CHAPTER 7

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

CAPITAL WORKS RESERVE FUND

GOVERNMENT SECRETARIAT

Environment, Transport and Works Bureau

GOVERNMENT DEPARTMENT

Highways Department

Deformation of road surfaces on bridges

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DEFORMATION OF ROAD SURFACES ON BRIDGES

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Summary and key findings

A. **Introduction.** Bridge decks in Hong Kong are usually laid with a bituminous pavement as the road surface. For four recently constructed bridges, namely the Ting Kau Bridge (TKB), the West Kowloon Expressway Viaduct (WKEV), the Kap Shui Mun Bridge (KSMB) and the Ma Wan Viaduct (MWV), there had been reports of deformation of the road surfaces not long after the four bridges were opened to traffic. Extensive repairs and resurfacing works were required. The extent of the deformation of the road surfaces of these bridges was unusual and the timing was premature (paras. 1.2 to 1.4).

B. **Audit review.** Audit recently conducted a review to examine the premature deformation of the road surfaces of the four bridges (para. 1.12). The findings are summarised in paragraphs C to F below.

C. **Premature deformation of road surfaces.** The design life of the road surfaces and the associated waterproofing membranes of the four bridges was 20 years. However, due to the deformation of the road surfaces, ad hoc repair works were carried out to patch up the road surfaces of the four bridges to a serviceable condition. Rehabilitation works were required to resurface the entire road surfaces of the TKB, KSMB and MWV. The rehabilitation works are expected to be completed by late 2003. It was found that the deformation of the road surfaces was not entirely the result of normal wear and tear but was associated with the application of waterproofing membranes to the road surfaces. Up to September 2002, there were a total of 371 days of lane closures due to the ad hoc repairs and the rehabilitation works. Another 300 days of lane closures were also expected for the remaining rehabilitation works. In October 1998, a Legislative Council (LegCo) Member enquired about the causes of the premature deformation of the road surface of the TKB. The then Secretary for Works responded that, since the study into the deformation problem was in progress, it was not able to come to any conclusion about the cause of the deformation. However, after this initial response, the Administration has not kept LegCo informed of the progress in the matter (paras. 2.3 to 2.10, 2.12, 2.13, and 2.19 to 2.21).

D. **Need to conduct further study on the causes of deformation of road surfaces.** In November 1998, the Highways Department (HyD) commissioned a consultancy study to investigate the causes of deformation of the road surfaces. In October 1999, the Consultant submitted the Stage 1 study report to the HyD. According to the Consultant's report, the premature deformation might be associated with: (a) the low adhesion between the waterproofing membrane and the bituminous surfacing; and (b) the reduced thickness of the bituminous surfacing. In Audit's view, the HyD needs to conduct further study and research on the application of waterproofing membranes. The HyD also needs to lay down guidelines to specify the circumstances under which waterproofing membranes should be applied for bridge projects (paras. 3.3 to 3.4, 3.6, 3.9 and 3.11 to 3.15).

E. **Need to improve specifications on pavement thickness.** According to the HyD's technical circulars issued in 1985 and 1995, the total thickness of a bituminous pavement without a friction course should be 100mm. However, for high speed roads with a friction course, there were provisions for reduction in the pavement thickness. The design of the bituminous pavements of the four bridges was generally in accordance with the provisions of these two circulars. As a result, their structural thickness (total thickness less the thickness of the friction course) fell short of the recommended thickness of 100mm by 30mm to 45mm. The Consultant considered that the reduction in total thickness was only valid if a waterproofing membrane had not been used. He recommended that the minimum permitted thickness of the structural layer of the bituminous pavement should not be less than 100mm. Audit notes that, in drawing up the specifications on the thickness of bituminous pavement on bridge decks, the HyD had not envisaged the effects of the application of a waterproofing membrane. In November 2001, the HyD issued a new technical circular (HyD Technical Circular No. 11/2001) in which the permitted reduction in pavement thickness was not mentioned. Audit considers that there is a need for other measures to be in place to ensure that the structural thickness of all bituminous pavements can achieve the required structural strength, particularly for designs where a waterproofing membrane is to be applied (paras. 4.2, 4.6 to 4.9, 4.12 to 4.19 and 4.27).

F. **Need to step up inspection programme for segmental bridges.** For bridges in Hong Kong built by using the segmental construction method, they are more vulnerable to water seepage through the segment joints. This may cause corrosion to the reinforced concrete deck. The waterproofing membrane is the first line of defence in corrosion protection. According to the original design, the four bridges had waterproofing membranes on the entire deck surfaces. Audit noted that, during the ad hoc repair works carried out on the four bridges, the damaged waterproofing membranes were removed but not replaced. During the rehabilitation works, the waterproofing membranes were reinstated only around the segment joints but not on the entire deck surface. This is at variance with the original design. Audit also noted that, the bridge deck of the Kwun Tong Bypass (KTB — which was the first bridge structure built using the segmental construction method in Hong Kong) had not been provided with a waterproofing membrane and signs of rusting were observed. For the recently built Hung Hom Bypass (HHB), the application of a waterproofing membrane had been included in the original design. However, during the construction stage, it was decided not to apply the waterproofing membrane because of the concern over the possible deformation of the road surface in connection with the use of waterproofing membrane. Audit considers that there is a need to step up the inspection programme of bridges so as to monitor closely the structural integrity and long-term durability of the segmental bridges (paras. 5.4 to 5.17 and 5.22).

G. **Audit recommendations.** Audit has made the following main recommendations that the Director of Highways should:

Premature deformation of road surfaces

(a) monitor closely the road surfaces of the four bridges to ensure that they are in a good serviceable condition (para. 2.22(a));

(b) submit a detailed report to the Environment, Transport and Works Bureau and LegCo to inform them of the causes of the premature deformation of the road surfaces of the four bridges and the actions taken to rectify the problem (para. 2.22(b));

(c) in future, take proactive action to keep the Environment, Transport and Works Bureau informed of matters of an exceptional nature with substantial financial implications. LegCo should also be kept informed so as to enhance public accountability (para. 2.22(c));

Investigation into the causes of deformation of road surfaces

(d) based on the findings of the Stage 1 study and the subsequent actions taken (in particular, the trials/tests under the Ngong Shuen Chau Viaduct Contract), consider undertaking further studies to establish the underlying causes of the premature deformation of road surfaces of the TKB, WKEV, KSMB and MWV (para. 3.16(a));

(e) carry out further research on the application of waterproofing membranes with a view to promulgating guidelines on:

(i) the circumstances under which waterproofing membranes should be applied and the most effective way for their provision for future bridge projects (para. 3.16(b)(i)); and

(ii) the specifications on bonding strength between the waterproofing membrane and the bituminous surfacing for use in future bridge projects (para. 3.16(b)(ii));

Specifications on pavement thickness

(f) in order to minimise the risk of premature deformation of road surfaces, critically assess the thickness of bituminous pavements of future bridge projects so that the pavements are in a good serviceable condition during their design life (i.e. without the need for major rehabilitation works) (para. 4.34(a));

(g) in future, critically consider all the circumstances that would affect the validity of the specifications and guidelines to be promulgated on the construction and maintenance of highways, and revise the specifications promptly in the light of new developments (para. 4.34(b));

(h) in view of the fact that the minimum thickness of pavements is not specified in HyD Technical Circular No. 11/2001, consider taking other measures to ensure that an adequate structural thickness is provided in the pavement design of bridges (para. 4.34(d));

Corrosion protection for segmental bridges

(i) step up the inspection programme so as to monitor closely the structural integrity and long-term durability of bridges built using the segmental construction method (in particular, the TKB, WKEV, KSMB, MWV, HHB and KTB (para. 5.23(a)); and

(j) continue to carry out research on corrosion protection of bridges and, where appropriate, promulgate guidelines on corrosion protection of bridges (para. 5.23(b)).

H. **Response from the Administration.** The Administration has agreed with most of the audit recommendations.

PART 1: INTRODUCTION

Bridge structures

1.1 The road network of Hong Kong consists of a large number of bridge structures, including bridges, viaducts, flyovers, etc. (In this Audit Report, bridge structures are hereinafter referred to as bridges for simplicity.) In the 1990s, several long-span bridges had been built to form part of the transport network linking the Hong Kong International Airport at Chek Lap Kok to other parts of Hong Kong. As at December 2001, there were a total of 1,021 bridges in Hong Kong.

1.2 Most of the bridges in Hong Kong are concrete bridges (Note 1). Concrete bridges use large quantities of steel in the form of bars and tendons (tensioned cables) to reinforce the structure and deck. A bituminous pavement is usually laid on the deck surface of a bridge to form the road surface.

Early deformation of road surfaces on bridges

1.3 There have been reports of deformation of the road surfaces on the following four recently constructed bridges:

(a) ***Ting Kau Bridge (TKB).*** The TKB is a 1,177-metre long cable-stayed bridge over the Rambler Channel, linking the Ting Kau headland and Tsing Yi Island. It is part of Route 3, the transport link that connects the west and northwest New Territories to the urban areas of Kowloon and Hong Kong Island, and the Hong Kong International Airport. It was opened to traffic in May 1998;

(b) ***West Kowloon Expressway Viaduct (WKEV).*** The West Kowloon Expressway is a 4,000-metre expressway running from the Kwai Chung Viaduct to the Western Harbour Crossing tunnel toll plaza. Its northern section is carried on a viaduct and the southern section is at ground level. It was opened to traffic in February 1997. The deformation problem of the West Kowloon Expressway was confined to the road surface of the viaduct section, referred to as the WKEV in this report;

Note 1: *A notable exception is the Tsing Ma Bridge which is a steel suspension bridge with a unique design on its structure and deck surface.*

(c) ***Kap Shui Mun Bridge (KSMB).*** The KSMB is 820 metres long and is the world's longest cable-stayed bridge carrying both road and rail traffic. Together with the Tsing Ma Bridge, it provides a direct access to the Hong Kong International Airport. It was opened to traffic in May 1997; and

(d) ***Ma Wan Viaduct (MWV).*** The MWV is 503 metres long. It connects the Tsing Ma Bridge and the KSMB and was opened to traffic in May 1997.

Appendix A is a summary of the particulars of the four bridges. Figure 1 on the centre pages shows the location of the TKB, KSMB and MWV. Figure 2 on the centre pages shows the location of the West Kowloon Expressway.

1.4 Not long after these four bridges were opened to traffic, there were reports of deformation of the road surfaces. Extensive repairs and resurfacing works were required. The extent of the deformation of the road surfaces of these bridges was unusual and the timing was premature. The cost of ad hoc repairs for the road surfaces was about $4.86 million (see Table 2 in para. 2.6 below). The cost of full-scale rehabilitation works was estimated to be $47.2 million (see Table 3 in para. 2.7 below).

1.5 The segmental construction method was used for building these four bridges. The bridge deck was constructed segment by segment, leaving a number of construction joints between the adjacent segments. Corrosion protection is of vital importance for segmental bridges to prevent the seepage of water through the segment joints, which may cause rusting to the steel reinforcement.

1.6 For corrosion protection purposes, waterproofing membranes were applied to the decks of the four bridges. The application of a waterproofing membrane was not commonly adopted in Hong Kong before the use of the segmental construction method. The purpose of the waterproofing membrane is to provide an impervious barrier between the bituminous pavement on the top and the reinforced concrete deck below. The premature deformation of the road surfaces on the four bridges is associated with the application of the waterproofing membrane to the bridge deck.

The Highways Department

1.7 The Highways Department (HyD) is responsible for the implementation of highway projects in the Public Works Programme. This involves the planning, design and supervision of the construction of roads and bridges. The HyD is also responsible for maintaining the road network, with particular emphasis on safety and serviceability.

1.8 ***Highway maintenance works.*** For the maintenance of roads and bridges, the three Regional Offices of the HyD are responsible for the roads and bridges in the Kowloon Region, the New Territories Region and the Hong Kong Region. For the Tsing Ma Control Area (TMCA) (Note 2), special arrangements have been made under which the management, operation and maintenance (MOM) of the highway facilities are contracted out to a private company (hereinafter referred to as the TMCA Company) in accordance with an MOM Contract. The TMCA Division of the HyD monitors the TMCA Company's performance on the maintenance of the highway facilities. The TKB, KSMB and MWV are within the TMCA and are thus maintained by the TMCA Company. The WKEV is maintained by the Kowloon Regional Office of the HyD.

1.9 ***Funding for highway maintenance works.*** The HyD has two funding sources for highway maintenance works, as follows:

(a) the Maintenance Vote under the General Revenue Account for routine maintenance works. The Maintenance Vote is used for funding routine highway maintenance works including the repair of potholes, minor road resurfacing, maintenance of street furniture and emergency repairs; and

(b) the Block Vote under the Capital Works Reserve Fund for minor capital projects. Minor capital projects may include road reconstruction or resurfacing, improvement or stabilisation of roadside slopes and minor improvement works. The financial limit of an individual works item under the Block Vote is $15 million. For a works item with an estimated cost exceeding $15 million, funding approval from the Finance Committee of the Legislative Council (LegCo) is required. In such case, a paper setting out clearly the proposal, the justification, the financial implications (both capital and recurrent), the commencement and completion dates and any important relevant background information has to be prepared.

1.10 According to the HyD's Maintenance Administration Handbook, resurfacing works of an area not more than 1,000 square metres (m^2) should be charged to the Maintenance Vote. Resurfacing works of an area more than 2,000m^2 should be charged to the Block Vote. For resurfacing works of an area more than 1,000m^2 but not more than 2,000m^2, the engineer in charge has the discretion to charge either to the Maintenance Vote or the Block Vote.

Note 2: *The TMCA is an integrated expressway system linking the Hong Kong International Airport to Kowloon Peninsula and the northwest New Territories. It includes the Kwai Chung Viaduct, the Rambler Channel Bridge, the Cheung Ching Tunnel, the TKB, the Lantau Link (consisting of Tsing Ma Bridge, KSMB and MWV), and part of the North Lantau Expressway.*

1.11 ***Funding for highway maintenance works in the TMCA.*** Highway maintenance works within the TMCA are financed by the toll revenue of the Lantau Link collected by the TMCA Company on behalf of the Government. Under the MOM Contract, scheduled maintenance works during the term of the Contract are covered by the fixed management fee paid to the TMCA Company. For non-scheduled maintenance works, the TMCA Company is reimbursed the expenditure incurred plus a supervision fee.

Audit review

1.12 Audit recently conducted a review to examine the premature deformation of the road surfaces of the four bridges. The review focused on the following areas:

(a) premature deformation of road surfaces (see PART 2 below);

(b) investigation into the causes of deformation of road surfaces (see PART 3 below);

(c) specifications on pavement thickness (see PART 4 below); and

(d) corrosion protection for segmental bridges (see PART 5 below).

The audit has revealed that there is room for improvement in the above areas. Audit has made a number of recommendations to address the issues.

PART 2: PREMATURE DEFORMATION OF ROAD SURFACES

2.1 This PART examines the deformation problem of the road surfaces on the four bridges. The audit has revealed that the deformation has shortened the expected service life of the road surfaces and substantial cost has been incurred in the repair and the rehabilitation works.

Road surfaces on bridge decks

2.2 Bridge decks in Hong Kong are usually laid with a bituminous pavement. The bituminous pavement usually consists of two layers, a **base course** and, on top of it, a **wearing course**. For high speed roads with a speed limit of 70 kilometres per hour or above, a **friction course** is usually laid as the uppermost layer. All the four bridges carry high speed roads and therefore have a friction course. Figure 3 on the centre pages shows the typical layers of a bituminous pavement on a bridge deck. The characteristics of different bituminous layers are further discussed in paragraph 4.3 below.

Design life of road surfaces

2.3 The design life of a road surface is the period for which the road, with regular inspection and routine maintenance, will fulfil its intended function. In Hong Kong, the design life of bituminous materials laid as underlying layers on the pavement is 20 years. As for the uppermost layer on the bituminous pavement, e.g. the friction course on a high speed road, there is no specified design life. According to the HyD's information, under normal circumstances, the friction course would usually require to be resurfaced once every three to five years. These design specifications are applicable to the construction of the bituminous pavements of the TKB, WKEV, KSMB and MWV. According to the contract provisions of the four bridges, the road surface and the associated waterproofing membranes, with the exception of the friction course, were expected to have a service life of 20 years.

Deformation of road surfaces

2.4 The deformation of the road surface is a change of the road surface from the intended profile, which leaves the road surface in a shape different from the one intended. It may be due to load associated (traffic) or non-load associated (environmental) influences. The deformation of the road surface affects its serviceability and may reflect structural inadequacies. Deformed road surfaces affect the safety and riding quality of the pavement.

2.5 Despite the design service life of 20 years for the bituminous pavements and the associated waterproofing membranes (see para. 2.3 above), the deformation of the road surfaces was observed on the TKB, WKEV, KSMB and MWV not long after they were opened to traffic. Table 1 below is a brief account of the early and unusual deformation of the road surfaces of the four bridges.

Table 1

Early deformation of road surfaces of the four bridges

Bridge	Date opened to traffic	First defects noted on	Particulars
TKB	5 May 1998	2 July 1998	**Two months** after road opening, severe movement and blistering of bituminous surfacing were found on the slow lane.
WKEV	20 February 1997	8 August 1997	**Six months** after road opening, serious rutting and movement of bituminous surfacing were found.
KSMB	22 May 1997	20 July 1998	**14 months** after road opening and shortly after opening of the new airport, rutting on the slow lane was found.
MWV	22 May 1997	20 July 1998	**14 months** after road opening and shortly after opening of the new airport, rutting on the slow lane was found.

Source: HyD's records

As shown in Table 1 above, the deformation of the road surfaces of the four bridges occurred not long after they were opened to traffic. In the case of the TKB, the defects were noted just two months after it was opened to traffic in May 1998. Subsequently, there were further reports of deterioration of the road surfaces. Photographs 1 and 2 on the centre pages show the defects on the road surfaces of the TKB and WKEV respectively.

Ad hoc repair works

2.6 In order to patch up the road surfaces to a serviceable condition, ad hoc repair works were carried out. Such ad hoc repairs were temporary measures to rectify the defects. Up to September 2002, ad hoc repairs had been undertaken for part of the road surfaces of the four bridges. Table 2 below shows the extent of the repair works and the cost incurred.

Table 2

Extent and cost of ad hoc repairs carried out on the deformed road surfaces of the four bridges Position as at September 2002

	Area of road surfaces			Cost of repairs (Note 1)
Bridge	**Overall**	**Repaired**	**% repaired**	
	(a)	**(b)**	$(c) = \frac{(b)}{(a)} \times 100\%$	
	(m^2)	**(m^2)**		**($ million)**
TKB	35,545	7,875 (Note 2)	22%	**1.31**
WKEV	61,104	17,935 (Note 2)	29%	**2.81** (Note 3)
KSMB	21,334	1,749	8%	**0.40**
MWV	17,100	1,077	6%	**0.34**
Total	**135,083**	**28,636**	**21%**	**4.86**

Source: HyD's records

Note 1: The cost of repairs carried out by the contractors during the maintenance period, if any, has not been included.

Note 2: The areas of road surfaces repaired included repair works carried out by the contractors to rectify defects during the maintenance period.

Note 3: The HyD recovered a sum of $3.27 million from the contractor of the WKEV who had been held liable for the defects. Therefore, the net cost to the Government for the ad hoc repairs of the WKEV was nil.

As shown in Table 2 above, over 20% of the road surfaces of the TKB and WKEV were subjected to ad hoc repairs. The percentages of road surfaces of the KSMB and MWV subjected to repairs were relatively smaller.

Rehabilitation works

2.7 The ad hoc repairs were carried out to rectify temporarily the defects in order to maintain normal traffic flow. The underlying causes of the deformation problem needed to be identified so that appropriate rehabilitation works could be taken (e.g. completely replace the road surfaces and repair the deteriorated waterproofing membranes). In November 1998, the HyD engaged a consultant to study the road surface deformation problem of the four bridges. In October 1999, the consultancy study was completed. Details of this consultancy study are covered in PART 3 below. After the completion of the consultancy study, the HyD started planning for the rehabilitation works. The schedule of the rehabilitation works and the estimated cost are shown in Table 3 below.

Table 3

Rehabilitation works for the road surfaces of the four bridges

Bridge	**Schedule of rehabilitation works**		**Estimated cost**	
	From	**To**		
			($ million)	**($ million)**
TKB	March 2002	September 2002		**27.30**
WKEV	(Note)			—
KSMB	December 2002	September 2003		**11.44**
MWV				
— slow lanes	July 2002	August 2002	2.30	
— fast and middle lanes	December 2002	September 2003	6.16	**8.46**
Total				**47.20**

Source: HyD's records

Note: Up to December 2002, no rehabilitation works had been scheduled for the WKEV.

2.8 According to the HyD's records, the scope of the rehabilitation works was as follows:

(a) milling off the existing bituminous surfacing up to full depth, including the friction course and the bituminous layers underneath;

(b) removing the deteriorated waterproofing membranes;

(c) re-applying new waterproofing membranes; and

(d) relaying the road surface with bituminous materials.

2.9 As shown in Table 3 in paragraph 2.7 above, the total cost of the rehabilitation works was estimated to be $47.2 million. Up to December 2002, the rehabilitation works for the TKB and the slow lanes of the MWV had been completed. The rehabilitation works for the KSMB and the fast and middle lanes of the MWV were scheduled to commence in December 2002. The target completion date is September 2003 (Note 3).

Audit observations on premature deformation of road surfaces

Expected service life of road surfaces not achieved

2.10 The construction of the TKB, WKEV, KSMB and MWV are considered as outstanding engineering accomplishments. These bridges contribute significantly to the transport infrastructure in Hong Kong. The road surfaces of the four bridges were constructed at a total cost of $68.84 million (see Table 4 in para. 2.11 below). **However, because of the premature deformation and the subsequent rehabilitation works, the road surfaces (excluding the friction course) and the waterproofing membranes failed to achieve the expected service life of 20 years.**

Substantial cost incurred in construction and rehabilitation works

2.11 Table 4 below shows the total construction cost and rehabilitation cost of the road surfaces of the four bridges.

Note 3: *As at February 2003, the scheduled rehabilitation works for the KSMB and the fast and middle lanes of the MWV had not yet started.*

Table 4

Cost of construction and rehabilitation of the road surfaces of the four bridges

Bridge	**Original construction** ($ million)	**Rehabilitation works** ($ million)	
TKB	13.99	27.30	
WKEV	44.10	—	(Note)
KSMB	6.44	11.44	
MWV	4.31	8.46	
Total	**68.84**	**47.20**	

Source: HyD's records

Note: Up to December 2002, no rehabilitation works had been scheduled for the WKEV.

As shown in Table 4 above, the road surfaces were constructed at the cost of $68.84 million. Apart from the ad hoc repair works of $4.86 million (see para. 2.6 above), rehabilitation works would be required. For the TKB, the cost of $27.3 million for the rehabilitation works of the road surface was substantial, which nearly doubled the cost of $13.99 million for the construction of the road surface. Similarly, the estimated cost for the rehabilitation works of the KSMB and the MWV would exceed the original cost for the construction of the road surfaces.

Premature deformation arising from structural defects

2.12 The engineers of the HyD noted that the deformation of the road surfaces was not a result of normal wear and tear but was associated with the application of waterproofing membranes to the road surfaces. In June 2001, commenting on the rehabilitation works proposed by the HyD's TMCA Division, the HyD's Research and Development Division said that:

(a) from the description of the defects found, it was very likely that the road distress of the road surfaces of the TKB was not simply caused by wear and tear. Conventional friction course materials did not normally fail in this way; and

(b) very likely, the underlying layer exhibited unexpected movement causing rutting and local depression. As such, the conclusion that the life of the friction course was about to end might not reflect the real situation. If the cause of the road defects was simply related to the friction course, a normal road resurfacing programme should be adequate to restore the pavement conditions.

2.13 **In October 2001, the Chief Engineer of the TMCA Division sought the approval of the Director of Highways to issue works orders for the rehabilitation works of the TKB. The Chief Engineer said that since the opening of the TKB in May 1998, deformation of its road surface had necessitated frequent ad hoc repairs. Over 20% of the road surface had been repaired. The best way forward was to repair the deteriorated waterproofing membrane and to completely replace the road surface with an increased thickness. The proposed rehabilitation works for the TKB were approved by the Director of Highways. (See PART 3 below about the HyD's investigation into the causes of deformation of the road surfaces.)**

2.14 **The rehabilitation works involved were beyond the scope of routine maintenance works. To enable the repair works of the waterproofing membranes to be carried out, the full depth of the entire road surfaces was milled off and relaid afterwards. The thickness of the TKB's road surface was also increased — see paragraph 4.22 below.**

2.15 In response to Audit's enquiry, the HyD said that the rehabilitation works for the TKB, KSMB and MWV did not arise from the need to rectify structural defects or to repair waterproofing membranes. The rehabilitation works were necessitated for replacing the 30mm friction course, which would normally be carried out every three to five years (see para. 2.3 above). However, Audit found that the cost of resurfacing the friction course in the rehabilitation works had not been separately accounted for. In this connection, Audit noted that in February 1997, the HyD prepared a long-term forecast for the non-scheduled maintenance works within the TMCA. Included in the forecast were estimates of $4.71 million, $3.39 million and $2 million (totalling $10.1 million) for resurfacing the friction course of the TKB, KSMB and MWV respectively. Therefore, only a part of the much higher cost of the rehabilitation works (see Table 3 in para. 2.7 above) was related to the normal resurfacing of the friction course.

Funding for the rehabilitation works

2.16 The TKB, KSMB and MWV are located in the TMCA and the rehabilitation works were carried out as non-scheduled maintenance works. As mentioned in paragraph 1.11 above, the highway maintenance works in the TMCA are funded by the toll revenue of the Lantau Link. The Director of Highways was the approving authority with no financial limit. The cost of the rehabilitation works had the effect of reducing the amount of the net toll revenue paid by the TMCA Company to the Government to pay off the outstanding balance in the advance account "Advances for Tsing Ma Control Area" of the General Revenue Account (Note 4).

2.17 For highway maintenance works other than those carried out within the TMCA, there are guidelines and financial limits for determining the appropriate funding source (see paras. 1.9 and 1.10 above). The resurfacing works of an area more than 2,000m^2 should be charged to the Block Vote. Moreover, for individual works items costing more than $15 million, funding approval from the Finance Committee of LegCo is required.

2.18 The individual area of resurfacing works for TKB, KSMB and MWV was far more than 2,000m^2. For the TKB, the estimated cost of the rehabilitation works was $27.3 million, which far exceeded the financial limit of $15 million for the Block Vote. If the rehabilitation works for the TKB had been funded under the normal HyD procedures, instead of under the TMCA arrangement, funding approval from the Finance Committee of LegCo would have been required.

Impact of defective road surfaces on road safety and traffic flow

2.19 Besides the cost of ad hoc repairs and the rehabilitation works, the deformation of road surfaces also had an impact on road safety and traffic flow. Lane closures were needed to make way for the ad hoc repairs and the rehabilitation works. Table 5 below shows the duration of the lane closures on the four bridges associated with such works.

Note 4: *The advance account was opened in May 1997 for payments made to the TMCA Company. When the revenue collected is insufficient to meet the TMCA Company's remuneration, the shortfall is financed through this advance account. This account will be cleared by the excess of the toll revenue over the TMCA Company's remuneration.*

In November 2001, when reviewing the General Revenue Account of the Government for the year ended 31 March 2001, the Public Accounts Committee asked the then Secretary for the Treasury for the reasons for the significant variance between the toll revenue and the related receipts collected, and the TMCA Company's remuneration. The Secretary explained that the variance was due to: (a) lower actual volume of traffic; (b) reduced toll; and (c) delay in opening the new airport and unforeseen economic downturn. The Secretary added that it was expected that the advance account could be cleared by 2006. The outstanding amount in the advance account was $295 million as at 31 March 2001 and $204 million as at 31 January 2003.

Table 5

Duration of lane closures to facilitate ad hoc repairs and rehabilitation works of the four bridges Position as at September 2002

	Duration of lane closures (Note 1)			Total
	Ad hoc repairs	Rehabilitation works		
	Undertaken	Undertaken	Scheduled	
	(a)	(b)	(c)	(d) = (a) + (b) + (c)
	(Days)	(Days)	(Days)	(Days)
TKB	24	176	—	200
WKEV (Note 2)	100	—	—	100
KSMB	24	—	200	224
MWV	8	39	100	147
Total	**156**	**215**	**300**	**671**

Source: HyD's records

Note 1: The duration of lane closures refers to the periods during which repairs and rehabilitation works were carried out or scheduled to be carried out. During such periods, lane closures would be required on a daily basis with varying lengths of time. Detailed information regarding the actual number of hours of lane closures was not readily available from the HyD's records. According to the HyD, very often, lane closures were implemented intermittently and lasted for only a few hours. In all cases, the lane closure arrangement was made without affecting the traffic flow.

Note 2: Up to December 2002, no rehabilitation works had been scheduled for the WKEV.

Up to September 2002, there were a total of 371 (156 + 215) days of lane closures due to the ad hoc repairs and the rehabilitation works. Another 300 days of lane closures were also expected for the remaining rehabilitation works for the MWV and KSMB scheduled to be completed by September 2003. During the lane closures, traffic flow would be affected and inconvenience would be caused to the public.

LegCo's concern over premature deformation of road surfaces

2.20 In September 1998, a local newspaper reported the premature deformation of the road surface of the TKB. On the same day, the HyD issued a press release assuring the public that the TKB was structurally safe for vehicular traffic. In October 1998, a LegCo Member enquired about the causes of the premature deformation of the road surface of the TKB. In a written reply, the then Secretary for Works informed LegCo that:

(a) **the road surface of the slow lane of the northbound carriageway of the TKB was found deformed in mid-August 1998 and remedial works were then carried out immediately;**

(b) site investigation and in-situ testing were also conducted concurrently and the findings of the tests were then being studied in detail; and

(c) **since the study was in progress, it was not able to come to any conclusion about the cause of the deformation.**

2.21 Audit noted that the HyD had not submitted a full report to inform the Environment, Transport and Works Bureau of the premature deformation of the road surfaces of the four bridges. Audit also noted that, after the initial response given by the then Secretary for Works to LegCo, the Administration has not kept LegCo informed of the progress of the investigation into the road surface deformation problem. **Audit considers that, given the unusual nature of the problem and the substantial financial implications of the repair and rehabilitation works, the Administration should have informed LegCo of the progress of the investigation and the actions taken to tackle the problem.**

Audit recommendations on premature deformation of road surfaces

2.22 **Audit has *recommended* that the Director of Highways should:**

(a) **monitor closely the road surfaces of the four bridges to ensure that they are in a good serviceable condition;**

(b) **submit a detailed report to the Environment, Transport and Works Bureau and LegCo to inform them of the causes of the premature deformation of the road surfaces of the four bridges and the actions taken to rectify the problem; and**

(c) **in future, take proactive action to keep the Environment, Transport and Works Bureau informed of matters of an exceptional nature with substantial financial implications. LegCo should also be kept informed so as to enhance public accountability.**

Response from the Administration

2.23 The **Director of Highways** agrees with the audit recommendations. He has said that the HyD will inform the Secretary for the Environment, Transport and Works and LegCo of the findings of the consultancy study. The HyD will continue to liaise with the Environment, Transport and Works Bureau and will inform LegCo of major issues. He has also said that:

(a) since 79% of the bridge road surface areas did not show signs of deformation or defects, and the defected surfaces, after repair, are functioning satisfactorily, there is no evidence to suggest that the road surfaces and the waterproofing membranes failed to achieve its design life;

(b) the rehabilitation works were necessitated for replacing the 30mm thick friction course. It was considered technically advisable in this case to mill off the bituminous material in full depth. The need for the reprovisioning of the waterproofing membrane at the construction joints was dependent on whether it was removed or loosened during the milling process;

(c) for the TKB, the reason for increasing the thickness of the structural layer from 55mm to 70mm was to take the opportunity to obviate one of the possible contributory factors (i.e. the thickness of road surface) which may lead to surface deformation, as stated in the consultancy study (see PART 3 below); and

(d) as the premature deformation of the road surfaces had not been identified to be a design fault and since LegCo did not pursue on this matter, a report had not been given. No further information on the causes of the deformation had been submitted to LegCo because the consultancy study did not reach definitive conclusions.

2.24 The **Secretary for the Environment, Transport and Works** appreciates very much the effort that Audit has made in the review. She has said that she will follow established procedures to keep LegCo apprised of issues of its concern.

PART 3: INVESTIGATION INTO THE CAUSES OF DEFORMATION OF ROAD SURFACES

3.1 This PART examines the actions taken by the HyD to identify the underlying causes of the road surface deformation. The audit has revealed that the HyD needs to carry out further study and research on the subject of the use of waterproofing membrane for future bridge projects in Hong Kong.

Consultancy study

3.2 In mid-1998, the early deformation of the road surfaces of the four bridges gave rise to concerns over the adequacy of the HyD's specifications in respect of the bituminous surfacing and the waterproofing membrane used. The underlying reasons for the deformation of the road surface needed to be identified.

3.3 In November 1998, the HyD commissioned a consultant (hereinafter referred to as the Consultant) to conduct a study entitled "Road Surface Failure on Bridges in Tropical Areas" to review all aspects of the design, construction and use of waterproofing membranes both in Hong Kong and other countries. The consultancy study (at a lump-sum fee of $900,000) commenced in November 1998. The objectives of the study were to:

(a) study the recent bridge projects in Hong Kong involving the use of waterproofing membranes;

(b) review the current practice in other countries, with particular emphasis on those having a climate similar to Hong Kong;

(c) identify possible causes of the deformation of the bituminous surfacing on bridges in Hong Kong; and

(d) propose further study and action.

3.4 The study was intended to be a Stage 1 study concentrating on the identification of the bonding problem and other possible factors leading to premature road surface deformation. At the conclusion of the Stage 1 study, the Consultant should formulate preliminary views regarding the possible causes of the road surface deformation problem. He should make preliminary recommendations on the means by which the risk of debonding and premature deformation of the road surfaces of future bridge projects could be minimised. However, such recommendations might be subject to review and revision in the light of the findings of a further Stage 2 study. The intention of the HyD was that:

(a) the Stage 2 study would proceed upon the completion of the Stage 1 study so as to identify appropriate solutions to the problem and develop a specification for the installation of waterproofing membranes in future bridge projects; and

(b) on completion of the Stage 2 study, further guidance would be provided to engineers on the means by which the risk of debonding and premature deformation of the road surfaces could be minimised in future projects.

3.5 In conducting the study, the Consultant examined a number of bridge construction projects, including the four bridges as mentioned in PART 1 where road surface deformation had occurred. He conducted interviews with the project staff, the contractors, the suppliers and trade associations. For some of the projects examined, he made field visits to inspect the deformation and to witness any investigative testing or repair works. Questionnaires were sent to waterproofing manufacturers to collect information relating to the application of waterproofing membranes. The Consultant also developed a simplified two-dimensional numerical modelling of a pavement to study the stress distribution of bituminous surfacing on top of a waterproofing membrane (see para. 4.11 below for details).

Findings of the consultancy study

3.6 In October 1999, the Consultant issued a report to the HyD. He identified a number of possible causes of the surface deformation and made an assessment of their likely influence on the problem. The main possible causes identified were: (a) low adhesion between the waterproofing membrane and the bituminous surfacing; and (b) reduced pavement thickness (Note 5).

Note 5: *The other possible causes identified were:*

- *(i) premature aggregate stripping;*
- *(ii) use of open graded friction course;*
- *(iii) inadequate drying of aggregates;*
- *(iv) weak friable aggregates;*
- *(v) early age trafficking;*
- *(vi) high ambient temperatures;*
- *(vii) mix design of wearing course;*
- *(viii) inadequate compaction; and*
- *(ix) excessive dust coating on aggregates.*

3.7 The Consultant said that there were a number of uncertainties surrounding the development of bonding between the waterproofing membranes and the bituminous surfacing. Resolution of these uncertainties would require further research. He recommended further investigations into the following areas:

(a) laboratory testing;

(b) site trials;

(c) model test of sub-surface drainage; and

(d) numerical modelling of pavement.

Audit observations on the investigation into the causes of deformation of road surfaces

Investigation into the causes of deformation not fully completed

3.8 It is essential to find the causes of the deformation of the road surfaces for formulating remedial measures, and for developing appropriate specifications for the application of waterproofing membranes for future bridge projects. Audit noted that the original intention of the HyD was that the investigation would be a two-stage study.

3.9 **The HyD had intended that the Stage 2 study would proceed upon the completion of the Stage 1 study. The Consultant had made a number of recommendations for further investigation in a Stage 2 study. However, as at December 2002, the HyD had not yet started the Stage 2 study. In this connection, the investigation into the causes of the surface deformation cannot be regarded as having been satisfactorily completed.**

3.10 In response to Audit's enquiry, in February 2003 the HyD confirmed that there had been no further study after the Stage 1 study. The HyD also informed Audit that the following actions had been taken subsequent to the completion of the Stage 1 study:

(a) in-situ trial panels had been conducted under the West Kowloon Expressway Contract;

(b) provisions had been made in the Ngong Shuen Chau Viaduct Contract (Note 6) to carry out some trials/tests on the waterproofing membrane proposed for the viaduct. The tests to be carried out would provide more reference information to enhance the body of knowledge available. After the tests, the HyD would consider whether there was a need to issue further guidelines on the application of waterproofing membrane; and

(c) a technical circular (see para. 4.27 below) and a technical report (see para. 5.5 below) concerning the bituminous surfacing and corrosion protection of bridge decks had been issued.

Need to conduct a further study

3.11 In response to Audit's enquiry, the HyD said that the Consultant's report had listed out a number of contributory factors leading to the road surface deformation problem. The findings were qualified by uncertainties and there were no definitive conclusions. **In Audit's view, the HyD needs to consider, on the basis of the Stage 1 study and the results of its actions, undertaking further studies to establish the underlying causes of the problem and to provide guidelines and specifications, particularly regarding the application of waterproofing membranes for bridges in Hong Kong.**

Need for better specifications on application of waterproofing membranes

3.12 As mentioned in paragraph 3.6 above, the Consultant had identified a number of possible causes of the deformation problem. According to his assessment and the HyD's analysis, the causes of the premature deformation might be associated with the following:

(a) low adhesion between the waterproofing membrane and the bituminous surfacing; and

(b) reduced thickness of the bituminous surfacing. The thickness of bituminous surfacing on the bridge decks in Hong Kong was generally thinner than that in other countries. The reduced thickness would induce increased stress at the interface between the bituminous surfacing and the waterproofing membrane. Further discussion of this issue is at PART 4 of this report.

Due to the combined effect of low adhesion and high induced stress, movement of the bituminous surfacing under traffic would occur, resulting in premature deformation. If the stress was less, or if the adhesion was sufficiently strong, deformation would not occur.

Note 6: *The Ngong Shuen Chau Viaduct is part of Route 9 which links up the Lantau Island and Shatin. Construction of the viaduct commenced in April 2002 and was scheduled for completion by December 2006.*

3.13 As regards the issue of low adhesion, the Consultant considered that there were a number of factors that would affect the bonding between the waterproofing membrane and the bituminous surfacing. He suggested that the effect of these factors on the performance of bonding under the Hong Kong conditions should be further studied.

3.14 The Consultant also noted that there were anomalies in the contract specifications of the bridge projects on bonding between the waterproofing membrane and the bituminous surfacing. The bonding strength was expressed in terms of two adhesion values, namely the tensile adhesion value and the shear adhesion value (Note 7). For the four bridge projects, it was noted that no shear adhesion values had been specified. As for the tensile adhesion values, only the TKB and WKEV projects had specified the minimum values required. However, the tensile adhesion values specified for these two projects were different and no reference to the Hong Kong conditions was made under the contract specifications. The Consultant considered that there was a need to improve the contract specifications to ensure that the pavement system would achieve the expected service life.

3.15 **The HyD has not yet issued guidelines to specify the circumstances under which waterproofing membranes should be applied for bridge projects. There are also no specifications on the adhesion values to be adopted to ensure that the waterproofing membrane is satisfactorily bonded to the bituminous surfacing. Audit considers that there is a need for the HyD to conduct further studies and develop appropriate contract specifications on the application of waterproofing membrane for corrosion protection of segmental bridges in Hong Kong (See also PART 5 below).**

Audit recommendations on the investigation into the causes of deformation of road surfaces

3.16 **Audit has *recommended* that the Director of Highways should:**

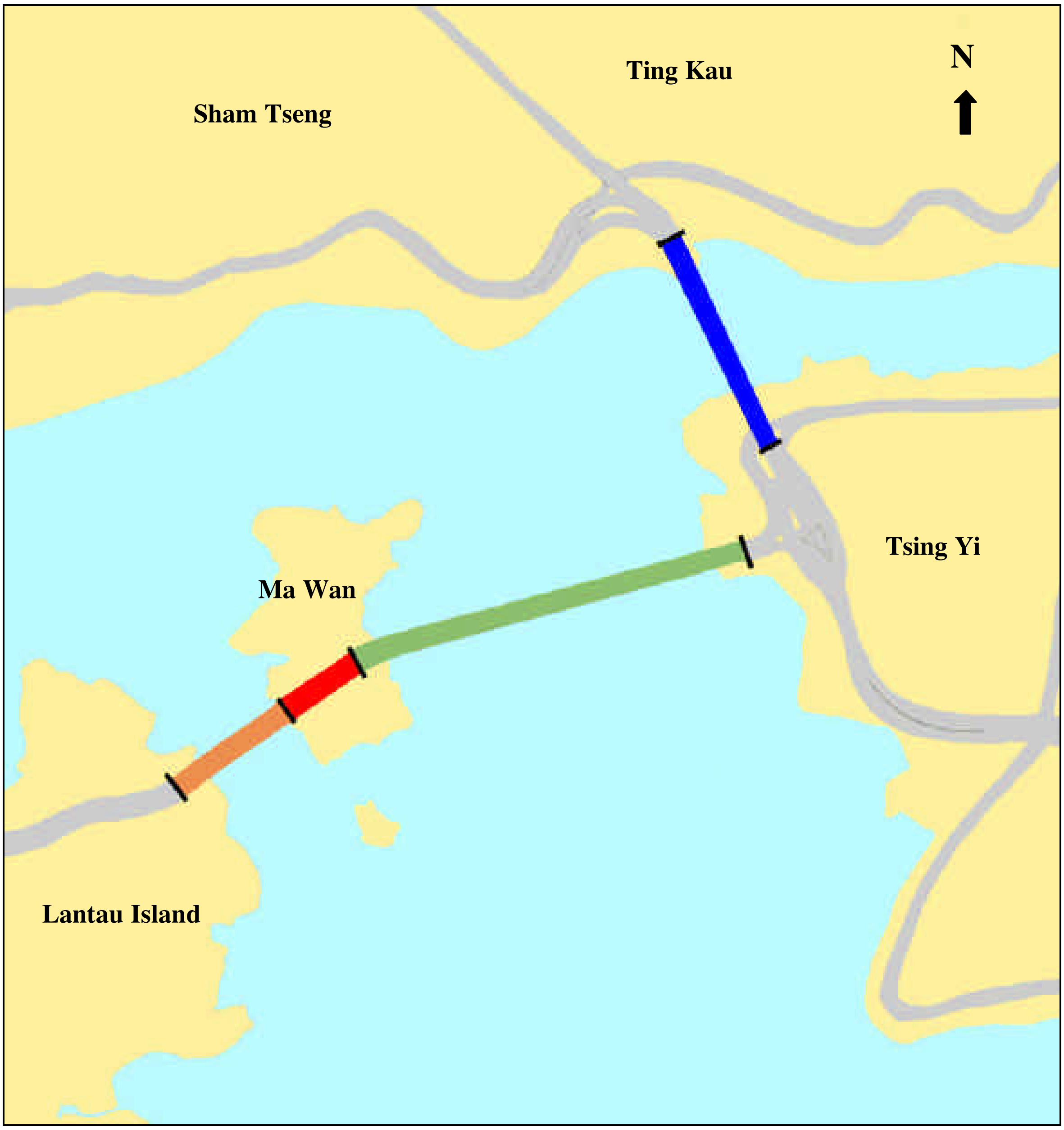
(a) **based on the findings of the Stage 1 study and the subsequent actions taken (in particular, the trials/tests under the Ngong Shuen Chau Viaduct Contract), consider undertaking further studies to establish the underlying causes of the premature deformation of road surfaces of the TKB, WKEV, KSMB and MWV; and**

(b) **carry out further research on the application of waterproofing membranes with a view to promulgating guidelines on:**

Note 7: *Tensile adhesion value and shear adhesion value refer to the measurement of bonding strength between the bituminous surfacing and waterproofing membrane to resist separation caused by induced tension (a pulling force) and shear (a sideways or twisting force) respectively.*

Figure 1

Location of the Ting Kau Bridge, Kap Shui Mun Bridge and Ma Wan Viaduct
(para. 1.3 refers)

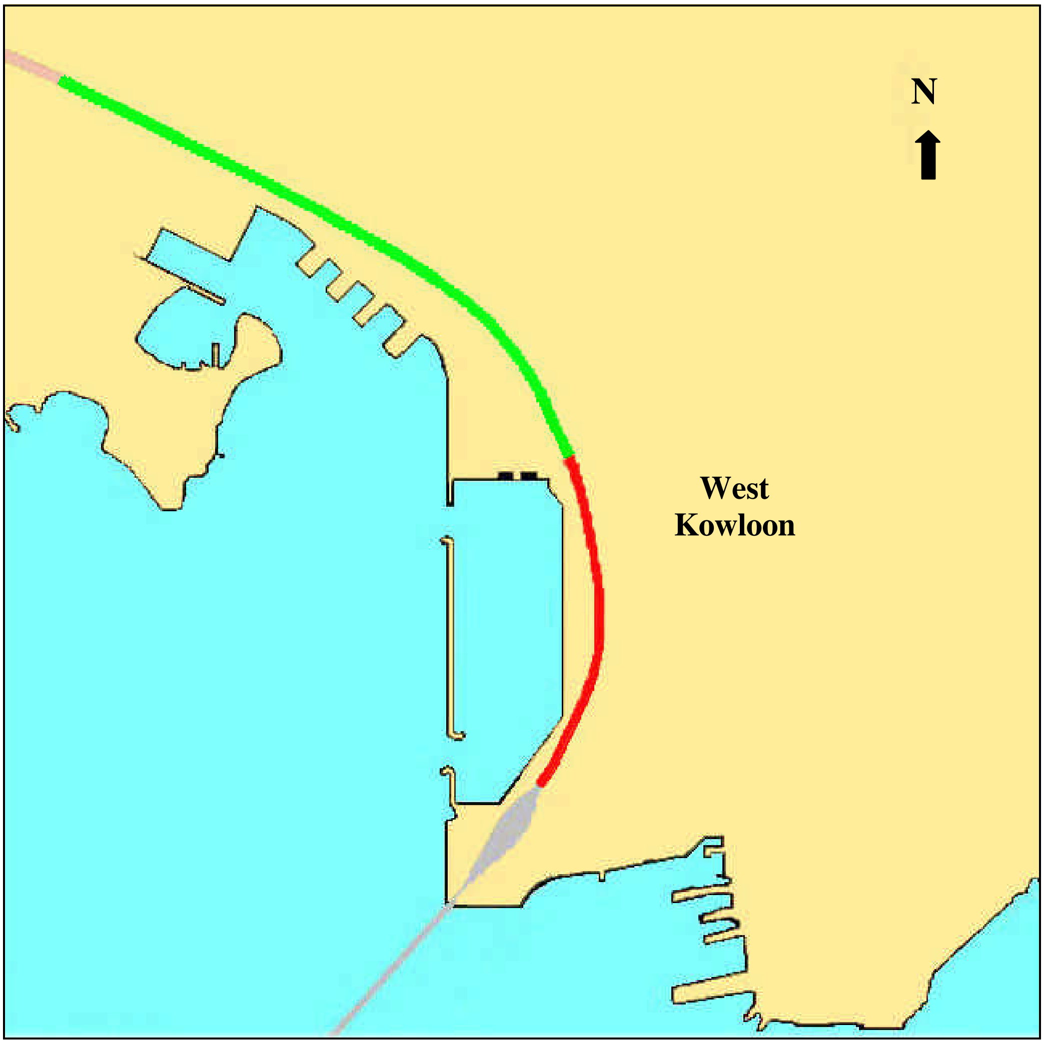


Legend:
- (blue) Ting Kau Bridge
- (orange) Kap Shui Mun Bridge
- (red) Ma Wan Viaduct
- (green) Tsing Ma Bridge

Source: HyD's records

Figure 2

Location of the West Kowloon Expressway
(para. 1.3 refers)

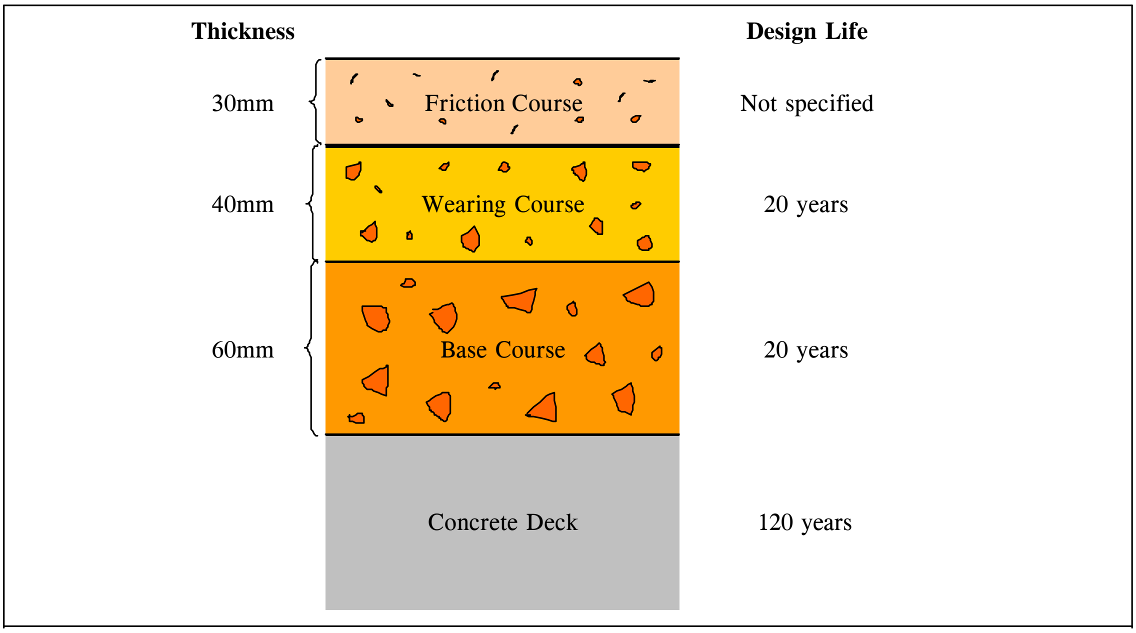


Legend:

Green	West Kowloon Expressway – northern section (on viaduct)
Red	West Kowloon Expressway – southern section (at grade)
Grey	Western Harbour Crossing

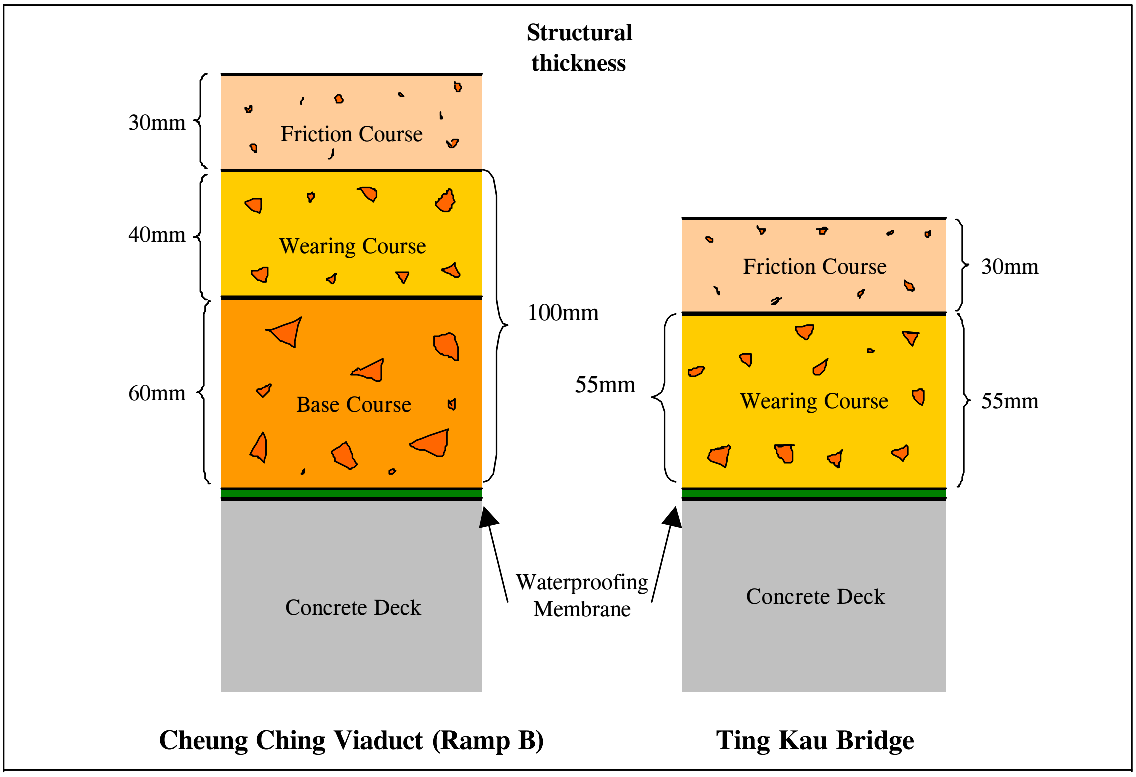
Source: HyD's records

Figure 3
The layout of a bituminous pavement on a bridge deck
(with typical thickness and design life)
(paras. 2.2 and 4.3 refer)



Source: HyD's records

Figure 4
Thickness of the bituminous pavements of
Cheung Ching Viaduct (Ramp B) and Ting Kau Bridge
(para. 4.13 refers)



Source: HyD's records

Photograph 1
An example of a defect on the road surface of the Ting Kau Bridge
(para. 2.5 refers)

Source: HyD's photo taken in August 1998

Photograph 2
An example of a defect on the road surface of the West Kowloon Expressway Viaduct
(para. 2.5 refers)

Source: HyD's photo taken in July 1998

(i) **the circumstances under which waterproofing membranes should be applied and the most effective way for their provision for future bridge projects; and**

(ii) **the specifications on bonding strength between the waterproofing membrane and the bituminous surfacing for use in future bridge projects.**

Response from the Administration

3.17 The **Director of Highways** generally agrees with the audit recommendations. He agrees to carry out further research on the application of waterproofing membranes. The HyD will continue to gather information and to enhance the knowledge on the design and construction of bridge pavement with waterproofing membranes under the Hong Kong conditions. He has said that:

(a) the provision of waterproofing membranes on deck surfaces is a complicated and relatively new technology. The performance of the waterproofing membrane is affected by many factors. It is therefore a technology which has yet to be perfected by further design and local site experience;

(b) due to the technical nature of the matter, the HyD will need more research rather than relying on a consultancy study similar to the study carried out by the Consultant to arrive at useful conclusions on the surface deformation issues; and

(c) the HyD will focus on researching specific waterproofing materials proposed for use in individual projects in Hong Kong. Under the on-going Ngong Shuen Chau Viaduct Contract, tests will be carried out on a number of waterproofing membranes to provide both laboratory and site performance data for future reference in the design of pavements.

3.18 The **Secretary for the Environment, Transport and Works** has said that the main underlying causes leading to the road surface deformation have apparently been identified in the Stage 1 study. The failure is due to the combined action of a number of contributory factors which can hardly be segregated in a quantitative manner.

PART 4: SPECIFICATIONS ON PAVEMENT THICKNESS

4.1 This PART examines the HyD's specifications for determining the thickness of bituminous pavement on the bridge deck. The audit has revealed that there is room for improvement in the drawing up of specifications on pavement thickness by the HyD.

Road surfaces on bridge decks

4.2 In the 1970s, bridges in Hong Kong were designed with the concrete deck surface as the riding surface. In November 1985, the HyD promulgated HyD Technical Circular (HyDTC) No. 11/85 entitled "Running Surface of Bridge Decks". The circular required that new bridges should be provided with bituminous surfacing, as follows:

(a) the bituminous surfacing could achieve a far superior riding quality and allowed much greater flexibility in providing and maintaining a textured running surface, although it would add to the dead weight of the bridge structure;

(b) the bituminous surfacing could also be used in conjunction with a waterproofing membrane to seal the bridge deck and thereby reduce maintenance costs; and

(c) the bituminous surfacing should be designed with a thickness of 100mm. For high speed roads, the 100mm surfacing should also include a friction course.

Different types of bituminous layer

4.3 The bituminous pavement on a bridge deck is typically made up of two or more layers of bituminous materials with different mix of constituent components. The typical layers are the base course, wearing course and friction course. A base course usually forms the underlying layer above the bridge deck with a wearing course laid on top. The base course distributes the traffic load over the bridge deck, and provides a regular surface on which to lay a relatively thin wearing course. The wearing course provides a safe, skid-resistant surface, and withstands the effect of abrasion and stresses from traffic. For high speed roads, a friction course is laid as the uppermost layer to reduce tyre noise and to improve skid resistance and surface drainage. Table 6 below shows the characteristics of the different bituminous layers. (Figure 3 on the centre pages shows the typical layers of a bituminous pavement on a bridge deck.)

Table 6

Characteristics of different bituminous layers

Bituminous layer	**Nominal maximum aggregate particle size**	**Recommended layer thickness**			**Structural property**
		Minimum	**Maximum**	**Typical**	
	(mm)	**(mm)**	**(mm)**	**(mm)**	
Friction course	10	30	35	**30**	**Non-structural**
Wearing course	20	40	50	**40**	**Structural**
Base course	37.5	60	80	**60**	**Structural**

Source: HyD's records

Note: It is generally accepted that the thickness of individual bituminous layers should be within the range of about 1.5 to 3 times the nominal maximum aggregate particle size, although there is no definitive rule. Thinner layers make the mix hard to compact because of the mechanical interlocking of the large aggregate, while thicker layers may be too plastic and prone to deformation during the compaction stage.

Total pavement thickness and structural thickness

4.4 The total thickness of a pavement is the sum of the thickness of the individual layers. In terms of stress distribution, it is the base course and the wearing course that are considered as being structurally significant because they help distribute the wheel load from traffic over the bridge deck. The base course and wearing course are therefore regarded as structural layers. On the other hand, the friction course contributes very little to the distribution of traffic load. It is considered as a non-structural layer. **In determining the structural thickness of a pavement, the thickness of the friction course is excluded.**

Permitted reduction in structural thickness of bituminous pavement

4.5 According to HyDTC No. 11/85, the general requirement was that the bituminous surfacing should be designed with a thickness of 100mm. This generally comprised a base course and a wearing course, both of which were structural layers. For high speed roads, HyDTC No. 11/85 stated that the 100mm bituminous surfacing should also include a friction course. Since the friction course was non-structural, the structural thickness of the pavement would be reduced by the thickness of the friction course. If a friction course with a typical thickness of 30mm was provided, the structural thickness of the pavement would be reduced to 70mm (100mm less 30mm).

4.6 In March 1995, the HyD issued HyDTC No. 3/95 to supersede HyDTC No. 11/85. HyDTC No. 3/95 stated that, to achieve better riding quality of bridge decks and to allow greater flexibility in maintaining the road surfaces, bridge structures should be designed with 100mm thick bituminous surfacing.

4.7 HyDTC No. 3/95 also provided for a reduction in pavement thickness for high speed roads on bridges where a friction course was laid. It stated that:

> "For bridges where a friction course is to be the top layer of the bituminous surfacing, the design thickness of the bituminous surfacing should be reduced to 80mm taking into account the practicability of layer thicknesses so specified in achieving successful laying and compaction of the bituminous materials concerned. This 80mm thick bituminous surfacing should include a 30mm thick friction course laid on top of a 50mm thick wearing course."

4.8 A comparison of the thickness of the pavements specified in HyDTC No. 11/85 with that in HyDTC No. 3/95 is shown below:

		HyDTC No. 11/85	**HyDTC No. 3/95**
(a)	Total thickness of a bituminous pavement without a friction course	100mm	100mm
(b)	Thickness of a bituminous pavement of a high speed road with a friction course:		
	(i) Total thickness	100mm	80mm
	(ii) Structural thickness (total thickness less the 30mm friction course)	70mm	50mm
	(iii) Reduction in structural thickness as compared with (a) i.e. (a) – (b)(ii)	30mm	50mm

The Consultant had expressed reservations about the reduction in the structural thickness — see paragraphs 4.9 to 4.14 below.

Findings of the consultancy study

4.9 As mentioned in paragraph 3.12 above, one of the causes of the premature deformation of road surfaces might be associated with the reduced pavement thickness. The Consultant considered that pavement thickness clearly played a significant role with regard to the ability of the bituminous surfacing to resist the wheel load, and the magnitude of the stresses developed at the interface between the bituminous surfacing and the waterproofing membrane.

4.10 The Consultant considered that, under HyDTC No. 3/95, the permitted reduction in total pavement thickness to 80mm was derived in order to overcome difficulties in laying the wearing course or base course materials in a single 70mm thick layer. Alternatively, if two layers were laid, the thickness of each layer would be less than the recommended thickness for the bituminous materials (see Table 6 in para. 4.3 above). The Consultant also noted that the HyD's Standard Drawings (Note 8) showed a typical bituminous pavement with a total thickness of 130mm, consisting of a 30mm friction course, a 40mm wearing course and a 60mm base course. This pavement design was one option to achieve a structural thickness of 100mm when a 30mm friction course was laid over the wearing course and the base course.

4.11 The Consultant considered that, where a friction course (30mm) was provided, the permitted reduction of the total thickness of the bituminous pavement to 80mm would leave a structural thickness of only 50mm. This would significantly reduce the stress distribution ability of the bituminous pavement, resulting in an increased stress at the interface between the bituminous pavement and the waterproofing membrane. The Consultant developed a numerical modelling of the pavement to verify the stress variations against changes in the thickness and modulus of the bituminous layer. It was revealed that the stress induced at the interface would increase significantly when the thickness of the bituminous pavement was reduced from 100mm to 50mm.

4.12 The Consultant noted that:

(a) where a waterproofing membrane had *not* been used, the increased stress might not have a detrimental effect on the ability of the bituminous pavement to withstand the imposed load. The reason was that the bituminous surfacing would be directly laid onto the concrete bridge deck with a high bonding. Under these circumstances, the permitted reduction in total pavement thickness to 80mm (i.e. 50mm of structural thickness) as given under HyDTC No. 3/95 would be valid; and

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Note 8: *The Standard Drawings are issued by the HyD to give guidance on suitable design details and solutions for commonly encountered situations.*

(b) **where a waterproofing membrane had been used, the low adhesion between the bituminous surfacing and the waterproofing membrane might not be able to withstand the increased stress due to the reduction in pavement thickness. The pavement thickness might need to be increased so as to reduce the level of stress.**

4.13 In support of his analysis, the Consultant also pointed out that for other bridge projects where a waterproofing membrane was used but the structural thickness was about 100mm or more, little deformation was observed. The bridge projects concerned were as follows:

	Bituminous pavement	
	Total thickness	**Structural thickness**
	(mm)	**(mm)**
(a) Cheung Ching Viaduct (Ramp B)	130	100
(b) Cheung Ching Viaduct (Mainline Deck)	140	110
(c) Rambler Channel Bridge	125	95

Figure 4 on the centre pages shows the thickness of the bituminous pavements of the Cheung Ching Viaduct (Ramp B) and TKB.

4.14 The Consultant considered that, even where the adhesion between the waterproofing membrane and the bituminous surfacing was probably low, provided that the pavement thickness was sufficient, the pavement was capable of withstanding the imposed traffic load. One option to overcome the premature failure of the bituminous pavement was to adopt a thickness to a level that the traffic induced stress could be tolerated by the adhesion of the waterproofing membrane. **The Consultant considered that, for future bridge projects, the minimum permitted thickness of the structural layer (i.e. the wearing course and the base course) of the bituminous pavement should not be less than 100mm.**

Audit observations on specifications on pavement thickness

Structural thickness of bituminous pavement

4.15 As mentioned in paragraphs 4.5 to 4.7 above, in accordance with HyDTC No. 11/85 and No. 3/95, the general requirement for the structural thickness of a bituminous pavement was 100mm when a friction course was ***not*** used. When a friction course was laid as the top layer of the bituminous surfacing, there was provision for reduction in the structural thickness.

4.16 The design of the bituminous pavements of the four bridges which had deformation problems was generally in accordance with the provisions of HyDTC No. 11/85 and No. 3/95. The total thickness and structural thickness of the bituminous pavements of the four bridges are shown in Table 7 below:

Table 7

Thickness of the bituminous pavements of the four bridges

	Total thickness	**Friction course thickness**	**Structural thickness**	**Reduction in structural thickness as compared with 100mm (Note)**	
	(a)	**(b)**	**(c) = (a)–(b)**	**(d) = 100–(c)**	**(e) = $\frac{(d)}{100} \times 100\%$**
	(mm)	**(mm)**	**(mm)**	**(mm)**	**(%)**
TKB	85	30	55	**45**	**45%**
WKEV	100	30	70	**30**	**30%**
KSMB	100	30	70	**30**	**30%**
MWV	100	30	70	**30**	**30%**

Source: HyD's records and Audit's analysis

Note: The Consultant considered that the structural thickness should not be less than 100mm — see paragraph 4.14 above.

4.17 Table 7 in paragraph 4.16 above shows that the structural thickness of the pavements of the four bridges fell short of 100mm by 30% to 45%. As mentioned in paragraph 4.11 above, the Consultant found that reduction in the structural thickness would result in an increased stress at the interface between the bituminous surfacing and the waterproofing membrane. **When the adhesion between the bituminous surfacing and waterproofing membrane was low, the increased stress could have contributed to the premature failure of the bituminous surfacing of the four bridges. In cases where a waterproofing membrane is used, the reduction in the structural thickness for high speed roads may not be appropriate.**

Inadequate guidelines on pavement thickness

4.18 **Audit notes that, in drawing up the specifications on the thickness of bituminous pavement on bridge decks and the permitted reduction in structural thickness where a friction course would be used, the HyD had not envisaged the effects of the application of a waterproofing membrane between the bituminous surfacing and the concrete deck.**

4.19 In December 1999, the consultant of a development project intended to follow the guidelines in HyDTC No. 3/95 to determine the thickness of bituminous surfacing to be provided on a bridge deck. He sought the advice of the HyD. In reply, the HyD advised the consultant that the minimum thickness of the wearing course and friction course as specified in HyDTC No. 3/95 was generally applicable to concrete decks "without the installation of a waterproofing membrane". If a waterproofing membrane was to be installed, the designer should carefully determine the required thickness of the bituminous materials taking into account the type of bridge structure, the type of waterproofing membrane, and the types and properties of the bituminous materials.

4.20 **In Audit's view, in future, the HyD should critically consider all the circumstances that would affect the validity of the specifications to be promulgated. The HyD should also supplement or revise the specifications promptly in the light of new developments that may affect the validity of the specifications previously promulgated.**

Structural thickness of the bituminous pavements after the rehabilitation works

4.21 As mentioned in paragraph 2.8 above, in the rehabilitation works for the TKB, KSMB and MWV, the scope of the works included relaying the road surface with bituminous materials.

4.22 In 2002, in relaying the bituminous pavement, the HyD increased the pavement thickness of the TKB from 85mm to 100mm and the structural thickness from 55mm to 70mm. Table 8 below shows the total thickness and the structural thickness of the bituminous pavement of the TKB before and after the rehabilitation works:

Table 8

Thickness of bituminous pavement of the TKB before and after rehabilitation works

		Pavement thickness	
		Before the rehabilitation works	**After the rehabilitation works**
		(mm)	**(mm)**
(a)	Total thickness	85	100
(b)	Structural thickness (total thickness less the 30mm friction course)	55	70
(c)	**Shortfall in structural thickness as compared with 100mm — see paragraph 4.14 above (100 - (b))**	**45**	**30**
(d)	**Percentage shortfall ((c)/100´ 100%)**	**45%**	**30%**

Source: HyD's records

For the rehabilitation works of the KSMB and MWV, the HyD did not increase the structural thickness of the bituminous pavements, which remained at 70mm (see Table 7 in para. 4.16 above).

4.23 Audit noted that, after the completion of the rehabilitation works, the thickness of the structural layer of the four bridges would only be 70mm. **This would still fall short of the recommended structural thickness of 100mm by 30mm (or 30%). There may be future maintenance implications for the long-term durability and serviceability of the bituminous pavements. In Audit's view, there is a need to monitor closely the conditions of the bituminous pavements and consider the need to increase their structural thickness when future maintenance works are undertaken.**

4.24 In the case of the TKB, the HyD had considered the option of relaying the pavement with two structural layers with a thickness of 100mm, and a 30mm friction course on top. However, it was considered that this would increase the dead weight of the bituminous pavement. On the advice of the bridge designer, the HyD determined the total thickness of the pavement of the TKB at 100mm, with a 30mm friction course and a 70mm base course. Audit noted that the requirement to accommodate a friction course and the structural considerations limiting the dead weight of the bituminous pavement had prevented the construction of the pavement of the TKB to a structural thickness of 100mm. In Audit's view, the HyD needs to explore ways of laying a pavement of adequate structural strength within the total thickness of 100mm. In this connection, Audit noted that the HyD had conducted tests and trials on the use of other special bituminous materials, such as mastic asphalt and stone mastic asphalt. The HyD had also considered developing an improved mix of more stiff and dense bituminous material to achieve better structural strength. These special bituminous materials had better rutting resistance than the conventional materials, and could be laid in a relatively thinner layer. For example, mastic asphalt was used as the riding surface of the Tsing Ma Bridge. A waterproofing membrane had been installed between the steel bridge deck and the thin pavement consisting of a 40mm layer of mastic asphalt.

4.25 In response to Audit's enquiry, the HyD said that the road surface of the Tsing Ma Bridge has been in a very good and serviceable condition since its opening to traffic. The HyD did not have any plan to promote the use of mastic asphalt because it was more expensive and there was very limited local experience on its use. Although the service life of some special bituminous materials (such as mastic asphalt) seems to be longer than that of the traditional surfacing materials, their performance in the medium to long term is unknown. There are also other considerations such as cost and availability of supply that will affect the decision on such type of material. **Audit considers that the HyD needs to continue its research on the use of special bituminous materials to improve the structural strength of bituminous pavement on bridges.**

Revision of the specifications on pavement thickness

4.26 As mentioned in paragraph 4.14 above, the Consultant considered that, for future projects, the minimum permitted structural thickness of bituminous pavement on bridge decks should not be less than 100mm. In September 1999, at a meeting attended by representatives of the different divisions of the HyD to discuss the findings of the Consultant's report, the HyD decided to amend HyDTC No. 3/95 to the effect that the required structural thickness of the bituminous pavement on bridge decks should be specified at 100mm instead of 50mm. If there was a friction course, the total thickness should be at least 130mm.

4.27 In November 2001, a revised technical circular HyDTC No. 11/2001 entitled "Running Surfaces of Bridge Decks" was promulgated. **The circular withdrew the permitted reduction of the structural thickness in connection with the use of a friction course in HyDTC No. 3/95. However, contrary to the recommendation of the Consultant and the decision of the September 1999 meeting, the HyD did not specify a minimum thickness for the bituminous surfacing in HyDTC No. 11/2001.** Paragraph 3(a) of HyDTC No. 11/2001 states that:

(a) the designer is responsible for determining the types of bituminous material and individual layer thickness to be used in the running surface taking into account the requirements of relevant specifications, design standards and guidance notes; and

(b) the thickness of individual layers may need to be adjusted to limit the stresses induced in the bituminous materials and, where present, the waterproofing membrane and its interfaces with the running surface and the bridge deck.

4.28 A comparison of the thickness of the pavements specified in HyDTC No. 3/95 and HyDTC No. 11/2001 is shown below:

	HyDTC No. 3/95	**HyDTC No. 11/2001**
(a) Total thickness of a bituminous pavement without a friction course	100mm	Not specified
(b) Thickness of a bituminous pavement of a high speed road with a friction course:		
(i) Total thickness	80mm	Not specified
(ii) Structural thickness (total thickness less the 30mm friction course)	50mm	Not specified
(iii) Reduction in structural thickness as compared with (a) i.e. (a) – (b)(ii)	50mm	Not specified

4.29 During the internal consultation stage for revising HyDTC No. 3/95, there were divided views within the HyD on the matter. There were suggestions that a minimum thickness of the bituminous pavement should be specified for the guidance of the bridge designers and for the sake of a uniform approach to deck surfacing construction. Audit considers that, for the guidance of the bridge designers and for the adoption of a uniform approach to deck surfacing construction, the HyD should have provided some typical examples in respect of material, thickness and specification to HyDTC No. 11/2001.

4.30 Audit notes that it is an international practice to specify a minimum pavement thickness when a waterproofing membrane is applied to a bridge deck. **In the UK, the standard for "Waterproofing and surfacing on concrete bridge decks" requires that the minimum structural thickness of bituminous surfacing should generally be 100mm. The Transport Research Board of the USA had published a report which mentioned that the thickness of bituminous surfacing had a major influence on the performance of waterproofing membranes. The report also mentioned that a minimum thickness of the bituminous surfacing should be specified.**

4.31 Audit notes that the HyD has not specified a minimum thickness for the bituminous pavement in HyDTC No. 11/2001 (see para. 4.27 above). In this connection, in February 2003, the HyD said that:

(a) the thickness for bituminous pavements on bridges was dependent on the particular bridge design and this would vary from project to project. There were different types of corrosion protection methods, proprietary waterproofing membrane systems, and bituminous asphalt mix designs to choose from. They had to be considered together so as to produce an optimum solution that would not induce an unacceptable loading on the bridge; and

(b) designers should have the freedom and the responsibility to choose the best combination of pavement and waterproofing system to arrive at the most economical and effective designs. Rather than issuing specifications on the minimum thickness, the HyD had already made clear in HyDTC No. 11/2001 the key factors on choosing the most appropriate type of road surfaces on bridges. Designers would have to determine the type and minimum thickness of the pavement to cater for the waterproofing membrane they had chosen.

4.32 **Audit considers that, without a specific reference for pavement thickness in HyDTC No. 11/2001, there is a need for other measures to be in place to ensure that the structural thickness of all bituminous pavements can achieve the required structural strength, particularly for designs where a waterproofing membrane is to be applied.** For example, the HyD may need to check thoroughly the design and thickness of the bituminous pavements of future bridges to ensure that the structural thickness is adequate.

4.33 In response to Audit's enquiry, in September 2002, the HyD said that HyDTC No. 11/2001 would be updated in future as the situation warranted, such as when new technology or more conclusive evidence on the causes of the deformation of road surfaces was available.

Audit recommendations on specifications on pavement thickness

4.34 **Audit has *recommended* that the Director of Highways should:**

(a) **in order to minimise the risk of premature deformation of road surfaces, critically assess the thickness of bituminous pavements of future bridge projects so that the pavements are in a good serviceable condition during their design life (i.e. without the need for major rehabilitation works);**

(b) **in future, critically consider all the circumstances that would affect the validity of the specifications and guidelines to be promulgated on the construction and maintenance of highways, and revise the specifications promptly in the light of new developments;**

(c) **monitor closely the conditions of the bituminous pavements of the TKB, WKEV, KSMB and MWV, and, for future maintenance works, consider the feasibility of using special bituminous materials (such as mastic asphalt) so as to provide sufficient structural strength and to prevent the premature deformation of the road surfaces; and**

(d) **in view of the fact that the minimum thickness of pavements is not specified in HyDTC No. 11/2001, consider taking other measures to ensure that an adequate structural thickness is provided in the pavement design of bridges (e.g. carry out a thorough check on the design of bituminous pavements on bridges).**

Response from the Administration

4.35 The **Director of Highways** and the **Secretary for the Environment, Transport and Works** agree with the audit recommendations that the HyD should critically assess the thickness of bituminous pavements of future bridge projects and critically consider all the circumstances that would affect the validity of the specifications and guidelines to be promulgated.

4.36 The **Director of Highways** agrees to monitor the conditions of the bridge decks closely, and consider the possible use of special bituminous materials in future maintenance works. He has said that:

(a) the Consultant did not come to a definitive conclusion relating the pavement thickness to the surface deformation. The HyD had accepted the Consultant's recommendation and increased the structural thickness of the bituminous surfacing of the TKB from 55mm to 70mm; and

(b) the HyD's technical circulars issued in 1985 and 1995 permitting a reduction in the structural thickness had not included the use of the waterproofing membrane. If a waterproofing membrane is used, the pavement thickness will have to suit the requirements of the membrane material and the tack coat used over the membrane. There are many types of waterproofing membranes. The designer should choose the appropriate type to suit the particular bridge design, and the type and thickness of the pavement chosen. Unduly thick bridge deck surfacing will induce unnecessary loading leading to an uneconomical bridge design.

PART 5: CORROSION PROTECTION FOR SEGMENTAL BRIDGES

5.1 This PART examines the effectiveness of corrosion protection for bridges built in Hong Kong using the segmental construction method. The audit has revealed that there is scope for improvement in the application of waterproofing membranes to these bridge projects.

Need for corrosion protection of bridge decks

5.2 In Hong Kong, a bridge structure is usually designed to have a serviceable life of 120 years. The reinforced concrete structure of a bridge uses large quantities of steel bars and tendons (tensioned cables) to reinforce the structure and deck. Corrosion of the steel reinforcement and internal tendons may reduce the lifespan of the bridges. Repairs or reconstruction of bridges having corrosion problems involve significant cost, and cause disruption to traffic and inconvenience to road users. Therefore, there is a need to provide corrosion protection on the surface of the bridge deck to prevent the ingress of water into the bridge deck.

5.3 In the 1960s, the premature deterioration of concrete bridge decks was recognised by some countries as a serious problem. Investigations were carried out to identify the role of moisture and de-icing salts in causing the corrosion of embedded reinforcement. Consequently, particularly in the USA and the UK, a variety of waterproofing membranes were developed. In 1965, the waterproofing of bridges in the UK was made mandatory.

Corrosion protection for segmental bridges in Hong Kong

5.4 In Hong Kong, the general practice is not to provide a waterproofing membrane for bridges as de-icing salts are not used on roads. However, with the introduction of the segmental construction method in Hong Kong in the late 1980s and the subsequent increasing popularity of this method, the need for protection of the bridge deck surfaces takes on greater importance. For segmental bridges, the construction joints between the adjacent segments make up a large number of segment joints over the bridge deck. These segment joints are vulnerable to the ingress of water through the pavement layers which may cause corrosion to the reinforced concrete deck. Therefore, it is important to provide waterproofing membrane on segmental bridges in Hong Kong to prevent water seepage. Most of the expressway bridges built in Hong Kong in the mid-1990s have therefore been provided with waterproofing membranes.

Technical report on corrosion protection

5.5 In August 2002, the HyD issued a technical report entitled "Corrosion Protection of Concrete Bridge Decks". In this report, the HyD summarised the current state of technology of corrosion protection strategies. The following strategies for corrosion protection of bridges were stated in the technical report:

(a) waterproofing membrane;

(b) epoxy coated reinforcement and galvanised reinforcement;

(c) cathodic protection; and

(d) enhanced construction procedures.

5.6 The technical report was intended to give an outline of the state of technology of the various corrosion protection strategies. In particular, the technical report was intended to form a basis for discussions among the various HyD offices. The technical report emphasised that it was the responsibility of the bridge designer to identify the most appropriate corrosion protection method, taking into account the technologies available and the type of the bridge structure adopted.

5.7 The technical report mentioned that the corrosion protection of bridge deck included a package of measures to provide multi-layer protection. If any individual layer of protection became ineffective, the other layers of protection would still give adequate assurance of protection against corrosion. The waterproofing membrane was the first line of defence against the ingress of water through the segment joints.

Audit observations on corrosion protection for segmental bridges

Repairs of waterproofing membranes

5.8 ***Deformation of road surface impaired waterproofing membranes.*** According to the technical report, a waterproofing membrane is considered to have failed if water penetrates through the membrane to the concrete, or the bituminous surfacing over the membrane has broken up due to poor bonding. Under these circumstances, the waterproofing membrane is no longer watertight. The deformation of the road surface may also damage the waterproofing membrane and prevent it from functioning effectively to guard against water seepage.

5.9 As mentioned in paragraph 2.6 above, ad hoc repair works were carried out for the TKB, WKEV, KSMB and MWV not long after they were opened to traffic. The ad hoc repair works mainly included the patching up of the bituminous pavement. The damaged waterproofing membranes were removed. However, no new waterproofing membranes were applied immediately. The waterproofing membranes were to be reinstated when the rehabilitation works were carried out.

5.10 ***Waterproofing membranes not fully repaired during rehabilitation works.*** According to overseas engineering guidelines and practices, for a waterproofing membrane to be effective, it should form a continuous layer uniformly bonded to the deck surface. The original waterproofing membranes of the four bridges were designed in accordance with this practice, i.e. the waterproofing membranes were applied to the entire deck surfaces with no breaks.

5.11 As mentioned in paragraph 2.7 above, rehabilitation works were carried out to resurface the entire road surfaces of three of the four bridges. According to the contract documents of the rehabilitation works, the waterproofing membranes were only applied to areas around the segment joints but not to the entire deck surface. In September 2002, the rehabilitation works for the road surface of the TKB were completed. However, new waterproofing membranes were only applied to about 17% of the total deck surface. This is at variance with the original design of the waterproofing membrane of the TKB in which waterproofing membranes were applied to the entire deck surface. Audit considers that when rehabilitation works for the bituminous pavements of the four bridges are required, the HyD should consider the need to re-apply waterproofing membranes to cover the entire deck surfaces. In response to Audit's enquiry, in February 2003, the HyD said that, unless unexpected situations occurred, it was not considered necessary to re-apply waterproofing membranes to the entire deck surfaces.

Segmental bridges without waterproofing membranes

5.12 ***Waterproofing membrane for the Hung Hom Bypass omitted during construction.*** The Hung Hom Bypass (HHB) is a dual carriageway road linking Hung Hom Road with Salisbury Road, and other elevated roads to the Princess Margaret Road and Chatham Road. The HHB was opened to traffic in August 1999. The elevated sections of the HHB are reinforced concrete bridge structures which were built using the segmental construction method. In the original design of the HHB, the intention was to apply a waterproofing membrane to the bridge deck. A number of site trials were conducted by the contractor using a variety of waterproofing membranes.

5.13 In November 1998, during the construction stage of the HHB, the road surface deformation problems in connection with the use of waterproofing membranes were experienced for the four bridge projects. There was concern over whether similar problems would occur for the HHB. In view of the uncertainties on the use of the waterproofing membrane, the HyD decided not to apply the waterproofing membrane to the HHB. It was considered that, after the completion of the investigation into the causes of the road surface deformation problem (see PART 3 above), a satisfactory solution would have been identified for the application of the waterproofing membrane. The need for the application of a waterproofing membrane to the HHB could then be revisited and installation could be made during the normal resurfacing programme of the deck surface.

5.14 **In response to Audit's enquiry, the HyD said that the original proposal to install the waterproofing membrane on the bridge decks of the HHB was withdrawn and no alternative materials were used. No compensatory measures for the omission of the waterproofing membrane on the HHB were recommended. However, special sealants were applied to the segment joints and tbe joints of prestressed tendon ducts. In Audit's view, the HyD needs to consider the installation of a waterproofing membrane during the maintenance programme of the HHB in future.**

5.15 ***Signs of rusting on Kwun Tong Bypass.*** According to the HyD's records, the Kwun Tong Bypass (KTB) is the first bridge structure built using the segmental construction method in Hong Kong. The KTB is part of Route 6 which provides a high speed road link between Hong Kong Island and Shatin. It is 4.8 kilometres long from the Kowloon side of the Eastern Harbour Tunnel to the Tate's Cairn Tunnel. Construction of the KTB was completed in 1991.

5.16 **Audit noted from the HyD's records that the bridge deck of the KTB had not been provided with a waterproofing membrane for corrosion protection.** Because of the concern over water seepage, the segment joints had been sealed with epoxy glue. However, it was discussed in February 1993 that even though the segment joints were glued, they were not watertight. To mitigate the problem of water seepage, the HyD provided waterproofing membranes for most of the expressway bridges built in the mid-1990s using the segmental construction method.

5.17 In September 1999, at a meeting held to discuss the Consultant's report (see para. 3.3 above), the Assistant Director of the HyD's Headquarters Division commented that waterproofing membranes were necessary to prevent prestressed tendons from rusting due to water seepage through the bituminous layers. He instructed the Structural Division to conduct a survey to investigate the severity of the rusted tendons for all the existing bridges. **In reply, the Chief Engineer of the Structural Division said that the KTB did have such a problem as the prestressed tendons were found rusted some years ago.** However, the inspection records related to the rusting problem of the KTB and the results of the survey were not available for audit inspection.

5.18 In response to Audit's enquiry, in December 2002, the HyD said that stain marks were observed at the segment joints of the KTB in 1992. This suggested that there might be a possibility of leakage through the joints. However, no further leakage had been observed in subsequent inspections. This shows that the crack seepage path formed has been sealed itself. No corrosion of the prestressed tendons was therefore envisaged. The TKB was found to be in good condition during recent bridge inspections.

5.19 **The reported signs of leakage and rusting on the KTB have indicated the importance of corrosion protection for segmental bridges. Since the KTB had not been provided with waterproofing membranes, Audit considers that, in the future maintenance programme of the KTB, the HyD needs to consider whether waterproofing membranes should be installed.**

5.20 In response to Audit's enquiry, in February 2003, the HyD said that, unless unexpected situations occurred, it was not considered necessary to re-apply waterproofing membranes to the HHB and the KTB.

Need to strengthen inspection programme for segmental bridges

5.21 The HyD has put in considerable effort in carrying out research on the subject of corrosion protection of bridges. The HyD has prepared a technical report about the state of technology of the various corrosion protection strategies. Further research on the corrosion protection of bridges should be conducted to update the guidelines and specifications on the technologies and engineering practices on the subject.

5.22 The incidents mentioned in paragraphs 5.8 to 5.19 above have raised concern over the effectiveness of the waterproofing membranes for corrosion protection of bridges built using the segmental construction method in Hong Kong. Without protection against the ingress of water by an effective waterproofing membrane, the segmental bridges may be subject to a higher risk of corrosion. This would in turn affect the design life of 120 years. **Audit considers that there is a need to step up the inspection programme of bridges so as to monitor closely the structural integrity and long-term durability of the segmental bridges.**

Audit recommendations on corrosion protection for segmental bridges

5.23 **Audit has *recommended* that the Director of Highways should:**

(a) **step up the inspection programme so as to monitor closely the structural integrity and long-term durability of bridges built using the segmental construction method (in particular, the TKB, WKEV, KSMB, MWV, HHB and KTB); and**

(b) **continue to carry out research on corrosion protection of bridges and, where appropriate, promulgate guidelines on corrosion protection of bridges.**

Response from the Administration

5.24 The **Director of Highways** agrees to monitor closely the structural integrity and long-term durability of the bridges built using the segmental construction method. He has said that:

(a) waterproofing membranes are not normally provided to bridge decks in Hong Kong. Waterproofing membranes have been adopted in precast segmental constructions as an added line of defence for the prevention of water seepage through the segment joints;

(b) the HyD has gained from experience that waterproofing membranes are expensive to lay and maintain, and will therefore provide them only when there are major benefits to do so; and

(c) during the rehabilitation works of the TKB, it was considered still acceptable if no waterproofing membrane was applied to the precast concrete deck surface. As the construction joints might be prone to seepage, it was considered still preferable to apply waterproofing membranes to areas around the joints.

5.25 The **Secretary for the Environment, Transport and Works** has said that for normal concrete deck, it is widely accepted that the most effective corrosion protection method is to provide high quality concrete with adequate concrete cover to reinforcement.

Appendix A
(para. 1.3 refers)

Particulars of the Ting Kau Bridge, West Kowloon Expressway Viaduct, Kap Shui Mun Bridge and Ma Wan Viaduct

	TKB	WKEV	KSMB	MWV
Length (metres)	1,177	2,700	820	503
Cost of construction ($ million)				
— Total cost	2,077	641	2,180 (Note)	
— Cost of bituminous surfacing and waterproofing membrane	13.99	44.10	6.44	4.31
Opened to traffic	5 May 1998	20 February 1997	22 May 1997	22 May 1997
Function	It connects the west and northwest New Territories to the urban areas of Kowloon and Hong Kong Island, and also the Hong Kong International Airport at Chek Lap Kok.	It runs from the Kwai Chung Viaduct to the Western Harbour Crossing tunnel toll plaza.	Together with the Tsing Ma Bridge, it provides a direct access to the Hong Kong International Airport.	It connects the Tsing Ma Bridge and the KSMB.
Remarks	With three towers, it is the longest cable-stayed bridge in the world.	It is part of the four-kilometre long West Kowloon Expressway of dual carriageway.	It is the longest cable-stayed bridge in the world carrying both road and rail traffic.	It is a 503-metre long expressway carrying both road and rail traffic.

Source: *HyD's records*

Note: *The construction of the KSMB and the MWV was carried out under a single contract. A breakdown of the individual construction cost of the two bridges was not available from HyD's records.*

Chronology of key events

November 1985	The HyD promulgated HyDTC No. 11/85. New bridges should be provided with bituminous surfacing of 100mm in thickness.
Late 1980s	Segmental construction method for bridges was introduced in Hong Kong.
1991	The KTB, the first segmental bridge in Hong Kong, was completed and opened to traffic.
1992	Stain marks were observed at the segment joints of the KTB.
March 1995	The HyD promulgated HyDTC No. 3/95 to replace HyDTC No. 11/85. The circular provided for a reduction in pavement thickness for high speed roads on bridges where a friction course was laid.
February 1997	The West Kowloon Expressway was opened to traffic.
May 1997	The KSMB and MWV were opened to traffic.
August 1997	First defects were noted on the road surfaces of the WKEV.
May 1998	The TKB was opened to traffic.
July 1998	First defects were noted on the road surfaces of the TKB, KSMB and MWV.
September 1998	Premature surface deformation of the TKB was reported in a local newspaper.
October 1998	A LegCo Member enquired about the reasons for the premature deformation of the road surface of the TKB.

November 1998	The HyD engaged a consultant to study the problem of road surface deformation on bridges. The study was intended to be a Stage 1 study.
August 1999	The HHB was opened to traffic.
October 1999	The Consultant completed the Stage 1 study and issued the final report.
November 2001	The HyD promulgated HyDTC No. 11/2001 to replace HyDTC No. 3/95. The revised circular provided that the bridge designer is responsible for determining the types of bituminous material and layer thickness to be used in the running surface.
April 2002	The construction of the Ngong Shuen Chau Viaduct commenced in April 2002 and was scheduled for completion by December 2006.
August 2002	The HyD issued a technical report entitled "Corrosion Protection of Concrete Bridge Decks".
August 2002	The rehabilitation works for the slow lanes of the MWV were completed at an estimated cost of $2.3 million.
September 2002	The rehabilitation works of the TKB was completed at an estimated cost of $27.3 million.

Appendix C

Acronyms and abbreviations

HHB	Hung Hom Bypass
HyD	Highways Department
HyDTC	Highways Department Technical Circular
KSMB	Kap Shui Mun Bridge
KTB	Kwun Tong Bypass
LegCo	Legislative Council
MOM	Management, operation and maintenance
MWV	Ma Wan Viaduct
TKB	Ting Kau Bridge
TMCA	Tsing Ma Control Area
WKEV	West Kowloon Expressway Viaduct
m^2	Square metres
mm	Millimetres