

Bridge Retrofitting Method

No.2-1 Steel Plate Bonding

1. Description of Retrofitting Method

Steel plate is bonded with epoxy resin at the bottom or side face of existing girders. Bonded steel plate provides the same effect as that for installing additional rebar to existing girder.

This method is adopted for strengthening the slab or girder against bending moment as well as shear. Due to ease of application, this method as shown in Figure AP 2.1.1 is widely used. This measure is often performed for girders since it does not require restriction to traffic. However, in case where the deterioration of the concrete surface is too severe, other measures to improve the quality may be considered.



Figure AP 2.1.1 Retrofit of Concrete Girder by Steel Plate Bonding

2. Application Criteria

Steel plate bonding involves use of narrow steel plates installed in the longitudinal direction of the concrete girder. The bonding of steel plates to concrete members is achieved using pressure attachment method as discussed below.

Pressure Attachment Method

This method requires single plates of required thickness with gaps sealed at the edges between the steel and the concrete. Epoxy resin is injected to ensure that no voids occur between the plate and the concrete.

Pressure attaching method is normally adopted for narrow plate type considering the extent of surface preparation of both concrete and steel plate as shown in Figure AP 2.1.2.

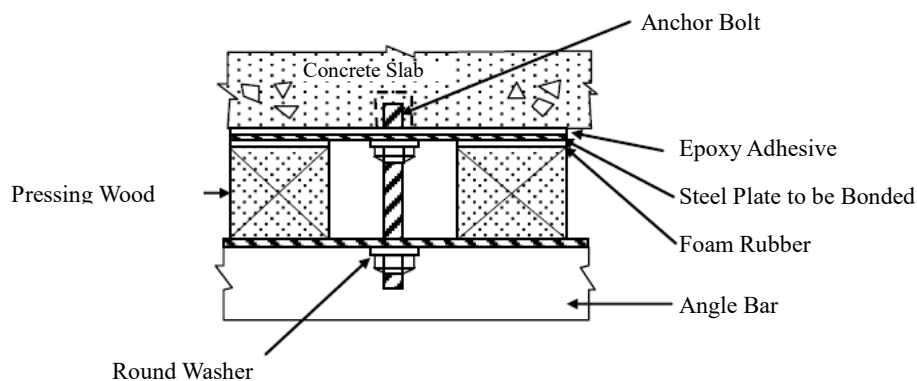


Figure AP 2.1.2 Detail of Pressure Attachment Method by Anchor Bolts

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3. Work Sequence

3.1 Surface Preparation

Bottom surface of concrete girder to be bonded with steel plate shall be cleaned. Any surface irregularities shall be leveled using a disc grinder.

The surface of the steel to be bonded must be completely free of any mill scale, rust, grease or other contaminants. The primer should be applied on the surface which is compatible with the adhesive.



3.2 Application of Epoxy Resin

The adhesive shall be thicker along the center of the steel plate than at its sides. The use of plastic spacers maintains minimum adhesive thickness of 1- 2 mm.



3.3 Pressure Attachment of Steel Plate

The epoxy resin adhesive is applied to the steel plate which is set at the required position of the girder, and pressed using the anchor bolts wedging off with the temporary stiff wood and steel angle bar.



3.4 Curing and Painting

A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all its components shall be adequately painted for corrosion protection.



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4. Required Materials and Tools/Equipment

4.1 Required Material

- Steel Plate
- Primer (Epoxy Base)
- Epoxy Resin Adhesive
- Epoxy Sealant
- Anchor Bolts
- Wood and Angle for Fitting

4.2 Required Tools/Equipment

- Disc Grinder
- Welder
- Electric Drill
- Epoxy Injection Pump with Accessories
- Wire Brush

5. Specification

5.1 Material Specifications

Epoxy Resin for Injection

The epoxy resin adhesive shall conform to the specifications shown in Table AP 2.1.1 or equivalent ASTM specifications. The material shall be approved by the Engineer through mill certificate of the supplier.

Table AP 2.1.1 Specifications of Epoxy Adhesive for Steel Bonding to Concrete

Property	Test Method	Unit	Specification
Specific Gravity	JIS K 7112/ASTM D792	-	1.16± 0.1
Compressive Strength	JIS K 7208/ASTM D695	N/mm ²	≥70
Flexural Strength	JIS K 7203/ASTM D790M	N/mm ²	≥40
Tensile Strength	JIS K 7113/ASTM D638	N/mm ²	≥40
Tensile Shear Bond Strength	JIS K 6850/ASTM D1002	N/mm ²	≥15
Bond Strength to Concrete Dry / Wet	JIS K5400/ASTM D7234	N/mm ²	≥3.5

5.2 Construction Requirement

(1) Surface Preparation

The concrete surface of an existing member will usually be contaminated and have out-of-plane imperfections and will therefore require preparation before plates are bonded to it. Cracks wider than 0.2 mm which could allow loss of adhesive and areas of concrete that appear porous should be sealed with a compatible resin.

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The surface of the steel to be bonded must be completely free of any mill scale, rust, grease or other contaminants. For successful adhesion of the resin, the contact surfaces of the steel plates should be degreased and blast cleaned at the fabricators premises. The primer, for the epoxy resin adhesive, should be an epoxy based system which is compatible with the adhesive.

(2) Steel Plate Setting

Steel plate shall comply with JIS or Equivalent Standard. The use of high yield steel does not exceed 150 N/mm² which is equivalent to SS400 class for JIS Standard. Minimum plate thickness should not be less than 4mm in order to avoid distortions during grit blasting and handling on site. Anchor bolts required to temporarily support steel plates in the event of setting on the girder. The bolt spacing should be sufficient to prevent deflection of the bonded plate within the defined headroom. Concrete structures to which plates are to be bonded shall be invariably smoothed and surface burnished using a disc grinder

(3) Application of Epoxy Resin

Procedure trials should always be carried out to confirm the quality of the method of application and acquaint the applicators with the materials to be used. Epoxy resin adhesive shall be spread immediately after mixing to dissipate the heat generated and extend its workability time. The adhesive shall be spread thicker along the center of the steel plate than at its sides. The use of plastic spacers maintains the minimum adhesive thickness of 1-2 mm. Excess adhesive can then be scrapped.

(4) Pressure Attachment of Steel Plate

The epoxy resin adhesive is applied to the steel plate which is set at the required position of the girder, and pressed using the anchor bolts wedging off with the temporary stiff wood and steel angle bar, in accordance with the shop drawings approved by the Engineer.

(5) Curing and Painting

To protect the adhesive against moisture ingress, the edges of the plate should be sealed with resin putty or mortar after the adhesive has cured. A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all associated components shall be adequately painted for corrosion protection.

6. Measurement and Payment

6.1 Method of Measurement

Steel plate bonding performed in accordance with the plans and this specification will be measured in square meters. The quantity to be paid for will be the square meters of steel plate bonded on the girder and accepted by the Engineer. No measurement will be made for epoxy injection of cracks, if required.

6.2 Basis of Payment

The quantity, measured as prescribed above, shall be paid for at the contract unit price. Epoxy injection of cracks will not be paid for directly and is considered subsidiary to the works. This unit price shall cover full compensation for all materials, labor, equipment, supervision, and related services necessary for reinforcing of the girder with steel plate as detailed in the plans and specifications.

Bridge Retrofitting Method

No.2-2 Continuous Fiber Sheet/Plate Bonding

1. Description of Retrofitting Method

Carbon fiber sheet for reinforced repair and strengthening systems are combination of carbon fiber sheet/plate material and resins such as epoxies and other adhesive materials, acting as a composite material to enhance the capacity and extend the life of concrete structures as shown in Figure AP 2.2.1. The role of the resin is to serve as adhesive bond to the concrete surface and facilitate the transfer of stresses to and from the carbon fiber sheet.

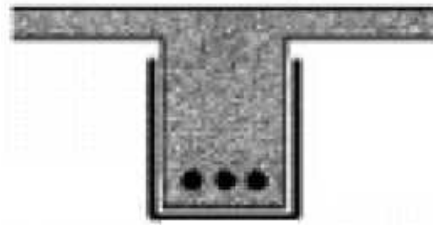


Figure AP 2.2.1 Continuous Fiber Sheet Bonding

2. Application Criteria

The first system for concrete girder shall generally consist of woven carbon fiber sheet (CFS) reinforcing layers bonded to the concrete surface with epoxy. The second system shall generally consist of carbon fiber plate (CFP) bonded to the concrete with epoxy.

As shown in Figure AP 2.2.2, the section of 1/4 in span from both ends is applied with CFS as protection against shear cracks (Figure AP 2.2.3) while the center section of 1/2 in span is applied with CFP for protection against flexural cracks (Figure AP 2.2.4) caused by live load.

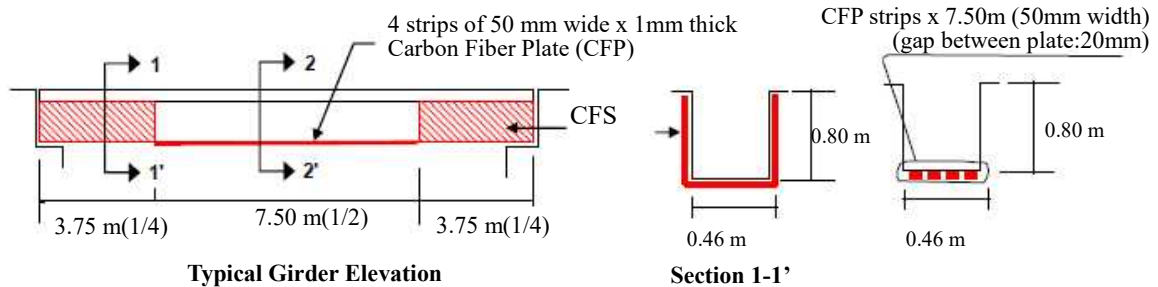
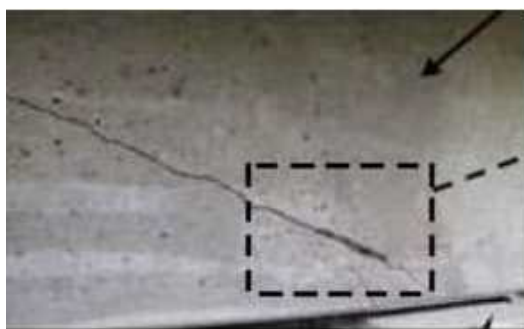


Figure AP 2.2.2 Arrangement of Carbon Fiber Sheet/Plate (for Reference)



Supporting Pier

Figure AP 2.2.3 Shear Cracks at both ends



Figure AP 2.2.4 Flexural Cracks at the Center Portion

Bridge Retrofitting Method

No.2-2 Continuous Fiber Sheet/Plate Bonding

3. Work Sequence

3.1 For CFS

(1) Preparation of Concrete

Disc grinder or abrasive sandblasting is used to clean the concrete and to ensure that the surface roughness is even and smooth. To avoid pollution impact to soil and water, dust, cement, paint and other contaminants were contained by covering the bridge with plastic sheeting.



(2) Application of Primer

Primer resin soaks into the surface of concrete, resulting in increased strength of the concrete surface and improved bonding with CFS.



(3) Adjustment of Unevenness with Putty

Any concave, pores, gaps on the concrete surface must be smoothed using epoxy putty. After the putty becomes tack-free, it is to roughen the surface with sandpaper, then cleaned.



(4) Application of Epoxy Resin for Undercoat

Using roller, epoxy resin is applied to the concrete as adhesive to bond with the CFS. It forms a molded composite by permeating into the CFS.



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(5) Installation of CFS (1st layer)

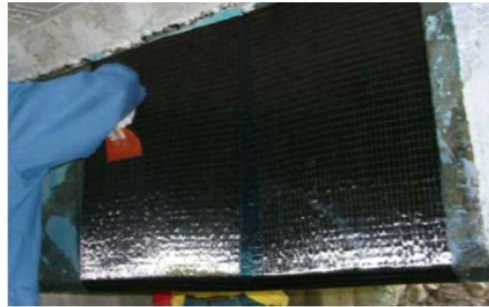
Properly aligned CFS are installed to the resin coated concrete surface to strengthen the section.

Press the CFS using deformed roller, starting from the center toward the edges.



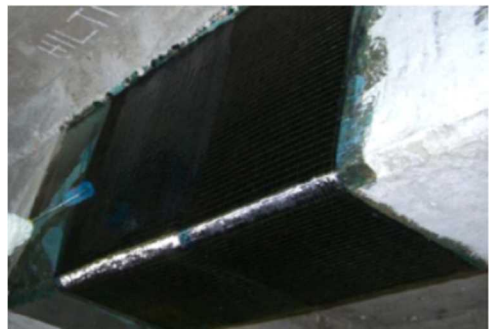
(6) Squeezing Out of Entrapped Air

For complete fusion, entrapped air is squeezed out of the carbon sheets using a roller, before applying the adhesive sets.



(7) Over Coating Resin Application

Epoxy resin is roller-applied to the 1st layer of CFS as adhesive to bond to 2nd layer, and to form a molded composite by permeating into the CFS.



(8) Installation of CFS (2nd layer)

Properly aligned CFS strips (2nd layer) are installed to the resin over coated surface to further strengthen the section.

Press the CFS using deformed roller starting from the center toward the edges.



(9) Surface Protection

For safety purposes, fire proof protection coating may be applied to the finished surface.



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No.2-2 Continuous Fiber Sheet/Plate Bonding

3.2 For CFP

(1) Preparation of Concrete

Disc grinder or abrasive sandblasting is used to clean the concrete and to ensure that concrete surface is even and smooth.



(2) Application of Primer

Primer resin soaks into the surface of concrete, resulting in increased strength of concrete surface and improve the bonding with CFP.



(3) Adjustment of Unevenness with Putty

Any concave, pores, gaps on the concrete surface must be smoothed with epoxy putty. After the putty becomes tack-free, it is required to roughen the surface with sandpaper, then cleaned.



(4) Application of Epoxy Resin for Undercoat

In order to reduce the formation of voids, epoxy based adhesive is applied to the CFP with molder to bond, forming a curved profile measuring approximately 3 mm in the center and 1 mm on the edges.





(5) Installation of CFP (1st Layer)

Properly aligned CFP is installed longitudinally to the adhesive coated concrete surface.

Press the carbon fiber plate manually using deformed roller, starting from the center toward the edges.



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No.2-2	Continuous Fiber Sheet/Plate Bonding
<p>(6) Squeezing Out of Entrapped Air</p> <p>For complete impregnation, entrapped air is squeezed out of the CFP using a roller, before applying the adhesive sets.</p> <p>(7) Over Coating Resin Application</p> <p>Set at position of the girder, then press using wooden anchor frame and set bolts for curing.</p>	 
4. Required Materials and Tools/Equipment	
4.1 Required Material	
<p><u>Carbon Fiber Products</u></p> <ul style="list-style-type: none"> • Continuous fiber sheet • Carbon fiber sheet strip • Continuous fiber plate 	<p><u>Epoxy Materials</u></p> <ul style="list-style-type: none"> • Epoxy primer • Epoxy putty • Epoxy resin
4.2 Required Tools/Equipment	
<ul style="list-style-type: none"> • Abrasive Sandblaster • Air Compressor • Disc Grinder • Portable Generator • Paint Roller/Brush 	
5. Specification	
5.1 Material Specifications	
<p>The CFS shall conform to the specification shown in Table AP 2.2.1.</p> <p>The CFP shall conform to the specifications shown in Table AP 2.2.2 or equivalent ASTM specifications.</p> <p>The epoxy adhesive for bonding CFS shall conform to the specifications shown in Table AP 2.2.3 or equivalent ASTM Specifications.</p> <p>The epoxy adhesive for bonding CFP shall conform to the specifications shown in Table AP 2.2.4 or equivalent ASTM Specifications.</p>	

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No.2-2 Continuous Fiber Sheet/Plate Bonding

Table AP 2.2.1 Specifications of CFS to Concrete Girder

Property	Test Method	Unit	Specification
Carbon fiber sheet weight	JIS K7071	g/m ²	200
Tensile Strength	JIS K 7073/ASTM D3039	N/mm ²	≥ 3400
Overlap Tensile Strength	JIS K 7073/ASTM D3039	N/mm ²	≥ 3400
Tensile Bond Strength to Concrete (Dry/Wet)	JIS K5400/ASTM D7234	N/mm ²	≥ 1.5 CF

The material test shall be applied tensile strength test for CFS to be approved by the Engineer.
CF –Concrete Failure

Table AP 2.2.2 Specifications of CFP to Concrete Girder

Property	Test Method	Unit	Specification
Carbon fiber plate weight	JISR 7603	g/m ²	1200
Tensile Strength	JIS K 7073/ASTM D3039	N/mm ²	≥ 2400
Bond Strength to Concrete	JIS K 5400/ASTM D 7234	N/mm ²	≥ 1.5 CF

The material test shall be applied tensile strength test for CFP to be approved by the Engineer.
CF –Concrete Failure

Table AP 2.2.3 Specifications of Epoxy Adhesive for Bonding CFS

Property	Test Method	Unit	Primer	Epoxy Putty	Penetrating Epoxy Resin
Viscosity	JIS K 6833/ASTM D2393	mPa-s	≤ 1000	Pate-like	15,000±5000
Tensile Strength	JIS K 7113/ASTM D638M	N/mm ²	≥ 15	-	≥ 30
Flexural Strength	JIS K 7203/ASTM D790M	N/mm ²	≥ 20	≥ 15	≥ 40
Compressive Strength	JIS K 7208/ASTM D695M	N/mm ²	≥ 20	≥ 40	≥ 50
Modulus of Elasticity	JIS K 7208/ASTM D695M	N/mm ²	≥ 1500	≥ 1500	≥ 1500
Slant Shear Bond to Concrete	ASTM C882	N/mm ²	≥ 15	≥ 15	≥ 15
Adhesive Strength (Dry/Wet)	JIS K5400/ASTM D7234	N/mm ²	≥ 1.5	≥ 1.5	≥ 1.5

The material shall be approved by the Engineer through mill certificate of the supplier

Bridge Retrofitting Method

No.2-2 Continuous Fiber Sheet/Plate Bonding

Table AP 2.2.4 Specifications of Epoxy Adhesive for Bonding CFP

Property	Test Method	Unit	Specification
Specific Gravity	JIS K7112/ASTM D792	-	1.7±0.20
Flexural Strength	JIS K 7203/ASTM D790M	N/mm ²	≥40
Compressive Strength	JIS K 7208/ASTM D695M	N/mm ²	≥70
Modulus of Elasticity	JIS K 7208/ASTM D695M	N/mm ²	≥4000
Tensile Strength	JIS K 7113/ASTM D638M	N/mm ²	≥25
Tensile Shear Bond	JIS K6850/ ASTM D1002	N/mm ²	≥10
Bond Strength to CFP and Concrete	JIS K5400/ASTM D7234	N/mm ²	≥3.5

The material shall be approved by the Engineer through mill certificate of the supplier

5.2 Construction Requirement

(1) Surface Preparation

All concrete surfaces shall be clean, sound and free from surface moisture. Crack sealing or water proofing shall be provided prior to concrete surface restoration. If water leaks through cracks on concrete surface to be covered with CFS, surface preparation and application of the CFS shall be in accordance with the approved manufacturer's application specifications. Both the Contractor and the manufacturer's technical representative must verify the suitability of any changes to the application methods proposed by the Engineer. Cracks larger than 0.3 mm shall be injected with epoxy using a system/method approved by the Engineer.

(2) Material Handling

The carbon fiber components shall be delivered in original, unopened (except carbon fabric or strips) containers clearly marked with the manufacturer's name, product identification, and batch numbers. Storage and handling of the various products shall be in conformity with the manufacturer's recommendations and instructions.

(3) Prime Coat

Contact surface shall be dry before coating with primer. The primer should be formulated and compatible with the carbon fiber material and not to be applied during rains, storms or when the air is misty or when conditions are unsatisfactory in the opinion of the Engineer.

Application rate shall be such as to ensure complete saturation of the contact surface. Primer should be cured between 2~3 hours before proceeding to the next step.

(4) Putty Application

This work involves application of epoxy putty to the primer coated concrete surface using trowel or spatula, to smoothen the surface. The putty is applied after the primer is tack-free.

- Mix 2 parts of epoxy putty until the mixture is homogenized.
- Apply the putty to smoothen the surface. Allowable unevenness after putty application is 1 mm/m

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No.2-2 Continuous Fiber Sheet/Plate Bonding

(5) Application of Epoxy Resin for Undercoat

1) For CFS

Prior to undercoating epoxy resin adhesive, ambient temperature at the work site shall be checked to confirm the curing conditions before applying the resin. The contractor shall check and confirm that the primer and putty have become tack-free and there is no clay and dust on the concrete surface prior to Engineer's Inspection. If there is a time interval of longer than 3 days after the primer and putty application, the primer and putty coated surface should be roughened with sandpaper, and the surface cleaned before the adhesive application

The contact surface condition shall be tack-free and application shall not be done during rains or storms or when the air is misty, or when in the opinion of the Engineer, conditions are unsatisfactory to carry out the work. The following specified quantity of the resin is only reference. The actual quantity should be determined in consideration with ambient temperature and manufacturer's recommendation in the work site, subject to Engineer's approval.

- The mixing and application of the adhesive (resin and hardener) should be in accordance with the manufacturer's instructions approved by the Engineer.
- Apply the epoxy resin on the surface at the rate of 0.7 kg/sq.m

2) For CFP

The Contractor shall submit for the Engineer's approval, his proposed method of application of epoxy resin undercoat, in accordance with approved manufacturer's specifications for the CFP system. The contact surface condition shall be tack-free and application shall not be done during rain or storms or when the air is misty, or when in the opinion of the Engineer, conditions are unsatisfactorily to carry on with the work. The following specified quantity of the adhesive is only for reference. Actual quantity should be determined in consideration with ambient temperature and manufacturer's recommendation in the work site, subject to Engineer's approval.

- The mixing and application of the adhesive (resin and hardener) should be in accordance with the manufacturer's instructions approved by the Engineer.
- Apply the adhesive on the surface at the rate of 0.2 ~ 0.3 kg/m²

(6) Carbon Fiber Application (First Layer)

1) For CFS

The standard length of carbon sheet will be cut from 4 to 6 m. If standard cut length is exceeded, wrinkles will appear and installation becomes more difficult. The CFS shall be applied in accordance with the following procedures:

- Install the CFS in the longitudinal direction 20 to 30 minutes after the epoxy resin application,
- Press the CFS using a roller (plastic roller is preferred) starting from the center towards the edge to squeeze out entrapped air before the epoxy resin sets.
- When lapping of two CFS is required, a lap length of not less than 20 cm shall be provided.

The specified normal curing time is only for reference purposes. The actual curing period should be determined considering the ambient temperature and manufacturer's recommendation in the work

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No.2-2 Continuous Fiber Sheet/Plate Bonding

site, subject to Engineer's approval.

2) For CFP

CFP shall be cut to 4 to 6 m length and applied considering the following measures.

- CFP may be used at surfaces where some abrasion is required as per manufacturer's recommendations, provided that the plates are manufactured according to the required roughness.
- Apply the adhesive on the surface at the rate of 0.4 ~ 0.5 kg/m²
- The adhesive layer shall be applied to the plates in a curved profile measuring 3 mm in the center and 1 mm on the edges, in order to reduce formation of voids.
- During installation of CFP, uniform pressure using roller should be applied, moving from the longitudinal centerline then outwards. This is intended to expel excess adhesive and produce even edges.

(7) Over Coating Resin Application

1) For CFS

Verification and confirmation of resin mixing and application procedure shall be executed similar to that of the under-coating resin. The standard quantity of over-coating resin of 0.2 - 0.3 kg/m² is for reference purposes only. The actual quantity should be determined considering the ambient temperature and manufacturer's recommendation in the work site, subject to Engineer's approval.

2) For CFP

No over coating is required for CFP since no second layer is usually required.

(8) Carbon Fiber Sheet/Plate Application (Second Layer)

Repeat the steps for the first layer CFS application, except that the sheet will be placed in the opposite (transverse) direction.

(9) Quality Control and Inspection

The Contractor shall conduct a quality control program that includes, but not limited to the following:

- Inspection of all materials to ensure conformity with contract requirements, and that all materials are new and undamaged.
- Inspection of all surface preparation is carried out prior to CFP application.
- Inspection of work in progress to ensure work is being done in accordance with Standard Specifications in Lao PDR and approved manufacturer's instructions.
- Inspection of all work completed including sounding of all repairs to check for any debonding and correction of any defective work.

(10) Testing

After allowing at least 24 hours for the initial resin saturate to cure, the Contractor shall perform a visual and acoustic tap test inspection of the layered surface. All voids, bubbles and delaminations

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shall be repaired in accordance with the manufacturer's recommendations. The Contractor shall conduct adhesion testing of the fully cured CFS and CFP installation using direct pull-off tests, at locations determined by the Engineer. Failure at the bond line at tensile stress below 14 kgf/cm²(200 psi) will be the cause for rejection of the repair. A minimum of two pull-off tests per system (span) shall be performed. The test shall be completed prior to the application of the protective topcoat on the CFS or CFP.

6. Measurement and Payment**6.1 Method of Measurement**

CFS installed in accordance with the plans and specifications will be measured in square meters, while CFP in liner meters. The quantity to be paid for will be the square meters of CFS or liner meters of CFP used and accepted by the Engineer. No measurement will be made for epoxy injection of cracks.

6.2 Basis of Payment

The quantity, measured as prescribed above, shall be paid for at the contract unit price. Epoxy injection of cracks will not be paid for directly and is considered subsidiary to the works. This unit price shall cover full compensation for all materials, labor, equipment, supervision, and related services necessary for reinforcing of the concrete as detailed in the plans and specifications. If an alternative carbon fiber system is used, the price shall also include all engineering, design, and technical services, as well as contractor submittals required as per specifications.

Bridge Retrofitting Method

No.2-3 Carbon Fiber Plate Bonding for Steel Girder

1. Description of Retrofitting Method

Steel girders near sea shore are prone to corrosion which could accelerate, consequently leading to section loss, especially of the bottom flange plates and sections near the bearings.

Repair method using carbon fiber plate (CFP) bonding to steel plate provides the same function as the additional steel plates presented in previous section.

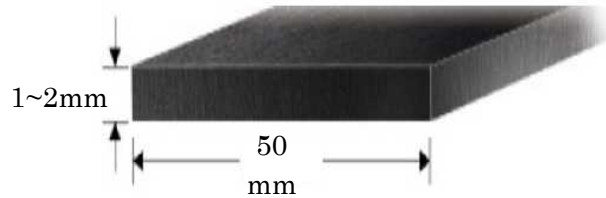


Figure AP 2.3.1 Continuous Fiber Plate Size

Repair method for adding steel plates involve complicated steps such as fabrication of the steel plates in the factory, cut and drill holes for HTB to existing bridge plate in the field and assembling of the additional steel plate. On the other hand, CFP method involves simple application of bonding to steel bridge surface using epoxy resin adhesive. In case of section loss or defective holes, the purpose of bottom flange repair shall be to restore the original strength of the section by installing required area of CFP as shown in the example in Figure AP 2.3.1 and Figure AP 2.3.2.

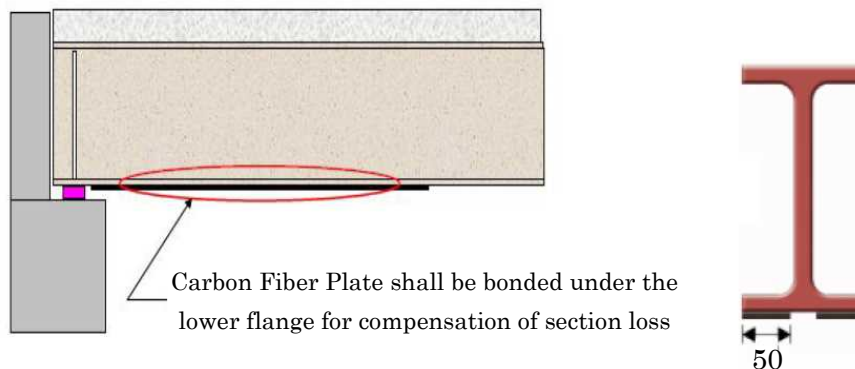


Figure AP 2.3.2 CFP Added at Bottom Flange

2. Application Criteria

In order to restore the lost strength, CFP shall be installed at the portion of existing steel where section loss is more than 20%. This repair method shall be further supplemented by repainting or by application of anti-corrosion coating.

3. Work Sequence

3.1 Scaffoldings

Scaffolding for safe and efficient repainting works shall be provided. Chain or wire ropes shall be attached to bottom flanges or stiffeners to tie the supporting timber or steel pipes, which serve as framing for the wooden planks.

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No.2-3 Carbon Fiber Plate Bonding for Steel Girder

3.2 Surface Preparation of Steel Plate

All surfaces to be provided with carbon fiber plates shall be thoroughly cleaned of all rust, dirt, oil or grease, and other foreign substances. Moreover, surfaces to be painted shall be lightly grinded to increase adhesion of the new paint required. The grade of surface preparation shall conform to Appendix.1 No.1-11 Steel Plate Bonding for repainting system or shall be as recommended by the manufacturer.



3.3 Adjustment of Unevenness with Putty

Surfaces of corroded steel plate may have holes and dents. Reduction of original thickness of the steel plate could as well vary. After surface preparation, epoxy putty is applied to level the surface of the existing steel plate and recover its original thickness and shape. Epoxy putty coating shall be applied after steel surface preparation. The surface where the CFP will be placed shall be smoothed using #60 - #100 sandpaper.



3.4 Application of Epoxy Resin for Undercoat

Using a roller, epoxy resin shall be applied as adhesive to bond to CFP, thus forming a molded composite through impregnation into the CFP.



3.5 Carbon Plate Bonding

An epoxy-based adhesive is applied to the CFP with molder to bond. To reduce formation of voids, the adhesive is spread forming a curved profile that measures 3 mm at the center and 1 mm at the edges. CFP should be installed by applying manual uniform pressure along the longitudinal centerline.



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No.2-3 Carbon Fiber Plate Bonding for Steel Girder

3.6 Squeezing Out of Entrapped Air

For effective impregnation, entrapped air is squeezed out of the strips using roller, before the adhesive sets.



4. Required Materials and Tools/Equipment

4.1 Required Material

- Epoxy putty
- Carbon Fiber Plate

4.2 Required Tools/Equipment

- Electric disc grinder
- Generator
- Wire brush, scraper, etc.

5. Specification

5.1 Material Specifications

CFP is made from pre-laminated carbon fiber. Each roll unit roll of CFP has width: 50 mm; thickness: 1 mm, 1.5 mm, and 2 mm; and length: 50 m. The specification shall be in accordance with the following or equivalent ASTM specifications in Table AP 2.3.1. High-Elasticity (ML) type shall be applied to steel bridges where section loss need to be compensated. The material shall undergo tensile strength test for CFP to be approved by the Engineer.

Table AP 2.3.1 Strength of Carbon Fiber Plate

Property	Test Method	Unit	Specification
Carbon fiber plate weight		g/m ²	1200
Carbon fiber plate density		g/cm ³	1.6
CFP Tensile Strength	JIS K 7073/ASTM D3039	N/mm ²	2400
Tensile Bond to Concrete			
Dry	JHS-411/ JIS K6852/	N/mm ²	≥2.0
Wet	ASTM C882		≥2.0

The epoxy adhesive for bonding CFS shall conform to the specifications shown in Table AP 2.3.2 or equivalent ASTM Specifications. The material shall be approved by the Engineer through mill certificate of the supplier.

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No.2-3 Carbon Fiber Plate Bonding for Steel Girder

Table AP 2.3.2 Epoxy Adhesive (Putty) for CFP Bonding with Steel

Property	Test Method	Unit	Specification
Specific Gravity	JIS K 7112/ASTM D792	-	1.7± 0.1
Compressive Strength	JIS K 7208/ASTM D695	N/mm ²	70
Flexural Strength	JIS K 7203/ASTM D790M	N/mm ²	45
Modulus of Elasticity	JIS K 7113/ASTM D638	N/mm ²	4000
Tensile Strength	JIS K 7113/ASTM D638	N/mm ²	25
Tensile Shear Bond Strength	JIS K 6850/ASTM D1002	N/mm ²	15
Bond Strength to CFP & Steel	JIS K5400/ASTM D7234	N/mm ²	3.5

CFP and Epoxy adhesive (putty) should be selected in accordance with manufacturer's instructions.

5.2 Construction Requirement

(1) Surface Preparation

All surfaces to be provided with CFP shall be thoroughly cleaned of all rust, dirt, oil or grease, and other foreign substances and smoothed using disc grinder, hammer, scraper or brush. If the surface is not flat enough for the installation of CFP, epoxy putty shall be applied to achieve required even finish. Material Handling

The carbon fiber components shall be delivered in original, unopened (except carbon fabric or strips) containers clearly marked with the manufacturer's name, product identification, and batch numbers. Storage and handling of the various products shall be in conformity with the manufacturer's recommendations and instructions.

(2) Material Handling

The carbon fiber components shall be delivered in original, unopened (except carbon fabric or strips) containers clearly marked with the manufacturer's name, product identification, and batch numbers. Storage and handling of the various products shall be in conformance with Manufacturer's recommendations and instructions

(3) Prime Coat

Contact surface shall be dry prior to application of coating primer. The primer should be formulated and compatible with the carbon fiber material and should not be applied during rain, storms or when the air is misty or when in the opinion of the Engineer, weather condition remains unsatisfactory.

Application rate shall be such as to ensure complete saturation of the contact surface. Primer should be cured between 2 to 3 hours before proceeding to the next step.

Bridge Retrofitting Method

No.2-3 Carbon Fiber Plate Bonding for Steel Girder

(4) Putty Application

This work involves application of epoxy putty to the primer coated concrete surface using trowel or spatula, to smoothen the surface. The putty is applied after the primer is tack-free.

- Mix 2 parts of epoxy putty until the mixture is homogenized.
- Apply the putty to smoothen the surface. Allowable unevenness after putty application is 1 mm/m

(5) Application of Epoxy Resin for Undercoat

The Contractor shall submit for the Engineer's approval, his proposed method of application of epoxy resin undercoat, in accordance with approved manufacturer's specifications for the CFP system. The contact surface condition shall be tack-free and application shall not be done during rain or storms or when the air is misty, or when in the opinion of the Engineer, conditions are unsatisfactorily to carry on with the work. The following specified quantity of the adhesive is only for reference. Actual quantity should be determined in consideration with ambient temperature and manufacturer's recommendation in the work site, subject to Engineer's approval.

- The mixing and application of the adhesive (resin and hardener) should be in accordance with the manufacturer's instructions approved by the Engineer.
- Apply the adhesive on the surface at the rate of 0.2 ~ 0.3 kg/m²

(6) Carbon Fiber Plate Application

CFP shall be cut to 4 to 6 m length and applied considering the following measures.

- CFP may be used at surfaces where some abrasion is required as per manufacturer's recommendations, provided that the plates are manufactured according to the required roughness.
- Apply the adhesive on the surface at the rate of 0.4 ~ 0.5 kg/m²
- The adhesive layer shall be applied to the plates in a curved profile measuring 3 mm in the center and 1 mm on the edges, in order to reduce formation of voids.
- During installation of CFP uniform pressure using roller should be applied, moving from the longitudinal centerline then outwards. This is intended to expel excess adhesive and produce even edges.

(7) Quality Control and Inspection

The Contractor shall conduct a quality control program that includes, but not limited to the following:

- Inspection of all materials to ensure conformity with contract requirements, and that all materials are new and undamaged.
- Inspection of surface preparation carried out prior to CFP application.
- Inspection of work in progress to ensure work is being done in accordance with Standard

Bridge Retrofitting Method	
No.2-3	Carbon Fiber Plate Bonding for Steel Girder
<p>Specifications in Lao PDR and approved manufacturer's instructions.</p> <ul style="list-style-type: none"> • Inspection of all work completed including verification of all repairs to check for debonding and correction of any defective work. • After allowing at least 24 hours for the initial resin saturate to cure, the Contractor shall perform a visual and acoustic tap test inspection of the layered surface. All voids, bubbles and delaminations shall be repaired in accordance with the manufacturer's recommendations. The Contractor shall conduct adhesion testing of the fully cured CFS and CFP installation using direct pull-off tests, at locations determined by the Engineer. Failure at the bond line at tensile stress below 14 kgf/cm² (200 psi) will be cause for rejection of the repair. A minimum of two pull-off tests per system (span) shall be performed. 	
6. Measurement and Payment	
6.1 Method of Measurement	
<p>The method of measurement for this repair method shall be by linear meter of CFP, checked and approved by the Engineer.</p>	
6.2 Basis of Payment	
<p>CFP bonding work shall be paid for at a unit price per linear meter. The unit price shall include all materials, containers, equipment, tools, labor, service advisor and required incidentals for the work. Any indirect cost item shall not be paid separately. Such cost shall be deemed included in the unit price.</p>	

Bridge Retrofitting Method

No.2-4 Steel Plate Bonding for RC Deck Slab

1. Description of Retrofitting Method

The technique of bonding steel plates to concrete deck slab using epoxy adhesives has been used on a number of bridges to enhance their load carrying capacity. The viability of this technique for a particular structure should be considered carefully due to its sensitivity to standards of workmanship and need for regular in-service inspection. Economical evaluation should be carried out in order to compare this technique with other methods of strengthening. The effect of bonding a plate to the tension face of a reinforced concrete section is to increase the depth from the compression face to the neutral axis and the area of effective reinforcement, thus, increasing the moment of resistance of the section.

The steel plate bonding has two types, namely, wide plate and narrow plate as shown in Figure AP 2.4.1. Wide plates are used for strengthening the slab in both the main reinforcing bar and distribution bar directions. Narrow plates are used for strengthening the slab in one direction only.

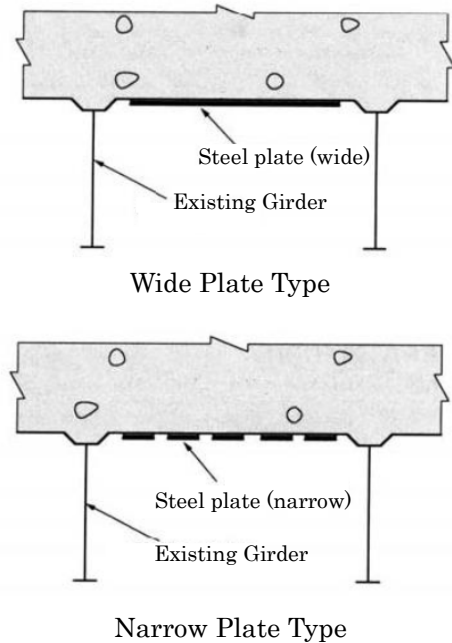


Figure AP 2.4.1 Types of Steel Plate Bonding

2. Application Criteria

Type of steel plate bonding (wide and narrow steel plates) to be applied shall be according to the direction of the damaged rebar of the deck slab, as discussed above. The bonding of steel plates to concrete members has been undertaken considering two methods as follows:

- Injection Method

This method involves single plates of required thickness, with gaps sealed at the edges between the steel and the concrete. Resin is then pumped ensuring that no voids occur between the plate and the concrete as shown in Figure AP 2.4.2.

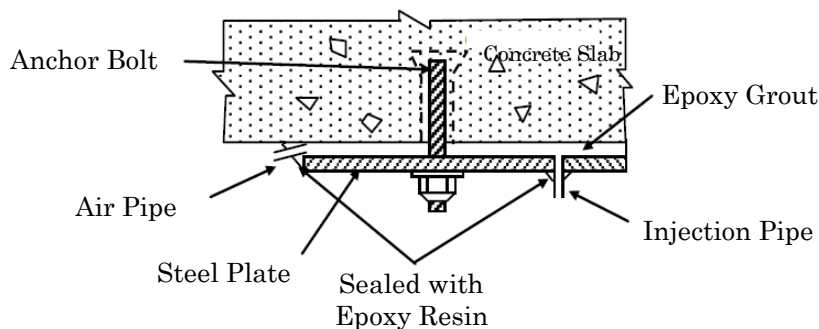


Figure AP 2.4.2 Detail of Injection Method with Epoxy Adhesive

Bridge Retrofitting Method

No.2-4 Steel Plate Bonding for RC Deck Slab

- Pressure Attaching Method

Similar to injection method, this requires single plates of required thickness with gaps sealed at the edges between the steel and the concrete. However, epoxy resin in this method is injected to ensure that no voids occur between the plate and the concrete.

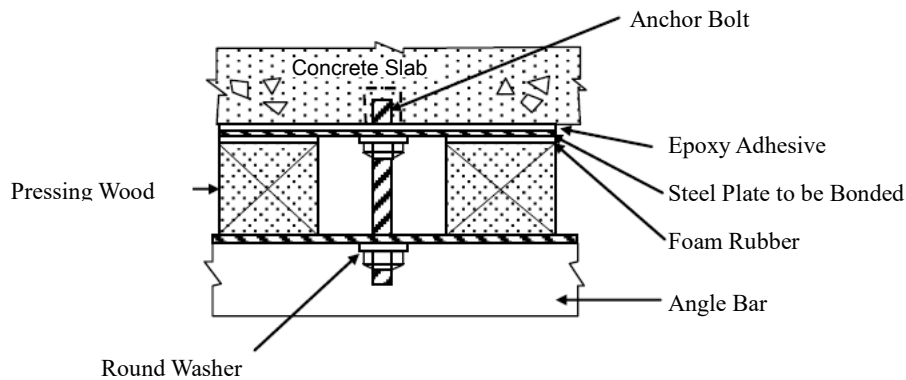


Figure AP2.4.3 Detail of Pressure Attaching Method by Anchor Bolts

Injection method should be applied for wide plate type while pressure attaching method for narrow plate type, with due consideration to the extent of surface preparation of both concrete and steel plate.

3. Work Sequence

3.1 Injection Method

(1) Surface Preparation

Bottom surface of slab to be bonded with steel plate shall be cleaned. Any surface irregularities shall be leveled using a disc grinder.

The surface of the steel to be bonded must be completely free of any mill scale, rust, grease or other contaminants. The primer should be applied on the surface which is compatible with the adhesive.



(2) Setting of Steel Plate on the Slab

Injection pipes are attached to the steel plate. Anchor bolts shall be provided to temporarily support steel plates (placed below the slab surface with an average gap of 5 mm) in the event of that the deck slab settles. Joints between steel plates are welded at site.



Bridge Retrofitting Method

No.2-4 Steel Plate Bonding for RC Deck Slab

(3) Sealing of Steel Plate

The periphery of the steel plate is sealed with epoxy putty as well as the area surrounding the injection holes.



(4) Injection of Epoxy Resin

Mixing is continuously done during the injection. Inject the epoxy grout through injection pipes to fill the gap between the plate and the concrete.



(5) Curing and Painting

A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all its components shall be adequately painted for corrosion protection.



3.2 Pressure Attaching Method

(1) Surface Preparation

Bottom surface of slab bonded with steel plate shall be cleaned. Any surface irregularities shall be leveled using a disc grinder.

The surface of the steel to be bonded must be completely free of any mill scale, rust, grease or other contaminants. The primer should be applied on the surface which is compatible with the adhesive.



(2) Application of Epoxy Resin

The adhesive shall be thicker along the center of the steel plate than at the sides. The use of plastic spacers maintains minimum adhesive thickness of 1- 2 mm



Bridge Retrofitting Method

No.2-4 Steel Plate Bonding for RC Deck Slab

(3) Pressure Attachment of Steel Plate

The epoxy resin adhesive is applied to the steel plate which is set at the required position of the deck slab, and pressed using the anchor bolts wedging off with the temporary stiff wood and angular.



(4) Curing and Painting

A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all its components shall be adequately painted for corrosion protection.



4. Required Materials and Tools/Equipment

4.1 Required Material

Injection Method

- Steel Plate
- Primer (Epoxy Base)
- Epoxy Resin Adhesive for Injection
- Epoxy Sealant
- Anchor Bolts

Pressure Attaching Method

- Steel Plate
- Primer (Epoxy Base)
- Epoxy Resin Adhesive
- Epoxy Sealant
- Anchor Bolts
- Wood and Angle for Fitting

4.2 Required Tools/Equipment

Injection Method

- Disc Grinder
- Welder
- Electric Drill
- Epoxy Injection Pump with Accessories
- Wire Brush

Pressure Attaching Method

- Disc Grinder

Bridge Retrofitting Method

No.2-4 Steel Plate Bonding for RC Deck Slab

- Welder
- Electric Drill
- Epoxy Injection Pump with Accessories
- Wire Brush

5. Specification

5.1 Material Specifications

The epoxy resin adhesive shall conform to the requirements of the specifications shown in Table AP 2.4.1 to Table AP 2.4.3, or equivalent ASTM Specifications. The material shall be approved by the Engineer through mill certificate of the supplier.

Table AP 2.4.1 Epoxy Grout for Steel Bonding to Concrete

Property	Test Method	Unit	Specification
Specific Gravity	JIS K 7112/ASTM D792	-	1.15± 0.1
Viscosity	JIS K 6833/ASTM D2393	mPa-s	≤ 1000
Compressive Strength	JIS K 7208/ASTM D695	N/mm ²	≥ 50
Flexural Strength	JIS K 7203/ASTM D790M	N/mm ²	≥ 40
Modulus of Elasticity	JIS K 7208/ASTM D695	N/mm ²	≥ 1000
Bond Strength to Concrete (Dry/Wet)	JIS K 5400/ASTM D 7234	N/mm ²	≥ 1.5 CF
Tensile Shear Bond to Steel	JIS K 6850/ASTM D1002	N/mm ²	≥ 15

The material shall be approved by the Engineer through mill certificate of the supplier. CF – Concrete Failure.

Table AP 2.4.2 Specification of Epoxy Sealant for Steel Bonding to Concrete

Property	Test Method	Unit	Specification
Specific Gravity	JIS K 7112/ASTM D792	-	1.50± 0.3
Flexural Strength	JIS K 7203/ASTM D790M	N/mm ²	≥ 15
Compressive Yield Strength	JIS K 7208/ASTM D695M	N/mm ²	≥ 50
Tensile Shear Bond to Steel	JIS K 6850/ASTM D1002	N/mm ²	≥ 10
Slant Shear Bond to Concrete	JIS K 6852/ASTM C882	N/mm ²	≥ 15

The material shall be approved by the Engineer through mill certificate of the supplier.

Table AP 2.4.3 Specification of Epoxy Resin Adhesive for Steel Bonding to Concrete

Property	Test Method	Unit	Specification
Specific Gravity	JIS K 7112/ASTM D792	-	1.16± 0.1
Flexural Strength	JIS K 7203/ASTM D790M	N/mm ²	≥ 40
Compressive Strength	JIS K 7208/ASTM D695M	N/mm ²	≥ 70
Tensile Strength	JIS K 7113/ASTM D638	N/mm ²	≥ 40
Tensile Shear Bond to Steel	JIS K 6850/ASTM D1002	N/mm ²	≥ 15
Bond Strength to Concrete (Dry/Wet)	JIS K 5400/ASTM D7234	N/mm ²	≥ 3.5

The material shall be approved by the Engineer through mill certificate of the supplier.

Bridge Retrofitting Method

No.2-4 Steel Plate Bonding for RC Deck Slab

5.2 Construction Requirement

5.2.1. Injection Method

(1) Surface Preparation

The concrete surface of an existing member will usually be contaminated and have out-of-plane imperfections and will therefore require preparation before plates are bonded to it. Cracks wider than 0.2 mm which could reduce adhesion and areas of concrete that appear porous should be sealed with a compatible resin.

The surface of the steel to be bonded must be completely free of any mill scale, rust, grease or other contaminants. For successful adhesion of the resin, the contact surfaces of the steel plates should be degreased and blast cleaned at the fabricator's premises. The primer, for the epoxy resin adhesive, should be an epoxy based system compatible with the adhesive.

(2) Steel Plate Setting

Steel Plate shall comply with JIS or ASTM A36. Yield strength should not less than 240 N/mm² which is equivalent to JIS SS400 or ASTM A36. Minimum plate thickness should not be less than 4 mm in order to avoid distortions during grit blasting and handling on site. Anchor bolts are required to temporarily support steel plates in the event of setting on the deck slab with an average gap of 5mm between the slab surface and steel plate. The bolt spacing should be sufficient to prevent deflection of the bonded plate within the defined space. Concrete structures to which plates are to be bonded shall be invariably smoothed and surface burnished using a disc grinder.

(3) Injection of Epoxy Grout

Procedure trials should always be carried out to confirm the quality of the method of application and acquaint the applicators with the materials to be used. Where epoxy grout is to be injected, mix continuously during injection. The epoxy grout shall be injected through injection pipes, gradually withdrawn as filling takes place. The manufacturer's instructions on safe use of resins should be followed.

(4) Curing and Painting

To protect the adhesive against moisture ingress, the edges of the plate should be sealed with resin putty or mortar after the adhesive has cured. A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all associated components should be adequately painted for corrosion protection.

Bridge Retrofitting Method

No.2-4 Steel Plate Bonding for RC Deck Slab

5.2.2. Pressure Attaching Method

(1) Surface Preparation

The concrete surface of an existing member will usually be contaminated and have out-of-plane imperfections and will therefore require preparation before plates are bonded to it. Cracks wider than 0.2 mm which could allow loss of adhesive and areas of concrete that appear porous should be sealed with a compatible resin.

The surface of the steel to be bonded must be completely free of any mill scale, rust, grease or other contaminants. For successful adhesion of the resin, the contact surfaces of the steel plates should be degreased and blast cleaned at the fabricators premises. The primer, for the epoxy resin adhesive, should be an epoxy based system which is compatible with the adhesive. After allowing at least 24 hours for the initial resin saturate to cure, the Contractor shall perform a visual and acoustic tap test inspection of the layered surface. All voids, bubbles and delaminations shall be repaired in accordance with the manufacturer's recommendations. The Contractor shall conduct adhesion testing of the fully cured CFS and CFP installation using direct pull-off tests, at locations determined by the Engineer. Failure at the bond line at tensile stress below 14 kgf/cm² (200 psi) will be cause for rejection of the repair. A minimum of two pull-off tests per system (span) shall be performed.

(2) Steel Plate Setting

Steel plate shall comply with JIS or Equivalent Standard. The use of high yield steel does not exceed 150 N/mm² which is equivalent to SS400 class for JIS Standard. Minimum plate thickness should not be less than 4mm in order to avoid distortions during grit blasting and handling on site. Anchor bolts are required to temporarily support steel plates in the event of setting on the deck slab. The bolt spacing should be sufficient to prevent deflection of the bonded plate within the defined space. Concrete structures to which plates are to be bonded shall be invariably smoothed and surface burnished using a disc grinder.

(3) Application of Epoxy Resin

Trials should always be carried out to confirm the quality of the method of application and acquaint the applicators with the materials to be used. Epoxy resin adhesive shall be spread immediately after mixing to dissipate the heat generated and extend its workability time. The adhesive spread shall be thicker along the center of the steel plate than at its sides. The use of plastic spacers maintains the minimum adhesive thickness of 1-2 mm. Excess adhesive can then be scrapped.

(4) Pressure Attachment of Steel Plate

The epoxy resin adhesive is applied to the steel plate which is set at the required position of the deck slab, and pressed using the anchor bolts wedging off with the temporary stiff wood and angle bar, in accordance with the shop drawings approved by the Engineer.

(5) Curing and Painting

To protect the adhesive against moisture ingress, the edges of the plate should be sealed with resin putty or mortar after the adhesive has cured. A suitable chamfer/fillet could also be formed in the adhesive around the edge of the plates and the concrete surfaces. Steel plates and all associated components shall be adequately painted for corrosion protection.

Bridge Retrofitting Method	
No.2-4	Steel Plate Bonding for RC Deck Slab
6. Measurement and Payment	
6.1 Method of Measurement	
<p>Steel plate bonding performed in accordance with the plans and this specification will be measured in square meters. The quantity to be paid for includes the steel plate bonded on the deck slab in square meter, accepted by the Engineer. No measurement will be made for epoxy injection of cracks, if required.</p>	
6.2 Basis of Payment	
<p>The quantity measured as prescribed above, shall be paid for at the contract unit price. Epoxy injection of cracks will not be paid for directly and is considered subsidiary to the works. This unit price shall cover full compensation for all materials, labor, equipment, supervision, and related services necessary for reinforcing the deck slab by steel plate, as detailed in the plans and specifications.</p>	

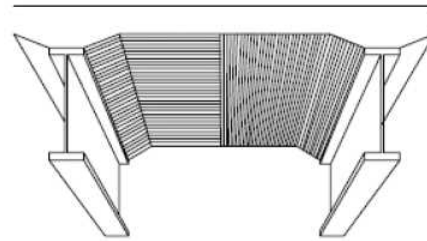
Bridge Retrofitting Method

No.2-5 Continuous Fiber Sheet Bonding to RC Deck Slab

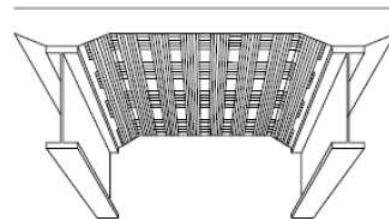
1. Description of Retrofitting Method

Carbon fiber sheet for reinforced concrete repairs and strengthening systems consists of a combination of carbon fiber reinforcing material and adhesive resin such as epoxies and other materials. This composite product is intended to enhance the capacity of the concrete deck slab and extend its service life. The function of the resin is to serve as an adhesive bond onto the concrete surface and facilitate the transfer of stresses to and from the carbon fiber sheet.

The works shall consist of furnishing and installing two types of Carbon Fiber Sheets as shown in Figure AP 2.5.1 for concrete strengthening systems in accordance with the plans and specifications. The systems shall be designed to strengthen and stiffen concrete bridge deck slab and tested by the Engineer to verify performance.



Continuous Arrangement



Grid Arrangement

Figure AP 2.5.1 Arrangements of Carbon Fiber Sheet

2. Application Criteria

The related strengthening system for the concrete deck slab shall generally consists of woven carbon fiber sheet (CFS) reinforcing layers, bonded to the concrete surface with epoxy adhesive.

The continuous arrangement is commonly used during the early stage of CFS bonding application at the bottom of the deck slab. However, in most of the cases observed, entrapped air which could not be easily released, were found in the installed CFS. These air voids reduce bond strength between CFS and concrete surface and must be squeezed out by roller. Meanwhile, in the grid arrangement, CFS does not totally cover the required surface. Instead, the CFS is installed in strap-type method in both directions. According to experimental results, effectiveness of the second system is almost same as the continuous arrangement. Moreover, entrapped air in the second system can be squeezed out easily using a roller. Thus, in this manual, the grid arrangement is recommended considering its ease of application, least cost and acceptable effectiveness. The carbon fiber sheet should be applied as two layers in both the longitudinal and transversal directions, as shown in Figure AP 2.5.2.

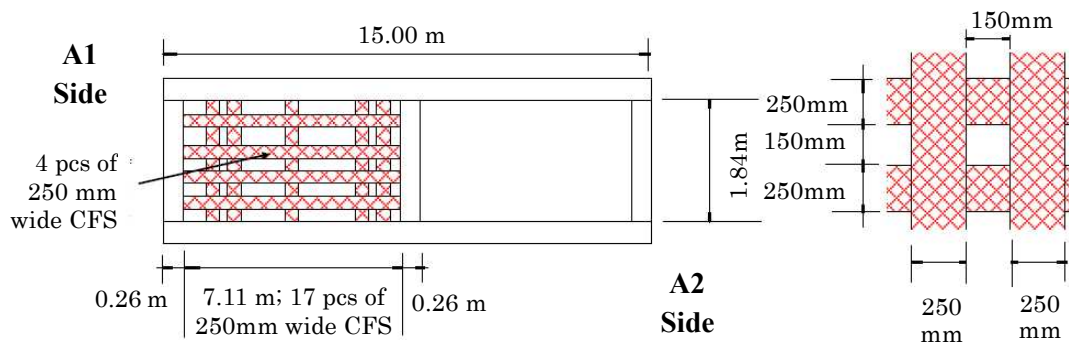


Figure AP 2.5.2 Arrangement of CFS (for Reference)

Bridge Retrofitting Method

No.2-5 Continuous Fiber Sheet Bonding to RC Deck Slab

3. Work Sequence

3.1 Preparation of Concrete

Disc grinder or abrasive sandblasting is used to clean and smoothen the concrete surface.



3.2 Application of Primer

The surface is coated with a primer resin to increase the strength of concrete surface and improve its bonding with CFS.



3.3 Adjustment of Unevenness with Putty

Any concave, pores, gaps on the concrete surface must be smoothed using epoxy putty.



3.4 Application of Epoxy Resin for Undercoat

When the epoxy putty becomes tack-free, epoxy resin is applied to the concrete, acting as adhesive to bond the CFS. The molded composite is achieved as the resin permeates into the CFS.



3.5 Installation of Longitudinal Layer CFS

Properly aligned CFS strips are installed in longitudinal direction to the adhesive coated concrete surface.

Press the carbon fiber sheet by using plastic roller starting from the center toward the edge.



Bridge Retrofitting Method

No.2-5 Continuous Fiber Sheet Bonding to RC Deck Slab

3.6 Installation of Transversal Layer CFS

Properly aligned CFS strips are installed in transversal direction to the adhesive coated concrete surface.

Press the carbon fiber sheet by using plastic roller starting from the center toward the edge.



3.7 Squeezing out Entrapped Air

For complete impregnation, entrapped air is squeezed out of the strips using roller, before the adhesive sets. Do not apply the roller against the direction of the placed CFS to avoid damaging the material



3.8 Surface Protection

For safety purposes, fire proof protection coating may be applied to the finished surface.



4. Required Materials and Tools/Equipment

4.1 Required Material

Carbon Fiber Products

- CFS (Strap Type)

Epoxy Materials

- Epoxy primer
- Epoxy putty
- Epoxy Resin Adhesive

4.2 Required Tools/Equipment

- Abrasive Sandblaster
- Air Compressor
- Disc Grinder
- Portable Generator
- Paint Roller/Brush

Bridge Retrofitting Method

No.2-5 Continuous Fiber Sheet Bonding to RC Deck Slab

5. Specification

5.1 Material Specifications

The CFS shall conform to the requirements of the specifications shown in Table AP 2.5.1, or equivalent ASTM Specifications. The material shall be approved by the Engineer through mill certificate of the supplier.

Table AP 2.5.1 Specifications of CFS to Deck Slab

Property	Test Method	Unit	Specification
Carbon fiber weight	JIS K 7071	g/m ²	200
Tensile Strength	JIS K 7073/ASTM D3039	N/mm ²	≥ 3400
Overlap Tensile Strength	JIS K 7073/ASTM D3039	N/mm ²	≥ 3400
Bond Strength to Concrete (Dry/Wet)	JIS K 5400/ASTM D 7234	N/mm ²	≥ 1.5 CF

The material shall be approved by the Engineer through mill certificate of the supplier.
CF –Concrete Failure

The epoxy adhesive shall conform to the specifications shown in Table AP 2.5.2. The material shall be approved by the Engineer through mill certificate of the supplier.

Table AP 2.5.2 Specifications of Epoxy Resin Adhesive for CFS

Property	Test Method	Unit	Primer	Epoxy Putty	Penetrating Epoxy Resin
Viscosity	JIS K 6833/ ASTM D2393	mPa-s	≤ 1000	Paste-like	15,000±5000
Modulus of Elasticity	JIS K 7208/ASTM D695M	N/mm ²	≥1500	≥1500	≥1500
Slant Shear Bond to Concrete	ASTM C882	N/mm ²	≥15	≥15	≥15
Bond Strength to Concrete (Dry/Wet)	JIS K5400/ASTM D7234	N/mm ²	≥1.54	≥1.54	≥1.54

The material shall be approved by the Engineer through mill certificate of the supplier.

5.2 Construction Requirement

(1) Surface Preparation

All concrete surfaces shall be clean, sound and free from surface moisture. Crack sealing or water proofing shall be provided prior to concrete surface restoration. If water leaks through cracks on concrete surface to be covered with CFS, surface preparation and application of the CFS shall be in accordance with the approved manufacturer's specifications. Both the Contractor and the manufacturer's technical representative must verify suitability of any changes to the application methods proposed by the Engineer. Cracks larger than 0.3 mm shall be injected with epoxy using a system/method approved by the Engineer

(2) Material Handling

The carbon fiber components shall be delivered in an original, unopened (except carbon fabric or strips) containers clearly marked with the manufacturer's name, product identification, and batch

Bridge Retrofitting Method

No.2-5 Continuous Fiber Sheet Bonding to RC Deck Slab

numbers. Storage and handling of the various related products shall be in conformance with manufacturer's recommendations and instructions.

(3) Prime Coat

Contact surface shall be dry before coating with primer. The primer should be formulated and compatible to the carbon fiber material and should not be applied when raining, storming or air is misty or when condition remains unsatisfactory in the opinion of the Engineer.

Application rate shall be such as to ensure complete saturation of the contact surface. Primer should be cured between 2~3 hours before proceeding to the next step.

(4) Putty Application

This work involves application of epoxy putty onto the primer coated concrete surface, using trowel or spatula, to smoothen the surface. The putty is applied when the primer is already tack-free. The application method is as follows:

- Mix 2 parts of epoxy putty until the mixture is homogenized.
- Apply the putty to smoothen the surface. Allowable unevenness after putty application is 1 mm/m

(5) Application of Epoxy Resin for Undercoat

Prior to undercoating epoxy resin adhesive, ambient temperature at the work site shall be checked to confirm the curing conditions for applying the resin. The Contractor shall check and confirm that the primer and putty have become tack-free and that no clay and dust exist on the concrete surface prior to Engineer's inspection. If there is a time interval of longer than 3 days after the primer and putty application, the coated surface should be roughened with sandpaper and cleaned before the resin application

The contact surface condition shall be tack-free and application shall not be done when raining, storming, air is misty, or when in the opinion of the Engineer, conditions are unsatisfactory to carry on with the work. The following specified quantity of the resin is estimated for reference only. The actual quantity should be determined in consideration with ambient temperature and manufacturer's recommendations, subject to Engineer's approval.

- Mix the 2 parts of epoxy resin until homogenized,
- Apply the epoxy resin on the surface at a rate of 0.5 kg/m².

(6) CFS Application (Longitudinal Direction)

The standard length of carbon sheet will be cut to 4 to 6 m. If standard cut length is exceeded, wrinkles will appear and installation becomes more difficult. The CFS shall be applied as per the following:

- Stick the CFS in the longitudinal direction with a reasonable lapse of 20~30 minutes after the epoxy resin application,
- Press the CFS using a roller (plastic roller is preferred) starting from the center towards the edge to squeeze out entrapped air before the epoxy resin sets.

Bridge Retrofitting Method

No.2-5 Continuous Fiber Sheet Bonding to RC Deck Slab

- When lapping of two CFS is required, a lap length of not less than 20 cm shall be provided.

The specified normal curing time is only for reference purposes. The actual curing period should be determined in consideration of the ambient temperature and manufacturer's recommendation in the work site, subject to Engineer's approval.

(7) Over Coating Resin Application

Mixing and application procedure for the over coat shall be similar to that of the under-coating resin. The standard quantity of over-coating resin is 0.2 kg/m². The actual quantity should be determined in consideration with ambient temperature and manufacturer's recommendation in the work site, subject to Engineer's approval.

(8) CFS Application (Transversal Direction)

After all longitudinal layer CFS application, the transversal layer CFS is applied at right angles to each other in same manner as the longitudinal direction.

(9) Quality Control and Inspection

The Contractor shall conduct a quality control program that includes, but not limited to, the following:

- Inspection of all materials to ensure conformity with contract requirements, and that all materials are new and undamaged.
- Inspection of all surface preparation carried out prior to CFS application.
- Inspection of work in progress to ensure work is being done in accordance with Standard Specifications of Lao PDR, and approved manufacturer's instructions.
- Inspection of all work completed including verification of all repairs for debonding, and correction of any defective work.
- After allowing at least 24 hours for initial resin saturate to cure, the Contractor shall perform a visual and acoustic tap test inspection of the layered surface. All voids, bubbles and delaminations shall be repaired in accordance with manufacturer's recommendations. The Contractor shall conduct adhesion testing of the fully cured CFS and assembly using direct pull-off tests, at locations determined by the Engineer. Failure at the bond line at tensile stress below 14kgf/cm² (200 psi) shall be cause for rejecting the repair works. A minimum of two pull-off tests per system (span) shall be performed. The test shall be completed prior to the application of the protective top coat on the CFS.

6. Measurement and Payment

6.1 Method of Measurement

CFS performed in accordance with the plans and specifications will be measured in square meters, while the carbon fiber plate in linear meters. The quantity to be considered for payment will include the CFS and carbon fiber plate used and accepted by the Engineer. No measurement will be made for epoxy injection of cracks, if required.

Bridge Retrofitting Method**No.2-5 Continuous Fiber Sheet Bonding to RC Deck Slab****6.2 Basis of Payment**

The quantity, measured as prescribed above, shall be paid for at a contract unit price. Epoxy injection of cracks will not be paid for directly and is considered subsidiary to the works. This unit price shall cover full compensation for all materials, labor, equipment, supervision, and related services necessary for strengthening the concrete, as detailed in the plans and specifications. If an alternate carbon fiber system is used, the price shall also include all engineering, design, and technical services, as well as contractor submittals required in the specifications

Bridge Retrofitting Method

No.2-6 Re-concreting (Partial Deck Slab Replacement)

1. Description of Retrofitting Method

Recasting is carried out to replace portion of the concrete that has been severely damaged. If damaged portion is not removed, as shown in Figure AP 2.6.1, further deterioration is expected, which could impair the strength, stability and serviceability of the structure. The cause of such damage could be corrosion of reinforcement, fracturing, spalling, delamination, honeycomb or water leakage.



Figure AP 2.6.1 Severely Damaged Deck Slab

Recasting generally involves removal of the deteriorated concrete, cleaning up the substrate and reinforcement, setting up formwork and placement of new concrete as shown in Figure AP 2.6.2.

If the bridge cannot be closed to traffic during repair, it is suggested to use fast-setting mortar instead of Portland cement concrete.

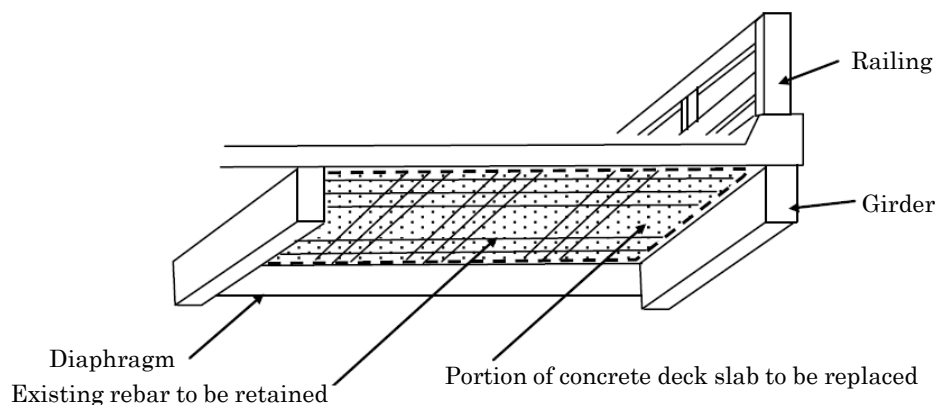


Figure AP 2.6.2 Detail of Partial Deck Slab Replacement

2. Application Criteria

The method of placement of slab concrete depends largely on particular situation. Nevertheless, it should ensure that well compacted concrete completely fills all the voids. The works generally include complete removal of defective concrete and its adjacent surfaces to its full depth, setting formworks, cleaning the existing rebar (and additional rebar, if required) and placing new concrete. Alternatively, only partial depth of the defective concrete will be removed, while the soffit formwork can be extended to provide a series of hoppers at its open sides, to allow for filling of super plasticized "flowing" concrete.

Said alternative method (Partial Depth) is similar to the recasting method for repair to girder and substructure, discussed in separate sections in this manual. However, it is not expected to be as effective considering the wide area and limited thickness of deck slab, subjected to repeated loadings due to traffic. In this manual, the first method (Full Depth), which is replacement of concrete by defect section or panel, is recommended for repair of severely damaged deck slab.

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3. Work Sequence

3.1 Support of existing Structure

The existing structure shall be properly supported to safeguard against instability and deformation during the repair work.

3.2 Removal of Deck Slab Concrete

All deteriorated or damaged concrete surface are cut by saw, forming vertical edges, and then removed using breaker and chisel. Rebar are examined for loss of section due to corrosion. If cross sectional area of the reinforcement has reduced by more than 20%, additional reinforcement is required and necessary.



3.3 Preparation of Old Concrete and Rebar

A suitable bonding agent for concrete and reinforcement should be selected taking into consideration the limited working time available for fixing the formwork and placing the new concrete. Concrete should be placed immediately after application of the bonding coat to the faces of the old concrete and rebar.



3.4 Setting of Formworks

Soffit formwork for re-casting deck slab must be very rigid and well-supported to prevent the new concrete from sagging due to its own weight.



3.5 Cutting of Existing Rebar and Addition of New Rebar

Deteriorated old rebar are cut up to the required lap length. New bars to be provided shall be of same or bigger diameter than the existing, considering the current loading condition. The lap length is calculated as 30 times the new rebar diameter. The new rebar shall be tied to the existing bars using tie wires or by welding.

3.6 Placing Concrete

Concrete is placed in the soffit formworks through a suitable method and compacted well using internal or external vibrators. Finish unformed surfaces by broom, wood float, or steel trowel to match the adjacent existing concrete.



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<p>3.7 Curing and Removal of Formworks</p> <p>Continuous water curing with wetted cotton mat is always preferable to slow down drying.</p> <p>Formworks for load bearing structural members shall remain in position until at least 80% of the 28 day compressive strength of the new concrete is achieved.</p>	
<p>4. Required Materials and Tools/Equipment</p>	
<p>4.1 Required Material</p> <ul style="list-style-type: none"> • Portland Cement • Silica Fume • Rebar (Reinforcing bar, use Grade 40 for 16mm diameter) • Epoxy Resin (Bonding Coat to Concrete) • Zinc Rich Primer (Bonding Coat to Rebar) <p>4.2 Required Tools/Equipment</p> <ul style="list-style-type: none"> • Sawing Equipment • High Pressure Water Blasting • Handy Concrete Breaker or Jackhammer • Handy Power Chisel • Concrete Mixer 30 liters • Vibrator • Troweling tools 	
<p>5. Specification</p>	
<p>(1) Removal of Concrete</p> <p>Concrete areas subjected for full-depth repair shall be removed, as determined by the Engineer. While, for partial depth repair it should extend below half the concrete deck thickness. Saw cuts shall be made on the perimeter of the deck to be replaced. Concrete saw shall then be used to form vertical edges, with approximately 20 mm deep, around the defined perimeter. Deck slab concrete is removed using a breaker while portable electric chisel is used near the vertical edges. Material Handling</p> <p>The carbon fiber components shall be delivered in an original, unopened (except carbon fabric or strips) containers clearly marked with the manufacturer's name, product identification, and batch numbers. Storage and handling of the various related products shall be in conformance with manufacturer's recommendations and instructions.</p> <p>(2) Concrete Mix</p> <p>The concrete mix used for partial replacement of slab concrete must be capable of producing highly impermeable concrete with adequate workability and low shrinkage. The repair mix should be ideally made with the same type of aggregate as the original concrete to minimize thermal stress. It is also usually necessary to use a smaller (20mm) maximum aggregate size for repairs because the space for</p>	

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placing concrete is often restricted. Care should be taken to ensure that aggregate will not react with alkali from the cement particularly as rich mix will be used.

The water cement ratio should not exceed 0.4 to minimize stresses caused by drying shrinkage. In some situations, it may be helpful to add shrinkage-compensating admixtures to the mix. These admixtures work by causing slight expansion to offset shrinkage and thermal contraction.

The fresh concrete should have high cement-paste content for proper bonding with the old concrete and reinforcement. It should also provide high alkalinity for the protection of steel. The mix should have a minimum cement content of 410 kg per cubic meter of concrete. The grading of aggregate and sand must be properly selected to produce a dense concrete and to keep bleeding to an absolute minimum, especially for soffit repairs where bleeding can lead to complete separation between old and new concrete.

For small repair jobs, concrete may be mixed at site using a small concrete mixer. On site batching should be avoided. It is preferable to make trial mixes and then pre-batch into convenient sized bags off site with only specified quantities of water and super plasticizer to be added at site. All materials must be weighed by batches.

An assumed mix design for small scale repairs is given below as reference. These quantities will make about 0.03 cubic meter of concrete and could be accommodated in a small mixer.

- a) Cement
 - Portland cement 13.0 kg
 - Silica fume (if silica fume is unavailable, use 13.5 kg cement)
- b) 10 mm crushed aggregate 36.0 kg
- c) Sand (assumed with 2% water content) 18.5 kg
- d) Water (maximum 5.4 liters)
- e) Super plasticizer (nominal) 25 ml

(3) Adding Rebar

Any damage to the rebar to remain in place shall be repaired or replaced to the satisfaction of the Engineer at the Contractor's expense. All existing rebar shall remain in place except those which are significantly corroded. Tying of loose bars will be required. Rebar which have been cut or have lost 20 percent or more of their original cross sectional area shall be supplemented with new reinforcing bars. The new bars shall be lapped a minimum of 30 times the new diameter to the existing bars, which shall be coated with zinc-rich primer. An approved mechanical bar splice capable of developing tension of at least 125 percent of the yield strength of the existing bar shall be used when it is not feasible to provide the minimum bar lap.

6. Measurement and Payment

6.1 Method of Measurement

Partial deck slab replacement performed in accordance with the plans and the specification will be measured in cubic meters. The quantity to be paid for includes the replaced concrete on the deck slab in cubic meters, accepted by the Engineer.

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<p>6.2 Basis of Payment</p> <p>The quantity, measured as prescribed above, shall be paid for at a contract unit price. This unit price shall cover full compensation for all materials, labor, equipment, supervision, and related necessary works for supporting the deck slab and girders and scaffolding.</p>	

Bridge Retrofitting Method

No.2-7 RC Concrete Wrapping Method

1. Description of Retrofitting Method

Concrete wrapping as shown in Figure AP 2.7.1 is mainly applied to substructure that has deteriorated concrete due to corrosion of rebar. It should be noted that splash zone portions of bridge concrete piles in marine environment are more exposed to corrosion. Although provision of wrappings could delay further chlorides from entering the pile, this does not guarantee complete mitigation of corrosion to the rebars.

Steel wrapping remains an effective alternative for strengthening piers or piles against structural failure, however, it is not included in the scope of this manual

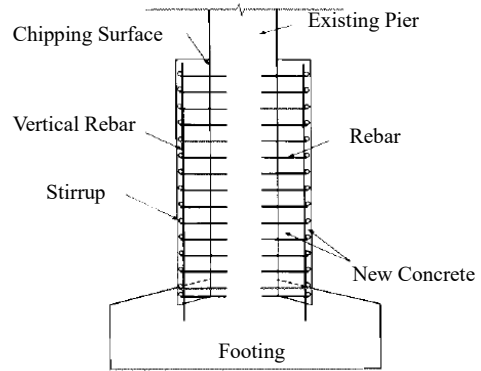


Figure AP 2.7.1 Concrete Wrapping

2. Application Criteria

Two methods of wrapping, namely concrete wrapping and steel wrapping, are discussed as follows:

Concrete wrapping is applied to protect the deteriorated concrete due to corrosion of rebars, damage due to rapid water flow or broken due to continuous impact from materials flowing in the channel such as drift woods. Concrete wrapping should be basically placed above water level as shown in Figure AP 2.7.2. If the damaged portion is submerged to water, cofferdam is necessary to achieve a dry condition during wrapping. To minimize cofferdam, related repair works are either carried out while water is at low level in the dry season, or using underwater concrete.



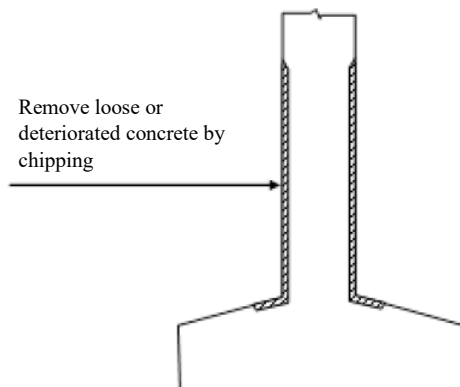
Figure AP 2.7.2 Concrete Wrapping for Repair Pier

3. Work Sequence

3.1 Removal of Deteriorated Concrete

All loose or deteriorated concrete shall be removed. Surface cracks shall also be removed by chipping. Hammer sounding shall be done to locate delaminated areas.

When corroded reinforcing steel is exposed during concrete removal, the corroded bars shall be further exposed by chipping until clean un-corroded steel is exposed.

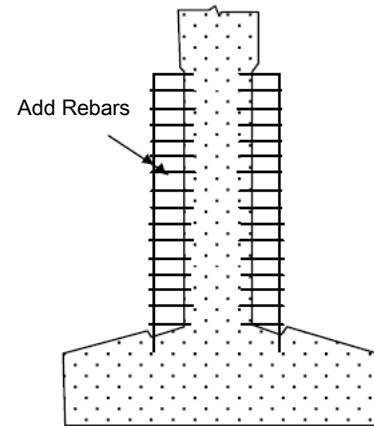


Bridge Retrofitting Method

No.2-7 RC Concrete Wrapping Method

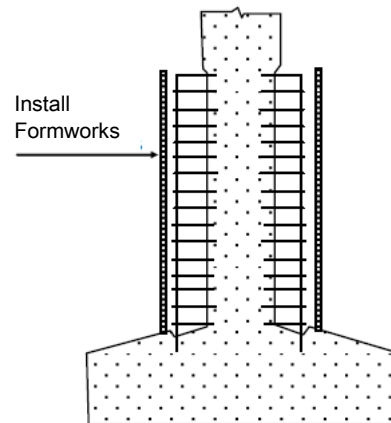
3.2 Addition of Rebar

Additional rebar are anchored into drilled holes in the concrete, and placed in conformity with the requirements shown on drawings. Heavily corroded rebar shall also be replaced. Clear concrete cover to rebar, for piers and piles, shall be 40 mm in normal environment, and 55 mm in marine environment



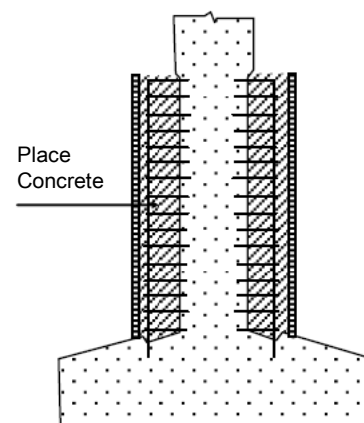
3.3 Setting of Formworks

Formwork for concrete wrapping is commonly circular or rectangular in shape. This formwork must be very rigid and well-supported to maintain the shape and the required covering of the new concrete. It should also be able to withstand pumping forces if concrete is to be pumped and vibrated.



3.4 Placing of Concrete

Concrete is placed in the formworks through a suitable method and compacted well using internal or external vibrators. Surfaces shall be finished using broom, wood floating, and steel troweling to match the adjacent existing concrete.



3.5 Curing of Concrete

Continuous water curing using wetted cotton mat is preferable to help slow down drying.

Formworks for load bearing structural members shall remain in position until at least 80% of the 28 day compressive strength of the new concrete is achieved.

Bridge Retrofitting Method

No.2-7 RC Concrete Wrapping Method

4. Required Materials and Tools/Equipment

4.1 Required Material

Concrete with Fine Aggregate

A suggested mix design for small scale repairs is given below as reference. These quantities will make about 0.03 cubic meter of concrete and could be fully accommodated in a small mixer.

- 1) Cement
 - Portland cement 13.0 kg
 - Silica fume 0.5 kg (If silica fume unavailable, use 13.5kg cement)
- 2) 10mm crushed aggregate 36.0 kg
- 3) Sand (assumed with 2% water content) 18.5 kg
- 4) Water (maximum) 5.4 liters
- 5) Super plasticizer (nominal) 25ml

Formwork

- Steel Formwork (Circular)
- Plywood formwork

4.2 Required Tools/Equipment

- Drilling Machine to Concrete
- Concrete Vibrator

5. Specification

(1) Removal of Deteriorated Concrete

The Contractor shall remove all loose or deteriorated concrete as directed by the Engineer. Surface cracks shall be removed by chipping. Hammer sounding shall be done to locate delaminated areas. Care shall be taken not to damage areas of sound concrete, reinforcing steel or other bridge components. Any such damage will be repaired by qualified personnel at Contractor's expense.

Removal of deteriorated concrete from the bridge structure shall be done in such a manner that the structural integrity of the bridge is unaffected. All concrete removed shall be replaced as soon as possible. It is the responsibility of the Contractor to design and provide shoring, when required, as directed by the Engineer. The designed shoring shall be signed and sealed, and submitted to the Engineer for his approval.

(2) Additional Rebar

Additional rebar shall be firmly anchored into the drilled hole filled with epoxy resin adhesive and arranged in conformity with the requirements shown on drawings. Prior to drilling holes, location of existing rebar in the pier shall be verified using an ultrasonic recorder (rebar locator). Actual ideal location of drilled holes for the additional rebars shall be consequently marked.

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No.2-7 RC Concrete Wrapping Method

When reinforcing steel appears corroded during concrete removal, further chipping shall be continued until clean and uncorroded portion of the bars are exposed. Chipping shall be done to a depth of 20 mm beneath the rebar. Perimeter of all chipped areas shall be saw cut to a minimum depth of 40 mm to minimize rough edges.

Rebar, which are exposed with significant section loss during repairs, shall be replaced as directed by the Engineer. In general this is implemented if the section loss at any portion of the rebar exceeds 20 percent. In cases of isolated section loss areas, the existing rebar need not be cut out, instead, extra rebar shall be added alongside in such a manner that voids will not occur during concrete placing. The minimum lap splice length of all new rebar required shall be 30 bar diameters. The minimum cover of new concrete above the reinforcing steel shall be 40 mm in normal environment and 55 mm in the marine environment.

(3) Setting Up of Formworks

The Contractor shall submit shop drawings, for the Engineer's approval, of the formwork for the concrete wrapping prior to commencement of the repair works. The formwork must be very rigid and well-supported to prevent the new concrete from leaking at the bottom of the formwork. It should also be durable enough to withstand its own weight, pumping forces, (if concrete is to be pumped into the forms) and forces due to clamped-on external vibrators.

Circular formwork, when required, should be made up of steel plate or appropriate materials approved by the Engineer. The diameter of the formwork shall be fabricated 500 mm larger than the existing pier or pile diameter. This is necessary in order to provide a space of 250 mm between the formwork and the surface of existing concrete, which is required for placing new concrete and inserting poker vibrators.

6. Measurement and Payment

6.1 Method of Measurement

Concrete warpping performed in accordance with the plans and this specification will be measured in cubic meters. The quantity to be paid for will be the cubic meters of concrete placed around the piers/piles and accepted by the Engineer.

6.2 Basis of Payment

The quantity, measured as prescribed above, shall be paid for at the contract unit price. This unit price shall include full compensation for all materials, labor, equipment, supervision, and related necessary works for supporting the substructure and scaffolding as detailed in the plans and specifications.