Chapter 3 Materials

3.1 General

This chapter shall cover the method of determining design values for the materials used in existing structures to be retrofitted, and the method of determining design values and quality requirements for the materials used with the external cable construction method, the bonding and jacketing construction method and the overlaying and jacketing construction method.

[Commentary]

The characteristics of materials in existing structures to be retrofitted may differ from those assumed when the structure was first designed and built, due to various factors at the construction stage as well as load action and environmental action during use. In retrofitting design, this must be considered and the design values for the materials in existing members must be determined. Even materials not covered here should be verified for quality before use.

3.2 Materials in Existing Structures

The design values for materials in existing structures used for retrofitting design shall be determined in accordance with inspection results.

(1) Characteristic values

The characteristic values for materials in the existing structure, after consideration of the variations in measurements obtained through inspections, shall be those that ensure that most of the measurements will not fall below those values. When sections are missing due to corrosion or the like, the cross-sectional area for steel shall be determined using measurements or recommended values calculated with appropriate methods.

(2) Material factors

As a rule, the material factors for materials in the existing structure shall be determined in accordance with the Standard Specification. When the characteristics of materials in the existing structure are different from those assumed at the time the structure was first built, or when the status of use after retrofitting will be different, material factors apart from the values in the Standard Specification shall be determined.

[Commentary]

(1) Characteristic values are determined by the distribution of test values and the likelihood that test values lower than the characteristic value will be obtained. In the Standard Specification, the explanation uses the example of a likelihood of 5%. As a rule, characteristic values are determined in the same manner for the materials in existing structures. However, in general there are few sample test values from inspections and it is difficult to identify the distribution of test values. Accordingly, here it was decided to make an overall judgement of inspections to estimate characteristic values.

The characteristic value for the tensile strength of steel is not thought to be dependent on time, but tensile strength will vary due to a reduction in cross-sectional area. To reflect this in design, here it was decided to consider changes in the cross-sectional area of the steel used in the existing structure. Other characteristic values relating to steel must be determined based on the status of corrosion, past stress history and other factors. When the steel has been subjected to considerable corrosion and a history of stresses exceeding the yield strength, it must be noted that the bond properties, fatigue properties, elongation properties and the like will have changed.

(2) Material factors for new construction and those for retrofitting are different. Material factors for newly built structures are determined based on the purpose of use, design service life, load and environmental conditions, construction/maintenance and other factors. Material factors for retrofitting design, however, should be determined through consideration of the load and environmental conditions, material characteristics, design service life after retrofitting and other factors that have been determined through inspections. If the status of the existing structure determined through inspections is the one assumed in the design, the material factors may be determined in accordance with the Standard Specification.

In general, the specified design strength was used as the characteristic value for the compressive strength of the concrete used in new structures, and the design value was derived by dividing this value by the material factor. The characteristic value for the concrete in the existing structure was known from inspections, reducing the uncertainty, and for this reason the material factor could be reduced. When determining the flexural strength, tensile strength, bonding strength, bearing strength and other characteristic values for concrete materials from the characteristic value for compressive strength, in accordance with Section 3.2 in the Standard Specification (Design), the status of deterioration of the concrete materials must be observed and the material factors handled carefully.

3.3 Quality of Materials

3.3.1 External Cables

(1) The quality of external cables shall be indicated by the tensile strength and other strength properties, Young's modulus and other deformation properties, and thermal properties and other material characteristics.

(2) As a rule, external cables shall be protected using protective tubes or rustproofing materials, and their quality shall be protected with suitable means so it does not change over time.

(3) Anchoring and connecting components must have a configuration and strength suitable to prevent them from experiencing failure or remarkable deformation below the standard values or characteristic values for the tensile load of the anchored or connected external cables.

[Commentary]

(1) External cables must have the quality enabling them to introduce and maintain the required prestressing force. The quality of external cables is generally indicated by tensile strength and other strength properties, Young's modulus and stress-strain relationship, creep properties and other deformation properties, coefficient of linear expansion and other temperature properties, relaxation properties, and so on. Accordingly, external cables that clearly possess the strength, elongation capacity, Young's modulus, creep failure resistance, coefficient of linear expansion and other values that can be relied upon from an engineering standpoint must be used.

When concrete prestressing steel is used for external cables, prestressing wires and stranded prestressing wires should conform to JIS G 3536, and prestressing bars should conform to JIS G 3109 and 3137; equivalents may also be used. When prestressing steel that has been rustproofed in advance is used, it must be confirmed as having the required quality. Also, when continuous fiber prestressing materials are used, as a rule those that conform to JSCE-E 131 "Quality Standards for Continuous Fiber Reinforcing Materials (draft)" (Japan Society of Civil Engineers) must be used. When continuous fiber prestressing materials that do not conform to JSCE-E 131 are used as external cables, they must be confirmed as having the specified quality.

The tensile properties of external cables must include fretting fatigue strength. Fretting fatigue generally refers to the fatigue of flexurally placed prestressing materials and must be distinguished from linearly placed materials.

(2) The quality of external cables is thought to change as a result of the intrusion of substances that accelerate steel corrosion, the action of chemical substances, the action of ultraviolet light, the action of friction at deviators and other factors during their service life. Also, the strength or other quality properties of continuous fiber prestressing materials may decline if they are scratched or otherwise damaged during construction. If the external cables ultimately break due to a decline in quality, the safety of the structure may be impaired and result in danger to human life, so this must be avoided.

With the development of rustproofing technologies for the prestressing steel for external cables, in recent years rustproofed materials have been used to prevent steel corrosion, or protective tubes or a combination of protective tubes and rustproofed materials have been used to enable external cables to be placed in an environment where they will not be affected by chemical substances or ultraviolet light. For these reasons, it was decided that, when external cables are used, suitable methods must be implemented to protect external cables from actions or environments that might cause their quality to change over time, in principle. However, this condition need not be observed if it can be confirmed from the results of appropriate numerical tests and accelerated exposure tests that the quality of the external cables does not change over time even if they are not protected, or if the decline in quality can be accurately predicted.

The protective tubes and rustproofing materials used to protect external cables must have the following properties.

(i) Protective tubes

Protective tubes are used to protect external cables and as fill tubes for rustproofing material. The protective tubes used must have the following properties:

1. Protective tubes must have sufficient rigidity and strength so they will not be damaged during transport, member attachment, tension work and rustproofing material fill work. They must also have sufficient strength to withstand long-term contact pressure at deviators.
2. Protective tubes must be made of a material that will not cause a chemical reaction with the fill material and must be strong enough to withstand the fill pressure.
3. Protective tubes must have adequate chemical stability in the anticipated temperature range for construction and use. For example, if the reaction of the protective tube to temperature is too sensitive, leakage of fill material or other unexpected accidents may result. Accordingly, study of the coefficient of thermal expansion for each material is needed.
4. When considering the replacement of external cables, a type of material that will make replacement work easy must be selected.

In general, steel pipes, polyethylene tubes, polypropylene tubes, metal-reinforced polyethylene tubes and fiber-reinforced plastics are used as protective tubes. The use of polyethylene tubes appears to be particularly common. Polyethylene tubes that conform to JIS K 6761 (general use) and JIS K 6762 (water) should be used. In recent years, high density polyethylene tubes have often been used.

(ii) Rustproofing materials

If rustproofing is a primary objective for protection when prestressing steel is used for external cables, a rustproofing material must be used to protect the external cables. The specific methods listed below are used to rustproof external cables. However, whichever method is used, it must be able to provide sufficient rustproofing performance until the end of the structure's service life.

1. Bare wire rustproofing (galvanizing, coating with epoxy resin, polyethylene sheath, etc.)
2. Fill (cement grout, grease wax, bituminous material)
3. Combination of 1 and 2

When using prestressing wires by themselves, without a protective tube, after they have been galvanized, coated or covered with a sheath, they should be maintained in a satisfactory state so they will not be greatly affected by the environment or chemical action. Moreover, a decline in quality through chemical action of the rustproofing material or changes over time will have a great affect on the quality of external cables, so their material properties must be ascertained and it must be confirmed that they will not react with the materials with which they come in contact.

(3) As a rule, the quality of anchoring and connecting components must be confirmed in accordance with JSCE-E 503 "Methods for Testing the Performance of Anchoring and Connecting Components for Prestressed Concrete Construction" (draft) (Japan Society of Civil Engineers) and JSCE-E 537 "Methods for Testing the Performance of Anchoring and Connecting Components for Prestressed Concrete Construction Using Continuous Fiber Reinforcing Materials" (draft) (Japan Society of Civil Engineers).

3.3.2 Steel Plates

(1) The quality of steel plates shall be indicated by their tensile strength and other strength properties, Young's modulus and other deformation properties, and thermal properties and other material characteristics. Steel plates must be those for which weldability and bonding with adhesives can be ensured when necessary.

(2) The surface of steel plates must be suitably protected to prevent their quality from changing over time.

[Commentary]

(1) SS 400 is a standard material used for steel plates. When SS 400 is used, it should have a JIS standard certificate. When welded joints are used to connect steel plates, the weld must be one for which the required strength can be ensured. When an adhesive is used to bond the steel plate to the concrete surface, one whose adhesive properties will enable the required bonding strength to be secured must be used. When steel plates of a material other than SS 400 are used, a separate study of bonding properties and weldability must be conducted when necessary.

(2) In general, the quality of steel plates will change over time through load action and environmental action. With the bonding method, steel plates are generally placed on the outer surface of the reinforced concrete members, so they tend to be affected by changes over time that result from corrosion caused by environmental action. As an anticorrosion measure for steel plates, in general, etching primer and zincrich primer are used; a material whose anticorrosion, adhesion and other quality requirements have been confirmed should be coated with a suitable coating thickness.

3.3.3 Continuous Fiber Sheets

(1) The quality of continuous fiber sheets shall be indicated by their tensile strength and other strength properties, Young's modulus and other deformation properties, and thermal properties and other material characteristics.

(2) As a rule, the surface of continuous fiber sheets shall be protected to prevent their quality from changing over time.

[Commentary]

(1) Continuous fiber sheets must be checked to confirm that they possess the strength, elongation capacity, Young's modulus, coefficient of linear expansion and material properties that can be relied upon from an engineering standpoint. Moreover, the quality of continuous fiber sheets will change depending on the resin with which they are impregnated and bonded, so the material properties of the continuous fiber sheets and the fiber-reinforced plastic composite material used for impregnating and bonding must be confirmed.

(2) In general, the quality of continuous fiber sheets will change over time due to load action and environmental action. With the bonding method, the continuous fiber sheets are placed on the outer surface of the structure, so as a rule a protective layer of paint, concrete, mortar or the like must be provided to prevent the reinforcing materials from changing over time. However, this condition need not be observed if it can be confirmed from the results of appropriate numerical tests and accelerated exposure tests that the quality of the continuous fiber sheets does not change over time even if they are not protected, or if the decline in quality can be accurately predicted.

3.3.4 Adhesive

(1) The adhesive used to bond the concrete and reinforcing material must be one that can ensure the required bonding strength.

(2) The adhesive used for the overlap splices for the reinforcing material must be one that can ensure the strength of the overlap splice section.

(3) The impregnation/adhesive agent used for the continuous fiber sheet bonding method must be one that ensures the strength, Young's modulus and other quality requirements of the continuous fiber sheets as a fiber bonding material.

(4) The adhesive must be one with suitable viscosity, shrinkage and other characteristics in keeping with the coating, fill or other construction method.

[Commentary]

(1) In performance verification, when surface holding is assumed, the reinforcing material must be bonded to the concrete by the adhesive. The bonding strength of the concrete and reinforcing material will vary depending on the type of adhesive and reinforcing material, the nature of the concrete surface and other factors, so suitable tests should be performed to check the bonding strength.

(2) The adhesive used for the overlap splices using steel splice plates and the lap splices for the continuous fiber sheets must have a bonding strength sufficient to enable the required overlap splice strength to be obtained.

(3) The continuous fiber sheet must have resin well impregnated between the continuous fibers to join the fibers to one another and transmit stress, in order to enable the sheet to function as a fiber-reinforced plastic with the proper strength, Young's modulus and other quality requirements. Accordingly, the impregnation/adhesive agent must function as an adhesive that bonds the reinforcing material to the concrete, as well as being able to ensure the strength, Young's modulus and other quality requirements for continuous fiber sheets as a fiber bonding material for fiber-reinforced plastics.

(4) With the bonding method, the structure is retrofitted at the site by using adhesive to bond the reinforcing material to the concrete. Accordingly, the adhesive must have viscosity, fluidity and other quality values suitable for site construction.

3.3.5 Fill Material

(1) The fill material used with the jacketing method must have the required fill properties and fluidity and must be able to seal the reinforcing material to the concrete.

(2) The fill material must form a thick hardening body and must transmit stress effectively between the reinforcing material and the concrete frame.

[Commentary]

(1) When using the jacketing method to improve the shear capacity and ductility of bar members, it is not always necessary to bond the reinforcing materials to the existing concrete; it is only important that the reinforcing materials and the existing concrete be sealed together. The fill material must have fill properties and fluidity that are appropriate for the interval between the reinforcing materials and the concrete and the injection method.

3.3.6 Cement-Based Reinforcing Material

(1) The quality of cement-based reinforcing material shall be indicated by the compressive strength, tensile strength and other strength properties, Young's modulus and other deformation properties, and thermal properties, watertightness and other material properties needed to evaluate the performance of the retrofitting structure.

(2) As a rule, good quality materials shall be selected for use in cement-based reinforcing materials, and trial mixing using an appropriate mixing design method shall be performed to determine the ideal mixture, so there will be as little change as possible in the quality over time after hardening.

[Commentary]

(1) Here cement-based reinforcing material refers to mortar, concrete and other materials. The quality requirements for these reinforcing materials will differ depending on the type and level of performance required for the retrofitted structure. Currently, the materials used with the overlaying and jacketing methods differ depending on the target method, and suitable types and quality of materials are used. Here, the reinforcing materials currently being used will be covered, but this is not meant to prevent the use of other reinforcing materials. Cement-based reinforcing materials must have little drying shrinkage and must attain practical strength quickly, and they also must have excellent cracking resistance and flexural and shear properties. Furthermore, they must also have excellent fatigue resistance when used with the upper surface overlaying method, steel reinforced upper surface overlaying method, lower surface overlaying method and lower surface spray method to reinforce bridge decks. With the lower surface overlaying method, cement-based reinforcing materials are applied to the underside through human labor and must bond to existing members, so they must have particularly excellent bonding properties.

In general, with the upper surface overlaying method and steel reinforced upper surface overlaying method, stiff-consistency steel fiber reinforced concrete utilizing ultra-quick hardening cement and high early strength Portland cement and other high early strength cements is used. With the lower surface overlaying method, polymer mortar with high bonding strength is used, while with the lower surface spray method steel fiber reinforced spray mortar utilizing ultra-quick hardening cement and the like are used. Steel fibers that fulfill the quality requirements in JSCE-E 101-1983 (SFRC guidelines) "Quality standards for steel fibers for concrete" should be used. With the reinforced concrete jacketing method, it is important to make sure no voids are created in the overlaying section, so flowing concrete with a slump of approximately 18 cm is used, in some cases together with an expansion material to reduce drying shrinkage. In the mortar spray method, the overlaying section formed by the spray mortar is thin, and so the mortar must have high fill properties and cracking resistance; accordingly, cement mortars that use expansion materials or cement mortars containing short plastic fibers are used. In addition, since after spraying the surface is finished with a metal trowel, the mortar must be of a type that will make troweling work easy. As a rule, the reinforcing material used with the precast panel jacketing method should be concrete containing lateral ties and joints or precast panels made of mortar. Gaps between the existing concrete and the precast panels must be filled with highly fluid grout mortar.

The quality of reinforcing materials is indicated by material properties such as compressive strength, tensile strength and other strength properties, Young's modulus and Poisson's ratio, and stress-strain relationship and other deformation properties. Reinforcing materials must be checked to make sure they have the strength, elongation capacity, Young's modulus, coefficient of linear expansion and other material properties that can be relied upon from an engineering standpoint. The quality of cement reinforcing materials is indicated not only by compressive strength but by a variety of material properties. Strength properties are indicated by compressive strength, tensile strength, flexural strength, bonding strength and other static strength as well as fatigue strength. With the overlaying and jacketing method, bonding strength and fatigue strength are important materia l properties. Also, in addition to the Young's modulus and Poisson's ratio, indicators of ductility, cracking resistance and other dynamic properties may also be required as deformation properties for the overlaying and jacketing method. Nevertheless, generalized numerical handling methods for these properties have not yet been established and are still at the research stage.

(2) Cement-based reinforcing materials are generally provided as ready mixed concrete or are mixed at the site. The quality of fresh concrete between the time that mixing is complete until it is laid will affect not only work performance but the material properties of the hardened concrete accompanying changes over time. Accordingly, the mixing conditions must be established and trial mixing performed to check the quality by means of the slump, air content, compressive strength and other material properties, in order to ensure that the required properties for hardened concrete are attained. It is also important to select good quality materials so alkali aggregate reaction and other problems with materials do not occur.

When appropriate testing and analysis have confirmed that the compressive strength and other material properties of cement reinforcing materials, which have been created with an appropriate mix design through the use of good quality materials, will exhibit almost no change over time, the material properties at the time of verification may be used as the properties for retrofitting construction. In the overlaying and jacketing method, the reinforcing materials are placed on the outer surface of the structure, so protection or the like should be applied to the retrofitted members in order to prevent changes in the reinforcing materials over time. When changes in the material properties over time can be prevented through suitable protection, the material properties at the time of verification may be used as the properties for retrofitting construction.

In selecting the materials to be used and determining the mix design, reference should be made to the following Standard Specifications and guidelines.

- Standard Specification for Concrete (Design) (Construction) (Japan Society of Civil Engineers)
- Concrete Overlaying Method manual (among the individual methodology manuals) in Concrete Engineering Series No. 28 "The Future of Retrofit Design and Construction for Concrete Structures - Retrofit Design Guidelines with Performance Verification (draft)" (Japan Society of Civil Engineers) 1998
- "Guidelines for Steel Fiber Reinforced Concrete Design and Construction (draft)" (Japan Society of Civil Engineers) 1983
- Upper surface overlaying method design and construction manual (Express Highway Research Foundation of Japan) 1995
- Design Procedures, Second Edition (Japan Highway Public Corporation) 1997
- Design/Construction Guidelines for Seismic Retrofitting of Existing Concrete Railway Viaduct Piers, etc. - Spiral reinforcement jacketing construction method (Railway Technical Research Institute) 1996

- Design/Construction Guidelines for Seismic Retrofitting Method for Viaduct Piers using Spray Mortar (Railway Technical Research Institute) 1996
- Design/Construction Guidelines for Seismic Retrofitting of Existing Concrete Railway Viaduct Piers, etc. - Precast reinforced concrete mold construction method (Railway Technical Research Institute) 1996

3.3.7 Steel

The quality of steel used together with cement reinforcing materials shall be indicated by the compressive strength, tensile strength and other strength properties, Young's modulus and other deformation properties, and thermal properties, watertightness and other material properties needed to evaluate the properties of retrofitted structures.

[Commentary]

Here steel refers to reinforcing steel used together with cement reinforcing materials. This includes both steel reinforcement and prestressing steel as well as the steel, etc. used to anchor and connect these materials. These reinforcing steel materials should fulfill the quality standards noted in JIS standards.

3.4 Material Characteristic Values and Design Values

3.4.1 External Cables

(1) Characteristic values and design values for external cables must be derived using appropriate methods.

(2) Characteristic values and design values for prestressing steel shall be determined in accordance with the Standard Specification (Design).

(3) Characteristic values and design values for continuous fiber prestressing materials shall be determined in accordance with the "Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials (draft)" (Design).

(4) Material factors for external cables shall be determined in accordance with Section 2.6 (2) in the Standard Specification (Design) and Section 2.6 in the "Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials (draft)" (Design).

[Commentary]

(2) When using prestressing steel that conforms to JIS standards, the characteristic values and design values for external cables should be determined in accordance with Section 3.3 of the Standard Specification (Design). The external cables that can generally be used are shown by anchoring method in the Recommendation for Design and Construction of Structures Using Prestressed Concrete Construction Method (Japan Society of Civil Engineers), so this manual should be used as reference.

(3) When using continuous fiber prestressing materials that conform to JSCE-E 131 "Quality Standards for Continuous Fiber Reinforcing Materials (draft)," the characteristic values and design values for external cables should be determined in accordance with the "Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials (draft)" (Design) (Japan Society of Civil Engineers).

When using continuous fiber prestressing materials that do not conform to JSCE-E 131 as external cables, tests must be conducted to determine the design values (design strength and Young's modulus), design ultimate strain and other values. In such cases, the tensile strength, flexural tension breakage load, creep failure capacity, relaxation value, fatigue strength, coefficient of thermal expansion, shear strength and other values should be determined through test methods equivalent to those in JSCE-E 531 "Test method for tensile properties of continuous fiber reinforcing materials (draft)" and other Japan Society of Civil Engineers standards. However, even when other test methods are used, these values may be used if it is determined that sufficient performance results exist and the characteristic values (including the effects of anchorage components) can be relied upon. In addition, with the external cable method, the use of the multi-cable system that formerly was not often used with internal cables is expected to become more frequent. The characteristics of the multi-cable system include tensile strength that does not increase proportionally to the number of multiply anchored stressing components, so a thorough knowledge of the characteristics of this system is needed for it to be used.

(4) **Table C3.4.1** shows the standard material factors for protected external cables. This table should be referred to when determining material factors.

Table C3.4.1 Material factors for external cables

[Objective]	Steel	Continuous fiber prestressing materials
For serviceability verification	1.0	1.0
For safety verification	1.0- 1.05	1.15 - 1.30

3.4.2 Steel Plates

As a rule, characteristic values and design values for steel plates shall be in accordance with Guidelines for the Design of Steel Structures.

[Commentary]

Characteristic values and design values for the tensile strength of steel plates and the stress-strain relationship, Young's modulus and other values should be in accordance with the Guidelines for the Design of Steel Structures (Japan Society of Civil Engineers). When using materials not covered in the Guidelines for the Design of Steel Structures, the strength, Young's modulus, stress-strain relationship, coefficient of thermal expansion and other material characteristic values and design values should be determined through testing.

3.4.3 Continuous Fiber Sheets

(1) As a rule, characteristic values for the tensile strength of continuous fiber sheets shall be determined through tensile tests.

(2) Characteristic values for the bonding strength of continuous fiber sheets to concrete shall be determined through appropriate testing.

(3) Compressive strength and shear strength of continuous fiber sheets shall not be considered in design.

(4) As a rule, the Young's modulus for continuous fiber sheets shall be determined through tensile tests.

(5) The tensile stress-strain relationship for continuous fiber sheets used for safety verification shall be assumed through a model consisting of the tensile strength determined through testing and a straight line passing through the ultimate strain point corresponding to this tensile strength value and the origin. The tensile stress-strain relationship for continuous fiber sheets used for serviceability verification shall be assumed through a model containing a straight line passing through the Young's modulus determined through tensile tests at the origin.

(6) As a rule, the coefficient of thermal expansion for continuous fiber sheets shall be determined through testing.

(7) The characteristic value for the fatigue strength of continuous fiber sheets shall be determined through appropriate testing.

(8) The characteristic value for bonding fatigue strength of continuous fiber sheets to concrete shall be determined through appropriate testing.

(9) The material factors for continuous fiber sheets shall be determined in accordance with Section 2.6 (2) of the Standard Specification (Design).

[Commentary]

(1) Tensile tests should use JIS K 7073 "Test method for tensile properties of carbon fiber strengthening plastic" as a standard. Continuous fiber sheets function as fiber-reinforced plastic in which the continuous fibers are bonded using an impregnation/adhesive agent. Even if the same strengthened fibers are used, the strength of continuous fiber sheets will differ depending on the form of the sheet and its combination with the impregnation/adhesive agent, so measurements should be performed with the continuous fiber sheet in fiber-reinforced plastic form, after it has been impregnated with the impregnation/adhesive agent and allowed to harden (see **Figure C3.4.1**). Variations in the tensile strength of continuous fiber sheets are known to be generally greater than steel, but the distribution can be thought of as an almost perfectly normal distribution. The characteristic value used for tensile strength is generally the average strength minus three times the standard deviation. This is equivalent to a 99.9% confidence limit for tensile strength. The cross-sectional area of only the continuous fibers is generally calculated from the fiber weight and used as the cross-sectional area for calculating the tensile strength of continuous fiber sheets. Here the fiber weight is the mass of continuous fibers included in a unit area of the continuous fiber sheet. The cross-sectional area for the fibers alone can be calculated from this value and the specific gravity of the continuous fibers.

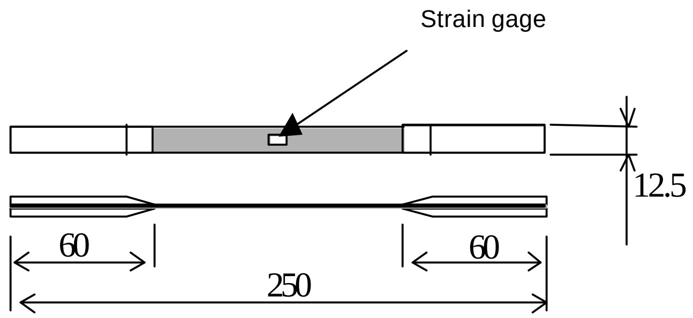

Figure C3.4.1 Sample tension test piece (unit: mm)

(2) The bonding strength of continuous fiber sheets to concrete will differ depending on the type of continuous fiber sheets, the type of adhesive, the strength and surface processing status of the concrete and other factors, so it was decided that, as a rule, this value should be determined through testing. The methods include the one shown in **Figure C3.4.2**, in which continuous fiber sheets were bonded to square columns and tensile force was then applied to the continuous fiber sheets and a tensile shear test was performed for the concrete surface and the continuous fiber sheets. The methods also include one in which continuous fiber sheets were bonded to the surface of a concrete beam test piece on which tensile stress was applied and then a bending test was performed and the bonding strength determined from the peeling load of the continuous fiber sheets. Since the method by which bonding force is transmitted differs depending on whether the continuous fiber sheets are attached to the tensile stress surface or the shear stress surface of the member, the appropriate method should be selected to derive the bonding strength.

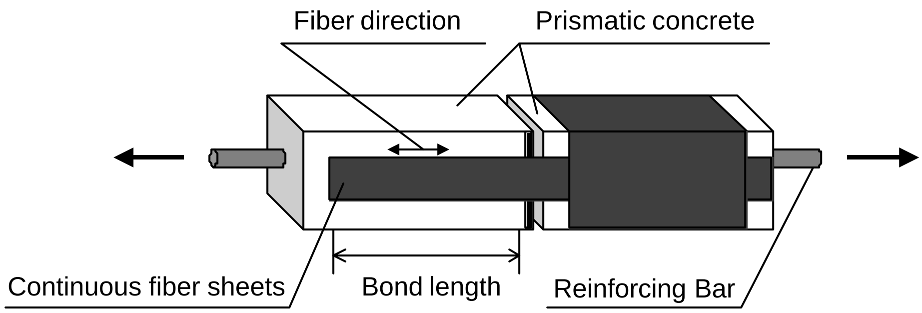

Figure C3.4.2 Sample bonding test piece

(3) As continuous fiber sheets are extremely thin in comparison with the dimensions of the members, it is difficult for them to bear compressive force. In addition, their shear rigidity and shear strength is extremely low compared to those of steel and concrete. For this reason, the compressive strength and shear strength of continuous fiber sheets are not considered in design.

(4) As a rule, tensile tests should be in accordance with JIS K 7073 "Test method for tensile properties of carbon fiber strengthening plastic." The Young's modulus of continuous fiber sheets is measured with the continuous fiber sheets in fiber-reinforced plastic status, after they have been impregnated with the impregnation/adhesive agent and allowed to harden. The cross-sectional area used to calculate the Young's modulus for continuous fiber sheets is generally calculated as the cross-sectional area for the continuous fibers alone from the fiber weight.

(5) The stress-strain curve for continuous fiber sheets will differ depending on the continuous fibers, the shape of the sheet and other factors. In general, the tangential Young's modulus will change depending on the stress level, so a model should be established in accordance with the performance being verified.

(6) The coefficient of thermal expansion in the fiber direction for continuous fiber sheets will differ depending on the type of continuous fibers, the specific volume of continuous fibers and impregnation/adhesive agent forming the fiber-reinforced plastic composite material, and the method of sheet manufacture, so it was decided that, as a rule, this value should be determined through testing. The coefficient of thermal expansion for continuous fiber sheets should be measured with the sheets in fiber-reinforced plastic form, with the sheets impregnated with impregnation/adhesive agent and allowed to harden. Currently there are almost no sample measurements of the coefficient of thermal expansion for continuous fiber sheets. However, it is known that the coefficient of thermal expansion for unidirectional fiber-reinforced plastic materials can be estimated using **Equation C3.4.1**, from the coefficient of thermal expansion and Young's modulus for the continuous fibers and the matrix resin and the specific volume of continuous fibers.

$$a_L = \frac{E_f \cdot a_f \cdot V_f + E_m \cdot a_m \cdot (1-V)}{E_f \cdot V_f + E_m \cdot (1-V_f)} \quad \text{....................................(\textbf{Equation 3.4.1})}$$

where:

a_L :Coefficient of thermal expansion in fiber direction for fiber-reinforced plastic

a_f :Coefficient of thermal expansion for continuous fibers

a_m :Coefficient of thermal expansion for matrix resin

E_f :Young's modulus for continuous fibers

E_m :Young's modulus for matrix resin

V_f :Specific volume of continuous fibers in fiber-reinforced plastic

(7)(8) When determining characteristic values for fatigue strength through testing, the type of continuous fiber sheet, the degree and frequency of applied stress, the environmental conditions and other factors should be considered.

(9) The "Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials (draft)" (Design) notes that the material factor for continuous fiber reinforcing materials may generally be set to 1.15 - 1.3. It is thought that continuous fiber sheets, as fiber-reinforced plastics, may be handled in the same manner as continuous fiber reinforcing materials. Accordingly, when appropriate construction and protection are performed, the material factor for continuous fiber sheets may be set to 1.15 - 1.3.

3.4.4 Cement-Based Reinforcing Materials

(1) Concrete

The characteristic values and design values for concrete shall conform to Section 3.2 in the Standard Specification (Design). Characteristic values and design values for materials not covered by the Standard Specification shall be determined through appropriate testing.

(2) Mortar

(i) As a rule, the characteristic values for the compressive strength, tensile strength, flexural strength and other properties of mortar shall be established through appropriate testing.

(ii) The Young's modulus for mortar shall be established through appropriate test methods. As a rule, the stress-strain curve for mortar shall be determined by assuming a suitable mortar in accordance with the objectives of the study, based on test results.

(iii) The material factors for mortar shall be established in accordance with Section 2.6 (2) in the Standard Specification (Design).

[Commentary]

(1) In the overlaying and jacketing construction method, special concretes are often used from the standpoint of bonding to existing concrete, suppression of cracking and so on. Accordingly, when the concrete demonstrates different dynamic properties from those of ordinary concrete, the characteristic values must be determined through appropriate testing. For example, within a suitable content range of 2% or less, steel fiber content will have almost no effect on the characteristic values for compressive strength and Young's modulus of steel fiber reinforced concrete, and these values may be considered to be the same as those for ordinary concrete. Nevertheless, to make the values for compressive toughness, flexural strength and toughness, tensile strength and shear strength greater than those of ordinary concrete with the same compressive strength, these values should be established through appropriate testing based on JCI-SF "Regulations Concerning Test Methods for Steel Fiber-Reinforced Concrete," JSCE-G 551 1983 (SFRC guidelines) "Test Methods for Compressive Strength and Compressive Toughness of Steel Fiber-Reinforced Concrete," JSCE-G 552 1983 (SFRC guidelines) "Test Methods for Flexural Strength and Flexural Toughness of Steel Fiber-Reinforced Concrete," JSCE-G 553 1983 (SFRC guidelines) "Test Methods for Shear Strength of Steel Fiber-Reinforced Concrete," and so on. In addition, regarding the flexural fatigue strength of steel fiber-reinforced concrete, it has been reported based on existing research that this value will be greater than that for ordinary concrete, but at the present time equations for calculating fatigue strength according to the type of steel fiber and the degree of fiber content have not yet been established. Accordingly, fatigue data should be accumulated through testing and an *S-N* curve derived to establish characteristic values for fatigue strength.

(2) (i) Based on the present situation in which various types of mortar are used, tensile properties should be determined based on concrete tests equivalent to those indicated in JSCE-G 505-1995 "Test Methods for Compressive Strength of Mortar or Cement Paste Using Circular Column Test Pieces," JIS R 5201 "Physical testing methods for cement" and Section 3.2 in the Standard Specification (Design).

(ii) The stress-strain curve for mortar will differ depending on the type of mortar and the mix, and in general the Young's modulus will change depending on the stress level. For this reason, a model in keeping with the performance to be verified should be established based on the results derived through JSCE-G 502-1988 "Test Method for Modulus of Static Elasticity for Concrete (draft)" and other appropriate tests.

(iii) Since having the same material properties as concrete is a necessary condition for overlaying mortar, the material factor for mortar, like that for concrete, should be in accordance with Section 2.6 (2) in the Standard Specification (Design).

3.4.5 Steel

The characteristic values and design values for steel shall be in accordance with Section 3.3 in the Standard Specification (Design). For those materials not covered by the Standard Specification, the characteristic values and design values shall be determined through appropriate testing.

[Commentary]

Values for materials not covered by the Standard Specification must be determined through appropriate testing or the like.