Chapter 9
Vehicular Parapet Design

INTRODUCTION

9.1 After the incident on 10 July, concern was expressed about the design of the vehicular parapet at the incident spot and other locations with similar characteristics. For this reason, the Panel has devoted much effort in reviewing the issue of parapet design and will set out its findings in detail in this chapter.

9.2 Although this chapter is not intended to be a technical report, the Panel considers it essential and beneficial for the fundamental concepts behind parapet design to be explained and understood. The engineering principles involved are complex and technical. Therefore, an attempt has been made to put these principles in layman terms to help the public better understand the matter.

9.3 Parapets are protective devices that are designed to reduce the severity of an accident when an errant vehicle leaves the roadway. They provide a passive line of defence. As such, they cannot be the cause of, or a contributory factor in, an accident. Properly designed, they can reduce the severity of the consequence of an accident. At the same time, these vehicle parapets are also obstacles which means that a vehicle hitting a parapet can result in injury to the occupants as well as vehicle damage.

BASIC DESIGN PRINCIPLES

What happens when a vehicle collides with a parapet

9.4 To aid understanding, some of the physical principles involved in a collision between a vehicle and a parapet are explained below.

9.5 When a vehicle collides with a parapet, there are several possible outcomes that depend on a number of factors, including the strength and rigidity of the parapet,
the speed of the collision, the angle of incidence, vehicle weight and the centre of gravity of the vehicle relative to parapet’s height. The result is that –

- the vehicle is retained and may either be stopped by, or rebound from, the parapet; or
- the vehicle may penetrate the barrier if it is not strong enough to withstand the impact; or
- the vehicle may roll over the parapet if the parapet is not high enough.

9.6 Where parapet retains the vehicle, the collision process may be broken down into four phases, as shown in Figure 9.1 –

- collision of vehicle’s front corner;
- lateral scrapping against the parapet;
- collision of vehicle’s rear corner; and
- re-entry of vehicle onto the carriageway.

Figure 9.1 – The four phases of collision against a parapet
9.7 The angle of incidence ‘$\phi$’ can be influenced by many factors such as site geometry, vehicle speed and friction on the road surface. The larger the angle of incidence, the more severe the collision. The likelihood of a vehicle penetrating the parapet will also be correspondingly higher.

9.8 The degree of the exit angle ‘$\alpha$’ depends on the amount of energy released in the collision. The more energy released (by deforming the parapet and/or the vehicle) the smaller the exit angle. The less energy released, the larger the exit angle. This will also increase the likelihood of secondary collisions by the errant vehicle running onto other vehicles on the roadway.

9.9 To analyse whether a vehicle will roll over a parapet is a complex process. It depends on the centre of gravity (CG) of the vehicle relative to the contact point with the parapet, the weight and speed of the errant vehicle, and the magnitude and duration of the reaction force the parapet exerts on the vehicle. If the vehicle’s CG is above the point of contact between the vehicle and the parapet, the more flexible the parapet and the vehicle are, then the less likely will the vehicle roll over the parapet.

Containment levels

9.10 It is international practice that safety features are developed and tested for selected normalised situations that are intended to encompass a large majority, but not all, of the possible in-service collisions. The Panel notes that lighter vehicles account for a much higher proportion of vehicle numbers, and are therefore more likely to be involved in a collision than other types of vehicles. Past accident records confirm that most crashes on vehicular parapets involved light vehicles.

9.11 Containment capacity refers to the ability of the parapet to contain the impact of an errant vehicle and to deflect it away in a controlled manner. A containment level is normally expressed in terms of the angle of incidence, the weight and speed of the vehicle which represent the magnitude of the impact that the parapet is designed to sustain.
9.12 Parapets are designed to satisfy a selected containment level. For any particular containment level, there can be a variety of designs.

9.13 A strong parapet designed to a higher containment level may stop a heavy vehicle in the desired manner, but may cause considerable damage to a smaller vehicle. Occupants of a small vehicle may also be subject to severe acceleration force and injury. Conversely, a parapet with a lower containment level designed for light vehicles would not perform as equally well for larger vehicles which, in case of a severe impact, may even penetrate the parapet. It is therefore important to seek a balance between risk and the level of containment.

Crash testing

9.14 Because crash dynamics are complex, the most effective means to verify the performance of a parapet design is to conduct a full scale crash test. These tests can be very expensive especially when heavy vehicles are involved. Testing facilities are not available in Hong Kong.

Testing standards

9.15 To ensure that parapet designs meet balanced requirements across all vehicle types and numbers, and to provide a unified standard for verifying parapet design, ‘test levels’ have been defined in more recent international standards. A ‘test level’ may include more than one containment level. In other words, for a particular ‘test level’ to be satisfied, parapet designs could be subject to multiple tests each representing a different containment level. Different international standards have slightly different ‘test levels’ defined. The range of ‘test levels’ also varies. Acceptance criteria for the tests are also different, but are normally expressed in terms of structural adequacy, vehicle occupant risk, vehicle damage and exit path requirements.
Computer simulation

9.16 Given that physical tests are expensive, and that it is not feasible to duplicate every possible impact scenario and have it tested, computer simulation provides a viable and more economical alternative. Once a computer model of a particular combination of vehicle and parapet type is developed and calibrated, the model can be used to simulate different collision scenarios.

Design objectives

9.17 The design objectives of all vehicular parapets are similar. The three main requirements are structural adequacy, reduction of occupant risk, and controlled post-impact vehicular response to avoid secondary accidents and to minimize undue risk to the errant vehicle and other road users.

9.18 Structural adequacy is a measure of the ability of the parapet being able to stop an errant vehicle from penetrating, under-riding or overriding the parapet, or to redirect the vehicle in a controlled manner. The parapet may undergo an acceptable sideway deflection.

9.19 Risk to occupant is based on the acceleration and deceleration experienced by the occupant during impact, and the hazard posed by detached elements. Consideration should be given to the risks posed to other road users by the detached fragments of the parapet after impact.

9.20 The third design objective is to control the exit angle and the post-impact vehicle direction to reduce the likelihood of subsequent multi-vehicle accidents involving the crash vehicle re-entering traffic after ‘bouncing’ off the parapet.
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PARAPET DEVELOPMENT IN HONG KONG

9.21 The Panel has examined the history of parapet design in Hong Kong. The Panel notes that constant review and improvement on protection requirements are carried out by the Highways Department (HyD) having regard to the latest international practices and local experience. Reference is made in particular to the requirements of British standards. Parapets are generally designed to prevailing standards at the time when new projects or major renovations are implemented. It is the opinion of the Panel that, since parapets only reduce the severity of an accident, and do not contribute directly to accidents, old designs should not be viewed as ‘unsafe’. It is also not a recognised international engineering practice to replace all existing parapets whenever a new standard emerges. A risk assessment and cost benefit analysis, taking into account the likely hazard, type and volume of vehicles, speed, road geometry, accident statistics and the surrounding environment etc, should be carried out before any enhancement programme is implemented.

9.22 Guidelines for the design of parapets are given in Chapter 15 of the Structures Design Manual (SDM) published by HyD. Parapets are classified for design purposes into five groups, namely P1 to P5. Only P1, P2 and P4 are designed for vehicle impact at different containment levels, viz. ‘normal’, ‘low’ and ‘high’ respectively. P3 and P5 are pedestrian and bicycle parapets not designed for vehicle impact. The section of parapet involved in the incident belongs to the P1 group.

9.23 The following summarises the history of parapet design development in Hong Kong and highlights the special features and properties of each type adopted. The design requirements on P1, P2 and P4 are reproduced from the SDM in the following table. As P2 only applies to low speed roads, the following discussion only focuses on P1 and P4. There are about 248.5 km of P1 parapet and 1.2 km of P4 parapet installed in the territory.
9.24 In the 1970s, parapets in Hong Kong were designed to meet the P1 standard following the requirements of the document ‘BE5’ published by the Department of Transport, United Kingdom (UK). A three-rail steel parapet (called the 1st generation) was adopted as the design (Figure 9.2). This type of parapet is light and attracts less wind load. It is designed to absorb part of the impact energy through deflection of the parapet components so that vehicles rebound back at a smaller angle and a relatively lower speed.

<table>
<thead>
<tr>
<th>Group</th>
<th>Containment level</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>To restrain vehicles up to 1.5 tonnes travelling at 113 kph and a 20° angle of incidence</td>
<td>On expressways and limited access roads</td>
</tr>
<tr>
<td>P2</td>
<td>To restrain vehicles up to 1.5 tonnes travelling at 80 kph and a 20° angle of incidence</td>
<td>On low speed roads</td>
</tr>
<tr>
<td>P4</td>
<td>To restrain vehicles up to 24 tonnes travelling at 50 kph and a 20° angle of incidence</td>
<td>At bridges over railways and other high risk locations</td>
</tr>
</tbody>
</table>

Figure 9.2 – First generation P1 three-rail steel parapet
9.25 In 1975, a three-rail aluminium P1 parapet was introduced (Figure 9.3). The performance of this type of parapet is basically the same as its steel counterpart. However, the maintenance cost of aluminium is lower as it does not rust. The material is also lighter and can be moulded into more aesthetically pleasing designs.

9.26 In 1981, HyD developed a concrete P1 parapet with a metal top rail (Figure 9.4). The ultimate containment capability is slightly higher, but the operation mode is different. An errant vehicle is lifted up by the profile of the parapet to dissipate a portion of the impact energy before being redirected back to the carriageway.

9.27 This type of parapet suffers less damage on impact, is easy to maintain, and has the advantage of preventing debris and splash from reaching the area beneath the elevated structure. However, this type of parapet absorbs less impact energy. Vehicles tend to rebound at a larger angle and a higher speed. There is also the risk of a vehicle overturning or overriding the parapet.
9.28 In 1979, Hong Kong considered it necessary to introduce a higher containment level for railway overpass parapets. The parapets were designed to contain a 24 tonne concrete mixer truck at 50 kph with an impact angle of no less than 20°. A fully loaded concrete mixer truck was the most common heavy vehicle at the time. This containment level was subsequently included in the SDM as the design requirement for the P4 Group parapet. A standard concrete design has been developed as shown in Figure 9.5.

9.29 Apart from the standard parapet designs, the Panel notes new parapet designs have been developed to meet special needs for individual projects. These designs may each offer a slightly different containment level.

9.30 For example, a special type of P4 was developed for the Tsing Ma Bridge, Kap Shui Mun Bridge and Ting Kau Bridge. This type of parapet consists of five high tension steel strands anchored on strong metal posts (Figure 9.6). It has the advantage of attracting minimal wind loads, is light, and is particularly suitable for long span bridges. However, they can only be applied on straight spans and cannot be applied over bridge expansion joints.
9.31 For the Ting Kau Bridge approaches, due to the relatively tight radius involved, and to maintain a gradual transition with the P4 parapet on the bridge, another special design was adopted (Figure 9.7). Two top rails instead of one on a concrete base have been used.

9.32 Between 1999 and 2000, HyD continued to refine the design of the P1 parapet. A new generation of the three-rail P1 parapet was developed. Major modifications consisted of re-orienting the top rail, strengthening the post-to-rail and post-to-base plate connections, and bolting the splicing between the rails. Example of a modified P1 steel parapet is shown in Figure 9.8, and an aluminium one in Figure 9.9.

Computer simulations for P1 parapet

9.33 To verify the field performance of the parapet designs adopted in Hong Kong, HyD commissioned a consultancy in August 2000 to assess the performance of the two generations of P1 parapet using computer simulation technique. The computer model was calibrated using full-scale field tests conducted in a testing laboratory in the USA (Figures 9.10 and 9.11).
9.34 The study covered the following five types of P1 vehicular parapets –

- three-rail steel vehicular parapet (1st generation);
- three-rail aluminium vehicular parapet (1st generation);
- concrete vehicular parapet with aluminium top rail;
- three-rail steel vehicular parapet (2nd generation); and
- three-rail aluminium vehicular parapet (2nd generation).

9.35 The test found that all five types of P1 vehicle parapet met the designed level of containment as required by the SDM. The computer simulation showed that the 2nd generation three-rail P1 parapet had a higher containment capability than the 1st generation. The 2nd generation three-rail P1 was capable of arresting a 1.5 tonne errant vehicle at 113 kph but at a higher impact angle of 40°.

9.36 HyD then proceeded to schedule replacement of all 1st generation three-rail P1 parapet in Hong Kong. Of 90 km of the 1st generation three-rail P1 parapet in Hong Kong, about 42 km have been replaced.

9.37 The Panel recommends that the replacement programme be expedited, taking into account other recommendations in this report.
Computer simulation for bus collision

9.38 As a double-decked bus was involved in the incident, the Panel has made some effort, but was unable to obtain any documented technical information in Hong Kong or abroad, on the containment capability of common parapet types in respect of a double-decked bus collision. On request of the Panel, HyD conducted computer simulations during the period of this review to determine the crashing capacities of P1 parapets for different scenarios of bus impact. The preliminary results show that the P1 parapets are capable of retaining a double-decked bus striking at a low angle of incidence.

<table>
<thead>
<tr>
<th>Parapet</th>
<th>Angle of Impact</th>
<th>Speed</th>
<th>Simulation Case Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Generation P1 Steel Parapet</td>
<td>10°</td>
<td>50 kph</td>
<td>double-decked bus retained</td>
</tr>
<tr>
<td>2nd Generation P1 Steel Parapet</td>
<td>10°</td>
<td>60 kph</td>
<td>double-decked bus retained</td>
</tr>
<tr>
<td>Concrete P1 Parapet with Top Rail</td>
<td>20°</td>
<td>50 kph</td>
<td>double-decked bus retained</td>
</tr>
</tbody>
</table>

9.39 The Panel recommends HyD to conduct further computer simulations to establish the ultimate capacity of all P1 vehicle parapets relating to an impact by a double-decked bus. In view of the particular situation in Hong Kong where double-decked buses are used on almost every part of the road network, the Panel further recommends that when new parapet designs are developed, double-decked bus should be included as one type of heavy vehicle for design consideration.
INTERNATIONAL STANDARDS

9.40 Owing to limited research activities in Hong Kong, and the lack of testing facilities, the Panel notes that HyD’s work in parapet design relied heavily on international standards, in particular the British Standard BS6779 (Highway Parapets for Bridges and Other Structures), based on which the current SDM was developed. The Panel notes that the European Standard – EN1317 (Road Restraint Systems), which is being developed, would ultimately replace BS6779. The design approach adopted in Report 350 of the National Cooperative Highway Research Programme (Recommended Procedures for the Safety Performance Evaluation of Highway Features) of the USA is very similar to EN1317. The Panel has therefore made a detailed examination of these standards to identify rooms for improvement in the design process in Hong Kong.

British Standard BS 6779

9.41 Three levels of containment are specified for metal parapets in BS6779 with the following minimum parapet height and vehicle impact characteristics –

<table>
<thead>
<tr>
<th>Level of containment</th>
<th>Minimum height of parapet (m)</th>
<th>Vehicle Mass (kg)</th>
<th>Height of CG (mm)</th>
<th>Angle of impact</th>
<th>Speed (kph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1.0</td>
<td>1 500</td>
<td>480 to 580</td>
<td>20°</td>
<td>113</td>
</tr>
<tr>
<td>Low</td>
<td>1.0</td>
<td>1 500</td>
<td>480 to 580</td>
<td>20°</td>
<td>80</td>
</tr>
<tr>
<td>High</td>
<td>1.5</td>
<td>30 000</td>
<td>1 650</td>
<td>20°</td>
<td>64</td>
</tr>
</tbody>
</table>

9.42 The standard sets out guidance on the choice of level of containment. For instance, the ‘low’ level of containment is used in urban situations where speed restrictions up to 80 kph apply.
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9.43 The ‘high’ level containment was introduced in the early 1980s, largely as a requirement of British Rail for certain railway lines, where a vehicle falling onto a track would almost certainly result in multi-casualty accident. However, high containment parapets are necessarily strong and hence less yielding. This means they are likely to cause additional damage to light vehicles that strike them and may result in vehicles being deflected at a greater angle than desirable, thereby increasing the risk of injury and secondary accident. It is therefore stated in the standard that the use of ‘high’ level containment should be largely restricted to cases such as bridges over railways.

European Standard EN 1317

9.44 EN 1317 contains five parts altogether and is still being developed. Currently, only three parts are available. This standard is set to replace the corresponding British Standard.

9.45 EN1317 is more sophisticated and comprehensive than BS6779. For vehicular parapets, in addition to containment capacity, the standard also includes requirements on vehicle deformation, parapet deflection and occupant risk. Occupant risk is expressed in terms of impact severity level, which is determined by the total acceleration and deceleration experienced by vehicle occupants during impact with the parapet.

9.46 For parapet design, the major differences between BS6779 and EN1317 are that –

- the containment level specification is more refined in EN1317;
- impact tests are required for both heavy and light vehicles in most cases for any particular design in EN1317; and
- the coverage of the impact test report in EN1317 is more comprehensive than BS6779, in particular on impact severity.
9.47 EN 1317 has taken a slightly different approach in defining containment level. Four containment levels are defined. Each containment level consists of a number of sub-levels. Each sub-level represents an impact scenario equivalent to a test level.

9.48 Instead of the two types of vehicle specified in BS 6779, eight types of vehicles of mass ranging from 900 kg to 38 000 kg (that is, car, rigid heavy goods vehicle, bus and articulated heavy goods vehicles of different sizes) are specified for acceptance testing. A set of 11 different tests is specified. The tests differ in terms of the impact speed (65 kph to 110 kph), impact angle (8° to 20°), weight and type of vehicles.

9.49 The extent to which a parapet is deformed on impact is characterised by the dynamic deflection and the working width. The working width is the distance between the parapet face on the traffic side before impact and the maximum dynamic lateral position of any major part of the parapet (Figure 9.12). The dynamic deflection and the working width can be used to define the conditions under which the parapet can be installed and the distance to be provided in front of obstacles.

9.50 Except for parapets specifically designed to contain light vehicles, the evaluation of containment levels will require the carrying out of two tests, one based on a heavier vehicle, and another using a lighter vehicle. This will ensure that while the heavy vehicle is contained (without excessively deforming the parapet), the light vehicle is not excessively damaged (or causes injury to the occupant).
Report 350

9.51 In Report 350, six test levels for different applications are specified. Test level ‘1’ is the lowest and ‘6’ the highest. The higher the test level, the more it applies to a road carrying a larger number of heavy vehicles.

9.52 For these tests, six types of vehicles ranging from 700 kg to 36 000 kg are specified for impact testing (the vehicle types range from car, pickup truck, van truck, tractor with van trailer or tanker trailer). For each test level, three to four tests are specified. Each test is based on a different size of a particular test vehicle impacting on the parapet at a certain speed (50 kph to 100 kph), and a certain angle (15° to 25°). The test criteria include the three major aspects of structural adequacy, occupant risk, and vehicle trajectory. The objective of all tests is generally to ensure that heavy vehicles are contained and damages to light vehicles are acceptable. In other words, the parapet design is expected to perform for both heavy and light vehicles.

9.53 Parapet design is evaluated using the dynamic performance criteria on the basis of real impact tests.

Application of international standards to Hong Kong

9.54 The Panel notes that, when compared with EN1317 and Report 350, the current SDM, which is based on BS 6779, is more restrictive in terms of the coverage of containment levels specified in the standard.

9.55 The Panel accepts that design standards are never static, but are constantly evolving based on local experience and sentiment, tradition, practice, technological level and economy of a particular country, or by borrowing from experience from other countries. What may be suitable for one country may not be entirely suitable for another. **The Panel considers that adoption of standards from other countries should be done judiciously.**
9.56 The Panel notes that HyD has constantly kept abreast of the latest international design standards, particularly in advanced countries and regions. The Panel accepts that the British Standard is still the mainstay for historical reasons, but expects HyD to adopt new unified standards where possible, besides evolving its own standards in new works and major renovations.

9.57 The Panel recommends that as the UK is also transiting from BS6779 to EN1317, HyD should follow closely the development of EN1317 and other international standards, and bring the SDM in line with the new internationally recognised standards in due course.

**Development of new designs**

9.58 Having examined the local and international standards, the Panel notes that there are very limited design choices for vehicular parapets in particular for the P4 high containment level. The standard P4 concrete wall configuration, though capable of containing double-decked buses, is not suitable for many forms of bridge design.

9.59 The Panel also notes that foreign standards do not make reference to double-decked bus. The extensive use of double-decked buses is a distinct feature of Hong Kong’s transport system, but the containment capacity of the various types of parapets for this type of vehicle has not been fully evaluated.

9.60 The maximum legislated weight for a vehicle in Hong Kong is 44 tonnes. The Panel considers that there is a need to review whether a higher containment level than P4 should be introduced for a certain combination of topographic and traffic conditions.

9.61 There is at present a technical dilemma in preparing a parapet design that can satisfy different containment levels at the same time. However, as technology develops, provisions have been made in more recent international standards, in particular in EN1317, for parapets to be designed to meet more than one containment level. This is to ensure that parapet designs will perform within acceptable limits for selected categories of heavy and light vehicles.
9.62 The Panel recommends that HyD expand the range of containment levels, in particular at the high end, having due regard to the extensive use of double-decked buses in Hong Kong, and the maximum legislated vehicle weight permitted on the road system. The Panel also recommends that HyD continue to monitor the development of multiple containment parapet in the international scene, and develop workable parapet designs for the Hong Kong situation.

9.63 The Panel is pleased to note that HyD has already taken forward this recommendation at the time of preparing this report. In line with the Panel’s recommendation, a comprehensive review of the design requirements for vehicular parapets will be carried out jointly with the Transport Department.

**Parapet Height**

9.64 After the incident, there was public concern that parapets in Hong Kong are not high enough. A parapet may be strong enough to prevent penetration by a vehicle, but unless it is also high enough, an impacting vehicle or its cargo hitting a parapet may roll over the railing. The Panel has therefore examined the mechanism behind roll-over scenarios using a simple static approach.

9.65 The following table shows the parapet height currently specified in the HyD Standard Drawings for parapet group P1, P2 and P4 –

<table>
<thead>
<tr>
<th>Group</th>
<th>Application</th>
<th>Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Normal vehicular parapets</td>
<td>1 100</td>
</tr>
<tr>
<td>P2</td>
<td>Normal vehicular parapets</td>
<td>1 100</td>
</tr>
<tr>
<td>P4</td>
<td>High containment vehicular parapets for railway overpasses and other high risk situations</td>
<td>1 500</td>
</tr>
</tbody>
</table>
The likelihood of a vehicle rolling over a parapet of a given height may be estimated using a simple static method by balancing the roll-over moment against the stabilising moment (Figure 9.13). The roll-over moment is the product of the 'lateral impact force exerted by the vehicle onto the parapet' and the 'difference in height between the vehicle CG and the effective parapet height'. The balancing moment is the product of the 'vehicle weight' and 'half the width of the vehicle'.

A double-decked bus has a large stabilising moment due to its typical weight, passenger loading and vehicle width. To roll over the parapet, the roll-over moment must be larger than this stabilising moment.

In a study conducted by HyD on a 1.1 m high post and rail type parapet, the roll-over moment during impact is envisaged to be much smaller than the stabilising moment. This is because the deflection of the parapet components and the deformation of the bus will lessen the impact force, and the corresponding roll-over moment.

Computer simulations on existing P1 parapets so far show that a 1.1 m parapet would be adequate to prevent a double-decked bus travelling at 50 km/h from rolling over if the impact angle is small.

Based on this analysis, the Panel does not at this stage consider a 2 m high parapet, as suggested by some members of the public, is necessary for the safety of double-decked buses.
The Panel recommends that HyD generate more simulation results involving other impact scenarios in order to fully evaluate the adequacy of the standard height adopted for the P1 parapets.

**Selection Criteria**

International standards do not normally provide guidelines to determine where a safety feature, satisfying a given test level and with specific performance characteristics, would have applications. That decision rests with the highway agency responsible for the implementation of the safety feature.

The Panel agrees with Report 350 on its recommendation that highway agencies should develop objective guidelines for the choice of safety features and the appropriate test levels, taking into account factors such as traffic conditions, traffic volume and heavy vehicle composition, site characteristics, the consequence of vehicle penetration and the cost effectiveness of other safety alternatives.

The current guidance provided in the SDM is relatively crude. A P1 parapet is suitable for general application, while a P4 parapet is used for bridges over railways and high risk locations. There is limited guidance as to what constitutes high risk. Professional experience is relied upon when deciding whether a new design has to be developed for certain site specific conditions.

The Panel recommends that, in anticipation of an expansion of the parapet hierarchy, and the possibility of introducing more height variations, detailed guidelines and analysis procedures be given to designers on the choice of containment level and parapet height with particular attention to the congested environment in Hong Kong and the unique situation of having a large fleet of double-decked buses operating on the road network.
DESIGN REQUIREMENTS FOR PARAPET COMPONENTS AND CONNECTION DETAILS

9.76 Chapter 15 of the SDM specifies the design requirements of metal parapets. It incorporates by reference the requirements from BS 6779, and qualifies by stating that ‘where Hong Kong specifications or conditions differ from the requirements or conditions described in the British Standards, adjustments appropriate to Hong Kong shall be made’.

9.77 For reinforced concrete parapets, a separate standard in the form of a table is set out in the SDM specifying the required strength.

MATERIALS AND WORKMANSHIP

9.78 BS 6779 specified in great detail quality control requirements. It contains strict specifications on workmanship control particularly on metals. Reference is made to other relevant British Standards for quality control on steel and aluminium alloys. Welding and testing requirements including non-destructive testing are also clearly specified.


9.80 The GS specifically provides that steel for vehicular parapets, including welding, should comply with the requirements of Section 18 on structural steelwork, but testing requirements are exempted.

9.81 The Panel understands that such an exemption does not mean the steelwork will not be tested. Particular specification on testing requirements may be included by the designer of individual construction contracts.
9.82 Taking into account the structural significance of the parapet, the Panel recommends that the GS be revised to include suitable testing requirements for fabricating the steel components used in vehicular parapets.

9.83 For aluminium, reference is made in the GS to other British Standards for welding and testing requirements.

NEW MATERIALS AND RESEARCH OPPORTUNITIES

9.84 The Panel has received public suggestions on new parapet designs and materials. A design by the University of Wisconsin involves a parapet made of reinforced glass fibre shaped into multiple rectangular sections in different sizes. Research work has indicated that the design is suitable for restraining both large and small vehicles. Other designs suggested include the use of rubber tubes containing rice husks and wood bran. A student has also made an innovative suggestion of using magnetic parapets.

9.85 The Panel does not rule out the potential of any particular design but notes that research work to properly evaluate the feasibility and effectiveness will be required. The Panel understands that HyD is also following closely the technological developments in the international scene, and is prepared to introduce new designs into Hong Kong for trial if they can be adapted to local conditions.

9.86 The Panel recommends that HyD could carry out some research work in collaboration with local tertiary institutions.

9.87 There is a suggestion to enclose a section of Tuen Mun Road with steel nets. The Panel has reservations about the technical viability of such a proposal, in particular the feasibility of such a retrofitting programme.
**In-service Evaluation**

9.88 The Panel notes that vehicular parapets are designed and tested to selected containment levels. However, testing cannot duplicate every roadside condition or vehicle impact situation. The evaluation process should not therefore stop with successful completion of crash tests.

9.89 The Panel recommends that HyD carry out in-service evaluation of the parapet designs on the basis of the damage information collected after traffic accidents so that various types of parapet design can be refined and improved on an on-going basis.

**High Priority Locations for Improvement**

**Collision statistics**

9.90 In conjunction with the HyD, the Panel conducted a desk-top study on traffic accident records in the past five years in which a vehicle ran into a vehicular parapet or a roadside safety barrier. Of the 2,000 cases identified, it was found that 94.3% involved light vehicles, 4.4% involved medium and heavy goods vehicles and 1.3% involved buses.

9.91 The records indicated that most of the errant vehicles were successfully retained by the vehicular parapets. Of all the recorded accidents, only four involved vehicles penetrating or rolling over a vehicular parapet.
9.92 Having examined the issues relating to parapet designs in great details and past collision statistics, the Panel considers that the existing standards adopted by the HyD for parapet design are generally in line with international practices. Taking into account the standards adopted for road design, and the measures in place to control various types of vehicles and drivers, the Panel is of the view that the various types of P1 parapet are suitable for general application and on elevated structures in terms of containment capacity and height protection. However, in view of the July incident, and the limited knowledge about bus collisions, the Panel considers that there is room for enhancement at critical locations where penetration of the vehicular parapet would result in catastrophic consequences. A proper risk assessment procedure should be developed for such situations.

**Priority locations for road safety enhancement**

9.93 Before a systematic procedure is fully developed for the selection of containment level and the assessment of parapet height, the Panel worked closely with HyD to identify a list of high priority locations having similar characteristics as the incident site where road safety enhancement, including where appropriate higher containment parapets, would have a significant effect in reducing the severity of an accident.

9.94 The July incident spot is identified as having the following characteristics –

- high posted speed limit;
- high traffic volume;
- high bus usage;
- high percentage of commercial vehicles;
- located near expressway entrance with weaving traffic;
- high level above ground; and
- having residents underneath the road structure.
A scoring system was then developed to rank bridges and elevated road sections against the above characteristics. Based on results made in the analysis, a preliminary list of road sections has been drawn up for which consideration should be given to providing some road safety enhancement work.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>District</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NT</td>
<td>Tuen Mun Road (7 locations)</td>
</tr>
<tr>
<td>2</td>
<td>NT</td>
<td>Tolo Highway (4 locations)</td>
</tr>
<tr>
<td>3</td>
<td>NT</td>
<td>Tsuen Wan Road (3 locations)</td>
</tr>
<tr>
<td>4</td>
<td>NT</td>
<td>Sha Tin Road (3 locations)</td>
</tr>
<tr>
<td>5</td>
<td>NT</td>
<td>Shing Mun Tunnel Road (3 locations)</td>
</tr>
<tr>
<td>6</td>
<td>NT</td>
<td>Tseung Kwan O Tunnel Road (2 locations)</td>
</tr>
<tr>
<td>7</td>
<td>NT</td>
<td>Yuen Long Highway (3 locations)</td>
</tr>
<tr>
<td>8</td>
<td>NT</td>
<td>Cheung Tsing Highway (3 locations)</td>
</tr>
<tr>
<td>9</td>
<td>NT</td>
<td>Lion Rock Tunnel Road, section between Kak Tin and Fung Shing Court</td>
</tr>
<tr>
<td>10</td>
<td>NT</td>
<td>North Lantau Highway (2 locations)</td>
</tr>
<tr>
<td>11</td>
<td>K</td>
<td>Ching Cheung Road (2 locations)</td>
</tr>
<tr>
<td>12</td>
<td>K</td>
<td>Kwun Tong Bypass, slip road connecting Lei Yue Mun Road</td>
</tr>
<tr>
<td>13</td>
<td>K</td>
<td>Kwai Chung Road, section fronting Mei Foo Shun Chuen</td>
</tr>
<tr>
<td>14</td>
<td>K</td>
<td>Lung Cheung Road near Tai Wo Ping Interchange</td>
</tr>
<tr>
<td>15</td>
<td>HK</td>
<td>Shek Pai Wan Road (2 locations)</td>
</tr>
<tr>
<td>16</td>
<td>HK</td>
<td>Island Eastern Corridor, section between Victoria Park Road and Healthy Street West</td>
</tr>
</tbody>
</table>
Chapter 9

9.96 The Panel considers that the incident on 10 July was a rare occurrence, the cause of which has yet to be established. Neither the incident site nor the list of road sections identified in paragraph 9.97 above are accident black spots. In considering measures that could enhance safety, expert world-wide will ask: does it make economic sense or is it appropriate to spend large sums to prevent accidents of very low probability (albeit entailing severe consequences), or is it better to spend resources on a package of known measures by which more lives could be saved and injuries prevented in general?

9.97 The Panel advocates a total safety management approach. A risk assessment should be conducted when road safety enhancement schemes are formulated. Strengthening the parapets is but one enhancement measure. It would not be the only measure and may not be the most cost effective option. In certain cases, a good traffic management scheme to accommodate driver behaviour may be more effective.

9.98 The Panel recommends that a detailed study be conducted immediately to formulate a package of road safety enhancement measures for these road sections.