For information

Legislative Council

Panel on Development

DEFORMATION OF ROAD SURFACES ON BRIDGES

PURPOSE

This paper is to inform Members of the causes of the premature deformation in parts of the road surfaces on the West Kowloon Expressway Viaduct, the Kap Shui Mun Bridge, the Ma Wan Viaduct and the Ting Kau Bridge (the four bridges), and the actions taken to rectify them.

BACKGROUND

2. The four bridges were constructed as part of the transport network linking the Hong Kong International Airport at Chek Lap Kok to other parts of Hong Kong. Shortly after the four bridges were opened to traffic in 1997 and 1998, deformation of parts of the road surface was reported. The Audit Commission investigated the issue and recommended in Chapter 7 of its report No. 40 issued in March 2003 that Highways Department should submit a detailed report to the then Environment, Transport and Works Bureau and Legislative Council to inform them of the causes of the premature road surface deformation and the actions taken to rectify them. After detailed investigation and various laboratory tests and site trials, Highways Department has now completed a technical report on the causes of the defects. This is attached at the Annex. The following is a summary of the key aspects of the report.

CAUSES OF PREMATURE ROAD SURFACE DEFORMATION

3. The four bridges were built using a construction technique in which segments of the bridge structure were precast and then lifted or launched into position and joined together. Asphalt was laid on top of the bridge deck to provide the riding surface. To prevent water from seeping through the asphalt surfacing and the joints between segments which might corrode the steel

reinforcement and stressed steel tendons inside the bridge, corrosion protection measures were adopted in these bridges. As an added line of defence, a waterproofing membrane was applied on the bridge deck surface. A layer of tack coat was applied to provide adhesion between the asphalt surfacing and the membrane. A typical cross section of a bridge deck of such construction is shown in Figure 1.

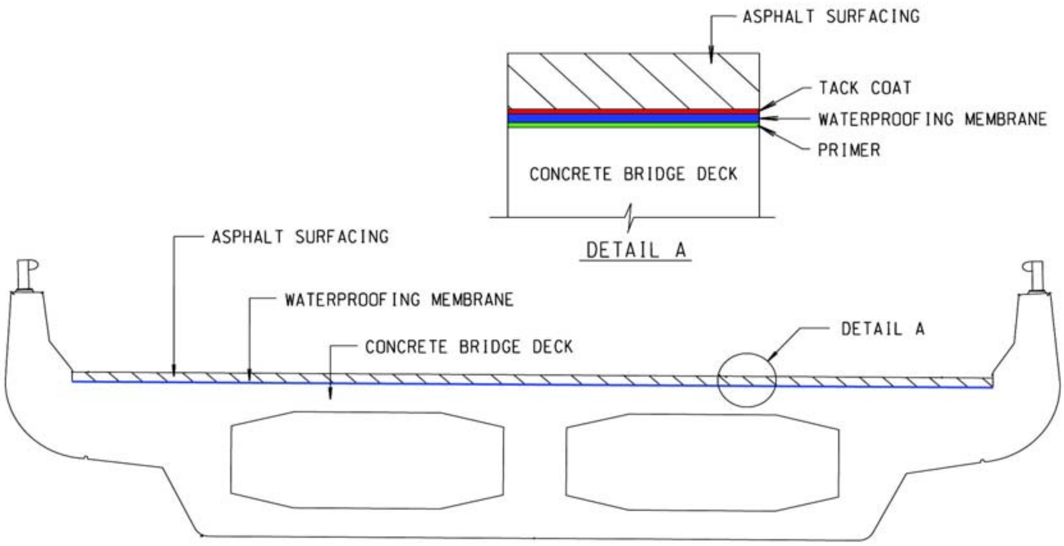

Figure 1 – Typical cross section of asphalt surfacing and bridge deck waterproofing membrane on a concrete bridge

4. Highways Department assigned the University of Hong Kong (HKU) to investigate the problem in November 1998. The study report completed in 1999 considered that the two most significant factors causing the deformation were:

i) low adhesion between the waterproofing membrane and the asphalt surfacing, and

ii) moisture saturation in the asphalt surfacing.

The report recommended that further laboratory tests and site trials be performed to verify the postulation.

5. Highways Department included the recommended laboratory tests and site trials in its Ngong Shuen Chau Viaduct (NSCV) contract which commenced in April 2002. The laboratory tests were carried out in 2004 and the site trial was conducted between February 2005 and February 2006. A

separate site trial was subsequently carried out between February 2006 and May 2007 on a bridge deck under the Yuen Long Highway contract.

6. The key findings of the laboratory tests and site trials have confirmed the findings of the HKU investigation and indicated that:

i) the low adhesion between the waterproofing membrane and the asphalt surfacing could cause premature deformation if the asphalt surfacing is not of sufficient thickness and the tack coat not properly applied;

ii) moisture saturation in the asphalt surfacing could cause premature deformation if the asphalt has cracked; and

iii) the tack coat between the waterproofing membrane and the asphalt surfacing could have been contaminated or damaged at the time of the construction of the four bridges.

7. The traditional method of laying asphalt had performed satisfactorily. In the absence of the waterproofing membrane, the adhesion between the asphalt and the concrete is adequate even if the tack coat is damaged.

8. When the waterproofing membrane is added, the situation changes. Where the tack coat was damaged, the asphalt surfacing lost its bond with the underlying waterproofing membrane. As a result, the asphalt surfacing moved and cracked under traffic loading at these locations. The cracks allowed water to seep through and accumulate in the asphalt surfacing, causing it to further deteriorate. This would have been the cause of the premature deformation of the asphalt surfacing at the four bridges.

RECTIFICATION WORKS

9. Highways Department had arranged for repairs of the deformed locations as and when they were reported.

10. Since the asphalt surfacing on bridge decks has a normal service life of around five years, the asphalt surfacing of the four bridges had all reached their service life and was replaced between 2002 and 2004. During the replacement, the waterproofing membrane was exposed and inspected. Loosened parts were replaced and the rest provided with an improved tack coat.

11. Since the replacement work, the bridge deck surfacing has been performing satisfactorily. Inspections have been regularly conducted and there has not been any sign of deformation or water seeping through joints between the bridge segments.

THE WAY FORWARD

12. The use of waterproofing membrane on bridge deck is a developing technology. Highways Department will continue to keep in view the latest developments and international best practices. Taking into account the experience gained from the extensive laboratory testing and field trials, Highways Department will promulgate guidelines on the use of waterproofing membranes.

13. The guidelines will cover the choice of waterproofing systems and asphalt surfacing materials, the adhesion strengths required between the waterproofing membrane and the asphalt surfacing, and assessment of the thickness of asphalt surfacing required. The guidelines will also make reference to successful examples in recent years of waterproofing membrane construction methods and associated quality control measures on site to reduce the possibility of damage to the waterproofing membrane and tack coat.

ADVICE SOUGHT

14. Members are invited to note the content of the paper and the detailed technical report attached.

Development Bureau
February 2008

Deformation of Road Surfaces on Bridges

Introduction

A number of bridges were constructed in the 1990s as part of the transport network linking the Hong Kong International Airport at Chek Lap Kok to other parts of Hong Kong. There were reports on the deformation of parts of the road surfaces of the following four bridges shortly after they were opened to traffic in 1997 and 1998:

a. the West Kowloon Expressway Viaduct (WKEV), now called the West Kowloon Highway;
b. the Kap Shui Mun Bridge (KSMB);
c. the Ma Wan Viaduct (MWV); and
d. the Ting Kau Bridge (TKB).

2. The Audit Commission investigated the issue, and reported their findings in Chapter 7 of Report No. 40 issued in March 2003. One of their recommendations was for Highways Department (HyD) to submit a detailed report to the Environmental, Transport and Works Bureau and LegCo to inform them of the causes of the premature deformation of the road surfaces and the actions taken to rectify them. This report describes the investigations undertaken by HyD, the findings and the actions taken to rectify the premature failures of the road surfacing on the four bridges.

Background

3. Since the late 1980s, many long span concrete bridges in Hong Kong are built using the precast segmental construction technique. Under this technique, the bridges are constructed using a number of precast reinforced concrete segments held together by stressed steel tendons. The benefit is that the segments are cast off the bridge site and are lifted or launched to the required position without the need for erecting extensive temporary scaffolding that obstructs traffic beneath the bridge. The WKEV and MWV are built using this technique. The KSMB and TKB are slightly different in that they are steel structures with precast concrete slabs as bridge deck. After the segments are erected, an asphalt surfacing comprising different layers is laid on the top of the bridge deck to provide a road surface that could be replaced as necessary. Since there are construction joints between the segments or slabs, there exists a possibility that water may seep through the asphalt surfacing and the joints between the segments, and may corrode the steel reinforcement and stressed steel tendons in the bridge structure if there is no proper corrosion protection.

4. A number of measures are used to prevent such corrosion. The steel tendons are encased in sheaths and grout is injected into the sheaths to fill up the space around the steel tendons. The reinforcements are embedded to sufficient depth in the concrete to prevent attack of corrosive materials seeping through shrinkage cracks at the concrete surface. The construction joints between segments are sealed with epoxy resin to prevent seepage of water. Above these corrosion protection measures, some bridge designers consider that a waterproofing layer should be provided before the asphalt surfacing is laid so that an added line of defence against corrosion can be provided. Figure 1 in the Appendix shows a typical cross section of a bridge deck with waterproofing membrane and asphalt surfacing.

5. At the time when the above four bridges were designed, a liquid applied type of polymer waterproofing membrane was widely used in the United Kingdom and Europe. Compared with other types of waterproofing membrane, this type of membrane was considered to have better waterproofing ability. It was sprayed on the surface of the concrete deck after applying a layer of primer. A layer of tack coat was then applied to provide adhesion between the membrane and the asphalt surfacing above. The four bridges adopted this design. However, deformations at parts of the asphalt surfacing occurred shortly after the bridges were put to use. Figure 2 in the Appendix shows a typical premature deformation of asphalt surfacing at the TKB.

Investigation

6. In November 1998, HyD assigned the University of Hong Kong (HKU) to investigate the premature deformation problem. The study was generally of a desktop nature.

7. The study report considered that there could be a number of factors leading to the premature failure, and suggested the two most significant ones to be the low adhesion between the waterproofing membrane and the asphalt surfacing, and the moisture saturation in the asphalt surfacing. It noted that the deformation only occurred at these four bridges where a relatively thin asphalt surfacing was used. For these four bridges, adhesion between the membrane and the asphalt surfacing relied on the use of a tack coat. The report also indicated that this adhesion could have been increased by increasing the tack coat application rate, and that the tack coat might have been affected by contamination or construction traffic during the surfacing operation. A factor special for the TKB was that some heavy vehicles using the bridge after its commissioning were grossly overloaded.

8. The report recommended that a series of laboratory tests be conducted at different temperatures and humidities to investigate the adhesion between the asphalt surfacing and waterproofing membrane. It also recommended that site trials be conducted to collect on site performance data.

Rectification Works

9. Two types of rectification works were carried out at the four bridge decks. The first type was repair of deformed locations that appeared shortly after construction, and was carried out by the contractors. The second type was ad hoc repair of asphalt road surfaces caused by the wear and tear of traffic at isolated spots after the bridges were opened to the public for some time, and was carried out by HyD.

10. At these high speed roads, the top layer of the asphalt surfacing is a friction course. It is required to provide anti-skidding properties even during rain. Because it is relatively porous, it is less durable than ordinary asphalt materials. Under normal circumstances, it has to be replaced in around five years. The first normal resurfacing cycle on the four bridges was thus undertaken between 2002 and 2004.

11. The resurfacing works consisted of milling off the friction course and the underlying asphalt layers. During the course of the works, the waterproofing membrane

exposed was inspected and loosened parts were replaced. In order to minimise the disruption to traffic and to re-open the traffic lanes as soon as possible, a bituminous waterproofing system that required a shorter construction period was adopted to replace the loosened waterproofing membrane. Where the membrane remained intact, a tack coat with improved adhesion properties was applied before resurfacing. Opportunity was also taken to increase the thickness of the TKB asphalt surfacing, taking into consideration the findings of the HKU study.

12. The bridge deck surfacing has been performing satisfactorily since the completion of the resurfacing works. Inspections of the four bridges have been regularly conducted and there has not been any sign of deformation or water seepage through the bridge deck construction joints.

Researches and Findings

13. Based on the HKU study completed in 1999, when adopting a polymer waterproofing membrane, the bridge deck surfacing system had to be carefully chosen. In particular, the surfacing thickness and the adhesion strengths between the membrane and the surfacing need to be studied. In order to obtain more information on the local application of this type of waterproofing membrane, laboratory tests and on site measurements would have to be carried out. Regarding the issue of moisture saturation in the asphalt surfacing, it was considered that trial panels should be constructed to test the field performance under both drained and undrained conditions.

14. At that time, the Ngong Shuen Chau Viaduct (NSCV) contract was the next major concrete bridge project in which the Consultants proposed a polymer waterproofing membrane as a corrosion protection measure. The opportunity was taken to conduct extensive laboratory testing on the properties of the three types of polymer waterproofing membrane systems proposed under the contract. Independent from the NSCV contract, HyD also conducted testing on the properties of the polymer waterproofing membrane system previously used at the four bridges.

15. Over 600 laboratory tests with about 3,000 samples were carried out in 2004. The adhesion strengths between the waterproofing membranes and two different asphalt materials using different tack coats were tested under various conditions. For the proposed membranes , only one membrane passed all the tests on the membrane properties, and none of the systems tested could fully meet the contract specification on adhesion strengths between the waterproofing membrane and the asphalt surfacing. For the membrane used at the four bridges, it passed virtually all tests on membrane properties, and the specified adhesion strengths were exceeded when a tack coat with improved adhesion properties was used.

16. The following observations were made on the adhesion between the polymer waterproofing membrane and the asphalt surfacing:

a. As the test temperature increased, the adhesion strengths decreased;

b. The adhesion strengths were not affected by test humidity;

c. The adhesion strengths provided by the tack coat between the asphalt surfacing and the concrete deck are higher than those between the asphalt surfacing and the waterproofing membrane, the only exception was when an improved tack coat was used in conjunction with the waterproofing membrane adopted in the four bridges;

d. Increasing the tack coat thickness increased the adhesion strengths for some systems, indicating that the adhesion can be improved by optimising the tack coat application rate; and

e. Contamination and damage to the tack coat on top of the waterproofing membrane during the laying of asphalt surfacing for sample preparation was observed at some locations, and the damaged samples had extremely low adhesion strengths. Damage to the tack coat by construction plant is an inherent weakness in the traditional construction method used to lay the asphalt surfacing at the time. In comparison, for asphalt surfacing laid directly on top of concrete, the concrete surface is rougher and can absorb some asphalt, resulting in higher adhesion strengths even without a tack coat. Therefore similar damages to the tack coat will not cause premature failure of road surfacings on concrete bridge decks without waterproofing membranes. Figure 3 in the Appendix shows the damage on tack coat during sample preparation.

17. The laboratory test results indicated that the adhesion between the waterproofing membrane and asphalt surfacing depended on the properties of the tack coat used. All proposed tack coats could not provide the adhesion strengths specified in the contract, but an improved tack coat used in conjunction with the waterproofing membrane adopted in the four bridges could achieve adhesion strengths higher than specified. It was also observed that more stringent control on site operation to prevent damage to the tack coat was critical in preserving the adhesion strengths.

18. A site trial consisting of seven trial panels was also conducted at a newly diverted at-grade section of Container Port Road South under the NSCV Contract. The purpose of the trial was to demonstrate the on-site application method of the waterproofing membranes, and to assess the long term adhesion performance of the waterproofing membranes to the concrete deck and the asphalt surfacing under real life traffic loading. The trial panels were constructed with the three waterproofing membranes proposed under the contract, with different asphalt surfacing thicknesses ranging from 50 mm to 120 mm (excluding friction course thickness) and different drainage conditions. Strain gauges connected to computers were installed in the asphalt surfacing to obtain field measurement data related to deformations. Figure 4 in the Appendix shows the construction of the trial panels under the NSCV contract and Figure 5 shows the computer installations. Trial panels were also constructed in two other contemporary bridge contracts to assess the site performance of other tack coat and polymer waterproofing membrane systems.

19. All the trial panels were monitored continuously for 12 months to assess their in-situ performance over seasonal weather variation. No deformation was observed during the period, except for one panel under the NSCV contract that had the thinnest asphalt surfacing of 50 mm, as shown in Figure 6 in the Appendix.

20. The following relevant observations were made on the results of the site trial monitoring:

a. The maximum temperatures recorded in summer at the waterproofing membrane and asphalt surfacing interface and close to the surface of the asphalt were 38^{o}C and 46^{o}C respectively; whilst the minimum temperatures recorded in winter at the same positions were 13^{o}C and 12^{o}C respectively;

b. Regarding temperature effect, it was noted that the variance in strain reading was much greater in summer. At lower temperature, the asphalt surfacing became more rigid and consequently the variance in strain readings due to temperature change was smaller; and

c. In the latter half of the 12-month trial period, the recorded strain reading has been relatively stable. No significant fluctuations were observed, and minor fluctuations were due to temperature variations. It could be concluded that the deformations in the asphalt surfacing are minimal at the end of the trial period. On this basis, it was strongly believed that the adhesion between asphalt surfacing and waterproofing membrane has largely remained intact at the end of the 12-month trial period. The fact that no significant surface irregularity or rutting was observed during the detailed visual inspections in this period supports this conclusion.

21. The field trial results indicated that although the adhesion strengths between the waterproofing membrane and asphalt surfacing were lower than specified, the bridge deck surfacing could still perform satisfactorily provided that its thickness was adequate. There was no performance difference between the drained and undrained panels, indicating that where the asphalt surfacing remained intact, premature deformation owing to moisture saturation would not occur.

22. Despite the useful information obtained in the NSCV research, it was not possible, with the equipment installed, to derive the actual stresses at the waterproofing membrane so as to decide whether the required adhesion strengths between the asphalt surfacing and the waterproofing membrane specified in the contract are adequate or over-provided. In order to investigate the actual stresses experienced by the waterproofing membrane, further trial panels with optical strain gauges embedded into the waterproofing membranes were constructed on a concrete bridge deck with an asphalt surfacing thickness of 100 mm in Yuen Long Highway in February 2006. Figure 7 in the Appendix shows the optical strain gauges installed on a waterproofing membrane.

23. Field monitoring data was collected up to May 2007. Analysis of the data showed that actual stress levels within the membrane under traffic loading were significantly lower than the specified adhesion strengths between the asphalt surfacing and the waterproofing membrane, and also below the laboratory test results of all the systems tested.

24. This explained why the trial panels with adequate asphalt surfacing thickness performed satisfactorily despite their adhesion strengths could not meet the specification. It also indicated that the premature deformations at the four bridges were unlikely due to membrane and tack coat material properties. The premature deformations were therefore most likely due to contamination or damage to the tack coat by construction plant and resulted in a loss of adhesion between the waterproofing membrane and the asphalt surfacing. The asphalt surfacing moved and cracked under traffic loading at these locations, and allowed water to seep through and accumulate in the asphalt surfacing to cause further deterioration.

Conclusions

25. Researches carried out by HyD reveal that for polymer waterproofing membrane, the adhesion strengths between the asphalt surfacing and the membrane depend on the temperature, the tack coat used and the rate at which it is applied. They are not affected by humidity but can be greatly affected by damages to the tack coat.

26. The use of a polymer waterproofing membrane, except for one system tested, can result in lower adhesion between the asphalt surfacing and the concrete bridge deck, as compared to laying the asphalt surfacing on the concrete deck. Therefore, the use of this type of waterproofing membrane has to be carefully gauged against the added waterproofing benefit achieved. Despite the lower adhesion, the actual stresses in the membrane are typically very low. Therefore provided that the asphalt surfacing is of sufficient thickness, it will remain intact and premature deformation will not occur.

27. If a polymer waterproofing membrane is to be used, tighter control has to be exercised on site during laying of the asphalt surfacing, as damage to the tack coat can cause loss of adhesion between the membrane and the asphalt surfacing, resulting in early deformation of affected areas.

28. Where the asphalt surfacing is not damaged, premature deformation owing to moisture saturation will not occur. As an added line of defence, it is considered that sub-surface drainage can be provided to drain away water that may seep through the asphalt surfacing.

29. It is concluded that the predominant factor leading to premature deformation at the four bridges was local damage to the tack coat and loss of adhesion to the waterproofing membrane. The asphalt surfacing moved and cracked under traffic loading at these locations, and allowed water to seep through and accumulate in the asphalt surfacing to cause further deterioration. The situation was exacerbated at the TKB due to the heavy traffic loading and relatively thinner surfacing.

30. HyD will promulgate guidelines regarding the use of bridge deck waterproofing membranes taking into account the experience gained from the extensive laboratory testing and site trials. The essential issues such as choice of surfacing material, surfacing thickness, and required adhesion strengths will be addressed. It will be made clear that the designer should review the thickness of the asphalt surfacing taking into account the waterproofing system, asphalt material and adhesion strength specified. Successful examples in recent years of waterproofing membrane construction methods and more stringent quality control measures on site to reduce the possibility of damage to the waterproofing membrane and tack coat will be provided for reference.

Highways Department
February 2008

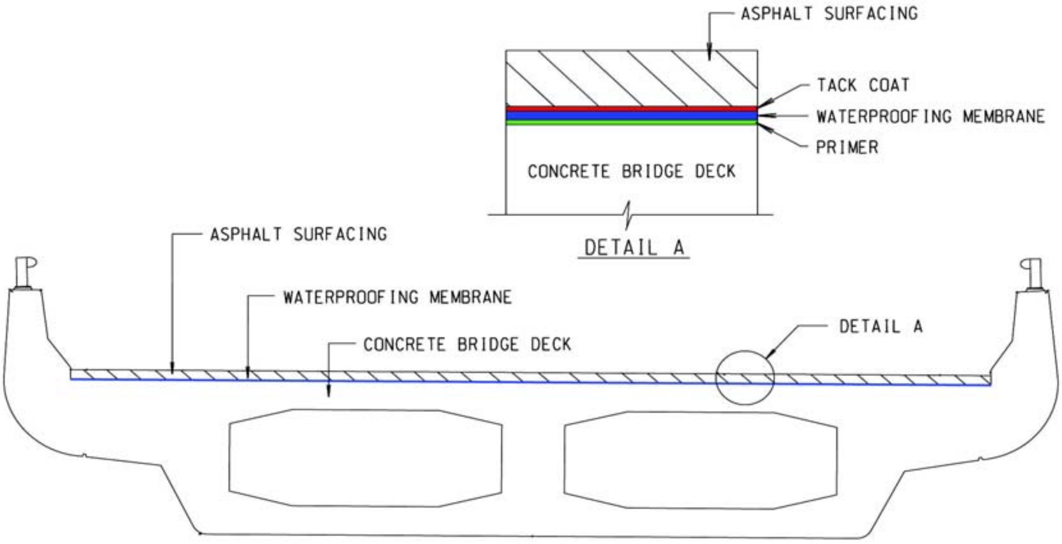

Figure 1 – Typical cross section of asphalt surfacing and bridge deck waterproofing membrane on a concrete bridge

Figure 2 – Premature deformation of asphalt surfacing at Ting Kau Bridge

Figure 3 – Damage on tack coat during sample preparation for laboratory testing. The area under the wheel of the paving machine show that the tack coat had been contaminated by dust brought by the wheels of the paving machine. The blue spots show that the tack coat had been damaged and the blue waterproofing membrane was exposed.

Figure 4 – Construction of trial panels of waterproofing systems under the Ngong Shuen Chau Viaduct Contract

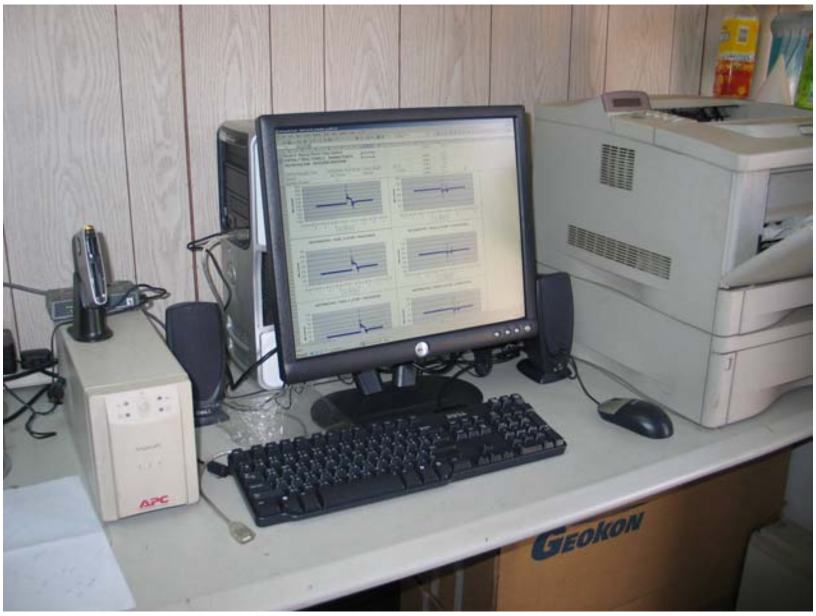

Figure 5 – Computer installations for the site trial of waterproofing systems under the Ngong Shuen Chau Viaduct Contract

Figure 6 – Conditions of trial panels of waterproofing systems under the Ngong Shuen Chau Viaduct Contract. The red dotted line shows the repaired area of deformation that occurred at the thinnest panel of 50mm thick.

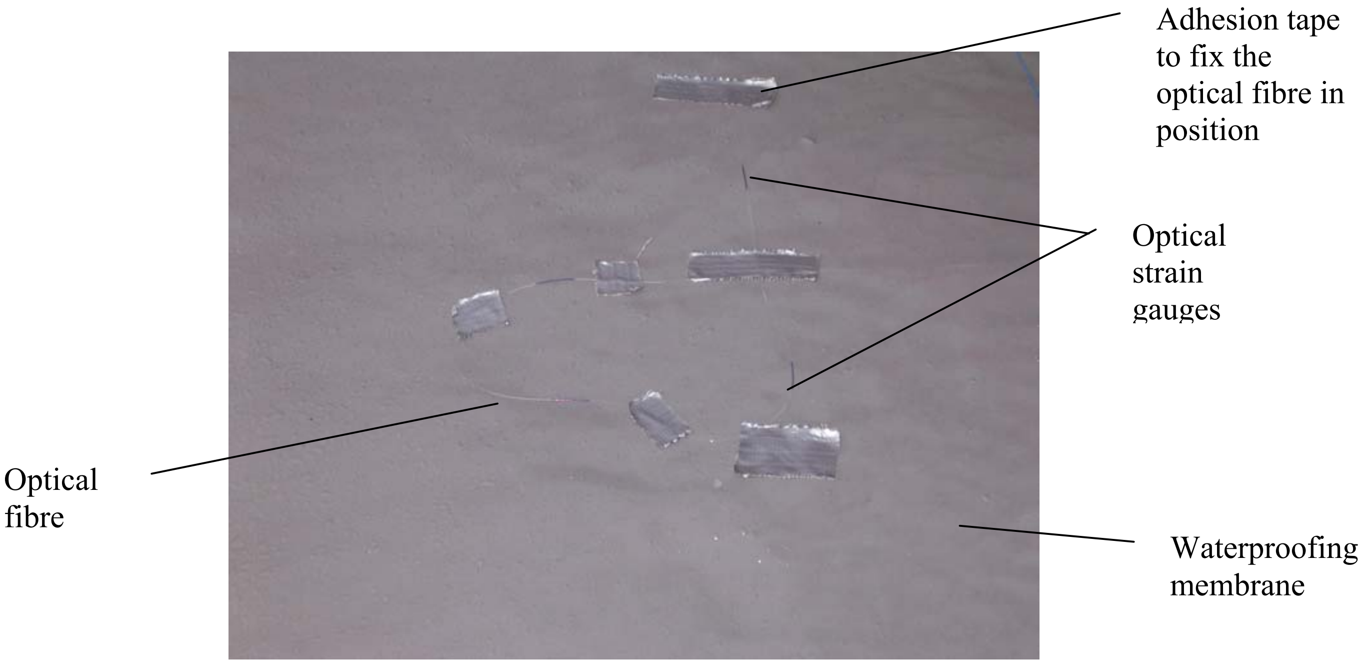

Figure 7 – Optical strain gauges installed on a waterproofing membrane trial panel on a bridge deck of Yuen Long Highway