

## CHAPTER 7 UPGRADING WORK

### 7.1 General

- (1) As a rule, upgrading work using continuous fiber sheets and continuous fiber strands shall be conducted in accordance with the provisions of this chapter.
- (2) As a rule, the upgrading work shall be performed under the supervision of an engineer who has thorough knowledge of these tasks.

#### [Commentary]

The continuous fiber sheet method and continuous fiber strand method involves using impregnation resin to bond or seal continuous fiber sheets and continuous fiber strands to the surface of the concrete. The reinforcement and the existing concrete structure become a single unit and demonstrate the required upgrading performance. Accordingly, in order to achieve this, appropriate techniques, material selection, construction and construction supervision are essential, and suitable maintenance should be performed to ensure that the performance requirements are maintained after upgrading.

In this chapter, considerations regarding the construction needed to achieve the designed upgrading performance are described. Upgrading using continuous fiber sheets and continuous fiber strands involves applying impregnation resin to the continuous fiber sheets and continuous fiber strands at the site in order to ensure the upgrading performance. Therefore, decisions should be made taking account of the condition of the work site and based on the unique operational and environmental conditions at the site, and the skill of the work supervisor who supervises the construction and the work personnel will have a comparatively great influence on the process. A qualification system for skills should be required and has been established in some areas. For these reasons, when implementing these techniques, it is important to consider qualifications, experience when selecting supervisors and work personnel.

## **7.2 Work plan**

- (1) The work using continuous fiber sheets and continuous fiber strands shall be done so as to satisfy the work requirements in accordance with a work plan based on the upgrading design of the concrete structure with considerations given to the construction and environmental conditions.
- (2) The work plan shall specify the work procedure, processes and quality control methods.

### **[Commentary]**

The quality of the work plan is a major factor on the reliability and safety of the structure. For this reason, necessary preliminary studies should be performed to ensure the performance requirements for the design and a work plan drafted based on the results.

To ensure that the work is performed reliably, the work plan should include the followings.

1. Reasonable work schedule considering possible working period
2. Adequate space for work
3. Preparation of necessary amount of materials with sufficient quality
4. Employment of construction workers with the necessary capabilities and adequate experience

The following items should be taken into account to ensure the safety of the work:

1. Measures to ensure the safety of work personnel.
  2. Measures to ensure the safety of third parties.
  3. Measures to prevent damage to shared facilities.
  4. Establishment of a system for quick countermeasures in the event of an accident.
  5. Measures for waste processing.
- (2) The continuous fibers used to upgrade concrete structures include those in sheet form and strand form. Work procedures should be established that utilize the characteristics by selecting the type that best satisfies the performance requirements of the design.

The following are the standard work procedures for upgrading using continuous fiber sheets and continuous fiber strands.

1. Delivery and storage of materials to be used
2. Preparation work
3. Surface preparation work
4. Primer coating work
5. Bonding of continuous fiber sheets and jacketing with continuous fiber strands
6. Finishing
7. Restoration of existing facilities

The procedures should include the environmental conditions at the construction site, the work period and other restrictions. They should also specify processes that match the construction tasks and quality control methods to ensure the performance requirements of the design.

### **7.3 Handling of materials**

The handling precautions relating to material deterioration and safety during delivery, storage, mixing and processing, and use shall be confirmed in advance and strictly observed.

#### **[Commentary]**

Materials used in the continuous fiber sheet method and continuous fiber strand method should be those for which quality has been confirmed, not only the mechanic characteristics of the continuous fiber sheets and continuous fiber strands but the quality of impregnation resin and all other materials. Moreover, the performance of the composite of all of these materials is crucial, and materials whose strength, deterioration characteristics and other properties as a composite have been confirmed through testing should be used.

Since the quality of the materials affects the effectiveness of upgrading, the quality should be confirmed upon receipt. In general, the materials are manufactured in

accordance with the quality standards of the manufacturer. Therefore, their quality may be checked by the test results submitted by the manufacturer.

If reinforcements, adhesives and other materials deteriorate during shipment, storage, mixing and processing, it is very difficult to ensure required upgrading performance. For this reason, materials should be properly shipped and stored considering material properties to ensure that no deterioration occurs during shipment and storage. Continuous fiber sheets and continuous fiber strands are easily damaged before being impregnated with impregnation resin, and some types of continuous fibers may deteriorate if exposed to ultraviolet light and moisture. Therefore, thorough precautions should be taken to ensure that they are handled properly. In general, to prevent deterioration of the resin materials used for bonding, the materials should be stored in a cool dark place without being exposed to direct sunlight.

Resins that contain diluents are harmful to the human body when the concentration of the fumes emitted exceeds a certain level. Accordingly, the container should be sealed securely and stored in a cool dark place. These resins are also flammable and fire precautions should be observed and the storage quantities kept within the limits prescribed by the Fire Defense Law (Class 4 primary petroleum products: designated quantity 200 or 400 liters). In addition, considerations should be given for material deterioration and safety in the handling of materials in accordance with the handling manuals prepared by the material manufacturer.

#### **7.4 Surface preparation**

- (1) Construction defects, remarkable deterioration and cracking in the surface of concrete shall be repaired appropriately.
- (2) Embrittled sections and projections, level differences and other unevenness in the surface of concrete shall be removed through chipping or polishing to make the surface smooth.
- (3) When continuous fiber sheets and continuous fiber strands are placed perpendicular to corner angles, the corner angles shall be rounded through chipping or polishing, or through the use of a smoothing agent.

**[Commentary]**

- (1) To ensure that the continuous fiber sheet method and continuous fiber strand method satisfy performance requirements, the continuous fiber sheets and continuous fiber strands should be properly bonded or sealed to the surface of the concrete. For this reason, suitable methods should be used to prepare the surface of the concrete. Surface preparation includes scouring, **sectional repair**, smoothing and so on, and should ensure that the condition of the concrete surface is as required for upgrading of the structure.

If there are rock pockets, honeycombs or other construction defects on the concrete surface, or if there is remarkable deterioration or cracking, the defects impairs the required performance even if there are no problems with the continuous fiber sheets or continuous fiber strands. Imperfection of surface reduces the effect of upgrading with continuous fiber sheets or continuous fiber strands. Accordingly, before attaching continuous fiber sheets or jacketing with continuous fiber strands, suitable methods should be used to repair the existing concrete surface.

- (2) (3) To ensure proper bond between the continuous fiber sheets or continuous fiber strands to the surface of concrete, deteriorated layers, oils and fats should be removed from the surface, and unevenness and projections that might hinder the bonding of the continuous fiber sheets or continuous fiber strands should be chipped away or removed with a smoothing agent.

Sharp projections, level differences, corner angles on the concrete surface are likely to reduce the strength of the continuous fiber sheets or continuous fiber strands by stress concentration. Accordingly, these projections and level differences should be cut away or smoothed using putty and mortar. Corner angles should be rounded by cutting them away or coating them with mortar. However, the strength reduction depends on the type of continuous fiber sheet or continuous fiber strand. Measures should be devised to match the type of continuous fiber sheets or continuous fiber strands.

## **7.5 Bonding and jacketing**

Bonding and sealing or wrapping with continuous fiber sheets and continuous fiber strands shall be done so as to ensure the performance requirements for upgrading. To ensure the reliability of construction, the following items shall be checked at each stage of the work.

- (1) The environmental conditions for the work is suitable.
- (2) Surface preparation is suitably performed.
- (3) Mixing and coating of primer are appropriately performed.
- (4) Mixing and coating of smoothing agent are appropriately performed.
- (5) When using continuous fiber sheets:
  - a) The sheets are attached at the specified position in the specified direction, with the specified number of plies.
  - b) The sheet is bonded or sealed securely to the concrete surface.
  - c) The impregnation resin is suitably mixed and applied and has thoroughly impregnated the sheet.
  - d) The impregnation resin is cured thoroughly.
- (6) When using continuous fiber strands:
  - a) The strand winding interval is appropriate.
  - b) The strand winding tension is constant.
  - c) The strand winding speed is appropriate and the strands are thoroughly impregnated with impregnation resin that has been suitably mixed and applied.
  - d) The impregnation resin is cured thoroughly.

### **[Commentary]**

- (1) In general, epoxy resin is used as the primer, smoothing agent, and impregnation resin. Since the viscosity, work life, and setting time are affected by the atmospheric temperature at the site and the surface temperature of the concrete, the proper type should be selected to match the temperature during the work (summer, winter and spring/fall types are available). In the case of epoxy resins, the environmental conditions that match the construction are a temperature of 5°C or higher and humidity of no more than 85%.

When the atmospheric temperature and the surface temperature of the concrete at the site are low (less than 5°C), the construction site should be warmed or low-temperature primer and resin may be used. If the surface of the concrete is not dry, special primers for wet surfaces should be used.

- (2) (3) (4) The level of smoothness matching the objective of upgrading should be confirmed for the prepared surface. In addition, the primer and smoothing agent should be mixed and agitated with the proper mix proportions. In general, the work life of epoxy resin depends on the mixing amount and temperature. Thus, the atmospheric temperature and concrete surface temperature should be carefully measured. The coat of primer and smoothing agent should be allowed to harden until it is firm to the touch, and should be checked visually and by touch to make sure there is no dust or moisture on the surface. If the primer and smoothing agent take a long time to harden causing a problem with bond to the surface, a countermeasure such as roughen the surface with sandpaper should be taken to increase its adhesion properties. To prevent improper hardening of the primer and smoothing agent, the materials should be applied to a dry surface. If there is condensation or other moisture on the surface before the initial hardening, causing whitening, that area should be wiped with solvent or removed with sandpaper.
- (5) A working schedule diagram matching the actual structure should be prepared based on the design. The diagram should clearly identify the reference point for attachment, the overlap splice positions and the number of plies to enable the sheets to be attached properly. After the primer and smoothing agent have been applied, the guide should be placed in accordance with the diagram and the continuous fiber sheets attached carefully along the guide.

The work should ensure that reliable bond strength is attained when stress is transmitted by the bond between the continuous fiber sheets and concrete surface. However, when the design requirements do not specify the bond strength, the concrete surface may be treated with finishing mortar or paint.

The continuous fiber sheets should be impregnated with impregnation resin for fibers being bonded together - each of the fibers is bonded and the entire sheet receives external stress evenly up to the specified strength. For this reason, the

impregnation resin should be made to thoroughly impregnate the sheet. Particularly in the overlap splice sections, the impregnation resin should thoroughly penetrate between the fibers and sheets to make them a unit.

After attaching the continuous fiber sheets, the inspection should be done visually or through sounding with regard to lift, swelling, peeling, slackness, wrinkles, and epoxy resin impregnation condition.

After the impregnation resin is applied, it should be cured for a suitable period of time before the next sheet is attached. Before the initial setting of the impregnation resin begins, the surface should also be covered with vinyl sheets to protect it from rain or dust and to prevent it from being affected by sudden climatic changes.

- (6) When carbon fiber strands are wound by hand, the tension force applied to continuous fiber strands is not constant, resulting in variations of stress distribution in the continuous fiber strands after completion. Moreover, since the winding speed is not constant, there may also be variations in the degree of permeation of the impregnation resin. Problems may remain with respect to ensuring the tensile strength of the continuous fiber strands. For these reasons, the use of a machine to wind the continuous fiber strands, to control the winding interval, tension and speed is recommended.

## **7.6 Finishing work**

Upgraded surfaces shall be finished appropriately to ensure that the performance requirements including weatherproofing, fire resistance, shock resistance, and appearance are satisfied.

### **[Commentary]**

Performance requirements for finishing include the following:

- (1) Resistance to direct sunlight
- (2) Shock resistance



- (3) Fire resistance (or noncombustability)
- (4) Appearance
- (5) Brightness
- (6) Roughness

Finishing work includes painting work for durability and appearance; surface protection work such as noncombustible cover and fire-resistant cover. The excellent durability of continuous fiber sheets after application of impregnation resin has been confirmed through outdoor exposure tests and accelerated exposure test. However, depending on the type of fiber, durability may be impaired by use conditions. In such cases, the finishing should be planned after carefully considering the properties of the fiber. The impregnation resin surface deteriorates and whitens when exposed to ultraviolet light and ozone, and its appearance is easily marred. Accordingly, when an aesthetic appearance and illumination are required in the environments exposed to direct sunlight, it should be finished with protective paint.

Materials shown in Table C7.6.1 may be used for finishing work. Finishing work is generally performed after confirming that the initial setting of the impregnation resin is complete.

Table C7.6.1 Finishing Work

Finishing Work	Applicable Objective	Sample Specification
Painting	Measures to prevent exposure to ultraviolet light Surface protection	Resin coating
Surface protection	Measures to prevent exposure to ultraviolet light  Surface protection Measures to prevent external damage and collision damage	Mortar spraying Composite paint film Mortar spraying Mortar coating
Noncombustible cover Fire-resistant cover	Noncombustible cover Fire-resistant cover	Mortar coating Attachment of fire-resistant panels

## **7.7 Inspections**

### **7.7.1 General**

- (1) Necessary inspections shall be conducted for upgraded concrete structures at each stage of the work to ensure that they have the required performance.
- (2) In general, the inspections needed at each stage of the work shall consist of receiving inspections for continuous fiber sheets or continuous fiber strands, primer, smoothing agent, impregnation resin and other materials; inspections of the storage condition of these materials; surface preparation inspections; and inspections of the bonding or jacketing condition of the continuous fiber sheets or continuous fiber strands after the work is completed.
- (3) If the work is judged to fail the inspection, suitable corrective measures shall be taken.

#### **[Commentary]**

Even when continuous fiber sheets or continuous fiber strands are used, the importance of quality control, quality assurance and inspections is the same as when conventional materials are used.

Upgrading with continuous fiber sheets or continuous fiber strands is done by using impregnation resin to make the continuous fiber sheets or continuous fiber strands harden on the concrete surface, and to make the continuous fiber sheets and the existing concrete structure bond together to achieve the required upgrading performance. The upgrading performance should last for a long period of time after completion. Accordingly, the performance of the composite formed by the combination of these materials is of importance, and therefore materials whose physical properties, deterioration and other properties should be confirmed and whose quality should be assured through the tests of the composites.

### **7.7.2 Receiving inspection for materials**

- (1) Continuous fiber sheets or continuous fiber strands, primer, smoothing agent, impregnation resin and other materials shall be inspected at the time they are received to determine whether or not they are of the required quality.

- (2) If the inspection finds that the quality is unsuitable, the material shall be changed or other appropriate measures taken.

**[Commentary]**

To confirm that each of the materials used for upgrading has the required quality, the material should be inspected at the time it is received and before work begins.

Inspection of materials should be done in accordance with the quality assurance sheet, test results or other documents issued by the manufacturer. However, if the materials have suffered significant damage during shipment, during long-term storage at the site, or due to errors during construction work, they should be tested to confirm the quality, even if they appear to be all right.

**7.7.3 Inspection of material storage condition**

- (1) Material storage condition shall be inspected to ensure that materials are being stored appropriately.
- (2) If the inspection finds that the storage condition is unsuitable, the method of storage shall be improved.

**[Commentary]**

In general, the materials should be stored indoors in a well-ventilated location away from direct sunlight, flame, humidity, and rain, and at appropriate temperature and humidity conditions to ensure that their quality is not adversely affected. Laws relating to storage should be strictly observed.

**7.7.4 Inspection of surface preparation, primer coating and smoothing**

- (1) Surface preparation shall be inspected regarding the completeness of sectional restoration work, surface smoothness, processing of corner angles, primer coating and smoothing condition.
- (2) If the inspection finds that the condition of surface preparation is unsuitable, measures to improve the situation shall be implemented.

**[Commentary]**

It should be confirmed by surface inspections that the objective of upgrading the concrete structure and the construction conditions at the site are maintained as shown in the upgrading design. The inspection items should include the completed condition of surface repair, surface smoothness and corner angle processing condition.

**7.7.5 Inspection of continuous fiber sheets and continuous fiber strands during and after construction**

- (1) During and after construction, continuous fiber sheets shall be inspected for attached position, lifting, peeling, slackness, wrinkles, overlap splice length, number of plies, and quantity of impregnation resin coated.
- (2) Bond strength test shall be conducted as needed for continuous fiber sheets bonded or used for jacketing, to check the bonding performance to concrete.
- (3) Continuous fiber strands shall be inspected for winding position, winding interval, winding tension and winding speed to ensure that these values are appropriate, and that they are thoroughly impregnated with impregnation resin.
- (4) If the inspection finds that the bonding or jacketing condition of continuous fiber sheets and continuous fiber strands is unsuitable, this situation shall be improved.

**[Commentary]**

- (2) The performance of continuous fiber sheets during and after construction can be confirmed by the bond strength test. The tensile strength performance of continuous fiber sheets during construction is generally checked by means of existing test data obtained under similar construction environments and conditions. However, if the scale of construction is large or the construction conditions are severe, it would be best to conduct confirmation tests using test specimens fabricated at the site.

The same materials as those used at the site should be used for tests, and as a rule the test should be performed on the concrete at the site. However, if it is difficult to perform the test on the concrete at the site, the test may be performed on a slab specimen whose concrete properties have been identified.

- (3) The performance of continuous fiber strands can be confirmed after construction by conducting a tensile strength test on a continuous fiber strand test specimen that has been bonded with impregnation resin. Accordingly, during construction, the quality can be checked by conducting inspections to make sure that the winding position, winding interval, winding tension and winding speed are appropriate and that the impregnation resin has impregnated the strands thoroughly. The tensile strength performance of the continuous fiber strands during construction is generally confirmed using existing test data. However, when necessary, it would be best to conduct confirmation tests using test specimens fabricated at the site.