Concrete", JIS G 3137 "Small Size Deformed Steel Bars for Prestressed Concrete", and JIS G 3536 "Uncoated Stress-relieved Steel Wires and Strands for Prestressed Concrete".

Corrosion-proofed or stainless prestressing steels have been developed in recent years. Where these steels are to be used, they must first be confirmed to have performance equivalent to the JIS standards quoted above, and, additionally, the effectiveness of their corrosion-proofing must be adequately assessed.

2.6 ANCHORAGES AND COUPLERS

(1) Anchorages and couplers shall be of a structure and strength such that they do not fail below the guaranteed capacity or undergo significant deformation.

(2) Materials used in anchorages and couplers shall be of confirmed quality.

(3) Anchorages and couplers shall be tested for performance according to JCSE-E 537 "Test Method for Performance of Anchorages and Couplers in Prestressed Concrete using Continuous Fiber Reinforcing Materials".

[COMMENTS]:

(1) Anchorages or couplers shall be of a structure and strength corresponding to or superior to the anchoring or coupling system using CFRM, allowing for safety during prestressing work, the need to prevent excessive set in anchorage etc. The guaranteed capacity of the anchorages or couplers, and the guaranteed capacity of the tendons, are treated separately here. The reason for this is that the tensile strength of CFRM is evaluated allowing for the effects of the anchorages, while in many cases the anchoring device does not allow the CFRM to exert its full tensile strength, and in multi-cables especially, the fall-off is significant. "Anchoring or coupling system using CFRM" here refer respectively to systems configured with CFRM and anchorages, and CFRM and couplers.

(2) "Materials used in anchorages and couplers" refers to synthetic resins, anchoring expansion agents,

grout, anchor bars etc. As these are the most important materials in anchoring and coupling of prestressed concrete structures, they must be of proven, reliable quality and outstanding durability.

(3) Performance testing of anchorages and couplers may be carried out according to JSCE-E 537. This test, however, is intended for new types or types for which adequate test data is not available; testing may be omitted for types of proven quality and reliability. for which test data is given in the Documentation section of this Recommendation.

2.7 SHEATHS

(1) Sheaths shall be of a type not easily deformed during handling or concrete placement, and capable of withstanding intrusion of cement paste at laps and joints.

(2) Sheaths should be preferably have low friction with tendons, and should not cause damage to tendons during tensioning.

(3) The effects of the sheaths on the structure must be fully known.

[COMMENTS]:

(1) Bonding between CFRM and prestressed concrete grout, or between sheaths and concrete, may or may not be factored into the design, therefore the sheath material and geometry must give the performance intended in the design. Plastic sheaths may be used, in addition to conventional steel sheaths. Plastic sheaths must be sufficiently rigid to prevent any hindrance of placement etc. Severe deformation of sheaths or leakage of cement paste may hinder or prevent prestressing work, therefore the use of non-rigid or damaged sheaths must be avoided.

(3) The bonding characteristics of the intended sheaths with concrete and grout, and the effects on the structure of cracking, differences in coefficients of thermal expansion etc. must be fully known in advance.

Details of handling of sheaths are given in section **3.3.4** below.

2.8 TENDON COATING MATERIALS AND TENDON PROTECTION MATERIALS

(1) Materials used for tendon coating shall not cause damage to CFRM tendons or to the concrete, and shall not cause bonding between CFRM tendons and the concrete during prestressing.

(2) Tendon protection materials shall protect CFRM tendons fully from damage due to external factors.

[COMMENT]:

Tendon coating materials are used to prevent bonding between CFRM tendons and concrete, whereas tendon protection materials are used to protect CFRM tendons from physicochemical deterioration due to external factors, hence the distinction drawn here between the two types of material. Both types should of course fulfill their intended purpose, and the materials used must be of guaranteed durability and quality.

2.9 GROUT FOR PRESTRESSED CONCRETE

- (1) Grout for prestressed concrete shall be of sufficient quality to protect the tendons and to form a monolithic structure by bonding with the member concrete and the tendons.
- (2) The quality and materials of cement grout for prestressed concrete shall satisfy the following conditions.
 - (a) Consistency: The consistency shall be set at a level appropriate for the construction, taking into account the length and shape of the sheaths and ducts, construction season and weather conditions, type of tendon and the proportion of the sectional area of the prestressing steel to that of the duct.
 - (b) Bleeding rate: The bleeding rate shall be not more than 3%, and preferably not more than 1%.
 - (c) Expansion rate: The expansion rate shall be not more than 10%. The expansion rate after grouting shall exceed the bleeding rate until maximum bleeding is reached. The standard time from the completion of agitation to the completion of grouting should be around 30 minutes.
 - (d) Strength: Compressive strength at 28 days shall be not less than 20 N/mm².
 - (e) Water-cement ratio: The water-cement ratio of the grout shall be not more than 45%.
 - (f) Cement: Cement used for grouting shall comply with JIS R 5210.
 - (g) Water: Water used for grouting shall not contain harmful levels of substances adversely affecting the grout or the prestressing tendons.
 - (h) Admixtures: The advisability of using admixtures, and the quality and method of use of the admixtures, shall be studied in advance.
- (3) Grout for prestressed concrete other than that specified in (2) above shall first be checked for quality and the method of use adequately studied.

[COMMENTS]:

(1) The purpose of grouting is to protect the tendons and to create a monolithic structure through bonding of member concrete and tendons. The grout must therefore fill ducts completely, and surround the tendons. The grout must therefore maintain good fluidity and workability up to the completion of grouting, with minimum bleeding, proper expansion after grouting, and adequate strength.

Grouting should ideally be carried out from below, causing the grout to flow gradually upwards. Where tendons are placed with multiple bend-ups and bend-downs, grout will shift from higher levels to lower levels, therefore the use of high quality grout with little or no bleeding is advised. Further, if the gap between sheaths and tendons is too narrow, it will not be properly grouted, therefore the use of large-diameter sheaths and high quality grout is advised.

(2) High-quality grouts are now available with superplasticizers in place of conventional plasticizers, giving little or no bleeding, and maintaining initial levels of fluidity for long periods while at the same time giving high viscosity.

The water-cement ratio should be kept as low as possible given the fluidity requirements. A high water-cement ratio will cause loss of strength and bonding, and incomplete grouting of ducts due to bleeding and shrinkage. Conversely, a low water-cement ratio will result in high viscosity and poor

workability. The standard water-cement ratio is therefore given as 45%. The use of recently developed superplasticizers allows the water-cement ratio to be reduced while giving a grout with high fluidity and workability.

(3) The use of cement-based grout may be inadvisable in certain circumstances owing to adverse effects on durability of CFRM tendons. In such cases, tests should be carried to check that the grout meets the required quality standards.

CHAPTER 3: CONSTRUCTION

3.1 GENERAL

(1) Handling and storage of materials, assembly and placement of CFRM and steel, placement of concrete, prestressing and grouting of prestressed concrete shall be carried out in the order given in the construction plan, and following the prescribed procedures.

(2) For the construction of concrete structures, engineers having sufficient knowledge of concrete construction shall be present on site.

[COMMENT]:

(2) "Engineers having sufficient knowledge of concrete construction" (concrete specialists) shall be construed as Concrete engineers or Chief Concrete Engineers authorized by the Japan Concrete Institute, Prestressed Concrete Engineers authorized by the Prestressed Concrete Technology Association, or other engineers with similar or superior specialist skills. The presence of such engineers on site to supervise construction appropriately is extremely important in obtaining the desired quality of concrete. For particularly important structures, it is recommended that such engineers be stationed permanently on site.

3.2 HANDLING AND STORAGE OF MATERIALS

(1) CFRM shall be handled carefully to prevent any damage to the surface.

(2) When storing CFRM outdoors, placing them directly on the ground should be avoided, and a suitable cover shall be provided. CFRM should also not be placed directly on the ground when stored in storehouses, and if necessary suitable covers should be provided. Environmental factors such as high temperature, ultraviolet rays, chemical substances etc. deleterious to CFRM should be eliminated, and the CFRM shall be stored in such a manner as to prevent damage or deformation.

(3) Anchorages, couplers and materials used in anchorages and couplers shall be stored in a storehouse, free from dust and protected from damage, deformation or deterioration.

[COMMENTS]:

(1) CFRM are generally made with a matrix of synthetic resin, rendering them liable to surface damage. Deep scoring by sharp steel edges etc. will significantly reduce their failure load, possibly resulting in serious accidents especially when the CFRM are used as tendons. Scoring of the surface of glass fiber based CFRM may cause loss of durability due to infiltration of alkalis through the damaged areas, therefore care is advised in the handling of these materials also.

(2) Storage of CFRM directly on earth or concrete, whether outdoors or in a storehouse etc., increases the likelihood of damage or loss of quality, and such locations should be avoided. High temperatures, ultraviolet rays, chemical substances etc. are also deleterious to CFRM, and these factors too should be

eliminated. CFRM must be stored in an environment free from possible sources of damage.

CFRM shipped in coil form should be stored in such a way that harmful kinks etc. do not develop when the coil is unwound.

(3) Anchorages, couplers and materials used in anchorages and couplers are important elements in prestressed concrete, therefore storage in a storehouse is prescribed. Parts destined to be in contact with concrete or grout must also be kept free from grease, dirt, dust etc. to ensure full bond strength.

3.3 PREPARATION, ASSEMBLY AND PLACEMENT OF CFRM TENDONS, CFRM REINFORCEMENT ETC.

3.3.1 Preparation and assembly of CFRM tendons

(1) CFRM tendons shall be prepared and assembled in such a way as to give the configuration and dimensions specified in the design, while avoiding any damage to the material. Any CFRM tendons found to be damaged on the surface, bent, subjected to high temperatures or stored out of doors for long periods shall be discarded.

(2) CFRM tendons shall in general not be bent. Where bending is unavoidable, this shall be done in a workshop using techniques that do not damage the material. The tensile strength of CFRM tendons after bending shall be confirmed using appropriate testing methods.

(3) CFRM tendons used in pretensioning, and CFRM tendons required to bond, shall be cleared of any oil, grease or foreign matter likely to impair bonding prior to assembly.

[COMMENTS]:

(1) CFRM tendons must be correctly formed into the configuration and dimensions specified in the design, without damaging the material. Cutting of CFRM tendons, preparation for anchoring or fitting of anchorages etc. should be carried out according to the proper method for CFRM tendons. CFRM tendons should be cut using an efficient high-speed rotatory grinder or similar manner which does not damage the material.

CFRM tendons which are bent or have surface damage must not be used, as there is a possibility of severe loss of tensile strength. CFRM tendons which have been subjected to high temperatures should also not be used, as the thermal deterioration of the resins causes loss of fiber binding performance, which could result in loss of tensile strength. Depending on the type of CFRM tendons, long exposure to direct sunlight may result in deterioration due to ultraviolet rays, therefore CFRM tendons stored out of doors for long periods should not be used.

(2) The fiber binding material in CFRM tendons is generally a thermosetting resin, and bending such a material on site while maintaining the required quality is technically difficult. Therefore, CFRM tendons should generally not be bent. If bending of CFRM tendons is unavoidable, this should be done in a workshop following methods which do not damage the material. As the tensile strength of CFRM tendons is thought to be reduced by bending and according to the bending radius, the tensile strength

should be confirmed by appropriate methods reconstructing the actual conditions of use, and checked against the design conditions.

(3) Foreign matter such as grease, paint and dirt may impair the bonding between concrete or grout and CFRM tendons, resulting in slippage of tendons. The surface of CFRM tendons must therefore be thoroughly cleaned before use.

3.3.2 Preparation and assembly of CFRM reinforcement

(1) CFRM reinforcement shall be prepared and assembled following methods which do not damage the material, so as to conform to the configuration and dimensions given in the design. Any CFRM reinforcement found to be damaged on the surface, bent, subjected to high temperatures or stored out of doors for long periods shall be discarded.

(2) Bending of CFRM reinforcement shall normally be done in a workshop, following methods which do not damage the material.

(3) Where the bending radius of the CFRM reinforcement is not given in the design, the bending radius and bending method shall be determined on the basis of tests conducted to confirm that the tensile strength required in the design is met.

(4) CFRM reinforcement shall be cleared of any oil, grease or foreign matter likely to impair bonding prior to assembly.

[COMMENTS]:

(1) CFRM reinforcement must be handled similar to the case of CFRM tendons according to the comment of section **3.3.1(1)**.

(2) For the same reason as that given in the comment of section **3.3.1(2)**, bending of CFRM reinforcement such as stirrups and spiral reinforcement shall normally be done in a workshop. Certain types of CFRM reinforcement may be bent and thermoset on site, or bent by heating on site using thermoplastic resins, but the tensile strength of CFRM reinforcement bent in this way must still be confirmed by appropriate testing methods.

(3) The tensile strength of bent CFRM reinforcement is known to be reduced by the bending process, but the level of strength loss depends on the type of continuous fiber, the manufacturing process of the reinforcement, the bending radius etc. The bending radius and method of bending must therefore be determined based on tests to confirm the extent of loss of tensile capacity, and the bending radius should be made as large as possible.

(4) See the comment of section 3.3.1(3).

3.3.3 Duct manufacture

The materials and methods used in duct manufacture shall not be injurious to CFRM tendons, reinforcement or concrete.

[COMMENT]:

Materials used in duct manufacture must be confirmed not to erode CFRM tendons or reinforcement, or to cause deterioration of concrete, prior to use. The manufacturing method must not cause cracking in concrete, significant increase in friction during prestressing, or damage to CFRM tendons. Where subsequent bonding is required, the concrete and CFRM tendons must act as a monolithic body, therefore a high level of bonding between the duct and the concrete or grout.

3.3.4 Placement of sheaths and CFRM tendons

(1) Damaged sheaths or sheaths with severe internal rusting shall not be used. Joints of sheaths shall be securely sealed to prevent penetration of cement paste during concreting.

(2) Sheaths and CFRM tendons shall be firmly supported at the required positions and in the required directions by methods not injurious to the material, and placed correctly to ensure their position and configuration remain unchanged during concrete placement. The bending radius of bent CFRM tendons shall be determined so as not to impair the tendon.

(3) CFRM tendons shall be placed in sheaths without any entanglement.

(4) CFRM tendons used in pretensioning shall be protected from damage due to contact with end forms. Unbonded CFRM tendons shall be carefully installed without any damage to the coatings.

(5) Sheaths and CFRM tendons shall be inspected after placement, and corrective measures such as repair or replacement shall be taken in the event of damage or dislocation being found.

(6) Tolerances for placement positions of CFRM tendons shall be determined within a range not affecting the members, and allowing for factors such as the size of the members.

[COMMENTS]:

(1) Steel sheaths with significant internal rusting must not be used. This is not only because of the increased friction during prestressing, but also because of possible damage to CFRM tendons and impairment of bonding. Foreign matter such as grease and loose rust likely to impair bonding shall be removed from the interior of the sheath before use.

Incomplete jointing between sheaths, between sheaths and anchorages, or between sheaths and couplers connectors may cause cement paste to leak into the sheath during concreting, leading to bonding impairment similar to that described in relation to damaged sheaths. The joints must be protected from ingress of cement paste by extending the lap, winding with insulating tape etc.

It is important to prevent corrosion of sheaths at anchorage ends by application of rust-preventive agents or similar treatment.

In order to prevent damage to CFRM tendons within the sheath, plastic sheaths etc. may be used, but their performance must be thoroughly evaluated first .

(2) If CFRM tendons are not maintained in their proper positions, the required prestress cannot be introduced into the concrete even if the specified tensile force is applied to CFRM tendons. CFRM tendons must therefore be accurately placed in each position.

CFRM tendons and sheaths must be firmly fixed using adequate supports placed at relatively short intervals, so that CFRM tendons and sheaths can resist the weight of fresh concrete and strong vibration caused by the vibrators during concreting. The spacing of the supports must be determined according to the types and rigidities of CFRM tendons and sheaths, allowing for the friction coefficient assumed in the design.

Where the bending radius of CFRM tendons is small, local stresses will be set up in CFRM tendons, causing loss of tensile strength. When straight CFRM tendons are bent into position, the minimum radius to which CFRM tendons can be bent by elastic deformation without causing damage must first be ascertained by testing. The minimum bending radius when sheaths are used should preferably be either 5 m or 100 times the sheath diameter, whichever is the greater. This is the minimum radius hitherto confirmed in tests. No useful data is yet available regarding minimum values when sheaths are not used, and loss of tensile strength must be checked by testing etc. As the loss of tensile strength varies depending on the type of CFRM tendons, testing is necessary in any case. When CFRM tendons are used as external cables, significant local stress is applied to the deviators where CFRM tendons are bent up, and determination of the bending radius, selection of sheath and wadding material etc. must be done after thorough safety testing etc.

(3) When multiple CFRM tendons are placed in a sheath, entangling not only increases friction during prestressing, there is also a possibility of uneven stressing in CFRM tendons. Suitable spacers should therefore be used to ensure CFRM tendons are parallel within the sheath.

(4) In pretensioning, CFRM tendons installed via placement holes in the end forms may fail when they are subjected to damage due to contact with the placement hole during prestressing or compacting of concrete. Measures must therefore be taken to prevent CFRM tendons from contacting the form directly, for instance by using wadding material in the placement holes.

CFRM tendons used in unbonded prestressing structures are generally protected by coating materials. If the coating materials are stripped off or damaged, insulation from the concrete is impaired and prestressing work becomes more difficult with possible loss of tensile strength of CFRM tendons. Corrective action must be taken in the event of stripping or damage of coating materials.

(5) Any dislocation or damage of sheaths or CFRM tendons during placement must of course be corrected during the installation work. Post-installation concreting work must also be attended by careful inspection and repair if necessary.

(6) Installation tolerances vary depending on the size of the members or the arrangement of CFRM tendons. Generally, the tolerance of the tendon centroid shall be not more than 5 mm when the member size is less than 1 m, and the lesser of 1/200 of the member size and 10 mm when the member size is equal to or greater than 1 m. If the error is greater than 10 mm, corrective action shall be taken.

3.3.5 Assembly and placement of anchorages and couplers

(1) Anchorages and couplers shall be assembled accurately in the configuration and dimensions specified in the design documents, and shall be properly installed in the location and direction specified in the design. Anchorages and couplers, and reinforcement in their vicinity, shall be corrosion-proofed if necessary.

(2) The bearing surface of the anchorage shall be installed perpendicular to CFRM tendons. Anchoring of CFRM tendons to the anchorages shall be carried out according to the prescribed procedures, and due care shall be taken to prevent any damage to CFRM tendons at the anchorage, or loss of anchoring capacity.

(3) When CFRM tendons are coupled, the couplers shall have sufficient capacity and corrosion-proofing, and the pulling side of the coupler shall be allowed adequate movement to apply tension to CFRM tendons.

(4) After the placement of the anchorages, an inspection shall be made, and damaged hardware shall be replaced or repaired. Dislocation of the hardware shall also be corrected.

[COMMENTS]:

(1) and (4): Anchorages are subject to tremendous forces, and their proper assembly and placement following the design drawings is important to ensure proper transfer of stresses and to avoid accidents. With current technology, the use of metal anchorages and couplers is unavoidable, thus proper corrosion-proofing is required to prevent loss of structure durability due to corrosion.

(2) If the bearing surfaces of anchorages are not placed perpendicularly to CFRM tendons, local bending of CFRM tendons during tensioning or anchoring may result. This local bending could lead to failure of CFRM tendons, or prevent the completion of anchoring work. The anchorages and tendons must therefore be installed perpendicularly to each other, and a straight portion of a certain length should be allowed in CFRM tendons around the anchorages.

As the anchoring methods used with CFRM tendons vary according to the construction technique, the prescriptions for anchoring given for each technique must be followed. The use of inappropriate anchoring methods could prove fatal for prestressed concrete structures, therefore proper technical controls on anchoring work must be enforced.

(3) When CFRM tendons are coupled, the couplers must be corrosion-proofed to prevent loss of member durability. The movement of the couplers during tensioning must be calculated and a sufficient space for the movement must be provided on the tensioning side of the couplers. The positions of joints must be checked after assembly of couplers.

3.4 CONCRETING

(1) Batching, mixing, transportation, placing, curing, surface finishing etc. of concrete shall be carried out according to the prescribed procedures.

(2) Casting and compaction of concrete shall be carried out taking due care to avoid disturbing the

placement of CFRM, reinforcing bars, anchorages, sheaths etc., avoiding damage to CFRM and ensuring full concreting of all areas around CFRM and reinforcing bars, anchorages, sheaths etc.

(3) Steam curing shall be performed following thorough assessment of the temperature characteristics of CFRM, anchorages, couplers etc. used, setting the curing temperature accordingly.

[COMMENTS]:

The general remarkable points for concreting are given in JSCE Standard Specification (Construction). Batching and mixing are covered in chapter 5 of JSCE Standard Specification (Construction), transportation and placing in chapter 7, curing in chapter 8 and surface finishing in chapter 12. Each of these chapters is followed here. In addition, the smaller member dimensions and higher strength of concrete are used in prestressed concrete structures as compared to normal reinforced concrete structures, therefore particular caution is advised during placement because of the use of different quality concrete from that used in reinforced concrete structures.

(2) In prestressed concrete, there is a danger of displacing not only CFRM and reinforcing bars and forms, but also anchorages and sheaths, therefore operations must be carried out with caution. It should be borne in mind that the lower weight and rigidity of CFRM in comparison to reinforcing bars renders it more liable to displacement due to buoyancy. Reinforcing-bar workers should stay during concrete placement work to correct any dislocation of CFRM or reinforcing bars, anchorages, sheaths etc.

CFRM may be damaged by direct contact with an internal vibrator, therefore the use of internal vibrators protected with polyurethane etc. is recommended.

(3) Certain types of CFRM , anchorages, couplers, sheaths etc. exhibit material quality change under steam curing temperatures, hence this provision is made. Particular care must be taken with regard to the increased relaxation and loss of bond strength in CFRM at high temperatures. When steam curing is used, heating should begin after not less than three hours after concrete placement, and the rate of temperature increase shall generally be not more than 15°C per hour. The curing temperature shall be not more than 65°C, and the temperature shall be low enough to avoid impairing the quality of CFRM and the anchorages or couplers.

3.5 PRESTRESSING

(1) The tensile forces to be applied to CFRM tendons in prestressing, the method of prestressing, safety measures during prestressing, method of calibration of the tensioning apparatus, minimum concrete strength for prestressing, and methods of prestressing control shall be determined according to the prescribed procedures.

(2) The coefficient of friction and apparent modulus of elasticity applied in control of prestressing work shall generally be determined based on prestressing tests on site.

(3) The coefficients of friction of the tensioning apparatus and the anchorages shall also be determined based on testing.

(4) Tendons shall be anchored to ensure that all the constituent CFRM tendons are subjected to the required tensile force.

[COMMENTS]:

Prestressing work is covered in section 27.6 of JSCE Standard Specification (Construction), which is also applied here.

For the techniques given in the Documentation section of this Recommendation, the control methods given for each technique shall be adhered to.

(1) Since the elongation of CFRM tendons is greater for a given prestressing level than the elongation of prestressing steel, use of a jack with a long stroke, use of a succession of different jacks etc. must be considered.

(2) Measurements of the coefficient of friction and apparent modulus of elasticity shall be made at the start of work, and redone if any anomalies are found during control of prestressing work. Control of prestressing may be carried out based on the measured coefficient of friction m . The tolerances for μ given in Table 27.6.1 in the comment to section 27.6.4 of JSCE Standard Specification (Construction) relate to prestressing steel only. For CFRM tendons, tolerances of m must be calculated in the same way as those for prestressing steel.

(4) For CFRM tendons, the stress - strain curve is linear with no yielding, and the ultimate strain is lower than that for prestressing steel. Further, as the strength loss in CFRM tendons due to bending is greater than in steel, tensioning of CFRM tendons and anchoring to the anchorage must be carried out carefully to avoid brittle failure. This will require initial alignment of parts exerting tensile force on each CFRM tendons and monitoring of extension during prestressing to be enforced more strictly than is generally the case for prestressing steel. Prestressing of CFRM tendons must be carried gradually, avoiding sudden increases in tensile force. The amount of slipping when anchoring CFRM tendons can be greater than with prestressing steel, but owing to the lower tensile rigidity, the reduction in tensile force in CFRM tendons due to slipping in the anchorages is generally less.

3.6 GROUTING

(1) Where integration of member concrete and CFRM tendons by grouting is required, grouting shall be carried out immediately after the completion of prestressing.

(2) Selection of grouting tools, batching, mixing, agitation, injection, requirements for work in hot or cold weather etc. shall be according to the prescribed procedures.

[COMMENT]:

For cement-based grout, specification(1) is given in the section of 27.7.1 and specifications(2) is given in the section of 27.7.2~27.7.6 of JSCE Standard Specification (Construction) and these specifications should be followed here. For non-cement grouts, suitable working procedures should be applied allowing for the differing characteristics of the materials, based on the above.

CHAPTER 4: QUALITY CONTROL AND INSPECTION

4.1 GENERAL

The necessary quality control and inspections of concrete materials, CFRM, steel used in conjunction with CFRM, other materials, equipment, working procedures and completed structures shall be carried out to ensure the safe and economic construction of continuous fiber reinforced concrete structures of the required quality.

[COMMENT]:

Quality control when using CFRM is equally as important as when conventional materials are used (c.f. the comment of section 13.1 of JSCE Standard Specification (Construction)).

4.2 TESTS

4.2.1 General

Quality control shall be carried out by testing of materials, equipment and machinery according to the prescribed methods, in order to ascertain their performance. Testing of CFRM shall generally be carried out according to this Recommendation.

[COMMENT]:

General provisions for quality control methods are given in the comments of section 13.1 and 13.2 of JSCE Standard Specification (Construction), but as JIS standards for testing of CFRM are not available, this Recommendation has been adopted as standard.

4.2.2 Tests for Concrete

The performance of concrete before and after work, and if necessary also during work, shall be tested according to the prescribed methods.

[COMMENT]:

Tests for quality control of concrete are given in section 13.5 and 27.10.1 of JSCE Standard Specification (Construction), and these specifications are followed here.

As noted in the comments of section 2.2 above, in structures where CFRM are not used in conjunction with steel and where there is no possibility of corrosion of anchorages and couplers, the requirements for chloride contents in concrete given in JSCE Standard Specification (Construction) need not be applied. Contents of chloride ions in concrete must still be tested and kept within strict limits in order to prevent deterioration of the concrete itself due to alkali-aggregate reaction etc.

4.2.3 Tests for CFRM tendons

(1) Quality tests shall be conducted on CFRM tendons prior to use, in order to ensure the required performance. Quality testing shall cover the following items:

- (a) Tensile strength (or maximum tensile load); tensile modulus of elasticity (or tensile rigidity), and ultimate strain;
- (b) Fatigue strength;
- (c) Relaxation rate;
- (d) Bond strength;
- (e) Coefficient of thermal expansion;
- (f) Other

The above tests may be dispensed with for materials of proven quality and performance.

(2) Quality of tensioning systems using CFRM tendons shall generally be tested for the whole system including anchorages and couplers, with quality testing carried out before use to ascertain performance. Quality testing shall cover the following items:

- (a) Tensile strength (or tensile load); tensile Young's modulus (or tensile rigidity);
- (b) Fatigue strength;
- (c) Relaxation rate

The above tests may be dispensed with for materials of proven quality and performance.

[COMMENTS]:

The handling of CFRM is generally very different from that of steel in terms of mechanical properties, durability and handling method, and quality controls must be implemented allowing for these differences.

(1) These tests are required to control the performance of CFRM tendons themselves; bond strength testing may be omitted for CFRM tendons to be used unbonded. "Other" tests refers to accelerated deterioration testing in high temperatures, alkaline or acid conditions, creep failure testing etc. Such tests shall be performed if necessary to ascertain quality.

Quality control through these tests is extremely important, but it normally requires special, precision testing equipment, extensive expertise in measurement and / or long periods of time. Adoption of manufacturers' guaranteed values has therefore been allowed where performance has been checked by suitable testing prior to shipment, and where the suitability of transportation methods has been confirmed. If there is a possibility of mishandling during shipment or of significant damage due to long periods of storage, however, the materials must not be used without first being tested, even in the absence of any visible damage. This shall also apply to materials during work; materials suspected of having suffered damage shall immediately be replaced and tested.

Possible factors affecting CFRM before and during work are given below.

-Factors affecting CFRM before start of work: Bending beyond prescribed limits, subsection to shocks, dragging etc. during transportation; temperature, humidity, dampness or direct sunlight (ultraviolet rays) during storage; welding sparks, chemicals etc.

-Factors affecting CFRM during work: Bending or impact force beyond allowed limits during placement; over-tight binding, welding sparks, chemicals, excessively high temperatures during curing

etc.

(2) The mechanical properties of CFRM tendons are significantly affected by the anchorages and couplers, and there is a tendency for systems as a whole to give lower performance than either single or multiple tendons alone. When using CFRM tendons, therefore, tests must be carried out on factors likely to be affected when anchorages and couplers are used in a complete system, in order to ascertain performance.

These tests may be dispensed with for CFRM tendons of proven quality used in conjunction with anchorages and couplers of guaranteed quality and known performance, which are specified in the Documentation section of this Recommendation as being designed expressly for use with CFRM tendons in question.

4.2.4 Tests for anchorages and couplers

Anchorage and couplers for use with CFRM tendons shall be tested for quality before use. Such tests may be dispensed with for materials of proven quality.

[COMMENT]:

The geometry, performance, service conditions etc. of anchorages and couplers vary significantly for different types, and also depending on the type of CFRM tendons they are used with. Such anchorages and couplers must therefore be tested following an appropriate method capable of reproducing the service conditions and expected tensile forces. Tests must confirm that the strength and structure of the materials are such that failure or significant deformation do not occur below the guaranteed tensile load, and that the required anchoring or coupling effect is achieved with the proposed CFRM tendons. Standard test methods for anchorages and couplers are given in JSCE-E 537 "Test Method for Performance of Anchorages and Couplers in Prestressed Concrete using Continuous Fiber Reinforcing Materials", and these test methods may be followed here. Depending on the type of anchorages and couplers, it is also important to check that set loss due to tendon slippage is within allowable limits; furthermore, given that continuous fiber reinforced concrete structures are often located in extreme environments, any steel anchorages and couplers must also be confirmed to be sufficiently durable for the environment.

Such tests may be dispensed with for materials of proven quality which are given in the Documentation section of this Recommendation.

4.2.5 Tests for other materials used in continuous fiber prestressed concrete

Materials used in anchorages and couplers, sheaths, tendon coating and protection materials, grout etc. shall be quality tested before use to ascertain their performance. Such tests may be dispensed with for materials of proven quality.

[COMMENT]:

The materials listed here must be tested according to appropriate methods to ensure they have no adverse physicochemical effect on CFRM tendons, and that they give the required performance.

For sheaths, in addition to testing according to section 27.10.4 of JSCE Standard Specification (Construction), the frictional force arising between sheaths and tendons must also be tested by methods capable of adequately reproducing service conditions, as the surface configurations of CFRM tendons are very varied. Where plastic or other non-conventional, non-steel sheaths are to be used, bonding characteristics with concrete and grout, thermal characteristics, durability etc. must also be ascertained by testing prior to use, in order to ensure the required performance is achieved in the structure.

Monitoring by tests for grout is covered in section 27.10.6 of JSCE Standard Specification (Construction), and this specification is followed here. Where non-cement grouts are used, further testing of bonding characteristics, thermal characteristics, and durability will also be required, in addition to the tests given in this Standard Specification.

4.2.6 Tests for CFRM reinforcement

(1) Quality tests shall be conducted on CFRM reinforcement prior to use, in order to ensure the required performance. Quality tests shall cover the following items:

- (a) Tensile strength (or maximum tensile load); tensile modulus of elasticity (or tensile rigidity), and ultimate strain;
- (b) Fatigue strength;
- (c) Bond strength;
- (d) Coefficient of thermal expansion;
- (e) Other

The above tests may be dispensed with for materials of proven quality and performance.

[COMMENT]:

Tests of CFRM reinforcement is broadly similar to that for CFRM tendons, covered in section 4.2.3 above, with the exception of relaxation test, omitted here as necessary only for tendons. .

4.2.7 Testing for other materials for use with continuous fiber reinforced concrete

Steel reinforcement etc. for use with CFRM in concrete shall be tested at the required times following the prescribed methods to confirm performance.

[COMMENT]:

Tests for monitoring of reinforcing bars, their joints, prestressing steels, their anchorages and couplers, prestressing steel sheaths, spliced materials, friction-reducing agents etc. used in conjunction with CFRM are covered in chapters 13 and 27 of JSCE Standard Specification (Construction) and this specification is followed here.

Testing of epoxy-coated reinforcing bars used in conjunction with CFRM shall follow chapter 2 of JSCE "Recommendations for Design and Construction of Reinforced Concrete Structures using Epoxy-Coated Reinforcing Steel Bars", .

4.3 INSPECTION OF STRUCTURES

Inspection of structures shall be conducted after the completion of concrete structures.

[COMMENT]:

Continuous fiber reinforced concrete structures are frequently located in harsh environments, and in such cases, more detailed inspection in preparation for future maintenance should be carried out, as outlined in the comments of section 13.9.1 of JSCE Standard Specification (Construction). When the loading test is necessary to confirm the safety of structures, the method should be followed in section 13.9.1 of JSCE Standard Specification (Construction).

4.4 CONSTRUCTION RECORDS

The construction program, working conditions, curing methods, meteorological conditions, air temperature, quality controls and inspections, structural inspections etc. shall be recorded during the construction as the circumstances demand. Construction records shall be retained in the long term.

[COMMENT]:

CFRM are generally more resistant to chloride ion corrosion than conventional steel, giving continuous fiber reinforced structures superior durability. In the longer term, however, CFRM may undergo complex forms of deterioration in various environments, either independently or through compound interaction with concrete. As stated in the comments of section 14.1 of JSCE Standard Specification (Construction), the keeping and preservation of construction records provides essential information for future maintenance of continuous fiber reinforced concrete structures.