MINISTRY OF TRANSPORT
ARAB REPUBLIC OF EGYPT

FOLLOW-UP COOPERATION STUDY ON THE PROJECT FOR CONSTRUCTION OF THE SUEZ CANAL BRIDGE (PAVEMENT on STEEL DECK)

FINAL REPORT

MARCH 2013

JAPAN INTERNATIONAL COOPERATION AGENCY

ORIENTAL CONSULTANTS CO., LTD.
CHODAI CO., LTD.

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Summary

① Outline of the Country

The Arab Republic of Egypt “herein after called Egypt” has a land area of about 100 million km^2, and is located in the northeastern part of Africa, bordering Libya to the west, Sudan in the south, Israel in the northeast, the Mediterranean Sea in the north, and the Red Sea in the east. Except for the valley and the delta of the Nile which flows from north to south, a large part of the land of Egypt is desert. Along the west bank of the Suez Canal, which the Bridge to be surveyed has been built across, is agricultural land, and the vast desert is spread on the east bank. The population of Egypt, ranking third behind Nigeria and Ethiopia on the African continent, is 8, 254 million (2011: World Bank), with the pyramidal demographic consisting of a huge young generation. About 70% of the population is concentrated in the area of the Nile Delta. Arabic Muslims and Christians (mainly the Coptic Church) occupy most of the ethnic composition, with others including Nubiru people, Armenians and Greeks.

The climate is generally dry; summer (from April to October) is hot, and there is little rain in the winter (from November to March). The number of rainy days per year in the study area is about 20 days, and the annual rainfall is very low at 30 mm. The maximum temparature recorded from 1984 to 1994 was 35.9℃ (in July), and the minimum temparature was 7.8 ℃ (in January). While the humidity is very low due to the desert climate, it is not uncommon for fog to occur in the early morning.

The oil industry, agriculture and mining, which account for half of the total, are the main industries in the country followed by trade, finance and insurance, and the transportation industry. Since the inception of the Nazif Cabinet in July 2004, the economy of Egypt has been growing rapidly recording around a 7% economic growth rate from 2006 to 2008, due to economical innovations, full-scale export of natural gas and others. As a result, the demand for transportation for passengers and cargo has increased rapidlly, and has led to new construction of a port, airport, expressway and upgrading of industrial parks.

The number of vehicles owned in Egypt has reached 4.66 million, and general private cars account for 55% of the total. Major arterial roads have been constructed nationwide and are managed by the Authority for Roads, Bridges and Land Transport (hereinafter called GARBLT) under the Ministry of Transportation. A road network has been developed from the capital Cairo to the Nile River Basin and the coast of the Red Sea, and toll expressways linking Cairo–Alexandria, and Cairo–Ismailia have been constructed. The roads across the Suez Canal are the Ahmad

Hamudi tunnel and the Suez Canal Bridge, which is the subject of this Survey. However, as a result of the rapidly progressing motorization around metropoltan Cairo in recent years, serious chronic road congestion has occurred; therefore, it is indispensable to restructure the road network, especially around urban areas.

A large-scale demonstration by people seeking the resignation of President Mubarak occurred throughout the country in January 2011. As a result, the 30-year administration by President Mubarak collapsed. After authorization of constitutional amendment by referendum in March 2012, Mr. Murusui, the leader of the Free and Fair Party, was appointed as a civilian preseident in an election in May 2012. Although small and medium-sized demos and riots have occured even after the launch of the new cabinet, development of the country is expected under continued political stability.

② Background and Progress of the Survey

The Suez Canal Bridge, hereinafter "the Bridge," is a long bridge constructed by cooperative works between Japan and Egypt with Japan's Grant Aid. The Bridge has played an important role for passage over the canal, and is a symbol of the friendship between both countries. After it was handed over in September 2001, the Bridge was inaugurated in October 2001 as a toll road. In May 2002, the ferry, which had been in service before opening the bridge, was canceled, and operation of the Bridge was started in earnest. After that, cracks on the bridge surface along the westbound lane were found, so the contractor investigated the cracks and carried out partial repair work. Furthermore, the defect liability period of the pavement was extended from one year to two years, and the contractor continued monitoring the crack condition with repairs carried out when necessary. In addition, GARBLT started to implement vehicle axle load limitations and other solutions in September 2002. It was expected that these solutions would work effectively to prevent the cracks from worsening.

After that, the inspection for defect liability of pavement was carried out In September 2003, and with submission of the analysis report, which mentioned that the passage of overloaded vehicles caused cracks and implementation of vehicle axle load limitations and further proper maintenance would keep the bridge functional without requiring re-pavement, repair material was donated as needed as of September 2006.

Despite GARBLT continuously enforcing vehicle axle load limitations, and crack repair work being conducted once every year since the defective liability inspection, the cracks on the surface of the Bridge have worsened. In particular, several cracks appear on right-side lanes along the position of wheel load running. There are strong concerns that without repair work, serious conditions such as potholes on the asphalt surface may occur and damage vehicles.

However, GARBLT has no experience in exchanging pavement on cable-stayed long-span bridges like the Suez Canal Bridge, except for repair work taught to them during the inspection for defective liability.

The consortium of Oriental Consultants Co., Ltd., and Chodai Co., Ltd., conducted a brief survey on the pavement situation when they conducted a follow-up cooperation study on the substructure of the Bridge in May and August 2011. At that time, it was confirmed that damage to the surface of the pavement had advanced.

Under these circumstances, GARBLT has requested JICA to implement a follow-up cooperation study to assess the damage conditions of the pavement.
In response to this, JICA had order the new study “Follow-up Cooperation Study on the Project for Construction of the Suez Canal Bridge (Steel Deck Plate)” (hereinafter called the study). Then the site surveys were conducted four times from November 2011 to September 2012.

- For the 1st survey from 15 November to December 2011, a survey team consiting of seven (7) members was dispached.
- For the 2nd survey from 21 to 28 February 2012, a survey team consiting of six (6) members was dispached.
- For the 3rd survey from 30 May to 6 June 2012, a survey team consiting of three (3) members was dispached.
- For the 4th survey from 31 August to 10 September 2012, a survey team consiting of two (2) members was dispached.

③ Objective of the Survey

The location of The Bridge is 48.5 km from the town of Port Said, which faces the Mediterranean. The Bridge is located along the trunk road between Ismailia and Port Said, and crosses the Suez Canal. It is an indispensable infrastructure to maintain stable transportation across the canal.

The purposes of the study are:

- To conduct a detailed survey concerning the damage on the surface of the Bridge, which has been constructed by Japan Grant Aid.
- To evaluate the degree of damage of the pavement and the soundness of the steel deck plate.
- To study the plan of repair work for the portion requiring repair.
- To recommend a future maintainance plan to the implementing authority.

④ **Outline of the Survey**

The main contents of this study are as follows: background and history and purposes as previously mentioned.

<table>
<tr><td rowspan="1">Confirmation and evaluation of damage of pavement and steel deck plate</td><td>

- Inspection of overall damage condition by photography for whole surface of pavement: measuring crack scale and making distribution map
- Surface inspection on steel deck plate by excavation test
- Confirming bonding layer condition and depth of cracks by core sampling test
- Visual inspection inside the steel box girder
- Inspection of cracks occurring on steel elements of the steel deck by magnetic particle test and ultrasonic method
- Measuring the thickness of the steel deck plate by ultrasonic method

</td></tr>
<tr><td colspan="2">Study and selection of pavement repair method and preparation of draft tender documents</td></tr>
<tr><td colspan="2">Survey of procurement conditions and estimation of outline of repair work cost.</td></tr>
<tr><td colspan="2">Temporary injection work for major cracks</td></tr>
<tr><td colspan="2">Survey of current operation and maintenance plan and recommendations for the future</td></tr>
</table>

1. Confirmation and Evaluation of the Damage of Surface of Pavement and Steel Deck Plate

Regarding the condition of the bonding layer, some places have deteriorated in ways such as falling apart in the process of peeling, while some places were not easy to peel off from the steel deck plate due to solidifying. Some other sections of the bonding layer were easy to peel off although they appear sound. Thus, it was determined that the bonding layer of the Bridge has deteriorated entirely although there are differences in the degree of degradation.

During the summary investigation for the surface of the pavement at the cooperation study for substructure of the Bridge, it was confirmed that cracks have occurred over a fairly large area on the pavement.

The crack portion had spread widely compared with the inspections conducted by the contractor at no charge at the request of GARBLT in July 2002 and January 2003. In particular, the area range of damage in the south section (down-direction lanes) was larger than in the north section (up-direction lanes), and in both sections, the degree of damage in the driving lane (outer lane) was more severe than in the passing lane (inner lane).

For a quantitative understanding of the condition of cracks occurring on the pavement surface, an inspection of overall damage conditions on the entire area of pavement on the surface of the Bridge was done. As a result of the inspection, the following information was revealed:

- The cracks occurred in 95% of the pavement area.
- Approximately 70% of the area had some cracks with a width of more than 10 mm.
- In particular, the crack width in the driving lane (outer lane) in the south section was severe.

Furthermore, in order to verify in detail the condition of the cracks, prominent parts of six damaged locations, were selected and drilled to remove the steel deck pavement in the range of 6 m length × 4 m width per location. The maximum crack width was 40 mm, and cracks of more than 10 mm in width had gone through the binder layer. Because the maximum crack width was 40 mm, the asphalt pavement was partially separated from the binder layer, and the bonding layer between the steel deck plate and the binder layer was deteriorated.

Also, in the core sampling test (100 mm diameter) for six points of damage, it was found that cracks completely penetrated the pavement and the bonding layer was not functioning properly. It was determined that the cracks were caused by passage of overloaded vehicles under uncontrolled axle load limitations soon after bridge inauguration. The crack width and depth developed further due to insufficient repair measures by GARBLT. Moreover, rainwater penetrated these cracks and the waterproof performance in the bonding layer was lost. This deterioration resulted in more crack development.

On the other hand, the main structure on the girders of the Bridge is a 3-celled steel box girder with a steel deck plate. The steel deck plate is composed of a steel plate of 12 mm with a longitudinal rib (U-shaped rib) reinforcing plate. Pavement cracks on the steel deck plate may be accompanied by fatigue cracking of the steel members of the steel deck girder.

Cracks occurring on the members of the steel deck plate girder are serious damage not to be overlooked in view of the structural stability, and depending on the degree of damage, there could be a need for emergency repair girder work. In order to investigate the existence of damage to the steel members of the steel deck, a surface inspection (visual inspection and measuring the thickness of the steel deck plate by ultrasonic method) and an inspection from inside of the box girder (visual inspection and the inspection of fatigue cracks occuring on the portion connected to U-shaped ribs by ultrasonic method) have been carried out.

After selecting two sound places (0.3 m length × 0.3 m width) and three places having significant damage (1 m length × 1m width), a surface inspection of the steel deck was conducted by visual inspection and ultrasonic investigation.

By visual inspection, water was found entering the lower side of the bonding layer and rust was found on the surface of the steel deck plate in all inspection areas.

The thickness of the steel deck plate reduced by rust was measured by ultrasonic method after carefully removing pitting corrosion attached to the upper surface.

The thickness reduction was different depending on the investigation position. The corrosion found on the driving lane of south section had progressed considerably compared with the north section. Sheet thickness reduction by corrosion was less than 1 mm and most parts were about 0.5 mm.

Reduction of thickness due to corrosion is not going to be a big problem at the moment in terms of structure. However, if no measures are carried out, fatigue cracks may be induced from the top deck plate and the reduced performance of the deformed steel deck will likely increase.

For securing structural safety of the Bridge, a summary stress analysis of the longitudinal ribs of the steel deck plate has been calculated in the case where the thickness of the steel deck plate has been reduced to 11.5 mm or 10.0 mm from the original thickness of 12.0 mm. As a result of the analysis, even if the plate thickness becomes 11.0 mm, the stress changes are small at less than 1%. Therefore, it was determined that there is sufficient margin for the allowable stress.

In addition, the investigation of damage existing in the internal structure of the steel box girder was carried out. In particular, the problem of internal damage in the steel plate deck box girder was fatigue cracks occurring at the connection between the U-shaped ribs and the deck plate. Fatigue cracks were not detected in the visual inspection or touching inspection surveys that were carried out at the sections of the U-shaped ribs and longtudinal ribs below the pavement cracks. The cracks, penetrating to the deck plate from the inside of the connections (welded portions) between the steel deck plate and U-shaped ribs, could not be detected by the naked eye. Therefore, the ultrasonic method was used to try to detect these. However, no fatigue cracks were found.

The results of the external and internal investigation over the steel deck plate box girder showed no fatigue cracks, but rust on the surface of the steel deck and deterioration of the bonding layer was confirmed. This is inferred to be a result of the progression of damage on the pavement and cracks reaching the surface of the steel deck.

In conclusion, it is indespensable to repair the existing pavement and the bonding layer on the entire surface of the steel deck plate using appropriate adjusted repair methods after removing the rust on the surface of the steel deck.

2. Study and Selection of Pavement Repair Method

In Japan, the guss asphalt pavement method is commonly used and has a good track record accounting for most of the steel deck plate bridges. However, the guss pavement method needs to be constructed at higher temparatures than the normal pavement method and requires special materials and equipment. In response to this, the SMA (stone mastic asphalt) method, which can be done using general equipment, has been developed. However, the flexibility regarding deflection of the SMA method is inferior compared to the guss method.

The exsisting pavement structure on the Bridge is constituted of a binder layer according to the SMA method and a surface layer using dense-graded modified asphalt. Since procurement of special materials, machinery and facilities was thought be difficult in developing countries on the grounds of the detailed design of the Bridge at that time, the SMA method, which is relatively easy regarding procurement and has higher rigidity against deflection and rutting than the general asphalt method, was employed.

In the middle stage of the Study, it had not been determined whether a contractor from a country like Japan having adequate pavement technology on steel deck plates would conduct the repair work, or Egyptian contractors would play the main role for the repair work.

Egyptian contractors have track records on steel plate deck girder viaducts constructed in Cairo city. They also have much experience and many track records on the general asphalt pavement method. On the other hand, many steel deck plate bridges have been found with serious pavement damage conditions bad enough to expose the steel deck plate. In addition, Egyptian contractors do not have the ability to conduct the SMA method by themselves.

Based on the above background, the following methods have been extracted and studied for comparison.

- Modified Asphalt Binder Layer + Dense-graded Modified Asphalt Surface Layer (most general pavement method, using RC-slab on steel girder bridge)
- SMA (Stone Mastic Asphalt) method Binder Layer + Dense-graded Modified Asphalt Surface Layer (existing pavement of the Bridge)
- Guss Asphalt Binder Layer + Dense-graded Modified Asphalt Surface Layer (used generally for steel deck plates)
- Epoxy Resin Binder Layer (New Technology)+ Dense-graded Modified Asphalt Surface Layer
- Steel Fiber Reinforced Concrete (SFRC) (New Technology) + Dense-graded Modified Asphalt Surface Layer
- Rubber Latex Mortar Binder Layer (New Technology) + Dense-graded Modified Asphalt Surface Layer

As a result of the comparison study, the Study Team recommended the guss asphalt method for the pavement repair work on the surface of the steel deck plate of the Bridge, considering the workability, possibility of procurement for materials and equipment and ensuring the soundness of pavement and the steel deck even after the repair work is conducted.

GARBLT well understood the guss method's good features but would not use it because it would be hard to procure the uncommon equipment necessary for this method in Egypt. GARBLT has no experience dealing with this method. Instead, GARBLT has insisted on using steel fiber reinforced concrete (SFRC) pavement. Regardless of their inexperience, GARBLT believed that they could easily procure equipment and produce SFRC because of the fact that it is merely made of cement-based components and they had experience on building similar concrete pavement. Then, GARBLT requested JICA to study cement-based pavement methods in Japan for reinforcement to the steel deck plate including engineered cementitious composite. Upon this request, the Study Team started the study on the assumption of re-comparison with the guss method. Multiple drafts were extracted considering procurement conditions and the ability of local contractors. Finally, the SFRC-stud type method was selected among the extracted methods.

- **SFRC-stud type → selected**
- SFRC-bond type (high-durability epoxy resin bond is used)
- SFRC-bond type + dense-graded modified asphalt surface layer
- SFRC-stud type + dense-graded modified asphalt surface layer

Again, the guss asphalt method was compared with the SFRC-stud type. As a result of the comparison focusing on the construction risk of failure, closing the bridge during construction, and on the reality of maintenance after repair work, finally, the guss asphalt method was selected.

Due to the thin layer of concrete (80 mm), cracks on SFRC-stud type could easily occur due to expansion and contraction during hardening, and the construction must be limited to be conducted in the winter season to avoid hot and dry conditions. In addition, due to the need to suppress the vibration until the concrete becomes hard, the bridge must be fully closed to traffic. Furthermore, quality control is very difficult due to the sensitivity of the high-durability epoxy resin bond and the intensive work of the huge number of studs requiring anti-corrosive treatment.

On the other hand, the guss method is not affected by outside temparatures and does not require any traffic closure on the Bridge. In fact, it is a feature of guss that the construction is relatively easy and less likely to fail as long as the established mix design is used. Economical features are about the same for both methods. For the above reasons, the Study Team again recommended the guss asphalt method to the Egyptian side as the appropriate repair method and obtained consent from them.

3. Temporary Injection Work for Major Cracks and Installing Monitoring Device

While the repair work for the damaged asphalt pavement on the Bridge is expected to be ordered by the Egyptian government based on the results of the report of the Study, a considerable period of time (years) will be required to complete the work. But, the current damage conditions are advancing resulting in a dangerous situation on the existing pavement. Pot holes also occur in some sections. In order to suppress the progression of the damage until repair work is commenced, temporary injection work into the cracks using hot-type seaking material was conducted at the time of the 1st site investigation. The injection work was carried out by the subcontractor under the presence of members of the the Study Team and GARBLT site office's staff and workers. The Study Team instructed on the procedure of temporary injection work in order that persons related to the site office could obtain the skill and conduct injection work independently until the repair work of the pavement commences.

In the Survey, it was found that moisutre entered the upper surface of the steel deck due to rainwater flooding from the cracks. To directly visually access the condition of the moisture on surface of the steel deck plate, a total of eight (8) monitoring holes were drilled in the vicinity of the road shoulder in places that do not interfere with running vehicles. After cutting the monitoring holes by core-cutter machine, PVC pipes with about a 100 mm inner diameter were installed. The monitoring holes were handed over to the members of the site office of GARBLT for periodic monitoring of moisture conditions on the surface of the steel deck plate.

4. Current Condition and Recommendation for Maintenance

The Suez Canal Bridge administration office (site office of GARBLT), is located around the crossing portion between Ismailia–Port Said Road and the aproach section of the Suez Canal Bridge. The site office has jurisdiction over the two toll gates (located on the east-side and west-side) equipping surveillance cameras, and 30 people, staff and workers, are engaged in the maintenance of the entire Suez Canal Bridge including both side approach viaduct sections. They have conducted periodic inspections on the inside of main girders, bearings, guardrails and others as well as the surface of pavement.

The annual budget for the site office is approximately 2,240,000 LE (about 29 million ¥ (1 LE = ¥12.883), estimated), which is not sufficient for the implementation of maintenance of highly important large-scale bridges. Special materials and equipment must be prepared regularly to conduct temporary injection repair work in addition to daily inspections for proper maintenance of the pavement surface. Improving the skills of employees belonging to the site office is essential in order for them to carry out the maintenance themselves. To realize the above, it is necessary to procure an annual budget of about 80,000 LE (about 1,000 thousand yen) in addition to the current annual budget.

⑤ Outline of Schedule, Main Quantities and Implementation System Construction

Major quantities of pavement construction by guss repair method are shown in the table below.

In summary, the construction schedule is expected to take 6.5 months. After changing the two lanes of the north section to flow in both directions, the existing pavement of the south section of the Bridge, which has relatively more damage, will be removed. Also, the bonding layer, binder layer, marking lanes and surface layer work will be carried out. After construction is shifted to the north section, similar procedures will be conducted.

Work Item	Unit	Quantities
Removal of existing pavement	m^2	11,824
Shot-blasting	m^2	11,824
Bonding layer	m^2	11,824
Epoxy primer	m^2	11,824
Guss asphalt binder layer	m^2	11,824
Tack coat	m^2	11,824
Dense-graded modified asphalt layer		11,824
Traffic lane marking	m	4,352
Pilot construction of guss asphalt	L.S	1

During the 4th site survey, GARBLT proposed that Egyptian contractors should do the repair work. In response to this proposal, the Survey Team asked some major Egyptian general contractors who have sufficient experience in bridge and pavement works to submit a quotation for the repair works.

As for the information, technical specifications (draft) for guss asphalt were given to the contractors to clarify the construction and material quality requirements to enable them to make an accurate quotation.

Unit Price / Total Summay Cost for Repair Work by Guss Asphalt Method

Campany	SAMCO					
Guss Asphalt Method						
No.	Work Items	Unit Price (L.E)		Quantity	Cost (L.E)	USD
1	Removal of Existing Pavement	90	/m2	11,824	1,064,160	176,000
2	Shot-Blasting	130	m2	11,824	1,537,120	254,000
3	Epoxy Primer	290	m2	11,824	3,428,960	566,000
4	Bonding layer	250	m	11,824	2,956,000	488,000
5	Guss As.Binder Layer	750	m2	11,824	8,868,000	1,463,000
6	Tack Coat	120	m2	11,824	1,418,880	234,000
7	Surface Layer (Modified As.)	200	m2	11,824	2,364,800	390,000
8	Traffic Line Marking	100	mL	4,352	435,200	72,000
9	Consulting	500,000	L.s	1	500,000	83,000
						1 (LE) =0.165 $
Total Cost					22,573,120	$3,725,000

As a result of the above, their estimated cost amounts to LE 22,573,000 (approx. US$ 3,725,000=approx. Yen 291,000,000, Exchange rate: LE 1=Yen 12.883) as shown below.

For reference, if a Japanese contractor conducted the repair work, the summary project cost estimate would be about 330 million yen, including construction management consultants in Japan.

⑥ Report of draft tender document and Recommendations for the Implementation of the Repair Project

The draft tender documents have been submitted to GARBLT. In the technical specifications (T.S), material requirements and criteria of quality requirements have been noted. Furthermore, in order to help the understanding of the Egyptian Contractor, construction procedures, indepensable machines and material, and points of concern regarding construction have been mentioned.

Also, methods to confirm the soundness of the steel deck have been added to the T.S.

- After completing shot-blasting, an inspection on the existance cracks ocurring inside the steel deck must be done by magnetic particle test. If fatigue cracks are found, the steel plate reinforcing method shall be adapted.
- To ensure that the thickness of the steel deck plate, especially along the portion of U-shaped ribs and longtuidinal ribs in severely damaged south lanes, has not been significantly reduced compared to the time of the study by ultrasonic test.

Recommendations for the Implementation of the Repair Project

Due to the wishes of the Egyptian government, the pavement repair project for the damage of pavement of the Bridge has been concluded to be ordered through local tender that targets Egyptian constrution companies.

At the meetings held during early site investigation, the Survey Team illustrated the points regarding technical concerns of the guss asphalt method to key officers of the relevant departments in GARBLT and executives of Egyptian construction companies. However, it can't be said that the degree of understanding of officers and executives on the guss method is sufficient due to their lack of experience. If fatigue cracks or thickness reduction of the steel deck plate is found by detailed inspection during the pavement repair project, reinforcing the steel deck plate by additional methods will be required. This raises similar concerns regarding experience.

Although the Bridge was constructed through Japanese Grant Aid funds, it is clear that the responsibility for operation and maintenance of the completed road infrastructure is borne by the recipient country Egypt. However, as a result of the Study, inadequacies cannot be denied from the viewpoint of the technical situation and facility conditions. Therefore, it is considered to be essential that technical support from Japan will be conducted regarding guss asphalt pavement construction and additional reinforcing plate method for success of the project. In addition, the contribution to the concerned institutions in Egypt shall be considered, which will help to improve awareness and technical capabilities of maintenance of the steel deck plate girders.

More specifically, it is considered necessary to carry out technical support services conducted by a Japanese engineer, to adjust to the schedule of the pavement repair project GARBLT has ordered.

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CHAPTER 1 SUMMARY OF THE SITE SURVEY

1.1 Objectives of the Study

1.1.1 Background of the Study

The Suez Canal Bridge, being a symbol of the friendship between Egypt and Japan, was constructed through cooperative works of both countries with Japan’s Grant Aid.

After it was handed over in September 2001, the bridge was inaugurated in October 2001 as a toll road. In May 2002, the ferry, which had been in service before opening the bridge, was canceled, and operation of the bridge began in earnest. After that, the contractor investigated cracks found on the bridge surface along the westbound lane and partially repaired them. The defect liability period of the pavement was extended from one year to two years, and crack repair was carried out as they were found. Furthermore, the Authority for Roads, Bridges and Land Transport (hereinafter called GARBLT), the implementation agency in Egypt, started to implement vehicle axle load limitations and other solutions in September 2002. It was expected that those solutions would work effectively to prevent the cracks from worsening.

In September 2003, after the inspection for defect liability of pavement had been carried out, the Consultant submitted the analysis report for the pavement cracks. The report stated that passage of overloaded vehicles caused cracks and both the implementation of vehicle axle load limitations and further proper maintenance would keep the bridge functional without requiring re-pavement. In addition, repair material was donated as needed as of September 2006.

The Follow-up Cooperation Study for the Substructures of the Bridge was conducted by Oriental Consultants and CHODAI from October 2010 to November 2011. In May and August 2011, the Consultants investigated the pavement condition briefly.

GARBLT has been continuously enforcing vehicle axle load limitations. Despite annual repairs to the cracks that have appeared since the defective liability inspection, cracks have worsened. Cracks on the surface of the Suez Bridge have progressed considerably since the inspection. In particular, several cracks have appeared on right side lanes along the position of wheel load running. There are strong concerns that without repair work, serious conditions such as potholes will occur in the asphalt surface.

However, GARBLT has no experience in exchanging pavement on cable-stayed long-span bridges like the Suez Canal Bridge, except for repair work taught to them during the inspection for defective liability. Under these circumstances, GARBLT has requested JICA to implement a follow-up cooperation study to assess the damage conditions of the pavement.

1.1.2 Objectives of the Study

Based on the background mentioned in the previous section, the objectives of the study have been specified as follows:

- To obtain detailed data of damage to the pavement and the condition of the steel deck.
- To evaluate the degree of deterioration.
- To study and determine the proper repair methods including SMA pavement and others.
- To prepare detailed design and cost estimations.
- To make a maintenance plan to enable GARBLT to keep up with the level required and independently perform work as appropriate.
- To implement temporary injection work for major cracks.

1.2 Summary of the Study

1.2.1 Study Schedule

The schedule of the Study is shown in Figure 1.2.1.

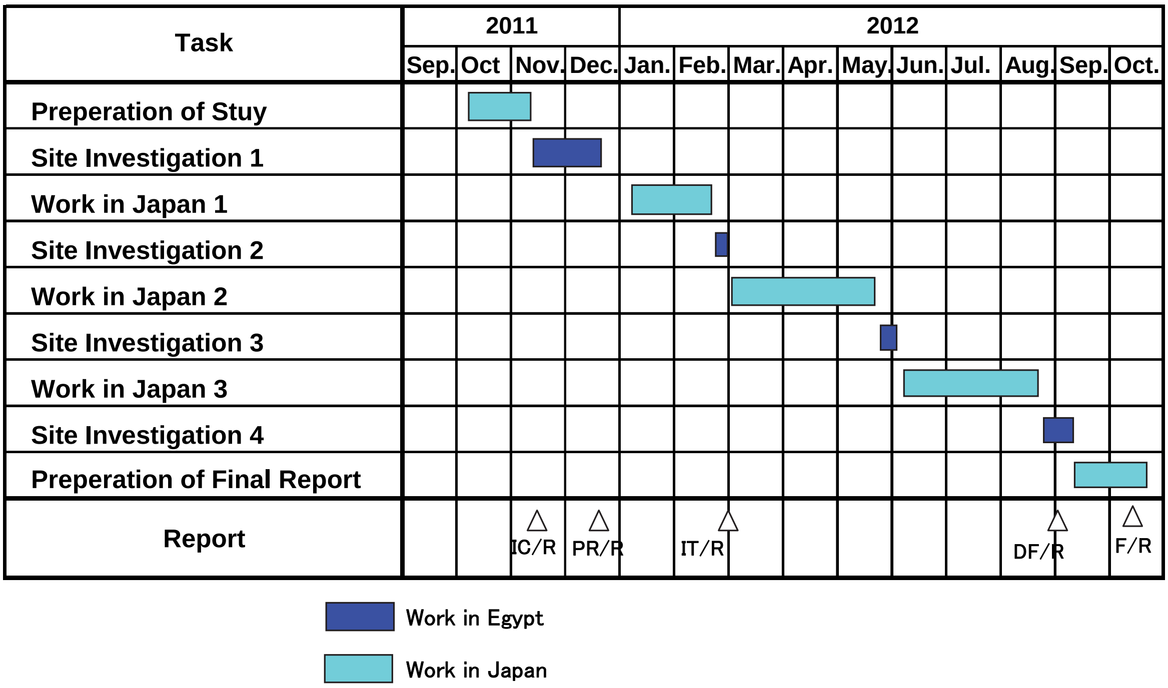


Figure 1.2.1 Study Schedule

1.2.2 Study Items

Study items in the follow-up cooperation study are shown in Table 1.2.1.

Table 1.2.1 Study Items

	Item
Site Investigations	1. Detailed Survey of Pavement - Overall Damage Conditions by Photographing - Damage Conditions in Detail (Selected Areas) - Core Sampling - Cut and Excavation Test 2. Detail Inspection on Steel Deck Plate - Top Surface of Steel Deck Inspection - Deck Plate Thickness Inspection - Visual Inspection - Magnetic Particle Test Inspection - Ultrasonic Inspection - Inspection of Waste Deposit inside the U-shaped Rib - Temperature Measurement inside Steel Deck Girder 3. Traffic Frequency and Limitation to Vehicle Weight - Traffic Frequency - Limitation to Vehicle Weight 4. Survey of the Configurations 5. Procurement Conditions and the Matters Related to Cost Estimation 6. Maintenance System for Suez Canal Bridge
Study / Analysis / Evaluation (Work in Japan)	1. Damage Assessment of Pavement and Steel Deck Plate - Evaluate Soundness of Pavement - Evaluate Soundness of Steel Deck Plate 2. Area for Repair 3. Study of Repair Method
Preparation of Tender Document / Study (Work in Japan 2)	1. Detailed Design of Repair - Detailed Design of Repair - Construction Planning - Construction Schedule 2. Cost Estimation 3. Draft Tender Document 4. Implementation Plan 5. Operation and Maintenance Plan
Temporary Repair Work	1. Temporary Injection Work for Major Cracks

1.2.3 Study Area

The Study area is shown in Figure 1.2.2.

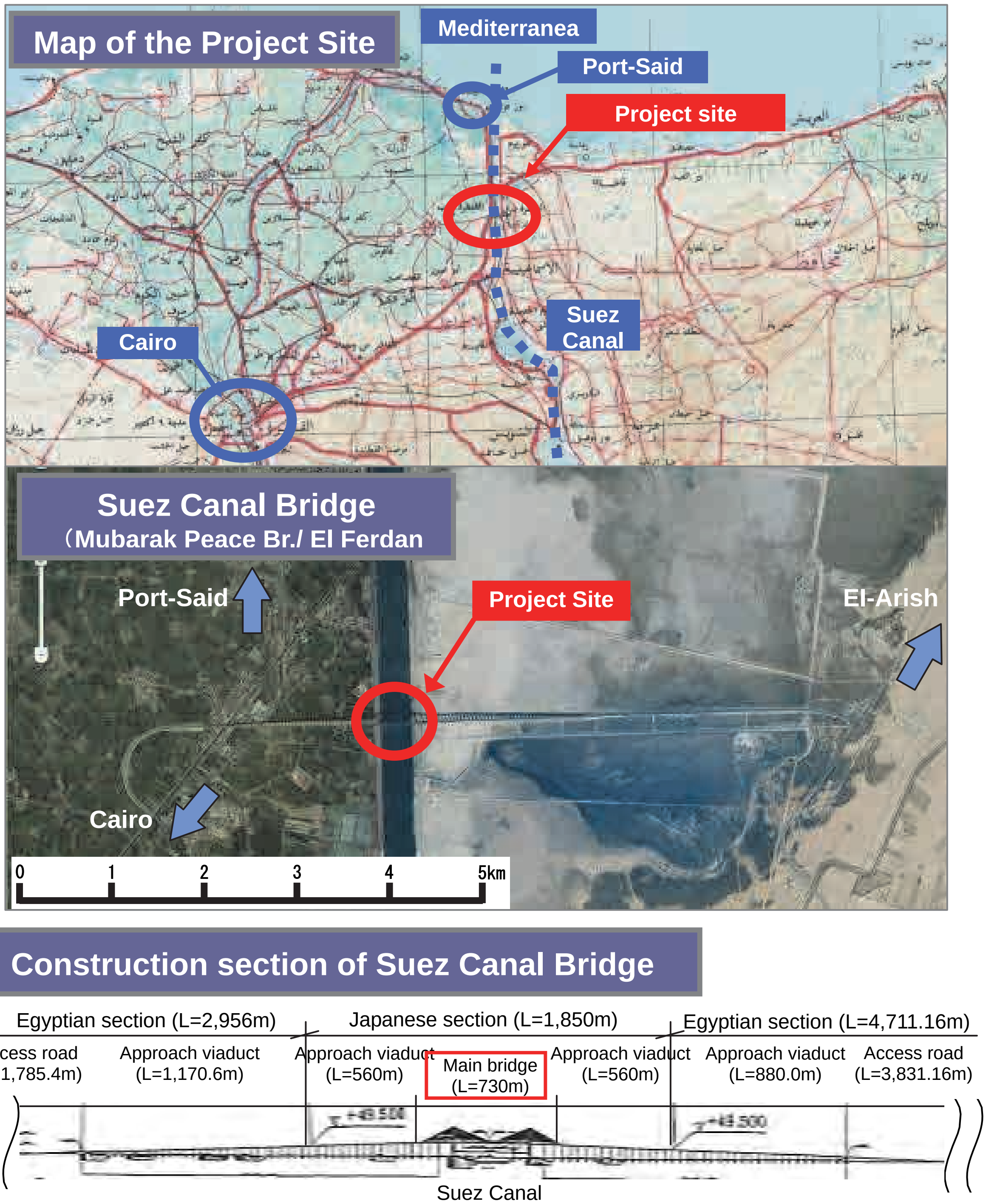


Figure 1.2.2 Study Area

CHAPTER 2 SITE INVESTIGATION

2.1 Executive Summary of Site Investigation

(1) Results of Pavement Survey

- Cracks occurred in 95% of the pavement area.
- Approximately 70% of the area had some cracks with a width of more than 10 mm.
- The average adhesive strength of the core testing points was measured at 0.113 $N/mm^2 < 1.4$ N/mm^2 of the criterion adhesive strength.
- Most of the cracks with a width of more than 10 mm are assumed to reach the steel deck plate.
- The adhesive strength under the base layer in the cracked area is approximately 70%, which is assumed to be insufficient.

(2) Results of Steel Deck Plate Survey

- Corrosion was found on the surface of the steel deck plate where the pavement was removed.
- The maximum thickness reduction of the steel deck plate was 0.5 mm. (The minimum thickness was 11.5 mm against the design thickness of 12.0 mm.)
- No fatigue cracks were found in the steel deck plate by Magnetic Particle and Ultrasonic Inspection.
- Thickness reduction due to corrosion is not a big problem at this moment from a structural point of view, but this could possibly induce fatigue cracks from the surface or affect the deformation capacity later.

(3) Conclusions

- The current situation of pavement is very dangerous for passing vehicles because of the possibility of detachment of a large segment of pavement from a pothole.
- Further thickness reduction due to corrosion of the steel deck plate must be prevented in order to secure the soundness of the bridge structure.
- Replacement of all of the pavement and adhesive layer, and removal of the corrosion on the steel deck plate are required as soon as possible.

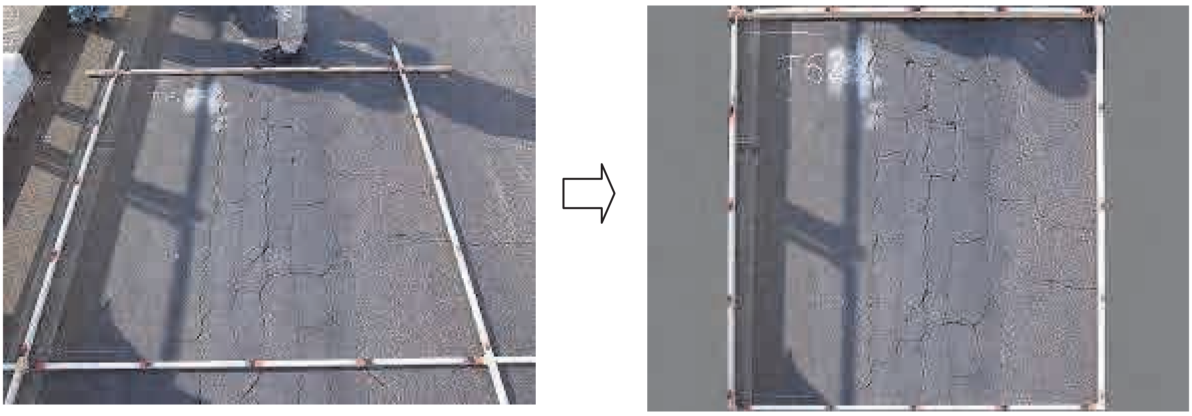
2.2 Inspection of Pavement Conditions in Detail

2.2.1 Overall Damage Conditions by Photographing

(1) Inspection Target

- A visual inspection was carried out over the entire surface of the pavement.
- The photographs were taken at a constant distance of 2 m on each carriageway with a projective transformation camera.
- The maximum width and depth of cracks in each photograph was measured.

Photo 2.2.1 Photographing Work



Original　　Projective Transformation

Photo 2.2.2 Modification of Photograph by Projective Transformation Camera

Photo 2.2.3 Measurement of Crack Size

(2) Inspection Results

- The photographs were arranged in a plane view to confirm the conditions easily.
- The crack map was made based on the photographs.

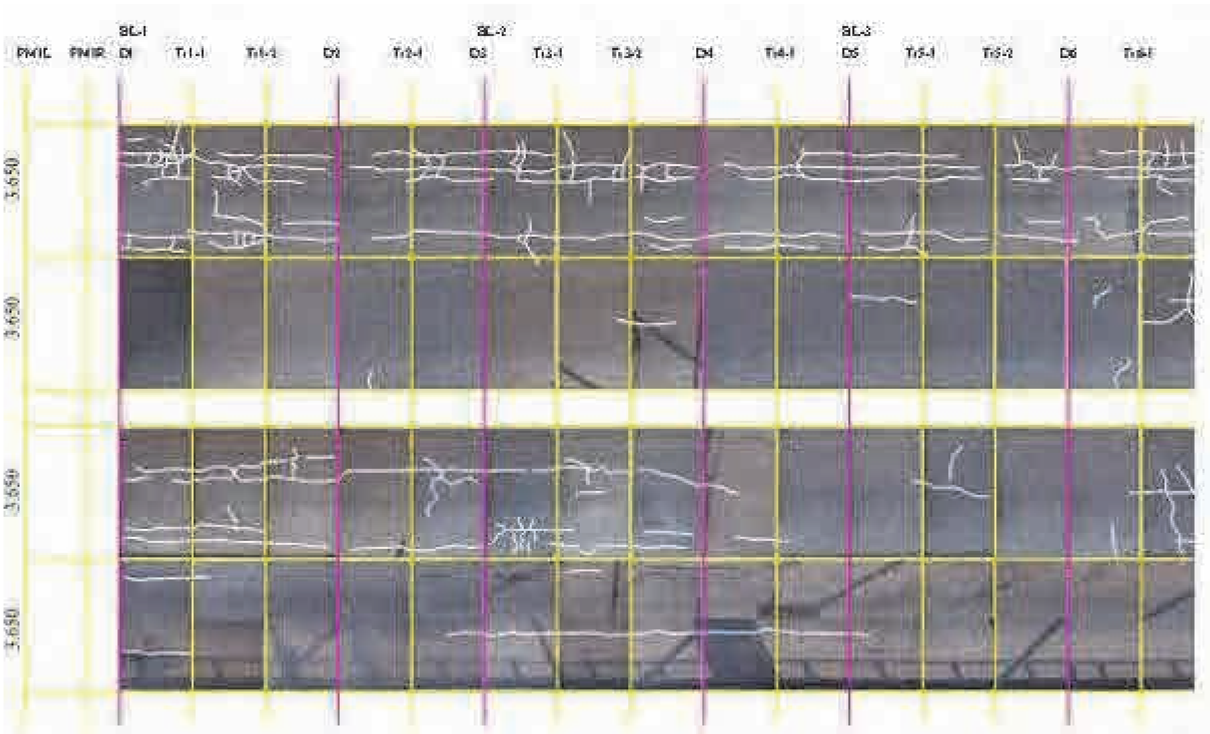


Figure 2.2.1 Crack Map (BL1 – BL 4)

The results of measurement of the cracks in each photograph are as shown in the following table.

Table 2.2.1 Crack Width and Depth (West Side)

Unit : mm

BLOCK No.	No.	South						North			
		outside lane				inside lane		inside lane		outside lane	
		Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
BL-1	PM1R	Non	Non	10	5	20	25	15	35	10	25
	D1	10	10	15	10	10	30	Non	Non	15	25
	TR1-1	10	8	5	10	10	25	10	35	15	25
	TR1-2	2	3	10	5	10	10	5	5	10	30
BL-2	D2	6	5	10	5	10	20	10	35	20	35
	TR2-1	2	2	5	5	10	15	5	5	25	25
	D3	4	4	5	5	25	35	15	30	29	35
	TR3-1	Non	Non	10	15	15	30	5	10	15	30
	TR3-2	Non	Non	10	10	10	15	Non	Non	15	30
BL-3	D4	5	5	10	5	5	10	5	5	25	35
	TR4-1	5	5	10	5	Non	Non	Non	Non	15	25
	D5	1	1	15	10	5	5	5	5	15	20
	TR5-1	2	2	10	10	5	15	5	5	25	30
	TR5-2	2	2	10	5	5	5	5	5	20	35
BL-4	D6	Non	Non	10	5	10	20	5	5	20	25
	TR6-1	Non	Non	15	15	10	15	5	5	20	45
	D7	2	2	10	5	15	25	5	5	15	30
	TR7-1	3	2	10	10	10	10	5	5	25	50
	TR7-2	Non	Non	10	10	10	15	5	5	10	30
BL-5	D8	Non	Non	10	10	10	15	5	10	10	40
	TR8-1	10	8	30	25	10	10	5	5	15	35
	PM2	3	2	5	5	10	30	5	10	10	20
	TR8-2	10	10	40	15	10	30	5	10	20	20
	TR8-3	6	6	25	25	10	25	5	10	20	40
BL-6	D9	6	6	25	20	10	20	5	10	15	30
	TR9-1	5	5	10	15	15	25	5	5	20	25
	D10	10	30	15	25	5	20	5	5	25	35
	TR10-1	10	10	25	15	10	20	5	20	20	25
	TR10-2	5	4	15	30	10	15	5	5	40	65
BL-7	D11	10	10	20	50	10	20	5	5	25	35
	TR11-1	10	10	10	10	30	30	Non	Non	25	30
	D12	8	6	20	25	15	30	5	5	15	20
	TR12-1	7	6	15	10	25	30	5	5	15	40
	TR12-2	8	8	15	10	15	20	5	5	25	25
BL-8	D13	7	17	10	10	20	35	5	5	25	40
	TR13-1	15	15	10	10	15	20	5	5	20	45
	D14	2	4	15	15	20	30	5	5	20	35
	TR14-1	13	20	10	10	15	25	5	5	25	35
	TR14-2	6	6	20	10	10	20	5	5	25	40
BL-9	D15	3	3	15	15	15	20	Non	Non	25	35
	TR15-1	20	12	15	20	20	30	5	5	20	45
	D16	10	20	20	20	15	30	5	5	20	20
	TR16-1	10	10	25	30	30	40	5	5	30	45
	TR16-2	17	10	15	10	15	30	5	5	30	30
BL-10	D17	1	1	25	25	10	20	Non	Non	30	50
	TR17-1	5	8	20	15	20	30	Non	Non	25	50
	PM3	Non	Non	15	15	5	20	5	5	20	55
	TR17-2	5	5	20	15	15	30	5	5	20	40
	TR17-3	2	3	25	15	20	40	Non	Non	45	65
BL-11	D18	5	5	20	15	15	20	Non	Non	25	45
	TR18-1	2	2	20	15	15	25	5	5	30	30
	D19	8	8	15	10	5	25	5	5	20	35
	TR19-1	5	6	15	15	5	15	5	15	30	65
	TR19-2	5	3	20	20	5	10	10	35	50	65
BL-12	D20	3	3	15	15	15	20	5	15	50	80
	TR20-1	5	4	25	15	5	15	5	10	20	60
	D21	7	6	20	15	25	25	5	10	30	40
	TR21-1	6	5	20	15	15	20	Non	Non	25	35
	TR21-2	2	2	30	30	10	25	5	5	30	30
BL-13	D22	25	20	20	20	15	20	5	5	20	35
	TR22-1	15	13	15	15	15	35	Non	Non	20	30
	D23	20	10	25	15	5	15	5	10	20	25
	TR23-1	10	15	15	10	15	30	Non	Non	15	20
	TR23-2	7	7	15	15	5	25	5	5	25	45
BL-14	D24	10	8	25	25	10	30	5	5	15	25
	TR24-1	16	13	20	15	10	20	5	5	15	25
	D25	25	10	15	20	15	45	5	5	15	25
	TR25-1	17	13	15	15	10	20	5	5	15	30
	TR25-2	12	7	20	15	10	20	Non	Non	30	35
BL-15	D26	20	10	20	10	5	25	5	5	20	30
	TR26-1	15	10	20	15	15	25	10	15	15	20
	D27	10	10	30	20	15	30	5	5	20	30
	TR27-1	8	10	30	15	25	30	5	10	10	25
	TR27-2	10	10	10	10	10	20	5	10	20	40
BL-16	D28	7	25	20	30	10	40	5	10	25	30
	TR28-1	13	8	20	15	5	15	Non	Non	20	25
	D29	12	8	15	25	5	15	5	5	15	30
	TR29-1	8	10	15	15	Non	Non	5	5	20	65
	TR29-2	20	10	5	10	Non	Non	5	5	20	30
BL-17	D30	12	10	30	10	10	15	5	5	5	10
	TR3-1	15	13	10	10	5	20	Non	Non	5	5
	T1	20	8	10	15	5	20	Non	Non	15	15
	TR30-2	20	10	15	15	5	10	Non	Non	10	10
	TR30-3	10	22	20	35	5	15	5	5	15	15
BL-18	D31	8	12	25	30	5	15	Non	Non	15	20
	TR31-1	20	8	20	25	10	20	Non	Non	20	20
	TR31-2	15	10	15	20	5	20	5	5	20	20
	D32	15	10	10	15	5	20	5	5	30	25
	TR32-1	8	8	20	15	5	10	Non	Non	20	20
	TR32-2	16	12	10	20	5	5	Non	Non	15	15

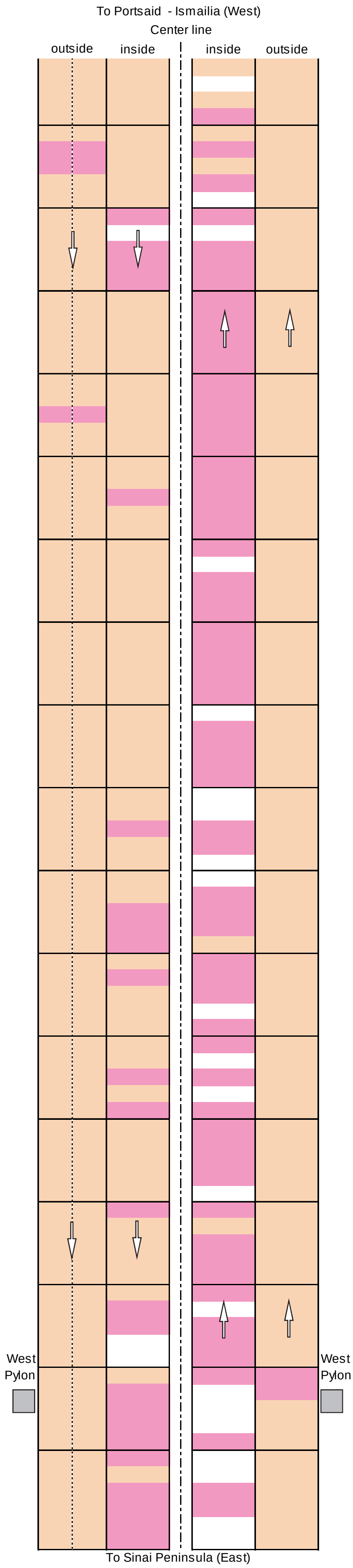


Table 2.2.2 Crack Width and Depth (West Side of Center Span)

Unit : mm

BLOCK No.	No.	South						North			
		outside lane				inside lane		inside lane		outside lane	
		Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
BL-19	D33	10	8	20	30	5	5	5	5	10	15
	TR33-1	25	14	20	25	5	15	5	10	10	10
	TR33-2	30	13	20	25	5	20	5	5	10	15
	D34	20	10	30	35	5	10	Non	Non	10	10
	TR34-1	20	15	30	25	20	20	5	5	10	20
	TR34-2	20	12	20	25	20	25	Non	Non	5	5
BL-20	D35	25	13	20	25	10	20	5	5	10	10
	TR35-1	17	11	15	15	10	20	Non	Non	10	10
	TR35-2	25	8	15	20	10	25	Non	Non	15	10
	D36	20	9	10	15	10	25	Non	Non	15	15
	TR36-1	20	10	10	10	5	35	Non	Non	15	25
	TR36-2	13	10	10	20	5	20	5	5	35	40
BL-21	D37	13	13	15	20	10	20	5	5	25	25
	TR37-1	5	2	10	15	5	10	5	10	10	15
	TR37-2	1	1	15	25	5	20	5	5	10	15
	D38	5	4	10	15	10	20	Non	Non	15	20
	TR38-1	7	5	15	15	10	25	Non	Non	20	30
	TR38-2	7	27	30	30	10	30	Non	Non	20	35
BL-22	D39	2	3	30	25	15	30	Non	Non	30	30
	TR39-1	1	3	25	25	5	40	5	5	20	30
	TR39-2	1	2	25	30	15	15	5	5	20	25
	D40	3	4	10	10	15	30	5	5	25	30
	TR40-1	6	6	10	10	20	20	5	5	25	35
	TR40-2	3	3	10	10	20	40	5	5	20	30
BL-23	D41	10	40	20	30	20	25	5	15	25	30
	TR41-1	10	12	25	25	15	20	5	10	25	30
	TR41-2	1	1	15	15	15	25	15	45	20	35
	D42	3	1	5	10	30	25	15	45	25	35
	TR42-1	5	5	5	5	20	35	5	10	25	30
	TR42-2	5	5	10	10	5	25	10	15	20	35
BL-24	D43	5	6	10	10	10	20	15	30	15	25
	TR43-1	7	8	15	20	20	35	15	25	30	35
	TR43-2	4	3	10	15	5	5	5	15	20	25
	D44	5	3	20	25	10	20	5	20	20	30
	TR44-1	4	2	15	20	5	5	5	15	30	40
	TR44-2	Non	Non	20	25	5	10	5	15	25	40
BL-25	D45	15	35	20	25	20	45	5	10	25	25
	TR45-1	6	8	30	25	15	30	5	10	30	25
	TR45-2	7	11	10	15	5	35	5	10	30	20
	D46	8	12	20	25	10	25	5	5	15	10
	TR46-1	20	15	20	35	15	30	5	5	15	20
	TR46-2	27	16	20	25	10	30	5	5	20	20
BL-26	D47	10	6	20	30	15	30	5	5	30	35
	TR47-1	13	9	20	20	10	15	5	5	20	25
	TR47-2	13	8	10	20	5	10	5	5	30	30
	D48	13	13	20	30	15	30	5	5	15	20
	TR48-1	6	8	20	20	5	5	5	15	20	25
	TR48-2	20	23	15	25	5	5	5	5	20	30
BL-27	D49	25	15	20	10	20	30	5	5	20	30
	TR49-1	7	22	20	20	5	20	5	5	30	30
	TR49-2	25	7	25	15	15	45	5	5	20	20
	D50	7	17	30	40	10	40	5	10	15	15
	TR50-1	10	15	20	35	30	25	10	30	15	20
	TR50-2	10	18	20	25	5	5	5	5	30	30
BL-28	D51	10	7	30	30	5	10	30	25	40	35
	TR51-1	10	24	30	40	25	45	5	5	10	15
	TR51-2	5	16	20	25	10	30	5	5	20	30
	D52	6	25	10	25	15	35	5	5	35	30
	TR52-1	12	27	20	30	5	25	5	10	15	25
	TR52-2	7	33	25	45	10	40	5	5	20	35
BL-29	D53	5	20	25	50	30	60	15	25	30	45
	TR53-1	7	20	20	25	20	50	5	5	20	25
	TR53-2	7	21	20	20	10	30	10	30	25	30
	D54	3	12	20	20	5	30	5	5	15	15
	TR54-1	6	21	5	10	5	10	5	19	25	25
	TR54-2	5	26	10	20	15	20	Non	Non	20	25
BL-30	D55	6	19	5	4	10	15	Non	Non	20	35
	TR55-1	8	24	20	20	10	15	10	10	40	50
	TR55-2	8	37	20	15	10	20	20	20	30	40
	D56	8	9	20	20	30	25	5	5	20	30
	TR56-1	7	19	20	25	10	35	20	30	20	30
	TR56-2	9	21	10	20	30	30	5	5	25	30
BL-31	D57	7	45	20	30	40	30	5	10	20	35
	TR57-1	15	20	40	35	5	30	10	45	50	40
	TR57-2	25	33	60	45	15	70	5	5	20	25
	D58	40	30	30	40	20	70	5	5	20	30
	TR58-1	10	28	40	40	20	35	5	5	20	25
	TR58-2	22	32	20	35	30	40	5	15	20	30
BL-32	D59	12	25	50	40	15	50	10	15	20	30
	TR59-1	10	26	30	30	15	40	5	5	20	20
	TR59-2	13	30	40	30	20	55	5	5	15	15
	D60	12	25	30	25	10	30	5	10	10	15
	TR60-1	16	29	30	25	15	20	5	5	15	25
	TR60-2	16	25	25	30	5	10	5	5	10	15
BL-33	D61	13	22	20	35	10	40	10	10	20	25
	TR61-1	13	30	30	35	10	40	25	25	20	30
	TR61-2	14	23	20	35	5	15	10	10	20	25
	D62	14	70	30	35	15	40	25	20	20	30
	TR62-1	10	40	30	25	15	20	10	15	20	25
	TR62-2	10	25	30	45	15	50	5	10	15	20

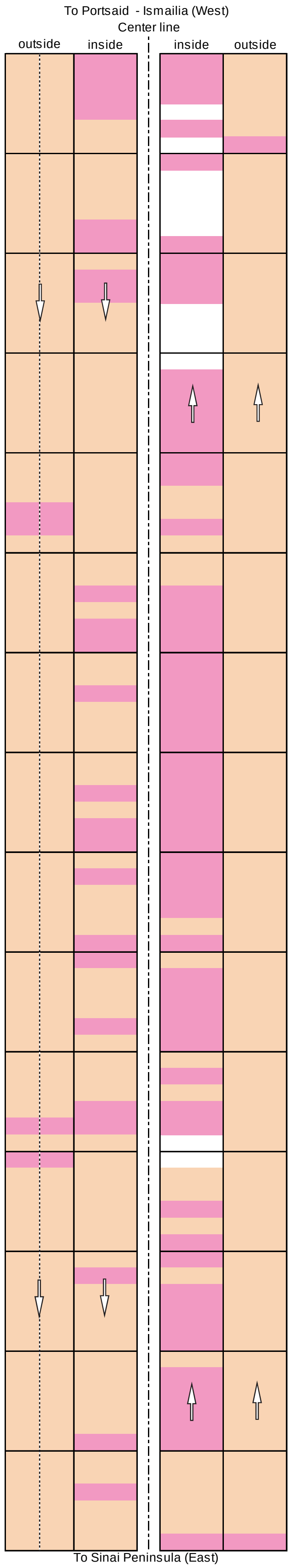


Table 2.2.3 Crack Width and Depth (East Side of Center Span 2)

Unit : mm

BLOCK No.	No.	South						North			
		outside lane				inside lane		inside lane		outside lane	
		Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
BL-34	D63	10	35	20	25	5	5	5	5	15	20
	TR63-1	10	29	40	50	10	65	5	5	15	20
	D64	7	21	10	30	15	45	5	10	15	20
	TR64-1	6	27	20	15	15	50	5	5	15	15
	D65	10	20	25	20	10	25	5	10	10	10
BL-35	TR62-2	10	35	10	30	10	30	5	15	20	35
	TR62-1	20	25	20	15	10	20	5	10	10	15
	D62	30	30	10	20	5	15	5	5	15	30
	TR61-2	20	25	10	15	10	30	5	10	20	30
	TR61-1	30	40	20	25	20	30	5	5	15	20
	D61	20	25	10	35	5	20	5	5	10	15
BL-36	TR60-2	20	30	15	25	25	25	5	5	30	40
	TR60-1	30	40	20	15	20	50	5	5	20	30
	D60	40	40	25	25	30	40	25	25	40	50
	TR59-2	40	40	25	15	15	30	20	30	25	35
	TR59-1	40	40	20	15	20	35	20	30	50	75
	D59	30	40	15	15	25	25	20	70	70	70
BL-37	TR58-2	40	30	25	20	10	40	5	15	20	30
	TR58-1	40	40	15	15	15	15	10	20	15	20
	D58	40	40	15	10	15	30	20	30	15	20
	TR57-2	40	40	20	10	10	30	20	20	20	25
	TR57-1	30	20	10	10	5	20	5	10	15	25
	D57	50	40	10	10	10	25	5	5	20	35
BL-38	TR56-2	30	35	25	15	15	35	5	5	20	35
	TR56-1	35	25	35	15	5	20	5	15	40	45
	D56	50	40	10	15	5	40	10	10	30	35
	TR55-2	50	40	20	35	10	15	15	15	30	35
	TR55-1	30	25	20	15	10	20	5	5	20	30
	D55	40	30	30	20	10	20	5	5	15	25
BL-39	TR54-2	30	25	20	15	20	35	Non	Non	15	20
	TR54-1	30	25	10	10	25	25	5	5	30	35
	D54	30	35	20	35	25	35	Non	Non	40	40
	TR53-2	40	30	10	10	10	40	5	10	25	30
	TR53-1	35	25	30	15	10	45	Non	Non	15	20
	D53	35	30	20	10	5	15	5	5	20	25
BL-40	TR52-2	40	30	15	10	10	30	5	5	20	30
	TR52-1	40	30	10	10	15	30	25	25	20	30
	D52	40	30	15	10	15	25	5	5	20	25
	TR51-2	30	25	30	15	10	35	Non	Non	20	25
	TR51-1	50	40	30	15	15	30	5	5	20	25
	D51	30	25	30	20	20	10	Non	Non	15	15
BL-41	TR50-2	20	20	30	10	15	30	20	20	30	10
	TR50-1	20	15	30	10	10	35	20	30	15	15
	D50	15	15	15	15	10	25	15	20	10	20
	TR49-2	25	25	20	15	10	20	15	25	20	25
	TR49-1	30	25	30	15	20	25	5	5	30	30
	D49	30	25	20	10	15	20	5	5	25	30
BL42	TR48-2	30	25	10	5	5	10	Non	Non	20	20
	TR48-1	25	20	10	10	10	25	5	5	10	15
	D48	40	30	10	10	15	20	5	5	10	15
	TR47-2	40	25	10	10	20	50	30	30	15	20
	TR47-1	40	25	15	10	10	20	Non	Non	15	15
	D47	30	25	10	10	5	15	Non	Non	15	20
BL-43	TR46-2	25	25	20	15	10	20	5	5	15	15
	TR46-1	40	30	30	20	15	40	10	20	15	30
	D46	20	25	30	20	10	20	10	10	15	25
	TR45-2	40	40	35	25	25	70	5	10	10	20
	TR45-1	30	25	30	15	15	25	5	10	10	15
	D45	30	30	40	25	15	35	15	40	15	20
BL-44	TR44-2	30	25	40	20	30	40	15	25	20	20
	TR44-1	50	40	60	20	15	25	20	30	20	30
	D44	50	35	20	20	20	25	10	30	15	15
	TR43-2	30	30	20	15	10	20	20	30	10	15
	TR43-1	40	30	30	20	25	25	10	35	10	15
	D43	45	35	30	10	10	20	10	15	10	10
BL-45	TR42-2	45	30	40	15	20	40	15	30	10	10
	TR42-1	45	35	20	15	15	35	15	25	10	15
	D42	70	40	25	15	30	25	5	10	10	15
	TR41-2	30	30	30	15	20	20	5	5	10	15
	TR41-1	35	30	60	20	15	30	5	5	10	10
	D41	30	25	50	15	5	10	5	5	5	5
BL-46	TR40-2	30	35	30	10	10	30	5	5	10	10
	TR40-1	50	40	50	15	20	20	5	10	5	5
	D40	40	30	50	15	15	20	5	5	10	10
	TR39-2	20	25	15	10	20	35	5	5	10	10
	TR39-1	35	30	60	15	10	30	5	10	15	15
	D39	45	30	25	15	10	15	5	5	15	10
BL-47	TR38-2	25	30	30	15	20	30	15	25	15	25
	TR38-1	30	30	50	25	20	20	5	10	20	25
	D38	25	25	40	15	10	20	5	5	20	25
	TR37-2	30	30	10	10	10	10	5	5	15	20
	TR37-1	40	30	25	45	10	20	5	5	10	10
	D37	25	25	40	20	15	20	5	10	10	25
BL-48	TR36-2	30	30	25	20	15	25	5	10	10	15
	TR36-1	30	25	30	20	15	20	5	5	10	20
	D36	25	20	20	20	10	20	5	5	15	15
	TR35-2	10	10	15	15	10	30	5	5	15	25
	TR35-1	15	20	25	20	20	20	5	5	15	25
	D35	10	10	20	10	10	20	Non	Non	10	10
BL-49	TR34-2	30	50	40	20	20	25	5	5	20	25
	TR34-1	30	25	30	25	10	30	5	5	15	25
	D34	10	10	20	25	10	15	5	5	15	25
	TR33-2	10	10	30	20	15	25	Non	Non	10	20
	TR33-1	10	10	30	25	10	15	5	5	10	25
	D33	10	5	20	15	20	25	5	5	20	20

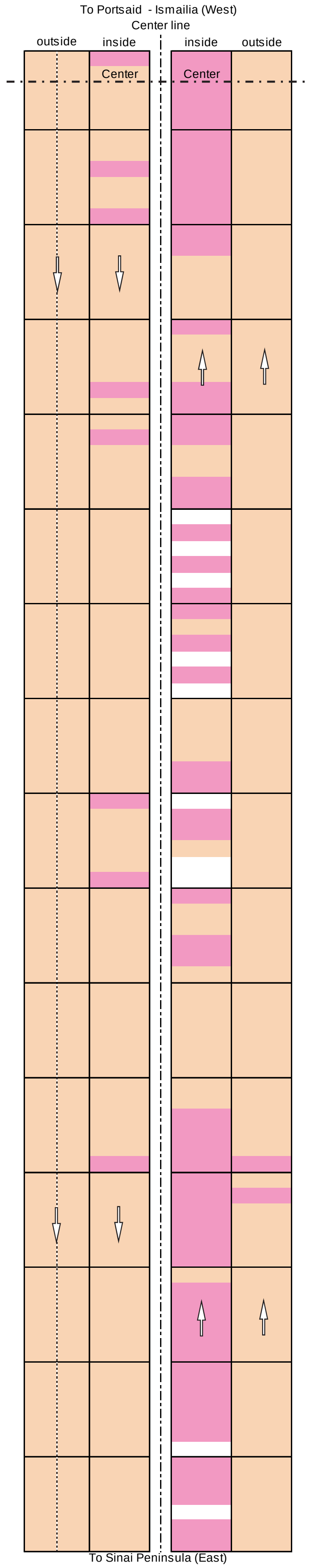
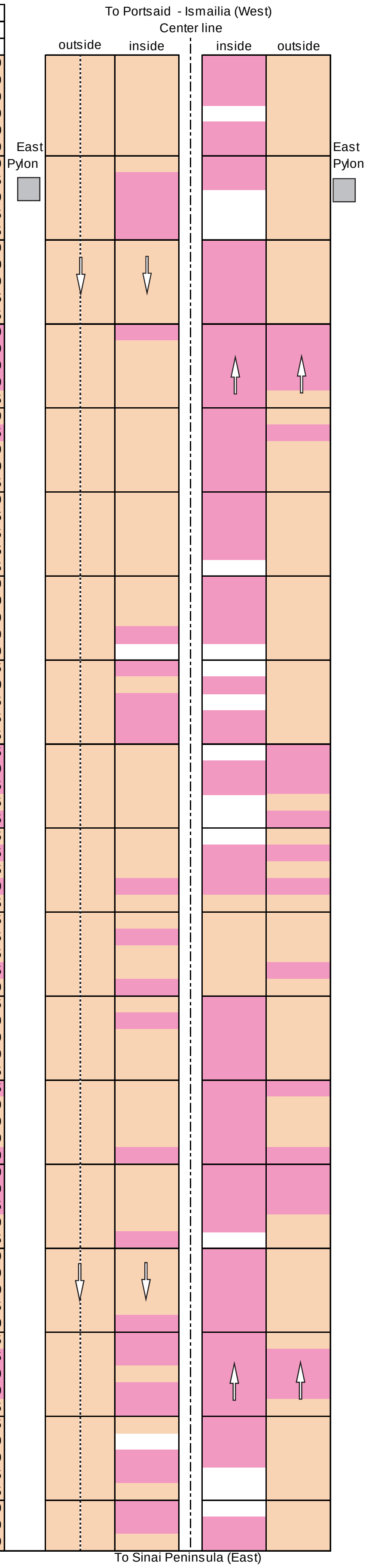


Table 2.2.4 Crack Width and Depth (East Side)

Unit : mm

BLOCK No.	No.	South						North			
		outside lane				inside lane		inside lane		outside lane	
		Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
BL-50	TR32-2	5	5	20	20	15	30	5	5	20	30
	TR32-1	5	5	15	10	10	15	5	5	20	40
	D32	15	15	25	20	15	20	5	5	40	30
	TR31-2	20	20	10	10	15	25	Non	Non	20	30
	TR31-1	10	10	20	15	20	25	5	5	70	40
	D31	5	5	20	15	10	20	5	5	15	30
BL-51	TR30-3	5	10	20	15	10	15	5	5	10	20
	TR30-2	30	30	25	20	5	10	5	5	20	25
	T2	30	30	20	15	5	10	Non	Non	15	30
	TR30-1	15	15	20	15	5	15	Non	Non	15	25
	D30	50	32	15	50	5	10	Non	Non	20	25
BL-52	TR29-2	28	22	40	20	10	20	5	5	25	30
	TR29-1	10	10	40	20	10	20	5	10	10	20
	D29	15	15	30	15	10	20	5	5	10	30
	TR28-1	15	10	30	25	15	30	5	5	10	25
	D28	15	25	25	15	25	20	5	5	20	35
BL-53	TR27-2	20	10	25	10	5	20	5	5	5	10
	TR27-1	30	20	20	20	10	20	5	5	5	10
	D27	15	15	30	25	10	20	5	5	5	10
	TR26-1	20	15	15	15	10	20	5	5	5	10
	D26	20	20	10	45	20	40	5	10	15	35
BL-54	TR25-2	50	20	20	15	20	20	5	5	10	20
	TR25-1	25	15	20	20	10	15	5	5	5	25
	D25	30	20	40	25	20	25	5	5	10	20
	TR24-1	20	10	30	15	10	30	5	5	15	20
	D24	60	30	20	15	20	30	5	5	15	15
BL-55	TR23-2	30	15	30	15	15	20	5	5	15	30
	TR23-1	20	20	15	15	15	20	5	5	10	15
	D23	10	10	20	20	15	20	5	5	10	15
	TR22-1	25	15	20	20	10	20	5	5	10	15
	D22	15	35	20	15	10	20	Non	Non	10	15
BL-56	TR21-2	25	15	15	15	10	35	5	5	10	40
	TR21-1	30	20	10	20	20	20	5	5	10	20
	D21	30	15	20	20	15	25	5	5	20	30
	TR20-1	10	10	15	15	5	5	5	5	10	20
	D20	30	15	10	10	Non	Non	Non	Non	10	20
BL-57	TR19-2	15	20	60	15	5	5	Non	Non	15	35
	TR19-1	30	20	20	25	15	30	5	5	20	30
	D19	40	20	20	20	5	10	Non	Non	30	45
	TR18-1	20	10	30	20	5	10	5	5	20	65
	D18	10	10	20	20	5	5	5	5	25	45
BL-58	TR17-3	10	10	15	15	10	45	Non	Non	5	15
	TR17-2	20	20	15	35	10	25	5	5	5	10
	PM4	25	15	20	15	20	65	5	5	5	15
	TR17-1	50	20	20	20	20	20	Non	Non	10	15
	D17	70	20	20	15	15	15	Non	Non	5	15
BL-59	TR16-2	80	20	25	20	10	25	Non	Non	15	15
	TR16-1	20	20	30	20	10	25	5	5	5	15
	D16	25	15	20	15	20	20	5	10	20	25
	TR15-1	25	25	20	15	5	5	5	10	5	10
	D15	25	20	20	20	20	35	15	20	15	25
BL-60	TR14-2	25	15	25	20	15	25	20	20	20	35
	TR14-1	20	15	20	15	5	10	20	20	15	15
	D14	10	20	25	20	20	30	10	25	20	35
	TR13-1	10	10	20	20	10	20	10	10	5	15
	D13	20	20	20	20	5	20	10	10	10	20
BL-61	TR12-2	20	15	10	10	15	20	5	15	10	15
	TR12-1	25	20	20	25	5	5	5	10	10	10
	D12	5	5	20	15	15	15	5	5	15	20
	TR11-1	40	30	30	25	20	40	5	5	15	20
	D11	15	50	20	45	15	30	5	10	15	25
BL-62	TR10-2	30	20	20	15	25	30	5	5	5	5
	TR10-1	20	15	15	15	20	25	5	5	10	10
	D10	30	20	10	10	20	25	5	5	10	10
	TR9-1	30	20	10	10	15	20	5	5	10	20
	D9	30	20	20	15	5	5	5	5	5	10
BL-63	TR8-3	60	15	20	10	15	40	5	5	5	10
	TR8-2	30	15	20	20	10	45	5	15	5	10
	PM5	20	15	20	20	10	25	5	15	5	15
	TR8-1	40	20	20	20	10	25	5	10	10	20
	D8	30	15	5	10	5	10	Non	Non	15	35
BL-64	TR7-2	20	20	20	15	20	25	5	5	20	30
	TR7-1	30	20	20	20	20	35	5	5	20	40
	D7	40	20	30	20	10	40	5	5	20	30
	TR6-1	40	20	30	20	15	20	5	10	10	15
	D6	50	20	20	20	5	10	5	10	10	20
BL-65	TR5-2	40	25	20	15	5	15	5	10	10	15
	TR5-1	30	20	40	25	5	5	5	10	5	15
	D5	40	20	20	15	20	25	5	5	5	10
	TR4-1	10	15	20	15	5	5	5	5	5	10
	D4	20	50	20	25	5	5	5	10	15	15
BL-66	TR3-2	25	20	20	45	10	20	5	10	10	15
	TR3-1	25	25	25	15	Non	Non	5	5	15	20
	D3	25	40	25	45	5	5	5	10	15	20
	TR2-1	30	20	25	20	5	10	Non	Non	10	15
	D2	20	45	30	40	10	60	Non	Non	10	15
BL-67	TR1-2	50	15	20	15	5	20	Non	Non	10	30
	TR1-1	25	15	30	20	5	10	5	10	20	30
	D1	20	15	Non	Non	10	30	5	10	20	60

Lane-3: Passing Lane for east side, Lane-4: Driving Lane for east side



(3) Comments

- Cracks occurred in 95% of the pavement area.
- Approximately 70% of the area had some cracks with a width of more than 10 mm.
- The outside lane of the south side was in the most serious condition.
- The inside lane of the north side seemed to be better; however, 80% of the pavement area had some cracks.

2.2.2 Damage Conditions in Detail

(1) Inspection Target

- Inspections were done in 6 spots, 4 m width x 6 m length with serious damage found in the carriageway.
- Inspection items were location, width, and depth of the major cracks, flatness of pavement surface and peeling off and/or voids by hammer testing.

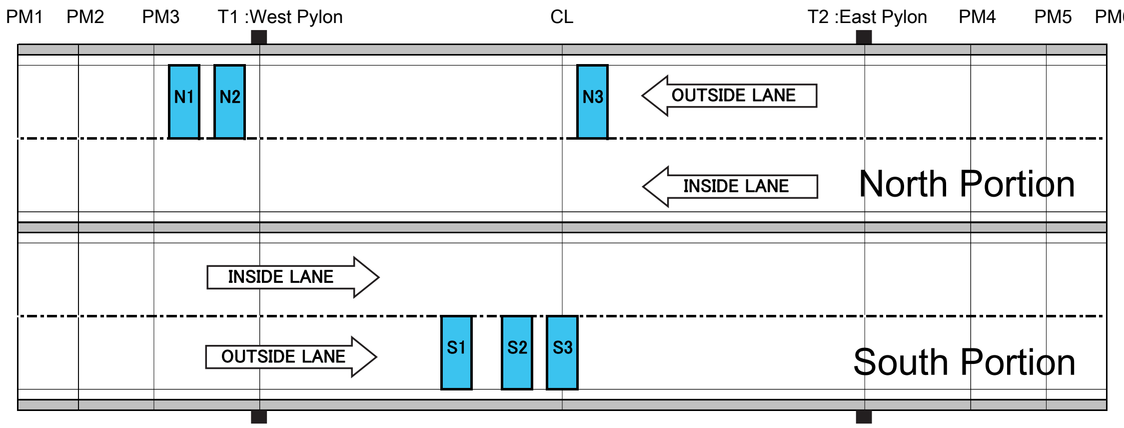


Figure 2.2.2 Locations of Detailed Inspection

Photo 2.2.4 Detailed Inspection Work

(2) Inspection Results

- The photograph shows the results of N1.

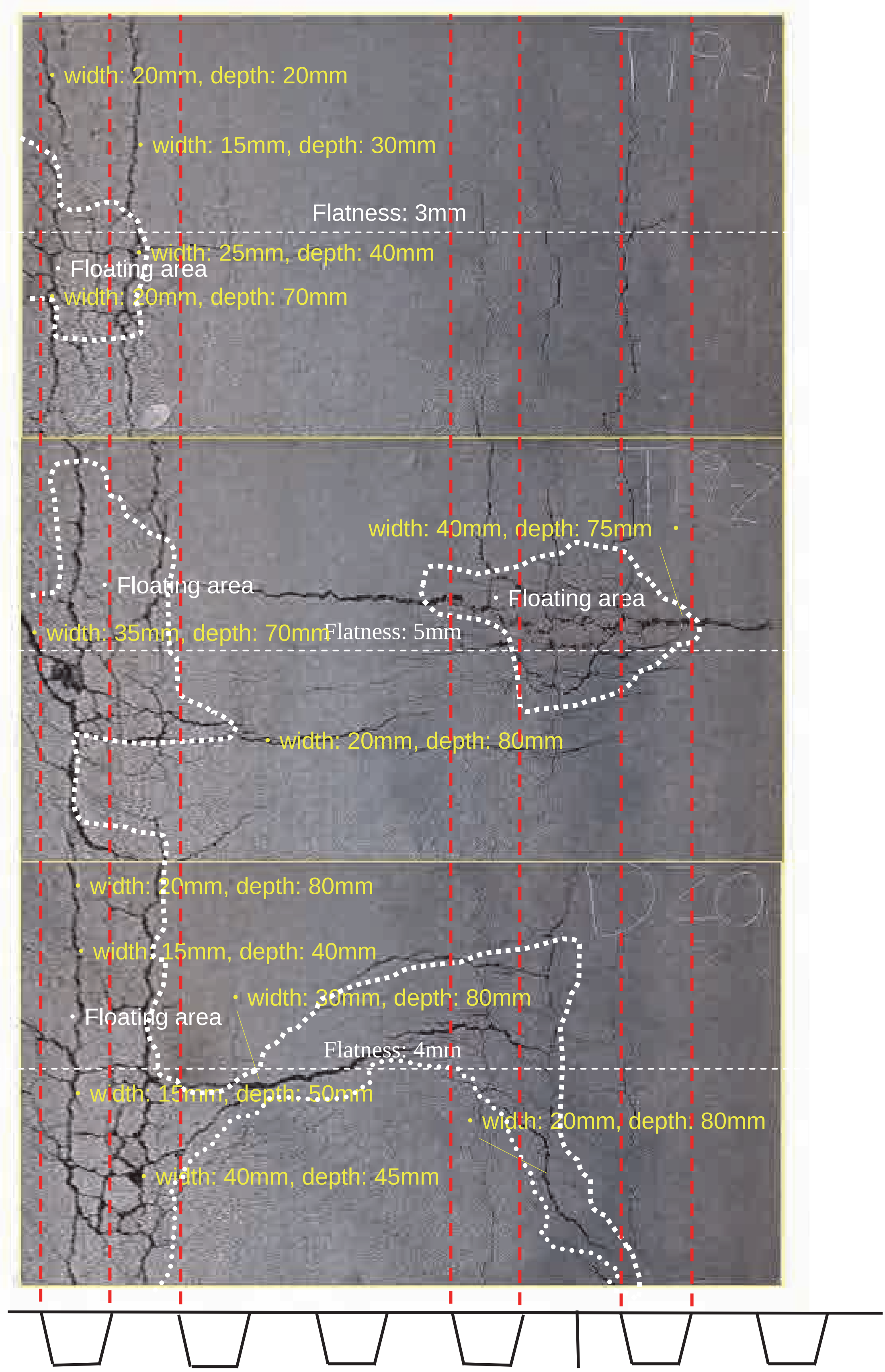


Figure 2.2.3 Results of Detailed Inspection (N1)

(3) Comments

- The largest crack was 40 mm in width and 80 mm in depth; thus, major cracks reached the steel deck plate.
- A pothole of 70 mm x 50 mm was found.
- Flatness of the pavement surface was good with a difference of less than 5 mm against the critical maintenance value of 20 mm.
- Some points were confirmed as isolated areas because of deterioration of bonding strength.
- Major cracks were intensively located under the wheel-loaded line.

Photo 2.2.5 Major Cracks on Wheel-Loaded Line

- In detail, major cracks occurred along the line between the rib plates.

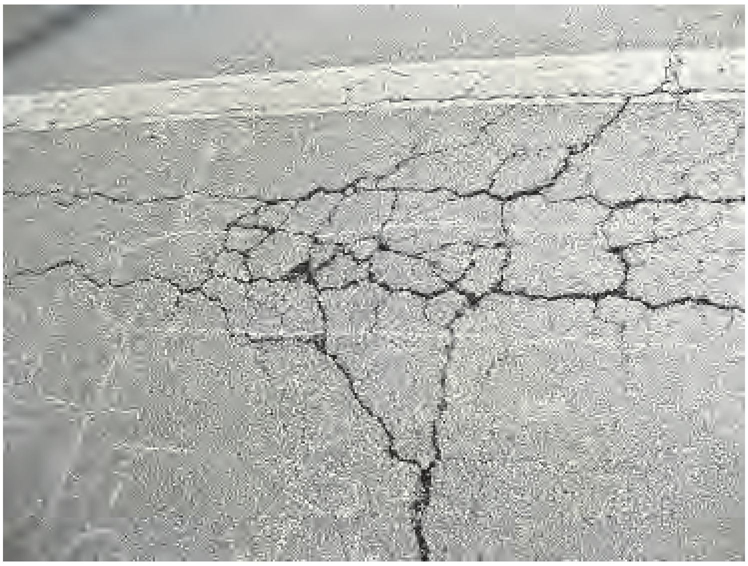


Photo 2.2.6 Major Cracks between the Rib Plates of the Steel Deck Plate

- Also, some major cracks in the transverse direction were located between the diaphragms.

Photo 2.2.7 Major Cracks between Transverse Diaphragms

- Initial cause of the cracks is assumed to be the large displacement of the steel deck plate due to the passage of heavy vehicles.
- The location of major cracks indicates that cracks were generated by compression.

2.2.3 Core Sampling

(1) Inspection Target

- Inspections were done in 6 spots by coring 100 mm in diameter.
- Adhesion tests were carried out for each core boring point.

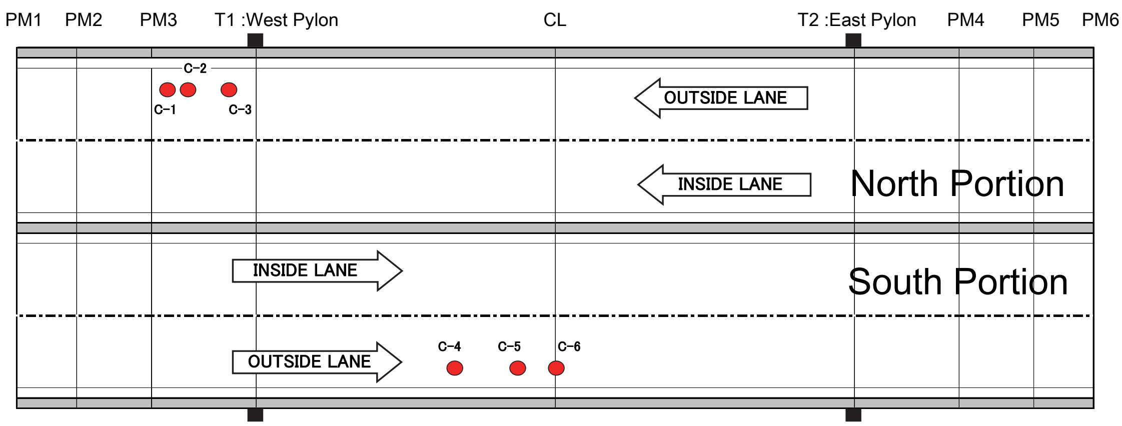
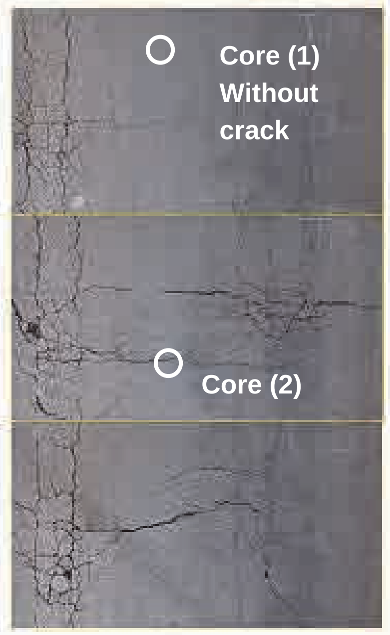


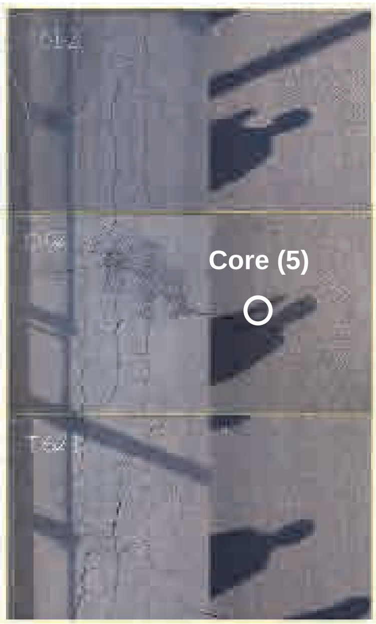
Figure 2.2.4 Location of Core Boring Points



N-1 (Tr19-1/Tr19-2/D20)

N-2 (Tr28-1/D29/Tr29-1)

S-1 (Tr57-2/D58/Tr58-1)



S-2 (Tr61-2/D62/Tr62-1)

S-3 (Tr63-1/D64/Tr64-1)

Figure 2.2.5 Detailed Location of Core Boring Points

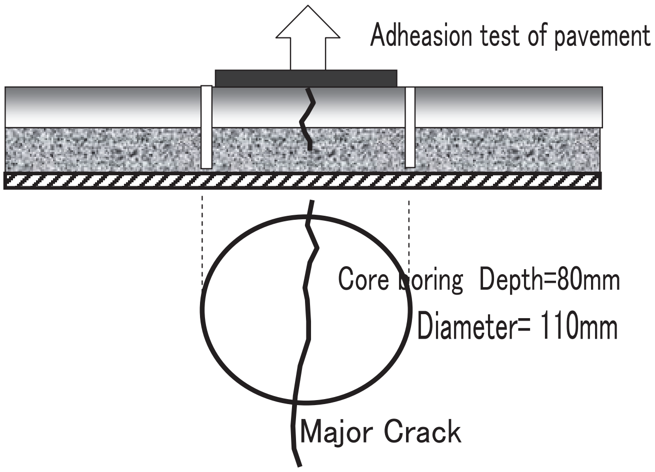


Figure 2.2.6 Asphalt Core Sampling (Actual Diameter 100 mm)

Photo 2.2.8 Coring and Adhesive Tests

(2) Inspection Results

- The average adhesive strength was measured 0.113 N/mm^2 < 1.4 N/mm^2 of the criterion adhesive strength.
- The adhesive strength of Core No. 1 without cracks was also 0.178 N/mm^2.
- The broken areas amounted to 16.7% of tack coat and 83.3% of the bonding layer.

Table 2.2.5 Results of Adhesive Strength Tests

Location	Adhesive strengths (N/mm^2)	Breaking parts(%)				Remarks
		Surface layer	Tack coat	Base layer	Bond layer	
C1	0.178				100	2011/12/6
C2	0.242				100	2011/12/6
C3	0.025		100			2011/12/6
C4	0.102				100	2011/12/5
C5	0.064				100	2011/12/5
C6	0.064				100	2011/12/5
Average	0.113		16.7		83.3	
Remarks						

Photo 2.2.9 Sampled Cores

(3) Comments

- The cause of low adhesive strength is assumed to be deterioration in the bonding layer because of water penetration through the pavement cracks.
- Deterioration of Core No. 1 (without cracks) was affected by water coming from the cracks around the coring point.
- All of the cracks in the sampled cores reached the steel deck plate.

2.2.4 Cut and Excavation Test

(1) Inspection Target

- An inspection was carried out in 7 spots: 3 spots of L type (1 m x 1 m), 2 spots of S type (0.3 m x 0.3 m) and an additional 2 spots (0.15 m x 0.15 m) that were located in sound areas of the outside lane on the north side.
- L type is located on severe grid-typed cracks and S type is located on line-typed cracks.
- Visual inspection of the condition of the cracks and bonding layer was carried out.

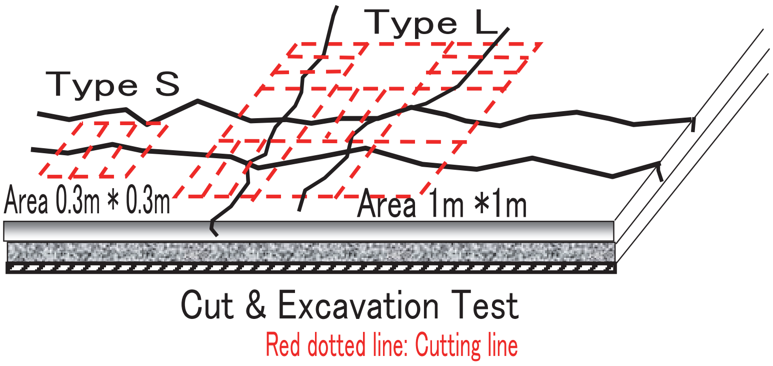


Figure 2.2.7 Cut and Excavation Test

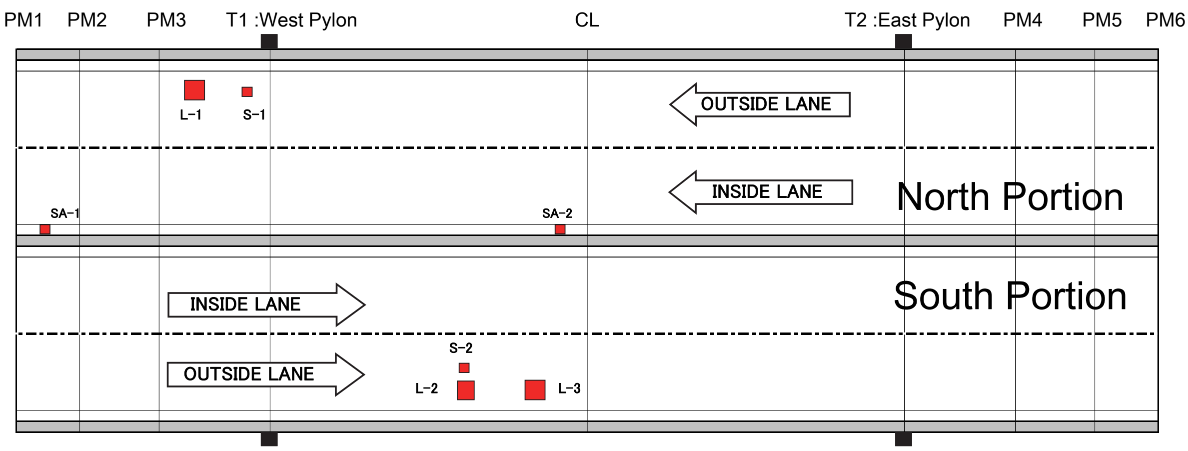


Figure 2.2.8 Location of Cut and Excavation Test

Photo 2.2.10 Cut and Excavation Work

Photo 2.2.11 Refill Work with Asphalt Material

(2) Inspection Results

- Some cracks with widths of 10 mm reached the steel deck plate.

Photo 2.2.12 Cross Section of Cut Pavement (L2)

- In all inspected spots, bonding strengths between the base course and steel deck plate were deteriorated.

Photo 2.2.13 Bottom Face of Excavated Block (Bonding Face) L2

Photo 2.2.14 Peeling of Bonding Layer with Corrosion (L2)

Photo 2.2.15 Peeling of Bonding Layer with Corrosion (L1)

- The condition of the adhesive layer of the two additional spots (sound area) seemed good.

Photo 2.2.16 Condition of Additional Spot (Sound Area) SA2

Photo 2.2.17 Condition of Additional Spot (Sound Area) SA2----Magnified

(3) Comments

- Most of the cracks with widths of more than 10 mm are assumed to reach the steel deck plate.
- The condition of the adhesive layer was wet because of penetrated water.
- The bonding strength of the tack coat between the surface course and base course seemed sound.
- The adhesive strength under the base layer in the cracked area, which amounted to approximately 70%, is assumed to be insufficient compared to design strength.
- The results indicated the necessity for the replacement of the entire base course and adhesive layer.

2.3 Detail Inspection on Steel Deck Plate

2.3.1 Top Surface of Steel Deck Inspection

(1) Inspection Target

- After the adhesive line is removed where the open cut is done, a VI is done to check the top surface of the steel deck plate to see if rust or corrosion is present. In addition, crack locations are determined and information about the causes of crack initiation and propagation can be gathered.
- The inspection items are as follows:
- Inspection area: 1 m wide x 1 m long x 3 spots and 0.3 m x 0.3 m x 2 in the traffic lane
- Inspection items: rust, corrosion, and crack location
- Inspection method: VI

(2) Results of inspection

In almost all of the inspected areas, the steel was corroded. Thickness reductions were different depending on the location. The south side driving lanes (L2, L3) are heavily corroded compared to the north side.

- In L2 cutout: the stick layer was changed to a layer of steel rust and could not be removed easily even with power tools. The thickness of the rust layer was about 0.5 to 1 mm.
- In L1 cutout: after the removal of the asphalt, red material (possibly rust) stuck to the stick layer. The stick layer (adhesive layer) seemed to be sound in L1, but could be removed easily in some parts. (Photo 2.3.1)
- There were some thickness reductions due to corrsion in the west part of the L1 cutout.

1) L1

After the Removal of Asphalt Layer,
Red Material Adheared to the Stick Layer

Stick Layer (Bonding and Corrosion)

Photo 2.3.1 Top Surface of Steel Deck (L1)

2) S1

A fter the Removal of Asphalt Layers

Ground Surface on the Rib

Photo 2.3.2 Top Surface of Steel Deck (S1)

3) L2

Before the Cutout L2 & S2

After the Removal of Asphalt Layers


Surface Condition after Removal of Corrosion

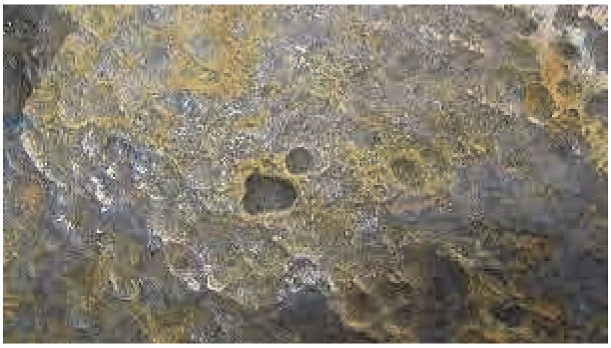

Surface Condition (Magnified)

Photo 2.3.3 Top Surface of Steel Deck (L2)

4) S2

- The rust layer was removed easily and broke into pieces.

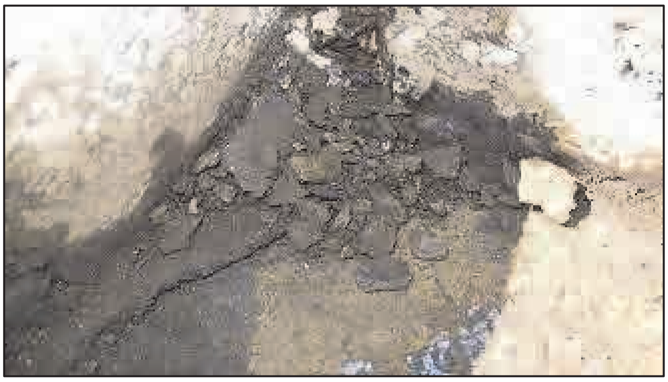


Photo 2.3.4 Top Surface of Steel Deck (S2)

5) L3

Photo 2.3.5 Top Surface of Steel Deck (L3)

(3) Comments

- Water invaded the area under the stick layer and the steel was corroded in every cutout.
- Corrosion conditions of the steel deck surface were different in each cutout.
- In the north side cutouts L1, there are sound steel surfaces in some areas but corrosion had propagated in part of the surface.
- In order to fix the corrosion, it is necessary to blast and remove the rust first, then apply a new asphalt layer with a waterproof layer.

2.3.2 Deck Plate Thickness Inspection

(1) Inspection Target

- Corrosion of the steel deck plate may lead to thickness reduction and make the surface more vulnerable to cracks or defects.
- The plate thickness reduction due to corrosion is measured after the removal of asphalt.
- Thickness is measured by using an ultrasonic thickness meter from the deck surface after the removal of surface roughness due to corrosion.
- Average thickness is calculated from 5 to 10 points in smoothed areas at 10 to 20 cm intervals.

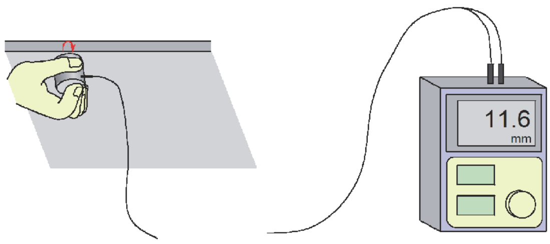


Figure 2.3.1 Plate Thickness Inspection with Ultrasonic Thickness Meter

Photo 2.3.6 Thickness Measuring

(2) Results of Inspection

- Thicknesses of plates were measured in 5 cutouts. L1, S1 (north side), L2, S2, L3 (south side).
- Corrosion on L2 seems to be the most severe in the inspection.
- Average thickness of L2 is 11.5 mm after the smoothing of the surface.
- L1: A little corrosion was observed on the center part. The corroded region in the west part was ground smooth and thicknesses were measured.

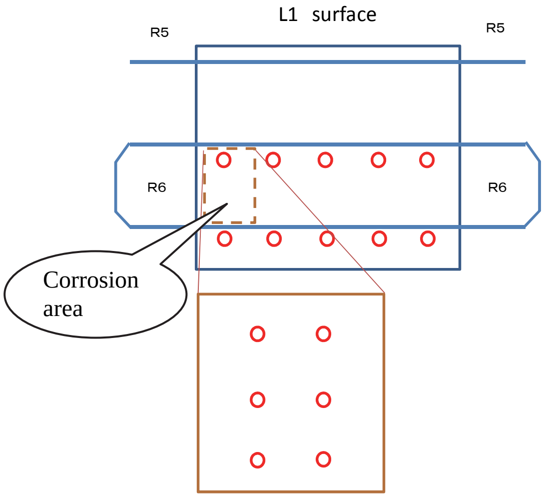


Figure 2.3.2 Thickness Measured on L1 Surface

- L1 on U-rib #6: 10 points

11.9	11.9	12.1	11.9	12.1
12.0	11.9	12.0	11.9	12.0

- L1 corrosion area: 6 points in 30 cm × 50 cm area after surface grinding

11.5	11.8	11.8
11.7	11.9	11.7

- S1 corrosion area: 6 points in 30 cm × 50 cm area after surface grinding

11.5	11.7	11.8
11.5	11.4	11.4

- L2

11.4	11.5	11.6	11.5	11.3
11.4	11.7	11.5	11.6	11.6

Average 11.5mm

- S2 corrosion area: 4 points in 30 cm × 50 cm area after surface grinding

11.5	11.6
11.7	11.9

- L3

11.5	11.5	11.4	11.5	11.6
11.4	11.6	11.3	11.7	11.6

- Average

L1 (no Gr.*)	L1(west)	S1	L2	S2	L3
12.0	11.7	11.6	11.5	11.7	11.5

* Before surface grinding

(3) Comments

- Average reduction of the thickness of L2 in the corroded regions is 0.5 mm, which is the maximum in the 5 locations.

- Small pits due to corrosion remained on the surface but were neglected in measurement.

- Thickness reduction due to corrosion is not a big problem at this moment from a structural point of view, but it will possibly induce fatigue cracking from the surface or affect the deformation capacity of the bridge if left as it is.

2.3.3 Visual Inspection

(1) Inspection Target

- Visual inspection (VI) was carried out to understand the level of deterioration of the bridge and to select the suitable locations to apply magnetic particle testing (MT) and ultrasonic testing (UT).

- VI was executed in the box girder. Hands-on (close) inspection will follow depending on the VI results.

- Fatigue prone details are visually inspected closely on the weld bead or weld toe.

- VIs were done in the following regions:

  - Weld connections between the deck and cross members between two diaphragms under the pavement cutouts (5 locations, yellow hatching).

  - Weld bead of the ORTHOTROPIC STEEL DECK (OSD) under the wheel lording position around U-rib #7 and #8(whole length of bridge).

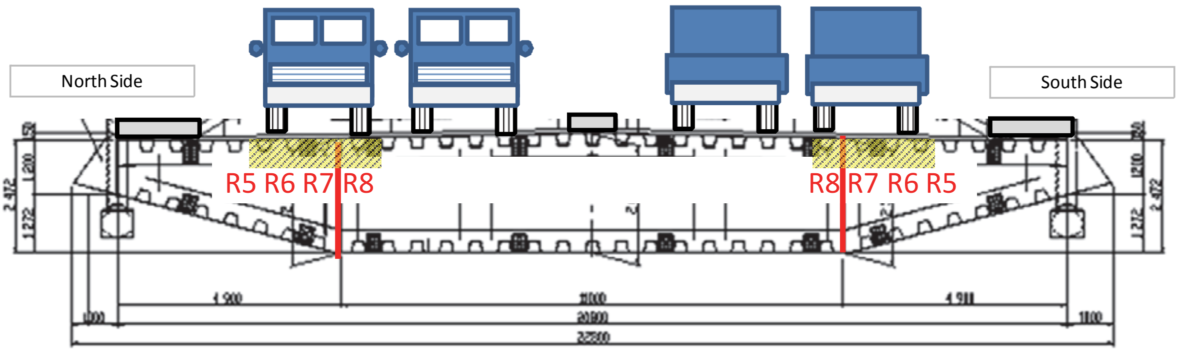


Figure 2.3.3 Location of Visual Inspection with Respect to Wheel Location

__Naming Rule for Location__

- **W Tr20-1 R6 S (5)** means west side of the bridge, transverse rib No. 20-1, south side U-rib No. 6 facing Rib No. 5.
- **W D21 E** means west side span, diaphragm (Dia.) No. 21, east side face of the diaphragm.
- **W 20(3)** means west side span, 3rd cell in a section between Dia. No. 20 and Dia. No. 21.
- U-ribs are numbered from the south side to the north side as R1S,…R15S, R16, R15N,…, R1N, where R16 is the center rib.

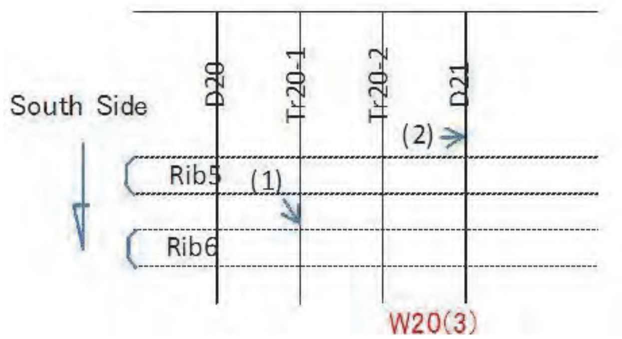


Figure 2.3.4 Naming Rule of Inspection Points

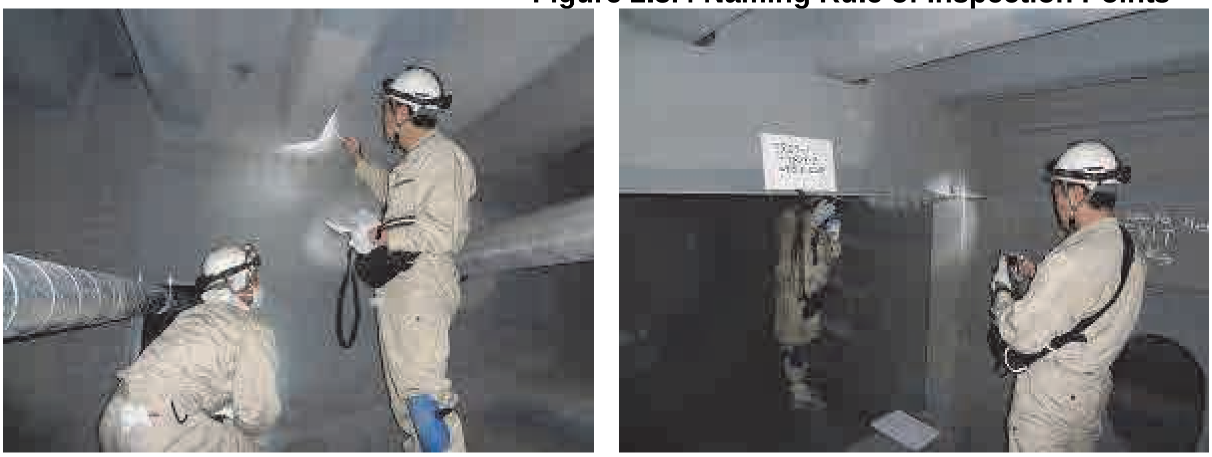


Photo 2.3.7 Visual Inspection Executed Inside of Box Girder

(2) Results of Inspection

- No fatigue cracks were detected by VI.

- Some poor welds were found and are listed in the appendix.

- A few paint cracks were found as shown in Photo 2.3.8. Patterns of these paint cracks are different from those of fatigue cracks.

Paint Crack L1 WTr20-1W-R6(5)

L1 WS-Tr20-1-R6_R5 Side

Photo 2.3.8 Paint Cracks

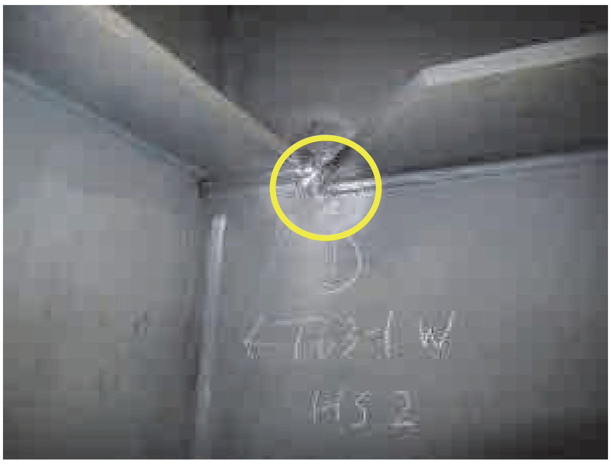
(3) Comments

- No fatigue cracks were detected either in the closely inspected area under the pavement cutouts or No. 7, 8 U-rib in the bridge.

- Fatigue prone details and welding of unfavorable quality were found in some parts.

- These parts should be inspected again later in periodic inspections. Such details are as follows:
  - ✓ Scallop of U-rib in transverse member connection (Upper left in Photo 2.3.9)
  - ✓ Vertical rib welded to deck plate, especially under the wheel location (center left and bottom left in Photo 2.3.9)
  - ✓ Flange of transverse rib adjacent and very close to horizontal stiffener (upper right in Photo 2.3.9)
  - ✓ U-shape rib weld bead (depends on weld root condition)
  - ✓ Scallops in the intermediate web (bottom right in Photo 2.3.9).

Boxing Weld on Scallop End of U-Rib



Butt Weld of T.Rib Flange, closely

Vertical Rib Welded to Deck Plate, Especially Harmful under Wheel Position

Adjacent to HS Horizontal Rib

Web Scallop on L.Flange

Rib for Erection, Boxing Weld on Deck Surface under Wheel Position

Photo 2.3.9 Parts that need Monitoring, Especially in the Steel Deck

2.3.4 Magnetic Particle Inspection

(1) Inspection Target

- A magnetic particle test (MT) is applied to the locations where paint cracks have been found by VI. It can detect small-size cracks (about 2-3 mm length) after the removal of paint.

- Magnetic particles used in this inspection are fluorescent coating particles that can reveal small surface discontinuities with bright colors in dark places when exposed to ultraviolet light (black light).

<u>Principles of MT</u>

- When the magnetizer is attached to the surface of the steel, magnetic flux runs in the steel near the surface. But, the flux leaks out into the air if a crack exists near the surface and interrupts the passage.

- Magnetic particles stick to the leaked flux indicating existence of a crack. These particles are easily detected by the inspector.

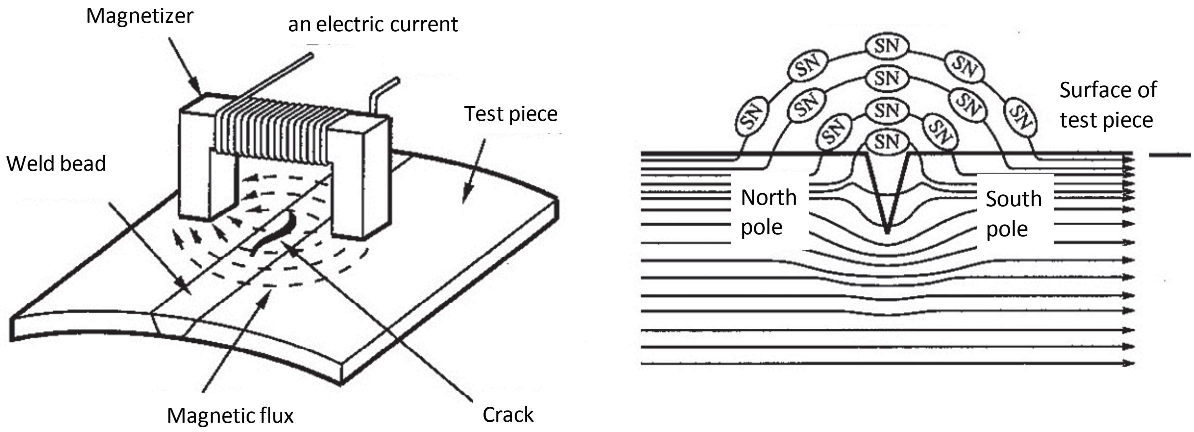


Figure 2.3.5 Function of Magnetic Particle Test: Magnetic Particles Stick to the Leaked Flux

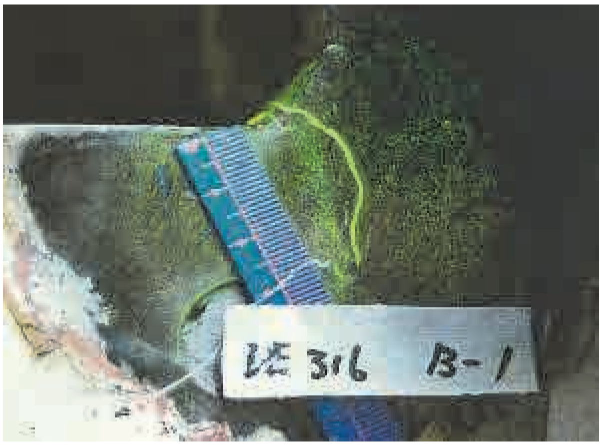


Photo 2.3.10 Example of MT Detection of Fatigue Crack (Other Bridge)

MT will be applied to find fatigue cracks in both the steel deck surface and inside of the box girder.

1) Deck surface side

- Initiation of fatigue cracks is anticipated both from the weld roots of the U-ribs and the surface of the deck where there is corrosion (embrittlement).
- MT is applied after the surface grinding of the corroded deck. Locations of MT inspection are shown below.
- A thick black sheet was used to cover the inspection area in order to shut out the sunlight.

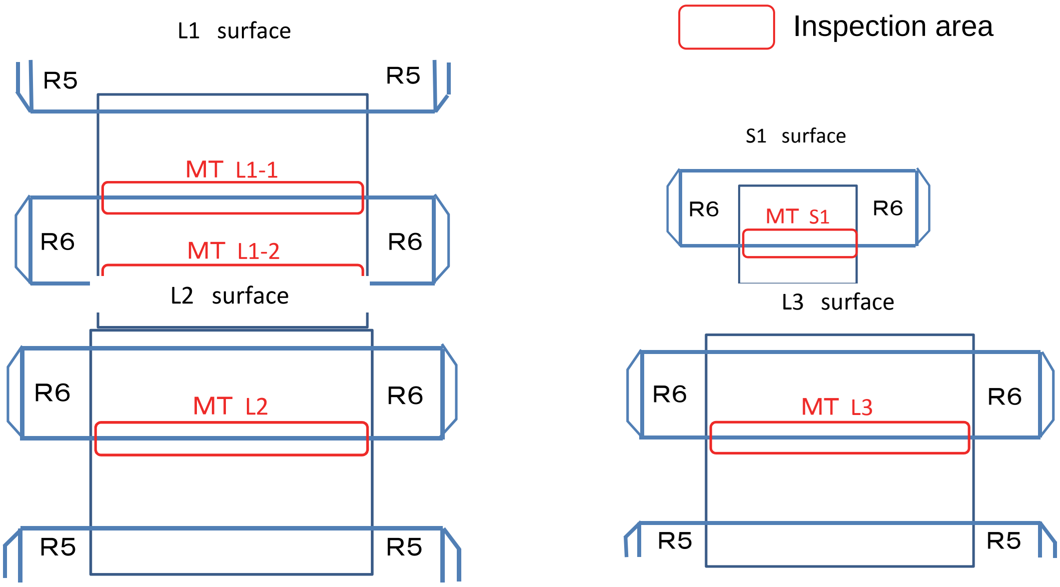


Figure 2.3.6 Location of MT Inspection on Deck Surface (Square is the Exposed Area of Deck)

Photo 2.3.11 MT Inspection Work on Deck Surface

2) Inside of box girder under the asphalt cut-out

- Detailed inspection areas were selected under the asphalt cutouts. (L1, L2, L3, S1, S2 and span center, same as UT inspections).

- Weld beads under the truck wheels were visually inspected closely and 3 to 6 points were selected for MT inspection.

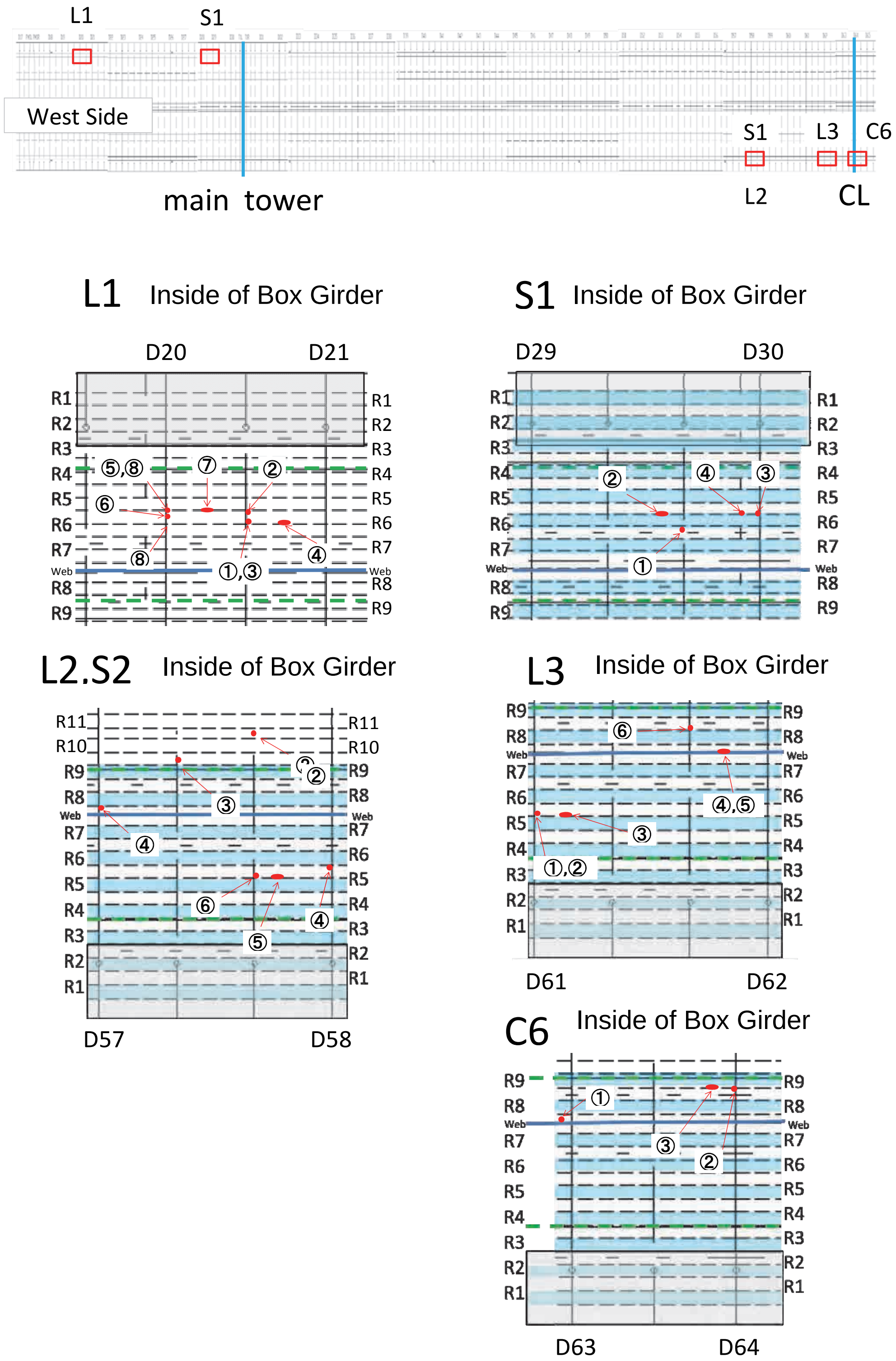


Figure 2.3.7 Location of MT Inspection Points under Cutouts

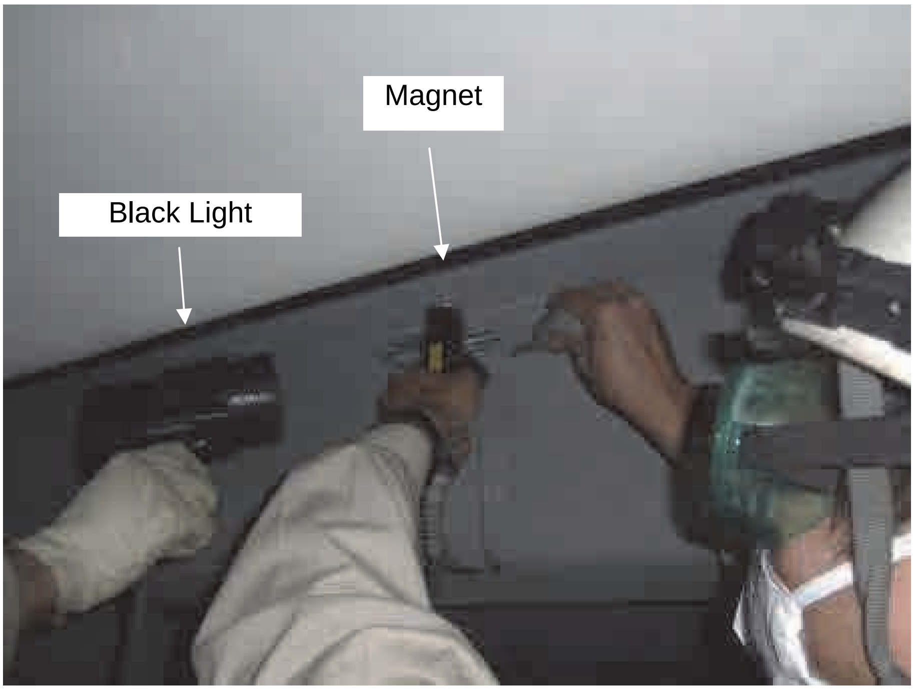


Photo 2.3.12 MT Inspection Work under the Cutouts

3) Inside of box girder deck under a wheel load location (around U-rib #7, #8)

- MT was applied to the points where paint cracks were found in the VI.

(2) Results of Inspection

1) Deck Surface MT Inspection

- MT was applied on the surface of the steel deck in the asphalt cutout areas (L1, L2, L3, S1, S2 surfaces).
- No fatigue cracks were detected.

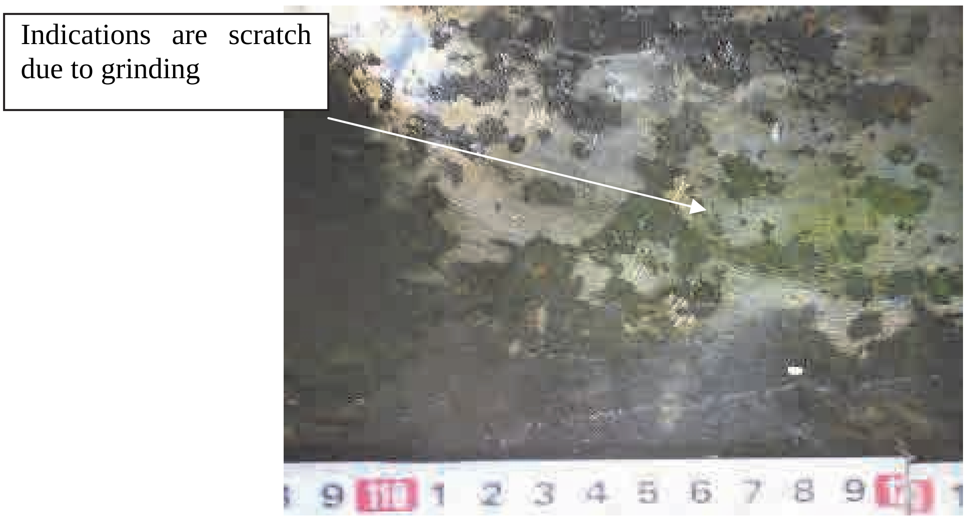
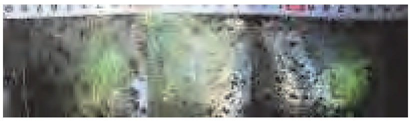


Photo 2.3.13 MT Inspection on Deck Surface S2

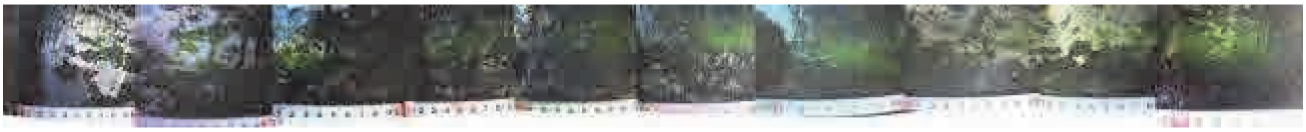
MT L1-1

MT L1-2

MT S1



MT L2



MT L3

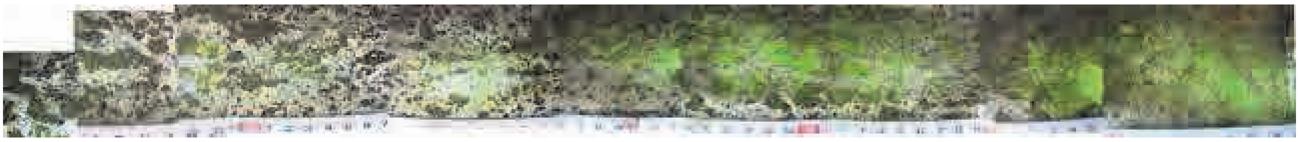
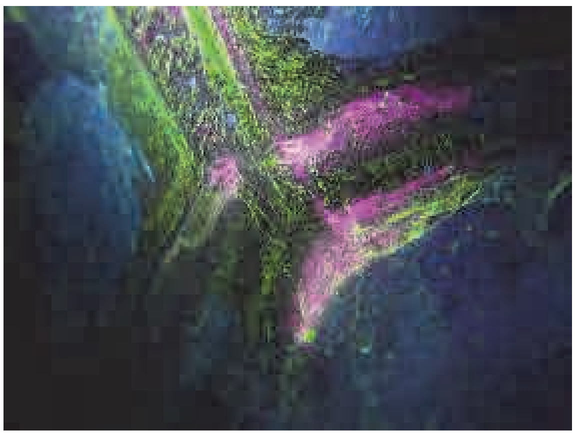


Photo 2.3.14 Results of MT Inspection on Deck Surface

2) Inside the box girder under the asphalt cutout

- No fatigue cracks were detected.
- A small crack on the weld bead was observed in L1 (Photo 2.3.15). It is a weld crack generated in the welding process and can be removed by surface grinding.
- MT results are summarized in the D/B form in the appendix.

Before Grinding



MT after Grinding

Photo 2.3.15 Weld Cracks on Weld Bead

3) Inside of the box girder deck around U-rib #8 :

- No fatigue cracks were detected.
- A few paint cracks were detected and MT was applied after removal of the paint coat as shown in Photo 2.3.16.

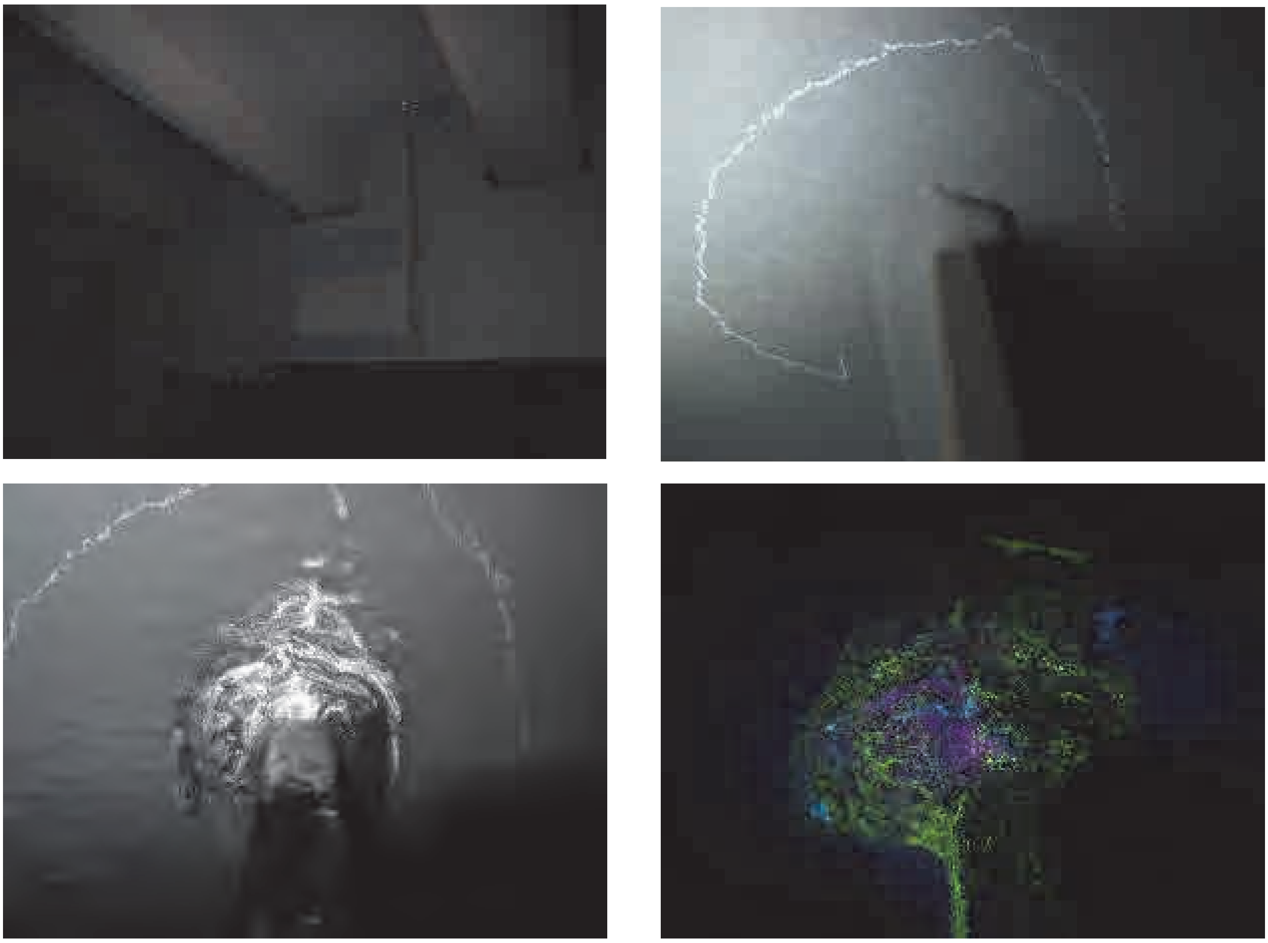


Photo 2.3.16 Example of MT Inspection under #7, 8 U-Rib: W T58-1E R9S(8)

(3) Comments

- Paint cracks that are suspected to have been caused by cracks in the underlying metal were investigated by MT. Some of them were only paint cracks and others were weld defects.
- No fatigue cracks were discovered in this 10-year-old bridge with close inspection of the selected areas.
- It can be said that the risk of fatigue cracks is low in this bridge at this moment.
- But, it is recommended to inspect fatigue prone details in periodic maintenance procedures.

2.3.5 Ultrasonic Inspection

(1) Inspection Target

- Ultrasonic testing was applied to detect cracks inside of weld beads.
- In the case of U-rib OSD[1], fatigue cracks initiate from the root of the weld metal and propagate into the deck plate as in Fig. 2.2.34.
- This type of crack is hard to detect visually and UT is the only method to detect it before the penetration.

<u>**Inspection Mechanism**</u>

- Ultrasonic waves have an angle of 70 degrees from the vertical and are focused on the tip of the root crack penetrating the deck plate.
- It is possible to detect a crack penetrating 6 mm or more (Figure 2.3.8).
- Semi-automatic UT was used and a 2-dimensional view of the crack location was presented soon after the inspection.
- It can also detect the existence of corrosion on the surface of the deck plate.

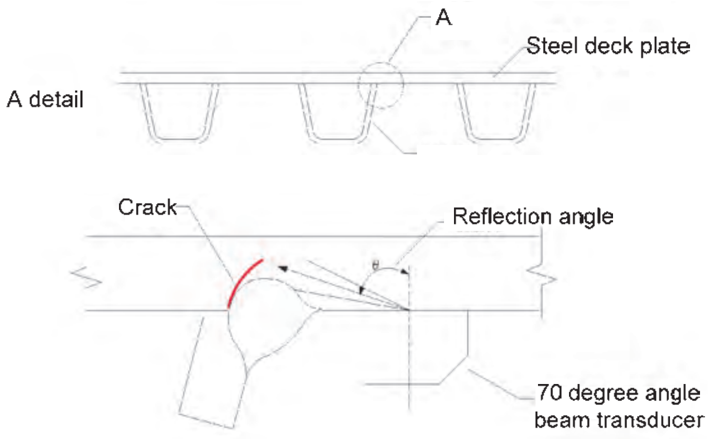


Figure 2.3.8 UT Inspection of OSD Deck Crack

[1] Orthotropic steel deck

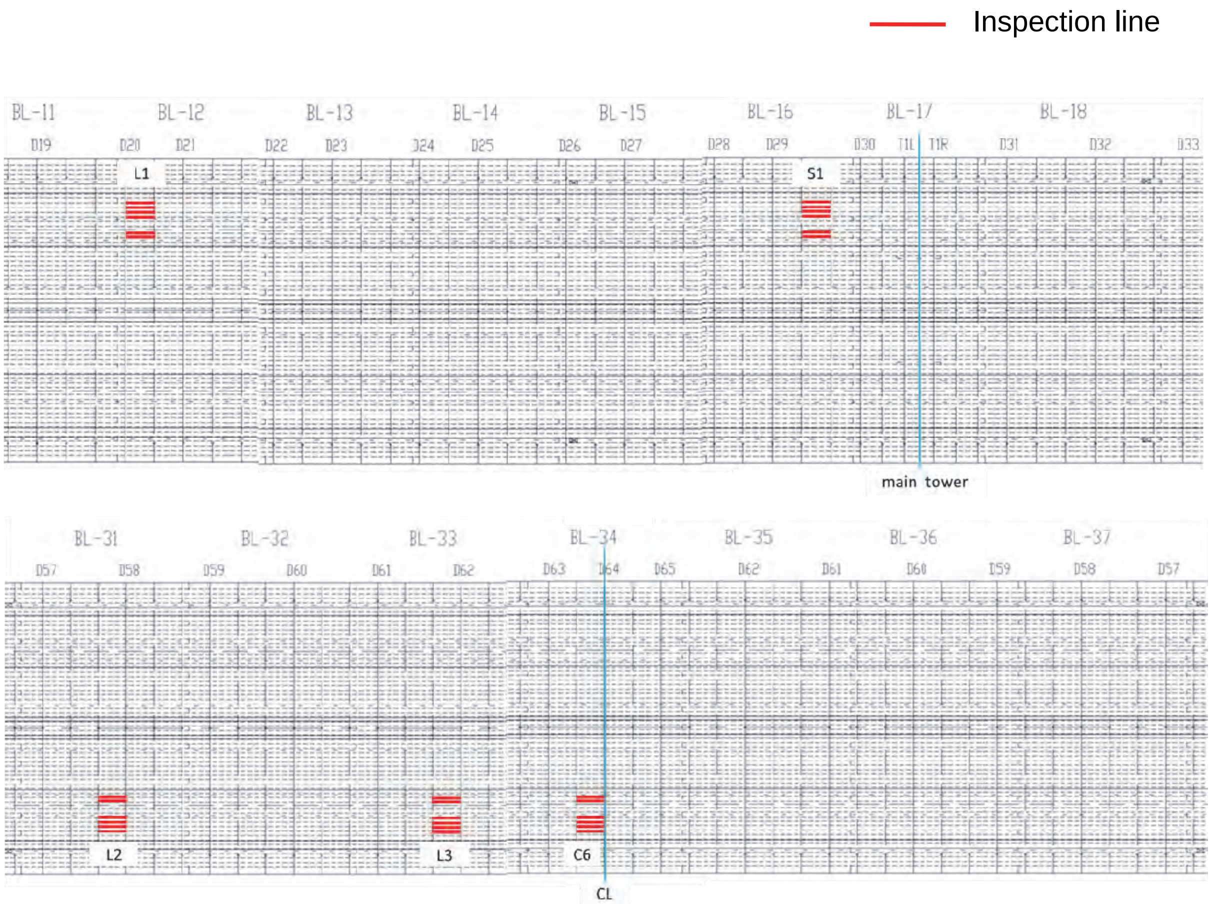


Figure 2.3.9 Location of UT Inspection of OSD

Photo 2.3.17 UT Inspection Work

(2) Results of Inspection

- There were no fatigue crack indications.
- Echoes from the corrosion on the surface were observed.
- It is possible to assume that the thicker the corrosion is, the stronger the density of the echo signal will be.

1) Inspection of fatigue cracks

There was no any indication of fatigue cracks. However, wide ranges of echoes were received in some areas.

Figure 2.3.10 Result of Inspection (No Echoes caused by a Crack or a Defect)

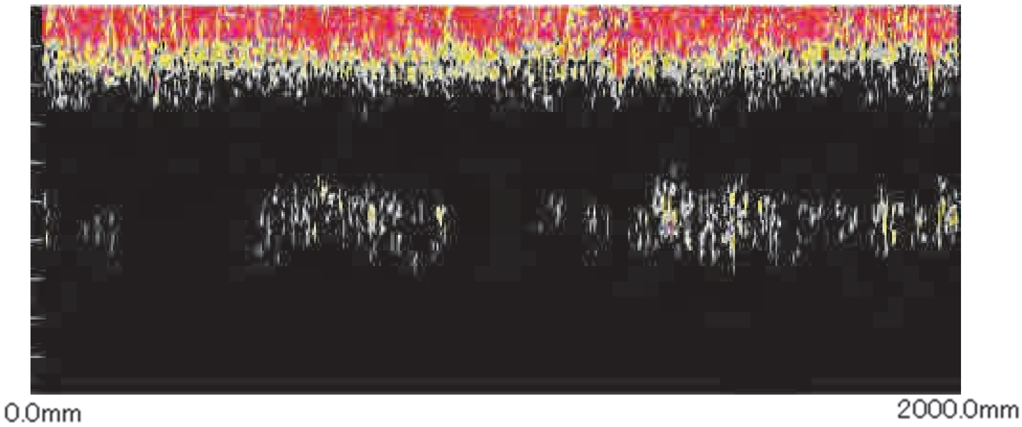


Figure 2.3.11 Result of Inspection (Corrosion on the Surface of Deck Plate)

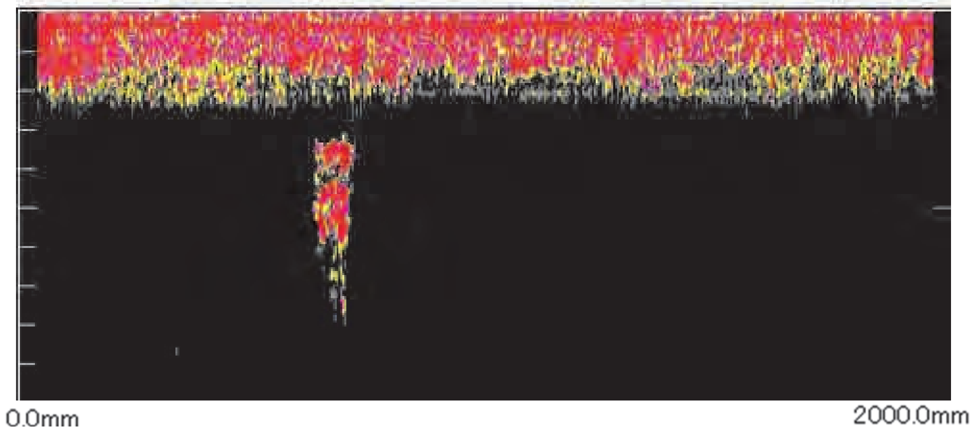


Figure 2.3.12 Example of Fatigue Crack Indication (Other Bridge)

2) Inspection of Corrosion

- Distribution of corrosion was inspected on two selected areas on the south west side. Results are shown in the appendix.
- 12 U-rib's weld line (length 2 m) between WTR63-1 and WD64 in the south side box girder.
- 12 U-rib's weld line (length 2 m) between WTR57-2 and WD58 in the south side box girder.

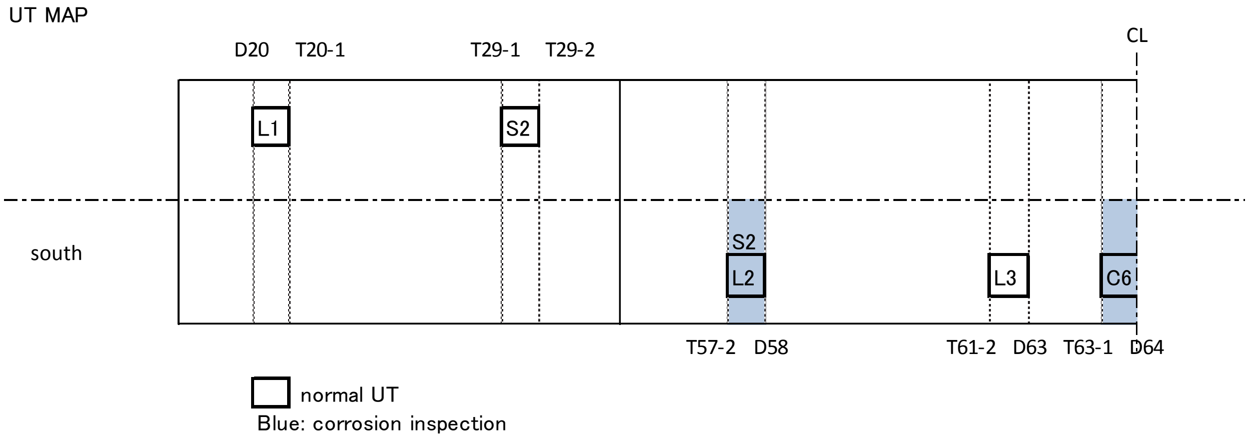


Figure 2.3.13 Location of UT Corrosion Inspection (Blue)

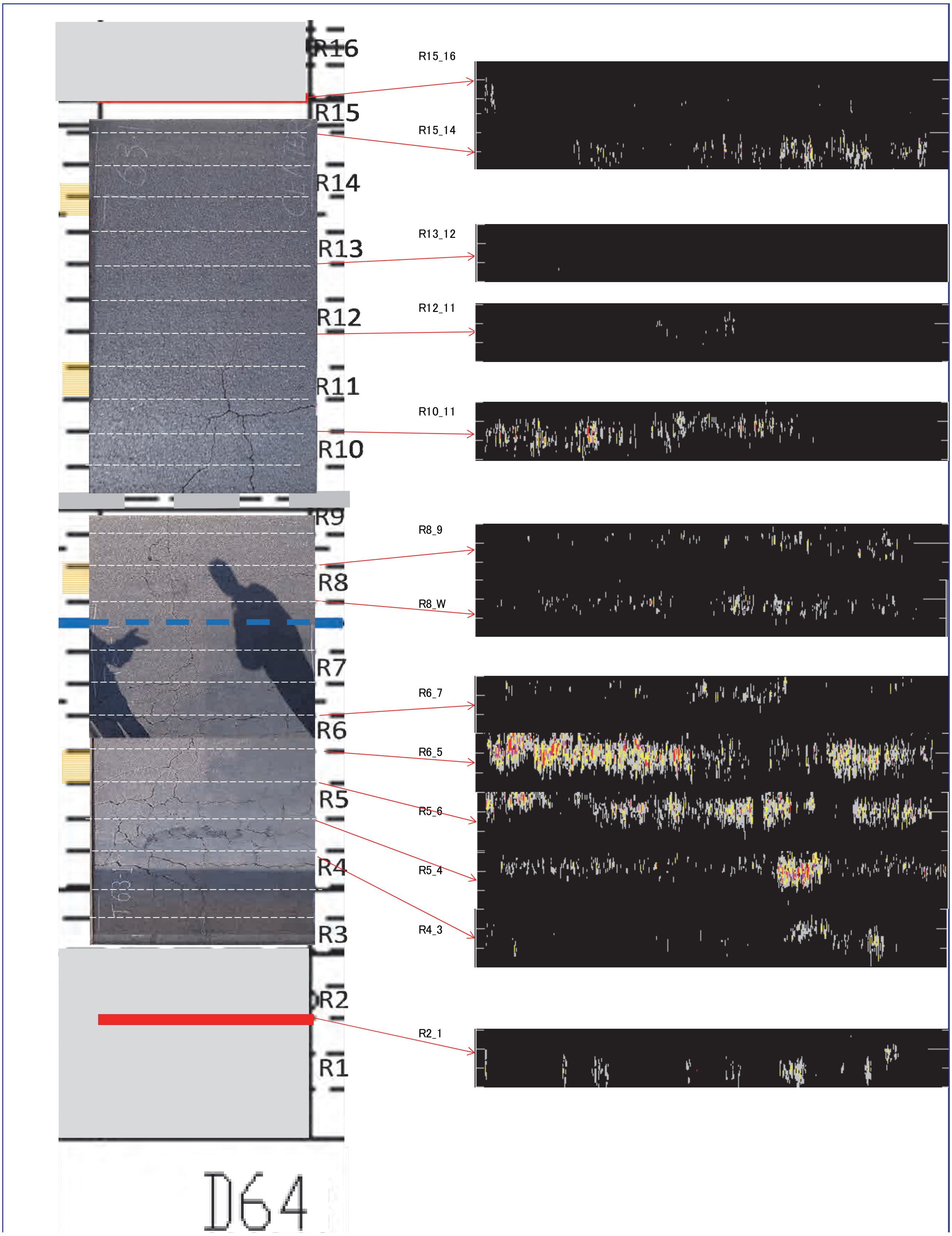


Figure 2.3.14 Pavement Crack Location and UT Signal of Corrosion (WTR63-1 to WD64)

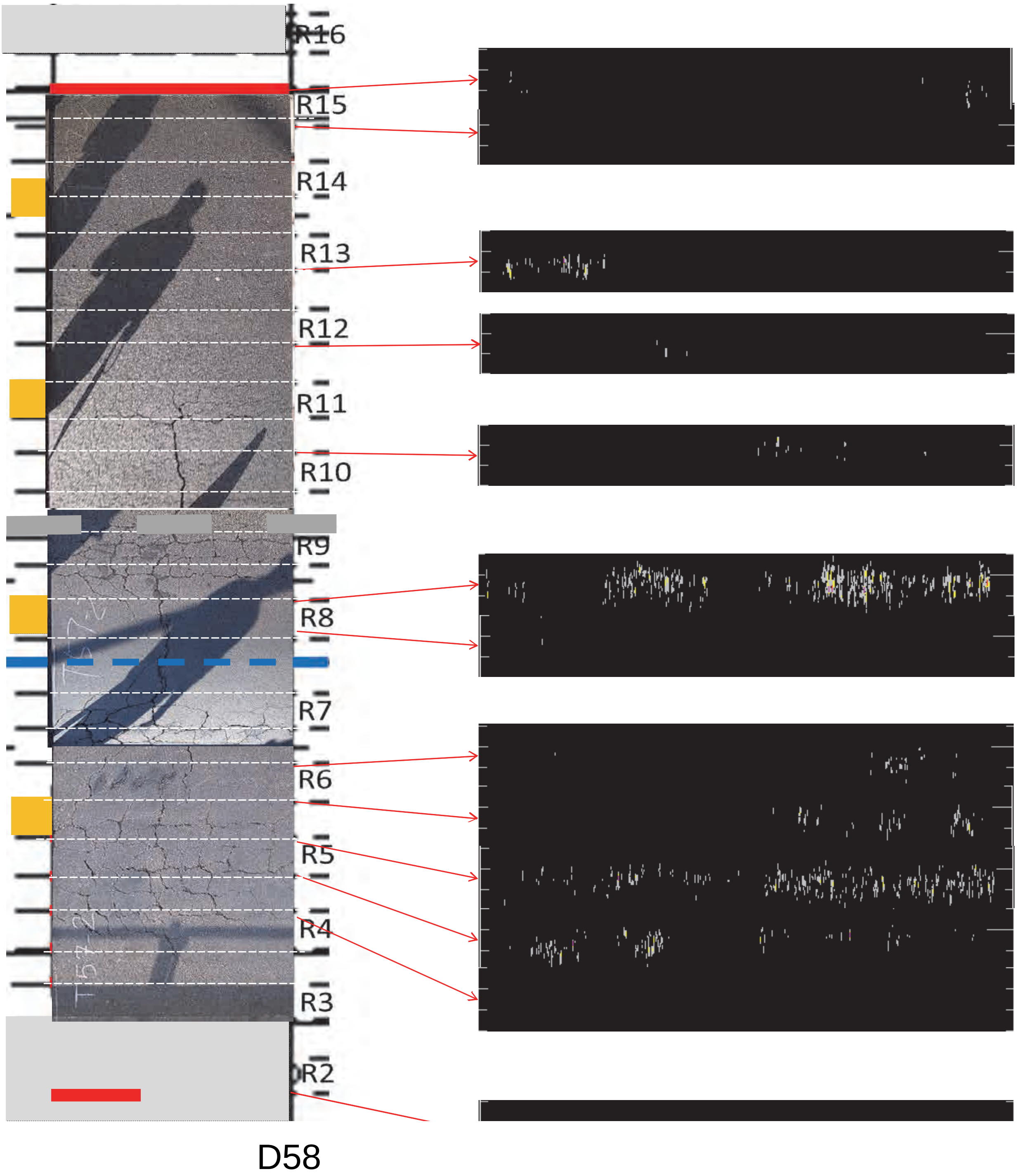


Figure 2.3.15 Pavement Crack Location and UT Signal of Corrosion (WTR57-2 to WD58)

(3) Comments

- By using UT, it is possible to detect deck plate penetrating cracks.
- These cracks are harmful for vehicles on the roadway because the penetration will cause cracks in the pavement and depression of the roadway might result.
- Distribution of corrosion parallel to the U-rib could be examined by using UT.

- By applying UT on several U-ribs in inspected areas, 2-dimensional maps of the corrosion can be obtained as shown in Figs. 2.3.14 and 15.

2.3.6 Inspection of Waste Deposit inside the U-shaped Rib

(1) Inspection Target

- Once cracks propagate and penetrate into the deck plate thickness, it is likely that soil, rust and water will also penetrate and remain inside the U-shaped rib.
- Hammer testing was carried out to detect such waste deposits inside the U-shaped rib.
- Hammer testing was carried out at the U-shaped ribs in 5 spots at which MT and UT had been already been applied. The location of hammer testing is shown in Figure 2.3.16.

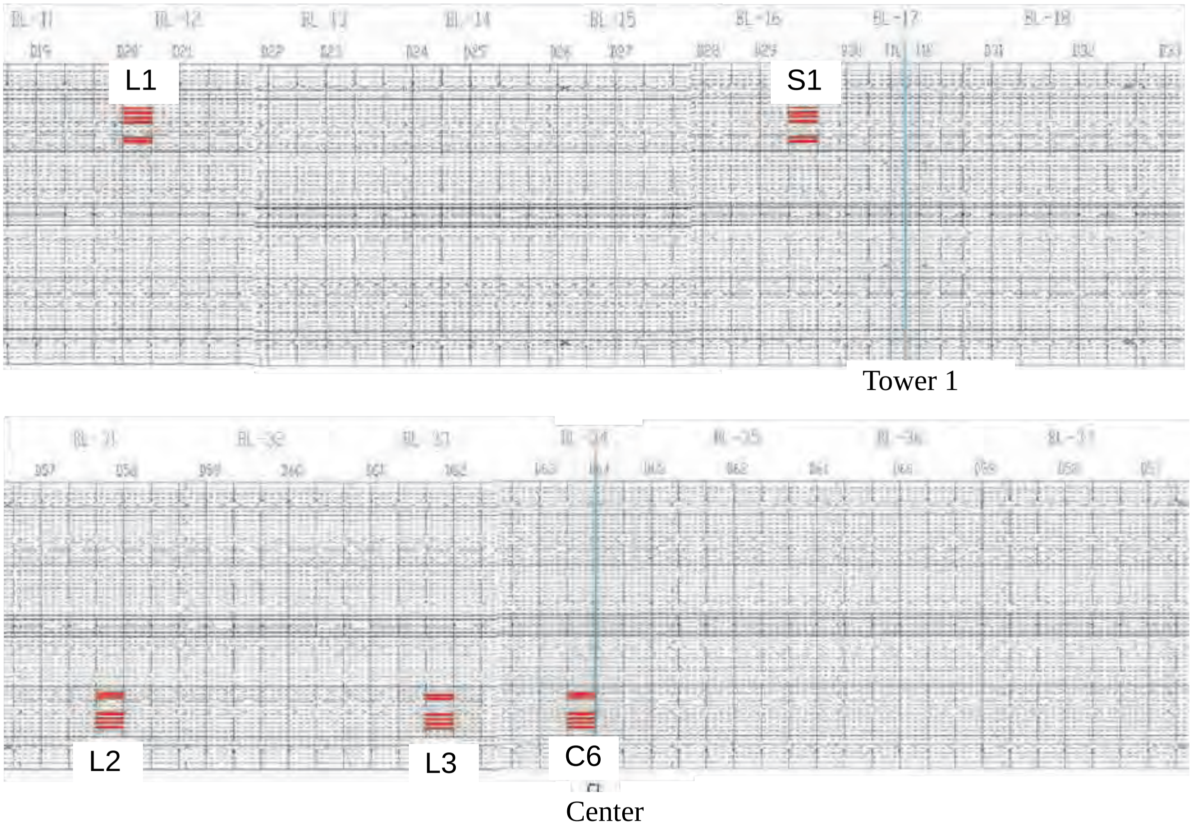
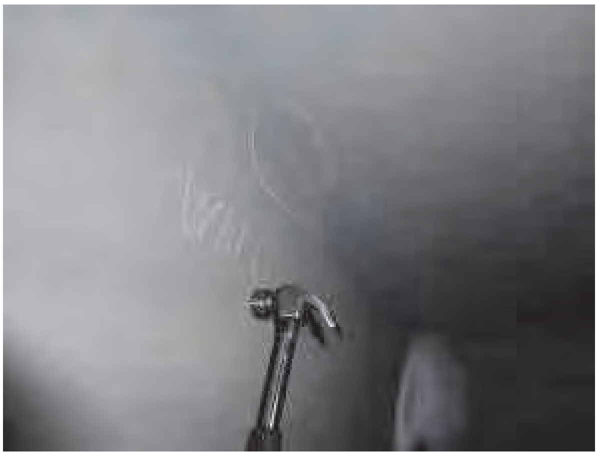


Figure 2.3.16 Location of Hammer Testing to Inspect for Waste Deposits Inside the U-Shaped Rib

L1 (D20 to TR20-1: Rib 6)

S1 (TR29-1 to TR29-2: Rib 6)



L3 (TR61-2 to D62: Rib 5)

Photo 2.3.18 Hammer Testing on U-Shaped Ribs

(2) Results of Inspection

- As a result of the hammer testing, no waste deposits were detected in any of the 5 spots.

Table 2.3.1 Hammer Testing Results

Location	Hammer Sound	Result
L1 (D20 to D21, R3 – R7)	Normal sound	No waste deposit
S1 (TR29-1 to D30, R3 – R7)	Normal sound	No waste deposit
L2 (TR57-1 to D58, R3 – R7)	Normal sound	No waste deposit
L3 (TR61-1 to D62, R3 – R7)	Normal sound	No waste deposit
C6 (D63 to D64, R3 – R7)	Normal sound	No waste deposit

(3) Comments

The hammer testing results indicate that no waste deposit remains inside and the deck plates have no crack penetration.

2.3.7 Temperature Measurement inside Steel Deck Girder

(1) Inspection Target

- This inspection included temperature and humidity measurements both inside and outside the girder. The measurements were carried out in the period from 29 November to 8 December 2011. The measurement points inside and outside the girder are NOB17 (GARBLT) and the surface of the cross beam at Tower 1, respectively.

- Temperature and relative humidity data inside the steel deck girder were summarized. These data were gained from measurements on 5 spots where the GARBLT took measurements for 4 months (June–October 2011). The locations of the measurements are shown in Figure 2.3.17.

- The temperature and humidity sensor used in this inspection was a *Thermal Recorder*, made in Japan. GARBLT has the same one.

-

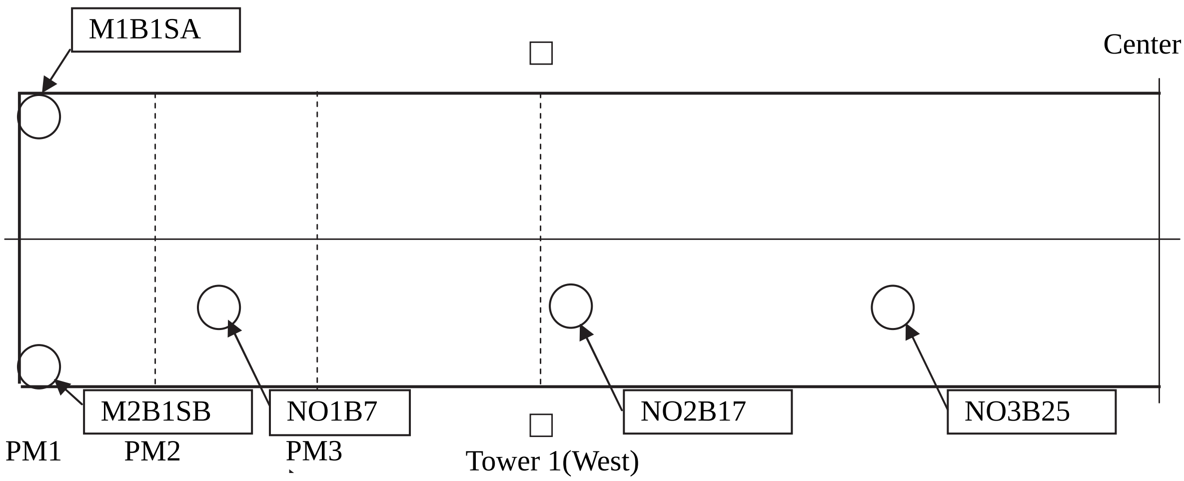
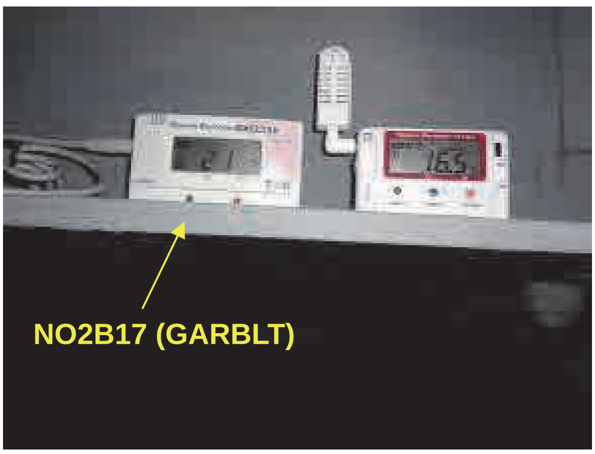


Figure 2.3.17 Location of Temperature and Humidity Sensors in the Girder (by GARBLT)



Inside of the Girder

Outside Girder on Tower 1

Photo 2.3.19 Temperature and Humidity Sensors (by Study Team)

M1B1SA

NO1B7

Photo 2.3.20 Temperature and Humidity Sensors (GARBLT)

(2) Results of Inspection

- This Study Team recorded that inside the girder, the highest temperature was 21.5°C, the lowest was 12.6°C, and the relative humidity was 23% at maximum.
- Outside the girder, the highest temperature was 20.7°C, the lowest was 11.5°C, and the relative humidity was 99% at maximum.
- GARBLT recorded that the highest temperature was 45.7°C and the lowest one was 19.3°C inside the girder. The relative humidity was 51% at maximum. The measurement period was 4 months, June–October 2011.

Table 2.3.2 Results of Temperature and Relative Humidity Measured in the Girder (Study Team)

Date (2011)	Maximum Temperature		Minimum Temperature		Maximum R. Humidity	
	Temperature	R. Humidity	Temperature	R. Humidity	Temperature	R. Humidity
Nov. 29-Nov. 30	**21.5** °C	7 – 9%	14.7 °C	16%	16.3 °C	19%
Dec. 1-Dec. 4	**21.5** °C	7%	15.0 °C	13 -16%	17.7 °C	22%
Dec. 8-Dec.12	20.2 °C	8 –10%	**12.6** °C	14%	14.3 °C	**23**%

Table 2.3.3 Results of Temperature and Relative Humidity Measured outside of Girder (Study Team)

Date (2011)	Maximum Temperature		Minimum Temperature		Maximum R. Humidity	
	Temperature	R. Humidity	Temperature	R. Humidity	Temperature	R. Humidity
Nov. 30-Dec. 1	18.4 °C	56%	12.1 °C	96-98%	13.1 °C	**99**%
Dec. 6-Dec. 8	**20.7** °C	35–36%	**11.5** °C	81%	12.0 °C	86%

Table 2.3.4 Results of Temperature and Relative Humidity Measured in the Girder (GARBLT)

Sensor Name (2011 Jun.-Oct.)	Maximum Temperature		Minimum Temperature		Maximum R. Humidity	
	Temperature	R. Humidity	Temperature	R. Humidity	Temperature	R. Humidity
M1B1SA	35.0 °C	14%	19.7 °C	29%	23.9 °C	50%
M2B1SB	36.3 °C	16%	19.9 °C	36%	21.1 °C	**51**%
NO1B7	**45.7** °C	6%	**19.3** °C	34%	20.3 °C	39%
NO2B17	42.0 °C	9%	20.3 °C	19%	21.4 °C	25%
NO3B25	44.8 °C	5%	19.9 °C	18%	24.8 °C	23%

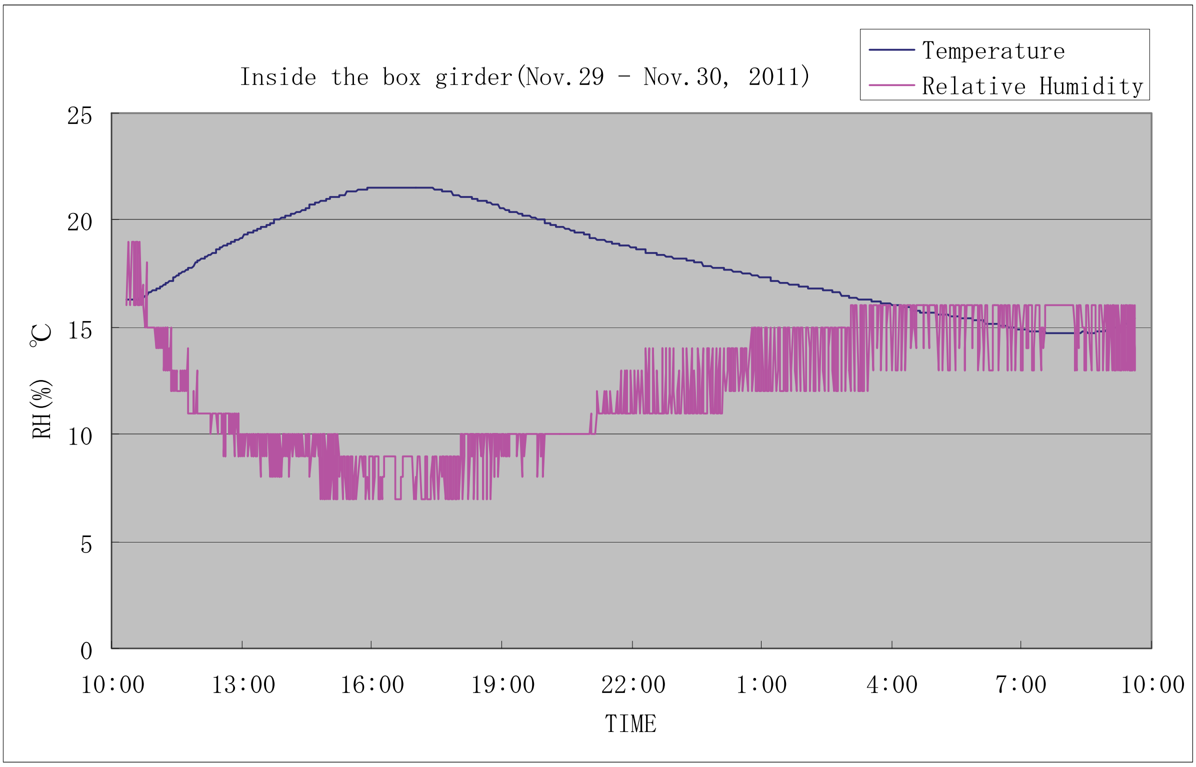


Figure 2.3.18 Temperature and Relative Humidity Data (Study Team)
(Inside of Girder, Nov. 29–Nov. 30, 2011)

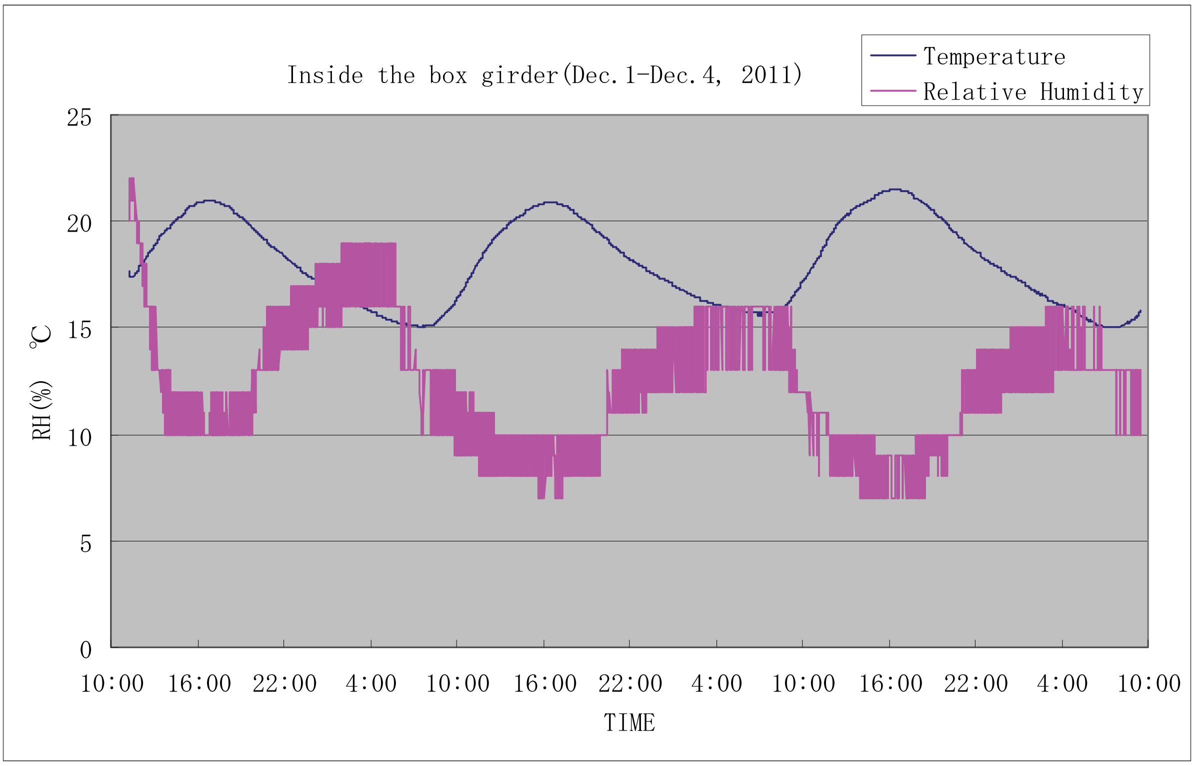


Figure 2.3.19 Temperature and Relative Humidity Data (Study Team)
(Inside of Girder, Dec. 1–Dec. 4, 2011)

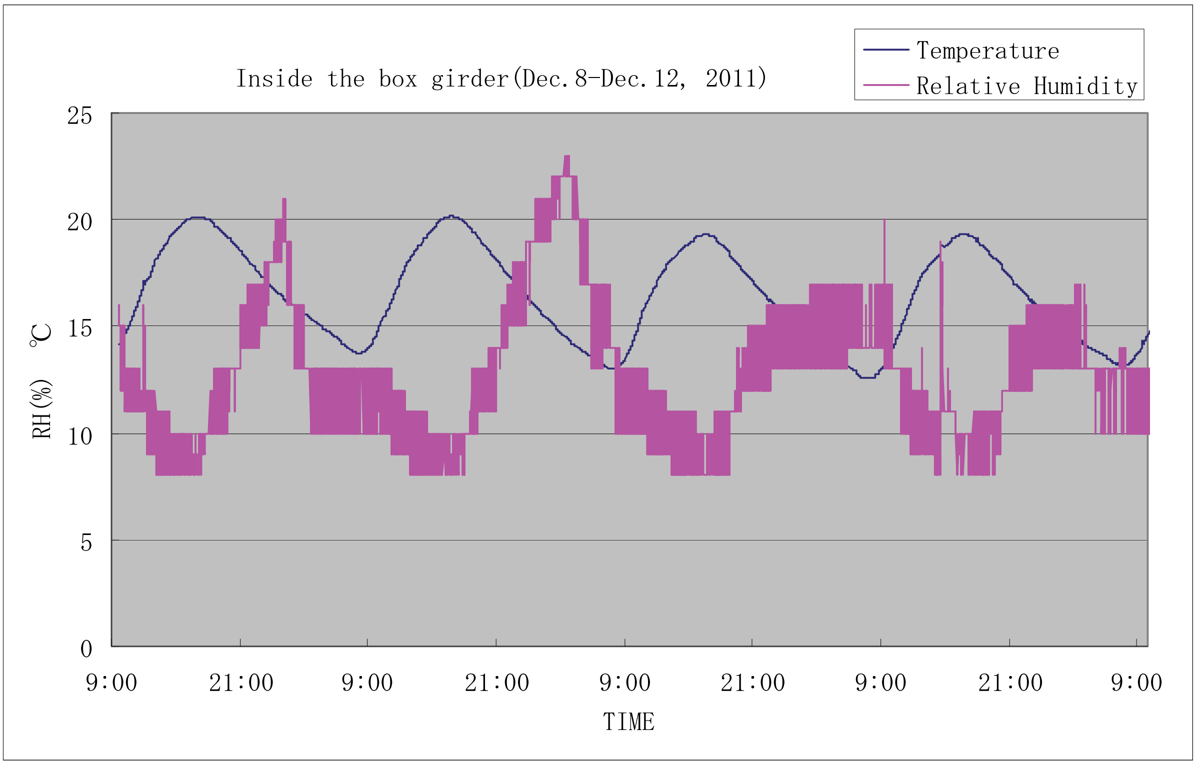


Figure 2.3.20 Temperature and Relative Humidity Data (Study Team)
(Inside of Girder, Dec. 8–Dec. 12, 2011)

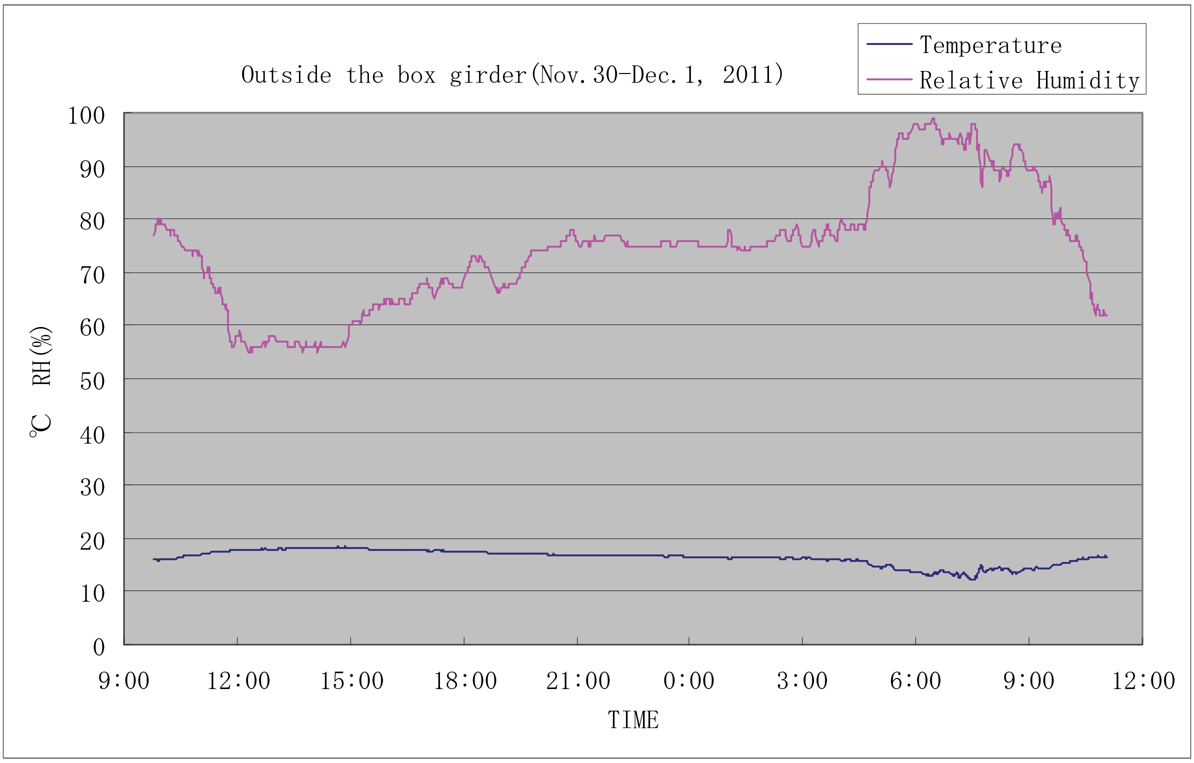


Figure 2.3.21 Temperature and Relative Humidity Data (Study Team)
(Outside of Girder, Nov. 30–Dec. 1, 2011)

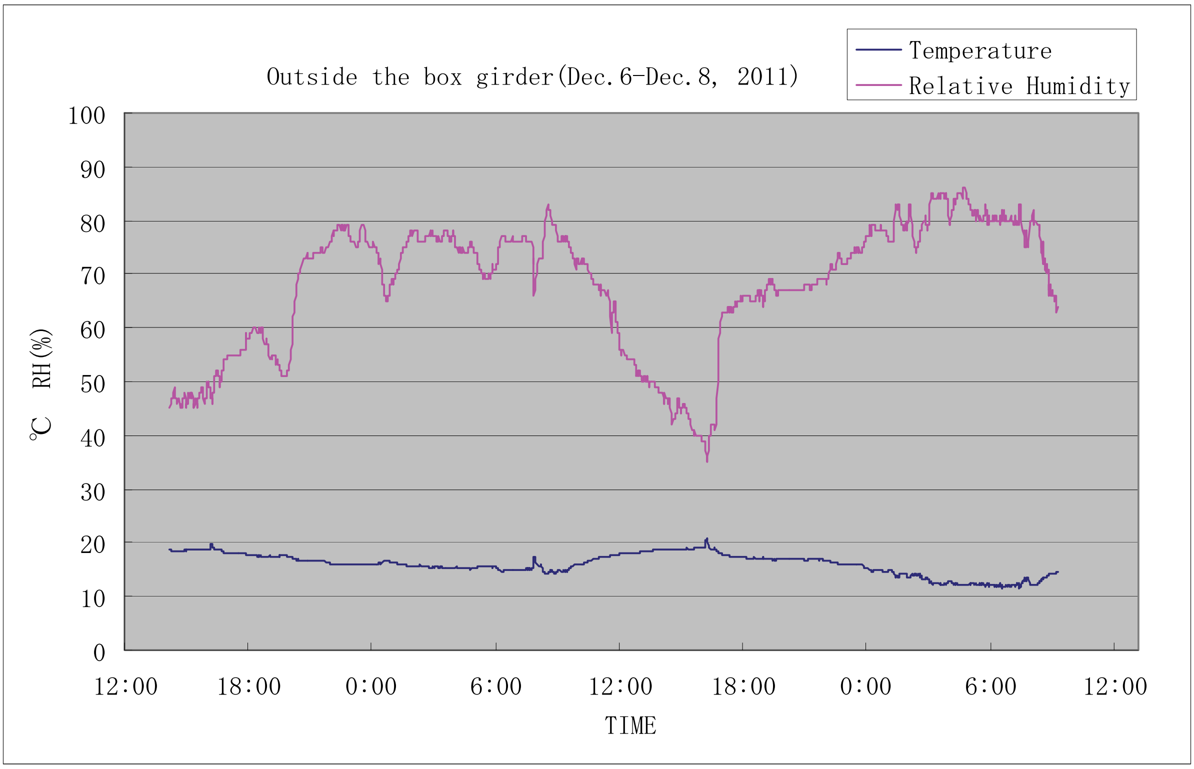


Figure 2.3.22 Temperature and Relative Humidity Data (Study Team)
(Outside of Girder, Dec. 6–Dec. 8, 2011)

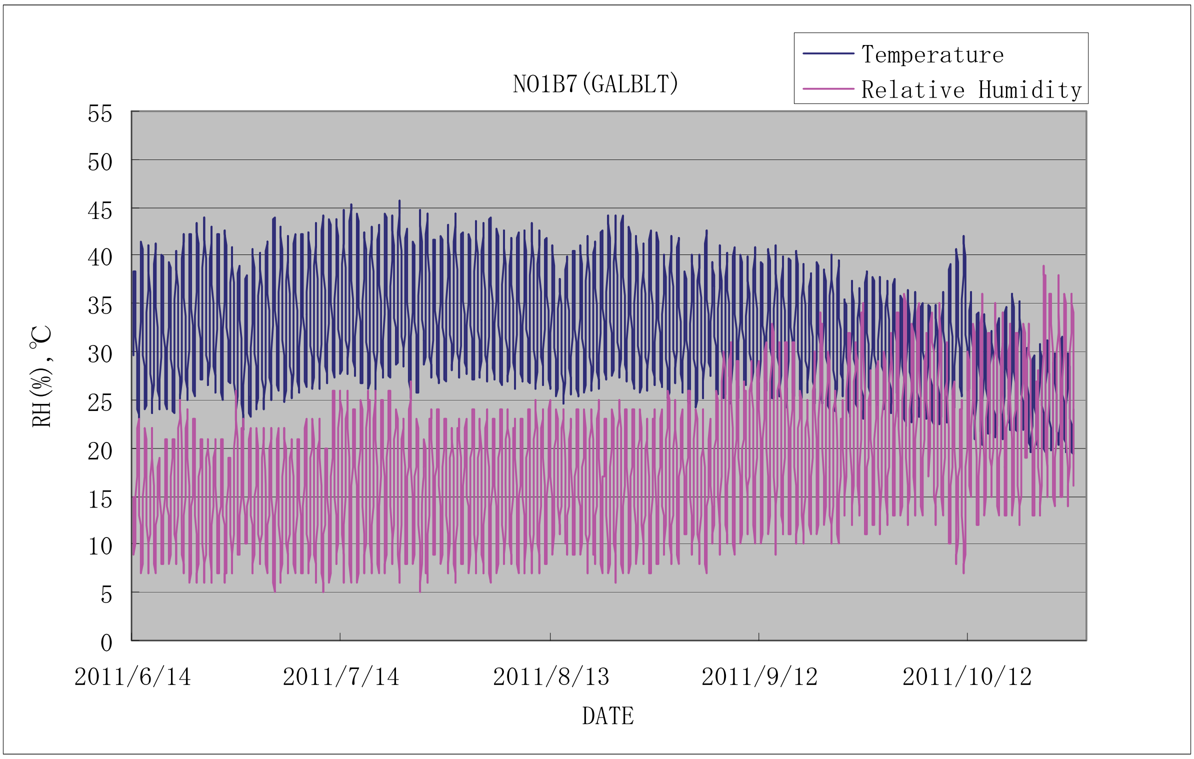


Figure 2.3.23 Temperature and Relative Humidity Data of NO1B7 (GARBLT)

(3) Comments

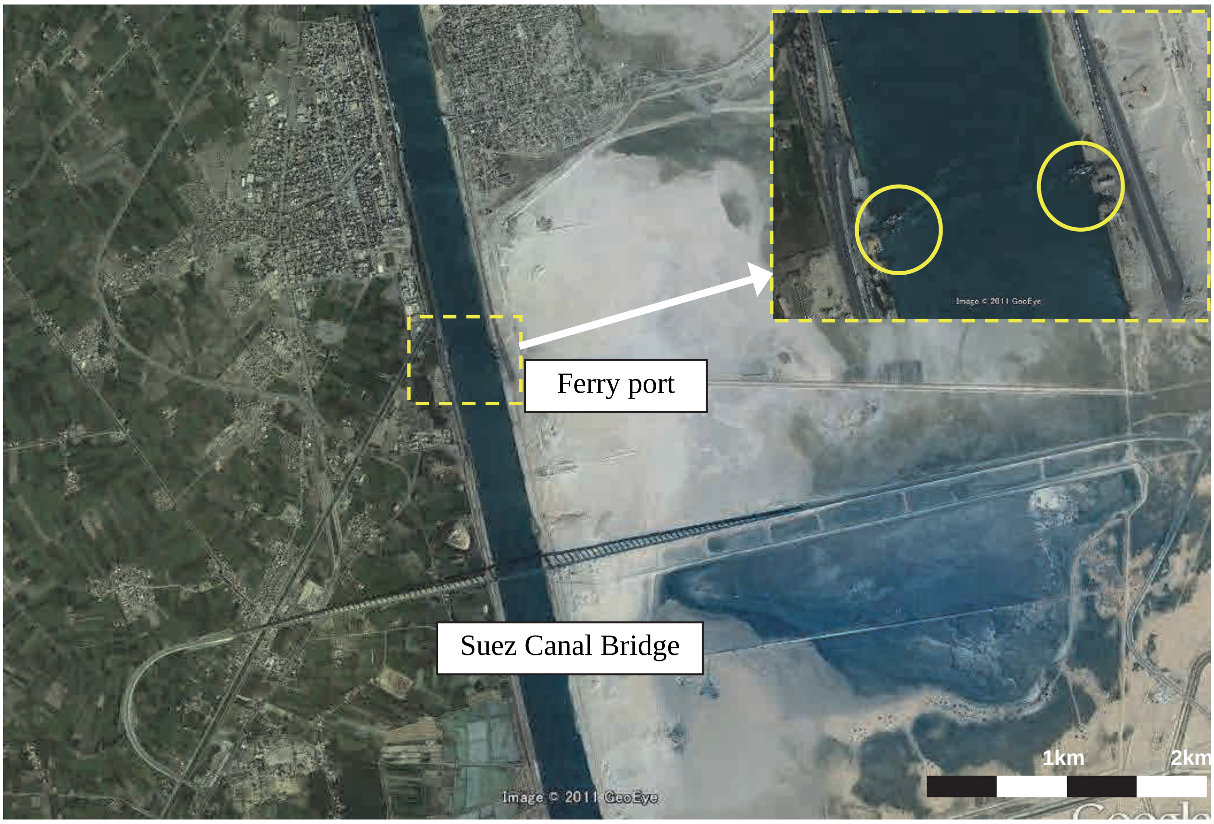
- The temperature inside and outside the girder varies from 12°C to 22°C when the lowest temperature is usually recorded in December every year. This means that the temperature difference is small. Moreover, the relative humidity inside the girder was below 23%. For this reason, it is hard for any dew condensation to occur inside the girder.

- The maximum relative humidity was recorded at 51% in 2011. This is below the 60% normally considered as the baseline of rusting, so the humidity state inside the girder is still good and no rust is expected.

2.4 Traffic Frequency and Limitation to Vehicle Weight

2.4.1 Traffic Frequency

There are two routes to cross the Suez Canal, one is this bridge, and the other is a ferry (toll free).



Source: Google Earth

Figure 2.4.1 Points to Cross the Suez Canal

Heavy trucks are waiting at the ferry port.

West-side of Port

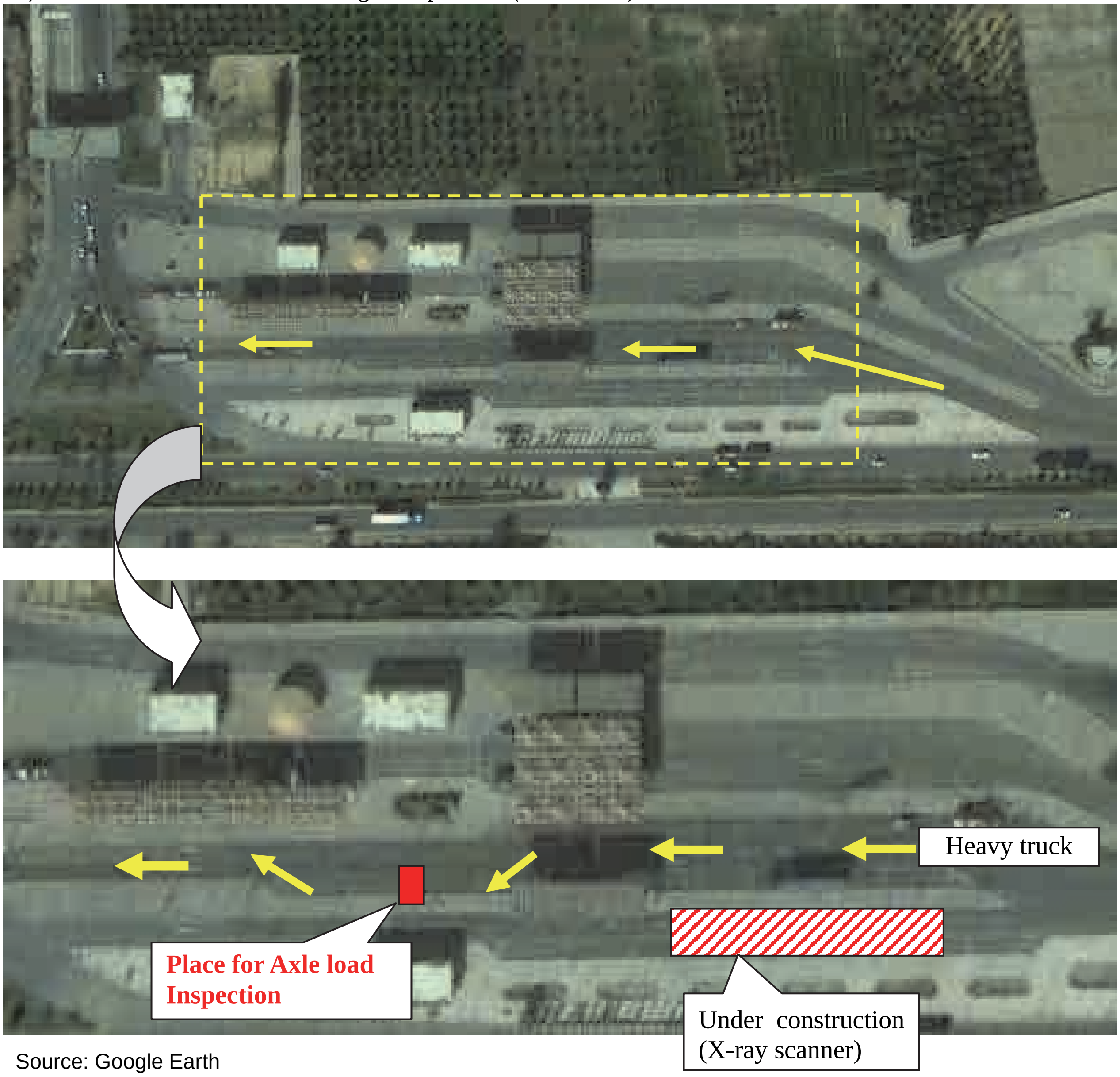
East-side of Port

Photo 2.4.1 Traffic Congestion at Both Port Sides

2.4.2 Limitation to Vehicle Weight

Since September 2002, axle loads of vehicles passing over this bridge have been limited to less than 13 tons. Vehicles suspected of excess axle load are measured with the load instruments that are placed near the toll gate. Then, overloaded vehicles are guided to the ferry port on the north side of the Bridge.

1) Current lane used for axle weight inspection (West Gate)



Source: Google Earth

Figure 2.4.2 Existing Lane for Axle Weight Inspection (West Gate)

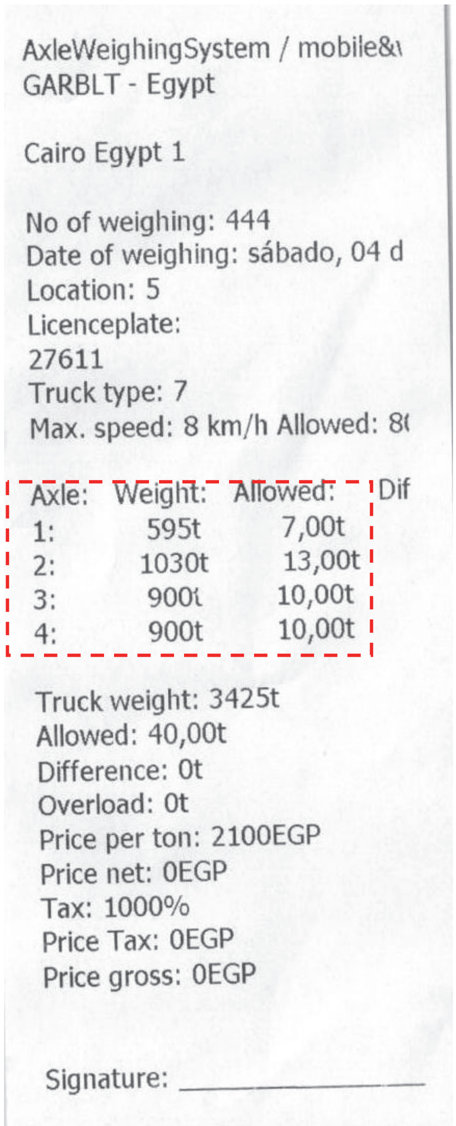
2) Inspection and inspection tools

Photo 2.4.2 Axle Weight Inspection and Portable Axle Weight Scale

Photo 2.4.3 Controller of Portable Axle Weight Scale

Photo 2.4.4 Printer of Portable Axle Weight Scale

Result
1st Axle: 5.95 t < 7.00 t ----O.K
2nd Axle: 10.3 t < 13.00 t ----O.K
3rd Axle: 9.00 t < 10.00 t ----O.K
2nd Axle: 9.00 t < 10.00 t ----O.K


AxleWeighingSystem / mobile&
GARBLT - Egypt

Cairo Egypt 1

No of weighing: 444
Date of weighing: sábado, 04 d
Location: 5
Licenceplate:
27611
Truck type: 7
Max. speed: 8 km/h Allowed: 8

Axle:	Weight:	Allowed:	Dif
1:	595t	7,00t	
2:	1030t	13,00t	
3:	900t	10,00t	
4:	900t	10,00t	

Truck weight: 3425t
Allowed: 40,00t
Difference: 0t
Overload: 0t
Price per ton: 2100EGP
Price net: 0EGP
Tax: 1000%
Price Tax: 0EGP
Price gross: 0EGP

Signature: ______________

Figure 2.4.3 Result Sheet (Sample) of Inspection

3) Current situation of axle weight inspection by GARBLT

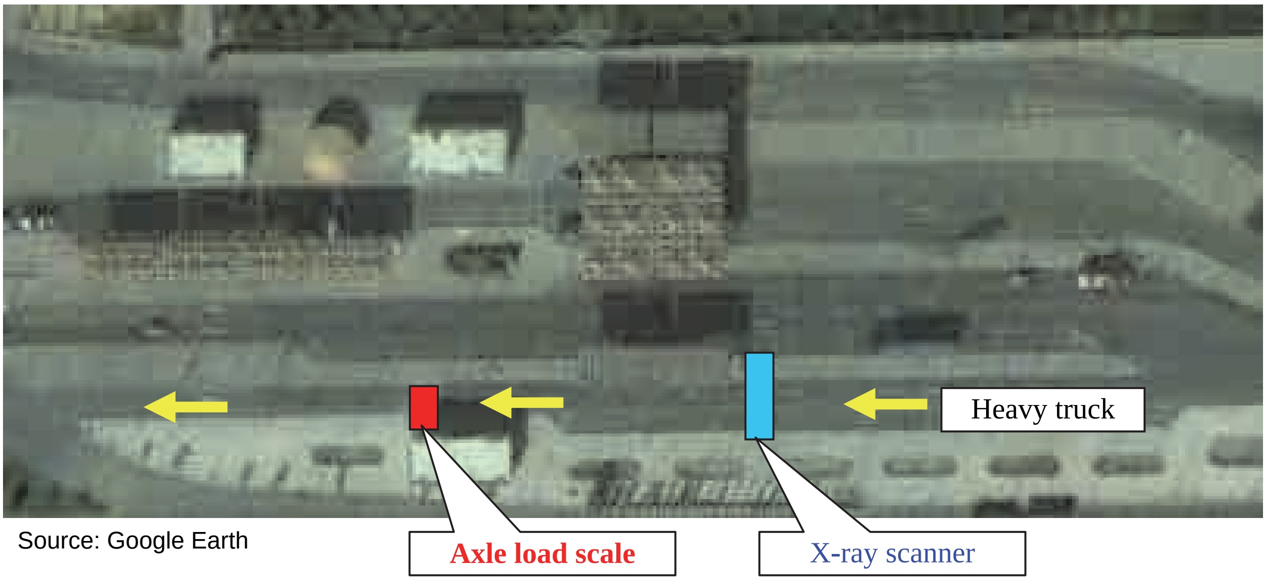
- Inspections are temporarily being implemented with portable scales on the roadside (because the freight scanner is under construction).
- 3 GARBLT staff work monitoring (24 hours/work in 2 shifts).
- Inspection time per vehicle is from 3 to 5 minutes on average.
- The eastern (Sinai) gate also works under the same system.
- According to an interview, trucks from the eastern side are heavier than those coming from the western side. The report in 2003 submitted after a defects liability inspection showed that most pavement cracks occurred in the outside lane on the north side. However, the outside lane on the south side had the most cracks (it is not known exactly why).

4) Comments

- The selection of heavy vehicles is executed by the judgment of GARBLT staff, but they are skilled in finding heavy trucks that are over axle load.

- According to the interview with GARBLT staff, overloaded vehicles have not entered the gate recently. This inspection has been implemented for a long time (heavy trucks are using the ferry to cross the canal).
- The toll fee for one large-sized truck is 10 LE. It is assumed that this is the reason why overloaded vehicles have not used the gate.
- After construction of the X-ray scanner, inspections will become more efficient.

The lane for the axle weight inspection after the construction of the X-ray scanner (west side) is shown below.



Source: Google Earth

Figure 2.4.4 Inspection Lane after the Construction of X-Ray Scanner (West Side)

Existing Axle Load Scale

X-Ray Scanner (Under Construction)

Photo 2.4.5 Equipment for the Inspection Lane (West Side)

2.5 Survey of the Configurations

A general view of the bridge was prepared based on the as-built drawings and measurements at the site.

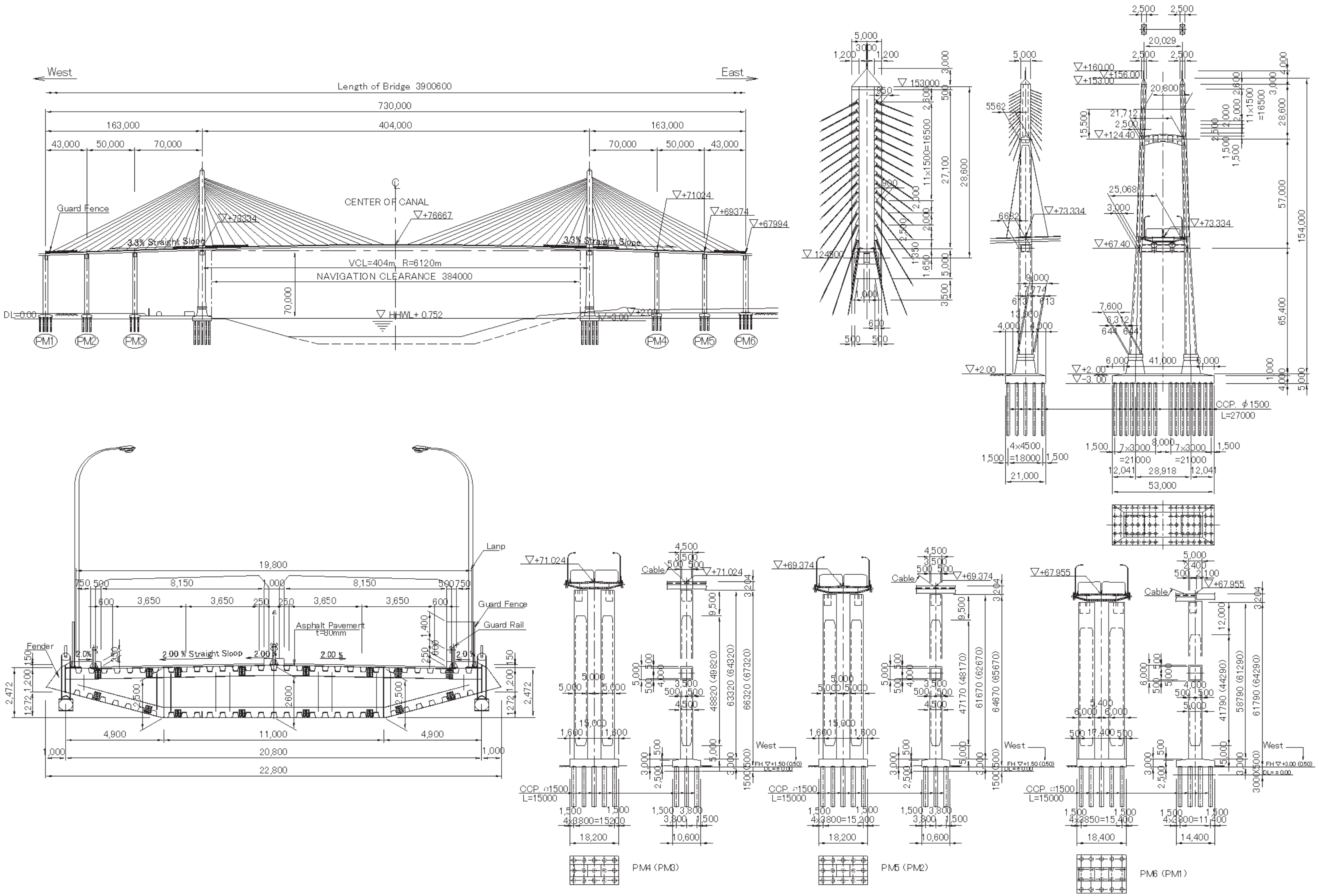


Figure 2.5.1 View of the Suez Canal Bridge

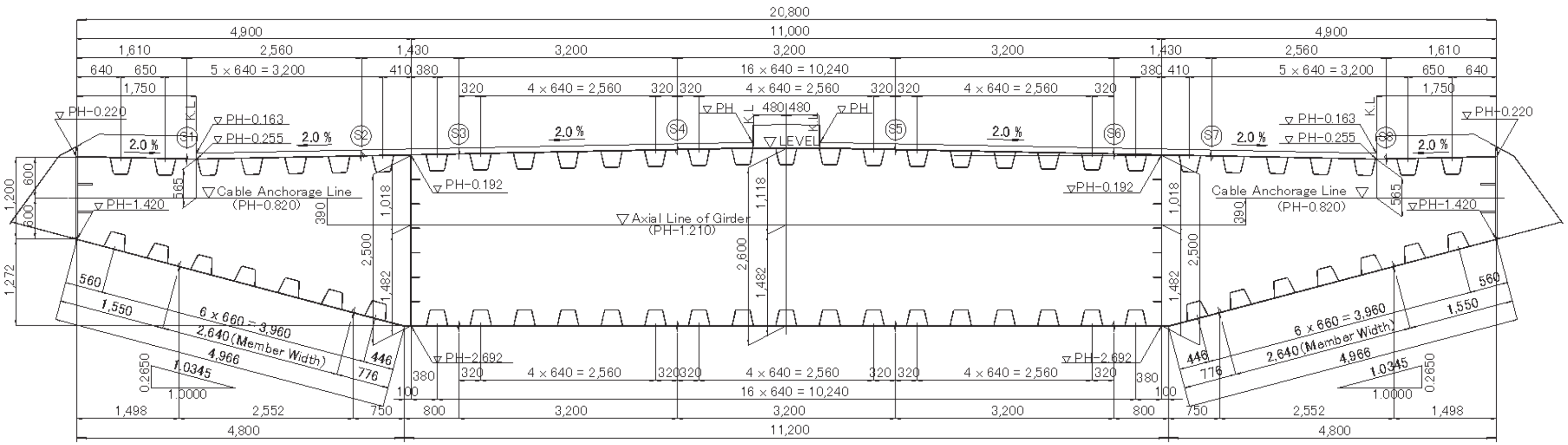


Figure 2.5.2 Standard Cross Section of Girder

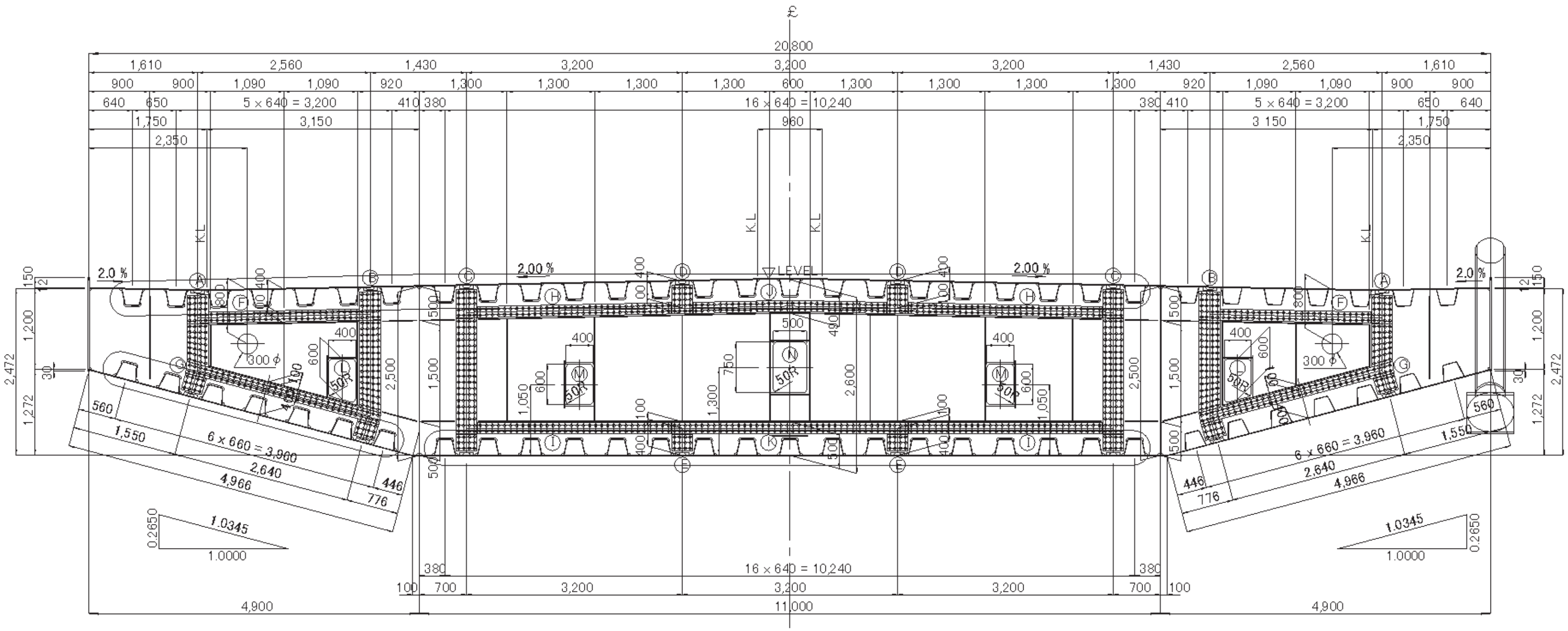


Figure 2.5.3 Standard Diaphragm of Girder

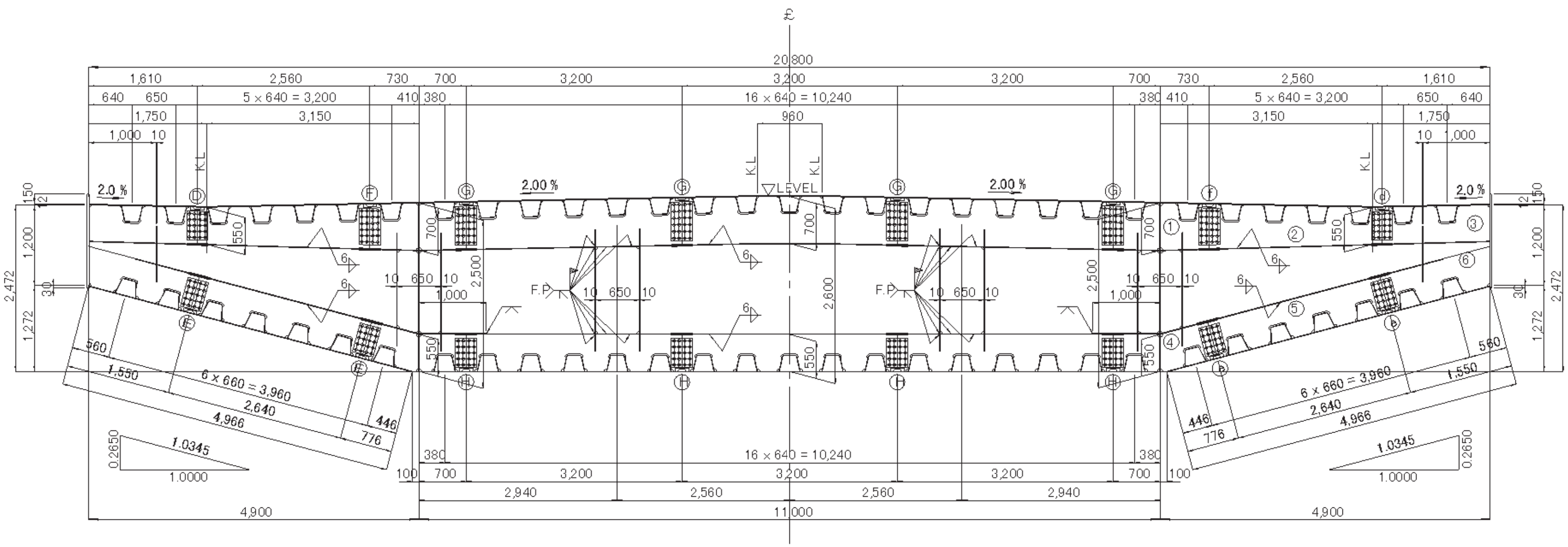


Figure 2.5.4 Standard Transverse Rib of Girder

2.6 Cause of damage

After opening the Bridge in October 2001, the ferry service, which was the only way to cross the canal, was cancelled in May 2002. Soon after that, cracks in the longitudinal direction were discovered in the westward lane. Interruption of the ferry service was thought to be the reason for the rapid increase of traffic volume of heavy vehicles passing over the Bridge, which might have caused the cracks.

In January 2002, The Contractor implemented the repair work of cracks and the defective liability period was extended for one more year. The limitation of vehicle axle load was changed to the more strict 13 tons from 17 tons in September 2002, and the ferry service resumed in January 2003.

In September 2003, after the inspection for defects liability of pavement was carried out, the Consultant submitted the analysis report of pavement cracks, and then GARBLT accepted it.

The report stated:

It is assumed that the passage of overloaded vehicles caused cracks

The continuation of limitation of vehicle axle load and further proper maintenance would keep the sound function of the bridge, without the implementation of re-pavement.

In addition, the repair material, which was deemed necessary during the three years up to September 2006, was given to GARBLT by the Contractor. GARBLT implemented the repair work by themselves after the defects liability period.

After that, GARBLT continued the repair work at a once-a-year pace. After the donated material was consumed, a variety of materials were purchased and injected into the cracks. However, a sufficient effect was not seen, and cracks seemed to develop further.

After the defects liability period, GARBLT continuously carried out repair work on hairline cracks, which were caused by the passage of overloaded vehicles under uncontrolled axle load limitations soon after bridge inauguration. However, because these measures by GARBLT were insufficient, the crack width and depth worsened. Moreover, rainwater penetrated into those cracks and the waterproof performance in the bonding layer was lost. This deterioration made more cracks develop.

Corrosion of steel deck plate: It is considered that the cause of corrosion was insufficient repair work depending on the extension range of the cracks, which were caused by over-limit-loaded vehicles

2.7 Procurement Condition, Construction Cost Survey and Construction Order Procedures

2.7.1 Status of Contractors in Egypt

Construction companies have been classified from 1st to 4th class based on the status of finance, numbers of employees and experience that they have. There are 13 major Egyptian companies that are classified as 1st class and have experience on bridge and pavement projects. From the viewpoint of the scale and difficulty of the repair pavement work of the Bridge, bidding requirements to be applied for 1st class construction companies shall be set. On the other hand, there is no record of projects using the guss asphalt method (which is the selected repair method mentioned on Chapter 5 REPAIR WORK PLAN) in Egypt, and no knowledge of the method in Egyptian construction companies. Therefore, the technical assistance shall be provided from Japan or Germany, which have accumulated technology on the guss method.

2.7.2 Procurement Condition and Construction Cost Survey

The procurement condition of the selected repair method is mentioned as follows;

- ✓ Natural materials such as aggregate, crushed stone, sand and stone powder for normal asphalt mixture are well traded in Egypt and are easily procured from local contractors or traders.
- ✓ Straight asphalt bitumen (penetration 60/70) can be easily procured from local traders selling petroleum products, but straight asphalt bitumen (penetration 40/20) used in the guss asphalt mixture shall be imported because it is neither produced nor traded in Egypt.
- ✓ Trinidad-lake asphalt (TLA) is indispensable natural material to make a guss asphalt mixture. The TLA shall be imported because it is produced only on Trinidad Island in the Republic of Trinidad and Tobago, an independent country in the British Commonwealth Caribbean in Central America.
- ✓ Cutback asphalt, which is generally used as the asphalt emulsion for the tack-coat, is well traded in Egypt.
- ✓ A surface layer will be applied to the dense-graded modified asphalt, which is suitable for steel deck plates. Modified additive shall be imported from Japan and other countries, as it isn’t traded in Egypt.
- ✓
- ✓ Dissolved-type rubber-asphalt used as a bonding layer for the guss asphalt method shall be imported, as it isn’t traded in Egypt.

As for construction machines, versatile machines can be procured in Egypt; however, special machines used for shot-blasting and guss asphalt shall be imported from Japan and other countries.

2.7.3 Process of Order of Repair Construction Project

After the coup of January 2011, a new presidential election was conducted in May 2012. Since then, the political situation has been generally advancing towards stability. However, the financial situation of Egypt has become increasingly severe due to the sharp decline in thorium revenue as a major income resource. As a result, difficult conditions to secure financial resources for projects on road construction and rehabilitation have continued. However, the government and related authorities are fully aware of that the bridge crossing the Suez Canal is one of the most important existing transport infrastructures, and they are aiming for early implementation of pavement repair work.

After submission of the selection of repair method, summary project cost and draft tender documents from the Survey Team, GARBLT started preparation related to the bidding for Egyptian contractors, aiming to start the pavement repair construction in the first half of this year (2013) at the earliest.

CHAPTER 3 TEMPORARY INJECTION WORK FOR MAJOR CRACKS AND INSTALLING MONITORING DEVICE

3.1 Propose of Temporary Injection Work for Major Ckracks

While the repair work for the damaged asphalt pavement on the Bridge is expected to be ordered based on the results of the report of the Study, the current damage condition is expected to advance during the period until the repair construction project is order. In order to suppress the progression of the damage until repair work is commenced, temporary injection work into the cracks using hot-type sealing material was conducted at the time of the 1st site investigation.

3.2 Selection of the Injection Material

As appropriate material, CETOKOL 200 of CMB was adopted with the following specifications:

- Penetration 25°C – Cone: 10 – 30 mm
- Softening Point: > 95°C
- Flow Resistance (Plate): < 5% (60°C x 5 hours)
- Specific Gravity: 1.1 – 1.2 kg/liter
- Extension Test: Pass (3 cycles of 50% 25°C)
- Appearance of Material

Photo 3.2.1 Appearance of Material for Injection

CMB
www.cmbgroup.org

CETOKOL 200

Advanced system for joints highway brid es

Description :-

*Cetokol 200 joint is an advanced system for providing mo ement joints in highway bridges .

*Cetokol 200 joint is a combination of rubberised bitume binder and carefully selected aggregate , the joint is constructed in situ sing the hot process .

Advantages :-

*High flexibility and complete water tightness .

*High resistance to longitudinal , transversal and rotationa novement .

*Provide a good riding surface without further treatment .

*It can be covered with the road surfacing materials .

*It can be easily and economically repaired or replacec in case of accidental damage without causing damage to the adjacent rc d surfacing .

*Longitudinal and transversal drainage tubes can be easily p ced during joint construction .

Properties of Cetokol 200 :-

Cetokol 200 is rubberised bitumen binder which is mixed w h specially selected single size hard aggregate to ensure high binder ontent and optimum combination of flexibility and load bearing capacity

Cetokol 200 binder has the following properties :-

*Pentration 25 ° C –Cone	: 10-30 dmm
*Softening point	: ≥ 95 ° C
*Flow resistance (plate) 60 ° C x 5 hours	: < 5 %
*Specific gravity	: 1.1 - 1.2 kg/Lit
*Extension test 3 cycles of 50 % 25 ° C	: pass

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E.mail : cmb@cmbegypt.com

Figure 3.2.1 Material Data Sheet

3.3 Implementation of Injection Work

Procedures for the injection work are as follows:

3.3.1 Melting of injection material

Photo 3.3.1 Injection Material in Hot Tank for Melting

3.3.2 Cleaning inside of cracks

Photo 3.3.2 Cleaning Inside of Cracks with an Air Compressor and Wand

3.3.3 Injection into cracks

Photo 3.3.3 Injection Work

3.3.4 Sprinkling cement powder

Photo 3.3.4 Sprinkling Cement Powder after the Injection Work

3.4 Installing a Monitoring Device for Water Exposure on the Surface of Steel Deck Plate

3.4.1 Objective

According to the results of an investigation on the soundness of pavement, the cracking problem has become serious on all the pavement on the steel deck plate. Boring into pavement to see the state of the interior has revealed water congestion and much corrosion on the steel deck plate. This indicates it is highly possible that the cracking problem may enable water to permeate into the pavement and further cause severe corrosive damage. So, it is necessary to figure out visually how much water comes into the pavement and stays on the surface of the steel deck plate by cutting open part of the pavement on which cars are usually not running.

3.4.2 Monitoring Device

- Do not scratch or damage the surface of the steel deck plate when drilling.
- Do scrapping on the surface of the steel deck plate exposed in the drilled hole and glue a waterproofing sheet or apply a waterproofing coat to form a waterproof layer.
- Insert a PVC (Polyvinyl Chloride) pipe, VP 100 mm, sized at 105 mm for outer diameter, and 100 mm in length, onto the waterproof layer after drilling four small holes — semicircle with approximately 10 mm in radius — to allow for water drainage at the bottom of the pipe.
- To prevent water intrusion, attach an end cap onto the top of the pipe. The cap can be opened and closed by screwing or a similar action.
- Seal up the gap around the top of the pipe and fill it with the sealant material to stop water intrusion due to rain.

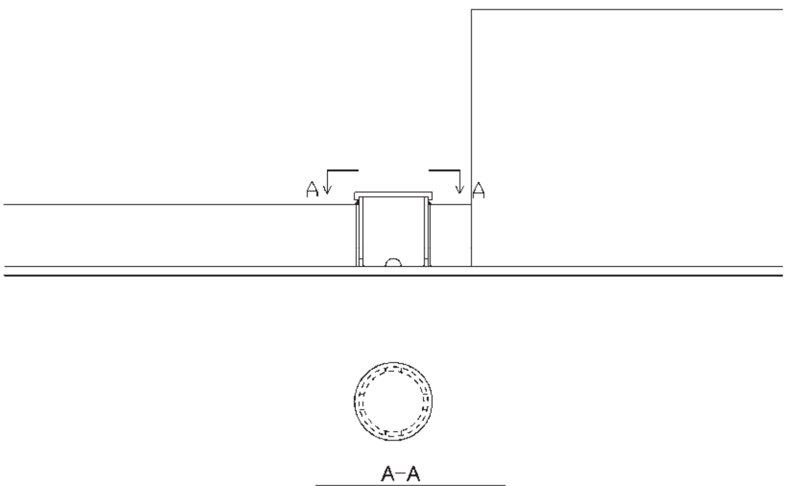


Figure 3.4.1 Monitoring Device for Water Exposure on the Surface of Steel Deck Plate

3.4.3 Procedure of Installing Monitoring Device

Photo 3.4.1 Elementts and Material of Monitoring Device

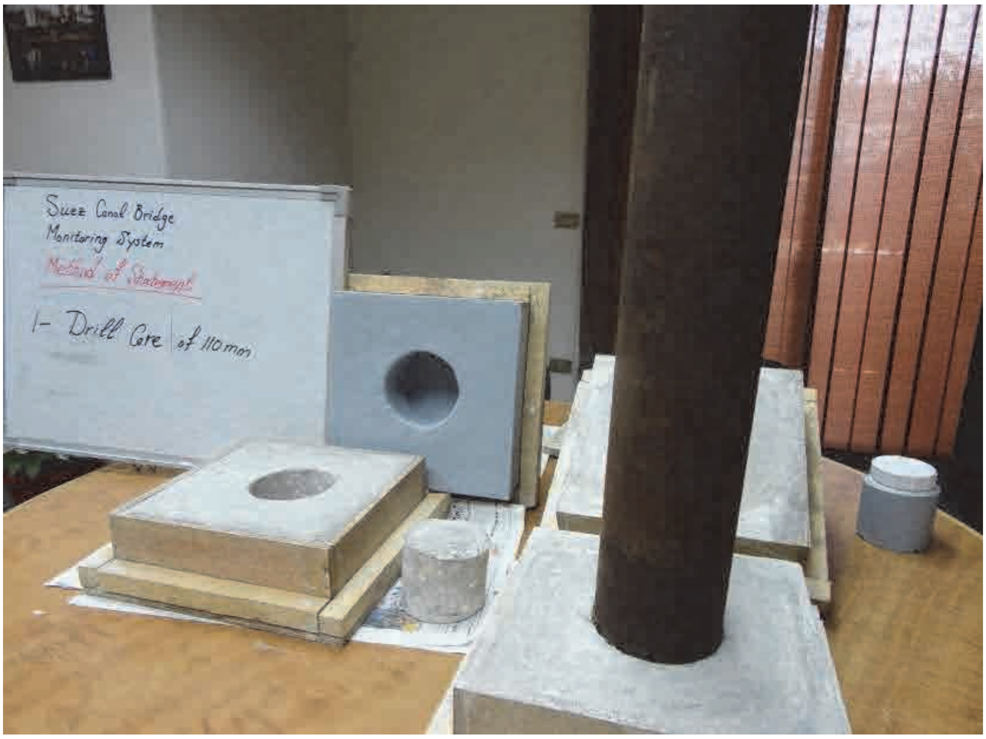


Photo 3.4.2 Drilling Hole with Diameter 110 mm

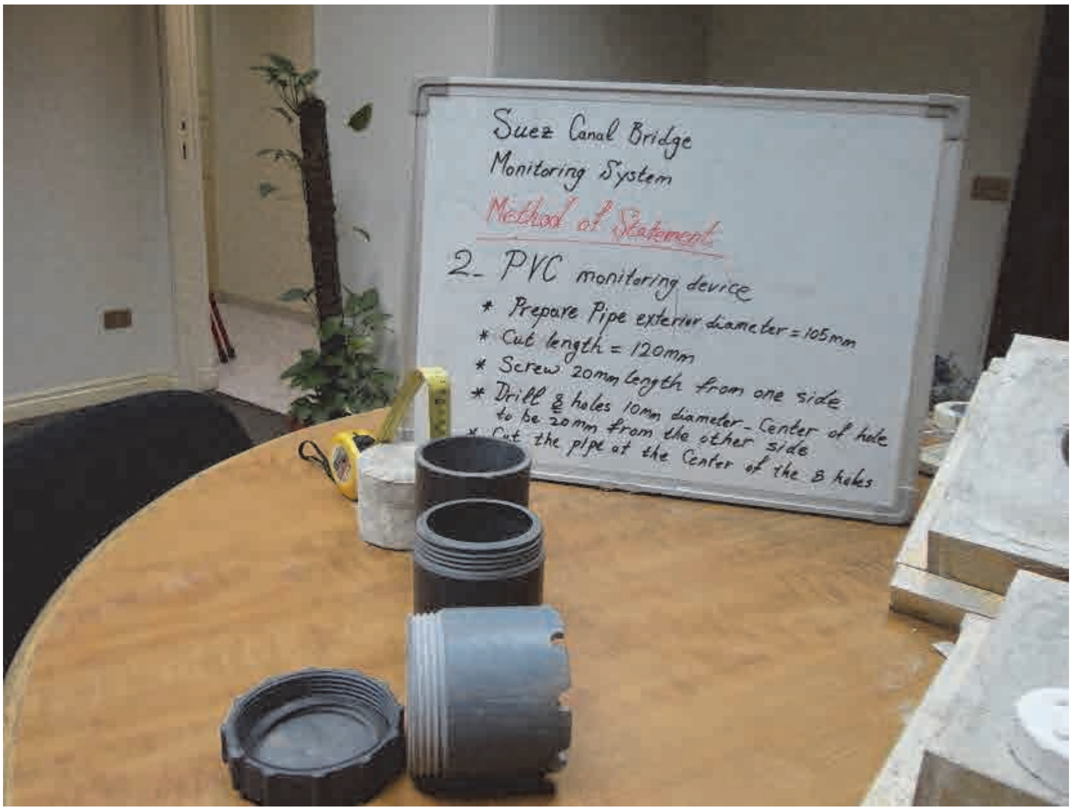


Photo 3.4.3 PVC Pipe with Diameter 105 mm

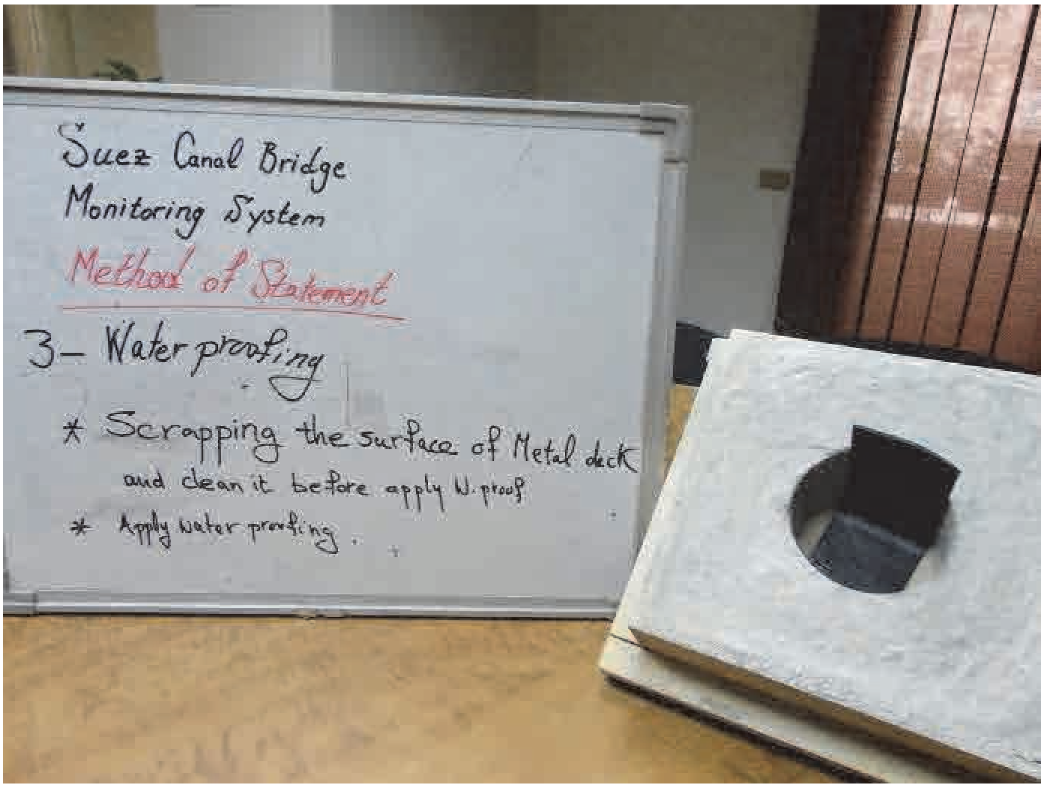


Photo 3.4.4 Setting Water Proofing on the Surface of Steel Deck Plate

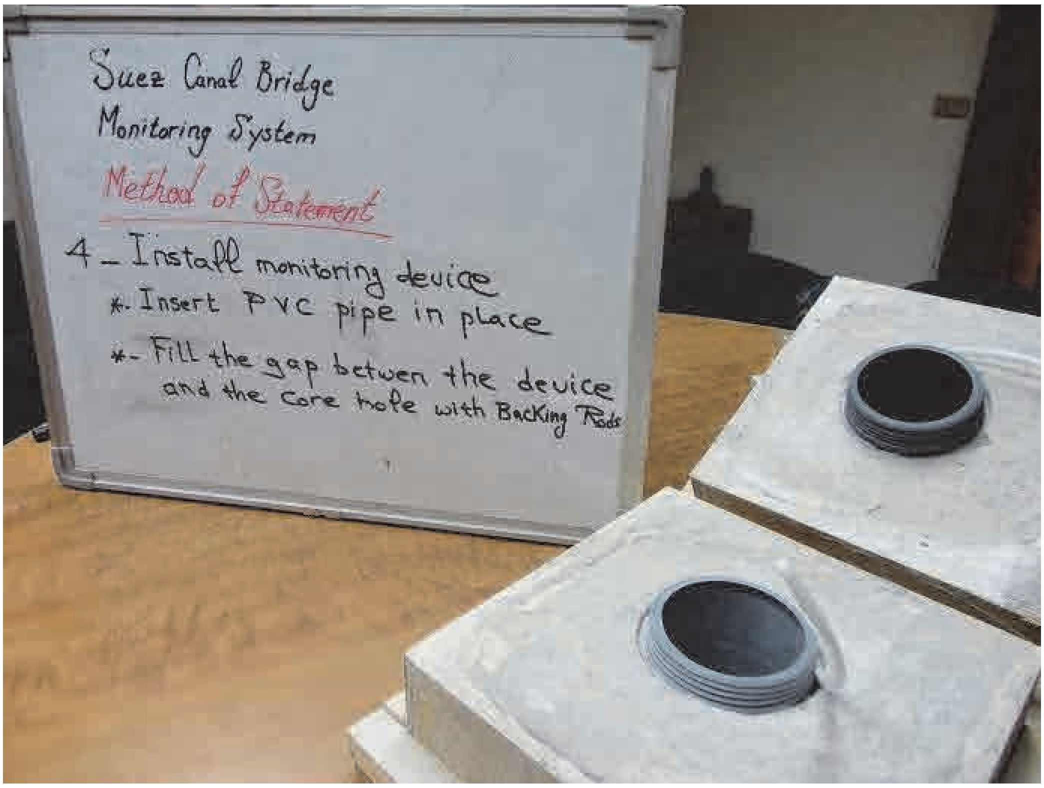


Photo 3.4.5 Seal up Gap around the Top of the Pipe

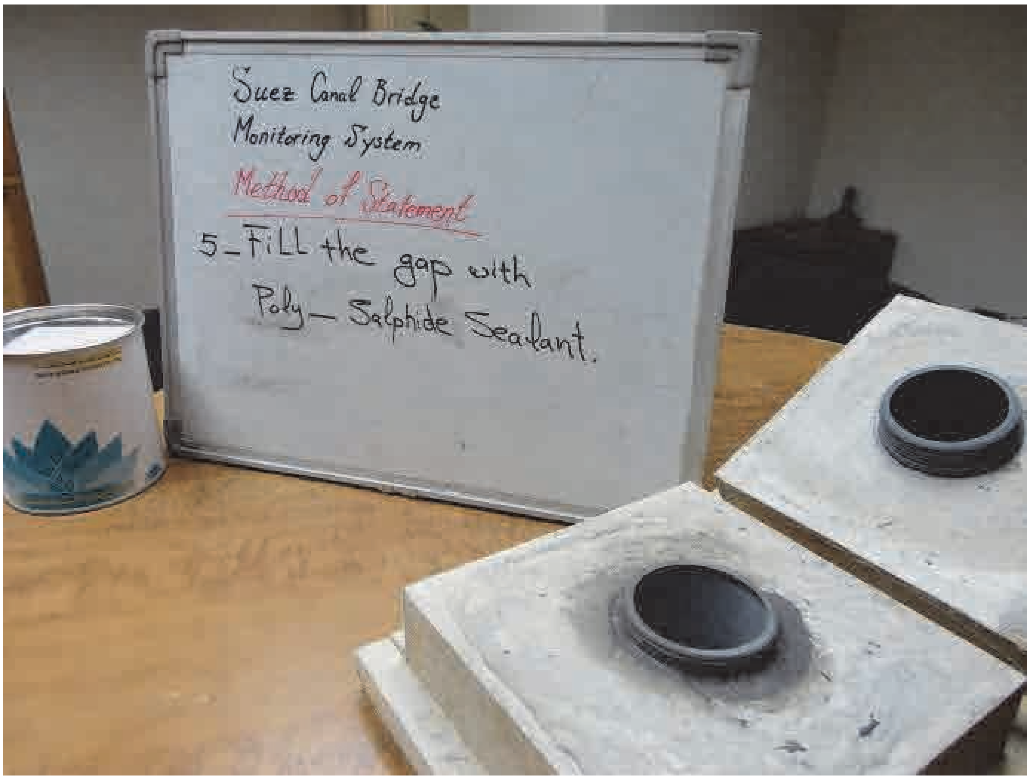


Photo 3.4.6 Filling the Sealant Material

Photo 3.4.7 Screwed Cap

Photo 3.4.8 Cover with the Screwed Cap

3.4.4 Quantity of Monitoring Device

- Install several monitoring devices where many cracks are found in pavement.
- Place 12 devices on both side spans and 8 devices at the center span. The total number of devices is 20.
- Locations of monitoring devices are shown in Figure 2.

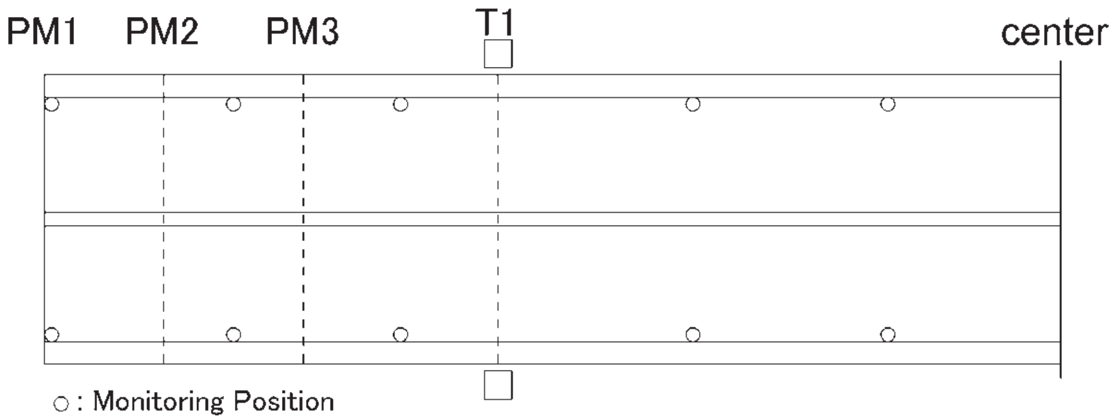


Figure 3.4.2 Location of Monitoring Devices

3.4.5 How to Monitor Water Exposure on the Surface of Steel Deck Plate

Tests and checking monitoring devices a few times are needed before determining how to monitor water exposure on the surface of the steel deck plate.

(1) Monitoring Test for 2 months after Installing Monitoring Device

1) Rainy days

- Visually monitor the state of water exposure every hour during rainfall without a break, even during nighttime and holidays.
- Monitor 5 times every 5 hours a day after the rain stops. Monitoring can be stopped after no water exposure is recorded. Until water exposure stops, keep monitoring every hour.
- During monitoring, touch the surface of the steel deck plate with fingers and figure out the degree of moisture on it.
- Once the degree of moisture becomes measurable, measure and record the water depth.

2) Foggy days

- Carry out monitoring every hour during the day and night and even on holidays to see if moisture occurs during winter or other seasons when foggy weather is forcasted.

- Monitor 5 times every 5 hours after the fog disappears. Monitoring can stop after no fog is confirmed.
- The method to check the degree of moisture is the same as that of rainy days.

3) Sunny days

- Sunny and partly cloudy days need monitoring 5 times every hour between 8 am and 2 pm.
- It is necessary to continue monitoring every hour for a full day once water exposure is detected.

4) Determine how to monitor water exposure

- As described above, determining how to monitor water exposure and define the proper time based on results from monitoring tests depends on each weather condition.

(2) Monitoring Implementation after the Test Period is Finished

Monitoring can be implemented in the same ways described above but it is tentative at this moment.

- Sunny and partly cloudy days need monitoring 5 times every hour between 8 am and 2 pm. If no water exposure is detected for more than five consecutive days, it is acceptable to stop monitoring until it rains.
- When it starts raining, monitoring needs to be done every hour. But when it stops raining, keep monitoring 5 times every 5 hours until water exposure is no longer found.
- Foggy and rainy days require monitoring.

CHAPTER 4 STUDY, ANALYSIS AND EVALUATION

4.1 Evaluation of the Soundness of the Pavement and Steel Deck Plate

4.1.1 Evaluation of the Soundness of the Pavement

1) Method for measurement of pavement crack rate

Initially, take pictures of all parts of the targeted inspection area prior to putting them together one by one to form a panoramic view of the targeted inspection area. This then can be divided into 50 cm x 50 cm rectangles. Next, the number of cracks shown in each rectangle is counted. If one crack is counted in each, the cracked area is considered to be 0.15 m^2, while if each rectangle includes more than two cracks, the cracked area is assumed to be 0.25 m^2. The equation for calculating the pavement crack rate is as follows:

Pavement crack rate (%) = cracked area / targeted inspection area x 100

$$= (0.15 \times N_1 + 0.25 \times N_2) \text{ / targeted inspection area x 100}$$

where N_1 is the number of cracks counted as being 0.15 m^2, and N_2 is the number of cracks counted as being 0.25 m^2.

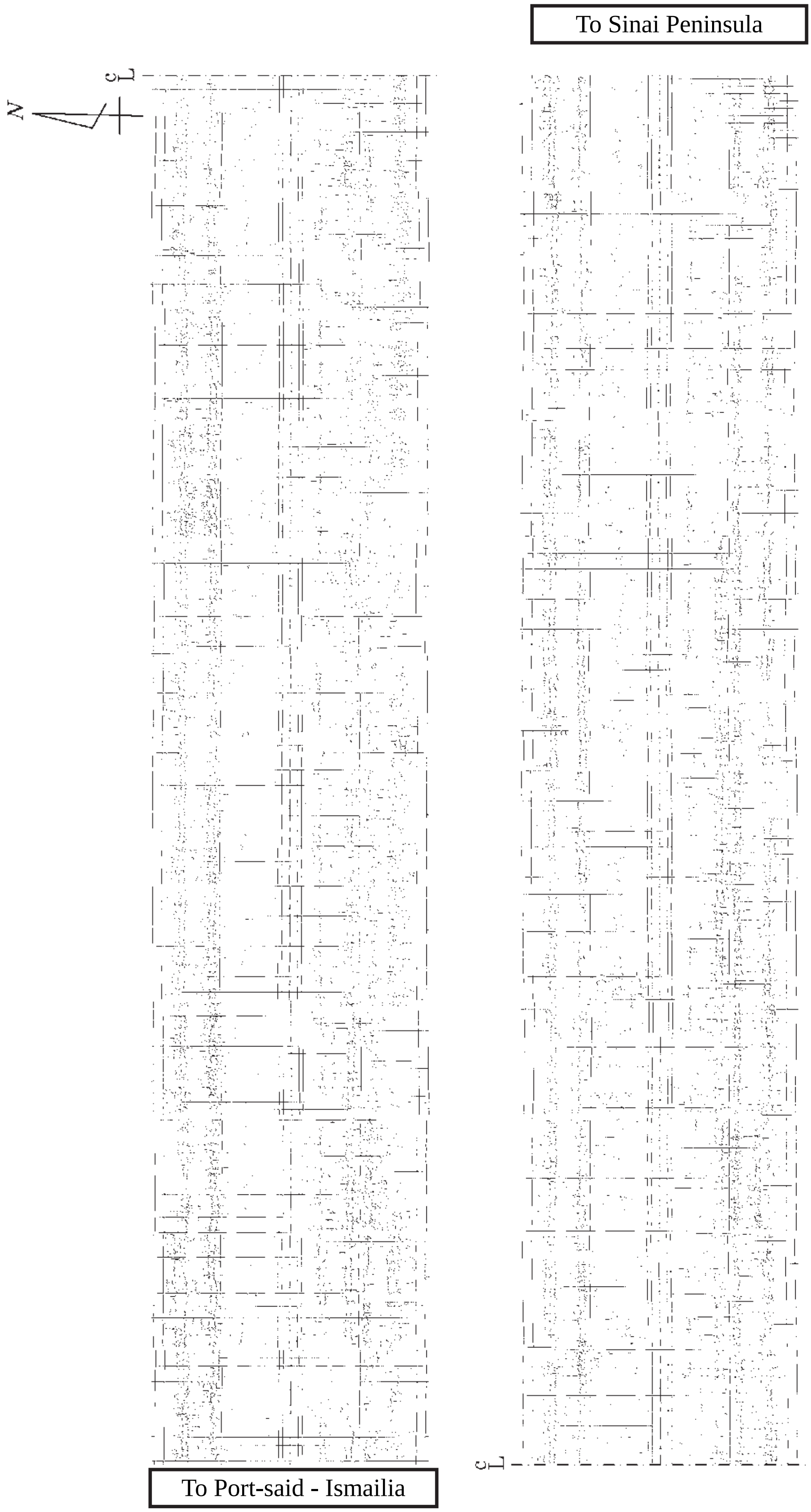


Figure 4.1.1 Condition of Pavement Surface Summary

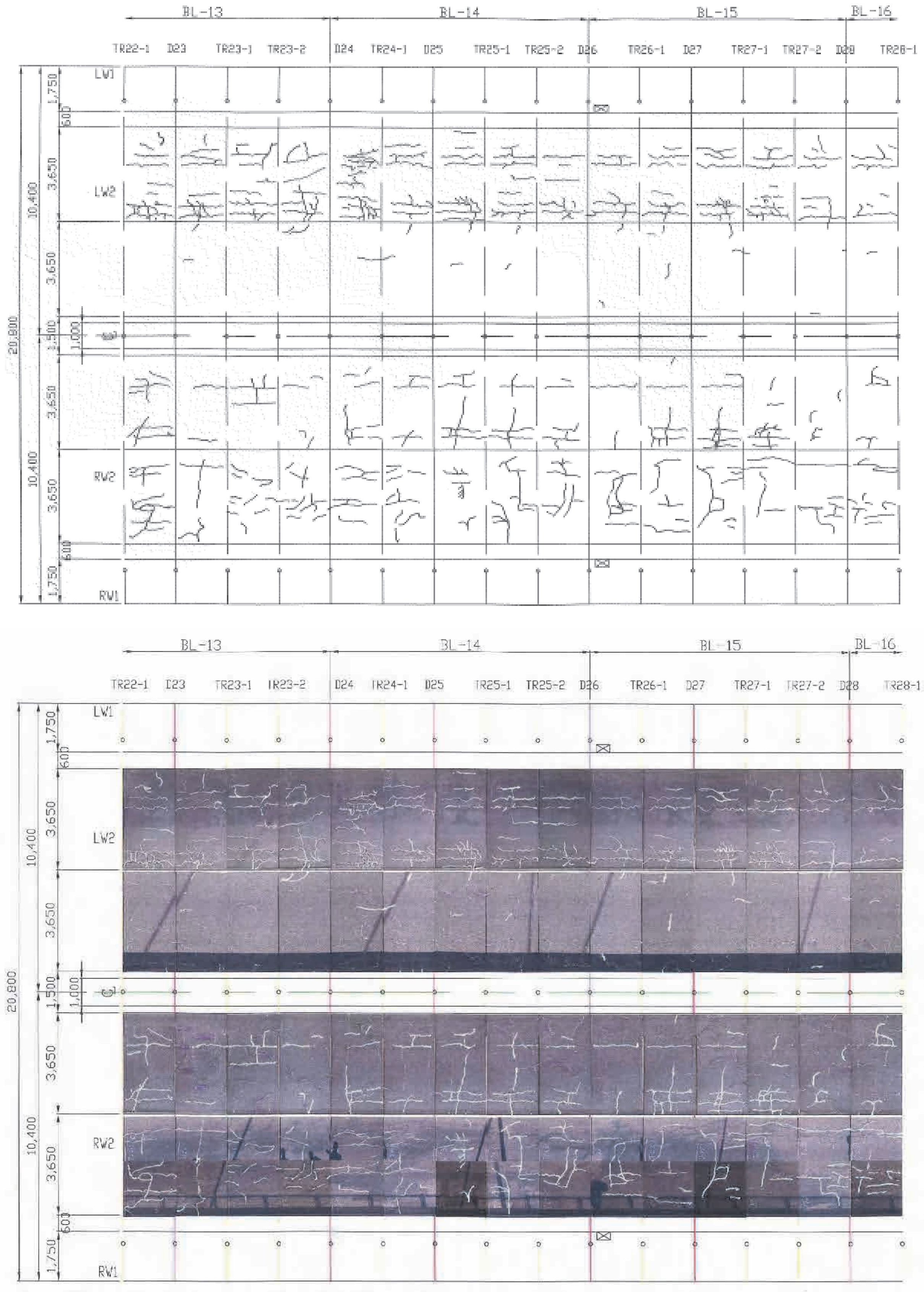


Figure 4.1.2 Condition of Pavement Surface (BL13–BL15)

Table 4.1.1 Rate of Cracks in Pavement on Steel Deck

Area (m2)		South (place)				North (place)			
		Out-side lane		In-side lane		In-side lane		Out-side lane	
		0.15m2	0.25m2	0.15m2	0.25m2	0.15m2	0.25m2	0.15m2	0.25m2
BL01	21.00	34	16	24	12	9		25	26
BL02	35.00	38	6	32	6	8		48	45
BL03	35.00	43	7	8		12		62	28
BL04	35.00	41	21	27	5	14		50	38
BL05	35.00	34	27	27	23	10		42	32
BL06	35.00	48	29	33	20	7		28	47
BL07	35.00	38	44	34	35	8		29	57
BL08	35.00	33	30	49	33	12		34	40
BL09	35.00	30	29	49	19	4		38	49
BL10	35.00	32	10	36	17	8		30	56
BL11	35.00	26	4	45	18	7	3	36	52
BL12	35.00	31	8	40	26	8		27	60
BL13	35.00	47	27	40	16	8		42	39
BL14	35.00	32	27	45	19	9		37	40
BL15	35.00	39	22	34	14	12		27	40
BL16	35.00	50	16	16	2	21		39	54
BL17	35.00	54	25	20		6	2	62	31
BL18	35.00	58	27	18	2	10		59	51
BL19	35.00	46	16	25	6	7		67	37
BL20	35.00	42	16	39	5	3		51	34
BL21	35.00	17	3	36	5	7		45	32
BL22	35.00	44	15	33	7	28	3	34	40
BL23	35.00	45	14	47	24	33	1	35	37
BL24	35.00	16	4	26	3	20	3	28	96
BL25	35.00	44	23	37	8	5		42	65
BL26	35.00	54	36	31	6	7	1	36	80
BL27	35.00	49	33	31	15	17	1	37	34
BL28	35.00	33	39	35	8	15	2	33	67
BL29	35.00	39	19	19	28	13	1	38	39
BL30	35.00	36	29	32	14	17	4	44	39
BL31	35.00	48	47	37	29	11		39	44
BL32	35.00	36	54	44	38	20		48	32
BL33	35.00	45	37	34	17	27	1	41	32
BL34	35.00	25	31	20	8	10	2	27	27
BL35	35.00	44	54	30	9	17		53	30
BL36	35.00	50	38	34	23	19	8	35	53
BL37	35.00	30	48	28	15	25	12	31	39
BL38	35.00	31	43	35	14	12	3	29	44
BL39	35.00	33	52	28	9	8	1	32	42
BL40	35.00	31	76	38	18	15		48	32
BL41	35.00	20	79	26	24	21	7	37	39
BL42	35.00	45	38	51	12	23	7	38	33
BL43	35.00	41	28	24	9	28	4	53	20
BL44	35.00	39	45	51	19	41	12	37	28
BL45	35.00	39	35	25	26	31	6	32	17
BL46	35.00	33	25	27	31	12	2	45	13
BL47	35.00	45	31	25	26	12	6	30	26
BL48	35.00	43	24	24	29	11		32	21
BL49	35.00	24	25	32	20	15	2	28	33
BL50	35.00	61	17	28	15	16	3	38	52
BL51	35.00	41	26	14		8		36	26
BL52	35.00	45	34	38	16	12	1	42	29
BL53	35.00	58	10	33	11	14	2	37	10
BL54	35.00	47	22	28	19	13	4	52	20
BL55	35.00	44	17	24	8	13	1	40	25
BL56	35.00	36	12	7	4	10	1	47	16
BL57	35.00	40	15	12		6		37	23
BL58	35.00	31	14	19	6	5	1	19	3
BL59	35.00	33	32	29	8	11	1	44	10
BL60	35.00	37	15	26	4	14	2	41	16
BL61	35.00	25	17	24	8	11		45	14
BL62	35.00	28	24	20	10	12		45	18
BL63	35.00	33	15	17	1	10		47	12
BL64	35.00	47	19	14	3	12	1	39	35
BL65	35.00	40	22	19		11	1	38	20
BL66	35.00	37	38	14		10	1	39	32
BL67	21.00	26	22	14		12		27	28
Total	2,317.00	2,584	1,803	1,961	885	903	113	2,633	2,379
Each Crack Area (m2)		387.60	450.75	294.15	221.25	135.45	28.25	394.95	594.75
Total Crack Area (m2)			838.35		515.40		163.70		989.70
Crack Parcentage (%)			36.18		22.24		7.07		42.71
Average Crack Parcentage (%)		27.05							

2) Method for evaluation of the pavement

Among the viable alternatives, the minimum value was finally chosen as the value of the Japanese standard Maintenance Control Index (MCI).

Formula:

$MCI_0 = 10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2}$

$MCI_1 = 10 - 1.51C^{0.3} - 0.30D^{0.7}$

$MCI_2 = 10 - 2.23C^{0.3}$

$MCI_3 = 10 - 0.54D^{0.7}$

C : crack rate (%)

D : depth of wheel depressions (mm)

σ : flatness (mm)

As a result of the above calculations, the minimum value is evaluated as being equal to the MCI.

3) Evaluation of the soundness and MCI

The soundness of the pavement and the MCI are shown in Table 4.1.2.

Table 4.1.2 Evaluation of the Soundness and MCI

Soundness rank	Condition of pavement surface	MCI
A	New pavement and good condition	6 < MCI
B	Older pavement but in good condition	5< MCI ≦6
C	Partially damaged pavement	4< MCI ≦5
D	Advanced damage pavement	3< MCI ≦4
E	Remarkably damaged pavement	MCI ≦3

The soundness of the pavement for each lane is evaluated as shown in Table 4.1.3.

Table 4.1.3 Soundness Ranks of Each Lane

	formula	South		North		Average
		Out-side lane	In-side lane	In-side lane	Out-side lane	
	C : Pavement crack percentage (%)	36.18	22.24	7.07	42.71	27.05
	D : Depth of wheel dents (mm)	0.00	0.00	0.00	0.00	0.00
	σ : Flatness (mm)	2.00	2.00	2.00	2.00	2.00
MCI_0	$10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2}$	5.12	5.71	6.80	4.90	5.48
MCI_1	$10 - 1.51C^{0.3} - 0.30D^{0.7}$	5.57	6.17	7.29	5.34	5.94
MCI_2	$10 - 2.23C^{0.3}$	3.46	4.35	5.99	3.12	4.00
MCI_3	$10 - 0.54D^{0.7}$	-	-	-	-	-
MCI		3.46	4.35	5.99	3.12	4.00
Soundnss of Pavement		D	C	B	D	D

4) Result of the evaluation of the soundness of the pavement

- Overall soundness of the pavement resulted in D-rank.
- The *soundness* of most parts of the pavement on both the north and south outside lanes has shown MCI=3.12~4.46 and is ranked as D. Concentration of wheel loading, however, as is evident from marks on the surface, has resulted in cracks with a hexagonal pattern that have propagated to the surface of the steel deck plate. This indicates the pavement state is badly unsound and is finally evaluated as E-rank.
- The *soundness* of the pavement on the south inside lane has shown MCI=4.35 and is ranked as C. As shown in the sketch illustrating cracking, overall cracks have been developed deeply except between the diaphragm and start and end point on the steel deck plate. This state implies cracking is progressing, and thus, its soundness could be categorized as D-rank.
- The soundness of the pavement on the north inside lane has shown MCI=5.99 and ranked as B. As shown in the sketch illustrating cracking, cracks have developed seriously around the diaphragms that are placed between BL37 and BL42. This indicates that pavement is partly damaged and could be categorized as C-rank.

4.1.2 Evaluation of the Soundness of the Steel Deck Plate

Evaluation of the soundness of the steel deck plate is described below.

(1) Inspection of the Top Surface of the Steel Deck

- Water invaded under the stick layer evenly and the steel was corroded in every cutout.
- In order to fix the corrosion condition, it is necessary to partially blast to remove the rust first, and then apply a new asphalt layer with a waterproof layer.

(2) Deck Plate Thickness Inspection

- The average reduction of the thickness of L2 in the corroded regions is 0.5 mm, which is the maximum found in the 5 locations. Small pits due to the corrosion remained on the surface but were neglected in the measurement.
- Thickness reduction due to corrosion is not a big problem at this moment from a structural point of view, but will possibly induce fatigue cracking from the surface or affect the deformation capacity of the bridge if left as it is.

(3) Visual Inspection

- No fatigue cracks were detected in the closely inspected areas under the pavement cutouts or in the No. 7, 8 U-rib in the bridge.
- Fatigue prone details and welding of unfavorable quality were found in some parts.

(4) Magnetic Particle Inspection

- Paint cracks that suggested the possibility of cracks in the underlying metal were investigated by MT. Some of them were only paint cracks and others were weld defects.

- No fatigue cracks were discovered in this 10-year-old bridge under close inspection of the selected areas.
- It can be said that the risk of fatigue cracks is small in this bridge at this moment.
- However, it is recommended to inspect fatigue prone details in the periodical maintenance procedures.

(5) Ultrasonic Inspection

- Using UT, it is possible to detect deck plate penetrating cracks.
- There were no fatigue crack indications.
- Echoes from the corrosion on the surface were observed.
- By applying UT on several U-ribs in the inspected areas, a 2-dimensional map of the corrosion can be obtained.

(6) Inspection of Waste Deposit inside the U-shaped Rib

- The hammer test results indicate that no waste deposit exists inside and the deck plate has no crack penetration.

(7) Temperature Measurement inside the Steel Deck Girder

- The temperature inside and outside the girder varies from 12°C to 22°C and the lowest temperature is usually recorded in December every year. This means that the temperature difference is slight. Moreover, the relative humidity inside the girder was below 23%. For this reason, it is difficult for condensation to occur inside the girder.
- The maximum relative humidity was recorded at 51% in 2011. This is below the 60% considered normally as the baseline of rusting, so that the humidity state inside the girder is still good and no rust is expected.

(8) Limitation to Vehicle Weight

- The selection of heavy vehicles is executed by the judgment of GARBLT staff. But, they are skillful in finding heavy trucks that are over the axle-load limit.
- According to the interview with GARBLT staff, overloaded vehicles have not entered the gate recently. This inspection has been implemented for a long time (heavy trucks are using the ferry to cross the canal).
- The toll fee for one large-sized truck is 10 LE. It is assumed that this is the reason that overloaded vehicles have not entered the gate.
- After construction of the X-ray scanner, inspections will become more efficient.

(9) Evaluation of the Soundness of the Steel Deck Plate

- Corrosion was found on the surface of the steel deck plate where the pavement was removed.
- The maximum thickness reduction of steel deck plate was 0.5 mm. (The minimum thickness was 11.5 mm against the design thickness of 12.0 mm.)

- No fatigue cracks were found in the steel deck plate by Magnetic Particle or Ultrasonic Inspections.
- Thickness reduction due to corrosion is not a big problem at this moment from a structural point of view, but will possibly induce fatigue cracking from the surface or affect the deformation capacity.
- With regard to the thickness of the deck plate at 12.0, 11.5 and 11.0 mm, design stress on U-ribs is calculated for each thickness and summarized in Table 4.1.4. As can be seen, regardless of the thickness reduction down to 11.0 mm, stress variance is less than 1% and all stresses calculated are within the range of allowable stress (σ a=1400 kg/cm^2) as specified.

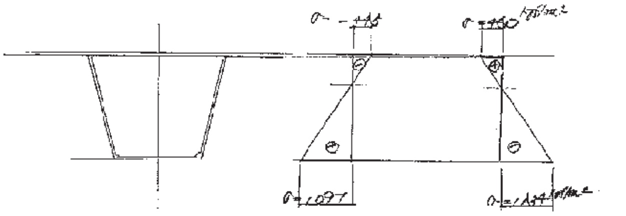
Table 4.1.4 Design stress on U-rib (unit : kg/cm^2)

Thickness of Deck Plate	t=12.0mm	t=11.5mm	t=11.0mm
Bending Moment max.	σ= 1097 (1.000)	σ= 1102 (1.005)	σ= 1106 (1.008)
Bending Moment min.	σ= - 1134 (1.000)	σ= - 1139 (1.004)	σ= - 1144 (1.009)

1. Thickness of Deck Plate = 12mm

U-RIB : Modulus of Section

SECTION		A (cm^2)	Y (cm)	A x Y (cm^3)	A xY^2+I_0 (cm^4)
1-Deck	456 x 12	54.72	15.74	861	13563
1-U RIB	320 x 240 x 6-40	40.26	-	-	2460
	A=	94.98 cm^2		861	16023
					-7814
	δ =	9.07 cm		Ir=	8209 cm^4
	YU=	-7.27 cm			
	YL=	17.93 cm			
	ZU=	-1129 cm^3			
	ZL=	458 cm^3			



Stress check of U-RIB

(1) Stress check for Mmax

σU= 502300 / ZU= -445 kgf/cm^2 < σca=-1400kgf/cm^2 : OK

σL= 502300 / ZL= 1097 kgf/cm^2 < σta= 1400kgf/cm^2 : OK

(2) Stress check for Mmin

σU= -519400 / ZU= 460 kgf/cm^2 < σta= 1400kgf/cm^2 : OK

σL= -519400 / ZL= -1134 kgf/cm^2 < σca=-1400kgf/cm^2 : OK

2. Thickness of Deck Plate = 11.5mm

U-RIB : Modulus of Section

SECTION		A (cm^2)	Y (cm)	A x Y (cm^3)	A xY^2+I_0 (cm^4)
1-Deck	456 x 11.5	52.44	15.715	824	12956
1-U RIB	320 x 240 x 6-40	40.26	-	-	2460
	A=	92.7 cm^2		824	15416
					-7326
	δ =	8.89 cm		Ir=	8090 cm^4
	YU=	-7.4 cm			
	YL=	17.75 cm			
	ZU=	-1093 cm^3			
	ZL=	456 cm^3			

Stress check of U-RIB

(1) Stress check for Mmax

σU=	502300 / ZU=	-460 kgf/cm^2	< σca=-1400kgf/cm^2	: OK
σL=	502300 / ZL=	1102 kgf/cm^2	< σta= 1400kgf/cm^2	: OK

(2) Stress check for Mmin

σU=	-519400 / ZU=	475 kgf/cm^2	< σta= 1400kgf/cm^2	: OK
σL=	-519400 / ZL=	-1139 kgf/cm^2	< σca=-1400kgf/cm^2	: OK

3. Thickness of Deck Plate = 11mm

U-RIB : Modulus of Section

SECTION		A (cm^2)	Y (cm)	A x Y (cm^3)	A xY^2+I_0 (cm^4)
1-Deck	456 x 11	50.16	15.69	787	12353
1-U RIB	320 x 240 x 6-40	40.26	-	-	2460
	A=	90.42 cm^2		787	14813
					-6844
	δ =	8.7 cm		Ir=	7969 cm^4
	YU=	-7.54 cm			
	YL=	17.56 cm			
	ZU=	-1057 cm^3			
	ZL=	454 cm^3			

Stress check of U-RIB

(1) Stress check for Mmax

σU=	502300 / ZU=	-475 kgf/cm^2	< σca=-1400kgf/cm^2	: OK
σL=	502300 / ZL=	1106 kgf/cm^2	< σta= 1400kgf/cm^2	: OK

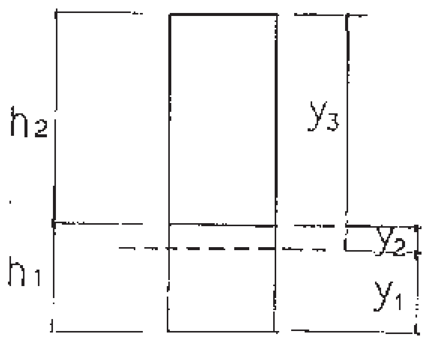
(2) Stress check for Mmin

σU=	-519400 / ZU=	491 kgf/cm^2	< σta= 1400kgf/cm^2	: OK
σL=	-519400 / ZL=	-1144 kgf/cm^2	< σca=-1400kgf/cm^2	: OK

- Table 4.1.5 shows the result of moment of inertia in a fully composite section with deck plate and pavement encasement with the thickness of the deck plate at 12.0, 11.5, and 11.0 mm. The moment of inertia, which represents the deformability of both deck plate and pavement subject to wheel load, would decrease according to deck plate thickness reduction. The moment of inertia decreased by 3.6% in the 11.0 mm thick deck plate, which is considered to have low impact on the deformability. It is recommended that deck plate thickness not be reduced to less than 11.0 mm.

Table 4.1.5 Moment of Inertia in Composite Section with Deck Plate and Pavement

Thickness of Deck Plate: h_1	12.0 mm	11.5 mm	11.0 mm
Elastic Modulus of deck Plate: E_1	2100000 kg/cm^2	2100000 kg/cm^2	2100000 kg/cm^2
Thickness of Pavement: h_2	80.0 mm	80.0 mm	80.0 mm
Elastic Modulus of Pavement: E_2	20000 kg/cm^2	20000 kg/cm^2	20000 kg/cm^2
Moment of Inertia for Deck Plate and Pavement (fully composite section): I	2.0663 cm^4/cm (1.000)	2.0287 cm^4/cm (0.982)	1.9924 cm^4/cm (0.964)



$$I = \frac{1}{3}\left\{h_1 y_1^{\ 2} + n h_2 y_3^{\ 2}\right\}$$

$$y_1 = \frac{1}{mh_1 + h_2}\left\{\frac{mh_1^{\ 2}}{2} + h_2\left(h_1 + \frac{h_2}{2}\right)\right\}$$

$$y_3 = h_1 + h_2 - y_1$$

$$n = E_2 / E_1$$

$$m = 1/n$$

(10) Stability of Structure System during Pavement Repair

- Pavement repair work includes removing all old pavement and implementing replacement with new pavement. Pavement weight is 2.999 t/m, which equals 16.5% of the total weight of dead load (18.152 t/m) imposed on the superstructure, as calculated and listed in Table 4.1.6. During the repair work, removing the existing pavement would lay the bridge upon the structural condition that is the same as the state in which main girder blocks are fully connected in the construction stages, so that the entire structure system is secure. The amount of deflection in main girder and the change of tensile force in cables are estimated and are found to be within allowable limits, as shown in Tables 4.1.7–10.

Table 4.1.6 Design Dead Load on Superstructure

Item	Dead Load (t/m/Br.)
Pavement	2 x 8.15 x 0.08 x 2.3 = 2.999 (0.165)
Wheel Guard, Guard rail, etc.	3.973
Rail of Inspection Vehicle	0.200
Steel Box Girder	10.380
Fender	0.600
Total	18.152 (1.000)

Case-1: Old pavement partially removed

- If the 8.15 m wide pavement on the south side is taken out alone, the weight of dead load decreases as much as 2.999/2=1.5000 t/m is decreased. At this time, the amount of deflection in the main girder and the change of tensile force of cables in the center span are calculated as listed in Tables 4.1.7 and 4.1.8. Tensile forces of cables in the center span are reduced by 15.6 t in the north and 21.8 t in the south, and the amounts of deflection in the main girder are 142 mm in the north and 200 mm in the south, which imply that the main girder may deflect upward a little. These are not much greater than the expected values so no problems should occur.

Table 4.1.7 Change of Tensile Force of Cable (Case-1)

ITEM	Cable Tension Force (C32NW)	Cable Tension Force (C32SW)	Allowable Tension Force
Design Maximum	T_{max}=485.3 t	T_{max}=485.3 t	< T_a=510.8 t
Dead Load Condition(18.152t/m)	T_D=292.9 t	T_D=292.9 t	
Removal of Pavement (W=-1.500t/m)	T_{RP}= - 15.6 t	T_{RP}= - 21.8 t	Δ=21.8-15.6=6.2t
Total ($T=T_D+T_{RP}$)	T=277.3 t	T=271.1 t	

Table 4.1.8 Amount of Deflection in the Center Span (Case-1)

ITEM	North Side	Center	South Side
Removal of Pavement (W=-1.500t/m)	D_{RP}= - 142 mm	D_{RP}= -171 mm	D_{RP}= -200 mm

Case-2: Old pavement fully removed

- If old pavement is fully removed, the amount of dead load decreases as much as 2.999 t/m is decreased. At this time, the amount of deflection in the main girder and the change of tensile force of cables in the center span are calculated as listed in Tables 4.1.9 and 4.1.10. Tensile forces of cables in the center span are reduced by 37.6 t, and the amounts of deflection in the main girder are 346 mm. Even though these values are larger than Case-1, they are not large enough to cause any problem.

Table 4.1.9 Change of Tensile Force of Cable (Case-2)

ITEM	Cable Tension Force (C32NW)	Cable Tension Force (C32SW)	Allowable Tension Force
Design Maximum	T_{max}=485.3 t	T_{max}=485.3 t	< T_a=510.8 t
Dead Load Condition(18.152t/m)	T_D=292.9 t	T_D=292.9 t	
Removal of Pavement (W=-2.999t/m)	T_{RP}= - 37.6 t	T_{RP}= - 37.6 t	
Total ($T=T_D+T_{RP}$)	T=255.3 t	T=255.3 t	

Table 4.1.10 Amount of deflection in the center span (Case-2)

ITEM	North Side	Center	South Side
Removal of Pavement (W=-2.999 t/m)	D_{RP}= - 346 mm	D_{RP}= -346 mm	D_{RP}= -346 mm

(11) Impact of Concrete Slab Deck Replacement

- Currently, GARBLT is planning to place a 15 or 20 cm thick concrete slab deck instead of pavement after pavement removal. This may induce the possibility of increasing the dead load, which then imposes a large impact on the entire structure system, so it is necessary to examine how much the bridge would be influenced.

Table 4.1.11 Calculation on Dead Load

Item	Pavement (t=8.0cm) (Original Design)	Deck Slab (t=15cm)	Deck Slab (t=20cm)
Pavement or Deck Slab	2 x 8.15 x 0.08 x 2.3 = 2.999	2 x 8.15 x 0.15 x 2.5 = 6.113	2 x 8.15 x 0.20 x 2.5 = 8.150
Wheel Guard, Guard rail, etc.	3.973	3.973	3.973
Rail of Inspection Vehicle	0.200	0.200	0.200
Steel Box Girder	10.380	10.380	10.380
Fender	0.600	0.600	0.600
Total	18.152 (1.000)	21.266 (1.172)	23.303 (1.284)

- The increase of dead load generates the fact that the entire structure system would change and the complete longitudinal line would be affected to an extent. When the concrete slab deck is newly placed, the amount of deflection in the center span increases to 359 mm or 594 mm.
- As can be seen in Table 4.1.12, due to the new concrete slab deck, tensile forces of cables in the center span exceed the allowable limits, so bridge security cannot be assured.

- It is necessary to make an assessment for wind resistance and seismic stability again because the increase of dead load would cause the bridge to have a different natural frequency.
- It is also required to correctly clarify how much the increase of dead load would affect other structures, towers, substructures, and the foundation.

Table 4.1.12 Impact Due to the Increase of Dead Load

Item	Pavement (t=8.0cm) (Original Design)	Deck Slab (t=15cm)	Deck Slab (t=20cm)
Increment of Dead Load	0.0 t/m	3.114 t/m	5.151 t/m
Deformation of Center Span	0.0	359 mm	594 mm
Cable Tension Force(C32)	485.3 t < Ta=510.8 t	524.3 t> Ta=510.8 t	549.8 t> Ta=510.8 t

4.2 Area for Repair

4.2.1 Area for Repair of Pavement

The soundness of pavement resulted in a D rank. As a result of the detailed investigation, the cracks longer than 10 mm went through the base course and even propagated to the surface of the steel deck plate. This indicates the overall pavement has been cracked and the base course is also cracked badly. Therefore, replacement of both surface and base courses is necessary.

4.2.2 Area for Repair of Steel Deck Plate

Repair of the steel deck plate is not necessary at the present time.

CHAPTER 5 STUDY OF METHOD OF REPAIR

5.1 Comparison and Study of Repair Method

The budget for the repair is not been developed yet so two plans can be suggested: pavement available from an Egyptian construction company, and pavement available through Japan-aid.

5.1.1 Pavement Available from a Construction Company in Egypt

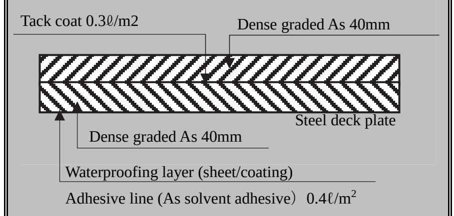
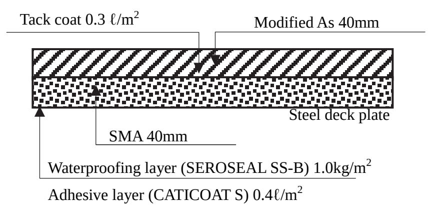
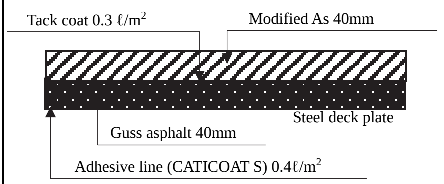
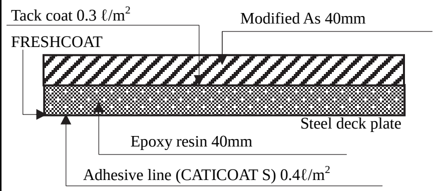
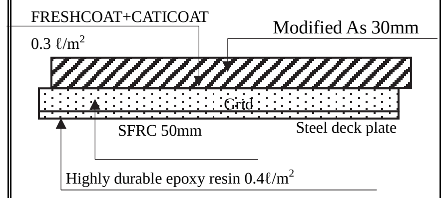
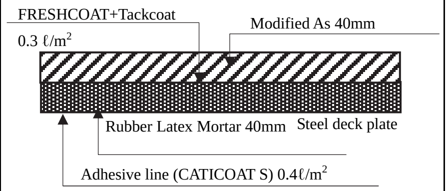
A few flyovers in Cairo have used pavement developed by a construction company in Egypt. But now, all pavement has worn off and the surface of the steel deck plate is exposed. In the Suez Canal Bridge, a construction company in Egypt has participated in the Stone Mastic Asphalt (SMA) pavement work but is not experienced enough to come into its own as an independent company to perform other pavement works. These findings indicate that only the dense graded asphalt concrete is available considering the level of construction technology in Egypt.

5.1.2 Pavement Available through Japan's Aid

In Japan, guss asphalt is mostly used in pavement on steel deck plates. Commonly, special equipment is needed to develop the guss asphalt at a high temperature during pavement. Because there is a lack of special equipment, attempts have been made to develop alternatives to guss asphalt that would produce similar performance. Stone mastic asphalt (SMA) is one of them. Recently, epoxy resin pavement has also been applied for testing. Moreover, recently, fatigue cracking has been found in orthotropic steel deck bridges (deck plate thickness = 12 mm) in Japan. This has led to the development of steel fiber reinforced concrete (SFRC) pavement to prevent fatigue cracking and reinforce the steel deck plate. In addition, for the same purpose, gum latex mortar (GLM) pavement was developed.

The pavements described above are detailed and compared on the next page.

Table 5.1.1 Comparison Table for Repair Method

Type	Steel Deck Plate Pavement				Reinforcement and Pavement	
	Ordinary (Dense Graded) Asphalt	Stone Mastic Asphalt (SMA)	Guss Asphalt	Epoxy Resin	Steel Fiber Reinforced Concrete (SFRC)	Rubber Gum Latex Mortar (RGLM)
Section Structure						
Overview	As the pavement technology, especially for steel deck plates, is not yet developed in Egypt, ordinary modified asphalt, normally used in concrete deck slab pavement, can be chosen instead. The ordinary modified asphalt can be easily made with the equipment that is commonly used for other normal asphalt pavement. It lacks water-tightness so it requires a waterproof layer. Sandblasting is used for grinding or abrading the surface of steel deck plate.	SMA was developed in Germany to create pavement with a good abrasion resistance. In Japan, it has been well used as an alternative of guss asphalt, because of its convenience, which allows the use of normal equipment, and the high water-tightness. SMA includes a large amount of coarse aggregate and cellulose fiber in order to increase the strength of composite structure that leads to the effect of coarse aggregate ligament resisting the internal wearing. Thus, high structural durability is obtainable. Shot blasting is used for not only grinding or abrading the surface of the steel deck plate, but also for preventing corrosion occurrence. **<u>SMA of steel deck is being developed in Japan for the purpose of improving the flexibility by way of greatly increasing the amount of asphalt by adding cellulose fiber and grading the size more precisely.</u>**	Guss asphalt was first developed in Germany for the pavement of steel deck plates. In Japan, since the 1950s, it has been applied as one way of alleviating dead load. In the 1970s, Honshi started developing it for application to pavement on long-span bridges. Now, many long-span bridges in Japan are using it. TLA (Trinidad Lake Asphalt, natural asphalt improved asphalt) is employed under high temperatures (220~260ºC) to produce guss asphalt, which is highly fluid. This requires special equipment, a cooking carer and paver finisher, to implement the appropriate process. No problem has been found over two decades since it has been applied to Honshu-Shikoku Renraku Bridges.	Epoxy resin pavement developed in the U.S. has recently been used for application to steel deck plates in Japan instead of guss asphalt because of its good flexibility to permit deflection. Fine graded mixture obtained from epoxy resin asphalt is used and does not require uncommon equipment. This pavement is considered as a new technology.	Fatigue cracks have recently been found in a more than 20-year-old orthotropic steel deck bridge (deck plate thickness = 12 mm) in Japan. As a measure to prevent fatigue cracking and reduce deflection, developing and applying the SFRC pavement was implemented This is a state-of-the-art technology in suppressing the level of stress concentration in ways that provide a strong internal resistance that results from utilizing the high-durable epoxy resin adhesive between the steel deck plate and steel fiber reinforced concrete. This pavement uses common equipment.	Mortar mixed with gum latex consisting of styrene-butadiene spreads over the surface of steel deck plate and hardens to form the pavement, so that would work together with the steel deck plate to enhance the fatigue durability. This is also one of the brand new technologies. This pavement uses common equipment. Test-oriented application is necessary to carry out a long-term performance assessment.
Performance	- Flexibility, which permits deflection caused by wheel load, is lacking so the pavement may not remain stuck on the steel deck plate. Stripping and damage could take place. (No good) - Highly concerning is low structural performance due to critical defects: pavement cracking and severe corrosion on the steel deck plate. (No good)	- Good durability is apparent but it is less flexible than guss asphalt, so that may weaken the adherence to the surface of the steel deck plate. Once the adherence becomes poor, slipping between the pavement and steel deck plate would take place and cause cracking in pavement. (No good)	- When traffic volume is expected to increase, the pre-coated crushed stone pressed into guss as surface pavement would contribute to preventing rutting on the surface of road. (Good) - Little void inside assures high water-tightness and demonstrates good waterproofing effect. (Good) - Good flexibility can maintain the pavement strongly stuck on the surface of steel deck plate. (Good)	- It has good resistance against rutting. (Good) - Little void inside provides the high water-tightness and demonstrates good waterproofing effect. Waterproofing layer is not necessary except on the end of the pavement. (Good) - Good flexibility can maintain the pavement strongly stuck on the surface of the steel deck plate. (Good) - Epoxy resin asphalt needs binder component available only for 3 hours during the period from production to completion. Once 3 hours have passed, it may not meet quality requirements. (Normal)	- This is good for solving fatigue cracking problems and enhancing the composite effect due to combining with the steel deck plate. (Good) - Concrete pavement may cause shrinkage cracking after completion. (Normal) - The SFRC pavement with a thickness of 50 mm is much too thin so it is necessary to develop a construction plan including epoxy resin adhesive and temperature control. (Normal)	- This is good for solving fatigue cracking problems and enhancing the composite effect due to combining with the steel deck plate. (Good) - The properties demonstrate good performance, but it is not obvious to what extent they fully satisfy the structural requirements under the test-oriented application. (Normal)
Constructability	- Normal equipment and materials enable the application of the ordinary modified asphalt. (Good) - Egyptian workers can carry out work according to the procedures described in the Egyptian specifications. (Good) - Resources, such as material and equipment, are procurable in Egypt. (Good) - Egyptian engineers can perform quality control. (Good) - No record for its application to steel deck plate so far. (No good)	- The SMA can be easily made with normal equipment and materials. (Good) - The application has been reviewed for over two decades by some expressway companies in Tokyo, Osaka, and Nagoya cities in Japan and its specifications were established in 2002. In Nagoya expressway, some defects, however, were found in 2007 so pavement specifications have excluded the use of it. Consequently, guss asphalt has been considered as a standard pavement on steel deck plate for 15 years. Double-layered sided SMA was developed and used once in China until damage occurred and thus, it is no longer employed. SMA is applied to the following: Metropolitan highway (Japan); Suez Canal Bridge (Egypt); Can Tho Bridge (Vietnam); Koror–Babeldaob Bridge (Palau); and Humen Pearl River Bridge, Haicang Bridge, and Yichang Yangtze River Highway Bridge (China). (Normal) - Guidelines comply with the Japanese or German specifications and the modified dense graded asphalt can be developed by a local construction company.	- Special equipment is necessary to deal with materials under high temperature. The construction procedure is rather simple. (Good) - Stains on the surface of steel deck plate may bring out blistering problems during pavement. This means shot blasting should be chosen for grinding or abrading the surface of steel deck plate. (Normal) - Most long-span bridges in Japan have been making use of guss asphalt for pavement for 25 years since the Honshu-Shikoku Renraku Bridges applied it. Guss asphalt has been well known as the mastic asphalt in some specifications in Europe and the 2nd Bosphorus Bridge is one of the bridges it is applied to. Anticorrosive paint needs zinc-rich primer and adhesive lines requires epoxy resin (eliminator) in Europe. It is applied to many bridges: long-span bridges and Metropolitan highway (Japan) and the 2nd Bosphorus Bridge (Turkey). (Good) - Guidelines comply with the Japanese or German specifications and the modified dense graded asphalt can be developed by a local construction company.	- Normal equipment and materials enable the application of the epoxy resin pavement. (Good) - Most orthotropic steel deck bridges in the U.S are employing it and China recently just started using it. The Kwangyang Bridge in Korea is also one of the bridges including it. No defects have been found so far in the U.S but in China some were found. In Japan, it has been used in the test-oriented application to the Metropolitan highway for over 1.5 years. (Normal) - Guidelines comply with the Japanese or U.S specifications and the dense graded asphalt can be developed by a local construction company.	- The application needs the use of a concrete pavement finisher and a mixer for agitating steel fibers into mortar. (Good) - Concrete pavement with 50 mm in thickness causes hair-like shrinkage cracking. To prevent this, it is important to give close attention to curing and quality control. In Egypt, it would be difficult to apply it because the status of equipment and material procurement and the level of quality control are not secure. (Normal) - Utilizing the high-durable epoxy resin adhesive needs advanced technology and is likely to be carried out with many efforts. (Normal) - In the past, it has been used in Japan's roadways: Yokohama Bay Bridge, National Route No. 50, and Nagoya expressway - for four years. (Normal) - Guidelines comply with the Japanese specifications and the dense graded asphalt can be developed by a local construction company.	- Normal equipment and materials enable the application of the GLMRLM pavement. (Good) - High-durable epoxy resin adhesive is not necessary here, which means it is easier to deal with the composite steel deck plate structure for replacement. (Good) - Test-oriented application to Yokohama Bay Bridge has been done for two years in a similar way to epoxy resin pavement. The result remains to be seen. (No good) - Guidelines comply with the Japanese specifications and the dense graded asphalt can be developed by a local construction company.

Type		Steel Deck Plate Pavement				Reinforcement and pavement	
		Ordinary (Dense Graded) Asphalt	Stone Mastic Asphalt (SMA)	Guss Asphalt	Epoxy Resin	Steel Fiber Reinforced Concrete (SFRC)	Rubber Gum Latex Mortar (RGLM)
Cost *1)	Initial Cost	Existing pavement cutting ¥7,000/m^2 x 12,000 m^2 = ¥84 million Sand blasting ¥3,000/m^2 x 12,000 m^2 = ¥36 million Coarse graded As ¥2,000/m^2 x 12,000 m^2 = ¥24 million Adhesive + Waterproofing layer ¥2,000/m^2 x 12,000 m^2 = ¥24 million Dense graded As (tack coat included) ¥2,000/m^2 x 12,000 m^2 = ¥24 million Consultant supervision cost = ¥0 Total = ¥192 million	Existing pavement cutting ¥7,000/m^2 x 12,000 m^2 = ¥84 million Shot blasting ¥5,000/m^2 x 12,000 m^2 = ¥60 million SMA (adhesive CATICOAT + waterproofing layer) ¥3,000/m^2 x 12,000 m^2 = ¥36 million Dense graded As (tack coat included) ¥2,000/m^2 x 12,000 m^2 = ¥24 million Consultant supervision cost = ¥60 million Total = ¥264 million	Existing pavement cutting ¥7,000/m^2 x 12,000 m^2 = ¥84 million Shot blasting ¥5,000/m^2 x 12,000 m^2 = ¥60 million Guss As (adhesive CATICOAT included) ¥5,000/m^2 x 12,000 m^2 = ¥60 million Cooker (3 cars) + Finisher *2 = ¥250 million Dense graded As (tack coat included) ¥2,000/m^2 x 12,000 m^2 = ¥24 million Consultant supervision cost = ¥60 million Total = ¥538 million	Existing pavement cutting ¥7,000/m^2 x 12,000 m^2 = ¥84 million Shot blasting ¥5,000/m^2 x 12,000 m^2 = ¥60 million Fine graded epoxy resin asphalt ¥4,000/m^2 x 12,000 m^2 = ¥48 million Equipment operation and labor cost ¥1,000/m^2 x 12,000 m^2 = ¥12 million Waterproofing cost ¥2,000/m^2 x 12,000 m^2 = ¥24 million Dense graded As (tack coat included) ¥2,000/m^2 x 12,000 m^2 = ¥24 million Consultant supervision cost = ¥60 million Total = ¥318 million	Existing pavement cutting ¥7,000/m^2 x 12,000 m^2 = ¥84 million Shot blasting ¥5,000/m^2 x 12,000 m^2 = ¥60 million Grid spreading ¥8,000/m^2 x 12,000 m^2 = ¥96 million Highly-durability epoxy resin bond ¥7,000/m^2 x 12,000 m^2 = ¥84 million Equipment for concrete pavement ¥4,000/m^2 x 12,000 m^2 = ¥48 million Sheet curing ¥3,000/m^2 x 12,000 m^2 = ¥36 million Dense graded asphalt (CATICOAT included) ¥2,000/m^2 x 12,000 m^2 = ¥24 million Consultant supervision cost = ¥60 million Total = ¥492 million	Existing pavement cutting ¥7,000/m^2 x 12,000 m^2 = ¥84 million Shot blasting ¥5,000/m^2 x 12,000 m^2 = ¥60 million Material + Mixing ¥35,000/m^2 x 12,000 m^2 = ¥420 million Waterproofing (CATICOAT S + FRESHCOAT) ¥3,000/m^2 x 12,000 m^2 = ¥36 million Dense graded asphalt (tack coat included) ¥2,000/m^2 x 12,000 m^2 = ¥24 million Consultant supervision cost = ¥60 million Total = ¥684 million
	Life Cycle Cost (LCC) (for 50 years)	Annual repair and pavement replacement once every 10 years ALL ¥192 million x 4 times = ¥768 million Repair ¥10 million x (50-1) times = ¥490 million Total = ¥1,258 million	Repair once every two years and surface course replacement once every 10 years Dense graded As (tack coat included) ¥24 million x 4 times = ¥96 million Repair ¥10 million x (50/2-1) times = ¥240 million Total = ¥336 million	Repair once every four years and surface course replacement once every 10 years Dense graded As (tack coat included) ¥24 million x 4 times = ¥96 million Repair ¥10 million x (50/4-1) times = ¥115 million Total = ¥211 million	Repair once every four years and surface course replacement once every 10 years Dense graded As (tack coat included) ¥24 million x 4 times = ¥96 million Repair ¥10 million x (50/4-1) times = ¥115 million Total = ¥211 million	Repair once every four years and surface course replacement once every 10 years Dense graded As (CATICOAT included) ¥24 million x 4 times = ¥96 million Repair ¥10 million x (50/4-1) times = ¥115 million Total = ¥211 million	Repair once every four years and surface course replacement once every 10 years Dense graded As (tack coat included) ¥24 million x 4 times = ¥96 million Repair ¥10 million x (50/4-1) times = ¥115 million Total = ¥211 million
		Total cost (Initial cost + LCC) = ¥1,450 million	Total cost (Initial cost + LCC) = ¥600 million	Total cost (Initial cost + LCC) = ¥749 million (¥499 million, if cooker and finisher are rented.)	Total cost (Initial cost + LCC) = ¥523 million	Total cost (Initial cost + LCC) = ¥703 million	Total cost (Initial cost + LCC) = ¥895 million
		Initial cost is the lowest compared to other types of pavement, while LCC becomes the highest. (6)	Total cost is the second lowest compared to other pavements. (2)	Equipment procurement plan must be properly developed. Purchasing needs a great amount of budget unless the equipment would be used frequently. Renting is more cost-effective. (4)	This costs less than SFRC and guss asphalt unless the equipment rental is considered. (1)	This costs more than epoxy resin but less than guss asphalt unless the equipment rental is considered. (3)	It costs much because of the new technology and no previous record. (5)
Review		- Low structural performance is expected due to low flexibility responding to deflection of steel deck plate. (No good) - The modified ordinary asphalt can be easily made with materials and equipment procurable in the Egypt. (Good) - Initial cost is low but total cost including LCC becomes very high. (No good) - Inappropriate to apply the modified ordinary asphalt as the pavement of the steel deck plate, because its low flexibility may cause damage at an early time and will make it permeable by water so that corrosion acceleration will turn into a very serious problem. (No good) - Once the steel deck plate is damaged and demands repair, long-term traffic regulations and steel deck plate replacement is unavoidable and costs too much. (No good)	- SMA has relatively low flexibility compared to guss asphalt, so it is inappropriate for the pavement of structures with a large deflection under wheel loading. But, a steel deck plate with 12 mm in plate thickness could use SMA. On November 2011, corrosive damage and plate thickness reduction in steel deck plate was investigated. As a result, water penetration was found in the pavement. There is no denying that corrosion could increase. These imply the SMA is inappropriate for use because corrosive damage may reduce the plate thickness and induce a large deflection of steel deck plate further. (No good) - The SMA can be easily made with normal equipment and materials, but the products - bond and waterproofing layerine - need to be procured from Japan or Germany. (Good) - Total cost is the second lowest compared to those of other pavements. (Good)	- Guss asphalt pavement has the features of good flexibility to permit deflection, hard adherence and effective water-tightness. (Good) - It can be developed easily using special equipment and fluid materials. (Good) - The use of cooking carer and paver finisher has a high cost financially, but if not purchased, i.e., rented from Japan or other countries in Europe, it could be economically feasible. (Normal) - The performance and reliability of it have been proven enough from examples in the past. Also, the good strength of resisting against plate thickness reduction due to corrosion could be expected because of good adherence, however, it is not as high as SFRC or Rubber Gum Latex Mortar. (Good) - Rutting problem is less likely to happen because it has been undetected so far in other approach roads. (Good)	- Epoxy resin pavement has the features of good flexibility to permit deflection, hard adherence and effective water-tightness, but the lack of performance record requires further quality assurance on a long-term basis. (Normal) - Highly advanced techniques are necessary to complete the pavement because the high-durability epoxy resin bond is employed for the bond line. The quality or performance has not been determined yet. (No good) - Total cost is the lowest among other pavements but may become higher than that of guss asphalt if the equipment rental is considered instead of the purchase. (Normal) - The lack of performance record of this application in Japan needs a long-term performance assessment. No examples following the Japanese guidelines are available. (No good)	- This represents good performance of decreasing the deflection of steel deck plate and increasing the capacity of strengthening steel deck plate through the composite effect against thickness reduction. (Good) - Concrete pavement with the thickness of 50 mm, much too thin, tends to cause shrinkage cracking after completion. (Normal) - Total cost is the third lowest, but may be higher than those of epoxy resin as well as guss asphalt if the equipment rental is considered instead of the purchase. (Normal) - It is very difficult to procure some of the concrete aggregate required for such thin pavement and to perform quality control properly in Egypt. (Normal) - Moreover, the durability of the steel deck plate could be put at risk again on a long-term basis because the cracking would hamper the function of the waterproofing layer. (Normal)	- This represents good performance of decreasing the deflection of steel deck plate and increasing the capacity of strengthening steel deck plate through the composite effect against thickness reduction. (Good) - No result from a long-term performance assessment. (No good) - Materials cost is high. (No good)
		No good	No good	**Good**	No good	**Normal**	No good

5.1.3 Feature of guss asphalt method

Guss asphalt pavement is a mixture of asphalt and mineral aggregates which at high temperature is sufficiently fluid to be poured into place, forming a voidless pavement. It is widely used as a binder course on the steel bridge deck. It is also used as surface course with pre-coat-chip spread and rolled on the top.

Guss asphalt pavement has been developed in German. It does not need roller compaction because the mixture has fluidity under the high temperature. It is widely used for autobahn in German. In Japan, it has been developed since 1950s and has been applied to the steel bridge deck pavement of Honshu-Shikoku Bridges in 1970s. Guss asphalt pavement has been widely used for most of steel decks of long span bridges in Japan. More than 20 years has passed at the Honshu-Shikoku Bridges, the Guss asphalt pavement is still resilient and wear-resistant.

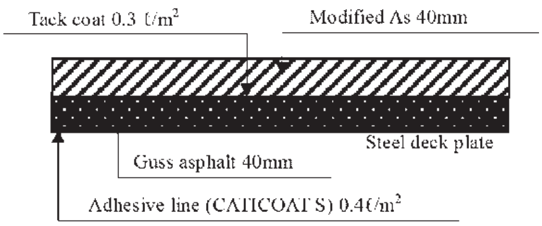


Photo 5.1.1 Status of Guss Pavement Construction on Long-span-bridge

<u>Feature of Guss asphalt</u>

Guss asphalt is a mixture of (Straight asphalt and Trinidad Lake Asphalt (TLA)) with (coarse and fine aggregates and filler), which will be mixed at guss asphalt mixing plant. Guss asphalt mixture has more

Asphalt and filler than ordinary Hot-mix asphalt mixture. Trinidad Lake Asphalt (TLA) is inevitable for Guss asphalt and is only obtained by purification of natural asphalt to be produced in the Pitch Lake (natural asphalt lake) on the island of Trinidad and Tobago in the Caribbean Sea of Central America.

Photo 5.1.2 Natural asphalt produced in PICH LAKE (material of T.L.A)

Note for Construction

To keep stability and workability (fluidity) of Guss asphalt mixture, it shall be transported by guss asphalt mobile cooker with temperature of 220～260℃, then paved by Guss finisher.

General Procedure of Guss asphalt pavement on steel deck plate			
Blasting on steel deck plate ➡	Paniting bond ➡	Supplying Asphalt Mixture by Cooker Car ➡	Paving by Guss Finisher
			

Advantages to ordinary asphalt pavement

Flexibility to deflection: Cracks can be avoided because Guss asphalt has strong adhesiveness to the steel bridge deck, flexible against expansion and contraction of steels due to temperature change and flexible against deflection by heavy vehicle loads.

Construction easiness: Guss asphalt mixture has so high fluidity that it can be poured to small corners, such as bolts and nuts of steel deck plate and gaps of the height. Voidless pavement is possible. Roller compaction is not needed for its fluidity.

Watertight and waterproof: With high water-tightness and no rain water penetration, Guss asphalt pavement function as waterproof for the bridge deck.

5.1.4 Cement-based Pavement for Reinforcement of Steel Deck Plate

Replacing only all the damaged pavement was deemed to be imperative as a result of three on-site investigations. After the type of pavement for repair in the Suez Canal Bridge was reviewed, the use of guss asphalt was recommended because it has the best structural performance, the highest reliability and the most cost-effectiveness among other types of pavement.

Although GARBLT understood its good features, they would not use it because it would be hard to procure the special equipment necessary for paving in Egypt, and GARBLT has had no experience with it previously. Instead, GARBLT has strongly supported the use of steel fiber reinforced concrete (SFRC) pavement. Regardless of their inexperience, GARBLT believed that they could undertake SFRC production and procure equipment easily because of the fact that it is merely made of cement-based components and they had experience in building a similar concrete pavement. In addition, GARBLT had a great interest in using Engineered Cementitious Composite (ECC), a high performance concrete developed in Japan, and asked how to use this a cement-based pavement. Hence, some cement-based pavements that a local company could develop itself are reviewed. Guss asphalt is also added and described.

(1) Cement-based Pavement Method for Reinforcement to Steel Deck Plate in Japan

At the time the Suez Canal Bridge was completed, steel deck plate with 12 mm thickness was commonly used – currently changed to 16 mm – for orthotropic steel deck plate bridges in Japan. In recent years, it has been reported many fatigue cracks are occurring in the vicinity of welded joints between the steel deck plate and trough ribs subject to cyclic local deformation due to wheel loading as shown in Figure 4.3.1. To reinforce or repair it, development of a method that provides a sufficient composite strength for less than 80 mm thick pavement has been considered. Thus, SFRC and ECC have been developed in order to suppress fatigue crack initiation and propagation by improving composite strength gained from integrating them rigidly with the steel deck plate.

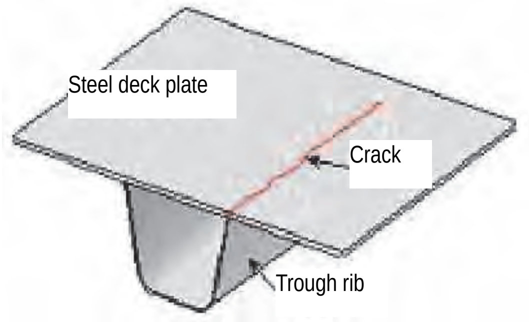


Figure 5.1.1 Fatigue crack in steel deck plate

Cement-based pavement for reinforcement has been reviewed according to the procedure as shown in Figure 4.3.2.

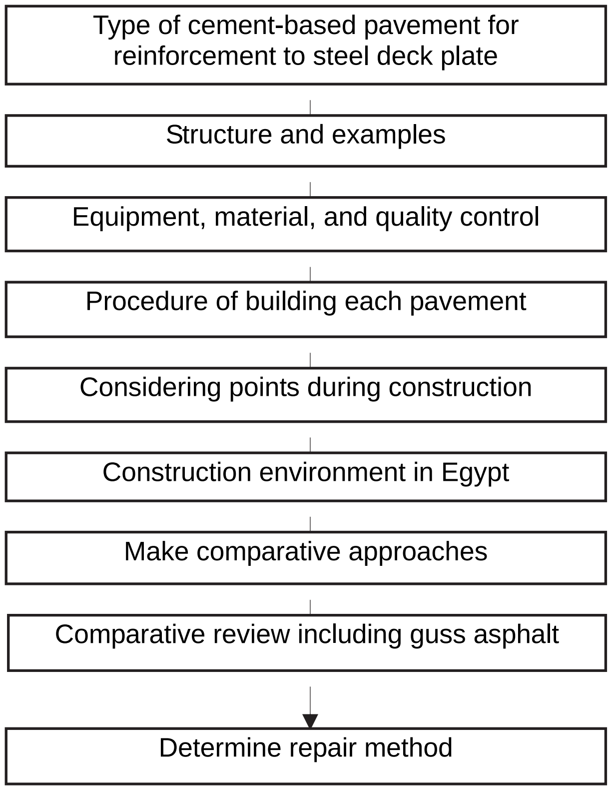


Figure 5.1.2 Procedure of Review

(2) Type of Cement-based Pavement Method for Reinforcement to Steel Deck Plate

Two types of cement-based pavement are usually used: SFRC and ECC. SFRC has small and multiple steel fibers embedded into concrete, and ECC is a cement-based composite concrete reinforced with polymer fibers with high toughness. SFRC usually includes three types of connectors to combine the concrete to the steel deck plate: studs, used in Nagoya Expressway; high durability epoxy resin bond, used in Yokohama Bay Bridge; and high durability epoxy resin bond along with surface course, applied to the Metropolitan Expressway.

On October 2009, regarding SFRC, Public Works Research Institute (PWRI) has published *A Manual of Design and Construction of SFRC Pavement for Reinforcement to Steel Deck Plate (draft)* resulting from *A Joint Study for Developing Technology to Enhance Fatigue Durability of an Orthotropic Steel Deck Bridge.*

(3) Examples of Cement-based Pavement Method

a. SFRC with studs (used in Nagoya City Expressway)

Since the mid-1980s, Nagoya City Expressway has used SFRC to prevent or repair the damaged pavement around tollgates or ramp sections with a large longitudinal gradient. The structure consists of SFRC and studs pitched at 200 or 300 mm on the steel deck plate in order to integrate the SFRC with the steel deck plate. High-durability epoxy resin bond is also applied to prevent delamination at the edge of the steel deck plate, construction joint or where a negative bending moment occurs, as shown in Figure 4.3.3.

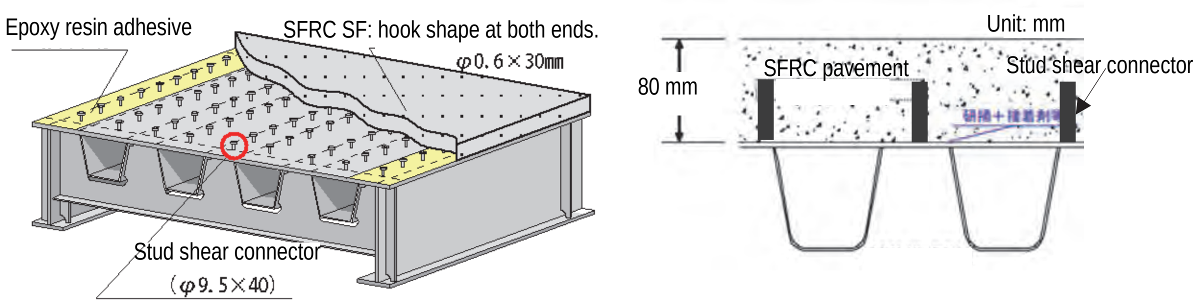


Figure. 5.1.3 SFRC Structure used in Nagoya City Expressway

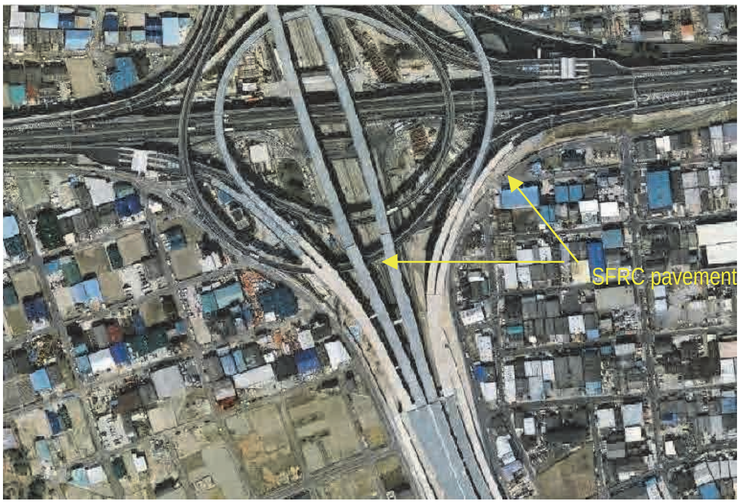


Photo 5.1.3 Kiyosu Junction on Nagoya Expressway

b. SFRC with high-durability epoxy resin bond (used in Yokohama Bay Bridge)

Instead of studs, high-durability epoxy resin bond is newly developed to tightly integrate SFRC with the steel deck plate by spreading it on the whole surface of the steel deck plate. Studs are only installed at the edge of the steel deck plate or where a negative bending moment occurs, as shown in Figure 4.3.4.

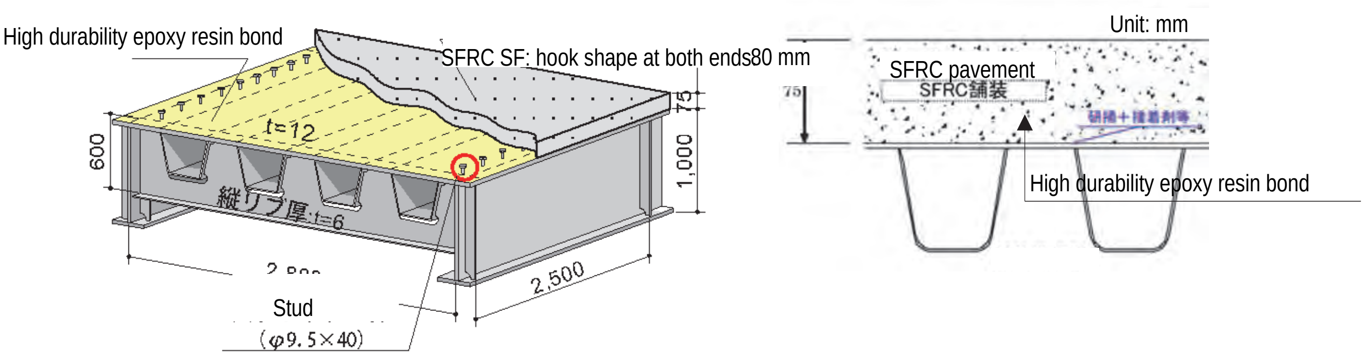


Figure. 5.1.4 SFRC Structure used in Yokohama Bay Bridge

This type of pavement has been applied to No. 357 route running under Yokohama Bay Bridge, Shonan Bridge on No. 134 route, Oohira viaduct on No. 50 route, and Central Ring Road on the Metropolitan Expressway.

Photo 5.1.4 No. 357 Route Running at the Lower Part of Yokohama Bay Bridge

c. SFRC with high-durability epoxy resin bond and asphalt surface (used in Tokyo Metropolitan Expressway

High-durability epoxy resin bond integrates SFRC with the steel deck plate, and a carbon-fiber-reinforced-plastic (CFRP) grid is added to reinforce the top of girder where a negative bending moment occurs. An asphalt surface is also laid on the surface of SFRC in order to reduce noise coming from the roadside, as shown in Figure 4.3.5.

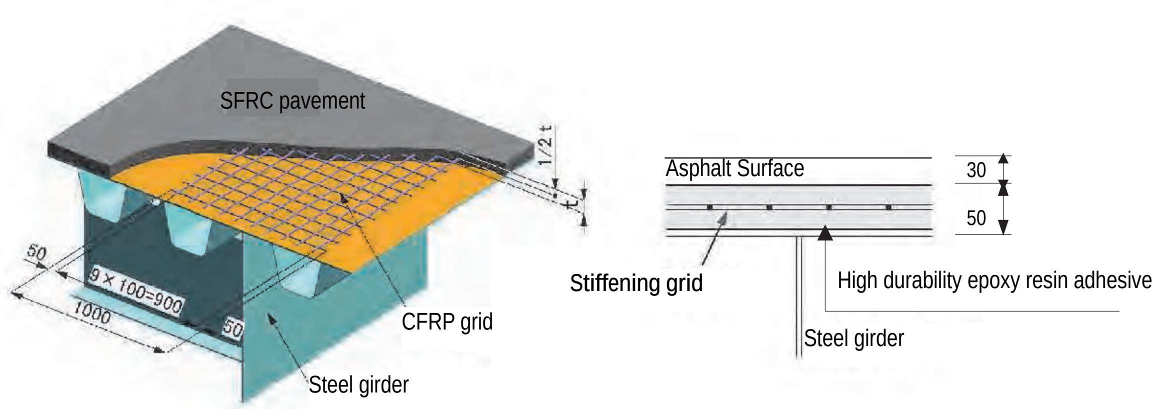


Figure 5.1.5 SFRC Structure used in Metropolitan Expressway

Construction Bond and Carbon Fiber Reinforced Plastic grid

Photo 5.1.5 Central Ring Road in Metropolitan Expressway

d. Engineered Cementitious Composite (ECC)

ECC consists of body structure, FRP plate dowel, and a waterproofing layer. The body structure is made up of cement, fly ash, water, fine aggregate, and short polymer fiber with 0.04 mm in diameter and a 12 mm length. ECC is a cement-based composite concrete reinforced with polymer fibers with high toughness and includes an FRP plate dowel fixed to the steel deck plate by a high-durability epoxy resin bond to make the composite effect more enhanced.

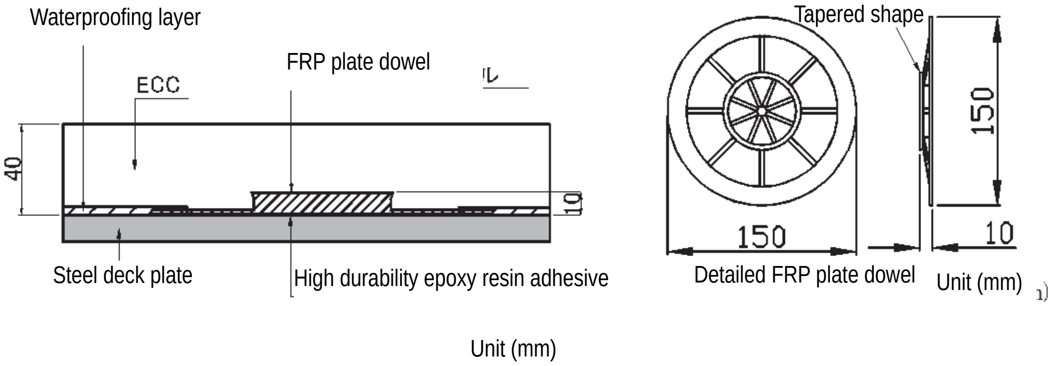


Figure 5.1.6 Scheme of set up of ECC

The Mihara Bridge has applied the ECC method as a trial construction.

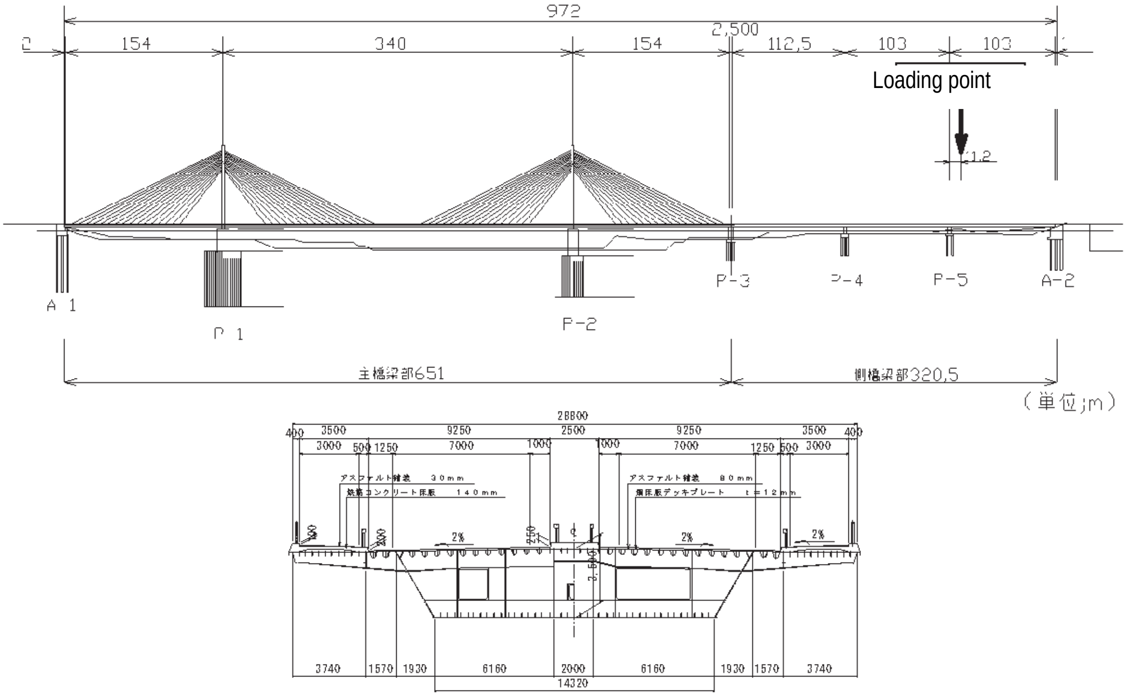


Figure 5.1.7 Side View of Mihara Bridge

Photo 5.1.6 Whole View of Mihara Bridge

Mihara Bridge started its service in March 2005 and just six months later, pavement damage was found. Repair work was carried out soon after investigation. For micro-scale damage, 40 mm thick pavement was changed to 50 mm thickness by adding fine-graded gap-ascon; for small-scale damage, aramid fiber grid was laid over the grinded surface; and for large-scale damage, ECC replacement was applied. In July 2012, however, since no improvement was seen, all pavement was replaced with guss asphalt. Consequently, this shows that ECC application is not yet successful.

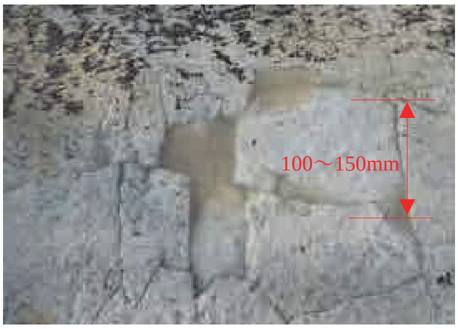


Photo 5.1.7 Damage Occuring on Mihara Bridge

(4) Equipment, Material, and Quality Control

Failure in ECC application gives no choice but to use SFRC as a cement-based pavement for reinforcement of steel deck plates in Japan. For SFRC pavement, equipment and quality control are described in the same way as Nagoya Expressway and Metropolitan Expressway previously.

- Equipment for SFRC pavement
  - ✓ Road surface cutting machine
  - ✓ Stud welder
  - ✓ Bond paste brush
  - ✓ Steel fiber agitator
  - ✓ Concrete finisher
  - ✓ Plate vibrator
  - ✓ Plane finisher

- Quality control

The components of SFRC are concrete, steel fiber, and additives. They comply with quality criteria as described below.

Table 5.1.2 Concrete

Maximum size of coarse aggregate (mm)	15
Cement Type	High-early-strength-cement
Slump after mixing steel fiber (cm)	8 ± 2.5
Water-cement ratio (w/c, %)	Less than 50
Air content (%)	5 ± 1.5
Contamination rate of steel fiber (%)	1.5
Volume of swelling agent (kg/m3)	30

Table 5.1.3 Steel Fiber

Material		Steel fiber specified in JIS G 3532
Shape		Hook shape at both ends
Size	Diameter	0.6mm
	Length	30mm
Tensile strength		600N/mm2 or more

Table 5.1.4 Stiffener with CFRP Grid

Material	Carbon Fiber Reinforced Plastic
Size	2,000mm x 3,000mm
Area	$39.2mm^2$ (approximately 6.3mm x 3.3mm)
Tensile strength	1,400 N/mm^2
Young's modulus	1.0×10^5 N/mm^2 Steel: 2.0×10^5 N/mm^2 Concrete: 3.0×10^4 N/mm^2
Pitch	100mm
Unit weight	1,120 g/m^2

Note that this kind of CFRP grid is unprocurable in Egypt so that instead, embedding rebar into SFRC after applying anti-corrosion coat to rebar is also effective for compressing construction time. At this time, overlaying rebar with another is not allowed to leave a SFRC section sufficient. Tensile strength must be kept.

Table 5.1.5 High-urability-Epoxy-Resin Bond

Item	Primary agent	Stiffening agent
Main component	Epoxy resin	aliphatic polyamine polythiol
Mix ratio	Primary: Stiffening=5~4: 1 (mass ratio)	
Specific gravity	1.35±0.05 (JIS K 7181)	
Compressive strength	50N/mm^2 or more (JIS K 7181)	
Young's modulus	$1.0*10^3$ N/mm^2 or more (JIS K 7181)	
Flexural strength	35 N/mm^2 or more (JIS K 7171)	
Tensile shear adhesive strength	10N/mm^2 or more (JIS K 6850)	

Table 5.1.6 Stud

Item	Standard
Body diameter	9 mm
Head diameter	19 mm
Head thickness	7 mm
Height	40 mm
Weld thickness	4 mm
Tensile strength	400~500 N/mm^2
Yield strength	235 N/mm^2 or more
Elongation	20％ or more

Note that it is unprocurable in Egypt so that instead it is better to newly make a product of it. At this time, all dimensions specified above must be satisfied.

(5) How to Build SFRC Pavement

The following sequence describes how to build SFRC pavement: remove all old pavement; shot blasting; apply corrosion prevention; install studs; paint bond on the surface; install CFRP grid; produce SFRC by putting steel fiber in and agitating; cast place concrete (SFRC); compact concrete; touch up rough surface; and start curing. In the case of adding asphalt to the surface course, after curing SFRC, install a waterproof layer; spread tack coat; distribute asphalt mix; and start rolling compaction with tire roller and steel wheel roller.

- SFRC construction in Nagoya Expressway



(1) Install stud (2) Cast concrete (3) Compact concrete with finisher


(4) Make broom marks (5) Spray curing compound

Photo 5.1.8 SFRC- Stud Type on the Saiwai Bridge in Nagoya Expressway

- SFRC construction in Metropolitan Expressway

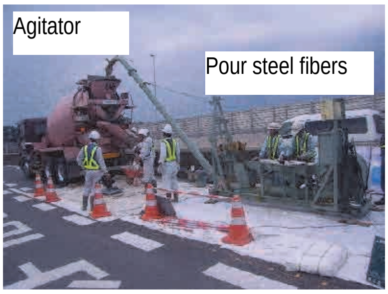


(1) Road surface cutting (2) Cutting work by labor (3) Shot blasting

(4) Install stud shear connector

(5) paint bon

(6) Add a CFRP grid



(7) Agitate steel fibers

(8) Cast concrete

(9) Compact by vibration

(10) Compact with finisher

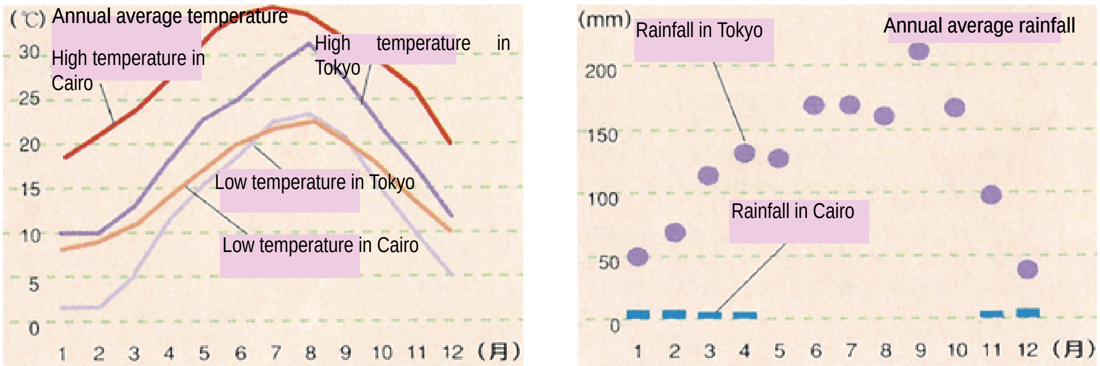
(11) Finish rough surface

(12) Sheet curing

Photo 5.1.9 Construction of SFRC – Bond Type on Tokyo Metropolitan Expressway

(6) Environmental Condition for Construction in Egypt

During SFRC paving, the high-durability epoxy resin bond pasted on the surface of the steel deck plate must remain moist. This infers that the construction time critically depends on temperature. Egypt has four different climates: the Mediterranean climate in the Delta and along the Mediterranean Coast; the semi-arid climate around Cairo; the semi-desert climate; and the desert climate in the east- and west-bound desert in the south. It hardly ever rains, but during winter, it rains around the Mediterranean Coast, and in the coastal regions, Cairo and the westbound desert it becomes quite cold. From March to May, hot and dry *Khamsin* winds blow. The Suez Canal Bridge is located in the regions with a semi-arid climate and a semi-desert climate. In winter, the temperature drops below 10 °C. The morning fog becomes thick around the Suez due to the temperature difference between the air and the water surface, and humidity increases. Low temperatures may rarely impact SFRC pavement but the high humidity over 60% may cause the occurrence of corrosion in the steel deck plate.



Note: Weather data of Cairo are from BBC Weather Centre, and those of Tokyo are from Tokyo Weather Center.

Figure 5.1.8 Average Temperature and Rainfall in Cairo and Tokyo

In June 2012, during the on-site investigation, the air temperature was 20°C at 10:00 AM and the temperature of the road surface was 56°C. Basically, SFRC pavement should be laid before the high-durability epoxy resin bond dries out, as described later in detail. On a road surface with a temperature of 56°C, SFRC pavement must be finished in just 30 minutes, which is logistically impossible.

Photo 5.1.10 Temperature on Road Surface in the Suez Canal Bridge (Pictured at 10:00 AM on 4 June 2012)

(7) Points to Consider for SFRC Pavement in Egypt

GARBLT has claimed that a cement-based pavement method would be achievable in Egypt but they should be aware that SFRC is fundamentally different from common concrete pavement. It is most important to determine how to build cement-based concrete pavement using Egyptian methods considering the current situation of material and equipment procurement, the level of technology that a local company demonstrates, and the features of climate. The points to consider regarding SFRC pavement in Egypt are described below.

- Material and equipment satisfying the given specifications should be procured and acquired without delay. In particular, high-durability epoxy resin bond cannot be obtained in Egypt so it must be imported from neighboring countries or Japan. KS bond made in Japan is well known to be effective under temperature change.

- Procurable material in Egypt must undergo material testing to verify its quality and specifications.

- Local companies have not experienced SFRC pavement work before so they should pay much attention to quality control and technology enhancement through guidance from Japan.

- In Egypt, sand blasting is commonly used to grind the surface of steel deck plates. This kind of blasting may induce many small particles of dust and sand, which take time to dispose of. Corrosion occurs easily. Thus, rather than sand blasting, shot blasting is more effective to clean up corrosion, and an anti-corrosion coat should be applied.

- High-durability epoxy resin bond is vulnerable to temperature so it needs a mild or warm climate. The hot and dry climate in Egypt may result in trouble when developing the SFRC pavement and requires a lot of effort for preparation and management. Regarding time, the surface of the steel deck plate must be maintained at a temperature of less than 30°C in order to develop the SFRC pavement before the high-durability epoxy resin bond dries out.

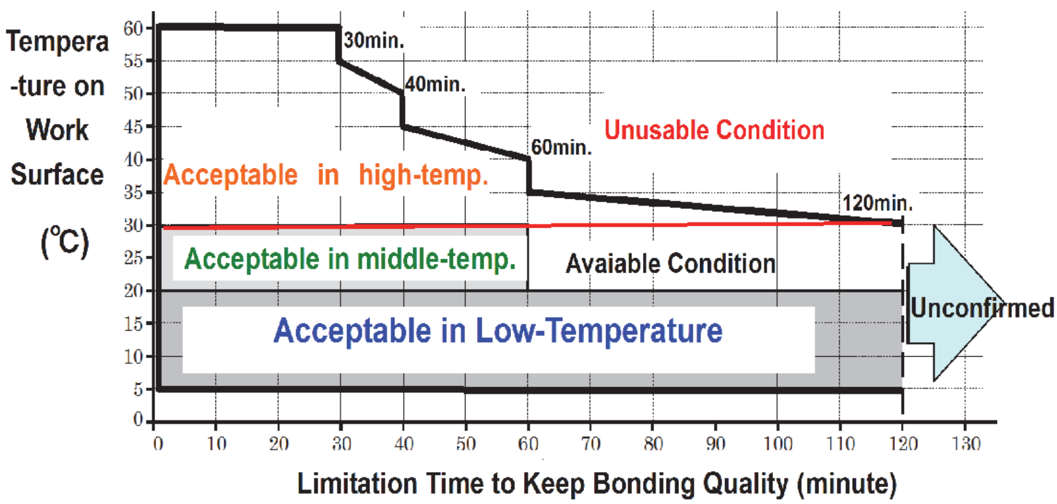


Figure5.1.9 Temperature vs. Construction Time

(8) Developing SFRC Pavement in Egypt

High-durability epoxy resin bond in SFRC pavement is vulnerable to temperature change and has strict construction time constraints. Considering the level of technology of local companies in Egypt, at least 120 minutes is needed to develop SFRC pavement with high-durability epoxy resin bond. That means it may be better to attempt to develop SFRC pavement with studs rather than use high-durability epoxy resin bond. SFRC is relatively thin and surface cracks occur easily. Such cracks have no structurally harmful effect but, if water penetrates into the cracks, there is no denying that it causes corrosion on the steel deck plate. For this reason, covering with asphalt surface after applying a waterproof layer on the SFRC surface is effective; however, it makes it difficult to search for cracks on the SFRC. Thickening the pavement may also cause an increased dead load so it is necessary to examine the effect of dead load increase on the bridge structure. Three types of SFRC can be developed as follows:

a. SFRC - Stud type

Studs play a role in anchoring SFRC to the steel deck plate and then work to enhance composite effect and anti-deflection. High-durability epoxy resin bond can be applied along the construction joint, on the edge of steel deck plate or at a negative bending moment portion. Construction is limited to the winter season.

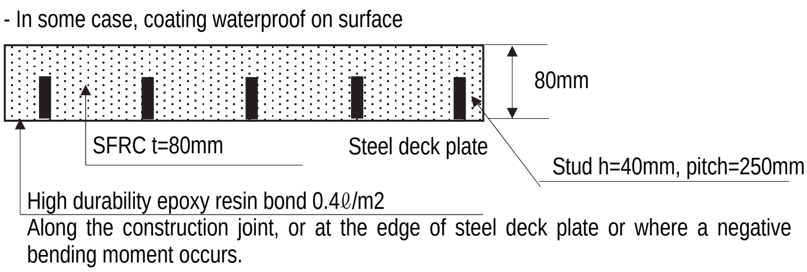


Figure 5.1.10 SFRC - Stud Type

b. SFRC - Bond type (high-durability epoxy resin bond)

Instead of studs, high-durability epoxy resin bond is mostly employed. Studs are used in part at the edge of the steel deck plate or where a negative bending moment occurs on the top of the girder. This is a single layer type.

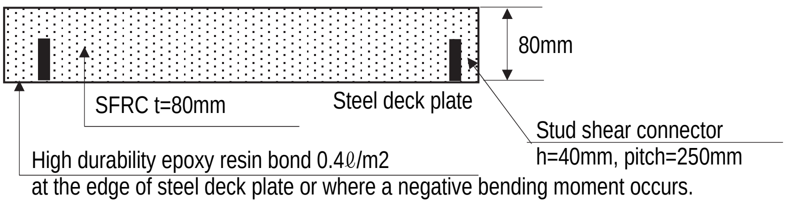


Figure 5.1.11 SFRC- Bond Type

c. SFRC - Bond type and asphalt surface

High-durability epoxy resin bond has enough bond strength to combine SFRC to the steel deck plate, and then works to enhance the composite effect and anti-deflection. A surface course is also applied on the surface of SFRC in order to reduce noise coming from the roadside. High-durability epoxy resin bond is vulnerable to temperature change and needs a lot of care. This is inappropriate in a hot and dry region like Egypt. Nonetheless, once temperature control is possible, it infers that only winter work is possible.

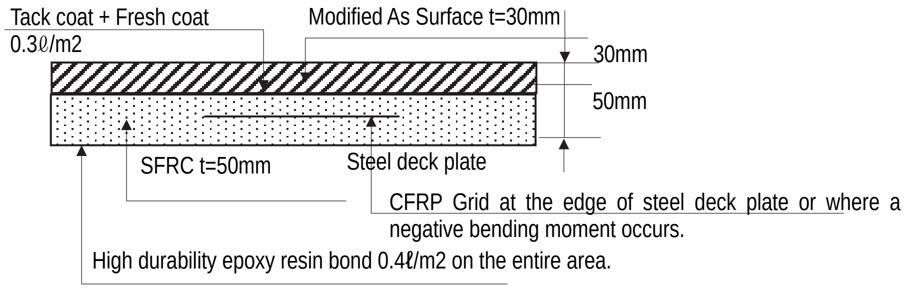


Figure 5.1.12 SFRC- Bond Type + Asphalt Surface

d. SFRC – Stud type and asphalt surface (new type)

Studs are 40 mm high. More than 30 mm is required to cover the margin from the top of the studs. The pavement thickness must not be less than 75 mm. To avoid corrosion problems, a waterproofing layer and asphalt surface need to be placed on the SFRC surface. Dead load increase and transition from the end of the steel deck plate must be properly dealt with. In Japan, dead load increase is the biggest reason for not permitting its application.

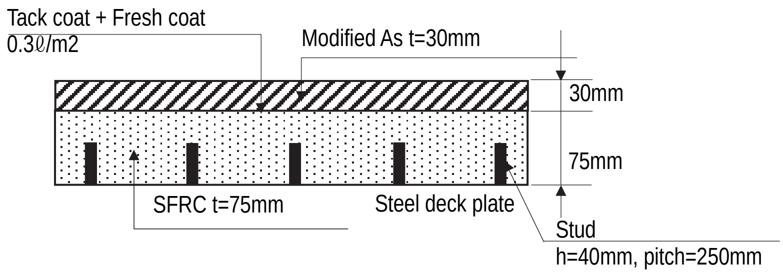


Figure 5.1.13 SFRC Stud Type + Asphalt Surface

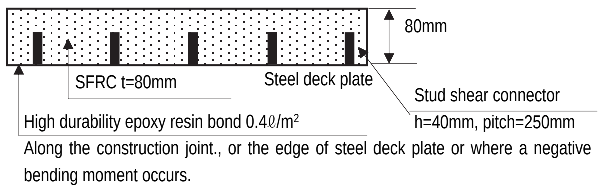
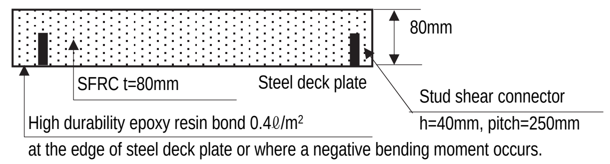
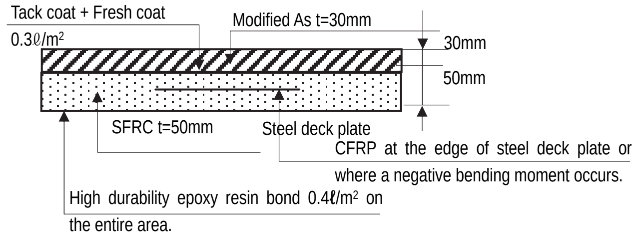
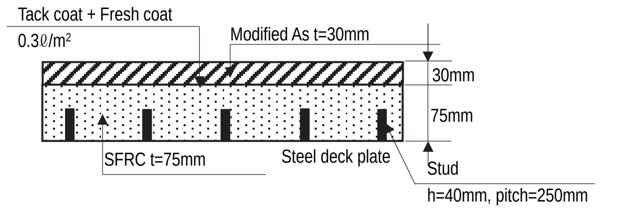
5.1.5 Result of Review on Cement-based Pavement for Reinforcement of Steel Deck Plate

Based on both the current state of material and equipment procurement and climate features in Egypt, types of SFRC available for construction are suggested and a comparative review is done.

In Japan, SFRC has been largely applied to reinforcing steel deck plates located in cities with high traffic volume. This implies that it is important to make much effort to keep the traffic flow as unchanged as possible during work. Thus, SFRC with high-durability epoxy resin bond, *KS bond*, has usually been employed to resume traffic flow as early as possible by way of skipping the installation of studs.

In Egypt, however, high-durability epoxy resin bond must be imported from neighboring countries or Japan. In addition, the hot and dry climate gives rise to difficulties in dealing with high-durability epoxy resin bond for most of the time except the winter season. In the winter, the morning fog becomes thick around the Suez Canal due to the temperature difference between the air and water surface, and may cause corrosion in the grinded steel deck plate. Thus, in Egypt, it is best to choose a type of SFRC pavement that enables easy procurement of material and equipment and is not influenced by weather conditions. Therefore, SFRC with studs plus a minimum use of high-durability epoxy resin bond is recommended.

Table 5.1.7 Comparative Description of SFRC Methods

Type	Cement-based pavement for reinforcement to steel deck plate			
	Steel Fiber Reinforced Concrete (SFRC) – Stud Type	Steel Fiber Reinforced Concrete (SFRC) – Bond Type	Steel Fiber Reinforced Concrete (SFRC) – Bond Type and Asphalt Surface	Steel Fiber Reinforced Concrete (SFRC) with stud and Asphalt Surface(new type)
Structure Section	- Surface course can include a waterproofing coat. 	- Surface course can include a waterproofing coat. 		
Overview	Fatigue cracks have found been recently in a more than 20-year-old orthotropic steel deck bridge (deck plate thickness = 12 mm) in Japan. A way of preventing fatigue cracks and reducing deflection was to develop and apply SFRC pavement including studs that enables tight combination of concrete and the steel deck plate. This is a state-of-the-art technology in effectively suppressing the level of stress concentration by providing a strong internal resistance from the composite effect between concrete and the steel deck plate. Pavement thickness is not less than 75 mm considering the cover margin from the top of studs. Since the mid-1980s, Nagoya City Expressway has used SFRC to prevent or repair the damaged pavement around tollgates or ramp sections with a large longitudinal gradient. The purpose of the use of SFRC is to either repair or reinforce the aging steel deck plate, and then to resume traffic flow as early as possible. For that reason, rather than studs, SFRC with high-durability epoxy resin bond is mostly being used. Recent examples, however, show SFRC with studs has been applied in making structures including snow-melting pipe in cold, snowy regions. Concrete finisher and steel fiber agitator are required exclusively.	Instead of studs, high-durability epoxy resin bond is mostly employed. Studs are only installed at the edge of the steel deck plate or where a negative bending moment occurs. This is a one-layer SFRC type. Concrete finisher and steel fiber agitator are required exclusively.	Without studs, high-durability epoxy resin bond is employed to shorten the period of time of road closure by reducing some complicated works like stud installation. Skipping installation of studs makes the pavement thinner. For waterproofing and anti-cracking, a fresh coat is added and asphalt is included in the surface course. Concrete finisher and steel fiber agitator are required exclusively.	A current state in which the steel deck plate is corroding shows the need for waterproofing. For waterproofing and anti-cracking, a fresh coat is added and asphalt is included in the surface course. Adding a surface course to the top of studs has not been tried in Japan.
Performance	・ This is good at creating an anti-slippage effect where a large longitudinal gradient continues; a composite effect by integrating SFRC with steel deck plate; and low deflection of steel deck plate. (Good) ・ The 80 mm thick pavement is too thin and causes shrinkage cracks but it is not structurally serious. (Normal) ・ Many studs enable tightly combining SFRC with the steel deck plate. (Normal)	・ High-durability epoxy resin bond is newly developed to reduce the use of studs. (Good) ・ The 80 mm thick pavement is too thin and causes shrinkage cracks but it is not structurally serious. (Normal) ・ The application of high-durability epoxy resin bond to the entire pavement area is inappropriate in a hot and dry region like Egypt. The careful use of high-durability epoxy resin bond permits only winter work. (Bad)	・ It works well for solving fatigue cracking problems and enhancing composite effect by integrating SFRC with steel deck plate. (Good) ・ The 50 mm thick pavement is too thin and causes shrinkage cracks, so it needs a waterproof layer between SFRC and surface course. (Normal) ・ Composite action can be gained from combining SFRC with steel deck plate with high-durability epoxy resin bond. If such thin pavement causes peeling itself, damage, cracks or fractures may take place. (Normal)	・ It works well for solving fatigue cracking problems and enhancing composite effect by integrating SFRC with steel deck plate. (Good) ・ The 75 mm thick pavement is too thin and causes shrinkage cracks, so it needs a waterproof layer between SFRC and surface course. (Good) ・ Many studs enable tight combination of SFRC to steel deck plate. (Good) ・ Pavement thickness changes from 80 mm to 105 mm, so this needs a detailed investigation. (Bad)
Constructability	・ Concrete finisher and steel fiber agitator are needed for the exclusive use. (Normal) ・ The 80 mm thick concrete pavement induces hair-like shrinkage cracking. To prevent this, paying close attention to curing and quality control is important. (Normal) ・ The application of high-durability epoxy resin bond only to the edge of steel deck plate outweighs the use of that to the whole area of pavement – used in Metropolitan Expressway – in a hot and dry region like Egypt. (Good) ・ Since 20 years ago, Japan has applied it to ramp sections with a large longitudinal gradient, and a tollgate in Nagoya Expressway. In 2009, Saiwai Bridge, for example, has employed SFRC with studs along with a snow-melting pipe. However, recently, SFRC with high-durability epoxy resin bond is more widely being used than that with studs in order to restore traffic flow quicker. (Normal) ・ Material, equipment and construction should comply with Japanese specifications. (Normal) ・ Studs need to be placed and welded on the steel deck plate at 250 mm pitch; at the same time, much attention must be paid to avoid both scratches and stains on the surface where anticorrosive primer is applied. (Normal) ・ The limited use of high-durability epoxy resin bond allows only winter work. (Normal) ・ To suppress cracking, controlling vibration and keeping temperature low are critical during construction. Road must be completely closed during winter work. (Normal)	・ Concrete finisher and steel fiber agitator are needed for the exclusive use. (Normal) ・ The 80 mm thick concrete pavement induces hair-like shrinkage cracking. To prevent this, paying close attention to curing and quality control is important. (Normal) ・ The application of high-durability epoxy resin bond to the whole pavement area is inappropriate in a hot and dry region like Egypt. The careful use of high-durability epoxy resin bond permits only winter work. (Bad) ・ Since 4 years ago, Japan has applied it to Yokohama Bay Bridge, Shonan Bridge, and Oohira viaduct in Metropolitan Expressway. (Normal) ・ Material, equipment and construction should comply with Japanese specifications. (Normal) ・ To suppress cracking, controlling vibration and keeping temperature low are critical during construction. Road must be completely closed during winter work. (Normal)	・ Concrete finisher and steel fiber agitator are needed for the exclusive use. (Normal) ・ The 50 mm thick concrete pavement causes hair-like shrinkage cracking. To prevent it, paying close attention to curing and quality control is important. (Normal) ・ The application of high-durability epoxy resin bond to the whole area of pavement becomes more difficult than that with studs – used in Nagoya Expressway – in a hot and dry region like Egypt. (Normal) ・ Since 4 years ago, Japan has applied it to Central Ring Road – from Shinjuku to Ikebukuro – in Metropolitan Expressway. (Normal) ・ Material, equipment and construction should comply with Japanese specifications, and a local company can develop the modified asphalt. (Normal) ・ High-durability epoxy resin bond is vulnerable to temperature change. Controlling the road surface temperature to under 30 °C is critical and only winter work is possible. Available times for SFRC pavement are 120 minutes at 30°C, 60 minutes at 35°C, or 40 minutes at 50°C. Any defects may not be removable. (Bad) ・ To suppress cracking, controlling vibration and keeping temperature low are critical during construction. Road must be completely closed during winter work. (Normal)	・ Concrete finisher and steel fiber agitator are needed for the exclusive use. (Normal) ・ The 75 mm thick concrete pavement causes hair-like shrinkage cracking. To prevent it, paying close attention to curing and quality control is important. (Normal) ・ The application of high-durability epoxy resin bond only to the edge of steel deck plate outweighs the use of that to the whole area of pavement – used in Metropolitan Expressway – in a hot and dry region like Egypt. (Good) ・ Japan has no record of application. (Normal) ・ Material, equipment and construction should comply with Japanese specifications, and a local company can develop the modified asphalt. (Normal) ・ Studs need to be placed and welded on the steel deck plate at 250 mm pitch; at the same time, much attention must be paid to avoid both scratches and stains on the surface where anticorrosive primer is applied. (Normal) ・ Thickness change from 80 mm to 105 mm may affect transition from the end of steel deck plate. A detailed analysis is necessary. (Normal) ・ The limited use of high-durability epoxy resin bond permits only winter work. (Normal) ・ To suppress cracking, controlling vibration and keeping temperature low are critical during construction. Road must be completely closed during winter work. (Normal)

Type		Cement-based pavement for reinforcement to steel deck plate			
		Steel Fiber Reinforced Concrete (SFRC) – Stud Type	Steel Fiber Reinforced Concrete (SFRC) – Bond Type	Steel Fiber Reinforced Concrete (SFRC) – Bond Type and Asphalt Surface	Steel Fiber Reinforced Concrete (SFRC) with stud and Asphalt Surface(new type)
Cost *) (unit = JPY) (million= 1,000,000)	Initial cost	Existing pavement cutting 11,824 m^2 x 0.14 k/m^2 x 1.83 (cost rate) = 3 million JPY Shot blasting 11,824 m^2 x 3.05 k/m^2 x 1.83 = 66 million JPY High-durability epoxy resin bond 1,460 m^2 x 3.83 k/m^2 x 1.83 = 10 million JPY Concrete pavement with machines 11,824 m^2 x 3.1 k/m^2 x 1.83 = 67 million JPY Sheet curing 11,824 m^2 x 1.61 k/m^2 x 1.83 = 35 million JPY Stud 11,824 m^2 x 0.6 k/m^2 x 1.83 = 130 million JPY Section arrangement 4,352 m^2 x 0.063 k/m^2 x 1.83 = 0.5 million JPY Traffic lane switching 200 m^2 x 0.27 k/m^2 x 1.83 = 0.1 million JPY Consultant supervision cost = 34.4 million JPY Sub total = 346 million JPY	Existing pavement cutting 11,824 m^2 x 0.14 k/m^2 x 1.83 (cost rate) = 3 million JPY Shot blasting 11,824 m^2 x 3.05 k/m^2 x 1.83 = 66 million JPY Grid spreading 2,920 m^2 x 4.4 k/m^2 x 1.83 = 24 million JPY High-durability epoxy resin bond 11,824 m^2 x 3.83 k/m^2 x 1.83 = 83 million JPY Concrete pavement with machines 11,824 m^2 x 2.22 k/m^2 x 1.83 = 48 million JPY Sheet curing 11,824 m^2 x 1.61 k/m^2 x 1.83 = 35 million JPY Section arrangement 4,352 m^2 x 0.063 k/m^2 x 1.83 = 0.5 million JPY Traffic lane switching 200 m^2 x 0.27 k/m^2 x 1.83 = 0.1 million JPY Consultant supervision cost = 34.4 million JPY Sub total = 294 million JPY	Existing pavement cutting 11,824 m^2 x 0.14 k/m^2 x 1.83 (cost rate) = 3 million JPY Shot blasting 11,824 m^2 x 3.05 k/m^2 x 1.83 = 66 million JPY Grid spreading 2,920 m^2 x 4.4 k/m^2 x 1.83 = 24 million JPY High-durability epoxy resin bond 11,824 m^2 x 3.83 k/m^2 x 1.83 = 83 million JPY Concrete pavement with machines 11,824 m^2 x 2.22 k/m^2 x 1.83 = 48 million JPY Sheet curing 11,824 m2 x 1.61 k/m^2 x 1.83 = 35 million JPY Modified asphalt 11,824 m^2 x 0.9 k/m^2 x 1.83 = 20 million JPY Asphalt kettle 1 set = 10 million JPY Section arrangement 4,352 m^2 x 0.063 k/m^2 x 1.83 = 0.5 million JPY Traffic lane switching 200 m^2 x 0.27 k/m^2 x 1.83 = 0.1 million JPY Consultant supervision cost = 34.4 million JPY Sub total = 324 million JPY	Existing pavement cutting 11,824 m^2 x 0.14 k/m^2 x 1.83 (cost rate) = 3 million JPY Shot blasting 11,824 m^2 x 3.05 k/m^2 x 1.83 = 66 million JPY High-durability epoxy resin bond 1,468 m^2 x 3.83 k/m^2 x 1.83 = 10 million JPY Concrete pavement with machines 11,824 m^2 x 3.10 k/m^2 x 1.83 = 67 million JPY Sheet curing 11,824 m^2 x 1.61 k/m^2 x 1.83 = 35 million JPY Stud 11,824 m^2 x 0.6 k/m^2 x 1.83 = 130 million JPY Modified asphalt 11,824 m^2 x 0.9 k/m^2 x 1.83 = 20 million JPY Asphalt kettle 1 set = 10 million JPY Section arrangement 4,352 m^2 x 0.063 k/m^2 x 1.83 = 0.5 million JPY Traffic lane switching 200 m^2 x 0.27 k/m^2 x 1.83 = 0.1 million JPY Consultant supervision cost = 34.4 million JPY Bridge structure review = 8 million JPY Sub total = 384 million JPY
	Life cycle cost	Repair twice every 10 years Repair 5, m x 10 times = 50 million JPY Sub total = 50 million JPY	Repair twice every 10 years and surface course replacement once every 10 years Repair 5, m x 10 times = 50 million JPY Sub total = 50 million JPY	Repair twice every 10 years and surface course replacement once every 10 years Surface course replacement 23, m x 4 times = 92 million JPY Repair 5, m x 10 times = 50 million JPY Sub total = 142 million JPY	Repair twice every 10 years and surface course replacement once every 10 years Surface course replacement 23, m x 4 times = 92 million JPY Repair 5, m x 10 times = 50 million JPY Sub total = 142 million JPY
		Total cost (Initial cost + LCC) = 396 million JPY	Total cost (Initial cost + LCC) = 344 million JPY	Total cost (Initial cost + LCC) = 466 million JPY	Total cost (Initial cost + LCC) = 526 million JPY
		(2)	(1)	(3)	(4)
Review		• An effective composite action works against steel deck plate thickness reduction, and high performance to resist against steel deck plate deflection can be gained. (Good) • The 80 mm thick concrete pavement causes shrinkage cracking but is not structurally serious. (Normal) • Because high-durability epoxy resin bond is vulnerable to temperature change, its application to the edge of steel deck plate may cause time constraints. It is inappropriate in a hot and dry region like Egypt; but, if the temperature is properly controlled, winter season can be a limited construction time. (Normal) • There is no record of its application in other countries except Japan. It is hard to ensure the performance and quality in other countries. (Normal) • Road needs to be completely closed to avoid vibration during winter work. (Normal) • Visual inspection makes it easier to detect cracks in SFRC and to repair them. (Good)	• An effective composite action works against steel deck plate thickness reduction, and high performance to resist against steel deck plate deflection can be gained. (Good) • The 80 mm thick concrete pavement causes shrinkage cracking but it is not structurally serious. (Normal) • The application of high durability epoxy resin bond to the whole area of pavement is inappropriate in a hot and dry region like Egypt. (Bad)	• An effective composite action works against steel deck plate thickness reduction, and high performance to resist against steel deck plate deflection can be gained. (Good) • The 50 mm thick concrete pavement causes shrinkage cracking but it is not structurally serious. (Normal) • The application of high durability epoxy resin bond to the whole area of pavement is inappropriate in a hot and dry region like Egypt. Even work during the winter season cannot assure the pavement quality. (Bad) • It costs more than SFRC with stud used in Nagoya Expressway. (Normal) • There is no record of its application in other countries except Japan. It is hard to ensure the performance and quality in other countries. (Normal) • Road needs to be completely closed during winter work. (Normal) • Difficult to detect cracks in SFRC, and if cracks are found in surface course, it means severe corrosion has already occurred in the steel deck plate. (Bad)	• An effective composite action works against deck plate thickness reduction, and high performance to resist against steel deck plate deflection can be gained. (Good) • The 75 mm thick concrete pavement causes shrinkage cracking but it is not structurally serious. (Normal) • Because high-durability epoxy resin bond is vulnerable to temperature change, its application to the edge of steel deck plate may cause time constraints. It is inappropriate in a hot and dry region like Egypt; but, if temperature is properly controlled, winter season can be a limited construction time. (Normal) • It costs the most among all types. (Bad) • Japan has no record of application. (Normal) • Road needs to be completely closed to avoid vibration during winter work. (Normal) • Dead load increase is concerning. (Bad) • Good for waterproofing but difficult to detect cracks in SFRC, and if cracks are found in surface course, it means severe corrosion has already occurred in steel deck plate. (Bad)
		Normal	Bad	Bad	Bad

NOTE: *) Cost estimates are based on NETIS (New Technology Information System).

5.1.6 Features of SFRC – Stud Type

The hot and dry climate in Egypt requires the use of SFRC with studs used previously in Nagoya Expressway. Here are features to be considered in quality and construction.

(1) Quality

- *Cement*: It is recommended that the type of cement be decided after reviewing the results of the shear strength test to verify compatibility with the chosen bond. If no difficulty arises in long-sustained traffic regulations during construction, high-early-strength concrete is preferable.

- *Fine aggregate*: It is undesirable to use crushed sand because it tends to increase water content per unit volume of concrete. Inevitably, if the crushed sand is employed, it is necessary to verify the required qualifications through a paste test while complying with the standards of *JIS A 5005 Crushed Stone and Sand for Concrete.*

- *Coarse aggregate*: Coarse aggregate size relies on steel fiber length and makes an impact on the flexural strength of SFRC. It is recommended the size be not more than two thirds of the length of steel fiber and 0.4 times pavement thickness. Alkaline aggregate reaction needs to be paid attention to in order to improve the quality by sorting and screening faultless aggregate.

- *Admixture*: It is recommended to use super water reducer or super AE water reducer in SFRC in order to reduce water content per unit volume of concrete in the given range considering desirable workability. To use high-early-strength concrete, a special plasticizer or retarding admixture is needed to delay hardening time. When early-strength concrete is used to reduce the amount of dry shrinkage, it is typical to add expansive admixture, which is specified in the standards of *JIS A 6202 Expansive Admixture for Concrete.*

- *Steel fiber*: SFRC strength and resistance against cracking depends on the size and shape of steel fiber and its volume. Steel fiber can be designed by complying with the Standards of SFRC Mix Design.

Standards of SFRC Mix Design

- ✓ SFRC must have a certain level of workability in terms of strength, durability, water tightness and performance, and satisfy the needed quality.
- ✓ Quality control should be done as follows:
- ✓ SFRC needs to be designed in order to reduce water content per unit volume of concrete in the given range considering preferable workability.
- ✓ Type of cement needs to be properly selected and used in SFRC considering construction constraints.
- ✓ Mixing amount of steel fiber normally reaches 100-120 kg/m^3.
- ✓ Water-cement ratio is basically less than 50%, and can be defined considering compressive

strength and durability of SFRC.

- ✓ Coarse aggregate has a size of not more than two thirds of the length of steel fiber and 0.4 times pavement thickness.
- ✓ Fine aggregate has a rate that enables reduction of the water content per unit volume of concrete in the given range considering desirable workability.
- ✓ Slump is equal to 8.0±2.5 cm.
- ✓ Air content is equal to 5.0±1.5% when early-strength concrete is made.
- ✓ Average design strength of SFRC is listed in Table 4.3.7.

Table 5.1.8 Average Design Strength of SFRC

Concrete	Curing	Period	Design strength	Test standard
Ultra High early-strength concrete	Wet	3 hrs	24N/mm^2 or more	JIS A 1108
Early-strength concrete	Under water	7 days	30 N/mm^2 or more	

- ✓ Amount of dry shrinkage should be controlled to a less extent to prevent inducing harmful cracks in SFRC.

- *Bond*: bond should be tested and verified individually to meet the needed performance.

Table 5.1.9 Test Items for Performance Verification

<table>
<tr><td colspan="2" rowspan="2">Description</td><td colspan="3">Test conditions</td></tr>
<tr><td>Test item</td><td>Environment</td><td>Test and result</td></tr>
<tr><td rowspan="2">Strength</td><td rowspan="2">Adhesive strength</td><td>・Bond
・Cement
・Primer (if necessary)</td><td>NO environmental effect
Temperature for test:
-10°C, 20°C, 50°C</td><td>Shear strength test,
More than 90% of fracture area in the mixed SFRC with the bond or in SFRC.</td></tr>
<tr><td>・Bond
・Cement
・Primer (if necessary)
・Temperature of steel deck plate
・SFRC placement time
・SFRC mix</td><td>NO environmental effect
Temperature for test: 20°C</td><td>Tensile bond strength test,
More than 90% of fracture area in the mixed SFRC with the bond or in SFRC.</td></tr>
<tr><td rowspan="2">Durability</td><td>Temperature change and water</td><td>・Bond
・Cement
・Primer (if necessary)</td><td>Soak for 27 days in water with 50°C, and dry for a day in air.
Temperature for test: 20°C</td><td>Shear strength test,
More than 90% of fracture area in the mixed SFRC with the bond or in SFRC.</td></tr>
<tr><td>Fatigue</td><td colspan="3">Fatigue test reflects on live loading condition and acting force to joint, adequately.
・Bond
・Cement
・Primer (if necessary)</td></tr>
</table>

- *Studs*: Installing studs at the edge of SFRC pavement or around construction joints is not an option. They are expected to suppress local deterioration induced by water intrusion and to hold back damage due to dry shrinkage.

(2) Construction

- There is concern that small amounts of corrosion left in the steel deck plate may expand and damage SFRC to be peeled off steel deck plate. To remove corrosion, shot-blasting treatment is more effective than sand blasting.
- During winter, the morning fog occurs around the Suez Canal. As an anti-corrosion treatment, primer should be applied following shot-blasting grinding on the surface of the steel deck plate.
- Maintaining the flat surface of SFRC is required. Flatness is a feature for providing mobility, safety and comfort to drivers, and it is important to prevent cracking or uneven stress arising. Flatness stays within ±2 mm at every 4 m distance.
- Studs should be upright installed at an equal pitch.
- Spreading high-durability epoxy resin bond at the edge needs to be uniformly done under cautious temperature control. After that, SFRC should be placed promptly.

Table 5.1.10 Quality Control of Bond during Construction

Time	Item	Test	Period	Description
Before construction	Amount of bond	Count number of bond cans	One time	Consistent with construction plan document
	Temperature on the surface of steel deck plate	Measure temperature with a thermometer	A point every 10 m	Within the defined temperature range
During construction	Mix ratio	Measure weight of primary and stiffening agents	During the bond mixing work	Predefined mix ratio of primary and stiffening agents
	Mix state	Visual observation	During the bond mixing work	Mix evenly
	Paste thickness	Measure with a gauge	Three points every 10 m in transverse direction	Average coating thickness is 1.0 mm, and the minimum is 0.5 mm
	Paste state	Visual observation	All over construction area	Paste the bond evenly all over the surface of steel deck plate. Paste on the splice plate of steel deck plate and construction joint
After construction	Tensile bond strength	Tensile bond strength test	Before open traffic for construction	Three specimens average strength is 1.0 N/mm^2 or more.
	Paste time	Measure time from when bond mixing starts	One time	Finish in the time the bond is available

- Inserting spacers and agitating the steel fibers is important to prevent the steel fibers from fusing.
- Prompt and sufficient compaction follows SFRC placement. The finishing surface should satisfy conditions of shape, quality and dimension to some extent.
- Curing should be carried out by maintaining the temperature and humidity necessary to harden the concrete during a certain period of time, and be free from dry shrinkage, drastic temperature change, and unfavorable effects due to wheel loading.

- While SFRC is hardening, vibration should be controlled. The road needs to be completely closed during the winter because of the use of high-durability epoxy resin bond. Road closure is required for three months to enable concrete to harden. Material and equipment supply must be on time, otherwise, the work schedule may be extended and the road will be closed for a longer period.

- When it comes to SFRC construction, the construction range depends on the maximum daily quantity of SFRC. Depending on the quantity of SFRC, a horizontal construction joint can be made. It is common to build SFRC by each lane and make a longitudinal joint at the edge of the lane to keep concreting constantly and smoothly. These construction joints are made by cutting a 20 mm depth and a 4 mm width and filling with a joint-filling compound.

(3) Apprehension about Practice Constrictions

- Welding a number of studs on steel deck plates takes much time. During welding, corrosion may reoccur on the grinded surface of the steel deck plate. This kind of corrosion will probably not only erode the steel deck plate but will also cause poor adhesion. This may result in severe damage to the SFRC and steel deck plate. Thus, anti-corrosion treatment should be carried out after grinding the surface of the steel deck plate.

- Installing studs upright at an equal pitch is important. This improves the quality of studs directly associated with lowering the risk of cracks or damage.

- Consistently agitating a number of small steel fibers is critical. If not sufficiently done, it may cause poor quality and result in a chunk of them to being unusable. In addition, corrosion or large cracks will probably emerge.

- Proper compaction and curing will assure the quality and prevent cracking or peeling.

5.2 Summary and Construction Plan of Selected Method in the Study

5.2.1 Summary of Selected Method

The selected SFRC pavement is compared again with guss asphalt pavement method.

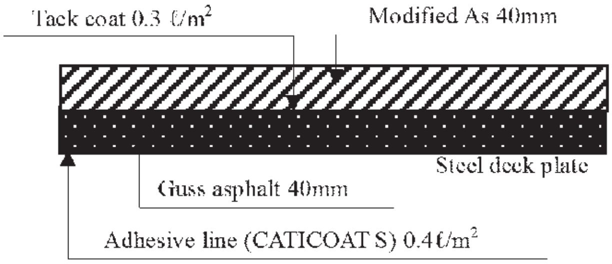
Since the concrete thickness of the SFRC is as thin as 80 mm, cracks due to shrinkage tend to occur during hardening. Work shall be limited to the winter season to avoid the high temperatures and drying circumstances. In addition, the traffic shall be fully closed to suppress the vibration until the concrete hardens.

Securing the quality requirement is difficult because a huge number of studs must be welded and painted with anticorrosive material, and high-durability epoxy resin bonding is very sensitive.

In contrast, the work using guss asphalt doesn't require traffic closure and isn't affected by temperature. Guss asphalt work has less chance of failure if the correct mix design is managed appropriately.

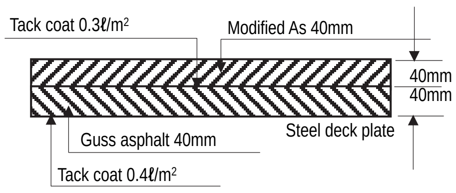
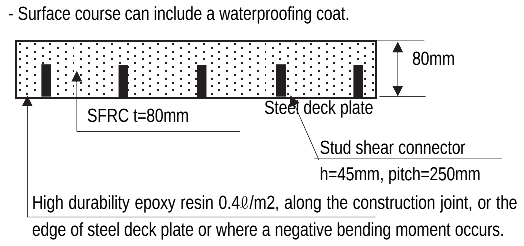
Based on the results of the re-comparison as explained above, the guss asphalt method is determined to be the most suitable method for pavement repair work for the Bridge, and is recommended.

Technical feature of guss asphalt and requirement on construction are mentioned as follow;



- Guss asphalt is the first developed in Germany for the pavement of steel deck plate.
- In Japan, since 1950s it has been applied, many of long-span bridges in Japan are using the method.
- It has well flexibility against deflection due to high adhesion with steel deck.
- TLA (Trinidad Lake Asphalt, natural asphalt improved asphalt) is employed under high temperature (220~260ºC) to produce Guss asphalt which is highly fluid. This needs the special equipments, guss-cooking-car and guss finisher.
- T.L.A shall be imported from third country, and guss-cooking-car and guss finisher shall be transferred from japan or Europe

Table 5.2.1 Guss Asphalt vs. SFRC with Stud Type

Type		Guss Asphalt	Steel Fiber Reinforced Concrete (SFRC) – Stud Type
Structure Section			
History of Development		・ Guss asphalt was first developed in Germany for pavement on steel deck plate. ・ In Japan, since the 1970s, it has been developed and applied to Honshu-Shikoku Bridges. Now, many long-span bridges in Japan use it as pavement on steel deck plate. ・ No problem has ever been found over two decades since it has been applied to Honshu-Shikoku Bridges.	・ SFRC has been developed to improve deteriorated steel deck plate in expressway bridges in Japan for about two decades. ・ Except for a few failure records, most improved bridges have kept good performance.
Technical Feature		・ Guss asphalt mixture is made by mixing TLA (Trinidad Lake Asphalt, natural asphalt) to asphalt bitumen under high temperature (220~260ºC).	・ SFRC is made of concrete mixed with many small steel fibers to increase its strength. ・ In SFRC-Stud Type, SFRC layer is integrated to the steel deck plate by a huge number of stud bolts.
Special Material and Equipment		・ TLA (Trinidad Lake Asphalt, natural asphalt) by import. ・ Setting the kettle for TLA in asphalt plant to produce guss asphalt. ・ Guss Finisher ・ Guss Cooker Car	・ Stud bolts to integrate SFRC Layer to steel deck plate. ・ High durability epoxy resin bond is applied along SFRC construction joint. ・ Steel Fiber ・ High-early-strength-concrete
Quality		・ Since flexibility against deformation of steel deck plate is superior, cracks are less likely to occur. ・ High water-tightness. ・ Good flatness.	・ Composite effect by integrating SFRC with steel deck plate results in low deflection of steel deck plate. ・ Low water-tightness. ・ Low flatness. ・ Since concrete pavement thickness is thin (80 mm), cracks intend to occur and develop on SFRC. ・ Once cracks develop, water penetration results in rust on steel deck plate again. ・ Serious quality control for high-durability epoxy resin bond and High-early-strength-concrete ・ Risk of remaining rust after sand blasting, insufficient stud welding and unequal mixing of steel fiber.
Constructability		・ Shot blasting should be chosen for grinding or abrading the surface of steel deck plate. (Normal) ・ Total construction period is 7 months. ・ Paving of guss doesn't depend on temperature condition of the site. ・ Public traffic needs restriction (total 4-lanes -> total 2-lanes).	・ Shot blasting should be chosen for grinding or abrading the surface of the steel deck plate. ・ Total construction period is from 11 to 19 months ・ Concrete shall be caste during the winter season (December to January). ・ Public traffic needs to be completely stopped due to concrete casting and curing for 7 days. Approximately a one-month closure for each side (south & north) is required. (Economical and social impacts)
Cost (Estimated by Local Contractor)	Initial cost	Existing pavement cutting 11,824 m² = 176,000 $ Shot blasting 11,824 m² =254,000 $ Bond spreading 11,824 m² =1,054,000 $ Guss Asphalt (labor cost included) 11,824 m² = 1,462,000 $ Modified asphalt 11,824 m = 624,000 $ Traffic lane marking 4352 m = 72,000 $ Technical Fee (by Associated firm) = 83,000 $ Subtotal = 3,725,000 $ Consultant supervision cost = 42,000 $	Existing pavement cutting 11,824 m² = 175,000 $ Sand blasting (including Epoxy Primer) 11,824 m² = 436,000 $ Installing Stud 11,824 m² = 213,000 $ High-durability epoxy resin bond 1,574 m² = 59,000 $ SFRC Layer 11,824 m² =291,000 $ Thermal Joint 1,574 m =336,000 $ Sub total = 1,581,000 $ Consultant supervision cost = 42,000 $
	Life cycle cost	Repair twice every 10 years and surface course replacement once every 10 years Surface course replacement 295,000$ x 4 times = 1,180 ,000 $ Repair 128,500$ x 10 times = 641 ,000 $ Subtotal = 1,821 ,000 $	Repair twice every 10 years Repair 5, m x 10 times = 640 ,000 $ Sub total = 640,000 $
		Total cost (Initial cost + LCC) = 5,588,000 $	Total cost (Initial cost + LCC) = 2,263 ,000 $
		(2)	(1)
Evaluation		The 80 mm thick concrete pavement is too thin and will easily result in shrinkage cracks. It may be hard to built it under hot and dry weather conditions. Winter can be a limited construction period. Serious quality control shall be needed to conduct SFRC method. SFRC requires closure of the whole bridge. It has economical and social effects. As a result, guss asphalt is recommended as the pavement repair method for the steel deck plate in the Suez Canal Bridge.	

NOTE: *) Cost estimates are based on NETIS (New Technology Information System).

Table 5.2.2 Outline of Construction Schedule for SFRC (1)

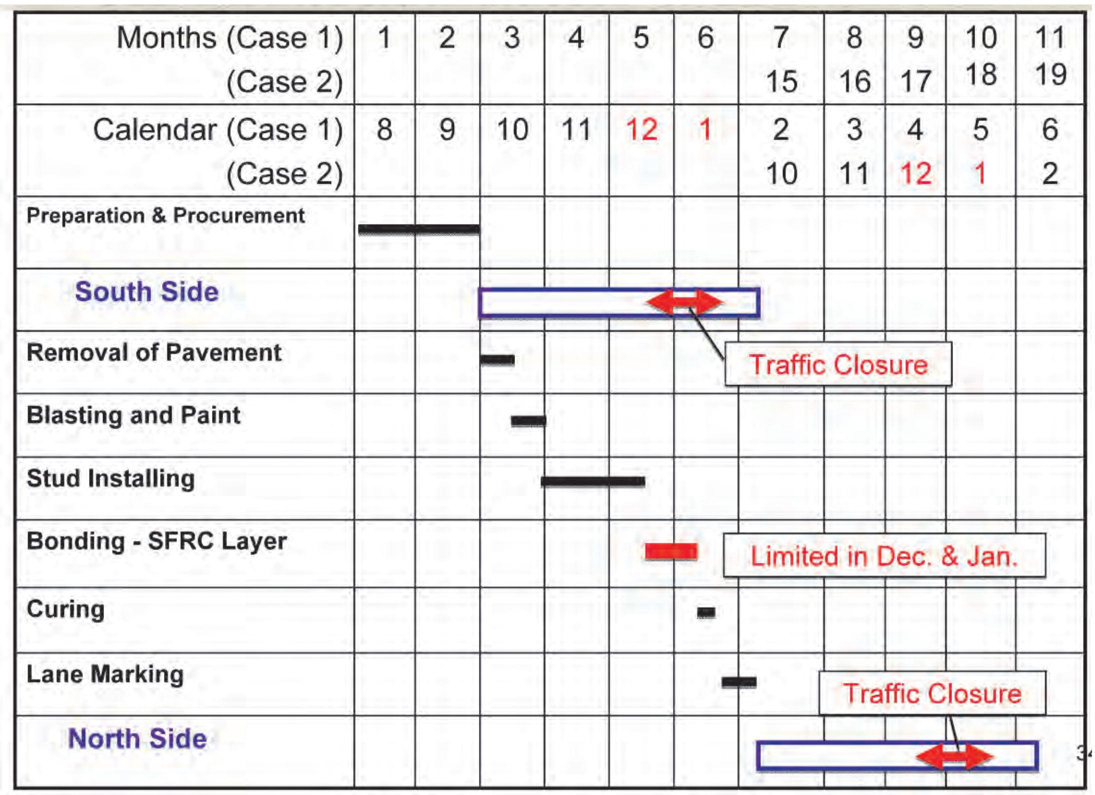


Table 5.2.3 Outline of Construction Schedule for SFRC (2)

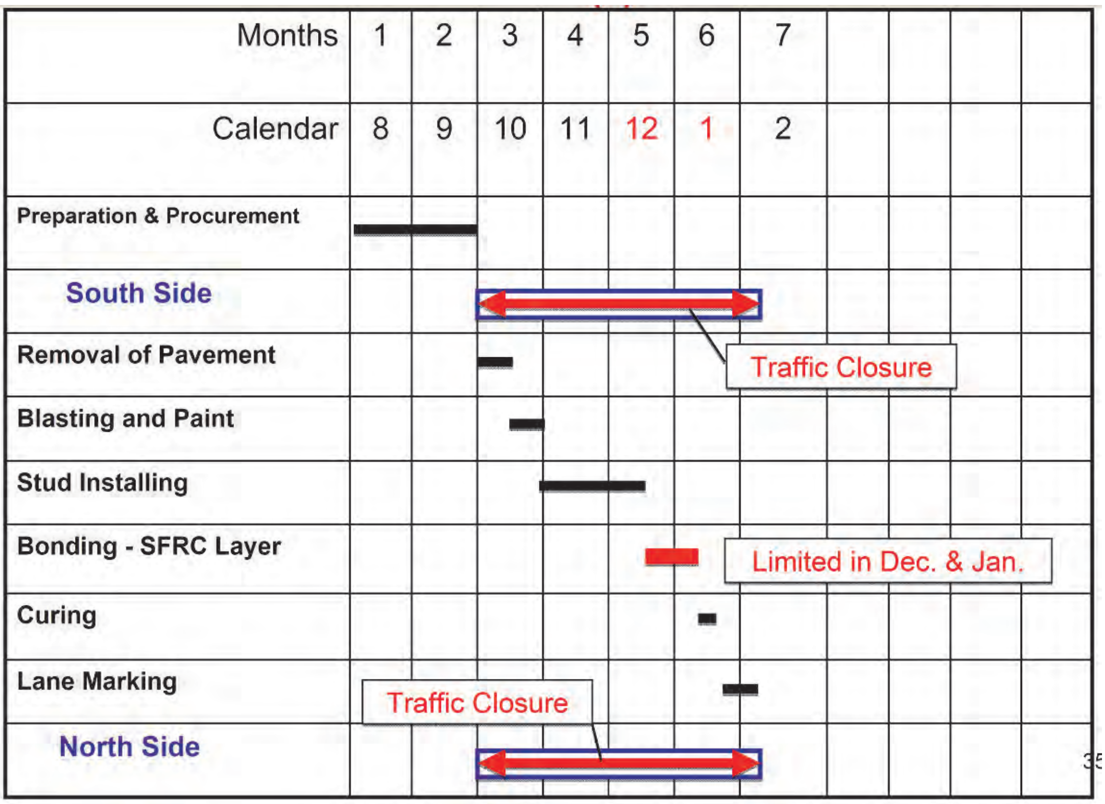
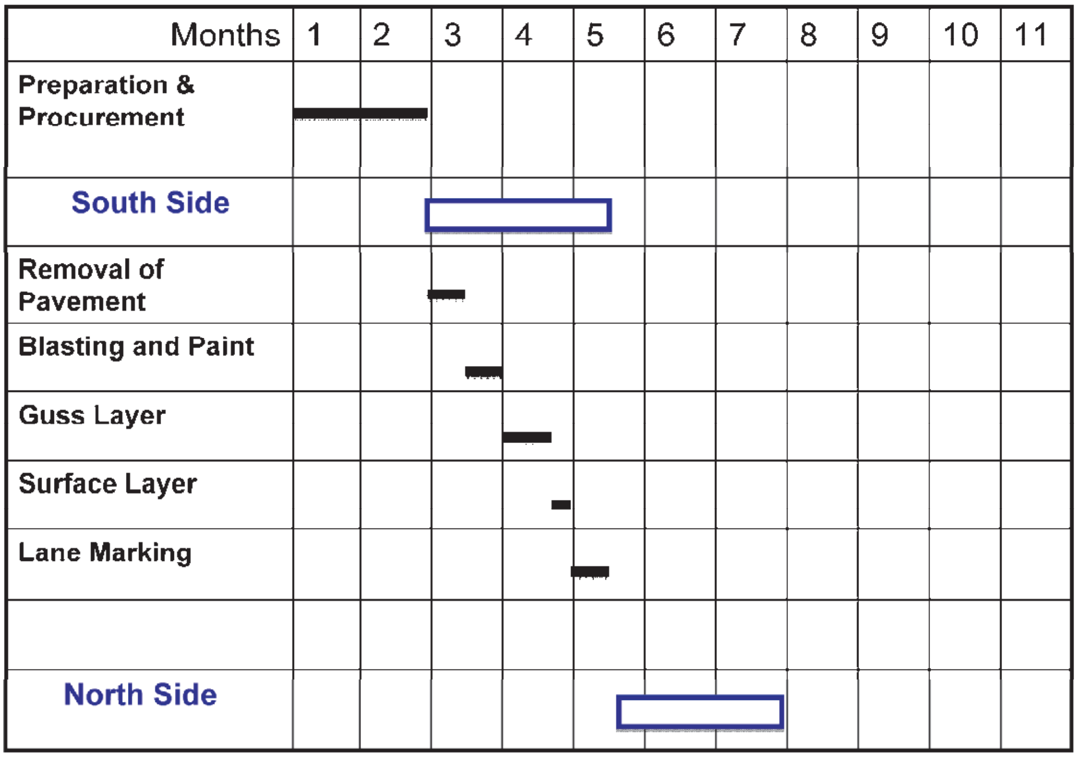


Table 5.2.4 Outline of Construction Schedule for Guss Asphalt



5.2.2 Summary of Construction Plan

(1) Removal of Existing Pavement

Existing pavement layers for both the surface course and binder course shall be broken and peeled off by excavator and rock drill. Rubble from pavement blocks shall be transported by dump truck. The structure of existing pavement is shown in the figure below.

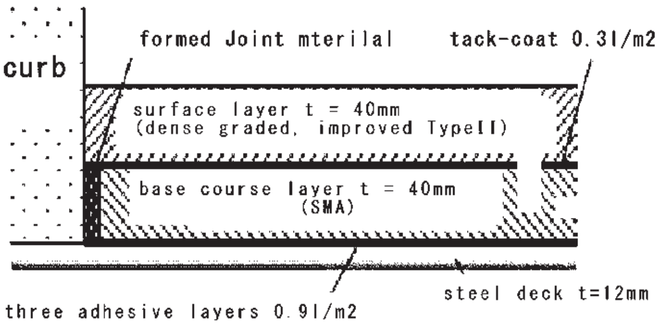


Figure 5.2.1 Exsisting Pavement Structure

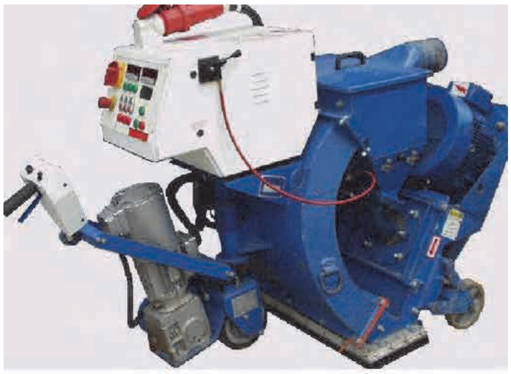
(2) Shot-blasting (Preparation of steel deck plate)

For preparation of the bonding layer on the steel deck plate, shot-blasting shall be carried out to remove the existing bonding layer, rust, oil and deteriorated paint. Prior to the blasting work, the surface of the deck plate shall be dried. After the blasting, the bonding layer work shall be immediately carried out because the surface of the steel deck plate tends to rust quickly.

Equipment to be used for shot-blasting

- Shot-blast projection machines
- Dust collector for suctioning dust, sediment piled from the surface of the steel deck plate.
- Trucks for delivery of the shot-blasting projection machines and removal of dust.

Shot-blast projecter



Dust-Collector

Photo 5.2.1 Equipment of Shot-blast Injection

(3) Bonding Layer

Prior to the work on the guss asphalt binder layer, the bonding layer made from dissolved-type rubber-asphalt shall be applied to combine the guss asphalt with the steel deck plate.

Photo 5.2.2 Status of painting Bonding Material

(4) Guss Asphalt Binder Layer

The guss asphalt mixture will be heated and mixed to 240ºC in a special cooker vehicle, and be placed on the steel deck plate by the guss asphalt finisher.

Guss Finisher Guss Mobile Cooker

Photo 5.2.3 Equipment for Guss Asphalt Pavement

(5) Tack Coat

After placing the guss asphalt layer, a tack coat shall be sprayed on it to ensure the bonding with the surface layer. In general, either emulsified cutback asphalt or emulsified rubberized asphalt is applied to be used as the bitumen material for the tack coat. A distributer shall be used to spray the emulsion.

Photo 5.2.4 Distributer

(6) Modified Asphalt for Surface Layer

The modified asphalt for the surface layer results in better performance than normal asphalt by adding modified additives, such as polymer or rubber.

Equipment to be used for placing modified asphalt

Asphalt finisher

Road roller

Tire roller

Vibration roller

Asphalt finisher

Road Roller

Tire-Roller

Vibration Roller

5.3 Summary Project Cost Estimation

Because the repair method using a guss asphalt binder (+modified asphalt surface layer) has been selected, the following surveys were conducted to estimate the construction cost:

During the 4th site survey, GARBLT proposed that Egyptian contractors should do the repair work. In response to this proposal, the Survey Team asked some major Egyptian general contractors who have sufficient experience in bridge and pavement works to submit a quotation for the repair works.

As for the information, technical specifications (draft) for guss asphalt were given to the contractors to clarify the construction and material quality requirements to enable them to make an accurate quotation.

After the evaluation of the quotations submitted, SAMCO was selected because their understanding of the construction method was technically correct and the quotation was reasonable. Then, SAMCO's quotation was submitted to GARBLT as the project cost estimate.

Their estimated cost amounts to LE 22,573,000 (approx. US$ 3,725,000=approx. Yen 291,000,000, Exchange rate: LE 1=Yen 12.883) as shown below.

Table 5.3.1 Unit Price/ Total Summary Cost for Repair Work by Guss Asphalt Method

Unit Price / Total Summay Cost for Repair Work by Guss Asphalt Method

Campany		SAMCO				
Guss Asphalt Method						
No.	Work Items	Unit Price (L.E)		Quantity	Cost (L.E)	USD
1	Removal of Existing Pavement	90	/m2	11,824	1,064,160	176,000
2	Shot-Blasting	130	m2	11,824	1,537,120	254,000
3	Epoxy Primer	290	m2	11,824	3,428,960	566,000
4	Bonding layer	250	m	11,824	2,956,000	488,000
5	Guss As.Binder Layer	750	m2	11,824	8,868,000	1,463,000
6	Tack Coat	120	m2	11,824	1,418,880	234,000
7	Surface Layer (Modified As.)	200	m2	11,824	2,364,800	390,000
8	Traffic Line Marking	100	mL	4,352	435,200	72,000
9	Consulting	500,000	L.s	1	500,000	83,000
						1 （LE） ＝0.165 $
Total Cost					22,573,120	$3,725,000

On the other hand, in the case of Japanese or German contractors (because guss asphalt technology has been developed in Japan and Germany), the Survey Team estimated the repair cost separately.

The repair cost in the case of Japanese contractors was estimated according to JICA's manual, "Preparatory Survey, Design and Cost Estimate Manual (Civil works), March 2009." The estimated cost is approx. Yen 330,000,000 including consultant fee.