CHAPTER 5 REPAIR OF CONCRETE STRUCTURE

5.1 Planning of Concrete structure repair

Before repair work, approximate concrete bridge repair plan and cost shall be prepared. In this manual, it is recommended that the planning and cost estimate should be done. This manual covers ‘repair plan’ and ‘repair cost’.

The repair plan shall include;

- Province (DPWT) that manages target bridge sections
- Location
- Work priority
- Repair method
- Reference No. of unit costs for cost estimate (refer to “Appendix”), and
- Total repair cost

Rough bridge repairing cost can be obtained by summing up unit cost estimates.
The typical repair code is shown in **Table5.1.1**. All repair codes are described in ‘Appendix’

Table 5.1.1Typical bridge repair code (Concrete)

No.	Code	Repair Work	Unit
1	1001	Concrete Crack Repair	m
2	1002	Concrete Defect repair	m^3
3	1003	Concrete Surface Reinforcement	m^2
4	1004	Reinforcement by Steel Plate	m^2

In the repair execution plan, work priority order has to be determined with comprehensive consideration of progressive speed, location and current severity of damages plus route importance and preference.

Since the bridge maintenance technology is constantly evolving, road administrator must keep obtaining new knowledge by dense communication and information exchange to relevant organizations.

5.2 Case of Concrete structure repair

This section is introduced to repair cases of concrete structures.

C-1 Concrete crack

(a) Conditions

There are alligator cracks or multiple numbers of linear cracks on the sides of concrete piers, and their width is more than 0.3mm (**Photo 5.2.1.1**). If this situation remains untreated, corrosion of reinforcements is in danger of progressing. As a result, spalling and decrease of concrete strength might occur in the future (**Fig. 5.2.1.1**).

Photo 5.2.1.1 Concrete crack on pier

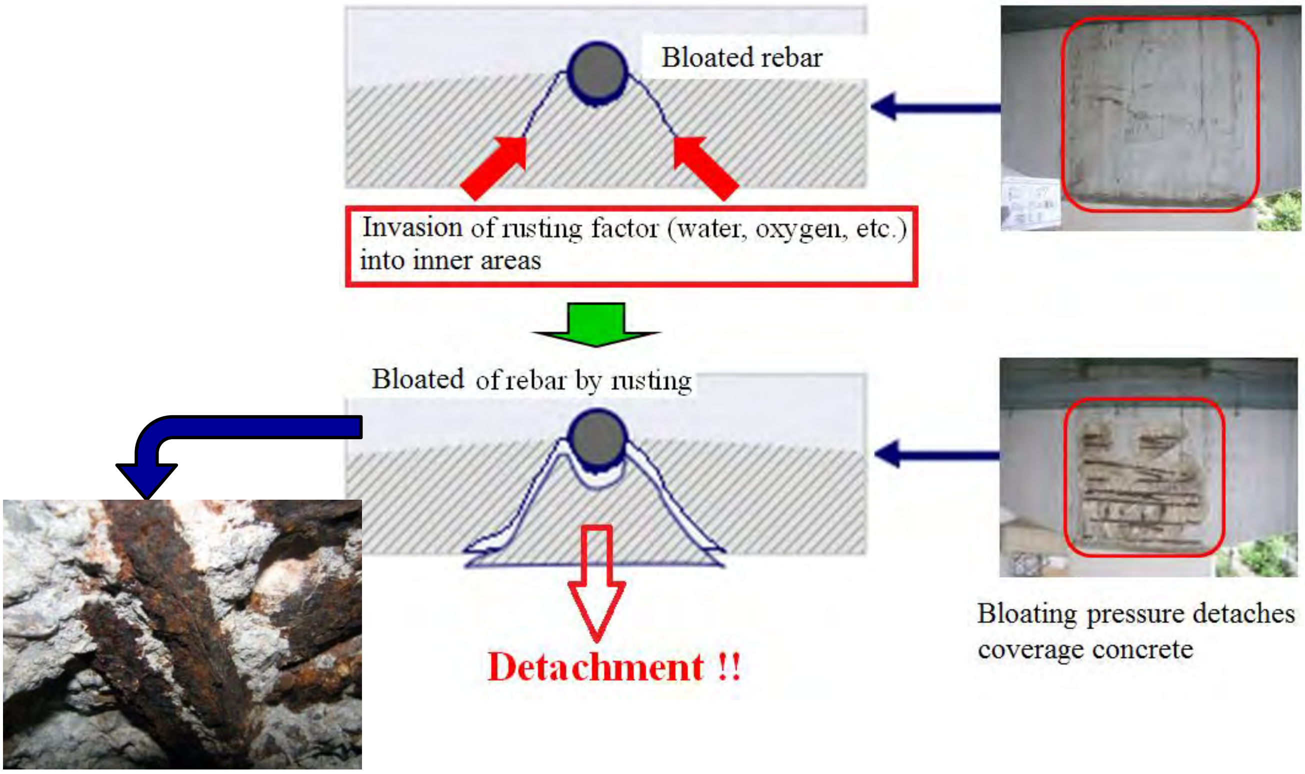


Fig. 5.2.1.1 Progress of concrete crack

(b) Possible Causes

Though there are some possible causes of the damage such as dry shrinkage during construction, it is difficult to identify to the one.

However, since many similar cracks exist in multiple directions and locations, the excessive external load from overloading vehicles can be excluded.

(c) Outline of repairs

Concrete cracks are filled with epoxy resin injection (**Photo 5.2.1.2**).

The procedures are as follows:

Photo 5.2.1.2 Concrete crack repair method

(1) Preparing of material (**Photo 5.2.1.3**)

* Epoxy resin and hardener
*Sealant (Sealing)
*Syringes set

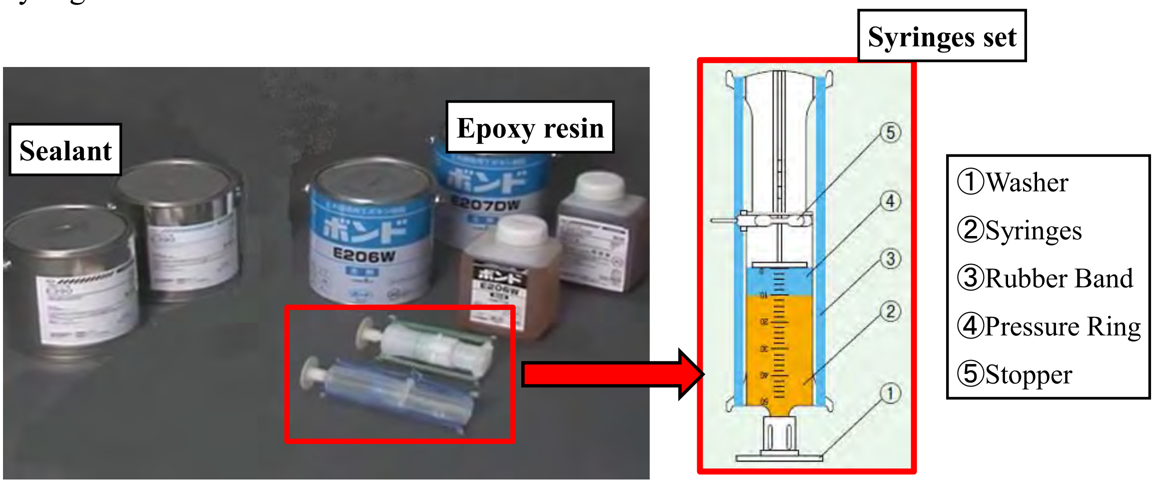


Photo 5.2.1.3 Concrete crack repair material

(2) Execution Procedures

This repair work is carried out by dividing three days (**Fig. 5.2.1.2**).

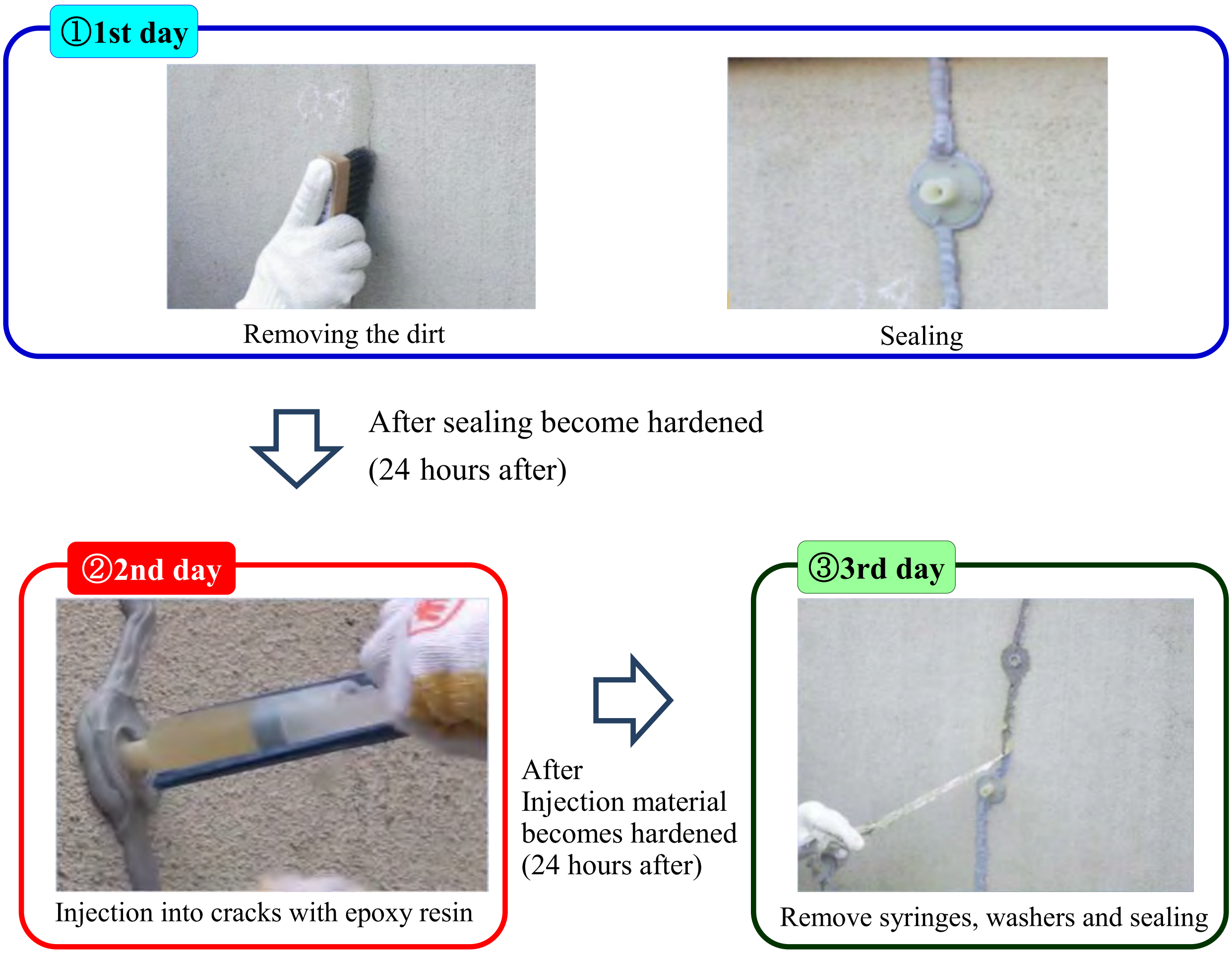


Fig. 5.2.1.2 Outline of crack repair method by Epoxy Resin

Work procedure

1) Measuring cracks (1st day)

To decide which cracks to be repaired, the width of cracks was measured and marked. And the length of cracks to be repaired was also measured and marked (**Photo 5.2.1.4**).

Photo 5.2.1.4 Deciding repair range

2) Cleaning the cracks (1st day)

To attach sealing and injection material well, cracks were cleaned by using wire brush (**Photo 5.2.1.5**) and air blower (**Photo 5.2.1.5**) along the crack for 50mm wide on both sides. Oil also should be wiped off with thinner.

(a) Wire brush **(b) Air blower**

Photo 5.2.1.5 Surface Preparation

3) Determining washer setting points (1st day)

Washer setting points are marked by chalk. **(Photo 5.2.1.6**) Their standard interval is 4 points per 1m.

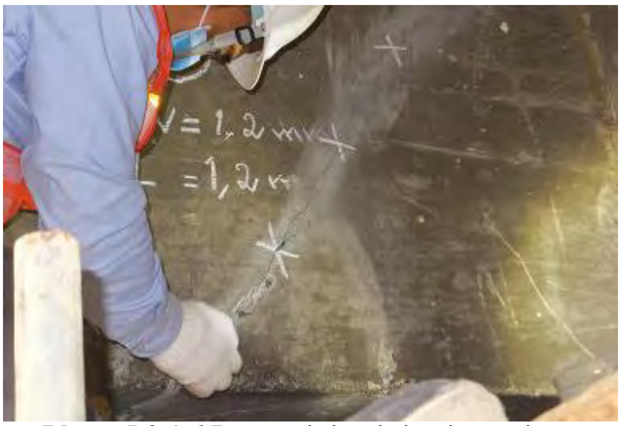


Photo 5.2.1.6 Determining injection points

4) Mixing sealing material (1st day)

Sealing material consists of 'Main material' and 'Hardener' (**Photo 5.2.1.7**).

Defined amounts of 'Main material' and 'Hardener' are weighed (**Photo 5.2.1.8**) and mixed to knead up to uniform texture (about 3 minutes) (**Photo 5.2.1.9**).

(Mixing Ratio (Weight); Main material: Hardener = 2:1)

After the materials are mixed, the material starts to become hard. It is necessary to mix well and use the material <u>within 30 min</u>. after starting mixing time (30 degree Celsius). Therefore, the mixing time (about 3 min.) and using time (30 min.) was measured by using a stopwatch.

Photo 5.2.1.7 Sealing material

Photo 5.2.1.8 Weighing material (Sealing material)

Photo 5.2.1.9 Mixing material (Sealing material)

5) Attaching washer (1st day)

By using sealing material, washers were attached on the marking point (**Photo 5.2.1.10**). And the plates are fixed on a crack aligning their center with crack line.

Photo 5.2.1.10 Attaching washer

6) Attached Sealing on the crack (1st day)

Sealing material was also attached on the cracks between the washers (**Photo 5.2.1.11**). If the cracks are not sealed well, injection material leaks. So it is necessary to seal well, especially around washers.

After the sealing work is finished, an interval of more than 24 hours is necessary for sealing to become hard (30 degree Celsius).

Photo 5.2.1.11 Attached Sealing on the crack

7) Mixing epoxy resin material (2nd day)

Epoxy resin material consists of ‘Main material’ and ‘Hardener’ (**Photo 5.2.1.12**).

Defined amounts of ‘Main material’ and ‘Hardener’ are weighed (**Photo 5.2.1.13**) and mixed to knead up to uniform texture (about 3 minutes) (**Photo 5.2.1.14**).

(Mixing Ratio (Weight); Main material: Harder = 2:1)

After the materials are mixed, the material starts to become hard. It is necessary to mix well and use the material within 30 min. after starting mixing time (30 degree Celsius).Therefore, the mixing time (about 3 min.) and using time (30 min.) was measured by using a stopwatch.

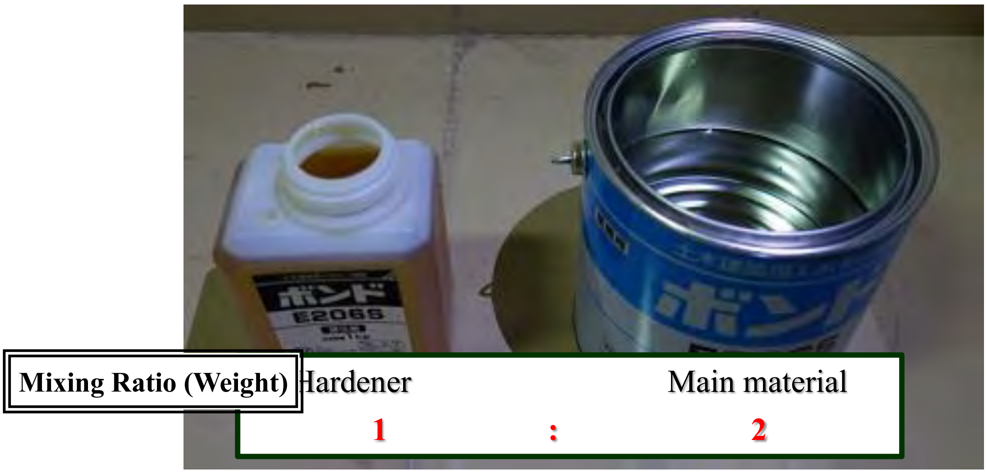


Photo 5.2.1.12 Sealing material

Photo 5.2.1.13 Weighing material (Epoxy resin material)

Photo 5.2.1.14 Mixing material (Epoxy resin material)

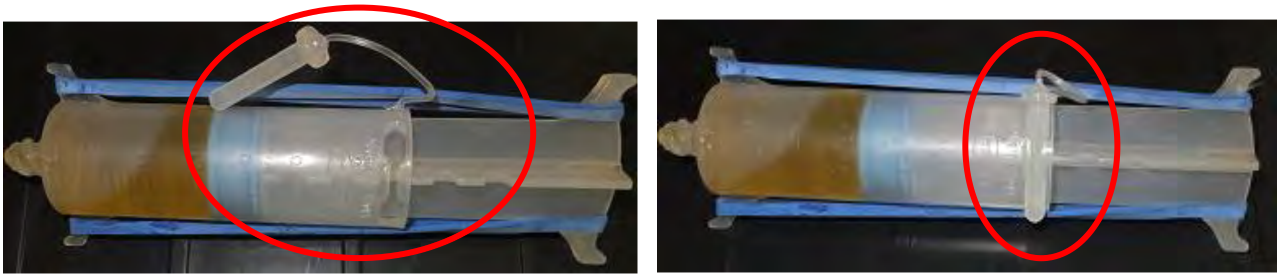
8) Epoxy resin injecting (2nd day)

Epoxy resin material was inserted into syringes with rubber band (**Photo 5.2.1.15**). Then, stoppers of syringes are set (locked) so that the syringes don't move (**Photo 5.2.1.16**).

After the syringes were set on the washers (**Photo 5.2.1.17**), stoppers of the syringes were removed (unlocked) and the injection started by rubber pressure. Do not remove any syringes until the curing is completely made.

After the injection work is finished, longer than 24 hours interval is necessary for epoxy resin material to become hard (30 degree Celsius).

Photo 5.2.1.15 Inserting into syringes



(a)Unlocked **(b)Locked**

Photo 5.2.1.16 Stoppers of the syringes

Photo 5.2.1.17 Syringes set

9) Removing syringes and washers (3rd day)

After Injection material became hard, the syringes and washers were removed (**Photo 5.2.1.18**).

(a)Removed syringes

(b)Removed washer

Photo 5.2.1.18 Removing syringes and washers

10) Completion (**Photo 5.2.1.19**) (3rd day)

Excess resin and dirt attached on the surface beyond repair section should be removed.

Work site must be cleared. And used equipment shall be checked, cleaned.

Photo 5.2.1.19 Completion

(d) Remarks

The cost of resin injection method for concrete crack repairing is relatively less expensive than other method (**Fig 5.2.1.3**). In case that the cause of the concrete cracks is not caused by external loading, repair budget is saved in the long run by this simple and reasonable method while the degree of cracks remains small.

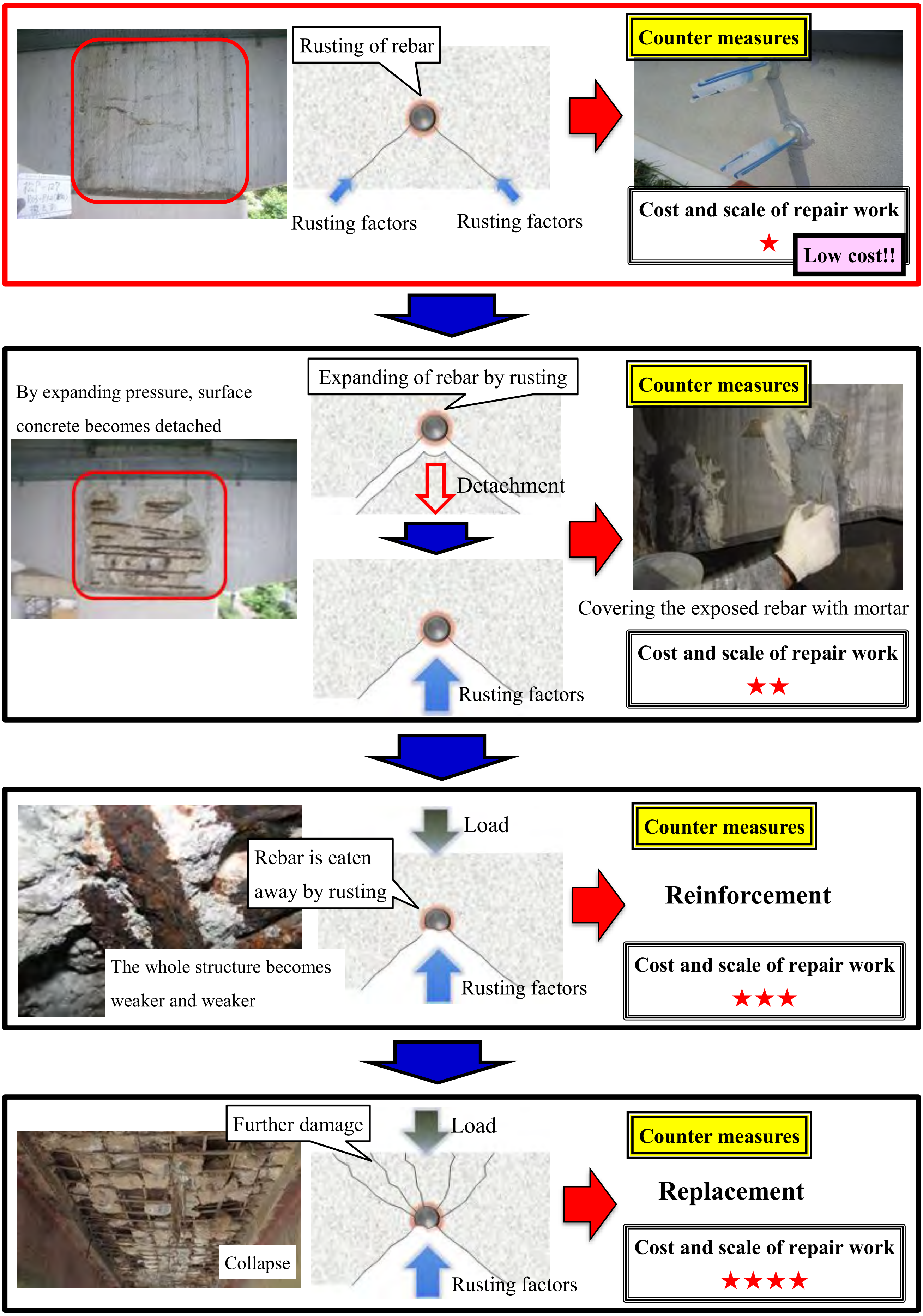


Fig. 5.2.1.3 Progress of concrete crack

C-2 Carbon Fiber Cloth (CFC) Reinforcement Method

(a) Introduction

1) Introduction

It analyzed the damage cause of the bridge in Cambodia from the inspection results. The followings are the main causes of bridge collapse or serious damage in Cambodia;

Case1: Insufficient strength capacity due to non-conforming work or design deficiency (**Photo 5.2.2.1**)

Case2: Overloading (**Photo 5.2.2.2**)

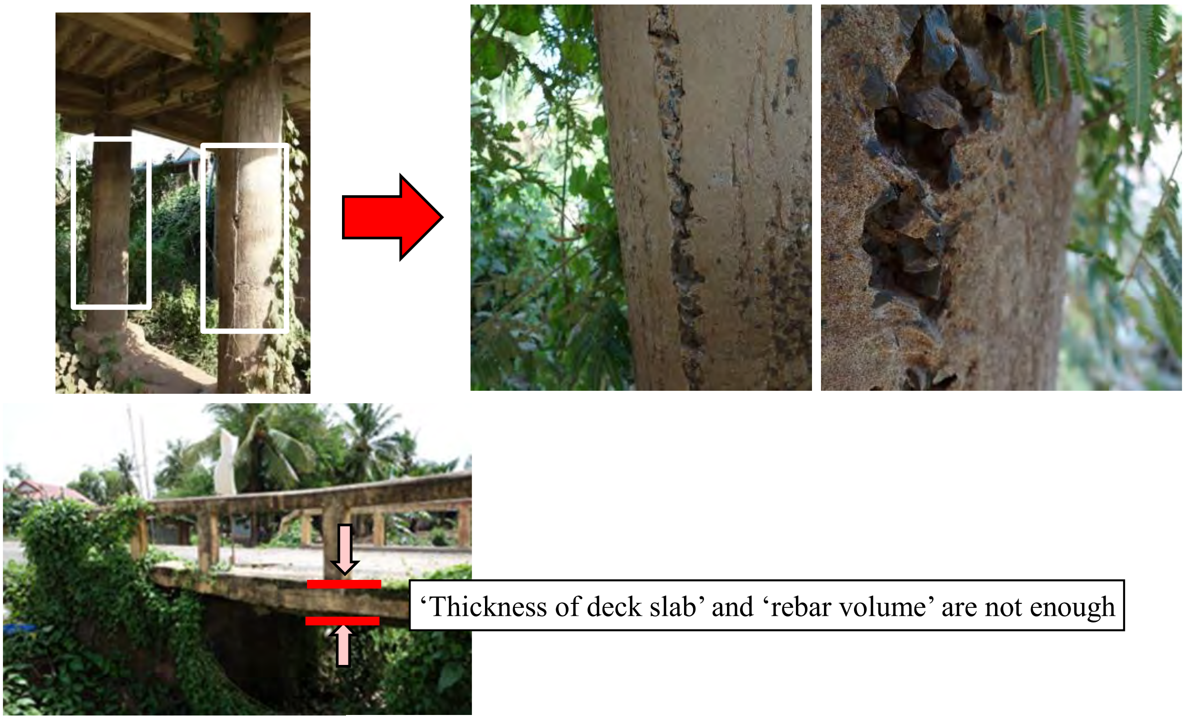


Photo 5.2.2.1 Insufficient strength capacity

Photo 5.2.2.2 Overloading

Basic policy of these countermeasures is shown following

Case1: Structural reinforcement bridge members in order to recover the losing strength

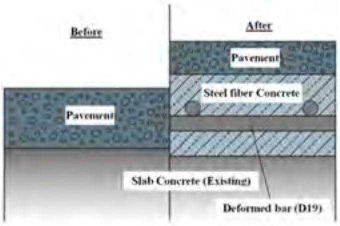
Case2: Strengthening law enforcement of overloading vehicles and structural reinforcement of bridge members in order to increase the strength capacity

Therefore as a feasible solution for the two main damages causes, structural reinforcement of bridge members' must be performed.

The structural reinforcement methods are shown in **Table 5.2.2.1**

Methods often applied for slab reinforcements are concrete overlaying, steel plate bonding and CFC (Carbon Fiber Cloth) bonding. In case of concrete overlaying and steel plate bonding methods, dead load is greatly increased by reinforcement. Therefore it is necessary to re-examine the capacity of existing girders, piers, and bearings. And according to the calculation, there is a case that requires redesigning for bearing replacement and pier reinforcement. (In case of re-designing, structural calculation reports and design drawing of existing bridge should be prepared.)

Table 5.2.2.1 The selection of concrete slab reinforcement method

	Concrete overlaying	Steel plate bonding	CFC bonding
Repair Method	Increasing the thickness of concrete slab from the surface   	Bonding steel plate from slab bottom with adhesive and anchor bolts  	Bonding CFSR from slab bottom with adhesive  
Merits	● Scaffolding not needed	● No traffic regulation needed ● Many applications for busy bridges in Japan	● No traffic regulation needed ● **Incremental weight is very small** ● Easier construction procedure
Demerits	● **Big incremental weight** ● **Heavy equipment needed** ● Chipping of existing concrete is necessary for firm fixing ● Road closure is needed during construction	● **Big incremental weight** ● **Heavy equipment needed** ● Scaffolding is needed ● Anchor's holding capacity is not guaranteed if the existing concrete is poor	● Scaffolding is needed ● Risk of energization
Judgment	**Medium**	**Not good**	**Good**

2) Features of CFC

The reinforcement is generally used as CFC (**Photo 5.2.2.3**) which is impregnated carbon fiber with resin, bonded and hardened on the concrete surface.

Photo 5.2.2.3 CFC (Carbon Fiber Cloth)

CFC reinforcement method merits are shown following.

-Excellent material properties.

-Lightweight

-High strength, high elasticity

(Tensile strength: 3,400N/mm^2, 10 times more compared with iron)

-High durability against ultraviolet ray

-Excellent workability

Density of CFC is approximately 1.6 g/cm3, and is only 1/5 compared to the density of steel. Therefore, there is very little weight increase if you reinforce by this material.

And CFC tensile strength of High strength is greater than 3,400 N/mm2. That means that it has ten times or greater than the tensile strength of steel.

There is very little size increase of concrete structure, even after CFC strengthening. It is thickness less than 0.35mm.

The unidirectional CFC has a high performance only in one direction. Therefore only one direction can be reinforced by the unidirectional CFC. In another way, if ‘both directions CFC’ is used, bi-direction can be reinforcement.

(b) Conditions and Possible of Causes

1) Condition

This bridge (**Photo 5.2.2.4**) is in National Road 4, Preah Sihanouk. On this bridge, many large vehicles pass through every day.

There are numbers of cracks on the slab, and their width is more than 0.6mm. If this situation remains untreated, this crack will progress. As a result, spalling and decrease of concrete strength might occur and this bridge will collapse in the future (**Photo 5.2.2.5**).

Photo 5.2.2.4 Concrete crack on slab

Photo 5.2.2.5 Collapsing bridge

2) Causes

It is a possibility of fatigue crack by overloading from the following reasons.

- These cracks occur in transverse direction.

-When overloaded vehicles pass, the vibration of the slab is large.

-There are many cracks near axle of vehicle.

(c) Outline of repair

This method is the reinforcement of concrete structure by CFC.

This method can be reinforced by hand without some heavy equipment because of a very light weight of CFC. In addition, CFC can be cut by scissors as you would like. Therefore CDC can be adjusted freely and flexibly with the surface of concrete.

The standard usage weight per unit area of epoxy resin is shown in **Table 5.2.2.2**. The execution of the little resin weight causes the deterioration of the reinforcement.

Table 5.2.2.2 The standard usage weight of epoxy resin (per unit area)

Type of resin	Areal weight of CFC (g/m2)	Standard usage weight per unit area (kg/m2)		
		Under applying	Over applying	Total
Primer	-	-	-	0.20
Smoothing Agent	-	-	-	1.00
Impregnating resin	400	0.50～0.60	0.50～0.40	1.00
CFC	-	1	-	-

* It depends on the type of CFC.

Required tools for CFC reinforcement are shown in **Table 5.2.2.3**.

Table 5.2.2.3(a) Required tools for CFC reinforcement

Process	Tool	Photo
Protection tool	Gloves	 
	Protect glass	 
	Helmet	 

Table 5.2.2.3(b) Required tools for CFC reinforcement

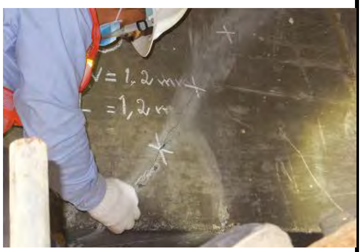
Process	Tool	Photo
Protection tool	Mask	 
a	Raincoat	 
Sectional repair Surface preparation	Chalk	 
	Wire brush	 
	Blower	 
	Crack gauge, Steel Tape	 

Table 5.2.2.3(c) Required tools for CFC reinforcement

Process	Tool	Photo	
Sectional repair Surface preparation	Thermo-hygrometer		
	Disk grinder		
	Pail		
	Pan balance		
	Stopwatch		
	permanent marker		

Table 5.2.2.3(d) Required tools for CFC reinforcement

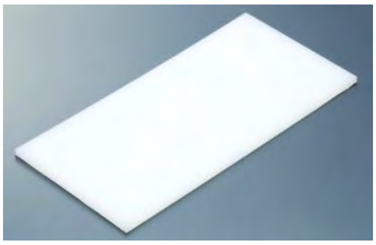
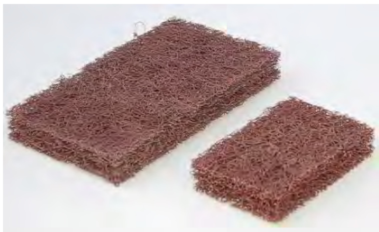
Process	Tool	Photo
Sectional repair Surface preparation	Spatula	 
	Board (Plastic type)	 
	Bucket	
	Polishing sheet	 
	Trowel	 
	Box cutter, and Scissors	 

Table 5.2.2.3(e) Required tools for CFC reinforcement

Process	Tool	Photo
	Agitator (Low speed type)	 
	Application roller (Handle)	 
	Application roller (Roller)	 
	Brush	 
	Paddle Roller	 

Table 5.2.2.3(f) Required tools for CFC reinforcement

Process	Tool	Photo	
For tool clean and for keeping clean site	Picnic sheet (Plastic type)		
	Paper towel		
	Thinner		
	Garbage bag		
	Tongs		

Work procedure

The purpose of this method is bridge reinforcement. Therefore, it is necessary to repair work before implementing this method. Also, it is necessary to measure repair and reinforcement part and to reflect them in the work plan before site work.

This workflow of CFC is shown in **Fig. 5.5.2.1**.

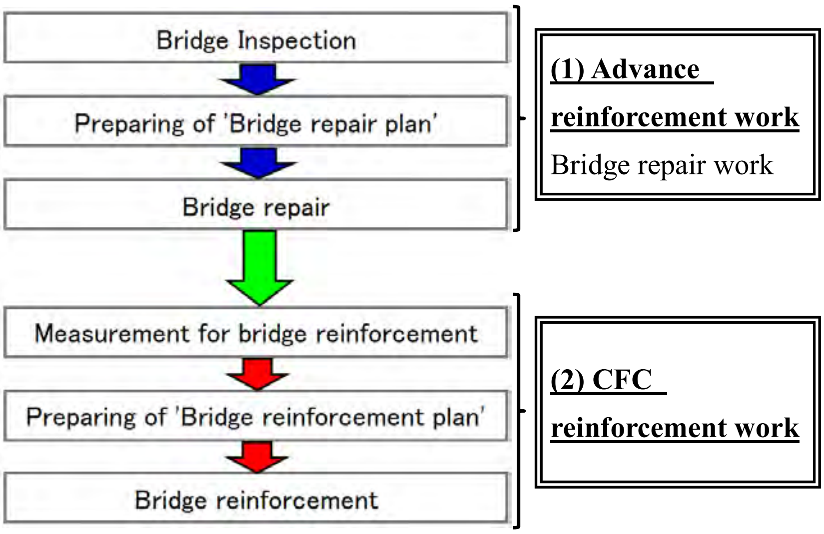


Fig. 5.2.2.1 Workflow of CFC

(1)Advance reinforcement work

1) Bridge inspection

Inspection and recording should be done so that you can make work plan.

Therefore, the bridge inspection should be done at first. And if there is crack wider than 0.3mm on the bridge, this crack must be repaired.

In addition, by hammering inspection, we check detached sections and remove them. We measure the reinforcing range and record it on the expansion plan. (**Photo 5.2.2.6**)

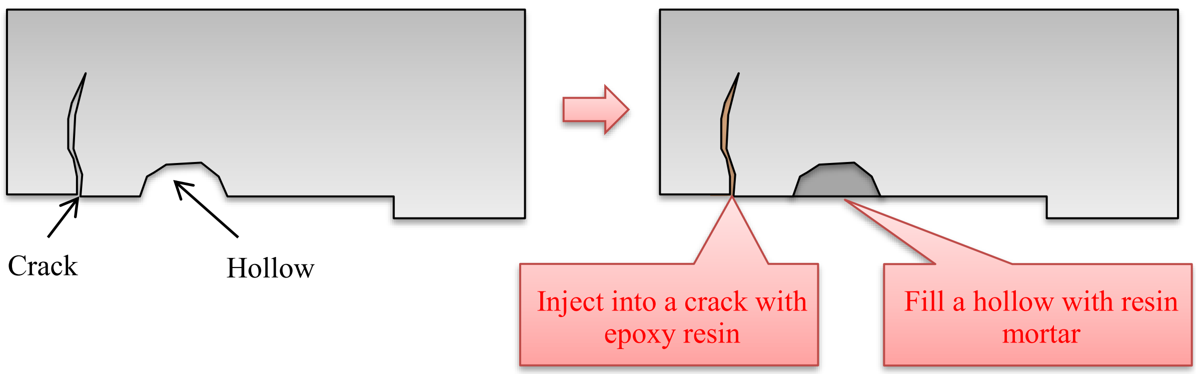
Photo 5.2.2.6 Measure the reinforcing range

2) Sectional repair

The oversight of hollows and cracks causes bad bonding.

Therefore if there is lacking parts and the hollows in concrete, it must be repair by resin mortar. And if there is crack wider than 0.3mm, it must be repair by epoxy resin (**Fig. 5.2.2.2**, **Photo 5.2.2.7**).

(Reference: Crack repair method is shown in **C-1 Concrete crack**)



Cross section of slab

Fig. 5.2.2.2 Crack and hollow repair

Photo 5.2.2.7 Crack repair (Reference: C-1 Concrete crack)

3) Surface Preparation (**Fig. 5.2.2.3**)

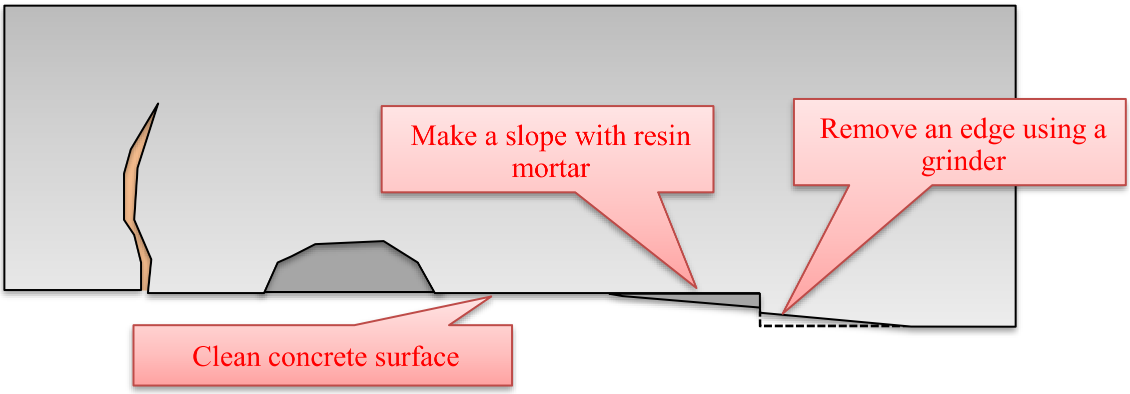
Surface difference in level or edge of the corner causes bad bonding and break of carbon fiber. Therefore, surface difference is flatten on the concrete surface by disk grinder (**Photo 5.2.2.8(a)**) (less than 1mm difference in level) or put resin mortar (larger than 30mm in radius).

And such as mortar, oil and dust are removed to expose the sound concrete by a disk grinder or a wire brush and a polishing scrubbing (**Photo 5.2.2.8(b)**).

(a) To flatten by disk grinder

(b) To remove dust by polishing scrubbing

Photo 5.2.2.8 Surface Preparation



Cross section of slab

Fig. 5.2.2.3 Surface Preparation

(2) CFC reinforcement work

This repair work is carried out by dividing four days (**Fig. 5.2.2.4**).

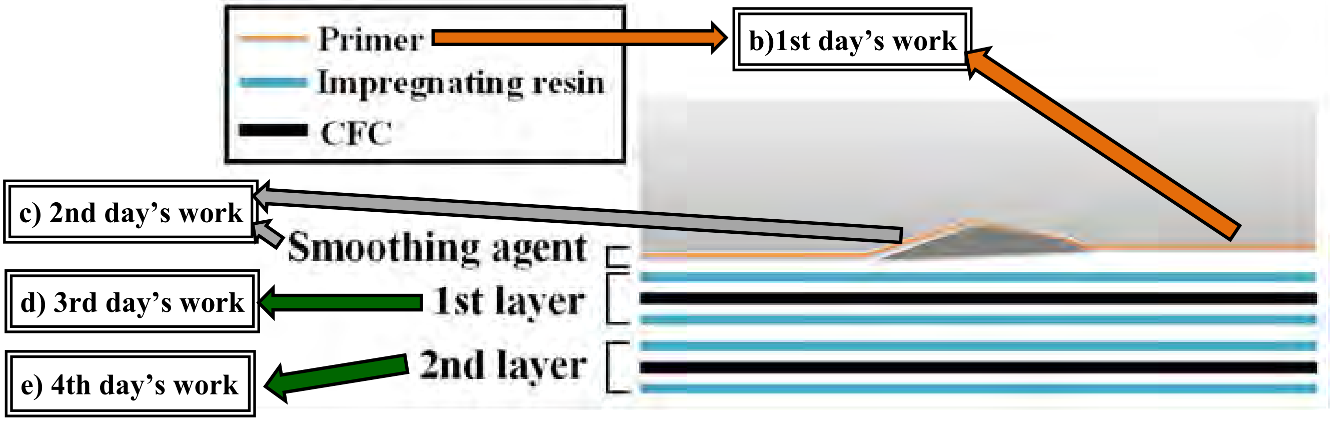


Fig. 5.2.2.4 Outline of CFC reinforcement work

a) Preparing reinforcement work

1) Measuring reinforce range

To decide which reinforcement range, it was measured and marked on site (**Photo 5.2.2.9**).

Photo 5.2.2.9 Measuring reinforce range

2) Preparing CFC reinforcement work plan

Using the measurement result of 1), it is prepared CFC reinforcement work plan.

We make arrangement plan of CFC based on the inspection result. Arrangement should be planed so that one piece of CFC cloth can be set and applied impregnating resin on within usage lead time of the impregnating resin (about 30 minutes). At that time, splice should be considered (**Fig. 5.2.2.5, Table 5.2.2.4**).

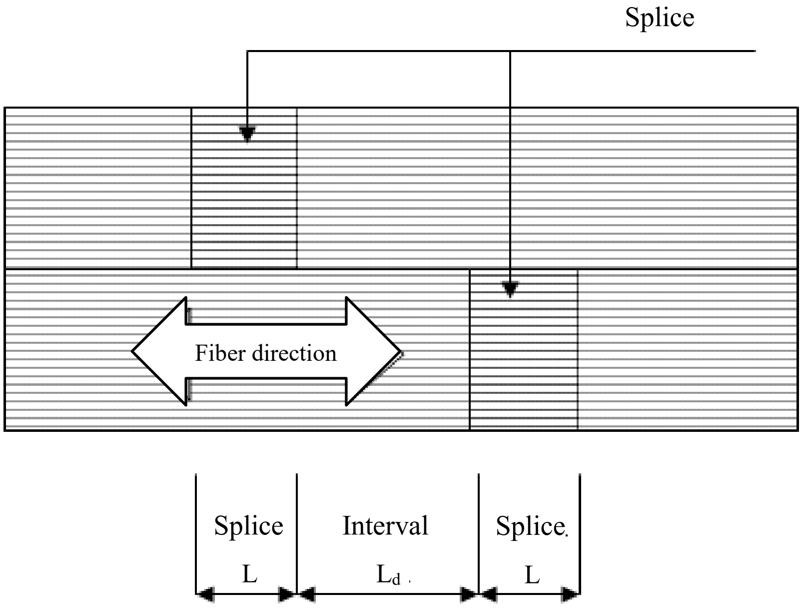


Fig. 5.2.2.5 Splice of CFC

Table 5.2.2.4 Splice length

Purpose	Splice length (L)	Detached (L_d)
Strengthening of bending, shearing	≧ 200mm	≧ 300mm

CFC should be executed each other without any gap or wrapped them each other. An allowance of wrap (l_0) is between 0 to 20mm (**Fig. 5.2.2.6**).

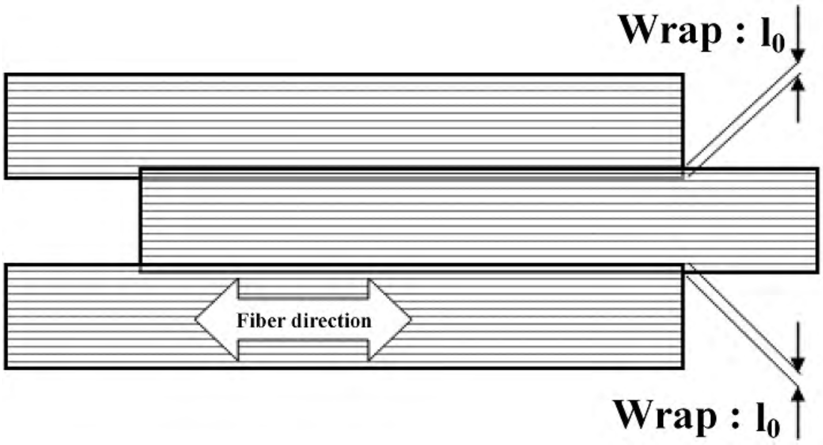


Fig. 5.2.2.6 Allowance of wrap

On December 2016 - February 2017, CFC reinforcement work was carried out in Preah Sihanouk (**Photo 5.2.2.4**, **Table 5.2.2.5**).

Table 5.2.2.5 Various factors of target bridge

Province	Preah Sihanouk
Road Name	National road 4
Bridge Name	Tro paing Sa-Ou
Latitude, Longitude	10.667072, 103.794133
Number of span	2span
	Concrete Bridge
Bridge width	9.9m
Bridge length	7.5m + 7.3m
Number of lane	2 lane

Using the measurement result, it was prepared this CFC reinforcement work plan before site work.
The layout plan of CFC is shown in **Fig 5.2.2.7**.
The material use plan is shown in **Fig 5.2.2.8**.
The resin mix plan of CFC is shown in **Fig 5.2.2.9**.

Layout of CFC (1st week work)

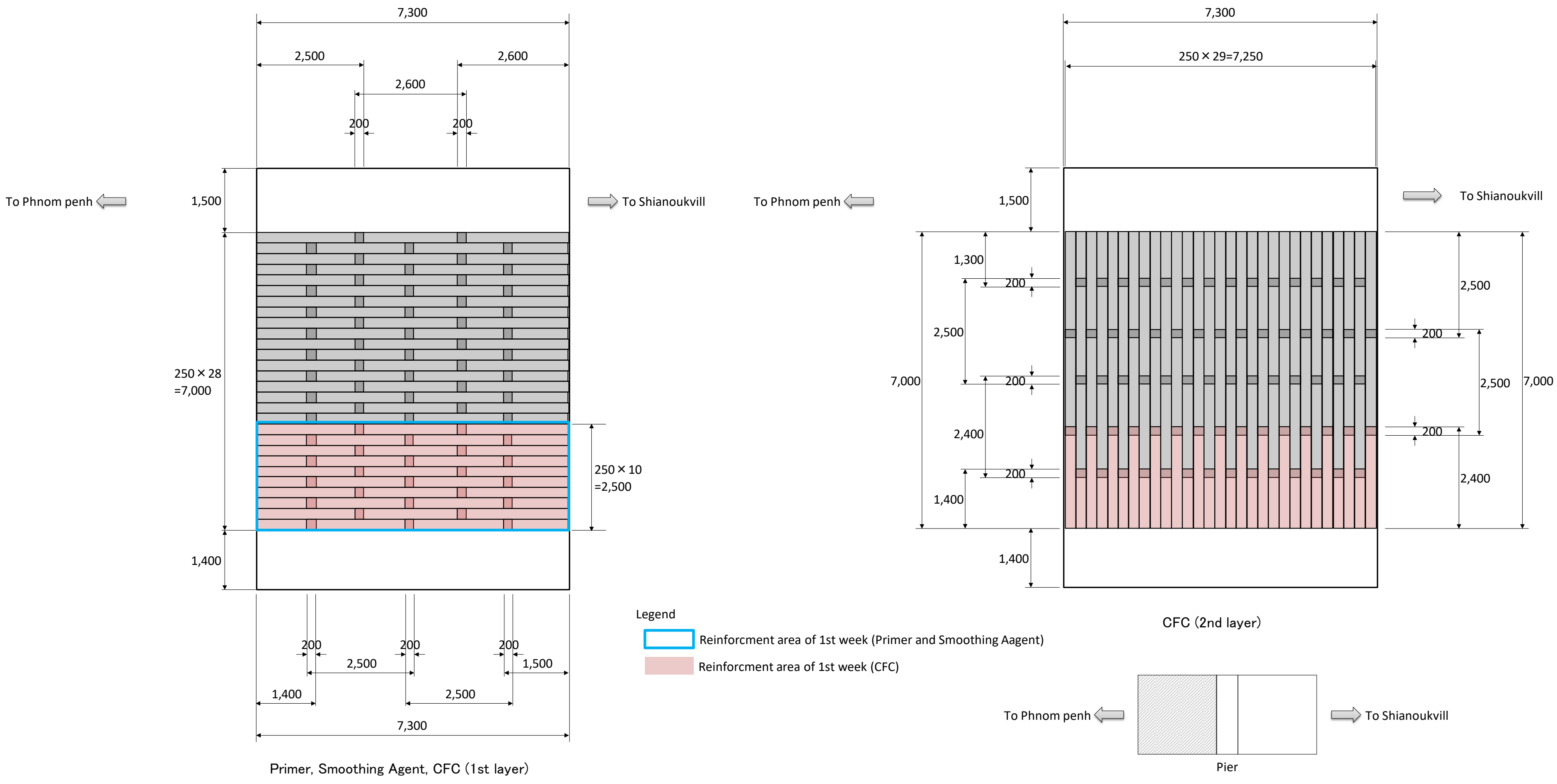


Fig. 5.2.2.7(a) Layout of CFC (1st week work)

Layout of CFC (2nd week work)

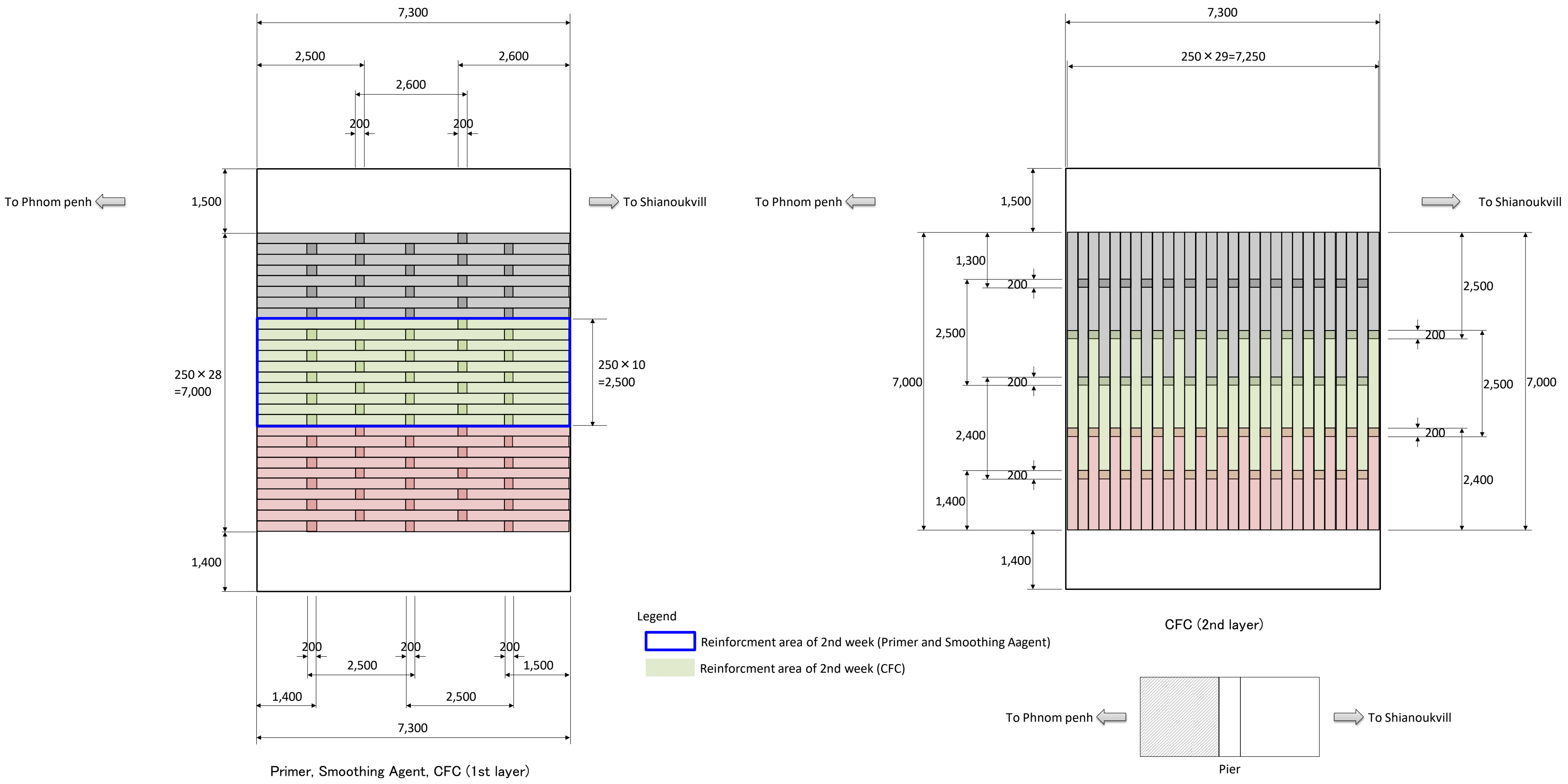


Fig. 5.2.2.7(b) Layout of CFC (2nd week work)

Layout of CFC (3rd week work)

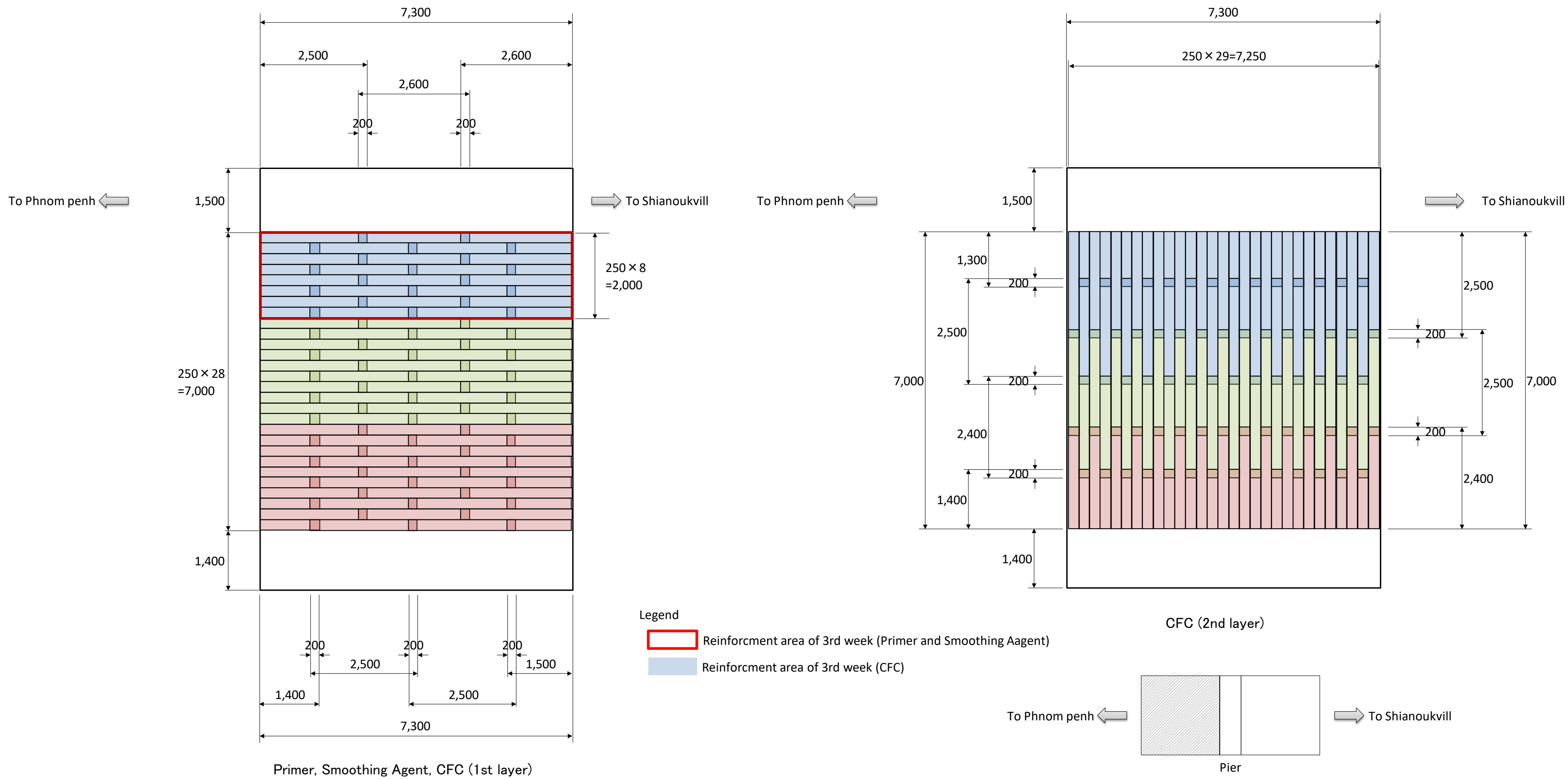


Fig. 5.2.2.7(c) Layout of CFC (3rd week work)

Layout of CFC (4th week work)

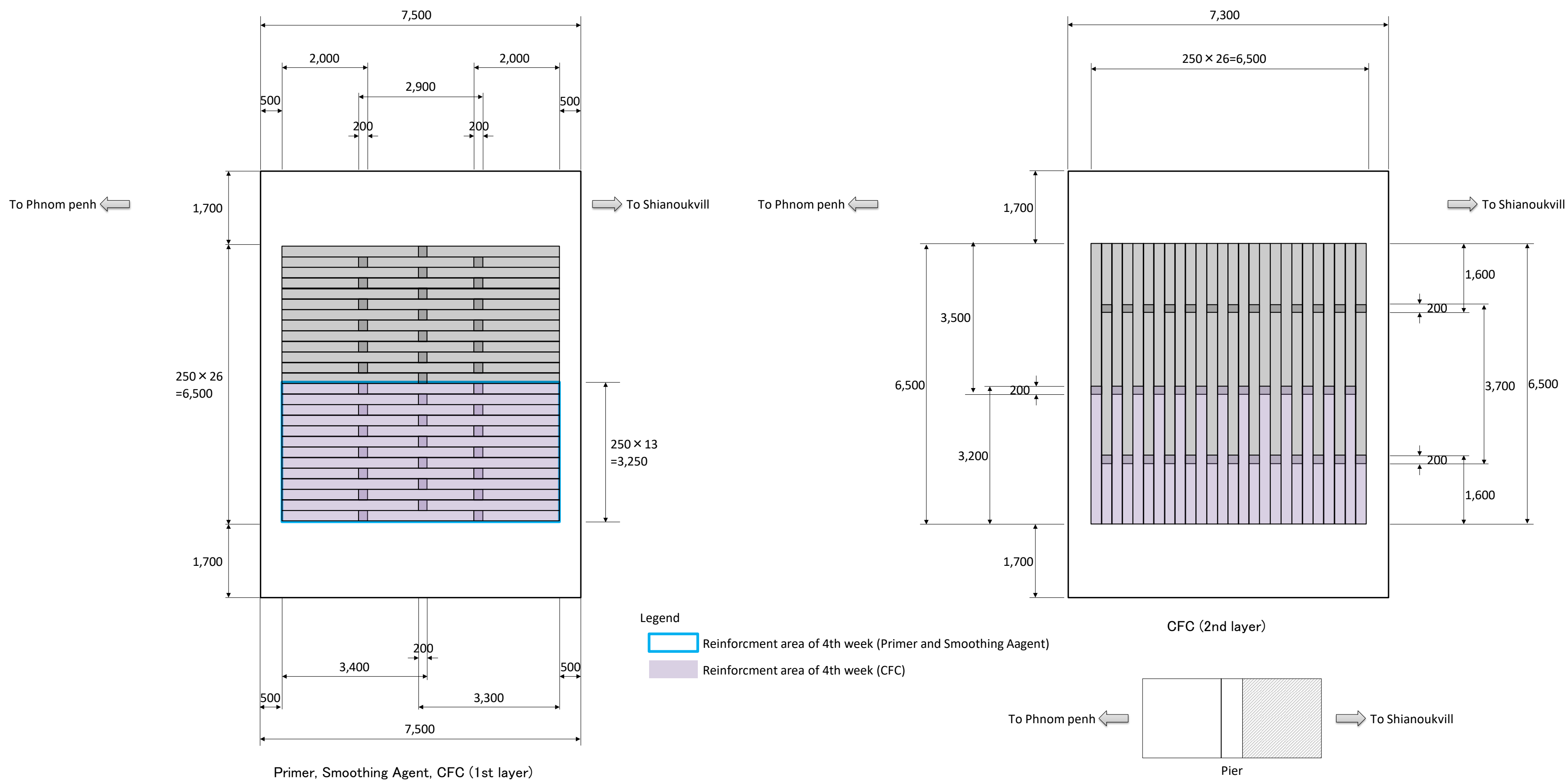
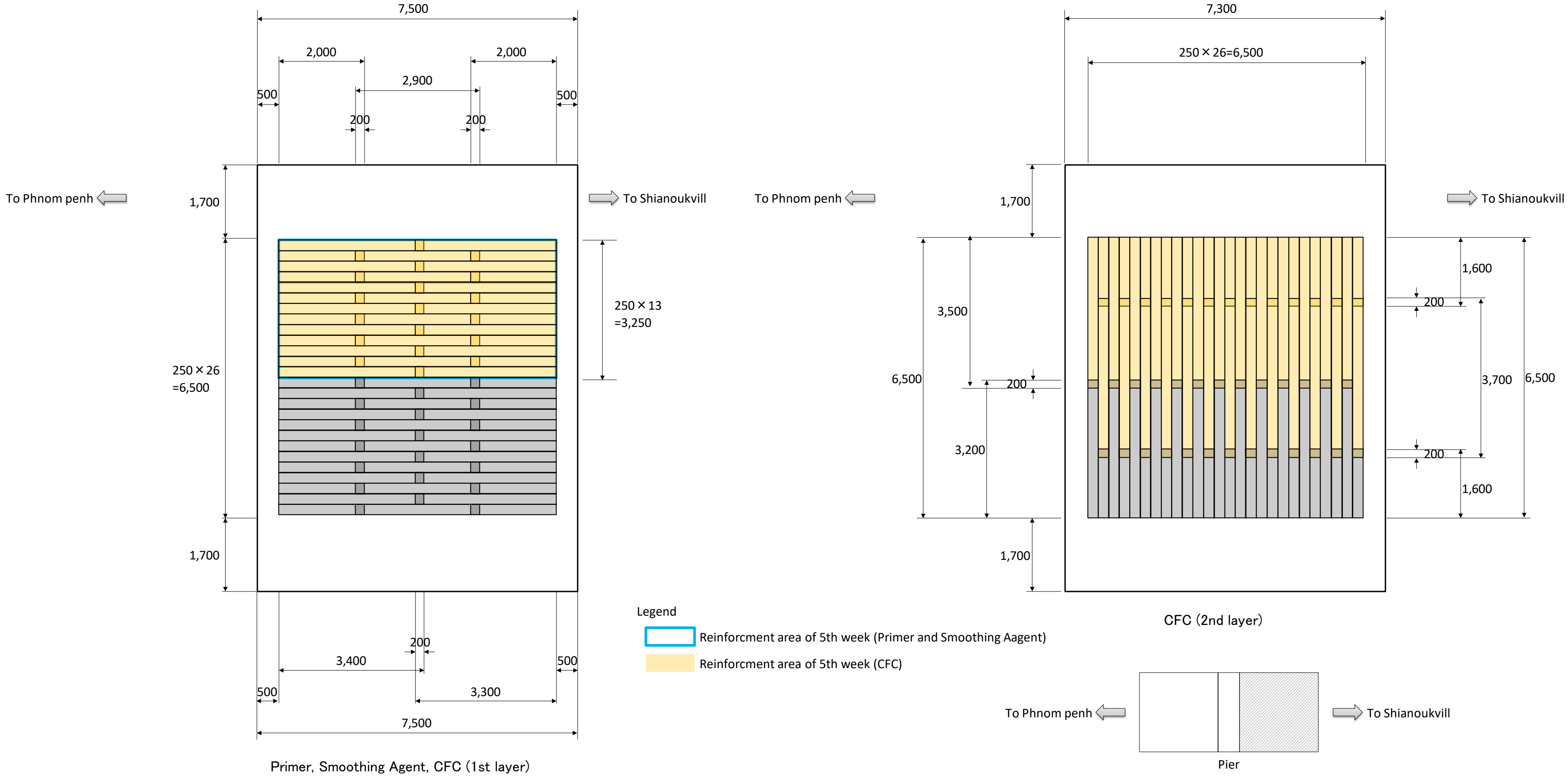


Fig. 5.2.2.7(d) Layout of CFC (4th week work)

Layout of CFC (5th week work)



Primer, Smoothing Agent, CFC (1st layer)

Fig. 5.2.2.7(e) Layout of CFC (5th week work)

●Material use plan

	Procedure	Area	Ability/day	Quantity of Material
Phnom Penh side Total	Primer	7.3m × 7.0m = 51.1m2		0.2kg/m2 Main 7.5kg Hardener 3.7kg (Including Loss 10%)
	Smoothing Agent	7.3m × 7.0m = 51.1m2		1.0kg/m2 Main 37.5kg Hardener 18.7kg (Including Loss 10%)
	CFC(1st layer)	7.3m × 7.0m = 51.1m2		Resin (1.0kg/m2) Main 37.5kg Hardener 18.7kg (Including Loss 10%) CFC 54.6 1.4m × 14 + 1.5m × 14 + 2.5m × 42 + 2.6m × 28
	CFC(2nd layer)	7.3m × 7.0m = 51.1m2		Resin (1.0kg/m2) Main 37.5kg Hardener 18.7kg (Including Loss 10%) CFC 54.35 1.3m × 14 + 1.4m × 14 + 2.4m × 29 + 2.5m × 44
1st week	Primer	7.3m × 2.5m = 18.3m2	46m2/day	0.2kg/m2 Main 2.7kg Hardener 1.3kg (Including Loss 10%)
	Smoothing Agent	7.3m × 2.5m = 18.3m2	24m2/day	1.0kg/m2 Main 13.4kg Hardener 6.7kg (Including Loss 10%)
	CFC(1st layer)	7.3m × 2.5m = 18.3m2	20m2/day	Resin (1.0kg/m2) Main 13.4kg Hardener 6.7kg (Including Loss 10%) CFC 19.5m2 1.4m × 5 + 1.5m × 5 + 2.5m × 15 + 2.6m × 10
	CFC(2nd layer)	(2.4m × 15 + 1.4m × 14) × 0.25m = 13.9m2	20m2/day	Resin (1.0kg/m2) Main 10.2kg Hardener 5.1kg (Including Loss 10%) CFC 13.9m2 1.4m × 14 + 2.4m × 15
2nd week	Primer	7.3m × 2.5m = 18.3m2	46m2/day	0.2kg/m2 Main 2.7kg Hardener 1.3kg (Including Loss 10%)
	Smoothing Agent	7.3m × 2.5m = 18.3m2	24m2/day	1.0kg/m2 Main 13.4kg Hardener 6.7kg (Including Loss 10%)
	CFC(1st layer)	7.3m × 2.5m = 18.3m2	20m2/day	Resin (1.0kg/m2) Main 13.4kg Hardener 6.7kg (Including Loss 10%) CFC 19.5m2 1.4m × 5 + 1.5m × 5 + 2.5m × 15 + 2.6m × 10
	CFC(2nd layer)	(2.5m × 15 + 2.4m × 14) × 0.25m = 17.8m2	20m2/day	Resin (1.0kg/m2) Main 13.0kg Hardener 6.5kg (Including Loss 10%) CFC 17.8m2 2.4m × 14 + 2.5m × 15
3rd week	Primer	7.3m × 2.0m = 14.6m2	46m2/day	0.2kg/m2 Main 2.1kg Hardener 1.1kg (Including Loss 10%)
	Smoothing Agent	7.3m × 2.0m = 14.6m2	24m2/day	1.0kg/m2 Main 10.7kg Hardener 5.4kg (Including Loss 10%)
	CFC(1st layer)	7.3m × 2.0m = 14.6m2	20m2/day	Resin (1.0kg/m2) Main 10.7kg Hardener 5.4kg (Including Loss 10%) CFC 15.6m2 1.4m × 4 + 1.5m × 4 + 2.5m × 12 + 2.6m × 8
	CFC(2nd layer)	(3.6m × 14 + 2.5m × 15) × 0.25m = 22.0m2	20m2/day	Resin (1.0kg/m2) Main 16.1kg Hardener 8.1kg (Including Loss 10%) CFC 22.7m2 1.3m × 14 + 2.5m × 29

CFC Cutting plan

				Remainder	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12	No.13	No.14	No.15	No.16
1st week	1st layer	1.3m		0																
		1.4m	5	0		5														
		1.5m	5	0	4	1														
		2.4m		0																
		2.5m	15	0	7	8														
		2.6m	10	0	10															
	2nd layer	1.3m		0																
		1.4m	14	0		3	11													
		1.5m		0																
		2.4m	15	0		7	8													
		2.5m		0																
		2.6m		0																
2nd week	1st layer	1.3m		0																
		1.4m	5	0			5													
		1.5m	5	0				1	4											
		2.4m		0																
		2.5m	15	0				12	3											
		2.6m	10	0			3	7												
	2nd layer	1.3m		0																
		1.4m		0																
		1.5m		0																
		2.4m	14	0					14											
		2.5m	15	0					1	14										
		2.6m		0																
3rd week	1st layer	1.3m		0																
		1.4m	4	0							4									
		1.5m	4	0						1	3									
		2.4m		0																
		2.5m	12	0							12									
		2.6m	8	0						5	3									
	2nd layer	1.3m	14	0							1	13								
		1.4m		0																
		1.5m		0																
		2.4m		0																
		2.5m	29	0								13	16							
		2.6m		0																
			Remainder of CFC		0.5m	0.5m	0.6m	0.3m	0.4m	0.5m	0.8m	0.6m	10.0m	50.0m	50.0m	50.0m	50.0m	50.0m	50.0m	50.0m

Fig. 5.2.2.8(a) Material use plan (1st-3rd week work)

●Material use plan

	Procedure	Area	Ability/day	Quantity of Material
Shianouk vill side Total	Primer	6.5m × 6.5m = 42.3m2		0.2kg/m2 Main 6.2kg Hardener 3.1kg (Including Loss 10%)
	Smoothing Agent	6.5m × 6.5m = 42.3m2		1.0kg/m2 Main 31.0kg Hardener 15.5kg (Including Loss 10%)
	CFC(1st layer)	6.5m × 6.5m = 42.3m2		Resin (1.0kg/m2) Main 31.0kg Hardener 15.5kg (Including Loss 10%) CFC 44.2 2.0m × 26 + 2.9m × 13 + 3.3m × 13 + 3.4m × 13
	CFC(2nd layer)	6.5m × 6.5m = 42.3m2		Resin (1.0kg/m2) Main 31.0kg Hardener 15.5kg (Including Loss 10%) CFC 44.2 1.6m × 26 + 3.2m × 13 + 3.5m × 13 + 3.7m × 13
4th week	Primer	6.5m × 3.25m = 21.1m2	46m2/day	0.2kg/m2 Main 3.1kg Hardener 1.5kg (Including Loss 10%)
	Smoothing Agent	6.5m × 3.25m = 21.1m2	24m2/day	1.0kg/m2 Main 15.5kg Hardener 7.7kg (Including Loss 10%)
	CFC(1st layer)	6.5m × 3.25m = 21.1m2	20m2/day	Resin (1.0kg/m2) Main 15.5kg Hardener 7.7kg (Including Loss 10%) CFC 22.1m2 2.0m × 14 + 2.9m × 7 + 3.3m × 6 + 3.4m × 6
	CFC(2nd layer)	(1.6m × 13 + 3.2m × 13) × 0.25m = 15.6m2	20m2/day	Resin (1.0kg/m2) Main 11.4kg Hardener 5.7kg (Including Loss 10%) CFC 15.6m2 1.6m × 13 + 3.2m × 13
5th week	Primer	6.5m × 3.25m = 21.1m2	46m2/day	0.2kg/m2 Main 3.1kg Hardener 1.5kg (Including Loss 10%)
	Smoothing Agent	6.5m × 3.25m = 21.1m2	24m2/day	1.0kg/m2 Main 15.5kg Hardener 7.7kg (Including Loss 10%)
	CFC(1st layer)	6.5m × 3.25m = 21.1m2	20m2/day	Resin (1.0kg/m2) Main 15.5kg Hardener 7.7kg (Including Loss 10%) CFC 22.1m2 2.0m × 12 + 2.9m × 6 + 3.3m × 7 + 3.4m × 7
	CFC(2nd layer)	(5.1m × 13 + 3.5m × 13) × 0.25m = 28.0m2	20m2/day	Resin (1.0kg/m2) Main 20.5kg Hardener 10.2kg (Including Loss 10%) CFC 28.6m2 1.6m × 13 + 3.5m × 13 + 3.7m × 13

CFC Cutting plan

				Remainder	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12	No.13	No.14	No.15	No.16
4th week	1st layer	2.0m	14	0									5	9						
		2.9m	7	0										4	3					
		3.3m	6	0										1	5					
		3.4m	6	0										5	1					
	2nd layer	1.6m	13	0											11	1	1			
		3.2m	13	0											1	11	1			
5th week	1st layer	2.0m	12	0												2	6	4		
		2.9m	6	0												2	1	3		
		3.3m	7	0												1	6			
		3.4m	7	0													3	4		
	2nd layer	1.6m	13	0														3	5	5
		3.5m	13	0															12	1
		3.7m	13	0														4		9
			Remainder of CFC		0.5m	0.5m	0.6m	0.3m	0.4m	0.5m	0.8m	0.6m	0.0m	0.1m	0.6m	0.1m	0.3m	0.1m	0.0m	5.2m

Fig. 5.2.2.8(b) Material use plan (4th-5th week work)

●Resin mix plan (1st week)

Loss 5%

Primer

← Total Width 7.3m →

Width 2.2m	Width 1.7m	Width 1.7m	Width 1.7m	
Area 5.5m2	Area 4.3m2	Area 4.3m2	Area 4.3m2	Hight 2.5m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 1.2kg	Total 0.9kg	Total 0.9kg	Total 0.9kg	
Main 0.8kg	Main 0.6kg	Main 0.6kg	Main 0.6kg	
Hardener 0.4kg	Hardener 0.3kg	Hardener 0.3kg	Hardener 0.3kg	

Standard usage weight	0.2kg/m2
Including Loss	5%

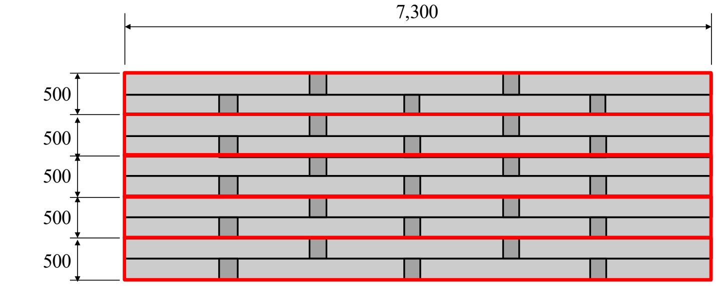
Smoothing Agent

← Total Width 7.3m →

Width 2.2m	Width 1.7m	Width 1.7m	Width 1.7m	
Area 5.5m2	Area 4.3m2	Area 4.3m2	Area 4.3m2	Hight 2.5m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 5.8kg	Total 4.5kg	Total 4.5kg	Total 4.5kg	
Main 4.0kg	Main 3.0kg	Main 3.0kg	Main 3.0kg	
Hardener 2.0kg	Hardener 1.5kg	Hardener 1.5kg	Hardener 1.5kg	

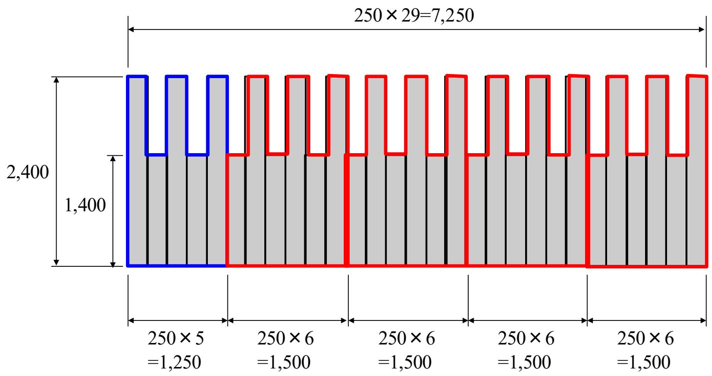
Standard usage weight	1.0kg/m2
Including Loss	5%

Impregnating Resin (1st Layer)



Standard usage weight				1.0kg/m2
	Under Application			0.6kg/m2
	Over Application			0.4kg/m2
Loss				5%
Each cycle (Total 5 cycle)				
Area				
7.3m	×	0.5m	=	3.7m2
Quantity of Material				
	Under Application			
		Total		2.3kg
		Main		1.6kg
		Hardener		0.8kg
	Over Application			
		Total		1.5kg
		Main		1.2kg
		Hardener		0.6kg

Impregnating Resin (2nd Layer)



Standard usage weight				1.0kg/m2
	Under Application			0.6kg/m2
	Over Application			0.4kg/m2
Loss				5%
1st - 4th Cycle				
Area				
(1.4m	+	2.4m)		
	×	3		
	×	0.25m	=	2.9m2
Quantity of Material				
	Under Application			
		Total		1.8kg
		Main		1.2kg
		Hardener		0.6kg
	Over Application			
		Total		1.2kg
		Main		0.8kg
		Hardener		0.4kg
5th Cycle				
Area				
(1.4m	×	2	+	
2.4m	×	3)		
	×	0.25m	=	2.5m2
Quantity of Material				
	Under Application			
		Total		1.6kg
		Main		1.2kg
		Hardener		0.6kg
	Over Application			
		Total		1.1kg
		Main		0.8kg
		Hardener		0.4kg

Fig. 5.2.2.9(a) Resin mix plan (1st week work)

●Resin mix plan (2nd week)

Loss 5%

Primer

← Total Width 7.3m →

Width 2.2m	Width 1.7m	Width 1.7m	Width 1.7m	
Area 4.4m2	Area 3.4m2	Area 3.4m2	Area 3.4m2	Hight 2.0m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 0.9kg	Total 0.7kg	Total 0.7kg	Total 0.7kg	
Main 0.8kg	Main 0.6kg	Main 0.6kg	Main 0.6kg	
Hardener 0.4kg	Hardener 0.3kg	Hardener 0.3kg	Hardener 0.3kg	

Standard usage weight 0.2kg/m2
Including Loss 5%

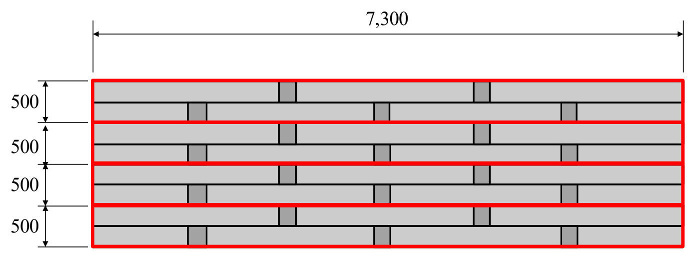
Smoothing Agent

← Total Width 7.3m →

Width 2.2m	Width 1.7m	Width 1.7m	Width 1.7m	
Area 4.4m2	Area 3.4m2	Area 3.4m2	Area 3.4m2	Hight 2.0m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 4.6kg	Total 3.6kg	Total 3.6kg	Total 3.6kg	
Main 3.2kg	Main 2.4kg	Main 2.4kg	Main 2.4kg	
Hardener 1.6kg	Hardener 1.2kg	Hardener 1.2kg	Hardener 1.2kg	

Standard usage weight 1.0kg/m2
Including Loss 5%

Impregnating Resin (1st Layer)

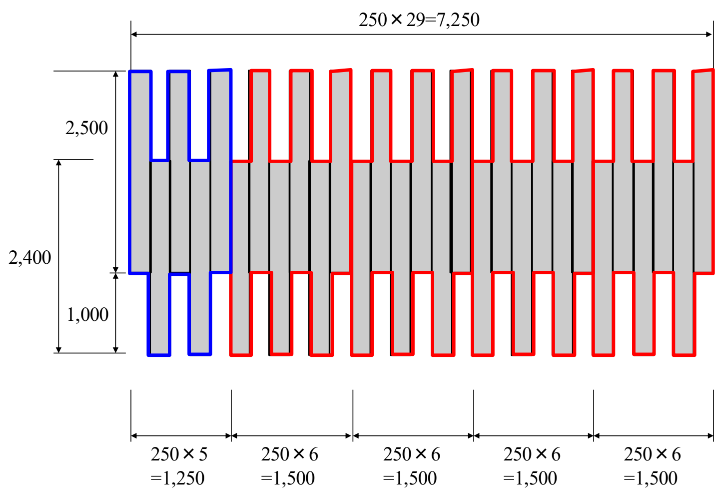


Standard usage weight 1.0kg/m2
Under Application 0.6kg/m2
Over Application 0.4kg/m2
Loss 5%

Each cycle (Total 4 cycle)
Area
7.3m × 0.5m = 3.7m2

Quantity of Material
Under Application
Total 2.3kg
Main 1.6kg
Hardener 0.8kg
Over Application
Total 1.5kg
Main 1.2kg
Hardener 0.6kg

Impregnating Resin (2nd Layer)



Standard usage weight 1.0kg/m2
Under Application 0.6kg/m2
Over Application 0.4kg/m2
Loss 5%

1st - 4th Cycle
Area
(2.5m + 2.4m)
× 3
× 0.25m = 3.7m2

Quantity of Material
Under Application
Total 2.3kg
Main 1.6kg
Hardener 0.8kg
Over Application
Total 1.5kg
Main 1.2kg
Hardener 0.6kg

5th Cycle
Area
(2.5m × 3 +
2.4m × 2)
× 0.25m = 3.1m2

Quantity of Material
Under Application
Total 1.9kg
Main 1.4kg
Hardener 0.7kg
Over Application
Total 1.3kg
Main 1.0kg
Hardener 0.5kg

Fig. 5.2.2.9(b) Resin mix plan (2nd week work)

●Resin mix plan (3rd week)

Loss 5%

Primer

← Total Width 7.3m →

Width 2.2m	Width 1.7m	Width 1.7m	Width 1.7m	
Area 5.5m2	Area 4.3m2	Area 4.3m2	Area 4.3m2	Hight 2.5m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 1.2kg	Total 0.9kg	Total 0.9kg	Total 0.9kg	
Main 0.8kg	Main 0.6kg	Main 0.6kg	Main 0.6kg	
Hardener 0.4kg	Hardener 0.3kg	Hardener 0.3kg	Hardener 0.3kg	

Standard usage weight 0.2kg/m2
Including Loss 5%

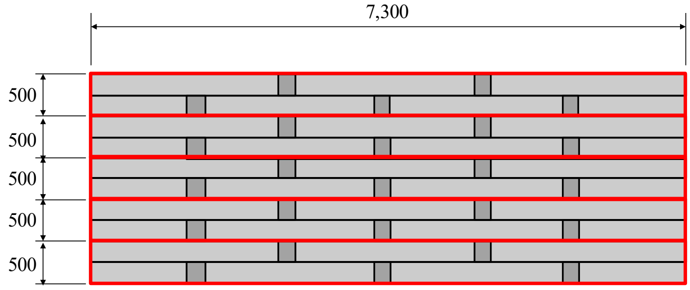
Smoothing Agent

← Total Width 7.3m →

Width 2.2m	Width 1.7m	Width 1.7m	Width 1.7m	
Area 5.5m2	Area 4.3m2	Area 4.3m2	Area 4.3m2	Hight 2.5m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 5.8kg	Total 4.5kg	Total 4.5kg	Total 4.5kg	
Main 4.0kg	Main 3.0kg	Main 3.0kg	Main 3.0kg	
Hardener 2.0kg	Hardener 1.5kg	Hardener 1.5kg	Hardener 1.5kg	

Standard usage weight 1.0kg/m2
Including Loss 5%

Impregnating Resin (1st Layer)

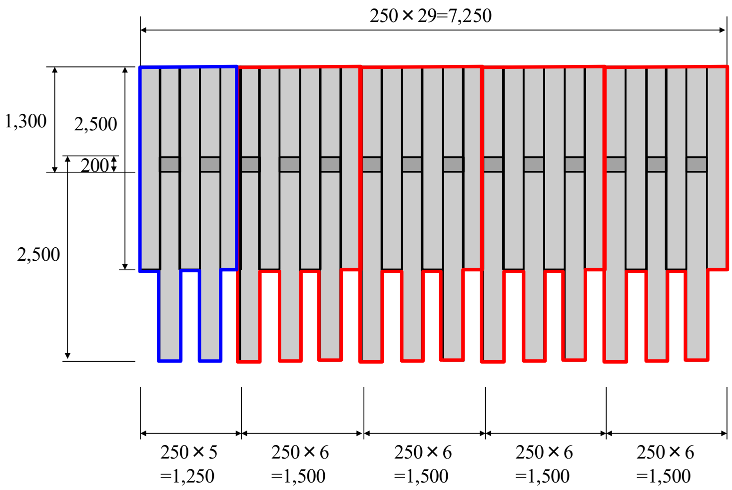


Standard usage weight 1.0kg/m2
Under Application 0.6kg/m2
Over Application 0.4kg/m2
Loss 5%

Each cycle (Total 5 cycle)
Area
7.3m × 0.5m = 3.7m2

Quantity of Material
Under Application
Total 2.3kg
Main 1.6kg
Hardener 0.8kg
Over Application
Total 1.5kg
Main 1.2kg
Hardener 0.6kg

Impregnating Resin (2nd Layer)



Standard usage weight 1.0kg/m2
Under Application 0.6kg/m2
Over Application 0.4kg/m2
Loss 5%

1st - 4th Cycle
Area
(2.5m + 3.6m) × 3 × 0.25m = 4.6m2

Quantity of Material
Under Application
Total 2.9kg
Main 2.0kg
Hardener 1.0kg
Over Application
Total 1.9kg
Main 1.4kg
Hardener 0.7kg

5th Cycle
Area
(2.5m × 3 + 3.6m × 2) × 0.25m = 3.7m2

Quantity of Material
Under Application
Total 2.3kg
Main 1.6kg
Hardener 0.8kg
Over Application
Total 1.5kg
Main 1.2kg
Hardener 0.6kg

Fig. 5.2.2.9(c) Resin mix plan (3rd week work)

●Resin mix plan (4th week)

Loss 5%

Primer

← Total Width 6.5m →

Width 1.6m	Width 1.6m	Width 1.6m	Width 1.7m	↑ Hight 3.25m ↓
Area 5.2m2	Area 5.2m2	Area 5.2m2	Area 5.5m2	
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 1.1kg	Total 1.1kg	Total 1.1kg	Total 1.2kg	
Main 0.8kg	Main 0.8kg	Main 0.8kg	Main 0.8kg	
Hardener 0.4kg	Hardener 0.4kg	Hardener 0.4kg	Hardener 0.4kg	

Standard usage weight 0.2kg/m2
Including Loss 5%

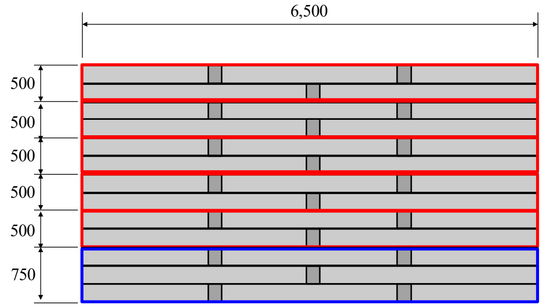
Smoothing Agent

← Total Width 6.5m →

Width 1.6m	Width 1.6m	Width 1.6m	Width 1.7m	↑ Hight 3.25m ↓
Area 5.2m2	Area 5.2m2	Area 5.2m2	Area 5.5m2	
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 5.5kg	Total 5.5kg	Total 5.5kg	Total 5.8kg	
Main 3.8kg	Main 3.8kg	Main 3.8kg	Main 4.0kg	
Hardener 1.9kg	Hardener 1.9kg	Hardener 1.9kg	Hardener 2.0kg	

Standard usage weight 1.0kg/m2
Including Loss 5%

Impregnating Resin (1st Layer)



Standard usage weight 1.0kg/m2
Under Application 0.6kg/m2
Over Application 0.4kg/m2
Loss 5%

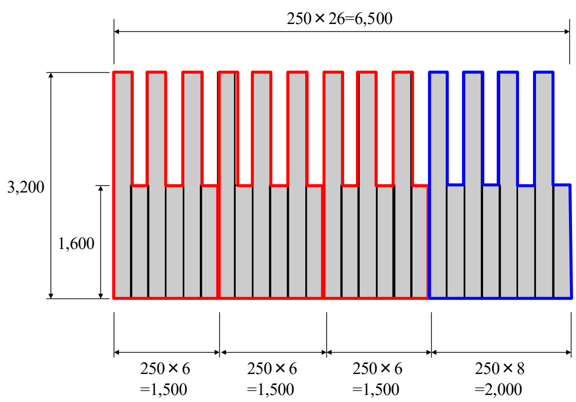
1-5th cycle
Area
6.5m × 0.50m = 3.3m2

Quantity of Material
Under Application
Total 2.0kg
Main 1.4kg
Hardener 0.7kg
Over Application
Total 1.4kg
Main 1.0kg
Hardener 0.5kg

6th cycle
Area
6.5m × 0.75m = 4.9m2

Quantity of Material
Under Application
Total 3.1kg
Main 2.2kg
Hardener 1.1kg
Over Application
Total 2.0kg
Main 1.4kg
Hardener 0.7kg

Impregnating Resin (2nd Layer)



Standard usage weight 1.0kg/m2
Under Application 0.6kg/m2
Over Application 0.4kg/m2
Loss 5%

1st - 3rd Cycle
Area
(1.6m + 3.2m)
× 3
× 0.25m = 3.6m2

Quantity of Material
Under Application
Total 2.3kg
Main 1.6kg
Hardener 0.8kg
Over Application
Total 1.5kg
Main 1.2kg
Hardener 0.6kg

4th Cycle
Area
(1.6m + 3.2m)
× 4
× 0.25m = 4.8m2

Quantity of Material
Under Application
Total 3.0kg
Main 2.2kg
Hardener 1.1kg
Over Application
Total 2.0kg
Main 1.4kg
Hardener 0.7kg

Fig. 5.2.2.9(d) Resin mix plan (4th week work)

●Resin mix plan (5th week)

Loss 5%

Primer

← Total Width 6.5m →

Width 1.6m	Width 1.6m	Width 1.6m	Width 1.7m	
Area 5.2m2	Area 5.2m2	Area 5.2m2	Area 5.5m2	Hight 3.25m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 1.1kg	Total 1.1kg	Total 1.1kg	Total 1.2kg	
Main 0.8kg	Main 0.8kg	Main 0.8kg	Main 0.8kg	
Hardener 0.4kg	Hardener 0.4kg	Hardener 0.4kg	Hardener 0.4kg	

Standard usage weight 0.2kg/m2
Including Loss 5%

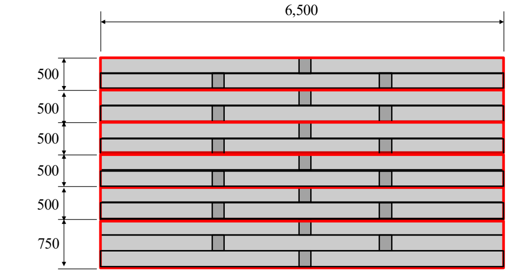
Smoothing Agent

← Total Width 6.5m →

Width 1.6m	Width 1.6m	Width 1.6m	Width 1.7m	
Area 5.2m2	Area 5.2m2	Area 5.2m2	Area 5.5m2	Hight 3.25m
Quantity of Material	Quantity of Material	Quantity of Material	Quantity of Material	
Total 5.5kg	Total 5.5kg	Total 5.5kg	Total 5.8kg	
Main 3.8kg	Main 3.8kg	Main 3.8kg	Main 4.0kg	
Hardener 1.9kg	Hardener 1.9kg	Hardener 1.9kg	Hardener 2.0kg	

Standard usage weight 1.0kg/m2
Including Loss 5%

Impregnating Resin (1st Layer)



Standard usage weight		1.0kg/m2
Under Application		0.6kg/m2
Over Application		0.4kg/m2
Loss		5%

1-5th cycle
Area
6.5m × 0.50m = 3.3m2

Quantity of Material

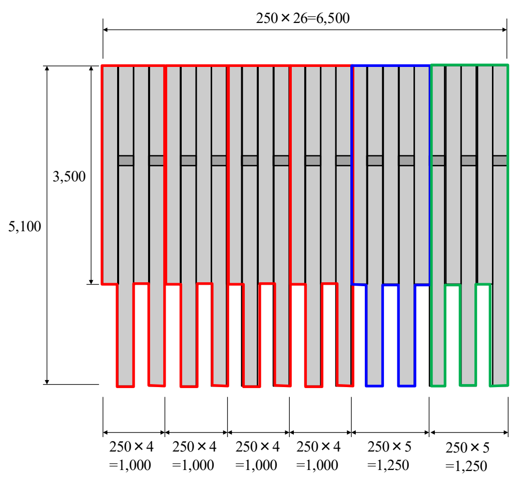
Under Application		
	Total	2.0kg
	Main	1.4kg
	Hardener	0.7kg
Over Application		
	Total	1.4kg
	Main	1.0kg
	Hardener	0.5kg

6th cycle
Area
6.5m × 0.75m = 4.9m2

Quantity of Material

Under Application		
	Total	3.1kg
	Main	2.2kg
	Hardener	1.1kg
Over Application		
	Total	2.0kg
	Main	1.4kg
	Hardener	0.7kg

Impregnating Resin (2nd Layer)



Standard usage weight		1.0kg/m2
Under Application		0.6kg/m2
Over Application		0.4kg/m2
Loss		5%

1st - 4th Cycle
Area
(3.5m + 5.1m) × 2 × 0.25m = 4.3m2

Quantity of Material

Under Application		
	Total	2.7kg
	Main	2.0kg
	Hardener	1.0kg
Over Application		
	Total	1.8kg
	Main	1.4kg
	Hardener	0.7kg

5th Cycle
Area
(3.5m × 3 + 5.1m × 2) × 0.25m = 5.2m2

Quantity of Material

Under Application		
	Total	3.3kg
	Main	2.2kg
	Hardener	1.1kg
Over Application		
	Total	2.2kg
	Main	1.6kg
	Hardener	0.8kg

6th Cycle
Area
(3.5m × 2 + 5.1m × 3) × 0.25m = 5.6m2

Quantity of Material

Under Application		
	Total	3.5kg
	Main	2.4kg
	Hardener	1.2kg
Over Application		
	Total	2.3kg
	Main	1.6kg
	Hardener	0.8kg

Fig. 5.2.2.9(e) Resin mix plan (5th week work)

b) 1st day’s work (Primer work)

1st day’s workflow is shown in **Table 5.2.2.6**.

Table 5.2.2.6 1st day’s workflow of CFC reinforcement

	Contents	Photo	Reference
1	Site meeting		
2	Site cleaning		
3	Confirmation of temperature and surface humidity		1-1)
4	Measurement of constructed range		1-2)
5	Surface cleaning		1-3)
6	Preparation of primer material		
7	Making of primer		1-4)
8	Applying primer		1-5)
9	End		

1-1) Confirmation of temperature and surface humidity

To measure moisture of the concrete surface (**Photo 5.2.2.10**) and if it is more than 8%, dry the concrete surface or postpone primer application work.

It is better to measure about 5 point per 1 span.

Photo 5.2.2.10 To measure moisture of the concrete surface

1-2) Measurement of constructed range

The measurement of constructed range is carried out to mark it (**Photo 5.2.2.11**).

Photo 5.2.2.11 Measurement of constructed range

1-3) Surface cleaning

By using polishing sheet or disk grinder, the dust and dirt is removed from the concrete surface (**Photo 5.2.2.12**).

Photo 5.2.2.12 Surface cleaning

1-4) Making of primer

Primer material consists of 'Main material' and 'Hardener' (**Photo 5.2.2.13**).

Defined amounts of 'Main material' and 'Hardener' are weighed (**Photo 5.2.2.14**) and mixed to uniform texture (about 3 minutes) (**Photo 5.2.2.15**).

(Mixing Ratio (Weight); Main material: Hardener = 2:1)

After the materials are mixed, the material starts to become hard. It is necessary to mix well and use the material within 30 min. after starting mixing time (30 degree Celsius). Therefore, the mixing time (about 3 min.) and using time (30 min.) was measured by using a stopwatch.

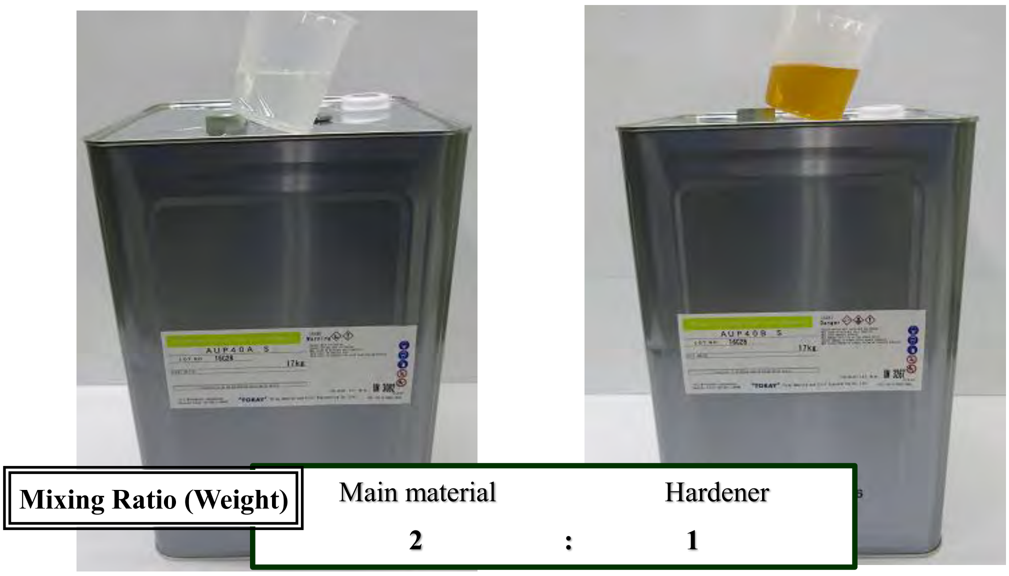


Photo 5.2.2.13 Primer material

Quantity of primer material used 0.9kg/1 time (Main: Hardener = 0.6:0.3)
0.21kg/m^2 (Main: Hardener = 1.4:0.7) (Depend on the worker's skill)

Photo 5.2.2.14 Weighing material (Primer material)

Photo 5.2.2.15 Mixing material (Primer material)

1-5) Applying primer

Uniform amount of primer is applied on the concrete surface by using an application roller or a brush (**Fig. 5.2.2.10**, **Photo 5.2.2.16**).

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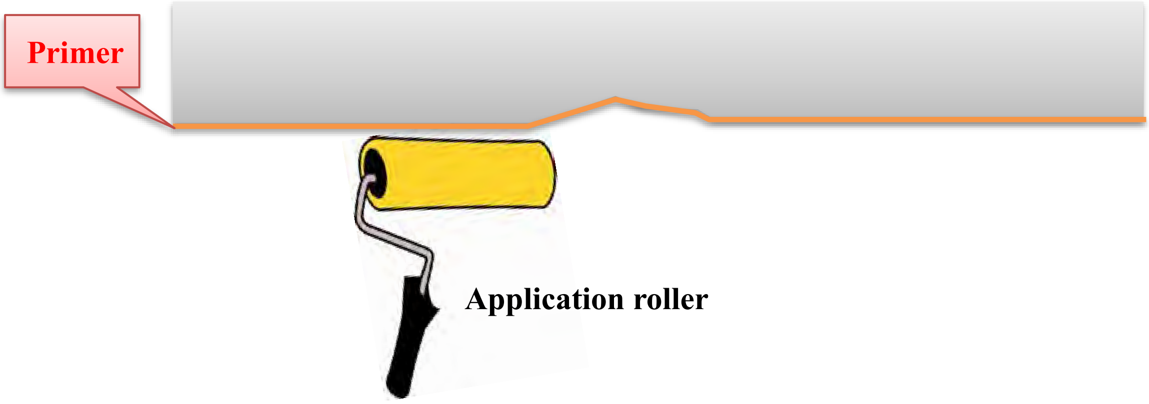


Fig. 5.2.2.10 Applying prime

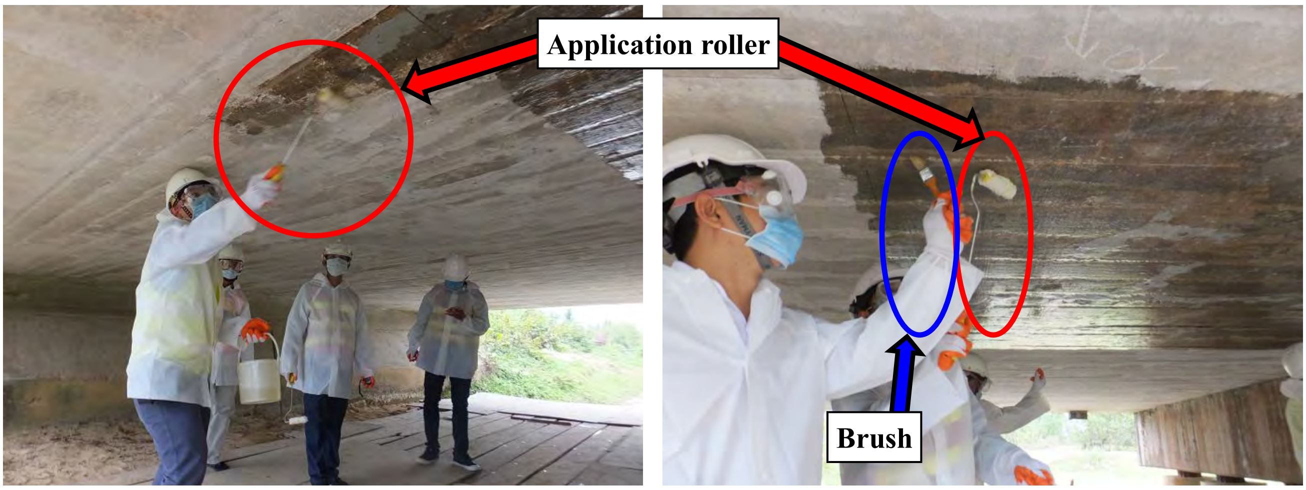


Photo 5.2.2.16 Applying prime

c) 2nd day's work (Smoothing agent work)

2nd day's workflow is shown in **Table 5.2.2.7**.

Table 5.2.2.7 2nd day's workflow of CFC reinforcement

	Contents	Photo	Reference
1	Site meeting		
2	Site cleaning		
3	Confirmation of temperature and surface humidity		
4	Confirmation of primer surface flatness		2-1)
5	Preparation of smoothing agent material		
6	Making of smoothing agent		2-2)
7	Applying smoothing agent		2-3)
8	End		

2-1) Confirmation of primer surface flatness

Before applying smoothing agent, it is needed to confirm primer surface flatness.

If the unevenness is found, it is necessary to remove it as much as possible. (**Photo 5.2.2.17**)

Photo 5.2.2.17 Confirmation of primer surface flatness

2-2) Making of smoothing agent

Smoothing agent material consists of 'Main material' and 'Hardener' (**Photo 5.2.2.18**).

Defined amounts of 'Main material' and 'Hardener' are weighed (**Photo 5.2.2.19**) and mixed to knead up to uniform texture (about 3 minutes) (**Photo 5.2.2.20**).

(Mixing Ratio (Weight); Main material: Hardener = 2:1)

After the materials are mixed, the material starts to become hard. It is necessary to mix well and use the material within 30 min. after starting mixing time (30 degree Celsius). Therefore, the mixing time (about 3 min.) and using time (30 min.) was measured by using a stopwatch.

Photo 5.2.2.18 Smoothing agent material

Quantity of smoothing agent material used 3kg/1 time (Main : Hardener = 2:1) , 1.5kg/m² (Main : Hardener = 1:0.5) (Depend on the worker's skill)

Photo 5.2.2.19 Weighing material (Smoothing agent material)

Photo 5.2.2.20 Mixing material (Smoothing agent material)

2-3) Applying smoothing agent

Smoothing agent is applied on the concrete surface flatten (less than 1mm difference in level) using by spatula or a trowel (**Fig. 5.2.2.11**, **Photo 5.2.2.21**) because surface difference in level or edge of the corner causes bad bonding and break of carbon fiber.

At first, hardening of the primer is confirmed before smoothing agent application.

After the smoothing agent application work is finished, an interval of more than 24 hours is necessary for smoothing agent to become hard (30 degree Celsius).

Fig. 5.2.2.11 Applying smoothing agent

Photo 5.2.2.21 Applying smoothing agent

c) 3^{rd} day's work (1^{st} CFC layer work)

3^{rd} day's workflow is shown in **Table 5.2.2.8**.

Table 5.2.2.8(a) 3^{rd} day's workflow of CFC reinforcement

	Contents	Photo	Reference
1	Site meeting		
2	Site cleaning		
3	Confirmation of temperature and surface humidity		
4	Confirmation of smoothing agent surface flatness		3-1)
5	Measurement of CFC construction range		3-2)
6	Cutting CFC		3-3)
7	Preparation of impregnating resin material		
8	Making of impregnating resin material		3-4)
9	Applying 1st impregnating resin		3-5)

Table 5.2.2.8(b) 3rd day's workflow of CFC reinforcement

	Contents	Photo	Reference
10	Setting CFC		3-6)
11	Pushing out air bubbles by paddle roller		3-7)
12	Applying 1st impregnating resin (once again)		3-8)
13	Applying 2nd impregnating resin (After 20 min of '12' work)		3-9)
14	End		

3-1) Confirmation of smoothing agent surface flatness

Before applying impregnating resin, it is needed to confirm smoothing agent surface flatness.

If the unevenness is found, it is necessary to remove it by using polishing sheet or disk grinder as much as possible. (**Photo 5.2.2.22**)

Photo 5.2.2.22 Confirmation of smoothing agent surface flatness

3-2) Measurement of CFC construction range

The measurement of CFC construction range is carried out to mark it (**Photo 5.2.2.23**).

Photo 5.2.2.23 Measurement of CFC construction range

3-3) Cutting CFC

CFC is cut at a right angle with fiber direction, according to the arrangement plan < example) **Fig. 5.2.2.7(a)-(e)** > by scissors or cutter (**Photo 5.2.2.24**). CFC's length should be including splice length.

Photo 5.2.2.24 Cutting CFC

3-4) Making of impregnating resin material

Impregnating resin material consists of 'Main material' and 'Hardener' (**Photo 5.2.2.25**).

Defined amounts of 'Main material' and 'Hardener' are weighed (**Photo 5.2.2.26**) and mixed to uniform texture by using agitator (about 3 minutes) (**Photo 5.2.2.27**).

(Mixing Ratio (Weight); Main material: Hardener = 2:1)

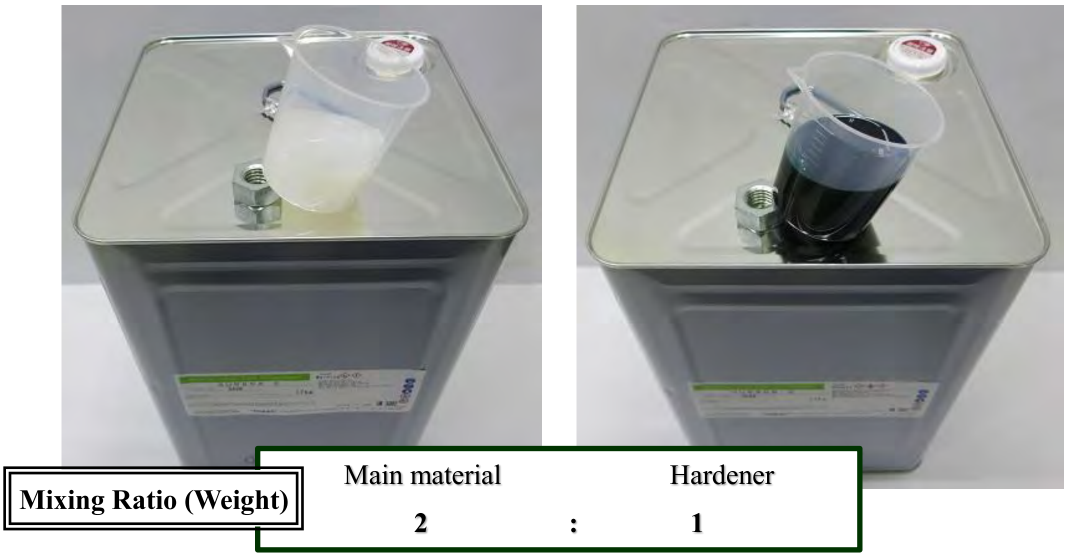


Photo 5.2.2.25 Impregnating resin material

Quantity of impregnating resin material used 2.4kg/1 time (Main : Hardener = 1.6:0.8) , 1.2kg/m^2 (Main : Hardener = 0.8:0.4) (Depend on the worker's skill)

Photo 5.2.2.26 Weighing material (Impregnating resin material)

Photo 5.2.2.27 Mixing material (Impregnating resin)

3-5) Applying 1st impregnating resin

Impregnating resin is applied by using an application roller. (**Fig. 5.2.2.12**, **Photo 5.2.2.28**). Short of impregnating resin causes lack of strength. Therefore impregnating resin must be applied sufficient amount.

<u>After the applying 1st impregnating resin work is finished, an interval of less than 24 hours is necessary to become hard (30 degree Celsius) until next work.</u>

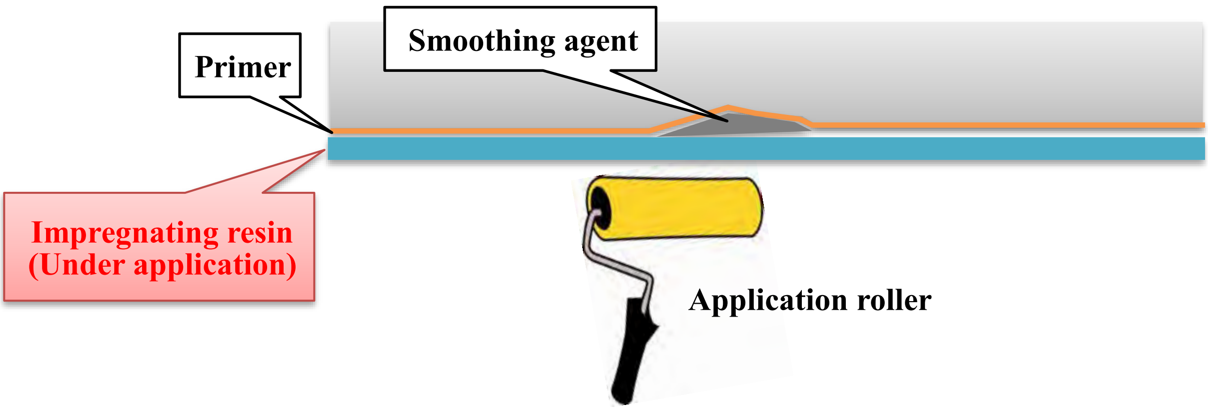


Fig. 5.2.2.12 Applying 1st impregnating resin

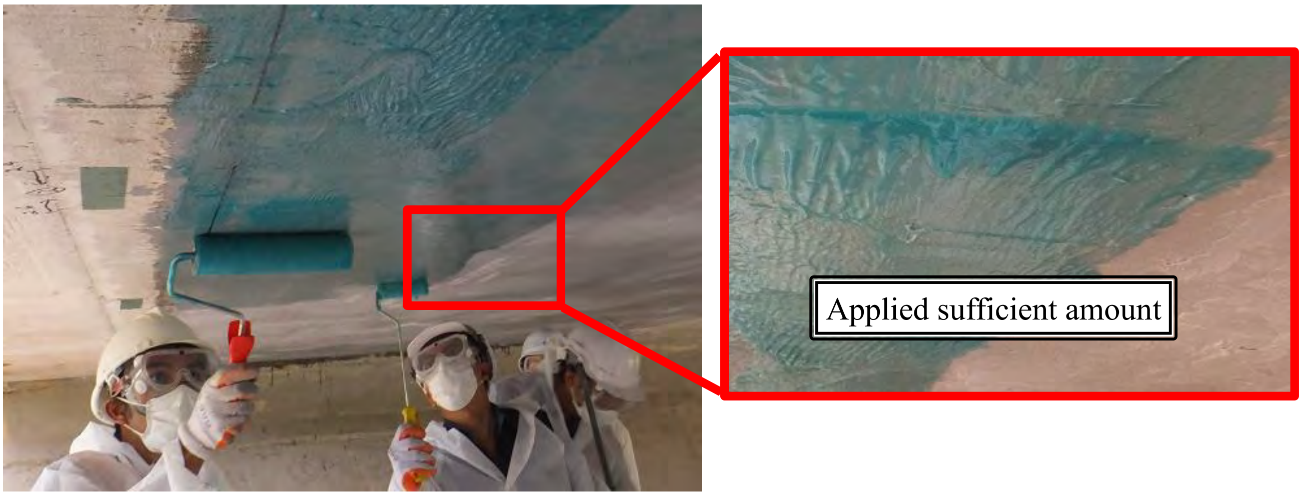


Photo 5.2.2.28 Applying 1st impregnating resin

3-6) Setting CFC

CFC arrangement plan (Including splice length.) should be prepared before site work (**Fig. 5.2.2.7(a)-(e)**).

And CFC is set on the under applying impregnating resin along the marking plan (**Photo 5.2.2.29**).

Photo 5.2.2.29 Setting CFC

3-7) Pushing out air bubbles by paddle roller

CFC should be pushed by using a paddle roller in order to push out air bubbles into CFC. (**Fig. 5.2.2.13**, **Photo 5.2.2.30**) At that time, the impregnation roller is rolled along the fiber direction.

<u>Pushing out air bubbles work should be finished less than 24 hours from setting CFC to become hard (30 degree Celsius).</u>

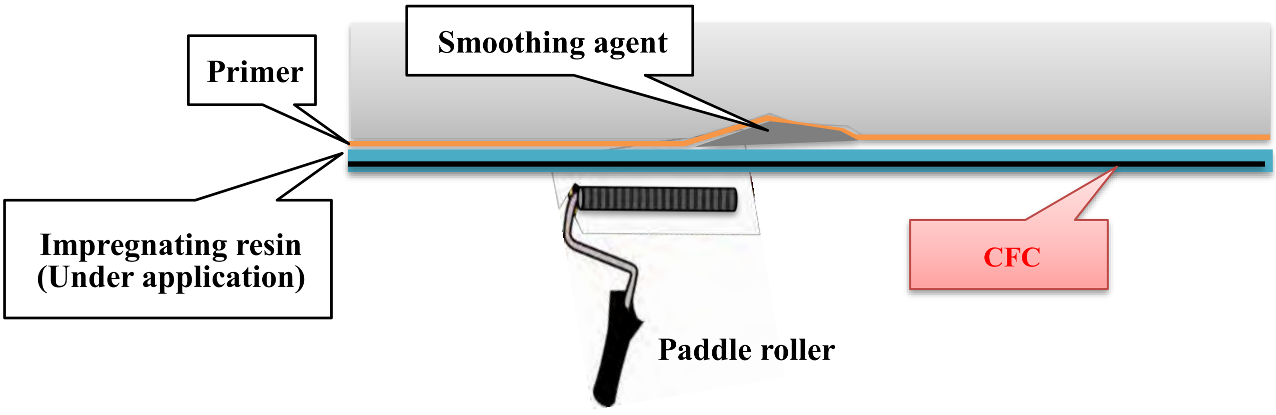


Fig. 5.2.2.13 Pushing out air bubbles by paddle roller

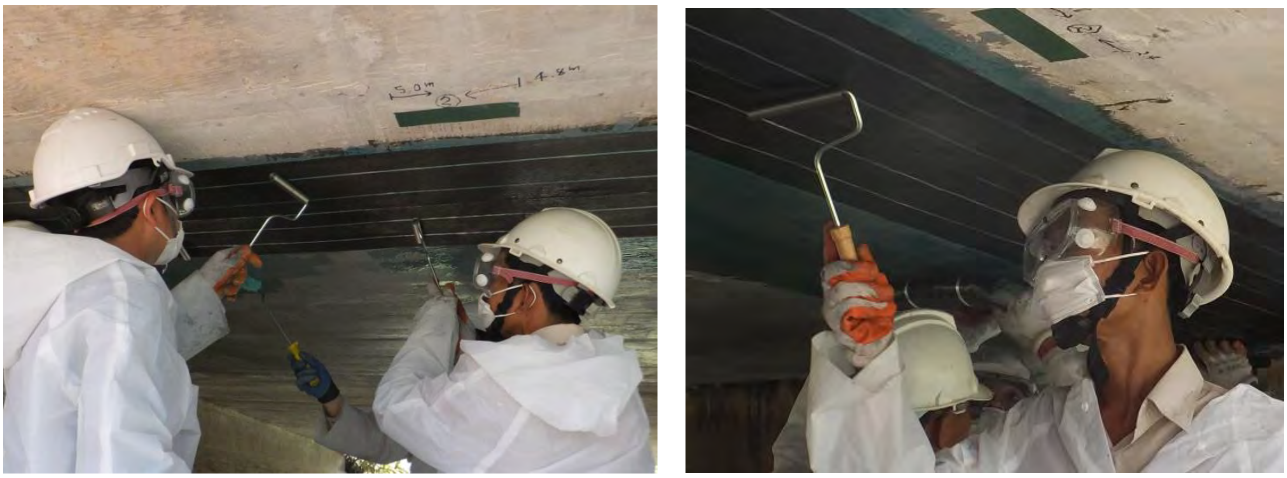
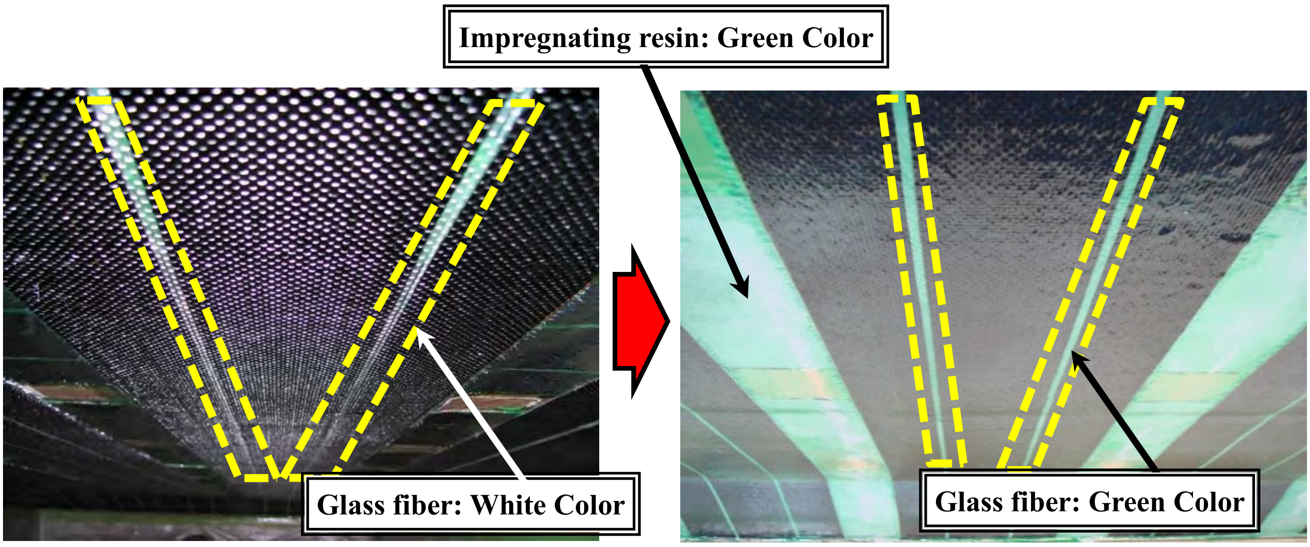


Photo 5.2.2.30 Pushing out air bubbles by paddle roller

If CFC is impregnated by impregnating resin, color of glass fiber in CFC turns to resin color. (**Photo 5.2.2.31**) So, please check glass fiber color after pushing out air bubbles.



(a) Before pushing out air by paddle roller **(b) After pushing out air by paddle roller**

Photo 5.2.2.31 Turning glass fiber color

3-8) Applying 1st impregnating resin (once again)

The impregnating resin is applied again for applied sufficient amount (**Photo 5.2.2.32**).

Photo 5.2.2.32 Applying 1st impregnating resin (once again)

3-9) Applying 2nd impregnating resin (After 20 min of '3-8)' work)

Impregnating resin material of 2nd layer consists of same to that of 1st layer. <Reference: 3-5) > Therefore defined amounts of 'Main material' and 'Hardener' are same weighed.

2nd impregnating resin is applied by using an application roller. (**Fig. 5.2.2.14**, **Photo 5.2.2.33**). Be careful not to move the CRC when applying. And check the usage limit time of 2nd impregnating resin.

After the 2nd impregnating resin application work is finished, an interval of more than 24 hours is necessary for 2nd impregnating resin to become hard (30 degree Celsius).

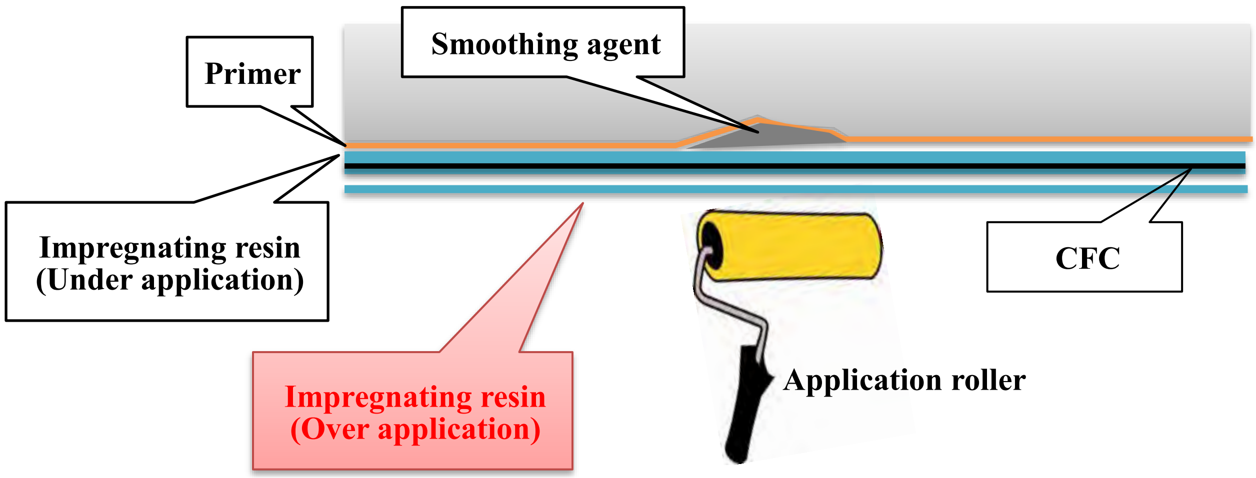


Fig. 5.2.2.14 Applying 2nd impregnating resin

Photo 5.2.2.33 Applying 2nd impregnating resin

d) 4^{th} day's work (2^{nd} CFC layer work)

4^{th} day's workflow is shown in **Table 5.2.2.9**.

Table 5.2.2.9(a) 4^{th} day's workflow of CFC reinforcement

	Contents	Photo	Reference
1	Site meeting		
2	Site cleaning		
3	Confirmation of temperature and surface humidity		
4	Confirmation of pushing out air bubbles		4-1)
5	Repairing after completely cured impregnating resin (If necessary from 4 work)		4-2)
6	Confirmation of impregnating resin surface flatness		4-3)
7	Measurement of CFC construction range		4-4)
8	Cutting CFC		
9	Preparation of impregnating resin material		

Table 5.2.2.9(b) 4th day's workflow of CFC reinforcement

	Contents	Photo	Reference
10	Making of impregnating resin material		4-5)
11	Applying 1st impregnating resin		4-6)
12	Setting CFC		4-7)
13	Pushing out air bubbles		4-8)
14	Applying 1st impregnating resin (once again)		
15	Applying 2nd impregnating resin (After 20 min of '14' work)		4-9)
16	End		

4-1) Confirmation of pushing out air bubbles

Before applying impregnating resin of 2nd CFC layer, it is needed to confirm of pushing out air bubbles of 1st CFC layer (**Photo 5.2.2.34**).

If the peeling is found, it is necessary to repair of this part < Reference: 4-2) >.

Photo 5.2.2.34 Confirmation of pushing out air bubbles

4-2) Repairing after completely cured impregnating resin

If the peeling is found from 4-1) work, it is necessary to repair this part (**Photo 5.2.2.35**).

1) The failure part is removed carefully by using disk grinder.

2) It is backfilled by impregnation resin.

3) CFC patch is overlapped with impregnation resin.

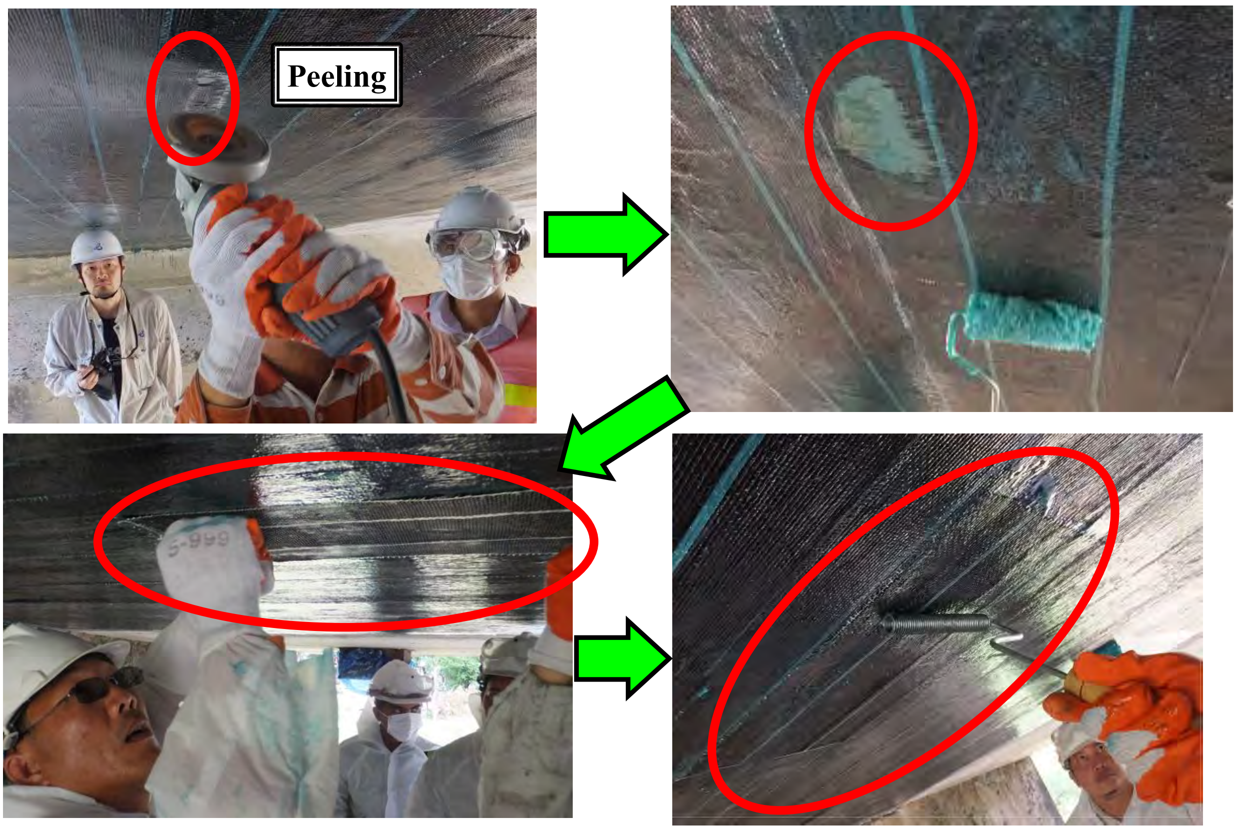


Photo 5.2.2.35 Repairing after completely cured impregnating resin

4-3) Confirmation of impregnating resin surface flatness

It is needed to confirm impregnating resin surface flatness.

If the unevenness is found, it is necessary to remove it by using polishing sheet or disk grinder as much as possible. (**Photo 5.2.2.36**)

Photo 5.2.2.36 Confirmation of impregnating resin surface flatness

4-4) Measurement of CFC construction range

The measurement of CFC construction range is carried out to mark it (**Photo 5.2.2.37**).

Photo 5.2.2.37 Measurement of CFC construction range

4-5) Making of impregnating resin material

Impregnating resin material is prepared < Reference: 3-4) >.

4-6) Applying 1st impregnating resin

Impregnating resin is applied by using an application roller. < Reference: 3-5) >.

4-7) Setting CFC

CFC arrangement plan (Including splice length.) should be prepared before site work < Reference: 3-6) >.

4-8) Pushing out air bubbles

CFC should be pushed by using a paddle roller in order to push out air bubbles into CFC < Reference: 3-7) >.

4-9) Applying 2nd impregnating resin (After 20 min of '14' work)

Impregnating resin material of 2nd layer consists of same to that of 1st layer < Reference: 3-9) >.

The completion status of this repair method is shown to **Photo 5.2.2.38**.

Photo 5.2.2.38 Completion

(d) Remarks

If the peeling of CFC is found out after completion of reinforcement work, it should be repaired partially.

.

a) Repairing at the initial curing (**Fig 5.2.2.15**)

1) It is cut several locations into the fiber direction on the surface by using box cutter.

2) 'Impregnating resin' is applied from the surface by using a brush or spatula.

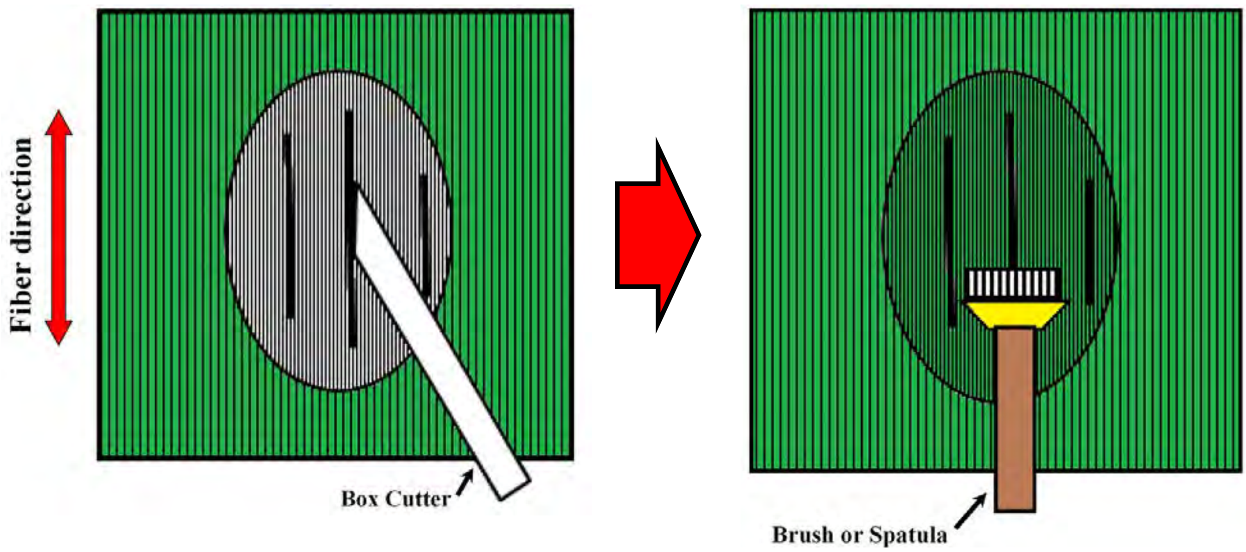


Fig 5.2.2.15 Repairing at the initial curing

b) Repairing after completely cured (**Fig 5.2.2.16**)

If the peeling of CFC is found out after completely cured, it should be cut open and patched.

1) The failure part is removed carefully.

2) It is backfilled by the smoothing agent.

3) CFC patch is overlapped with impregnation resin. (CFC patch is same number of layer as the original CFC)

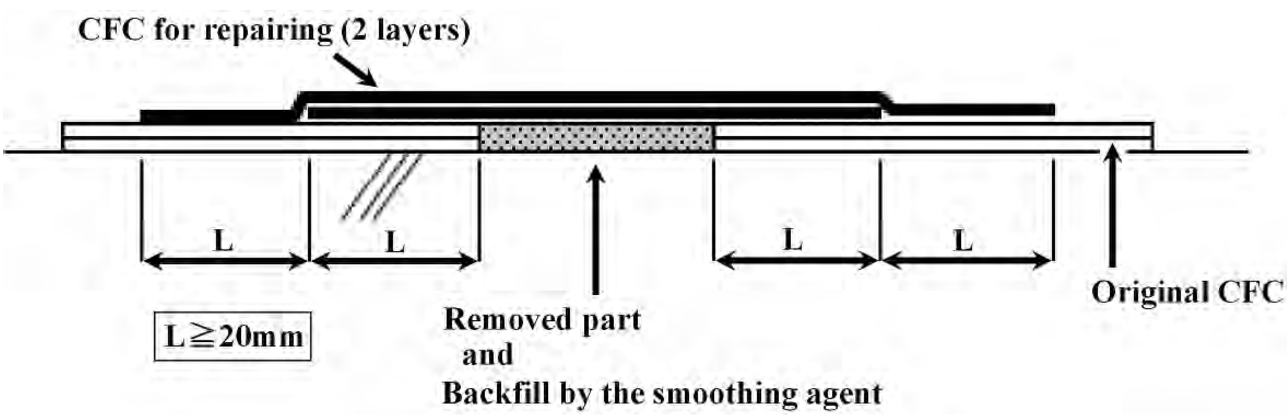


Fig 5.2.2.16 Repairing at the initial curing

Please pay attention to electric shock because CFC conducts electricity (**Fig 5.2.2.17**). And if there is electric wire near work space, it should be covered and sealed.

Fig 5.2.2.17 Patching repair method

C-3 Corrosion of reinforcement in concrete pier column

(a) Conditions

Concrete pieces were damaged to exfoliate from the column of rigid frame (**Photo 5.2.3.1**).

Through the hammer-tapping off the damaged concrete, corrosion on the RE-bars and rust float were observed along the hoop (**Photo 5.2.3.2** and **Photo 5.2.3.3**).

Photo 5.2.3.1 General view of damaged part

Photo 5.2.3.2 Concrete flake-off

Photo 5.2.3.3 Exposed RE-bars and concrete flake-off

(b) Possible Causes

The pier columns were made much higher than other columns to cross over the elevated railroad. It is speculated, in such a height, that conditions caused improper concrete placement, coarse aggregate segregation, and insufficient compaction.

Corrosion on RE-bars initiated because of the existence of honeycomb in concrete, insufficient thickness of covering concrete where cracks generate, ingress of rainwater. Such corrosion is understood to have caused the exfoliation and dropping of concrete.

In heavily exfoliated area, the honeycomb repairs with mortar had been experienced. Some of these repair patches caused exfoliation probably due to difference in material properties or vibration.

(c) Outline of repair

The honeycomb in concrete was completely chipped off. The chipped areas were covered by epoxy putty sealant with grout infection (**Photo 5.2.3.4** and **Photo 5.2.3.5**).

Photo 5.2.3.4 Repair by putty sealant

Photo 5.2.3.5 Grout injection hole provided

To prevent the concrete exfoliation, steel plates (4.5mm thick) were affixed on the concrete surface (**Fig. 5.2.3.1**, **Photo 5.2.3.6**).

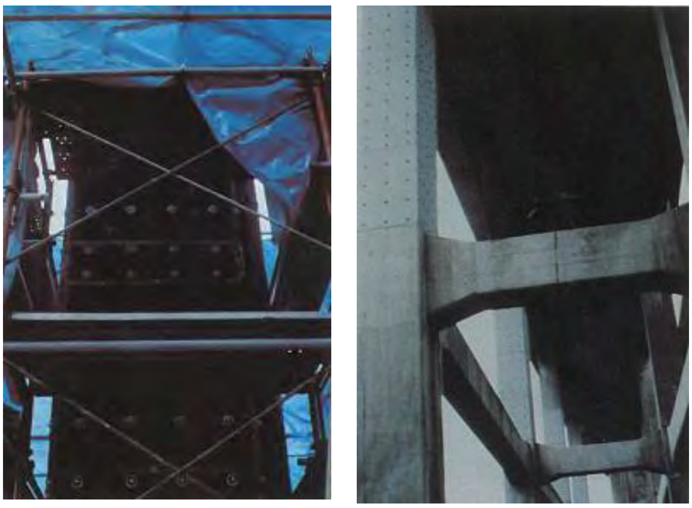


Photo 5.2.3.6 Steel plates affixed

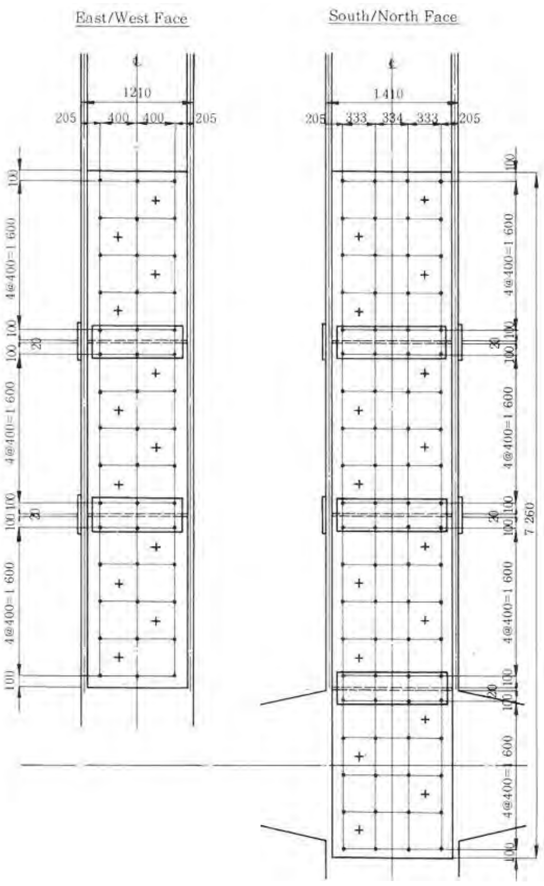


Fig. 5.2.3.1 Steel plates affixed

C-4 Damages on concrete pier plinth

(a) Conditions

The pier was designed to support the simple composite steel I-girder bridge (29m in span) on one side and another simple composite steel H-girder (19m in span) on the other, making 804mm level difference on the pier to top (**Fig. 5.2.4.1**).

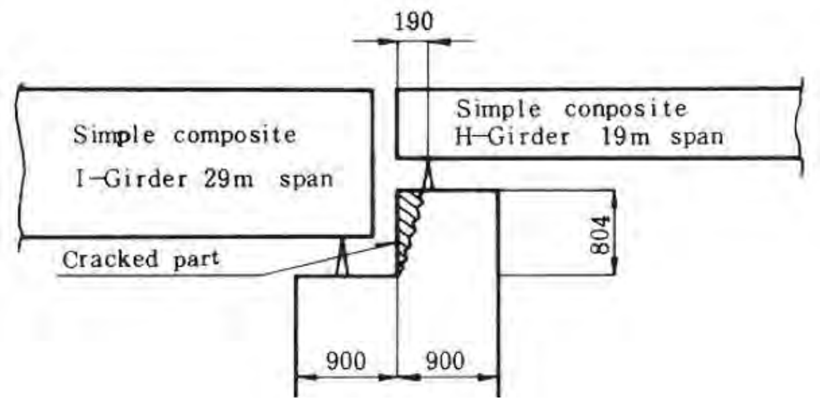


Fig. 5.2.4.1 Damaged position of concrete pier

Cracking initiated near the bearing and the partial concrete spalling took place in the pier top (**Photo 5.2.4.1**).

(a)Level-different plinth **(b)Bearing bed** **(c)Beam part** **(d)Beam end part**

Photo 5.2.4.1 Damages on concrete base

(b) Possible Causes

(1) The girder seat length was only 190mm from the bearing center. This length was insufficient for supporting the horizontal forces in the longitudinal direction. It was assumed, therefore, the shear force fractured the concrete base.

(2) With too much reinforcement clustered in the concrete base, concrete strength was not sufficient:

(a) Insufficient compaction during the concrete placement.

(b) Irregular arrangement of the reinforcement because of the presence of anchor bolts.

(3) The current design standard requires the seat length not to be less than 200mm for the staggered beam (**Fig.5.2.4.2**). In this condition, the staggered beam exhibits strong enough against the shearing force.

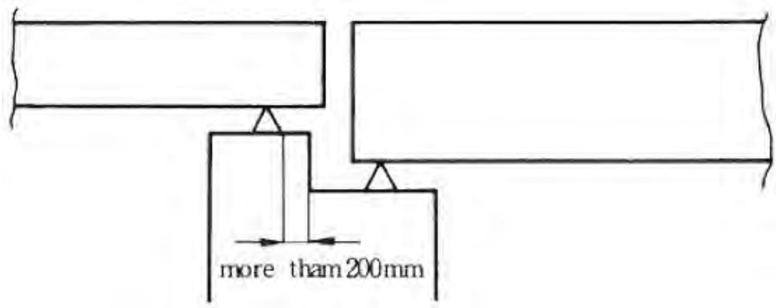


Fig. 5.2.4.2 Required seat length

(c) Outline of repairs

Fig.5.2.4.3 shows the repairing method of the damaged part of concrete base, with attaching steel plate. The steel plate serves dual purpose, reinforcement and form for concrete. The procedures taken in this repair is as follows.

(1) Install L-shape steel member to the girder web at the jacking position, reinforcing the temporary support for the bearing (**Fig. 5.2.4.4**).

(2) Install jacks (two sets of 100 ton hydraulic jacks) as temporary support.

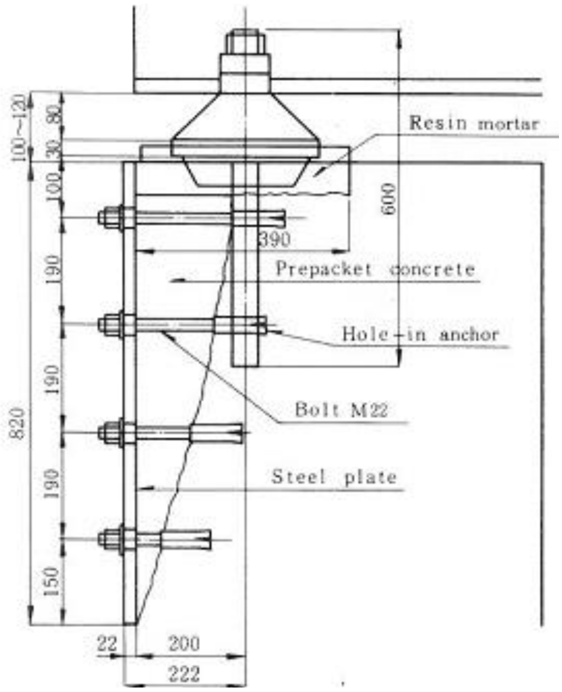


Fig. 5.2.4.3 Required bed edge distance

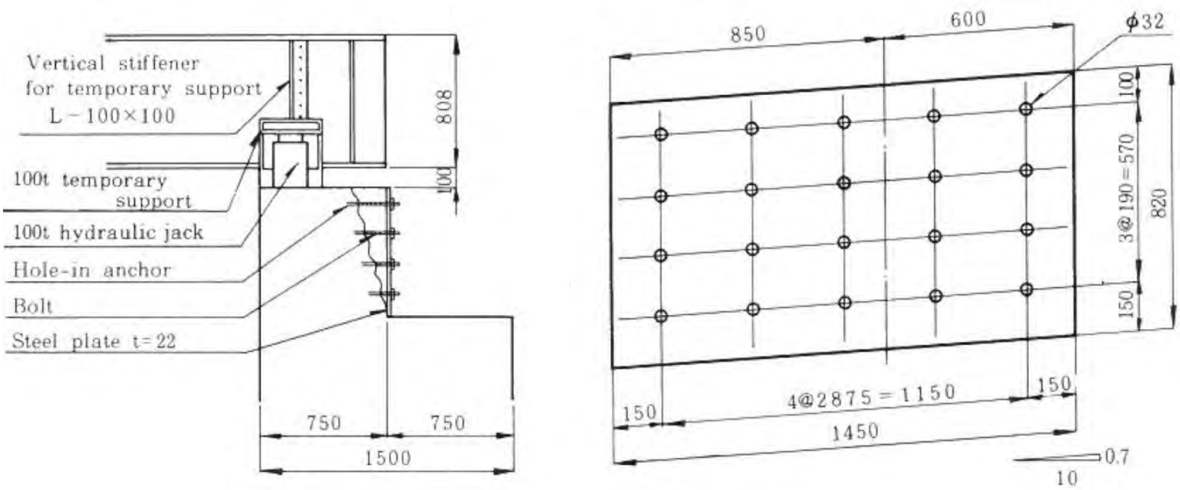


Fig. 5.2.4.4 Steel plate for reinforcement of pier plinth

(3) Jack up (**Photo 5.2.4.2**).

(4) Remove the damaged concrete part (**Photo 5.2.4.3**).

Photo 5.2.4.2 Temporary support by jack up

Photo 5.2.4.3 Damaged concrete chipped off

(5) Place hole-in anchors (**Fig.5.2.4.4**)

(6) Arrange reinforcement and install steel plate (**Photo 5.3.4.4**)

(7) Seal around the steel plate and the hole in anchors.

(8) Place prepacked concrete. Epoxy resin was injected as bonding material from the pier top after filing up the aggregate (**Photo 5.2.4.5**).

(9) Curing.

(10) Adjust the bearing position (height and level).

(11) Place mortar for bearing.

(12) Curing.

(13) Paint of the face plate (**Photo 5.2.4.6**).

Photo 5.2.4.4 Steel plate being mounted

Photo 5.2.4.5 Poring epoxy resin

Photo 5.2.4.6 Reinforcing steel plate painted

C-5 Cavity in the lower flange

(a) Condition

PC girder (Post-tensioned or Pre-stressed Concrete) was found to have cavity at a mid-span part in a lower flange (**Photo 5.2.5.1**). The hammer-tapping around the cavity broke off the concrete cover in about 30cm×100cm area exposed sheaths (**Photo 5.2.5.2**).

Photo 5.2.5.1 Cavity in flange

Photo 5.2.5.2 Condition after hammer-tapping

(b) Possible Causes

The damaged area and its surroundings had concrete paste. The possible cause was understood as insufficient compaction of concrete and lack of cover concrete thickness for the sheaths.

(c) Outline of repairs

Repair was carried out first by hammering and removing the damaged concrete, then by placing a putty sealant, and lastly by filling the cavity with epoxy resin mortar (**Photo 5.2.5.3**).

(a)Epoxy resin applied for the repair

(b)Repair working

Photo 5.2.5.3 Damage repair

(d) Remarks

The repair was performed without traffic suspension, and it was structurally doubtful if such repair was applied for pre-stressed concrete. In this case, insufficient fabrication workmanship of the main girder caused the defect. From now on, therefore, it is required to be much more careful for the sheaths arrangement and concrete quality control, especially of compaction, of the girder fabrication.

C-6 Water leakage from the lower flange

Photo 5.2.6.1 Deposit of free hanging like icicles

(a) Conditions

Efflorescence flowed out from the lower flange at a mid-span of the posttensioned pre-stressed concrete girder, its deposit hanging like icicles from the lower flange (**Photo 5.2.6.1**).

(b) Possible Causes

(1) In search of cause, from the road surface fluorescent paint material was poured over the damaged area. The paint flowed out from the damaged position of the lower flange of the girder, evidencing that the rainwater of road surface was penetrating into the girder.

(2) The leakage was located about 8.5m to the mid-span from the girder end (**Fig. 5.2.6.1**). It was judged it originated from C3 and C4 sheaths (**Fig. 5.2.6.2**).

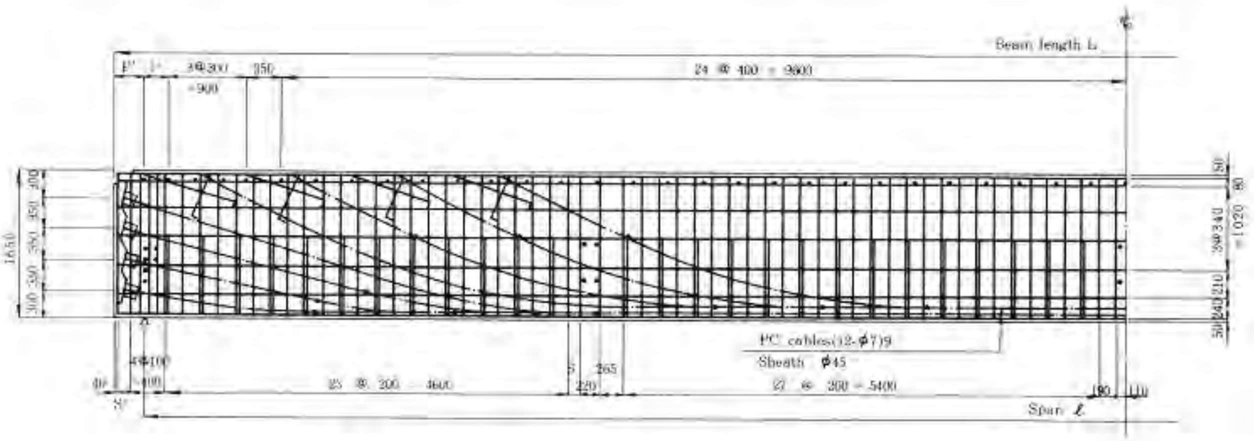


Fig. 5.2.6.1 Side view of main girder

(3) To confirm the grouting workmanship, soffit concrete portion was removed (**Fig. 5.2.6.2**). The sheath was easily broken when it was hammered.

(4) The site investigation revealed corrosion of PC steel wire and seepage of a small amount of water from the C4 sheath. It was assumed the rainwater came in from the girder end, penetrated the C4 sheath, and came out from the damage position.

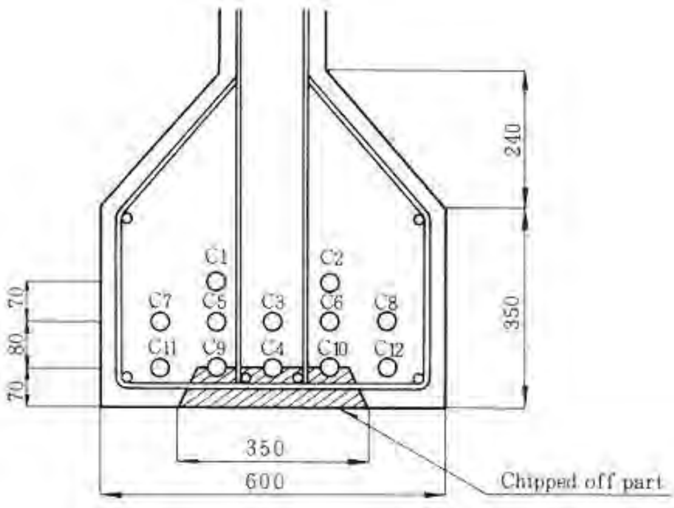


Fig. 5.2.6.2 Chipped part and arrangement of sheaths

(5) The cause for the damage was insufficient grouting work of sheath at the construction stage and subsequent rainwater.

Photo 5.2.6.2 Steel wire exposed by hammering

Photo 5.2.6.3 Lower flange after chipping-off

(c) Outline of repairs

The sheath location was identified by means of ultrasonic wave transmitted across the main girder section in the thickness direction.

To confirm of the sheath position in relation with the girder size, holes were drilled outside at the sheath position.

Grout filling was carried out through the holes, starting from the mid-span, until the grouting material flowed out from the inspection holes.

The repair was complete with the resin filling of inspection holes and the restoration of the gauged girder with resin.

(d) Remarks

(1) At the end of pre-stressed concrete girder, a number of PC steel cables were bent up and anchored on the deck surface (**Fig. 5.2.6.1**). With an insufficient grouting in the sheath, the rainwater came in through the pavement, entered the sheath from the anchoring position, and moved to the mid-span parts where it stayed.

(2) The mid-span was crowded with many PC cables, and the rainwater in the sheath would have damaged the lower flange concrete. (**Fig. 5.2.6.2**)

(3) A very careful girder fabrication, especially careful concrete placing, is required because the lower flange is not ideal for concrete placement because of:

a. Difficulty to obtain uniform quality concrete.

b. Difficulty to obtain good distribution of coarse aggregate.

(4) The repair in the early state is required because in the meantime the long run PC steel cables would eventually be broken due to corrosion.

(5) It was recommended to develop and establish a method to diagnose the soundness of PC cables.

C-7 Cracking damage on slab

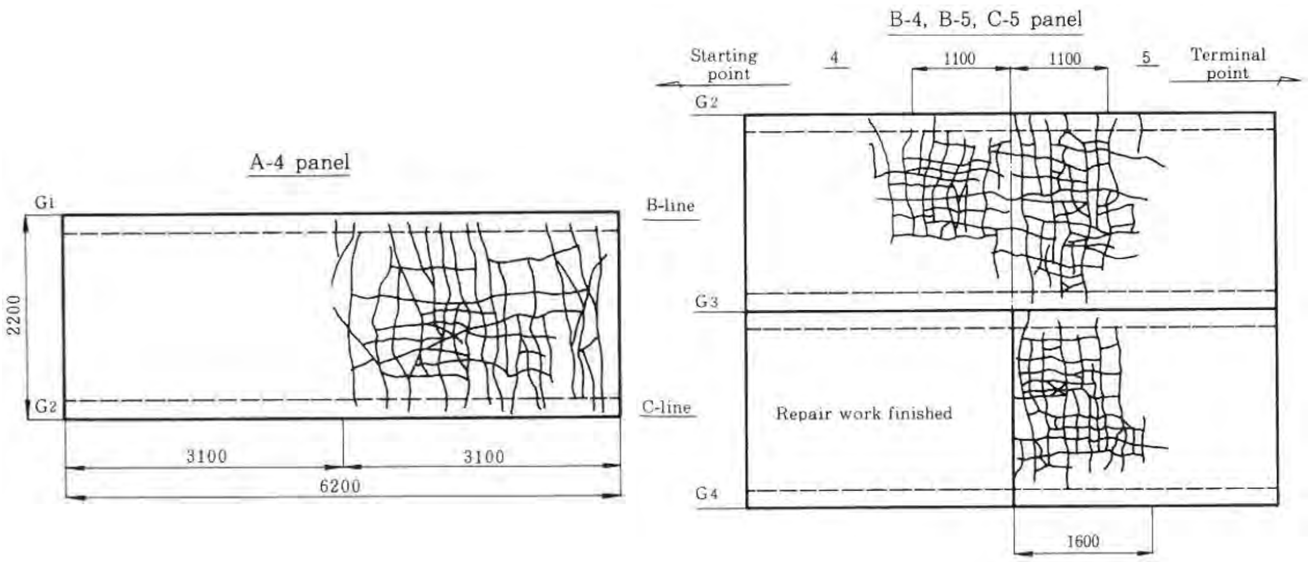
(a) Conditions

Honeycomb (or carapace shell) patterned cracking, 0.1mm-0.3mm, grew in the soffit of slab concrete (**Photo 5.2.7.1** and **Fig. 5.2.7.1**).

The cracks clustering area exhibited square pattern. From measurement, the cracking density was 7.5mm^2-10mm^2 (**Table 5.2.7.1**).

(a) A-4 panel damage **(b) B-5 panel damage**

Photo 5.2.7.1 Crack on the slab



(a) A-4 panel damage **(b) B-4 ,B-5.C-5 panel damage**

Fig. 5.2.7.1 Honeycomb patterned cracking

Table 5.2.7.1 Result of cracking density measurement

	B-4		B-5		C-5		A-4	
	Density (mm^2)	Ratio (%)	Density (mm^2)	Ratio (%)	Density (mm^2)	Ratio (%)	Density (mm^2)	Ratio (%)
Bridge axial direction	4.63	47.4	5.12	47.7	3.54	45.0	2.34	31.2
Orthogonal to bridge direction	5.13	52.6	5.62	52.3	4.32	55.0	5.26	68.3
Total	9.76	100.0	10.74	100.0	7.85	100.0	7.50	100.0

(b) Outline of repair

According to the criteria of slab damage, the slab needs to be repaired through the reinforcement method to restore its function, and if possible enhancement of rigidity was preferred.

The reinforcement method was as follows. The most suitable repair from method must be selected.

1) Epoxy Bonded Steel Plate Method

Set steel plate adhered on the slab underside surface with synthetic resin adhesive to increase bending strength.

Adoption of the method was decided as:

- Works on the roadway with traffic control must be restricted to ensure free and smooth traffic.
- Concrete pieces must be prevented from falling on to the roads at grade.

2) Additional Concrete Method

Place additional concrete on the slab surface to increase the slab thickness and to gain further shearing strength.

3) Girder Addition Method

Supply additional girder to the slab underside to shorten the span.

4) Reconstruction Method

Remove the damaged slab and install new slab cast in place. This is the most reliable repair method.

'Epoxy Bonded Steel Plate Method' which is most commonly adopted is shown in **Fig. 5.2.7.2**.

The deflection measurement and the load test proved increased bending rigidity of slab repaired by this method. However, steel plate adhered under the entire slab surface makes it unavailable to evaluate whether damages in the slab is progressive after the repair.

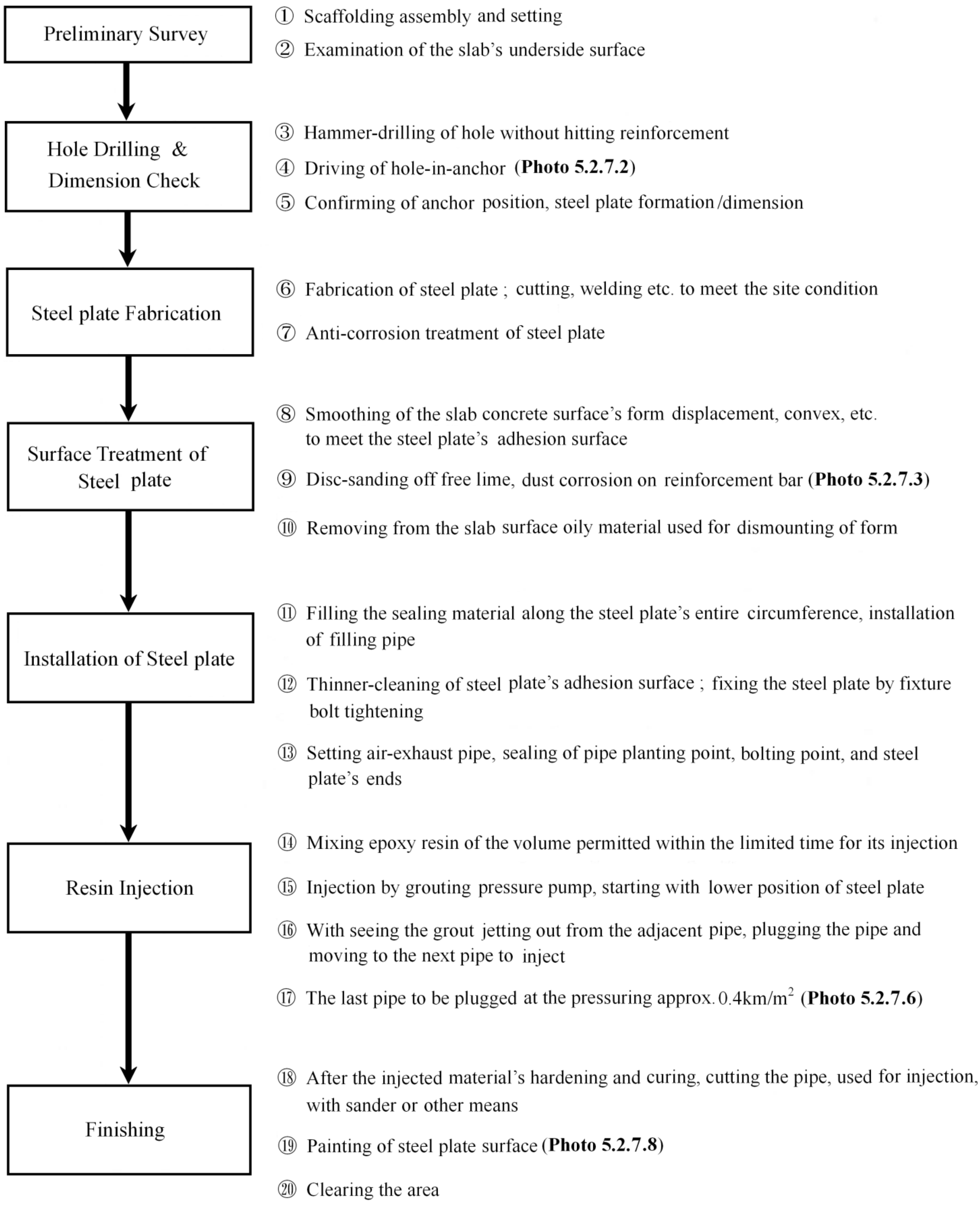


Fig. 5.2.7.2 Procedure of 'Epoxy bonded steel plate method'

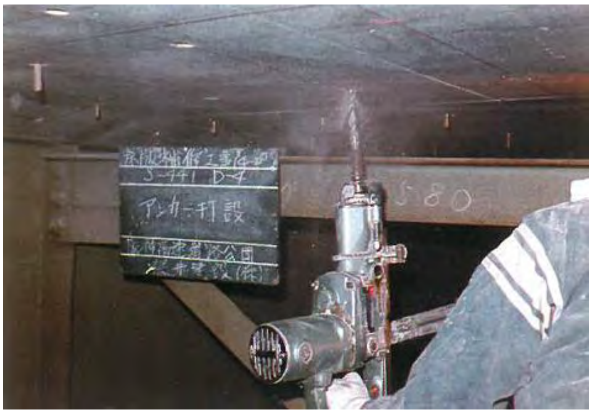


Photo 5.2.7.2 Driving of hole in anchor

Photo 5.2.7.3 Cleaning of efflorescence on concrete surface

Photo 5.2.7.4 Attach steel plate

Photo 5.2.7.5 Sealing steel pate edge

Photo 5.2.7.6 Measurement injection pressure

Photo 5.2.7.7 Cutting injection pipe

Photo 5.2.7.8 Painting of steel plate surface

C-8 Fracture damage

(a) Conditions

The concrete slab underside surface got cracked (**Photo 5.2.8.1**). In this damage, afterward, efflorescence flowed out from nearby slab haunch and the concrete spalled partially (**Photo 5.2.8.2**), inflicting distress on the pavement (**Photo 5.2.8.3**).

To avoid endangering the vehicles under such conditions, it was decided to suspend the traffic temporarily and to reconstruct the slab partially with reinforcement by the Epoxy Bonded Steel Plate Method.

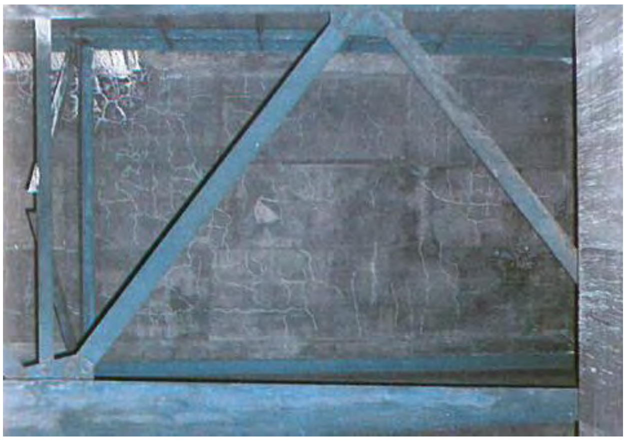


Photo 5.2.8.1 Crack on the slab

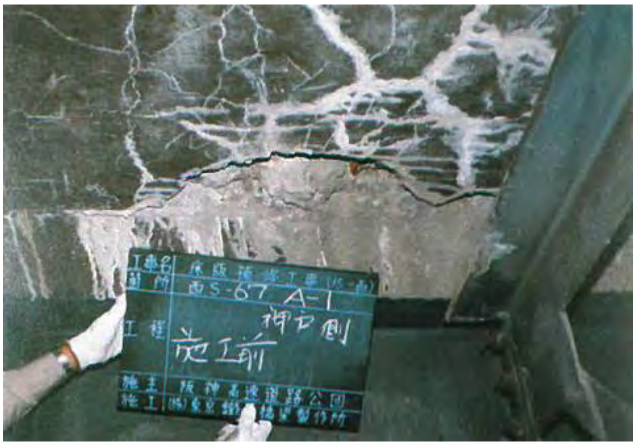


Photo 5.2.8.2 Concrete spall at the slab

Photo 5.2.8.3 Pavement distress due to slab concrete damage

(b) Outline of repair

The heavily damaged portion had penetrated cracks. Lime liberated due to rain water ingress, deposited on the slab soffit, and caused aggregate spalling (**Photo 5.2.8.4**).

Photo 5.2.8.4 Slab concrete being chipped off

Therefore, the slab got partial reconstruction as follows.

(1) Convert epoxy bonded steel plate method to slab reconstruction formwork with additional reinforcement.
(2) Decide and cut out the reconstruction area (**Photo 5.2.8.4**), removing the pavement, chipping off the heavily damaged concrete (**Photo 5.2.8.4**).
(3) Reinforce sound portion with the epoxy bonded steel plate method. As for reconstructed portion, the steel plate with bent-up bars served dual-purposes (**Fig. 5.2.8.1**), serving as a form for concrete placement and as slab reinforcement.

Photo 5.2.8.5 Chipping finished

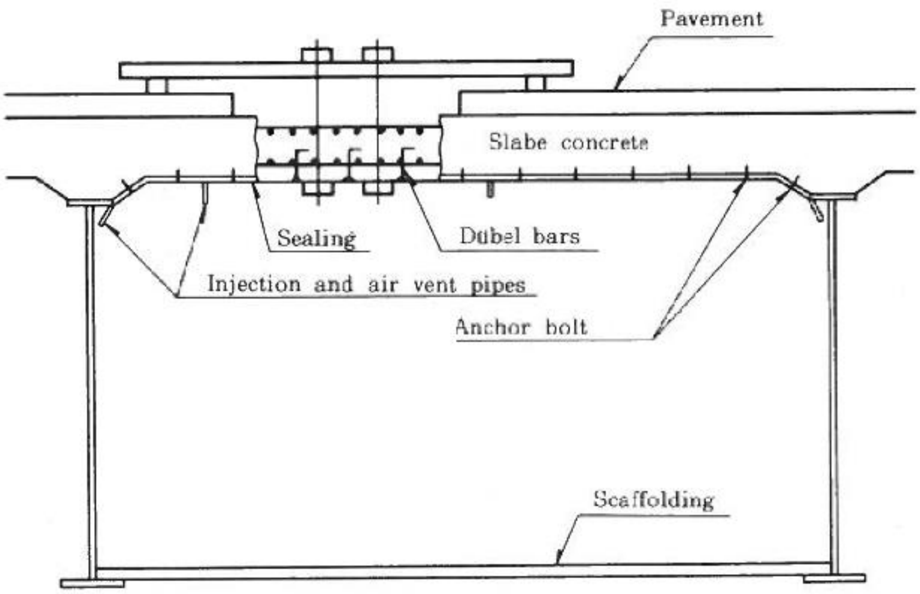


Fig. 5.2.8.1 Re-concreting of slab

Photo 5.2.8.6 Driving of hole in anchor

Photo 5.2.8.7 Drilling finished

Photo 5.2.8.8 Steel plate attached

Photo 5.2.8.9 Injection pipes and sealing are installed

Photo 5.2.8.10 Resin injection

(4) Concrete with ultra-high-strength cement, using field mixing to place concrete (**Photo 5.2.8.11**).

(5) To cure the placed concrete for about 4 hours, checking with the completed dimension (**Photo 5.2.8.12**).

Photo 5.2.8.11 Placing concrete

Photo 5.2.8.12 Checking re-concrete work

Photo 5.2.8.13 Pavement being placed and compacted

(c) Remarks

The regular periodical inspection in November 1980 revealed this damage, ranked as level A in damage degree (**Photo 5.2.8.1**). This damage, thereafter, developed to level AA by 31 August 1981 (**Photo 5.2.8.2**).

Like this case, the crack-penetrated slab degraded at an unexpected speed. Inspection with appropriate "prediction" is important.

Two methods are available for the adhering steel plate to slab underside surface with epoxy resin. One is to give resin spread on the steel plate's adhesion surface, to press the plate against the slab until resin cures (hardens), and to maintain for certain time the plate pressed against the slab, the pressure adhesion method (**Fig. 5.2.8.2**).

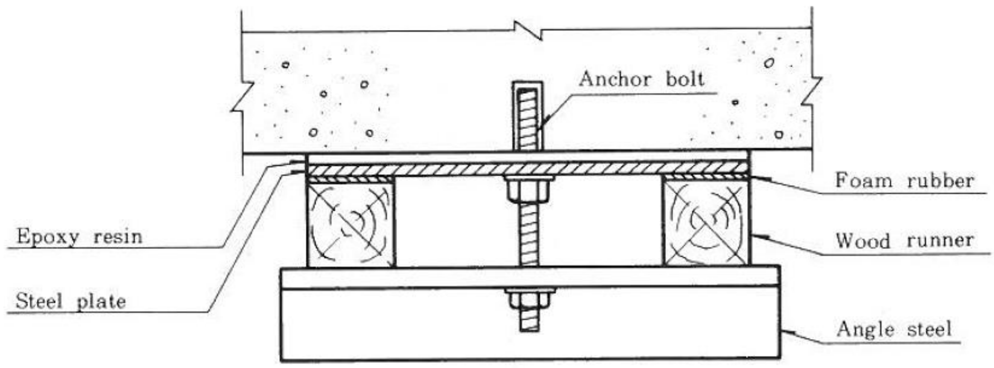


Fig. 5.2.8.2 Example of steel plate adhesion by pressure

Another is to hold the steel plate with chinks between the slab, to give resin sealing along the steel plate's edge all round, to inject an epoxy-based adhering agent in-between (**Fig. 5.2.8.3**). The injection pipe is usually installed at the lowest position. Epoxy is injected till the space is filled.

The current repair works include the resin injection method, expecting resin pressure to fill the slab crack.

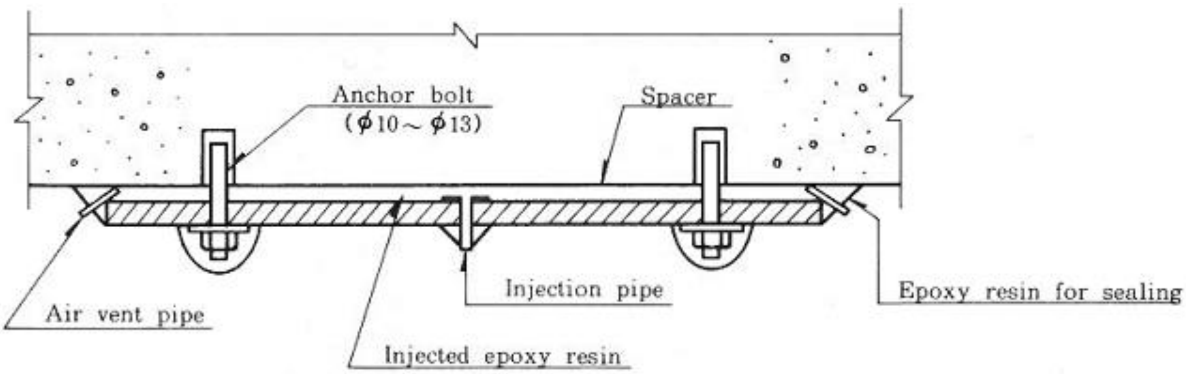


Fig. 5.2.8.3 Example of the epoxy bonded steel plate method

C-9 Corrosion of man Re-bars in concrete railing

(a) Conditions

D13 (Diameter 13mm) main reinforcement is used in concrete railing, got corroded and expanded out the cover concrete to spall at the main bar spacing (**Photo 5.2.9.1**).

(a) Inside

(b) Outside

Photo 5.2.9.1 Damaged railing

(b) Possible causes

The RE-bars arrangement in concrete railing is designed to have 30 mm distance between the bar center and concrete surface and to have 23.5mm clear cover. However, the actual construction is understood not to have designed value due to sorts of errors, etc. related to its construction work. From this, the carbon dioxide had the concrete neutralized, reinforcement bar corroded to expand and spall the concrete itself.

This type of damage took place in a wide area of the Expressway's existing railing.

(c) Outline of repairs

The exposed RE-bars received the repairs by application of epoxy-resin-base coating and toweling (**Photo 5.2.9.2**), finishing by brushing and rolling of acrylic resin (**Fig.5.2.9.1**).

(a) Inside

(b) Outside

Photo 5.2.9.2 Railing surface repair

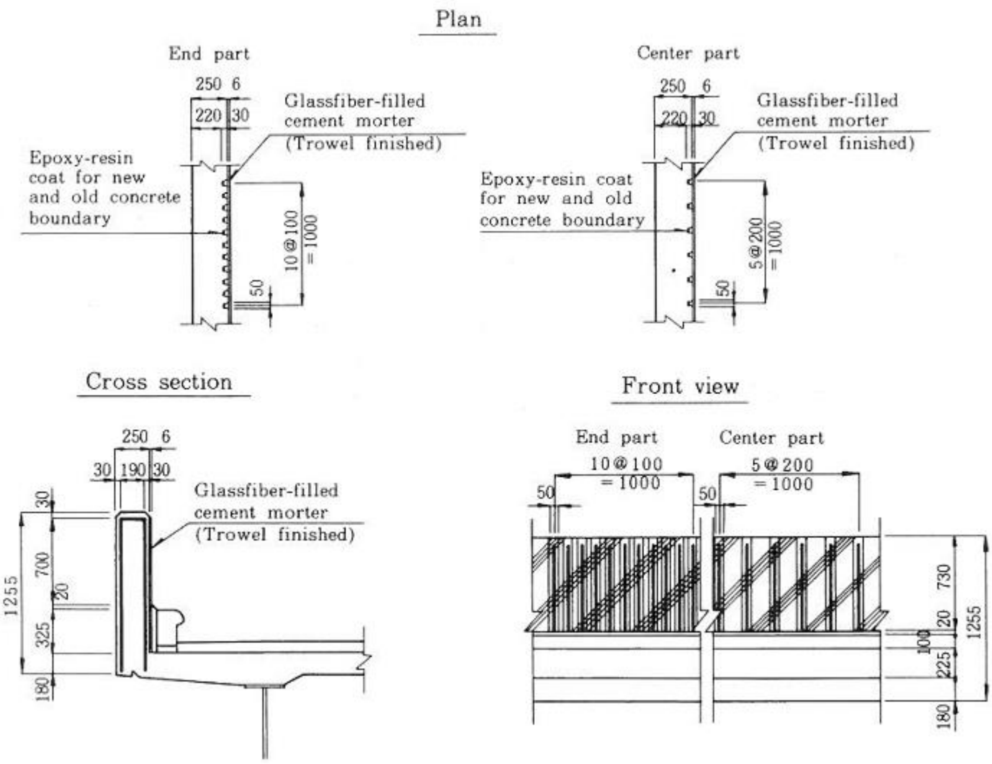


Fig. 5.2.9.1 Standard for repair work of exposed bars in railing

The procedure goes as shown in **Fig. 5.2.9.2** and **Photo 5.2.9.3** to **Photo 5.2.9.8**.

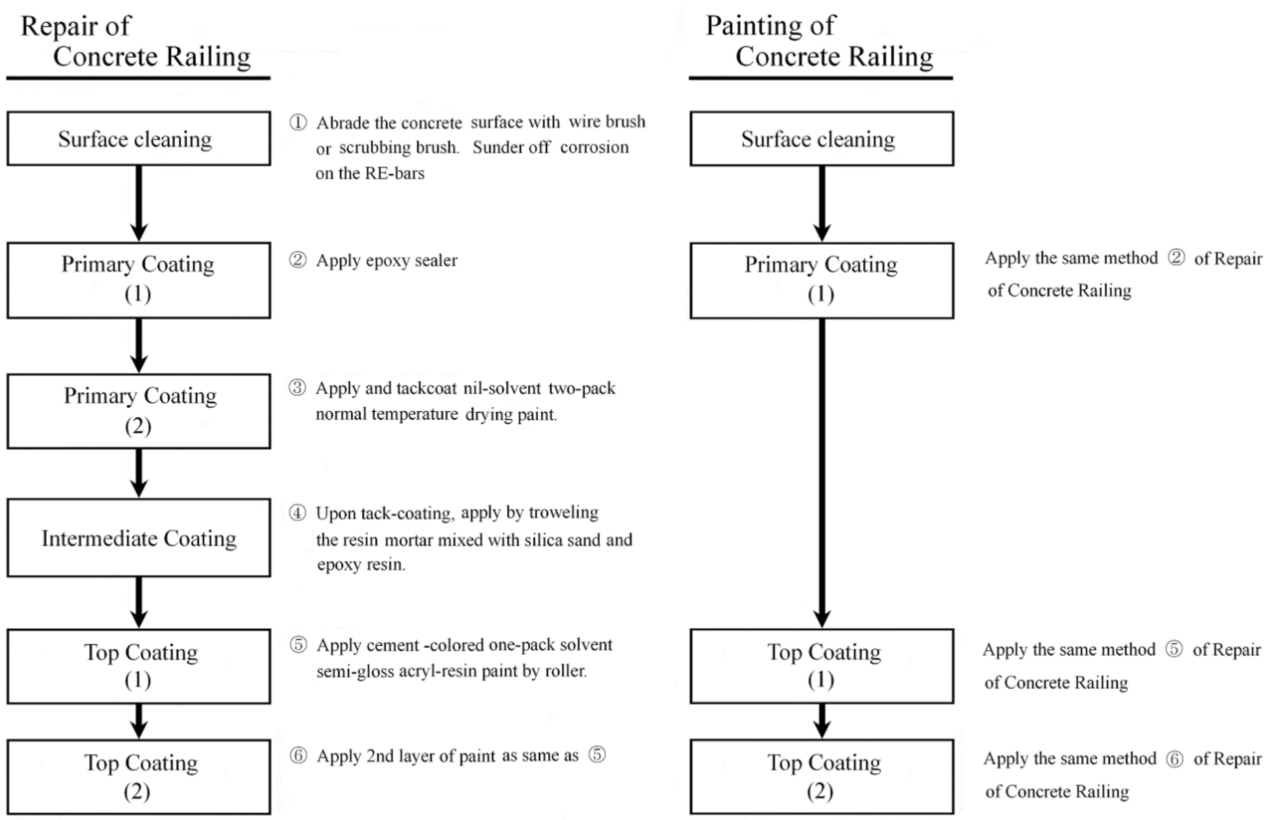


Fig. 5.2.9.2 Flow chart of repair work for concrete railing

Photo 5.2.9.3 Surface cleaning

Photo 5.2.9.4 Primary coat painting

Photo 5.2.9.5 Tack-coating for second coat

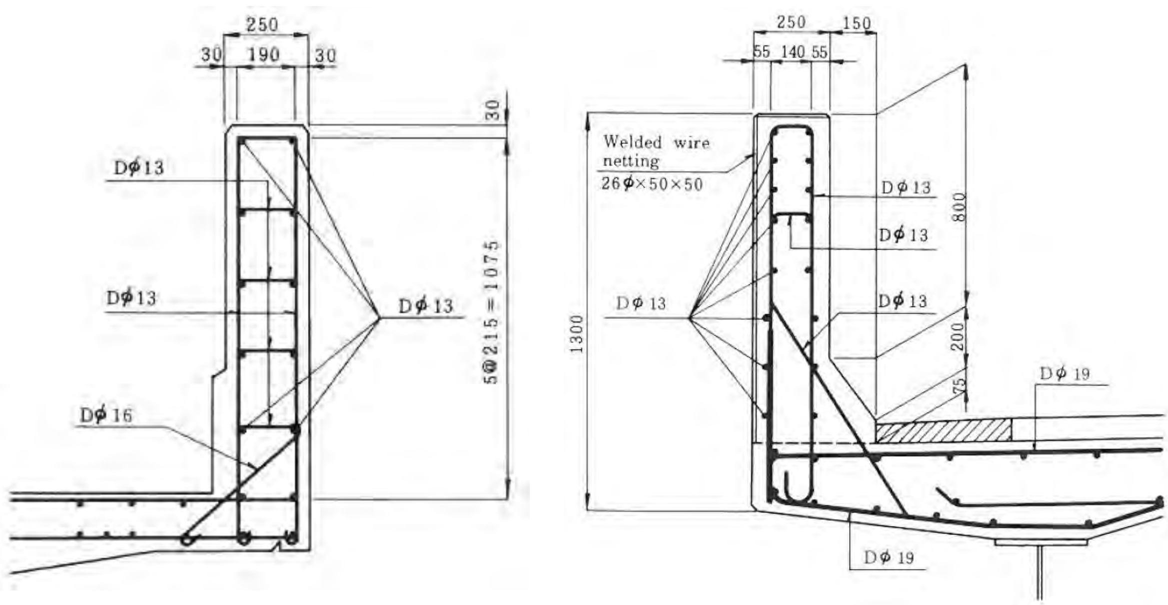
Photo 5.2.9.6 Tack-coating for intermediate coating

Photo 5.2.9.7 Intermediate coating of resin mortar

(d) Remarks

In new design type, the concrete cover is 45.5mm to expel this type of damage (**Fig. 5.2.9.3**). Furthermore, the concrete railing got embedding of welded steel netting (6.2mm×50mm×50mm mesh galvanized welding), inside by 1cm from concrete surface, to prevent flying of concrete pieces crashed asunder by vehicle collision.

Photo 5.2.9.8 Top coating



(a) Old design **(b) New design**

Fig. 5.2.9.3 Bar arrangement in concrete railing

This type of damage with concrete spalling inflicts injury to drivers and pedestrians going by under the Expressway. Especially outside of the concrete railing, it is imperatively necessary to devise a drastically improved method for prevention of concrete spalling.

The lightweight concrete railing also experiences this type of damage, even with trend of larger concrete spalling than other types of concrete.

C-10 Vehicle Collision Damage on Concrete Railing

(1) Case 1

(a) Conditions

Four vehicles running on the overtaking lane hit on one after another. The tail-end cargo vehicle steered to the left and collided with the concrete railing at an acute angle.

The collision damaged the railing and its concrete fell (**Photo 5.2.10.1**).

Photo 5.2.10.1 Damage condition (Case 1)

The damage, broke through RC railing wall, caused falling of 1.7m concrete lump downward from the Expressway.

Although crack in the concrete railing spread over 4.45m in length, the concrete slabs underside surface was intact.

(b) Outline of Repair

Repair generally takes the following procedure in these types of concrete railing damaged.

1) Chipping concrete of the damaged portion.
2) Repairing and assembly of reinforcement.
3) Placing of super quick strength concrete.
4) Installing of blocks.
5) Finishing of repair.

Photo 5.2.10.2 Repair method (Case 1)

(2) Case 2

(a) Conditions

Running at speed of 70km/h, a 14 tons trailer truck lost control due to improper wheel operation and hit the median guardrail, then colliding against the concrete railing. The railing was damaged (**Photo 5.2.10.3**) and concrete pieces dropped down.

Photo 5.2.10.3 Damage condition (Case 2)

(b) Outline of Repair

Repair generally takes the following procedure in these types of concrete railing damaged.

1) Chipping concrete of the damaged portion.
2) Repairing and assembly of reinforcement.
3) Placing of super quick strength concrete.
4) Installing of curb blocks.
5) Finishing of repair.

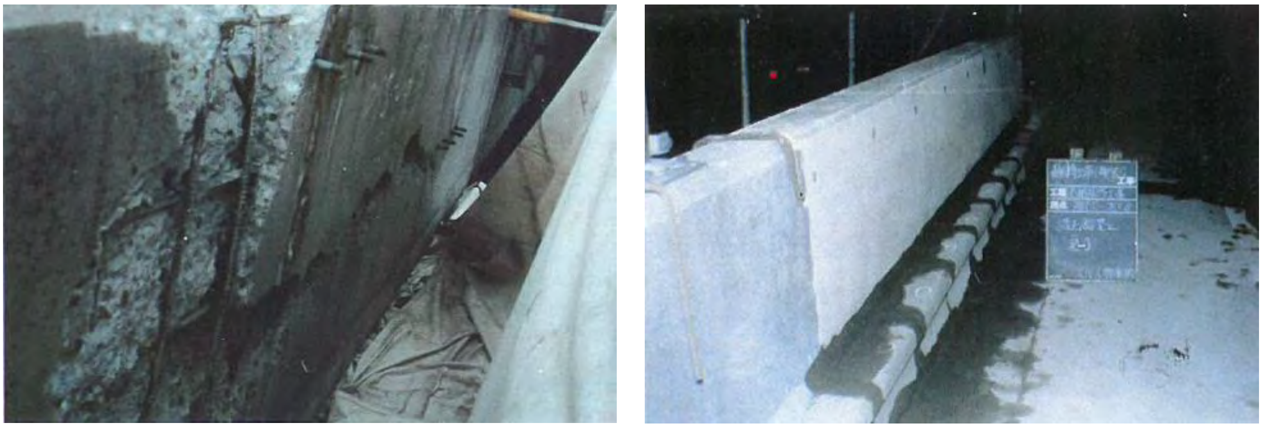


Photo 5.2.10.4 Repair method (Case 2)

(3) Case 3

(a) Conditions

A vehicle collision against the concrete railing spalled off its concrete (**Photo 5.2.10.5**).

In design and construction of construction of concrete railing of the curves with radius 200m and less, design load is 2t /m, 2 times railing collision load as that on the standard (straight) section. But this section of damage had no reinforcement and concrete block fell down.

Photo 5.2.10.5 Damage railing (Case 3)

(b) Outline of Repair

Repair generally takes the following procedure in these types of concrete railing damaged.

1) Chipping concrete of the damaged portion.
2) Repairing and assembly of reinforcement.
3) Placing of super quick strength concrete.
4) Installing of curb blocks.
5) Finishing of repair.

(4) Case 4

(a) Conditions

The lightweight concrete railing was damaged as if it were shaved with sharp cutlery (**Photo 5.2.10.6**).

Photo 5.2.10.6 Damage condition (Case 4)

(b) Possible cause

In general, the lightweight concrete has lower shearing resistance than the normal concrete does. In particular, against impact load, the lightweight concrete is understood to have 60% shear strength of that of the normal concrete.

When the damaged portion for repair was removed, reinforcements were found arranged 20cm below the concrete railing top. It proved the collided portion had no reinforcement, giving a “shaving off” of its concrete.

(b) Outline of Repair
Repair generally takes the following procedure in these types of concrete railing damaged.
1) Chipping concrete of the damaged portion.
2) Repairing and assembly of reinforcement.
3) Placing of super quick strength concrete.
4) Installing of curb blocks.
5) Finishing of repair.


Photo 5.2.10.7 Repair method (Case 4)

(5) Case 5
(a) Conditions
Due to vehicle collision, the curved concrete railing was damaged for about 5m long (**Photo 5.2.10.8**).


Photo 5.2.10.8 Damage condition (Case 5)

(b) Possible cause

The cause for such a large scale damaged was excessive loading caused by vehicle collision.

(c) Outline of Repair

Repair generally takes the following procedure in these types of concrete railing damaged.

1) Chipping concrete of the damaged portion.
2) Repairing and assembly of reinforcement.
3) Placing of super quick strength concrete.
4) Installing of curb blocks.
5) Finishing of repair.

(6) Remarks

While the direct causes for the damages were excessive loading from vehicle collision, some of damages were due to improper reinforcement arrangement in its concrete. It, therefore, requires careful management in construction not to cause such incident.

C-11 Longitudinal Crack in the Lower Flange of PC Girder

(a) Condition

A longitudinal crack was found along the sheaths on the lower flange of PC girder (**Photo 5.2.11.1**).

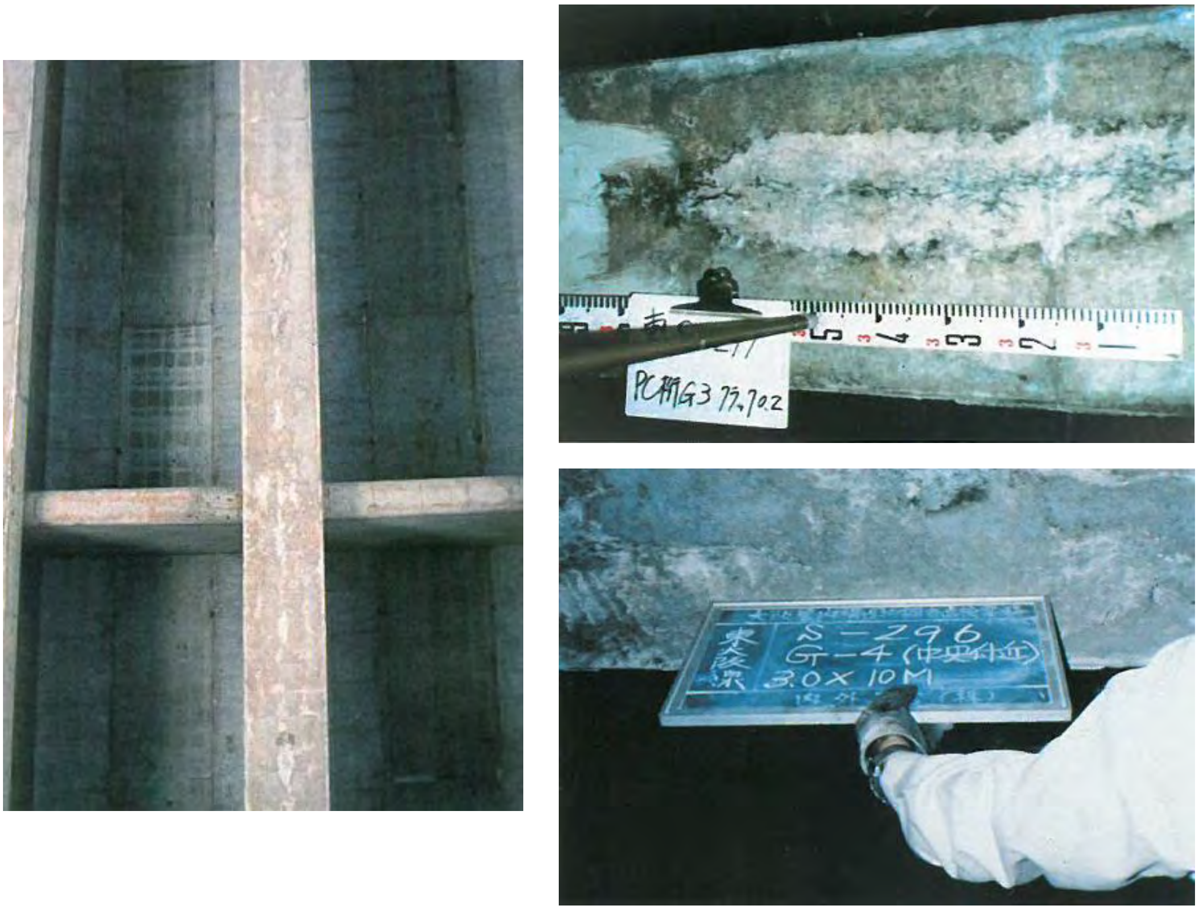


Photo 5.2.11.1 Crack on low flange

G4, the central girder, had crack of 0.5mm-1.0mm wide and approximately 18m long in its mid-span lower flange (**Fig. 5.2.11.1**).

Two cracks spread in the longitudinal direction, dividing 60cm-wide lower flange into trisections and trace of efflorescence at places. The ultrasonic detector measured the estimated crack depth as 6cm to 10cm.

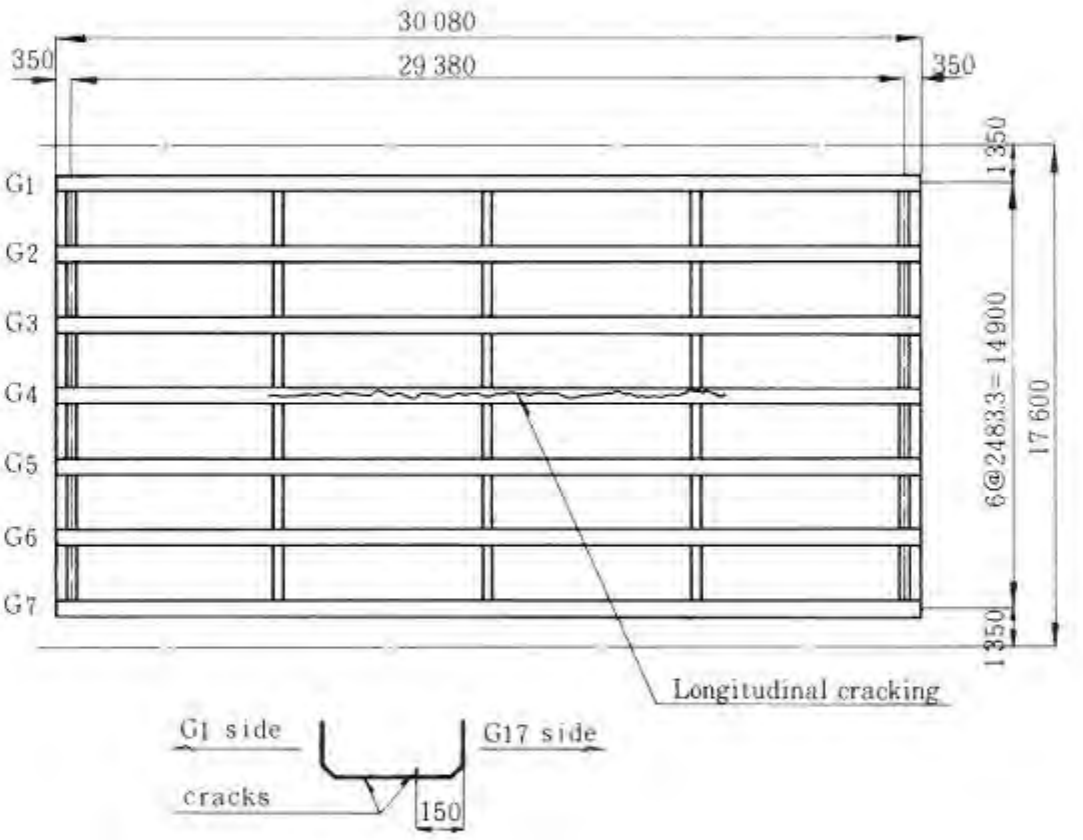


Fig. 5.2.11.1 Cracked position

(b)Possible Causes

Possible other causes are:

(1) Growth of lateral tension strain equivalent to Poison's ratio by pre-stressing.
(2) Excessive pressure by the grout injection
(3) Expansion pressure effect of grouting material due to expansion admixture.
(4) Internal pressure effect generated from the difference of thermal expansion coefficient and drying shrinkage between grout and concrete.
(5) Secondary lateral strain generated by PC cable tension.
(6) Lateral strain triggered by bucking of reinforcement bar.

A combination of some of these causes is understood responsible for this type of damage, as well as other factors such as construction workmanship (compaction, curing time length before formwork removal), etc.

Eventually, it is a matter of great importance to design about the eligible arrangement of reinforcement (stirrups, etc.), so that a sufficient cover thickness provides rational compaction and curing.

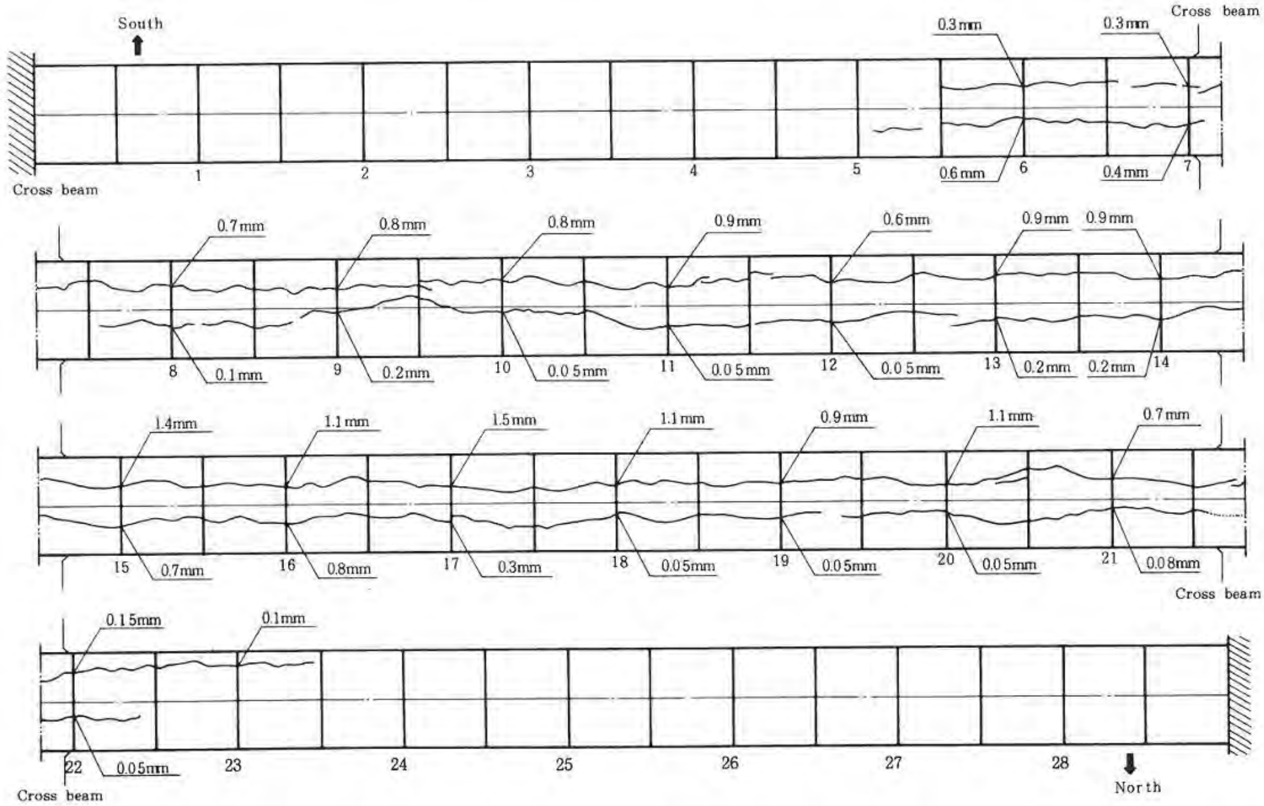


Fig. 5.2.11.2 Detail crack on low flange

(c)Outline of Repairs

The investigation confirmed the sheath completely filled with grout.

To prevent corrosion from starting on reinforcement and PC cables, sealing to the cracks of 0.2mm and larger width was implemented through injection pipes positioned at 20cm interval along the cracking line.

The repair was completed with the injection of epoxy resin grouts with pressure of about 0.2kg/m2 and with the surface finishing.

C-12 Concrete Pier Damaged by Alkali-Aggregate Reaction

(a) Condition

Fig.5.2.12.1 shows typical crack pattern in the column head caused by Alkali-Aggregate Reaction, illustrating wide cracks extending in horizontal direction.

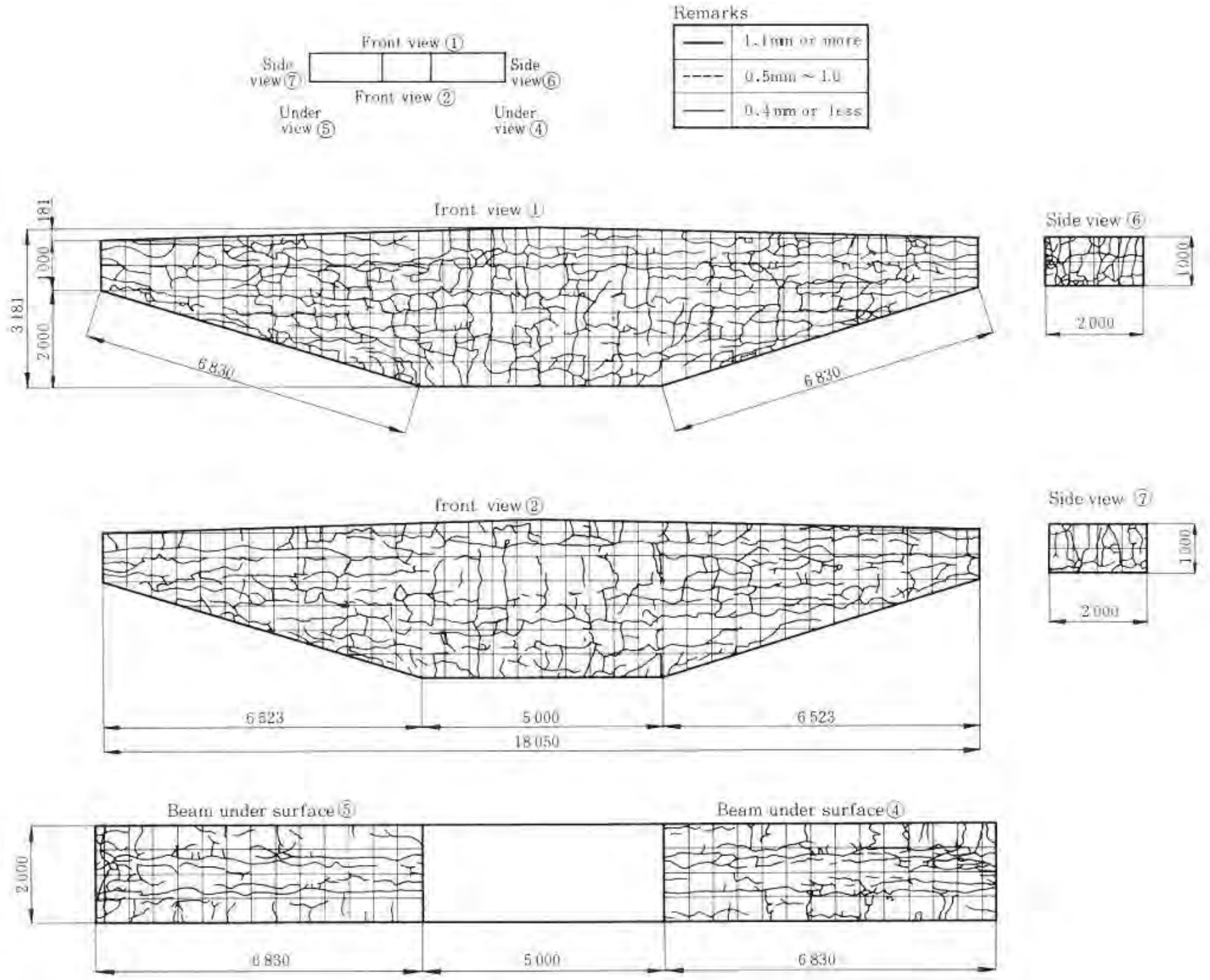


Fig. 5.2.12.1 Crack on the concrete pier beam

The widest crack (**Photo 5.2.12.1**) was 4 to 5 mm in width, located in the position where the column reinforcement terminates at the beam center.

(b)Pier beam **(b)Abutment**

Photo 5.2.12.1 Crack caused by alkali-aggregate reaction

As **Fig. 5.2.12.2** shows, each side of cracks of the beam surface had about 4mm dislocation. Except for this cracks, other cracks were not deep and stayed within the cover concrete according to the random core sampling. This type of cracking was found out also in the abutment and its core samples are shown in **Photo 5.2.12.1**.

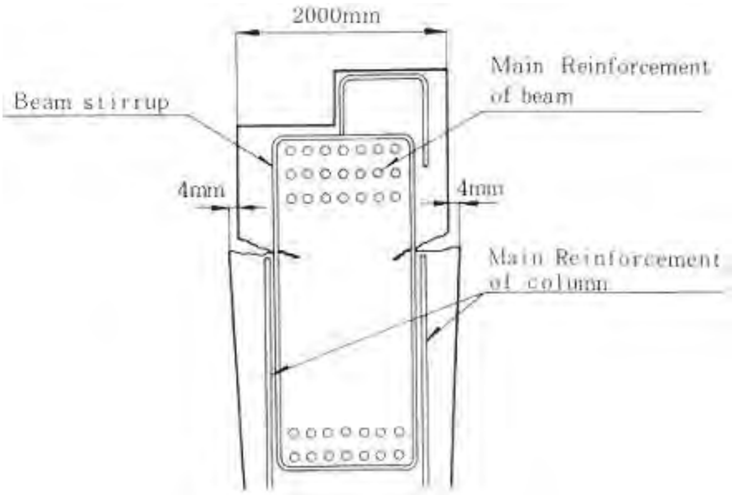


Fig. 5.2.12.2 Detail Crack on the concrete pier beam

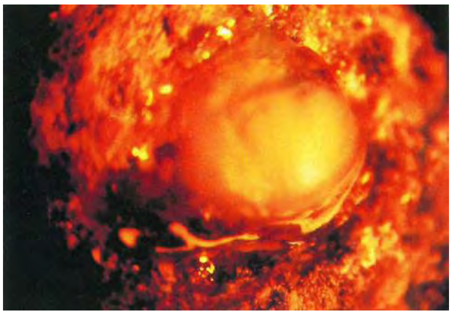
Photo 5.2.12.2 Surface observation by core sample

(b) Possible Cause

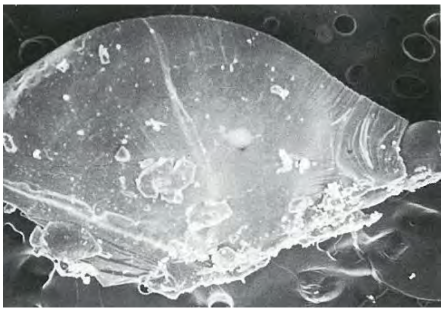
This type of cracking, dislocation in the concrete surface, was caused by concrete expansion. The surface of cores sampled from the beam was carefully observed (**Photo 5.2.12.2**) in pursuit of the cause of the concrete expansion.

The investigation confirmed aggregate reaction rings (**Photo 5.2.12.3**), and also revealed exudation of gel around each ring (**Photo 5.2.12.4**).

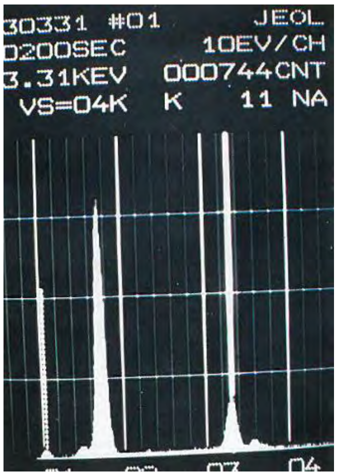
Photo 5.2.12.3 Reaction ring and crack inside of aggregate



(a) Gel exudation from aggregate



(b) Exuded gel observes with Scanning Electron Microscope



(c) X-ray intensity spectrum by elements exuded gel

Photo 5.2.12.4 Exudation of gel around each ring

A considerable elongation (expansion) was recorded through the measuring of variation of perimeter after core boring (**Photo 5.2.12.5**).

Photo 5.2.12.5 Sampled cores banded for change of perimeter measurement

Powdered x-ray analyzing and deflective microscopic observation of mineral composition in the aggregate of sampled core revealed the presence of reactive minerals. From such outcome of observation, it was concluded that the damage was caused by alkali-aggregate reaction.

The alkali-aggregate reaction in this case, more precisely, is defined as the alkali-silica reaction. And such alkali-silica reaction takes place when the three factors, reactive silica (SiO_2) in the aggregate, alkali metal (Na or K), and moisture-satisfy a certain condition, produce an alkali silica gel as follows,

$$SiO_2 + 2NaOH + 8H_2O = Na_2H_2SiO_4 \cdot 8H_2O$$

This gel is highly hygroscopic and expands by absorbing more moisture. The expansion in the surroundings of aggregate invites the expansion of concrete structure. The concrete structure gets cracked in its surface when it can no longer sustain such internal expansion.

(c) Outline of Repairs

No research or studies of alkali-aggregate has ever presented any perfect method for repair. Presently, single conceivable repair method is the waterproof of existing concrete structure to eliminate one of the aforementioned three factors. Available single method is surface coating after injection of flexible epoxy resins of high elongation type into cracks to shut out the moisture ingress. **Table-5.2.12.1** shows the coating specifications coded by 'Hanshin express company limited (In Osaka, Japan)' actually used in the repairing of existing structures. In general, if the base concrete can be completely cut off from the water, waterproof type is used. Otherwise, repellent water type is used.

Table-5.2.12.1 Concrete surface coating system

(a) Repellent water type

Process	Material	Coating conditions		
		Target film Thickness(μm)	Standard usage(kg/m²)	Method
Pre-treatment	Disc sander or Wire brushing			
First coating	Reactive silane impregnated material	—	0.20 – 0.24	Brush or roller
Second coat	Flexible polymer cement mortar	1050 - 1200	2.10 – 2.30	Brush or roller
Top coat	Acrylic emulsion paint	60 – 80	0.20	Brush or roller

(b) Waterproof type

Process		Material	Coating conditions		
			Target film Thickness(μm)	Standard usage(kg/m²)	Method
Pre - treatment	Primer	Epoxy or polyurethane primer	—	0.1	Brush or roller
	Putty	Epoxy resin putty	—	0.5	Spatula or trowel
Second coat 1		Flexible epoxy resin (Thick-film)	160	0.35	Roller
Second coat 2		Flexible epoxy resin (Thick-film)	160	0.35	Roller
Second coat 3		Flexible epoxy resin (Thick-film)	160	0.35	Roller
Top coat		Flexible epoxy resin	30	0.12	Brush or roller

One of recommendable way is that resin-injection by reasonable pressure into these kinds of cracks. (Reference: **5.2 Case of Concrete structure repair C-1 Concrete crack**)

In surface coating, brushing, roller, or spraying is generally applied.

It is essentially important for the suppressing of alkali aggregating reaction to keep moisture content as low as possible. For the purpose, the concrete surface must be checked for its fair dryness before the application of surface coating.

However, this method is suitable for repair of structures damaged by cracks but not deficient structurally deficient. In the structural proof-stress, it should specifically be repaired by steel plate bonding, carbon fiber sheet bonding, pre-stress introduction, structural member increment, or re-concreting, etc.

(d) Remarks

Various types of examination, field investigation through repairs, have been conducted on the cracks caused by alkali-aggregate reaction. The followings are summary of discussion.

(1) Field investigation and examination of causes

Table-5.2.12.2 shows the items of the field investigation carried out after finding cracks and of the core sampling examination to identify the causes of the defect.

Table-5.2.12.2 Investigation items on alkali-aggregate reaction

	Method	Item
Field investigation	Visual inspection on surface	Crack width, depth, length, distribution
	Hammering	Cavity, Loosening
	Schmidt rebound hammer test	Compressive strength
	Ultrasonic wave propagation velocity	Crack depth, strength
Core sampling	Visual inspection	Sol, gel, reaction ring
	Expansion measurement	Open expansion, residual expansion
	Aggregate analysis	Grain distribution by rock types, polarizing photomicrograph, Power X-ray diffraction
	Cement analysis	Mix proportions, cement used, amounts of alkalis and chlorine.
	Strength test	Compressive strength, elastic modulus, Poisson ratio, neutralization depth
	ASTM test (reproducibility)	Chemical method, Mortal bar method
	Gel analysis	Alkali silica gel

(2) Proof test

1) Loading tests on model beams

Bending load tests were conducted on two model beams with the same reinforcement ratio as designed in the existing column.

One model: a built beam with alkali-aggregate and wish typical cracks developed, and another: a beam with ordinary aggregate.

The tests revealed the compressive strength of standard concreted test specimen decreased by 40% with reactive aggregate than with ordinary aggregate, however the both models gave no substantial difference in structural behavior.

This, in the model with reactive aggregate, can be well understood that chemical pre-stress is generated in the concrete sections because of reinforcement restraints against concrete expansion. In addition to this static bending test on RC-beam, dynamic bending test, shearing test, and RE-bar adhesion test were carried out on the RC-beam. Static and dynamic bending tests were also carried out on pre-stressed concrete beam.

2) Load tests on actual (existing) bridge

Sound pier and damaged pier with alkali-aggregate reaction had little difference in their structural response under the live load condition.

CHAPTER 6 REPAIR OF STEEL STRUCTURE

6.1 Planning of Steel structure repair

Before repair work, brief concrete bridge repair plan and cost estimation shall be prepared. In this manual, it is recommended that the planning and cost estimate should be done, and due consideration is revealed in the manual.

The repair plan shall include;

- Province (DPWT) that manages the target bridge
- Location
- Priority
- Repair method
- Reference No. of unit costs for cost estimate (refer to “Appendix”), and
- Repair cost

Approximate repair bridge cost can be obtained by summing each cost estimate.
The typical repair code is shown in **Table6.1.1**. All repair code is described in ‘Appendix’

Table 6.1.1Typical bridge repair code (Steel)

No.	Code	Repair Work	Unit
1	2001	Steel Corrosion Repair	m^2
2	2002	Reinforcement by Steel Plate	m^2

In the repair execution plan, work priority order has to be determined with comprehensive considerations of time schedule, location, current severity of damages, route importance, and preference.

Since the bridge maintenance technology is constantly evolving, road administrator must keep obtaining new knowledge by dense communication and information exchange with relevant organizations.

6.2 Case of Steel structure repair

This section is to introduce repair case studies of steel structures.

S-1 Corrosion on steel girder due to water leakage

(a) Conditions

Corrosion was found at web, lower edge of the vertical stiffener and lower flange of the steel girder as shown in **Photo 6.2.1.1**.

Photo 6.2.1.1 Steel girder corrosion condition

The corrosion grew at the outer girder of 4 main girders at the center of the 2 span continuous non-composite I-girder bridge.

Based on a thickness measurement by ultrasonic tester, the corrosion was judged as serious and it was confirmed that decrease of the thickness is by 5.2mm for the lower flange compared to the original design (Web: 9mm, lower flange: 16mm to 19mm).

Also, a large amount of water leakage was found at the floor slab over the corroded area and a large amount of efflorescence had been deposited on the lower flange (**Fig.6.2.1.1**).

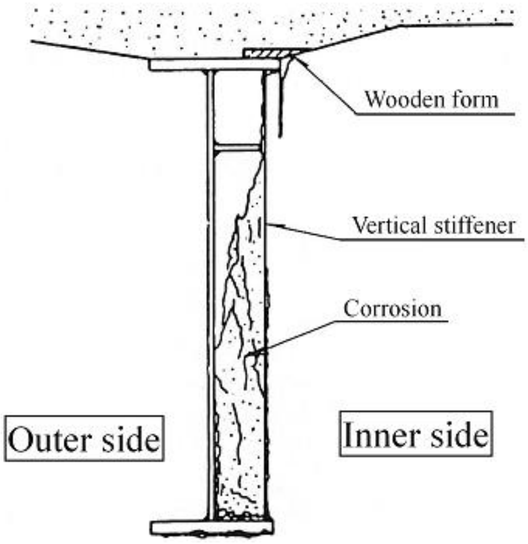


Fig. 6.2.1.1 Condition for corrosion

(b) Possible Causes

It is assumed that deterioration was caused by the water leakage from the construction joint of slab concrete which was insufficiently treated, and that rainwater has gradually leaked to the lower flange for a long period of time as shown in **Photo 6.2.1.2**.

Also, some of the wooden form which had accidentally came into the wrong position was left in the slab concrete during the construction (**Fig. 6.2.1.1** and **Photo 6.2.1.3**). It is assumed that the deterioration had developed as follows.

Photo 6.2.1.2 Water leakage from the construction joint of slab concrete

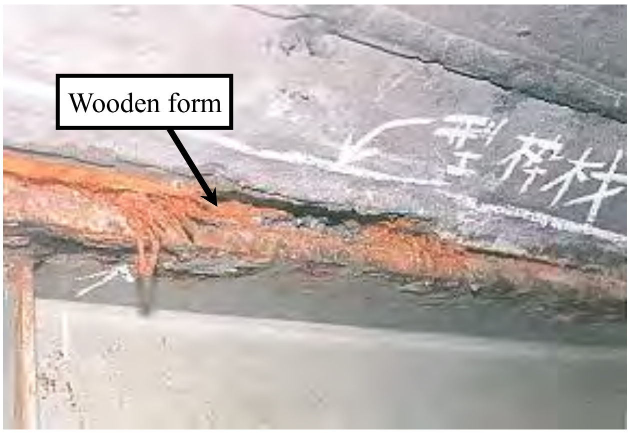


Photo 6.2.1.3 Wooden form which was left in the slab concrete

Rainwater with efflorescence coming though the slab concrete was stored around the wooden form and immersed out whenever traffic passed through. This efflorescence accumulated on the lower flange, and kept the area wet all the time. Therefore, deterioration had developed.

(c) Repair outline

Repainting is the normal repair method for this kind of deterioration. If the corrosion is very serious, placing of steel reinforcement with additional members after polishing the deteriorated area is usually used.

Because of its extremely serious loss of thickness for the designed section, repainting was not sufficient for this damage. Also, the repair method could not be applied in this case because the repair should be done without any supports from the ground at the site. In addition, the traffic could not be suspended during this repair.

Because of these, if the method would be applied, it would be very difficult to secure a stress transmission to the reinforcing members to observe whether the repair was effective or not.

The alternative repair was carried out as follows (**Fig. 6.2.1.2**):

(1) Install temporary members at both ends of the corroded member to divert stress to attached member.

(2) Remove the corroded area from the original structural member.

(3) Install reinforcing member consisting of a prefabricated I-shaped girder with high-strength bolts for the web and by welding the lower flange to the main girder.

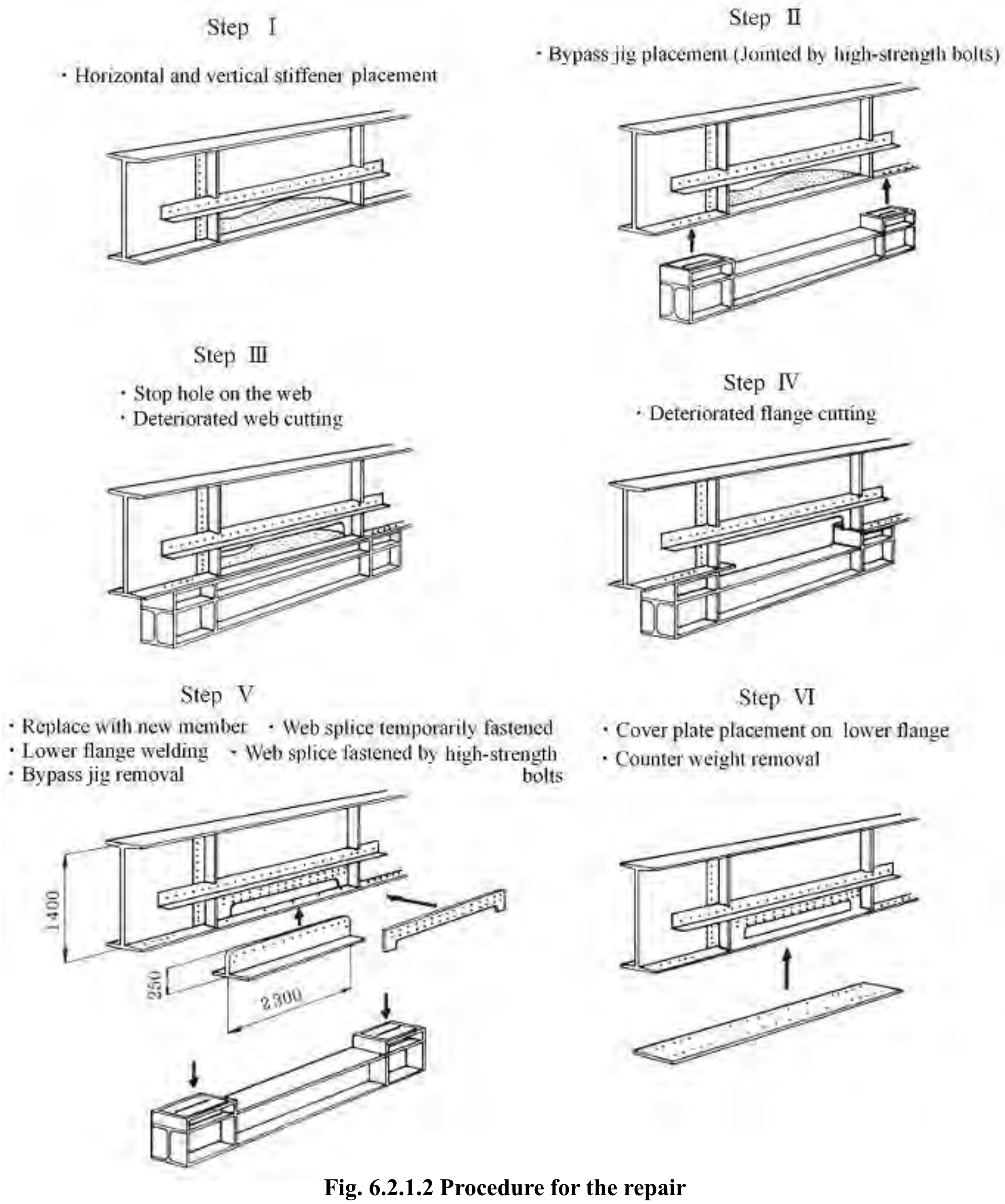


Fig. 6.2.1.2 Procedure for the repair

Prior to the repair work, the static test was carried out to confirm the effectiveness of the repair method and the dynamic test was done to investigate the most effective construction method at the site under traffic by utilizing a model girder. As the result of the static load test, it was clarified that temporary members (by-pass material) functioned well as a structural member to bear real stress when the original section was removed. The repair work could be completed under a stress-free condition.

Also, the following countermeasures were taken to keep a good condition for the work by taking into account of the test result.

(1) The groove (V-shape, back chipping) of the model girder produced a crack at the initial layer. Because of this, the groove shape was changed to an X-shape and the defective layer was removed by gouging.
(2) After placing a scallop on the web where welding lines cross, a overlapping weld system was performed.
(3) A vibration on the mother material was restrained as little as possible and the root gap was controlled as less than 1mm during the work at site.

After installing the new members, a water proof layer was placed on the slab to prevent water from leaking not to cause corrosion on the surface of the steel girder. Because the measurement showed that all internal stress was transferred onto the by-pass member when the deteriorated area was removed and there was no excessive stress around the area when the work was complete.

(d) Remarks
Careful attention for preventing rainwater leakage from road surface shall be given to construction joints of the slab concrete and expansion joint because rainwater leakage develops serious corrosion on the steel girder.
If the areas become rusty, action to stop the water leakage shall be immediately taken. Also, at the same time, partial re-painting shall be performed, if necessary.
The method used for the work can also be applied to other type of girders.
This method has a useful advantage because it can be completed in a short period without a temporary support from the ground under traffic load.

S-2 Cracks the jammed part connecting cross beam and vertical stiffener of I-girder

(a) Conditions

A crack was found at jammed part where so many members, such as cross beam sway bracing and main girder on the nearby upper flange and web, are connected by welding to the simple composite steel I-girder, as shown in **Photos 6.2.2.1** and **Fig.6.2.2.1**.

Photo 6.2.2.1 Cracks the jammed part connection cross beam and vertical stiffener of I- girder

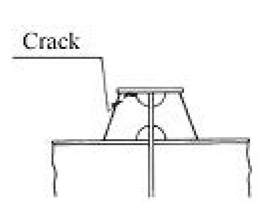
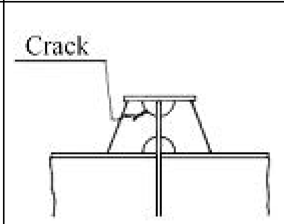
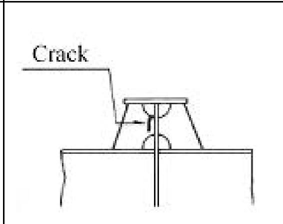
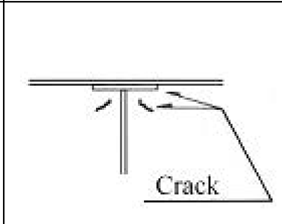
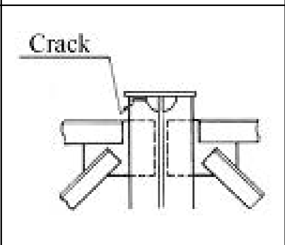
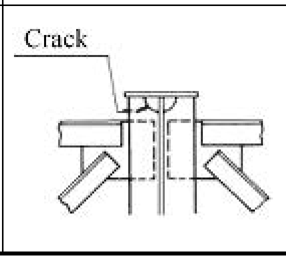
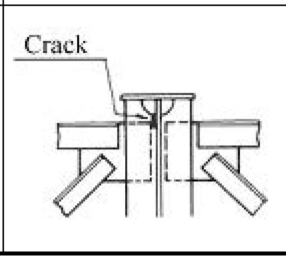
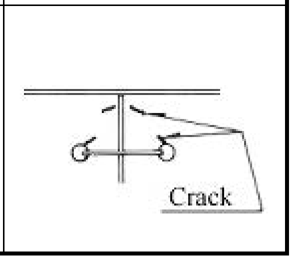
Type	1	2	3	4
Cross beam				
Sway bracing				

Fig. 6.2.2.1 Cracks pattern of simple composite I-girder

These cracks have been observed on almost all kinds of similar structures.

The cracks were classified as follows:

(1) Many cracks were found at the simple composite I-girder bridge or H-girder Bridge.

(2) Many cracks were found for bridges where the slab span is more than 3.5 meters and that the slab thickness of 17 to 22 centimeters is thin compared with the conventional slab span (main girder spacing).

(b) Possible causes

In order to investigate the cause, an elastic analysis was performed by using Finite Element Method with a solid model to review the stress condition in the damaged area. The result was outlined as follows:

(1) Large bending moment three times bigger than the allowable stress was observed at the rib plate and top of the vertical stiffener. Also, composite force of bending and shearing was observed at the jammed part welded with the rib plate and upper flange of the vertical stiffener (**Fig. 6.2.2.2**, **Fig. 6.2.2.3**).

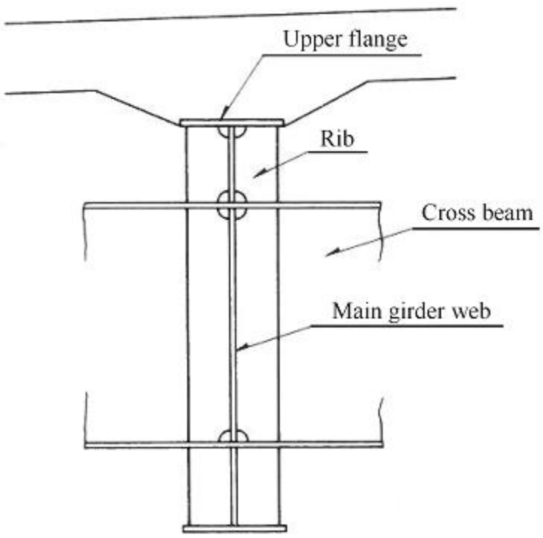


Fig. 6.2.2.2 Structural members

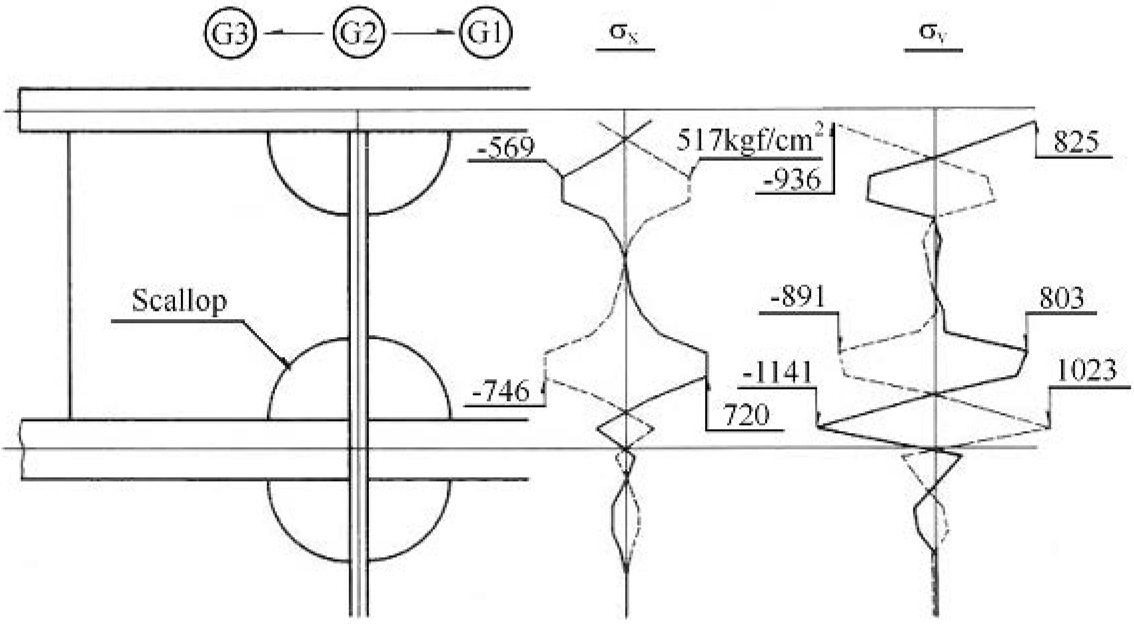


Fig. 6.2.2.3 Stress diagram on the web

(2) The stress on the web of main girder is disturbed at the scallop and has a great influence on flow of stress.
(3) The weld part exhibits bending. It is caused by structural members, such as upper flange, web of the main girder, rib plate and vertical stiffener.

In order to confirm the reliability of the analysis results, a load test was performed under the same conditions as those for the analysis.
The result shows that an excessive stress, exceeding the allowable stress which is not as large as that found in the analysis, exists at the welded part.
The major causes according to the investigation are as follows:

(1) An excessive secondary stress and its repetition caused by an oscillation phenomenon of slab due to live load.
(2) Concentrated stress due to existence of scallop.
(3) Insufficient welding caused by a gap between rib plate or vertical stiffener and the flange due to unskillful fabrication or assembly.

This crack seems to be not so serious for soundness of the girder itself when it stays only on the rib plate or on the vertical stiffener. However, when it develops into the web of the main girder, an urgent repair and reinforcement work is required.

(c) Repair Outline
(1) Preliminary study of repair work
The repair method shown in **Fig. 6.2.2.4** was studied according to the results of the stress analysis.

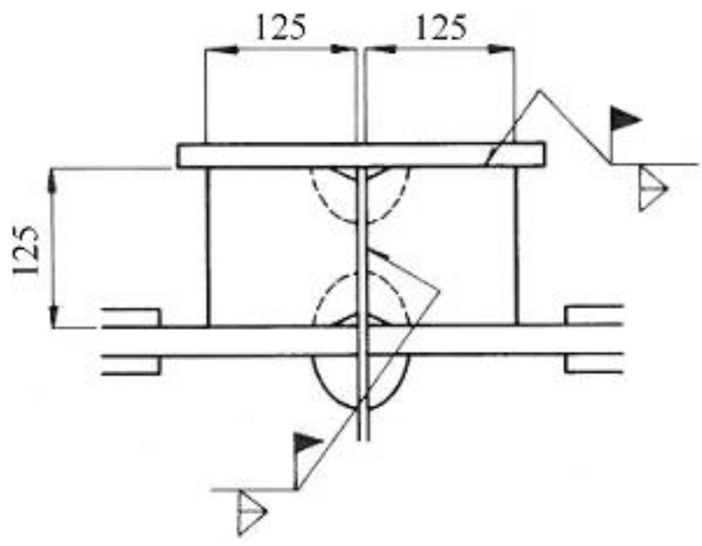


Fig. 6.2.2.4 Stress diagram on the web

The proposed method for the repair has advantages as follows:

1) Shearing deformation generated on the rib plate of the present model was minimized. Also, local bending deformation on the web of the main girder near the rib plate was eliminated.
2) Either main stress or equivalent stress was reduced to about 1/3 of that of the previous one. Also, stress disturbance nearby the scallop was reduced.

(2) Repair Method

A new design for the welded part based on the result of stress analysis was made and a preliminary repair was applied on the damaged part. As a result, the stress generated round the welded part was considerably reduced and the expected purpose was attained. However, local deformation was formed on the upper flange of the girder due to welding heat.

Therefore, an improved repair method was designed as follows:

1) After removing the damaged parts of the welded area, apply a sufficient welding on the necessary part.
2) Replace the present rib plate by a new thicker plate to distribute forces on cross beams.
3) Install a 12mm thick plate by welding around the upper rib of the vertical stiffener against the sway bracing.
4) Scallop is not allowed on the plate mentioned in 2), 3) above.
5) The welding for the new plates to be connected with main girder, cross beam and sway bracing must be strong enough for the stress obtained by an analytical design or test.

(d) Remarks

In this kind of repair works, trial work in advance must be considered to find problems and appropriate repair methods.

S-3 M-Cracks on connected part of gusset or lateral bracing around support of steel I-girder

(a) Conditions

The cracks shown in **Fig.6.2.3.1** and **Photo 6.2.3.1** were found on both welded parts of the main girder web and vertical stiffener connected with gusset for a lateral bracing at the end of the main girder, around the support, in the simple steel girder bridge.

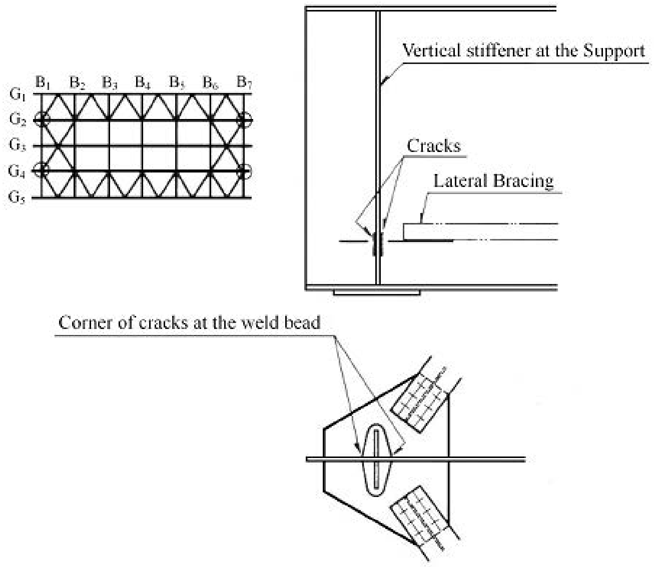


Fig. 6.2.3.1 Location of crack

Photo 6.2.3.1 Condition of crack

The characteristics of the cracks are as follows:

1) The simple steel composite I-girder has more cracks than the others.
2) Cracks have been found at the second panel of the main girder next to the outermost girder.
3) More cracks are observed at the superstructure support by a single T-type pier and on the slender superstructure supported by a steel pier. This was found through survey of relation between types of cracks in substructure.

(b) Possible causes

The causes can be summarized as follows on the characteristics of cracks and the results of elastic analysis by means of Finite Element Method by utilizing a complete solid model and a partial solid model.

1) A large axial force was found at the lateral bracing not only due to horizontal force caused by such as winds and earthquakes, that are normally considered in ordinary design, but also due to the vertical displacement difference between the main girders caused by dead loads, live loads and differential settlement of the support.

2) A large axial force is introduced on the web of the inner main girder from both sides of the lateral bracing by a live load.
3) Stress generated by the axial force is in disorder at the position of the scallop on the gusset plate and makes a local deformation on the web of the main girder (**Fig.6.2.3.2**).
4) Repetition of the deformation develops cracks at the toe of welding near the scallop of the gusset.
5) As the deformation becomes larger, the cracks grow on the welded part of the vertical stiffener on the support, too.

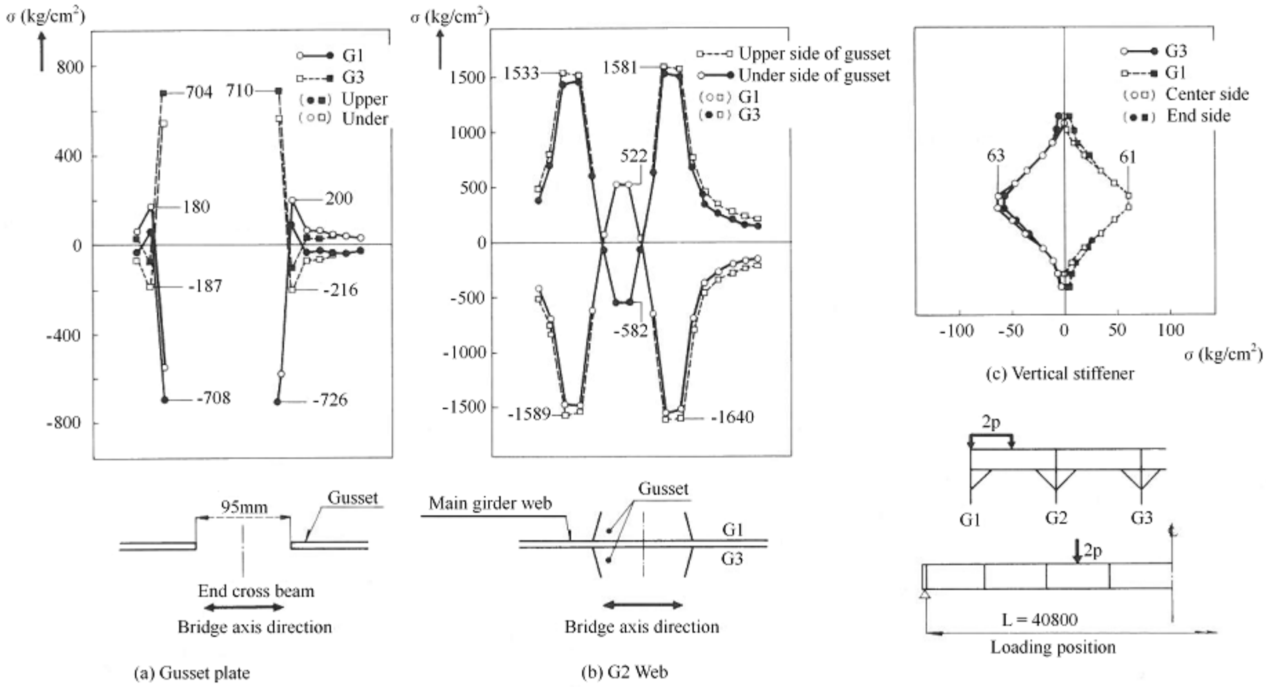


Fig. 6.2.3.2 Stress nearly gusset

(c) Repair Outline

A repair method was examined by the internal committee. The proposed repair method and the results of analysis were shown below.

Two repair methods were proposed as follows:

1) In order to eliminate the stress disturbance around the scallop of the gusset, the scallop must be buried by installing reinforcing plates as shown in **Fig.6.2.3.3 (a)**.
2) Unless the plate is effective for improving the stress flow, additional reinforcing members with the plate must be added to support an imbalanced axial force transmitted from both sides of the lateral bracing as shown in **Fig.6.2.3.3 (b)**.

According to Finite Element Method, the stress flow at the jointed part of the gusset can be sufficiently improved by eliminating the scallop. Effectiveness with additional members is almost the same as that with only reinforcing plates.

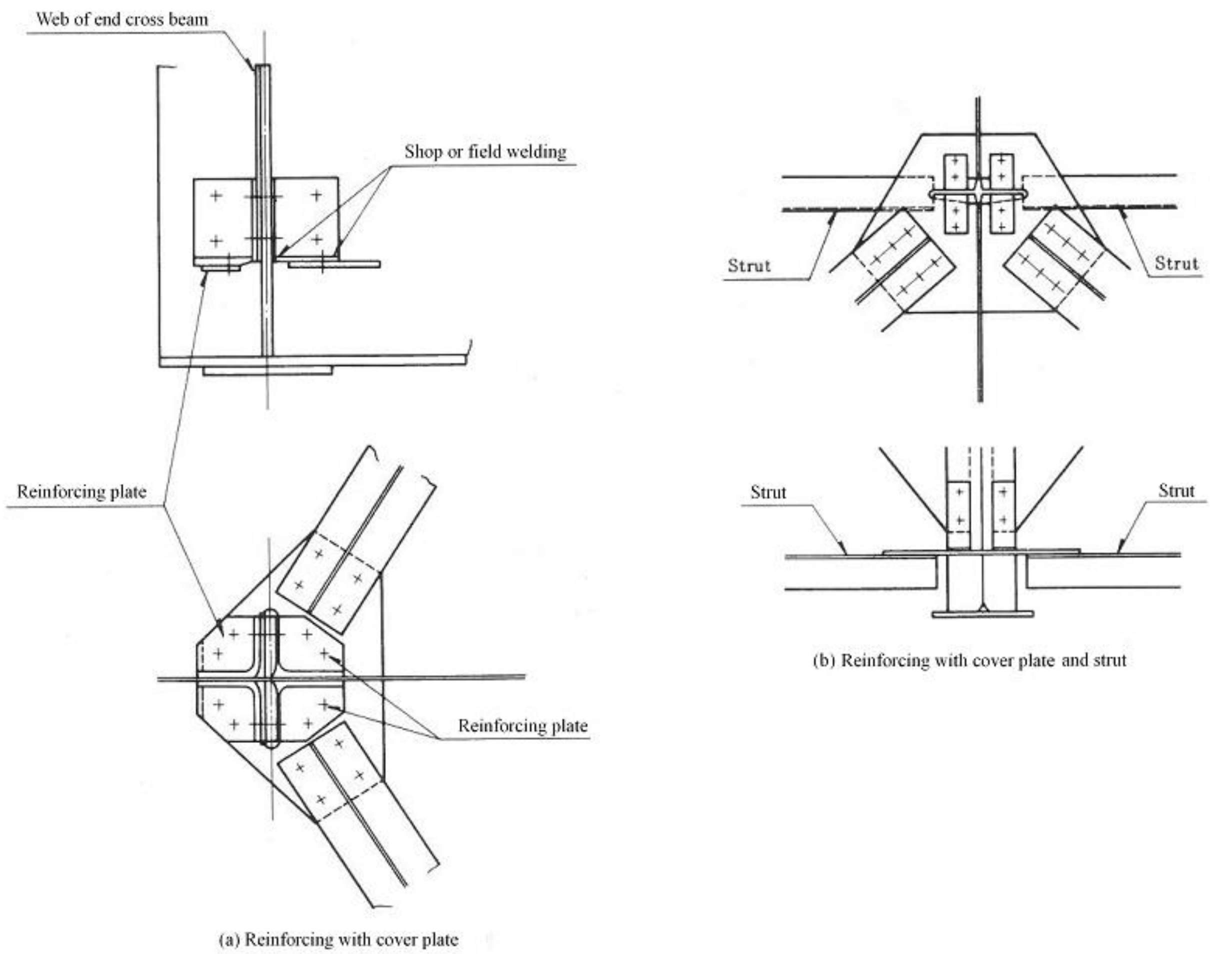


Fig. 6.2.3.3 Example of repair method

(d) Remarks

In the design for the secondary members, more careful attention is needed for the secondary stress and structure details that accompany deformation of the main girder.

S-4 Crack at haunch girder

(a) Conditions

A crack was found on the steel web and on the fillet welding area of lower flange at the hunched main girder as shown in **Photos 6.2.4.1**. Magnetic particle test revealed the crack dimension is in full size as shown in **Fig. 6.2.4.1**.

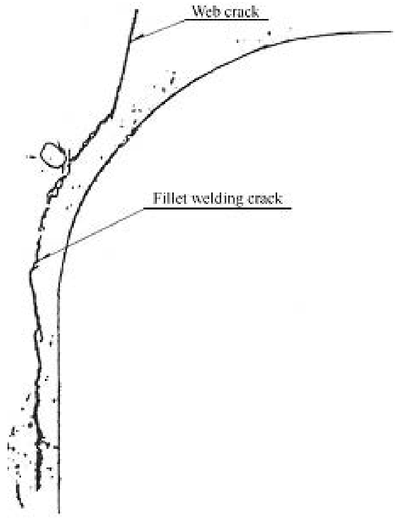


Fig. 6.2.4.1 Crack dimension in full scale drawing

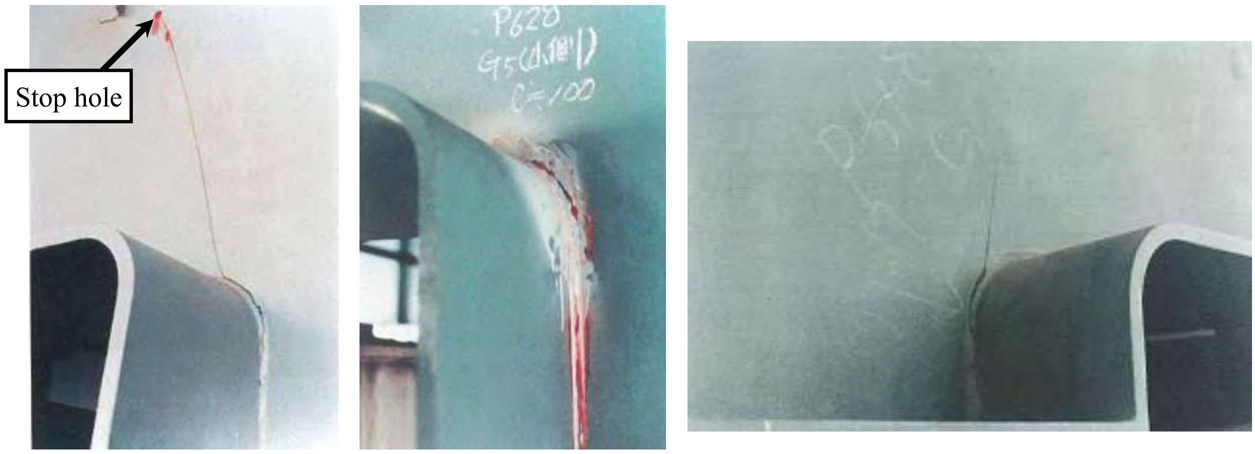


Photo 6.2.4.1 Crack on steel girder

This bridge, simple composite girder bridge which consists of 6 main I-girders, has been operating for 13 years. In survey of the other I-girders on the same bridge, cracks were found at four places of filet welding area on the middle girders. Also, similar kinds of cracks were found on the same type of three other bridges, including two cracks which expanded from the welded area to the web.

This bridge had been repainted a year before the cracks were found. According to the results of investigation, paint penetrated into the crack at the flange fillet welding, but it did not on the crack at web. It is assumed that the crack at the web developed about 60cm during the first year after repainting. Investigation by magnetic particle test showed obviously both a root failure of the weld bead and a toe failure of the mother material existed alternatively.

(b) Possible Causes

The causes of damage clarified up to the present time were as follows:

(1) It was determined from the fracture surface observation that the crack was caused by fatigue.

(2) The root gap for fabrication of notched part is 2.1 mm maximum. This dimension is bigger than that of normal standard, but it is not the main factor according to research data in the past. However, a larger root gap will become one of factors for slag inclusion. Also, a larger root gap increases such possibilities as an occurrence of a small pit to introduce stress concentration at bottom of the weld bead due to increasing a residual stress or extending a root crack.

(3) Results according to Finite Element Method (FEM) show that a normal stress at the R-Shape notched section (One of local stress existing between a lower flange plate and a web) exceeds the ultimate strength of the welding material during loading of the design load. This will be one of causes to encourage development of fatigue crack.

(4) As long as a crack exists only in the welded zone of the flange plate, the overall stress is almost the same as that of the sound structures. However, when the crack develops into the web the strength charged by the flange plate will be decreased and the stress acted on the web will be exceeded.

Therefore, while the crack stays in the R-shape notched section, it is not so serious from viewpoint on the strength of the structure. However, if the crack expands onto the web, it will introduce serious damage of the structure. Because of this, repair is necessary as soon as possible during the crack stays in the weld bead.

(c) Repair Outline

Repairing work for the crack reaching the web was carried out as follows:

(1) Confirming the location of the crack end on the web by means of SUMP photo, put a stop-hole with a diameter as big as the web thickness, at the point of the crack end.

(2) Reinforcing the I-girder with temporary support at 1/8 span of the girder, jack it up to remove the dead load.

(3) Keeping the notched part to be in the stress-free condition as much as possible, conduct the welding with an x-shape groove at site after bead gouging.

(4) Placing splice plates with reinforced flanges at the both sides of the web, by high-strength bolts shown in **Fig. 6.2.3.2** and **Photo 6.2.3.2**.

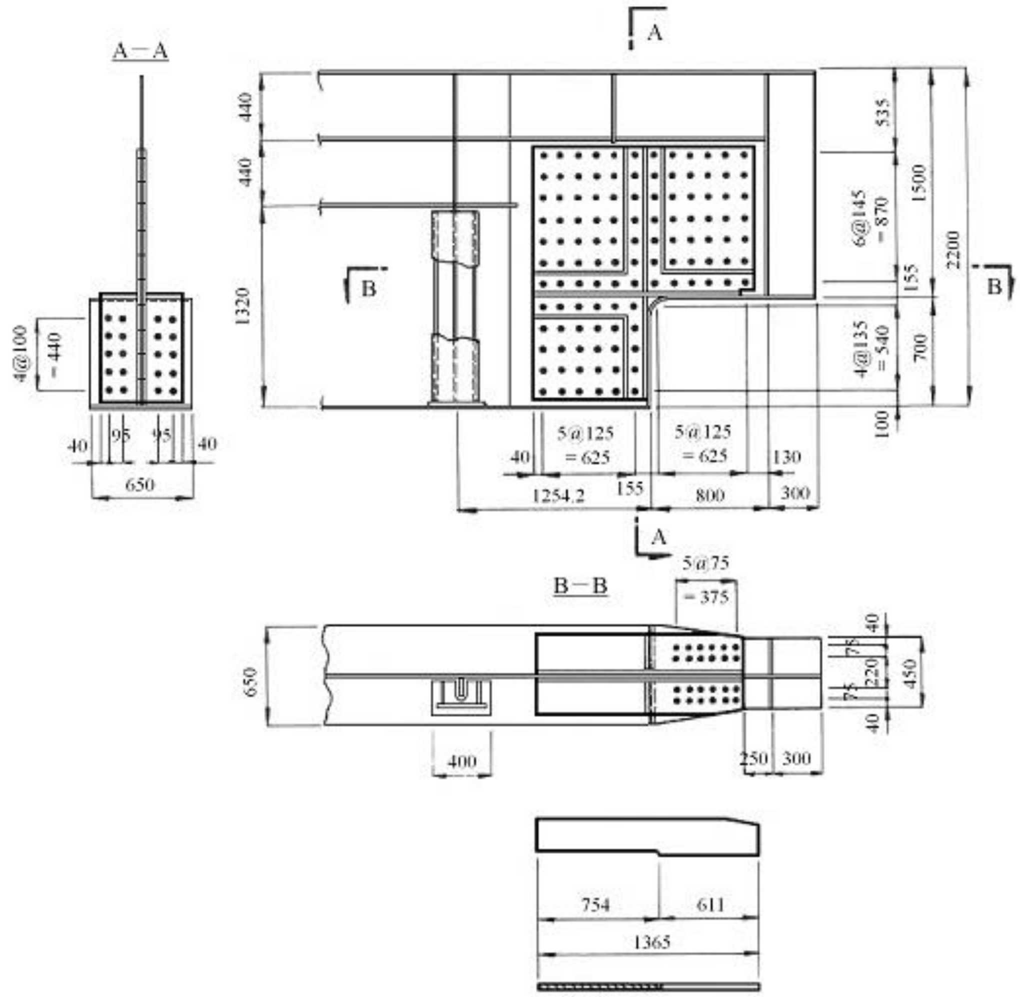
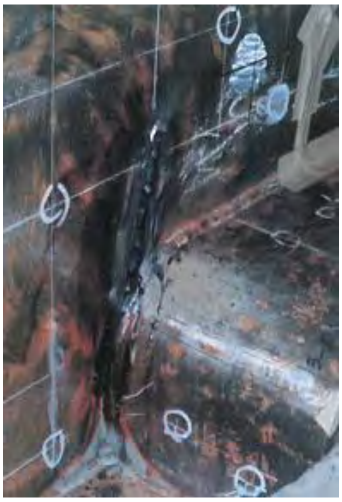


Fig. 6.2.4.2 Detail design of repair work



(a)Marking in full section web **(b)Bolted condition**

Photo 6.2.4.2 Plates with reinforced flanges

(5) In order to decrease a shear stress level, extend both ends of reinforced flanges vertically and horizontally at the corner according to a new design standard.

(6) Due to installation of new flanges the stress acted on the flange at the corner will be minimized and the stress by the curved flange will be distributed to the splice plate.

(7) With repainting the necessary parts complete the repair work.

(d) Remarks

The major advantages to make a notched part on the main girder are as follows in case of hanging girders which has a different height because of a different length of the span.

1) To keep enough clearance underneath a girder.
2) To avoid constructing a step beam,
3) To adjust the horizontal level of bearings.

To relieve concentrated stress appeared at the haunch girder, a careful investigation for various kinds of the shape as shown in **Fig. 6.2.4.3** was carried out. After the investigation with a load test, the new type of notches with reinforcing flanges was recommended in the present design standard.

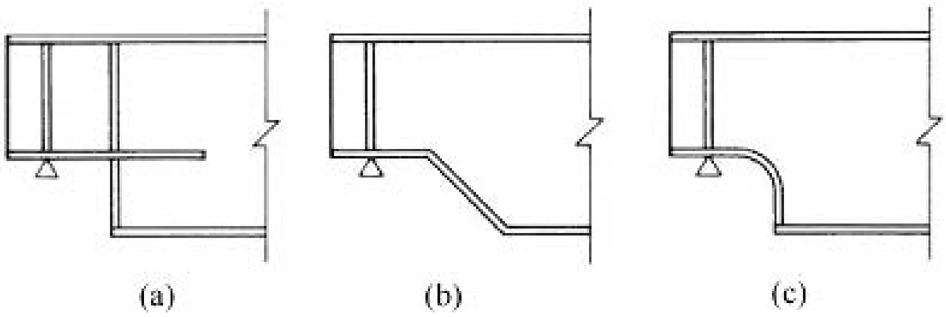


Fig. 6.2.4.3 Haunch girder

S-5 Steel pier corrosion

(a) Conditions

A serious corrosion due to an intensive dew condensation occurred in a steel pier as shown in P**hoto 6.2.5.1**. In a steel pier, sometimes paint-missing fault (usually 2-layer coat with tar epoxy must be applied) occurred because of tight condition. Rust due to dew condensation inside of the pier as shown in **Photo 6.2.5.1(b)**.

(a)Remarkable dew condensation

(b)Corrosion status (No painting)

Photo 6.2.5.1 Steel pier corrosion

(b) Possible cause

This kind of examples can be found out more often in structures with complicated shapes as shown in **Fig. 6.2.5.1**. The primary factors are assumed that the air circulation in the sealed area is not smooth because of its complicated shape, so dew condensation is introduced on the steel surface due to the temperature difference between inside and outside of structures.

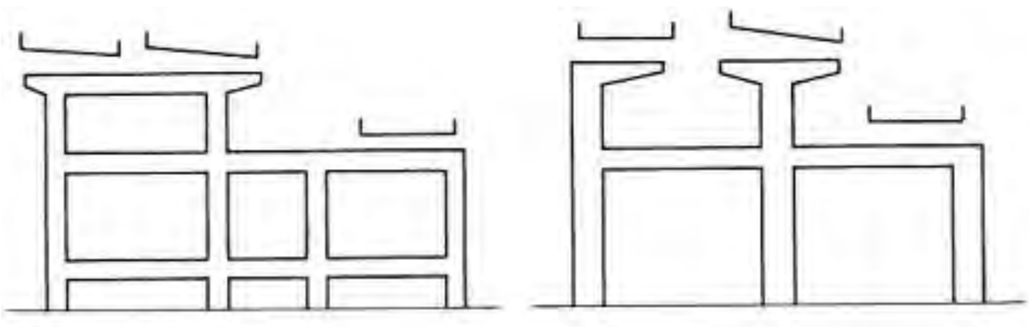


Fig. 6.2.5.1 Steel pier sectional diagrams

More careful supervision at site must be taken to protect the paint-missing for coating in accordance with the standards at the joint area.

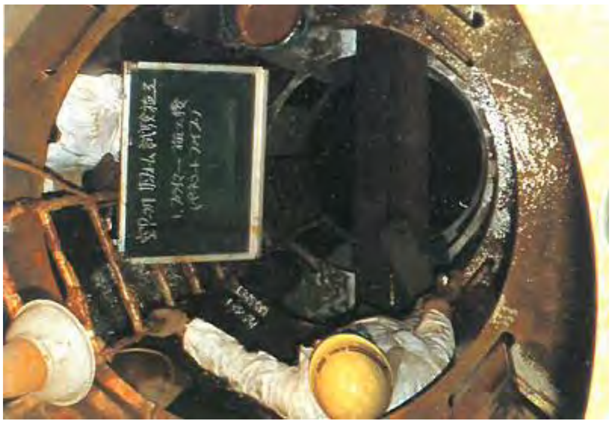
(c) Remarks
The best preventive way of this damage is to provide smooth ventilation.
No perfect painting material is now available for repairing of such a closed area, then the repair work is rather difficult now.
The following measures shall be taken in consideration.

(1) Painting of non-solvent paint
Perfect ventilation in the use of tar epoxy resin paint for the jointed area can be applied on the fabrication of steel structures in a workshop.
Especially for a safe of field working, however, it is difficult to provide perfectly controlled ventilation for repainting. In this context, non-solvent tar epoxy resin paint must be considered effective in such works.
Characteristics of the non-solvent tar epoxy resin paint can be compared with that of solvent tar epoxy resin paint as shown in **Table 6.2.5.1**. A serious risk for using non-solvent paint is that it is greatly influenced by the temperature and that a setting time is very short.
A low temperature is suitable for controlling a setting time, while a high temperature is useful for a promotion of a dry strength.

Table 6.2.5.1 Comparison of utilization properties for solvent and non-solvent tar epoxy resin paint

	Solvent tar epoxy	Non-solvent tar epoxy
Ventilation	bad	good
Dryness	good	bad
Rust proofing (for a bad surface)	bad	bad
Water proofing	good	good
Brush painting property	good	bad
Work safety	bad	good
Pot life	n.a.	bad
Economic view point	good	bad

(2) Spraying of urethane foam
Corrosion on the steel material is mainly caused by oxygen and water. In order to isolate these items, solid urethane foam resin with an excellent thermal insulation effect was tentatively applied on the structures as shown in **Photo 6.2.5.2**.



(a) Inspection

(b) Ventilation

(c) Rigid urethane spraying

(d) Rigid urethane spraying

Photo 6.2.5.2 Solid urethane foam resin

The procedure is as follow:

1) Draining the steel pier.
2) Ventilation
3) Rust removal
4) Cleaning (wiping with a rag)
5) Primer coating
6) Urethane foam spraying.

For using solid urethane foam resins, it is necessary to confirm properties such as:

1) Applicability of a combustible material like petroleum, class IV.
2) Cost
3) Adhesive effect
4) Viability and durability to follow the deflection of steel structures

(3) Providing a ventilation system with no temperature difference.
The condensation easily starts in high humidity. Also, when the humidity is low, a high temperature difference between the inside and outside is quite sensitive to initiate condensation.
Therefore, it is useful to provide manholes covered by a wire net (to protect entering of birds) to keep a smooth ventilation.

CHAPTER 7 REPAIRE OF FOUNDATION OR OTHER STRUCTURE

7.1 Case of other bridge structure repair

This section is to introduce repair cases of other bridge structures.

J-1 Damage on Expansion joint

(a) Conditions

For any bridges, expansion joints are essential components in order to adjust its displacement caused by such factors as temperature variation, concrete creep and shrinkage. However expansion joints are the weakest point among bridge structure components and their failure may cause unevenness on road surface and hinder smooth movement of vehicles.

Rubber joint and steel finger types are mostly used for the purpose of keeping road continuous and adjusted due to temperature change or live load. It is, however, rather difficult to provide a high quality joint to satisfy the requirements sufficiently.

There are several patterns of damages on expansion joints which are discussed below.

(b) Possible causes

Main causes of the damage to expansion joints are as follows:

1) As traffic volume and vehicle load increase, expansion joints of bridges suffer from abrasion and fatigue failures
2) Inadequate choice of expansion joints for a long-span bridge, skewed bridge or curved bridge causes malfunction, or they are not anchored properly to the main girders.
3) When a level difference exists between the expansion joint and the concrete deck of abutment parapet due to faulty construction, impact of vehicle's weight becomes greater and inflicts damage to expansion joints on bridge decks.

It is difficult to identify the cause of expansion joint damage, as the damages appear in a combination of several adverse conditions. Major causes mentioned above can be classified into several factors shown as follows:

1) Design factors
    * Insufficient rigidity of the slab ends,
    * Insufficient rigidity of expansion joint body,
    * Insufficient strength of expansion joint anchor members,
    * Mistakes in the selection of mounting materials,
    * Miscalculation of maximum expansion due to temperature change and creep,
    * Misallocation of drain facilities and drain water inlet.
2) Construction Factors
    * Construction error in slab spacing,
    * Insufficient construction control for mounting materials.

* Deflective beds including those for slab and bridge end concrete,
* Insufficient quality of joint material and poor compaction of pavement around joints.

3) Ambient Factors

* Increase of axial loads and load frequency,
* Deterioration of joints and pavement material caused by abrasion or heavy compaction,
* Aging of slab,
* Irregular road levels on both sides of expansion joint (dislocation caused by swelling of the pavement material),
* Insufficient cleaning of road surface (dust disposal and penetration of water),
* Damages of bearings, piers and abutments caused by deformation,
* Development of abnormal conditions such as fire hazards and earthquakes.

Typical types of damage on the steel finger type joint are as follows:

* Water leakage from drain inlet.
* Water outpour due to clogging in drainage gutter.
* Breakage of slab concrete at the ends of the slab.
* Generation of rust.
* Generation of noise.

Typical types of damages on the other types of joints are as follows:

* Generation of cracks at slab ends.
* Generation of noise.
* Water leakage from main structure.

(c) Introduction of Repair Methods

Repair methods for the damages of the expansion joints have been employed with good results in recent years as described in the following.

(1) Development of "no-joint", jointless system

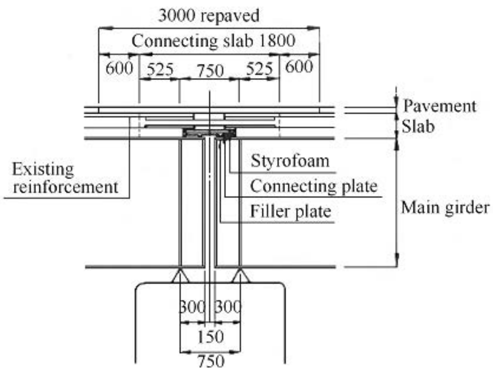
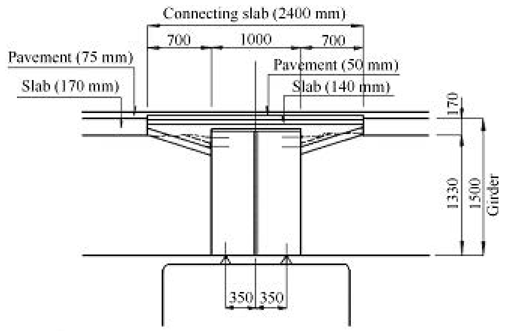
Joint-less system which eliminates expansion joints has been employed as a drastic measure for repairing the joint damage. This is a totally new concept to improve the driving comfortability, to decrease noise or vibration, and to reduce damages on the expansion joints.

This can be applicable to both steel girder and pre-stressed concrete girder bridges.

Basic outlines of the system are as follows:

1) Two adjacent single girders are coupled to be continuous by installing coupled plates on the main steel girders. The plate is not employed for the case of pre-stressed concrete girders.
   After interconnecting the girders (only in case of steel girders), adjacent slabs are connected together and pavement becomes continuous at the joint.
2) Countermeasures for temperature changes and horizontal force at the time of earthquakes are taking into account. All bearings, except for one fixed bearing, are converted to the movables with dampers for the steel girder bridges. Flexible pier system is used for the pre-stressed concrete girder bridges. **Table 7.1.1.1** shows a guideline of these couplings in the joint-less system.

Table 7.1.1.1 Guideline of joint-less system

<table>
<tr><th></th><th>Steel girder</th><th>PC girder</th></tr>
<tr><td>Coupling system</td><td>
</td><td>
</td></tr>
<tr><td>Condition and reaction force spreading system</td><td>Change from fixed bearings to movable bearing.
Stress spreading is done by means of viscous fracture model damper

</td><td>The current bridge bearing conditions are maintained.
Reaction force spreading is done by means of " flexible pier" system

</td></tr>
<tr><td>Outline of procedure</td><td>1) By connecting the top flanges of main girders with a splice plate, decrease the deformation of the connecting deck slab.
2) Continue deck slabs, and settle a buffer layer with a Styrofoam plate between the slab and girders to absorb the deformation due to rotation of girders.
3) Connect the top flanges of the end cross beams with a kin plate (6 -8mm), which is also used as the foam concurrently.
4) For the crack in deck slab, execute an anti-corrosive treatment to the reinforcing bars and perform a water proof coating on the deck slab.
5) For the thermal expansion of girders and transmission of horizontal seismic forces caused by continuing the top flanges and deck slab, though it is desired to absorb these forces by the deformation of the foundations and the piers, it will not be enough. Exchange therefore every fixing bearing into movable bearing except one and settle a damper system between girders and piers instead.</td><td>1) Continue deck slabs of girder ends, and settle a buffer layer made of a Styrofoam plate between the slab and the girder to separate their behaviors.
2) Because deck slabs will not be supported at the girder ends due to executing the term i), expand the haunch of the end cross beams and support the slab.
3) For the crack in deck slab, execute an anti-corrosive treatment to the reinforcing bars and perform a water proof coating on the deck slab.
4) For the thermal expansion of girders and transmission of horizontal seismic force caused by continuing the deck slabs, absorb these forces by the deformation of the foundations and the piers.</td></tr>
</table>

Detailed structural analysis is carried out for coupling parts as the key components of the system. Static and dynamic tests were executed by using a large scale model in a research laboratory.
Later, on the occasions of a major repair work by closing road traffic, the system has been applied to several bridges as shown **Photo 7.1.1.1** at several sections.

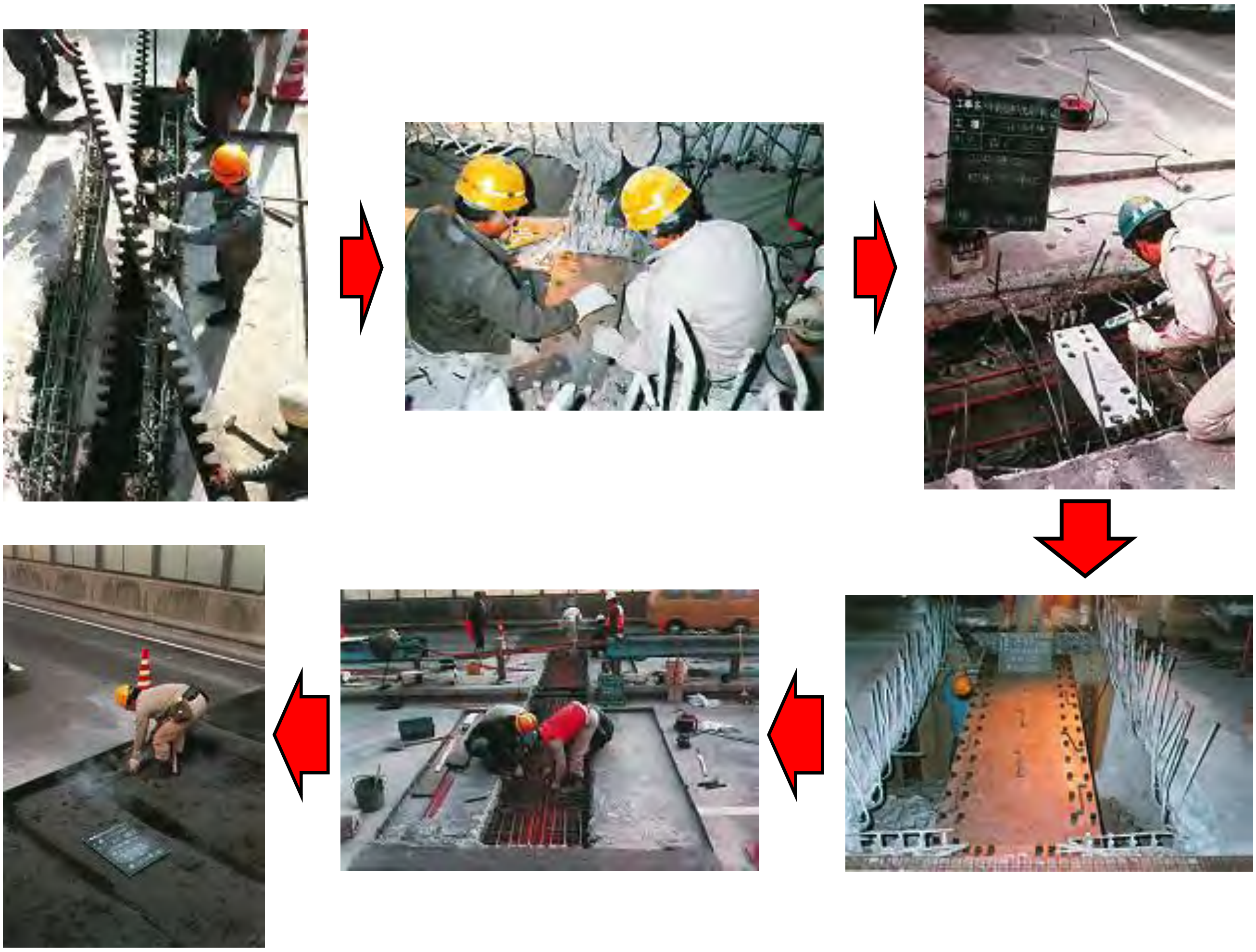


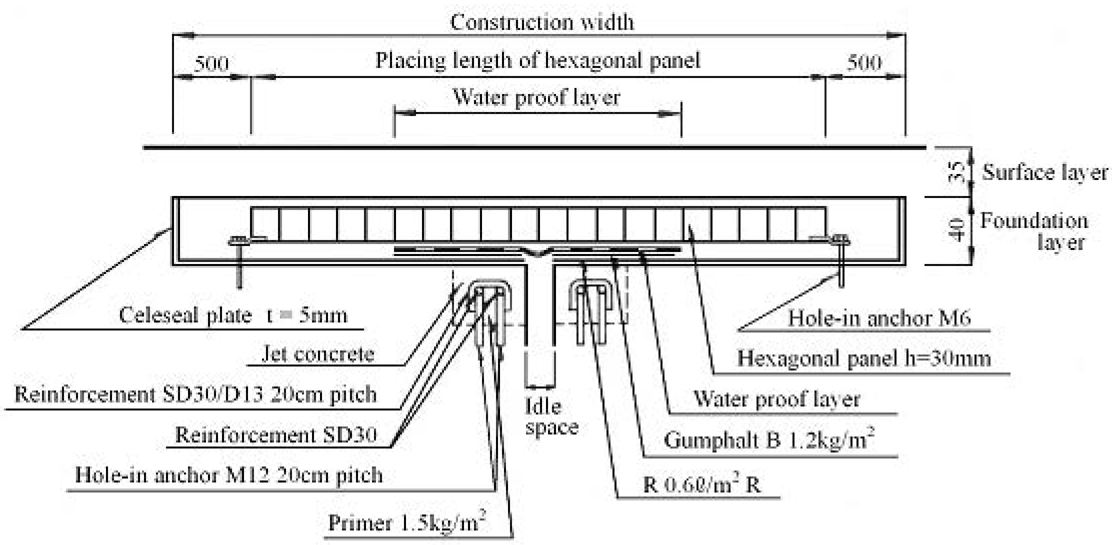
Photo 7.1.1.1 Construction of joint-less system

No abnormality has been appeared so far and, it is convinced that this application has been successful. Furthermore, a simplified joint-less system for the shorter span girders has been conducted tentatively.

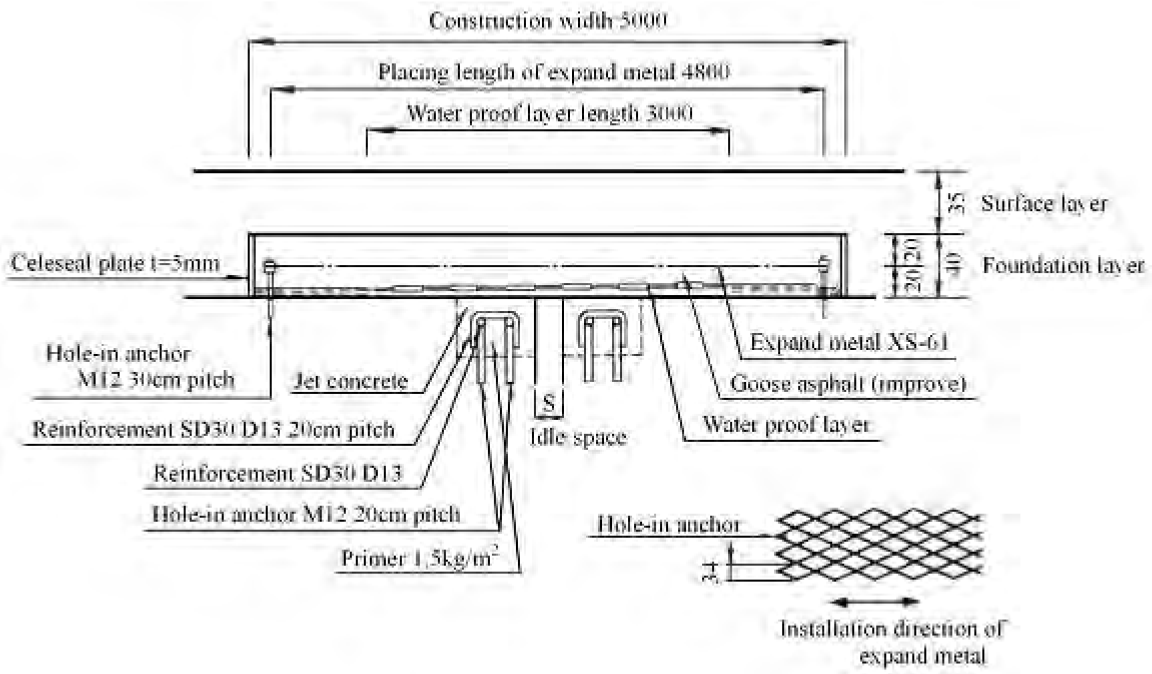
This could be classified into the following two methods:

1) Method by hexagonal panel:

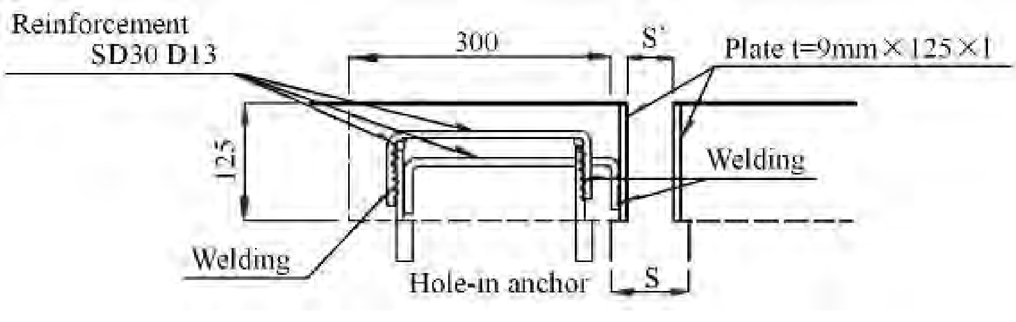
A light weight steel plate, hexagonally shaped porous panel is built in the asphalt pavement. Because of this arrangement, the rigidity and toughness of deformation of the pavement are improved. (**Fig.7.1.1.1 (a)**, **Photo 7.1.1.2**).



(a) Method by hexagonal panel



(b) Method by expand metal



(c) Idle space adjustment

Fig. 7.1.1.1 Simplified joint-less system

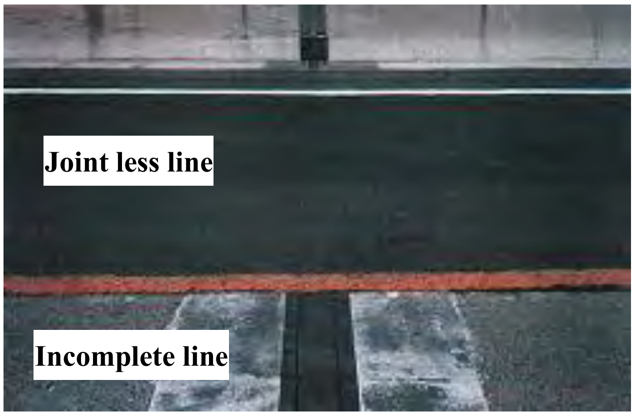


Photo 7.1.1.2 Joint less method by hexagonal panel

2) Method by expand-metal:

The expand-metal is buried in the pavement, instead of the hexagonal-panel. This method aims to improve the rigidity and toughness against the pavement deformation.

This also aims to get high ability for shear deformation of the water-proof layer installed on the surface of the slab. (**Fig.7.1.1.1 (b)**)

As a result of these applications, cracks in the pavement surface were found for the hexagonal panel after about one year.

The cracks were observed at locations where unevenness or bumping on the slab surface were conspicuous.

This suggested that it was important to give smooth finish in construction when this method was applied.

(2) Watertight system on steel finger joints

In the current design standard for new construction, this system with stainless steel gutter has been already introduced instead of the conventional drain type.

However, concerns still remain to be unimproved with the rainwater leakage from the joint's gutter.

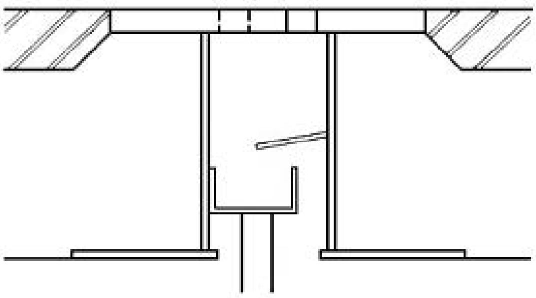
To eliminate the problem of water leakage, the watertight system on the steel finger joints is applied, as the design standard recommended, using elastic sealing materials.

Brief construction procedure of the system is as follows:

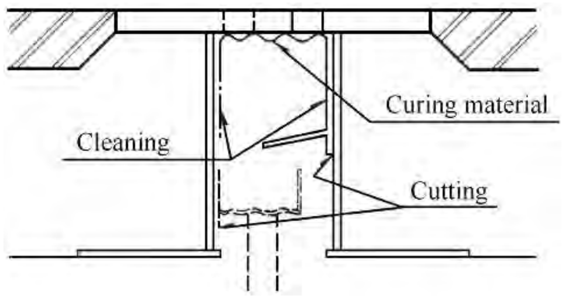
1) Taking away old type water gutters
2) Placing water cut-off member (made of thermoplastic elastomer) underneath the face plate of the finger joints.
3) Pouring the elastic sealing material (of poly-buthan-diethylene or like).

All works, except for around curb stones, must be done on the road surface.

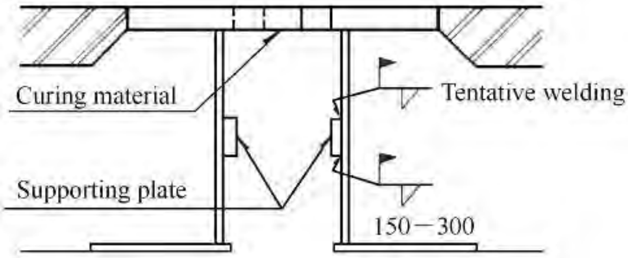
Fig. 7.1.1.2 and **Fig. 7.1.1.3** show the procedure of the works by the foamed water cut-off member. (As for the elastic sealing material, refer to **Fig. 7.1.1.4** and **Photo 7.1.1.7,** respectively)



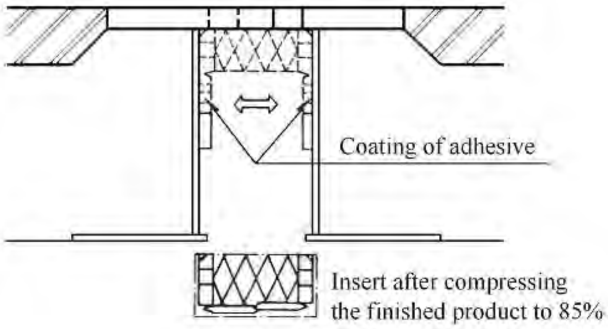
(a) Before the work



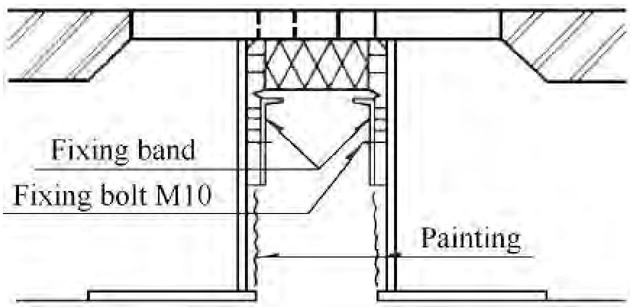
(b) Withdrawal of water gutter, cleaning



(c) Welding of supporting plate

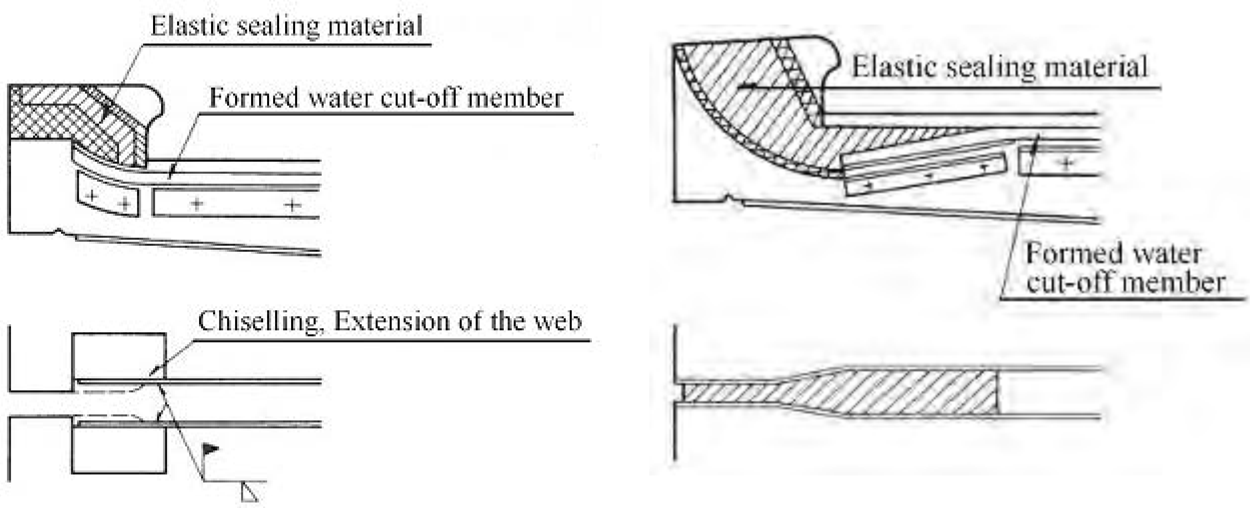


(d) Insert the formed water cut-off member



(e) Installation of fixing band, painting

Fig. 7.1.1.2 Improvement of water gutter by formed water cut-off member



(a) Improved type

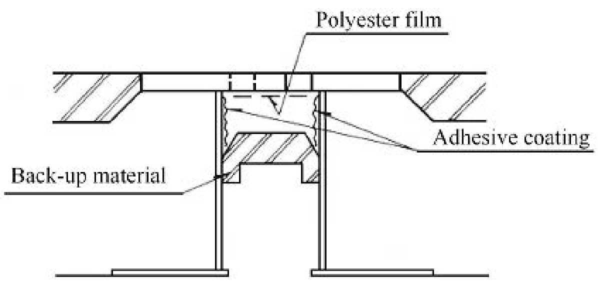
(b) Conventional type

Fig. 7.1.1.3 Improvement of water gutter by formed water cut-off member (2 types)

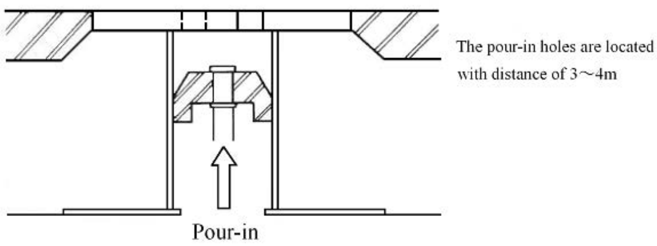
Photo 7.1.1.3 Cleaning of the web surface

Photo 7.1.1.4 Setting of formed water cut-off material

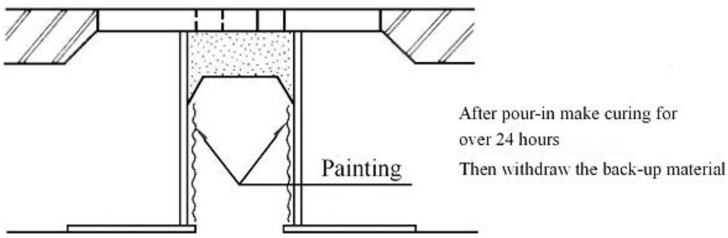
Photo 7.1.1.5 Installation of supporting metal pieces



(a) Adhesive coating and installation of back-up material



(b) Pouring of elastic water cut-off material



(c) Withdrawal of back-up material and painting

Fig. 7.1.1.4 Improvement of water gutter by elastic sealing material

(a) Installation of back-up material

(b) Pouring of elastic sealing

(c) Finished work

Photo 7.1.1.6 Improvement of water gutter by elastic sealing material

(d) Remarks

Damage of expansion joints not only causes traffic troubles but also causes discomfort and dangerous sensations to the drivers. Moreover, it has such serious effects as damaging slabs, causing rust generation and corrosion in the bearings and the bridge structures, especially on the steel bridge. At the same time, the noise and vibrations caused by passing vehicles inflict great discomfort to the inhabitants of the surrounding area.

Being subjected to direct loads, expansion joints are susceptible to the damage. And once they are damaged, expansion joints are so difficult to be repaired that many problems arise in maintaining and managing them because of their locations.

Because an expansion joint is directly subjected to the impact force of vehicles, it must be firmly attached to the main body of the bridge.

Although it is also difficult to restore them perfectly to the original state, it is often necessary to replace the whole equipment or to change to another type of structure depending on the damage.

In recent years in Japan, due to increase of traffic volume and heavy weight vehicles the conditions are aggravating. In consequence, even a slight defect in construction becomes the cause of a joint damage. Further, due to the restrictions imposed by the works conditions, sufficient repair measures cannot always be taken, so that it becomes necessary to perform repair now and then.

Suggestions for the maintenance of expansion joints

As even a slight defect in the expansion joint may develop into major damage, the best policy in management would be the early discovery of defects. However, when the damage reaches a advanced stage and restoration by routine management becomes no longer appropriate, it is essential that repair be performed before any serious consequences are generated. In the case of the expansion joint selection, it is necessary to give consideration to the following points.

a) Investigation of the cause of damage,
b) Nature of the Expressway in terms of service,
c) Bridge type……Construction of slab and bridge ends,
d) Required expansion movement and joint spacing,
e) Desired characteristics of expansion joint to be selected, such factors as:
    - Durability,
    - Levelness,
    - Water tightness,
    - Maintainability
    - Economical advantages.

As it is difficult to judge such matters as the 1) thickness at the slab ends, 2) degree of damage and 3) abnormality in the joint gap from the road surface, it will be necessary to chip off a part of the slab concrete, or a part of the bridge end, or the whole slab and to perform repair depending on the type of the expansion joint. During chipping work, particular attention must be paid toward avoiding damages to the RE-bars in the slab concrete. Particularly careful attention is required for pre-stressed concrete bridges as the anchoring of PC steel wires will be found concentrated in the bridge end sections.

Although in the constructions following factors are assumed; 1) the performance of each expansion joint and 2) the classification and type of the bridge in design and construction work. It is necessary to reexamine these factors before starting repair work.
Generally, the optimum type of expansion joint must be selected as i) design expansion amount, ii) design minimum joint gap and design maximum joint gap, and iii) allowance. By taking these into account, the capability and features of the expansion joints will be decided.

In setting up the repair work plan, restriction relating to traffic measures, construction method must be taken into account.

J-2 Bridge scour

Spread footings on soil or erodible rock shall be located so that the top of footing is below the design flood against bridge scour and the bottom of footing is below scour depths determined by the check flood for scour. Spread footings on scour-resistant rock shall be designed and constructed to maintain the integrity of the supporting rock.

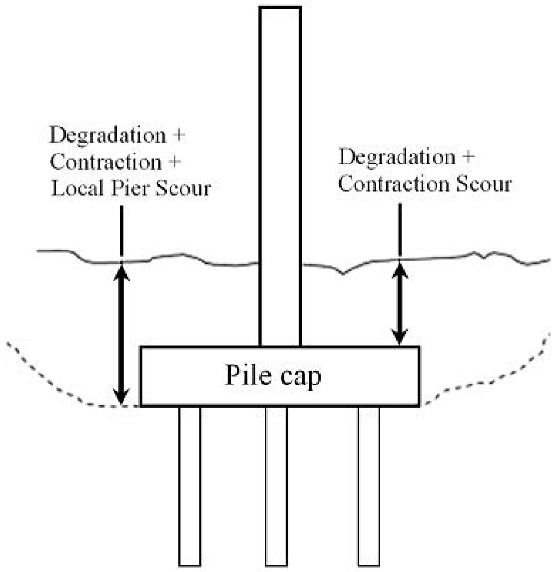


Fig. 7.1.2.1 Ground line from the foundation

Deep foundations with footings shall be designed to place the top of the footing below the estimated degradation plus contraction scour depth to minimize obstruction to flood flows and resulting local scour. Even lower elevations should be considered for pile-supported footings where the piles could be damaged by erosion and corrosion from exposure to stream currents. Where conditions dictate a need to construct the top of a footing to an elevation above the streambed, attention shall be given to the scour potential of the design.

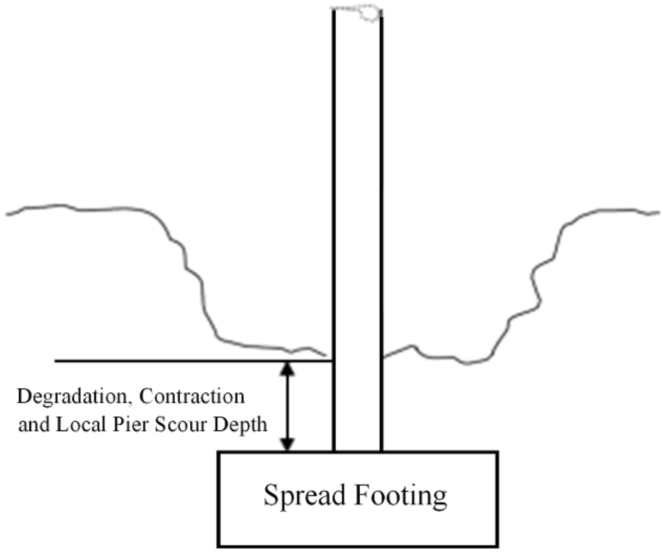


Fig. 7.1.2.2 Spread footings of the bridge

The stability of abutments in areas of turbulent flow shall be thoroughly investigated. Exposed embankment slopes should be protected with appropriate scour countermeasures. Abutment footings shall be designed so as to be stable for permanent loads and hydraulic forces assuming the loss of approach fill. Deep foundations may be necessary.

(a) Conditions

The most common cause of bridge failures is caused by floods scouring bed material from around bridge foundations. In 1985, 73 bridges were destroyed by floods in Pennsylvania, Virginia, and West Virginia in USA. The 383 bridge failures caused by catastrophic floods showed that 25 percent involved pier damage and 75 percent involved abutment damage in 1973, USA.

Photo 7.1.2.1 Condition of Bridge Score

(b) Possible causes

Total scour at a highway crossing is comprised of three components.

Aggradation and Degradation:

These are long-term streambed elevation changes due to natural or human-induced causes within the reach of the river.

Contraction Scour:

This type of scour involves the removal of material from the bed and banks across all or most of the width of a channel. Most commonly, this scour is the result of a contraction of the flow (**Fig. 7.1.2.3** and **Photo 7.1.2.2**).

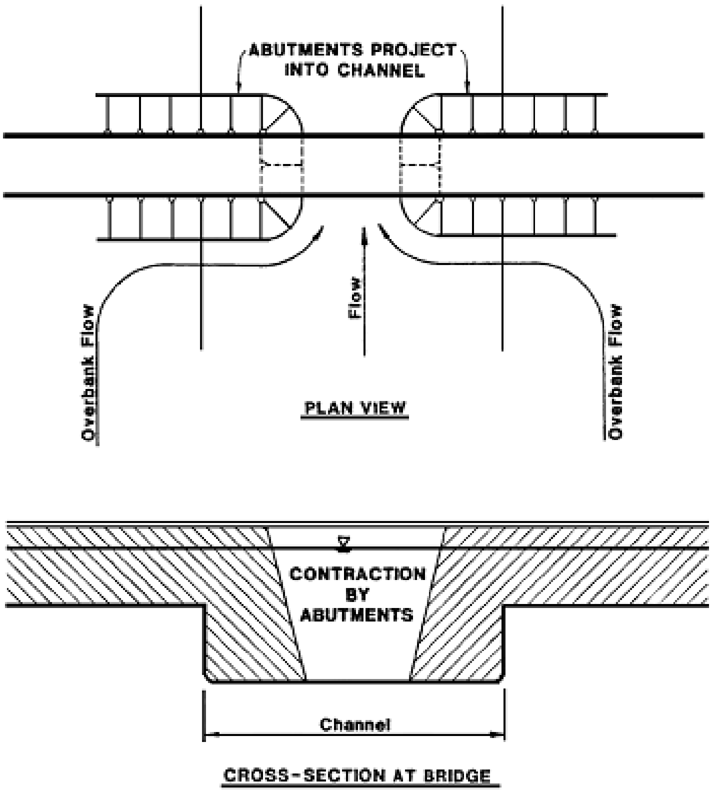


Fig. 7.1.2.3 Approach embankments

Photo 7.1.2.2 Narrow river width by old bridge abutment

Local Scour:

This scour occurs around piers, abutments, spurs, and embankments and is caused by the acceleration of the flows and the development of vortex systems induced by these obstructions to the flow **Fig. 7.1.2.4** and **Photo 7.1.2.3**).

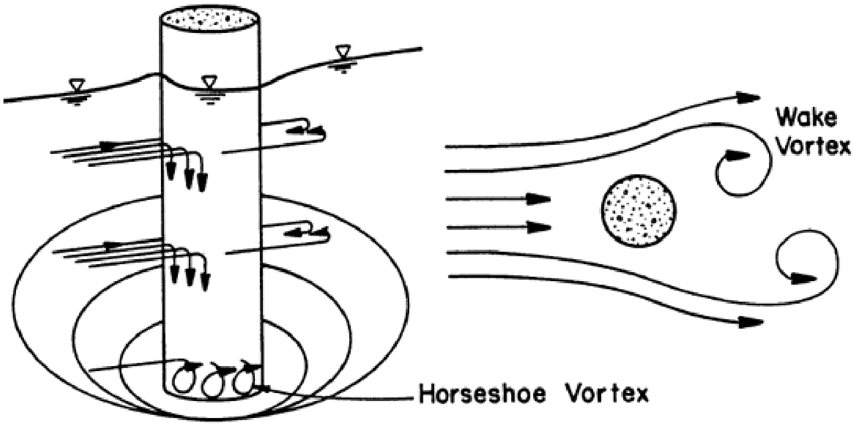


Fig. 7.1.2.4 Schematic representation of scour at a cylindrical pier

Photo 7.1.2.3 Schematic representation of scour at a cylindrical pier

(c) Outline of repair work

The selection of a countermeasure depends on the type of scour involved.

Different materials scour at different rates. Loose granular soils are rapidly eroded under water action while cohesive or cemented soils are more scour-resistant. However, ultimate scour in cohesive or cemented soils can be as deep as scour in sand-bed streams.

Scour will reach its maximum depth by materials as follows;

In sand and gravel bed materials in hours;
Cohesive bed materials in days;
Glacial tills, poorly cemented sand stones and shales in months;
Hard, dense and cemented sandstone or shales in years;
And granites in centuries;

a) Reduction of cause

Before carrying out the repair work, it is necessary to remove the cause of scouring as possible.

In the previous case of **Photo 7.1.2.2**, because the abutment of the old bridge wasn't removed, the river flow increased in rainy season, and the scouring progressed at an early stage. In this bridge, the old abutment of unnecessary had to be removed not to interfere with the river flow.

And as much trash is accumulated under the bridge shown **Photo 7.1.2.4**, it is needed to clear debris regularly because of the similar concern.

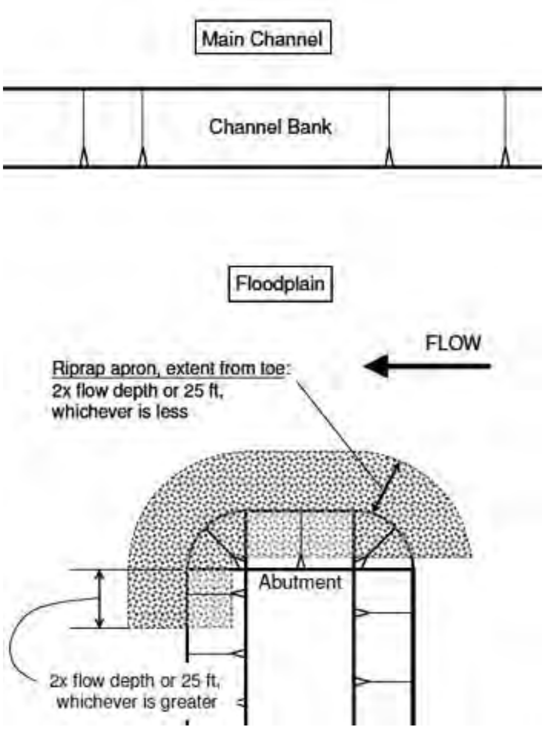
Photo 7.1.2.4 Trash under the bridge

b) Countermeasures for contraction scour

Design alternatives to decrease contraction scour include longer bridges, superstructures at elevations above flood stages of extreme events, and a crest vertical profile on approach roadways to provide for overtopping.

These design alternatives are integral features of the highway facility which reduce the contraction at bridges and, therefore, reduce the magnitude of contraction scour.

In general, design alternatives against structural failure from local scour consist of measures which reduce scour depth, such as pier shape and orientation, and measures which retain their structural integrity after scour reaches its maximum depth, such as placing foundations in sound rock and using deep piling.
The reinforcement of abutment and pier for scouring is shown in **Fig.7.1.2.5-Fig.7.1.2.7**.



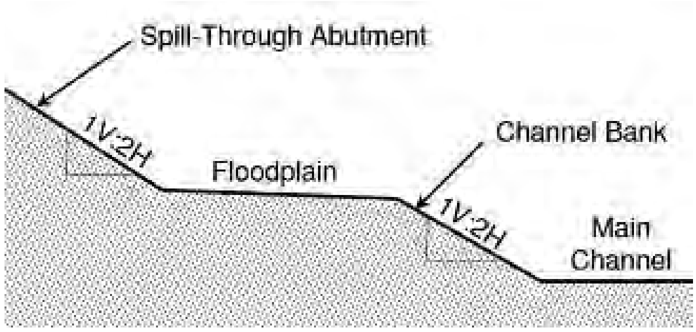


Fig. 7.1.2.5 Plan view of the extent of rock riprap apron

The stone size may be decided by the following formula.

$$\frac{D_{50}}{y}=\frac{K}{(S_S-1)}\left[\frac{V^2}{gy}\right]$$

$$V/(gy)^{1/2} \leqq 0.80 \quad (V^2/gy \leqq 0.64)$$

Where:

D_{50} ; Median stone diameter (m)
V ; Characteristic average velocity in the contracted section (explained below) (m/s)
S_s ; Specific gravity of rock riprap
g ; Gravitational acceleration (9.81 m/s^2)
y ; Depth of flow in the contracted bridge opening (m)
K ; 0.89 for a spill-through abutment
1.02 for a vertical wall abutment

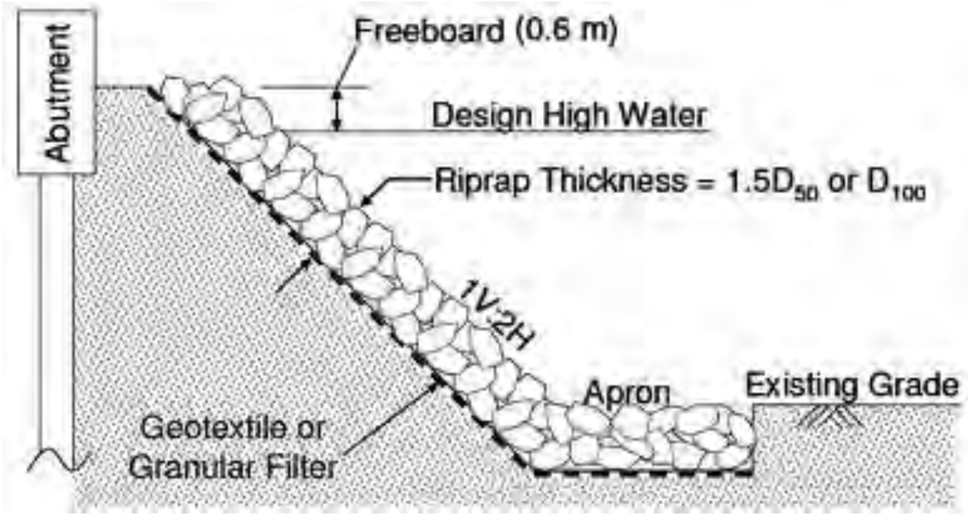


Fig. 7.1.2.6 Typical of cross section for abutment riprap

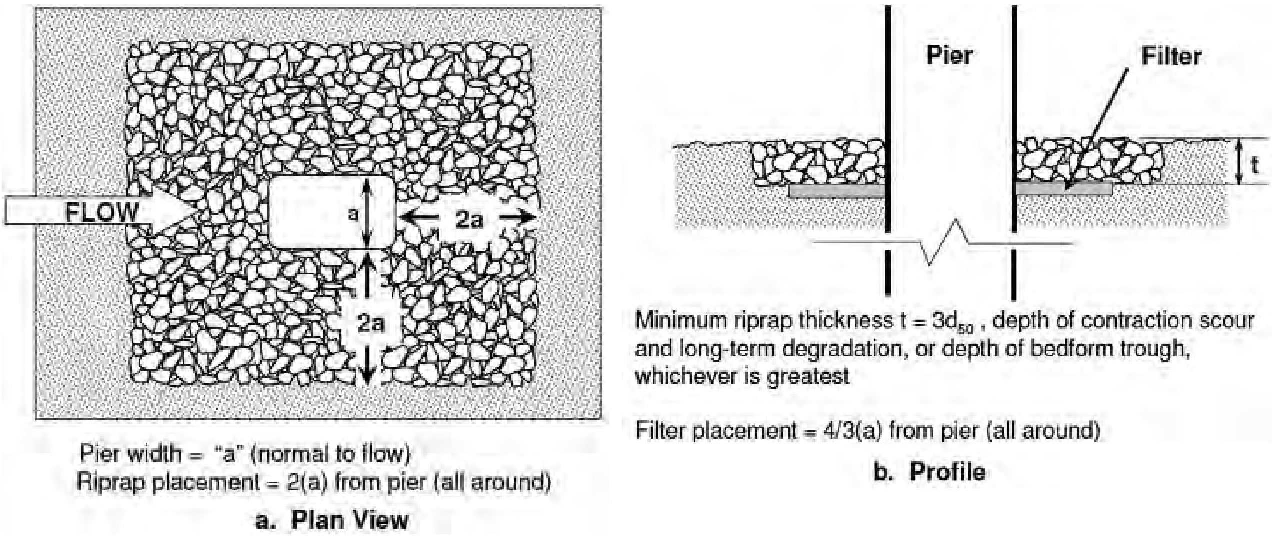


Fig. 7.1.2.7 Riprap layout diagram for pier scour protection

Countermeasures which can reduce the risk from local scour include placing armor (e.g., riprap) at the structure or installing monitoring devices.

Attachment

BRIDGE REPAIR WORK JOB SHEET

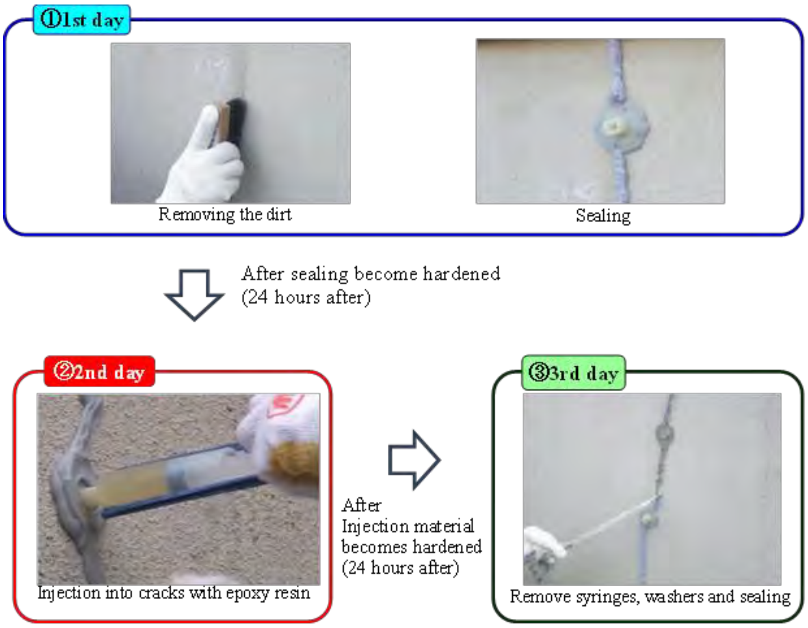
Code : 1 - 00001	Item : Concrete Crack Repair

Standard

* Concrete cracks are filled with epoxy resin injection
* This method for concrete crack repairing is relatively less expensive than other methodologies.

Work Method

* This repair work is carried out by dividing three days



Material	Tool (Main)	Safety Signs and Devices
*Epoxy resin *Sealant (Sealing) *Syringes set *Thinner *Chalk *Clay	*Platform scale *Trowel *Wire brush *Air blower *Stopwatch *Plastic cup *Plastic plate	*Scaffolding *Glove *Site Cleaning tool

Expensed

*Repair material (Epoxy resin, Sealant, Syringes set Thinner etc.)

*Labor cost *Site inspection cost *Transport worker and material cost

*Equipment hire *Safety cost

Remarks

* This method for concrete crack repairing is relatively less expensive than other methodologies.

Reference: C-1 Concrete crack

BRIDGE REPAIR WORK JOB SHEET

Code : 1 - 00002	Item : Concrete Defect repair

Standard

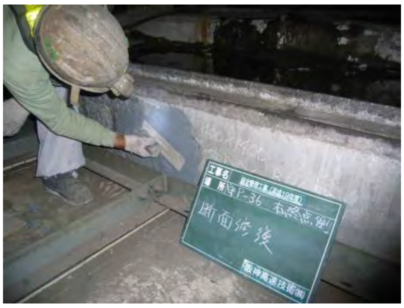
* After the degradation part of the concrete is removed by chipping, new concrete part is restored.

Work Method

*After the degradation part of the concrete is removed by chipping, new concrete part is restored.

* In practice, it is carried out survey before the repair work because of check peeling and the floating of the concrete by hitting test or visual survey.

*Since the high durability of the repair material is required, the polymer cement mortar material is usually used.



Material

*Polymer cement mortar

*Primer

Tool (Main)

*Generator

*Disc sander

*Hydraulics breaker

*Mortar mixer

*Trowel

*Plastic plate

Safety Signs and Devices

*Scaffolding

*Glove

*Site Cleaning tool

Expensed

*Repair material (Polymer cement mortar, Primer etc.) *Rental Fee

*Labor cost *Site inspection cost *Transport worker and material cost

*Equipment hire

Remarks

BRIDGE REPAIR WORK JOB SHEET

Code : 1 - 00003	Item : Carbon Fiber Cloth (CFC) Reinforcement method

Standard

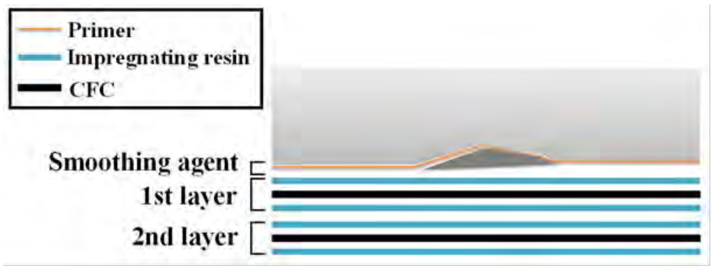
* This method is applied to the concrete structure of insufficient strength such as construction defect, design defect, strength lack due to overloaded vehicles.

Work Method

*Reinforced by carbon fiber cloth

*If concrete deficit is large, it is used in conjunction with the 'Concrete Defect repair method'.

*The carbon fiber sheet adheres to the existing concrete member, combines for reinforced between the fibers by synthetic resin adhesive.



Material	Tool (Main)	Safety Signs and Devices
*Carbon fiber Cloth (CFC)	*Generator	*Scaffolding
*Primer	*Disc sander	*Glove
*Smoothing agent	*Trowel	*Site Cleaning tool
*Impregnating resin	*Plastic plate	

Expensed

*Repair material (Carbon fiber cloth, Primer etc.) *Rental Fee

*Labor cost *Site inspection cost *Transport worker and material cost

*Equipment hire

Remarks

* This method isn't needed heavy equipment.

Reference : C-2 Carbon Fiber Cloth (CFC) Reinforcement Method

BRIDGE REPAIR WORK JOB SHEET

Code : 1 - 00004	Item : Reinforcement by Steel Plate (Concrete structure)

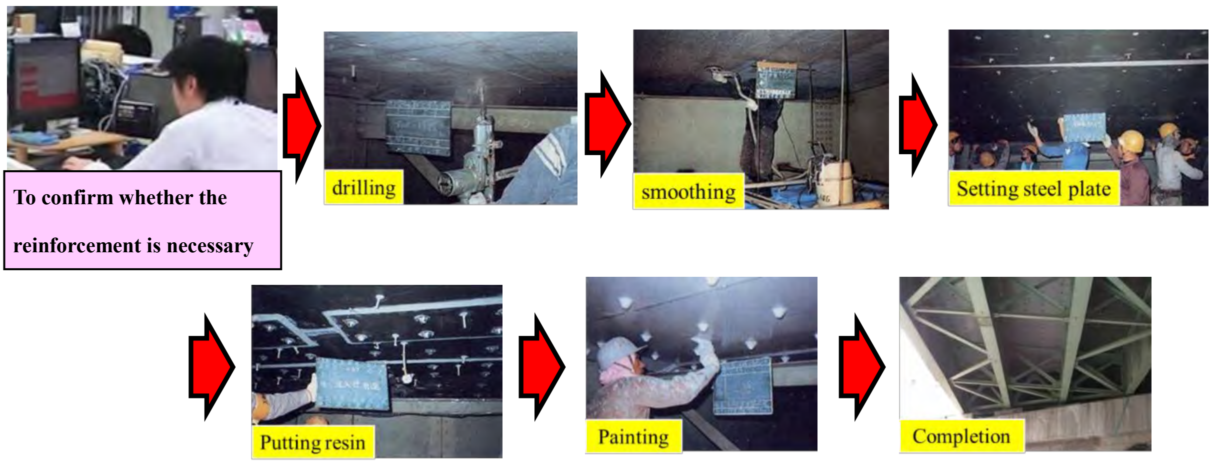
Standard

* This method is applied to concrete slab of insufficient strength such as construction defect, design defect, strength lack due to overloaded vehicles.

Work Method

*Reinforced by steel plate

*To be spliced steel plate, dead load of the slab is increased. If this method is applied, the bearing and the pier must be confirmed whether the reinforcement is necessary. For this reason, it is necessary to prepare the design document of the repair bridge.



Material	Tool (Main)	Safety Signs and Devices
*Steel Plate	*Generator	*Scaffolding
*Anchor bolt	*Drilling machine	*Glove
*Painting	*Electric hoist	*Site Cleaning tool
*Grout (cement between tile squares)	*Disc sander	
*Epoxy resin		

Expensed

*Repair material (Steel plate, Anchor bolt etc.) *Rental Fee

*Labor cost *Site inspection cost *Design coat

*Transport worker and material cost *Equipment hire *Safety cost

Remarks

* This method must be confirmed whether the reinforcement of bearing or pier is necessary.

BRIDGE REPAIR WORK JOB SHEET

Code : 2 - 00001	Item : Steel Corrosion Repair

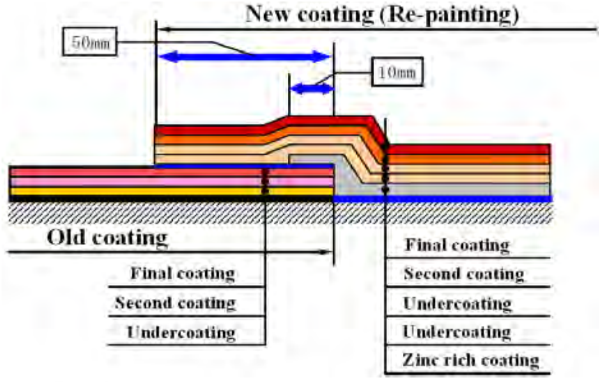
Standard

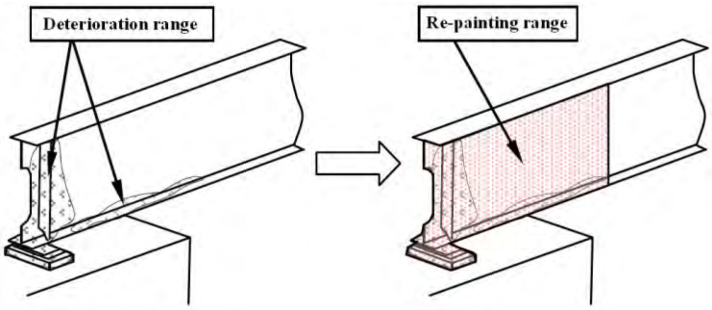
* Corroded parts are repainted.

Work Method

*The corrosion part is re-painted after cleaning to see surface of the iron by disc sander

* Re-paint in a 5 layer (include zinc rich coating)





Material

* Paint (undercoating, second coating, final coating)
* Thinner

Tool (Main)

*Generator
*Disc sander
*Brush
*Roller

Safety Signs and Devices

*Scaffolding
*Glove
*Site Cleaning tool

Expensed

*Repair material (Paint, Thinner etc.) *Rental Fee
*Labor cost *Site inspection cost *Transport worker and material cost
*Equipment hire

Remarks

BRIDGE REPAIR WORK JOB SHEET

Code : 2 - 00002	Item : Reinforcement by Steel Plate (Steel structure)

Standard

* This method is applied to reinforce the loss part by corrosion.
* This method is applied to reinforce of insufficient structure such as design defect, strength lack due to overloaded vehicles.

Work Method

*The rust part is removed the by disc sander.

*The deficit part is reinforced by spliced plate. It is designed to determine the size or spliced method of the spliced plate. For this reason, it is necessary to prepare the design document of the repair bridge.

* If the existing spliced plate need to be removed, it is necessary to carefully consider the removal method.

Material	Tool (Main)	Safety Signs and Devices
*Steel Plate	*Generator	*Scaffolding
*High strength bolt	*Impact wrench	*Glove
*Painting	*Drilling machine	*Site Cleaning tool
*Thinner	*Electric hoist *Disc sander	
	* Brush *Roller	

Expensed

*Repair material (Steel plate, High strength bolt etc.) *Rental Fee

*Labor cost *Site inspection cost *Design coat

*Transport worker and material cost *Equipment hire *Safety cost

Remarks

*This method must be designed to determine the size or spliced method of the spliced plate.

* If the existing spliced plate need to be removed, it is necessary to carefully consider the removal method.

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Guideline for Bridge Inspection and Repairing

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