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 as 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 ingression 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 by 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.