

Department for the Environment Transport and the Regions

Partners in Innovation Scheme Contract Ref: 39/3/570 CC1806

EDGE PROTECTION IN MULTI-STOREY CAR PARKS

- Assessment Method For Installed Restraint Systems

Final Report

October 2001

Prepared by: Dr C K Jolly MSc PhD CEng FIStructE MICE

Royal Military College of Science
Department of Engineering Systems

Cranfield
UNIVERSITY



**University
of Southampton**

**Department of
Civil and
Environmental
Engineering**

*University of
Southampton
Highfield
Southampton SO17 1BJ*

EDGE PROTECTION IN MULTI-STOREY CAR PARKS

- Assessment Method For Installed Restraint Systems

Contents

	Page
1. INTRODUCTION	1
2. BACKGROUND	1
2.1. The Need For Assessment	1
3. PROCEDURE	2
4. CLASSIFICATION AND ASSESSMENT OF EDGE PROTECTION	2
4.1. Classification By Type Of Edge Restraints	2
4.2. Classification Of Vehicle Edge Restraints By Construction Material	2
4.3. Vehicle Restraint And Pedestrian Protection Locations	3
4.4. Edge Restraint System Strength	4
4.4.1. Strength Of Vehicle Restraint Systems	4
4.4.2. Strength Of Pedestrian Protection	10
4.5. Strength Of Vehicle Restraint Fixings	10
4.5.1. Adequacy Of Bolted Connection Bolts	10
4.5.2. Adequacy Of Anchor Bolts Fixing Cantilevered Vehicle Restraints To Decks	10
4.5.3. Bolt Proximity Reduction Factors	11
4.5.4. Other Fixing Design Data	11
5. DETERIORATION OF INSTALLED EDGE RESTRAINT	12
5.1. Reinforced Concrete	12
5.2. Steel	13
5.3. Masonry	13
5.4. Timber	13
6. CONCLUSIONS	14
7. ACKNOWLEDGEMENTS	15
8. REFERENCES	16
APPENDICES	Separate Volumes

1. INTRODUCTION

This report provides a methodology and aide-memoire to facilitate inspection of existing multi-storey car park edge protection. It is one of the four outputs of a Partner in Innovation Project commissioned by the Department for the Environment Transport and the Regions (DETR). The overall objective of the Project was to provide a basis for the reduction of risks of death and injury occurring in car parks from accidents due to impact of vehicles with the edge protection restraints (both on elevated floors and on access ramps), and due to pedestrians falling over, under, or through those restraints. The other outputs are; Literature review of multi-storey car park edge protection barriers [1], Guidance on the inspection of MSCP barrier systems [2], and Edge Protection In Multi-Storey Car Parks - Design Specification and Compliance Testing [3].

This report draws substantially on the individual contributions of the Project Partners and on the discussions of the Steering Group, in addition to conclusions from the associated experimental research programme.

The participation of the key industrial suppliers and installers of car park edge protection restraint systems has led to implementation of the advanced methodology resulting from the research, even during the Project contract period.

2. BACKGROUND

2.1. The Need For Assessment

The Design Specification and Compliance Testing [3] identifies car park owners and operators as having a responsibility to ensure their premises are reasonably safe for use by lawful visitors under The Occupiers Liability Act of 1957. There are also provisions under the Health and Safety at Work etc. Act 1974 requiring employers to conduct their undertakings in such a way as to ensure so far as is reasonably practicable that persons not in their employment are not thereby exposed to risks to their health and safety.

However, car park owners and operators are at present under no obligation to carry out inspections at regular intervals to ensure public safety, and local authorities are powerless to intervene under the Building Act 1984 unless buildings are in a dangerous or obviously defective state. There are new recommendations in the Institution of Civil Engineers' Interim Guidance Document [4] to introduce regular and planned inspection, assessment and maintenance procedures.

Edge protection for vehicle restraint and pedestrian safety is one of the important aspects of any assessment of the safety of car parks. The purpose of this report is to provide guidance on the assessment of installed restraint systems to assist in-service evaluation and decisions on needs for strengthening or replacement. This report contains data applicable to vehicle restraint systems designed to withstand impact at 375 mm height (the standard UK requirement between 1972 and 2000). For future inspections of vehicle restraint systems designed to withstand impact at a height of 445 mm, the corresponding information is contained in Reference 3.

3. PROCEDURE

The procedure for assessment of an existing edge protection system should be divided into a number of discrete actions to aid the process. These actions, which are described separately below, may be summarised as:

Classification	of the type(s) of edge protection present, of the materials of their construction, of their method of restraining vehicles and pedestrians.
Assessment	of the adequacy of the original system design, of the extent of the installation, of the workmanship, of how deterioration has affected the protection provided.

4. CLASSIFICATION AND ASSESSMENT OF EDGE PROTECTION

4.1. Classification By Type Of Edge Restraints

The assessment of existing edge protection systems is facilitated by first identifying the type of system.

The types of restraint system in common use for edge restraint of vehicles are:

- **Spanning between main structural members** and acting as simply supported, single span or simply supported, continuous members, either
 - **Horizontally spanning** between structural columns, or
 - **Vertically spanning** between floors.
- **Cantilevered upwards from the car park deck** with the system including the restraint system rail and supporting posts.
- **Monolithic construction** of the edge protection with the deck, using concrete with reinforcement continuous into the floor, either
 - **Precast** with the reinforcement continuity established through an in situ concrete stitch through the joint interface into a structural topping, or
 - **In situ** with the reinforcement continuity established by anchorage bond within the in situ concrete.

Pedestrian edge protection may be integrated with the vehicle restraints. For example monolithic construction is effective for restraining both vehicles and pedestrians, provided it is high enough. If the pedestrian protection is separate, a greater range of forms may be appropriate, including decorative precast spandrel panels, coated weldmeshes, proprietary tubular systems, and post and rail balustrades.

4.2. Classification Of Vehicle Edge Restraints By Construction Material

Vehicle edge protection restraints can be made of any structural material. Historically, only steel and reinforced concrete have been extensively used. Both materials are available in a variety of forms, and more detailed classification may be possible by close inspection, reference to construction documents, non-destructive testing, or by local removal of test samples.

The material classification should therefore endeavour to provide sufficient information to enable assessment of the future performance of an existing installation, for example, by identifying the following:

Concrete

Grade (strength) from records or from cut cores.

Cement type from records or chemical analysis of drilling dust.

Additives to the original mix identifiable from records or by chemical analysis, particularly the presence of chlorides, and air-entrainment.

Cover from covermeter surveys and local inspection.

Reinforcement is today most commonly of high yield steel, but is more likely in older car park structures to be of mild steel. It can also be prestressed. Other reinforcement materials that may be found are stainless, galvanised, or epoxy coated steel or possibly a fibre composite.

Reinforcement strength may be identifiable from the material description, or may be obtained from tests on short lengths extracted from an area of the structure known to need replacement.

Reinforcement anchorage capacity may be judged visually at spalled locations or determined from samples extracted for strength tests. Capacity depends substantially on whether the bars are round, square twisted, or with a deformed surface.

Steel

Grade may be rolled into the section surface or may be determined from records or from coupon tests on samples.

Forming processes used are likely to be cold formed, or hot rolled, and will usually be visually discernible for each component of the edge protection system.

Pedestrian edge protection has less onerous loading requirements than vehicle restraints. A wider range of materials has therefore been used, including plastics and timber.

4.3. Vehicle Restraint And Pedestrian Protection Locations

The presence of appropriate vehicle restraint systems should be confirmed at all of the following locations:

- external edges of the deck,
- around lift and stair wells,
- at the ends of access lanes exceeding 20 m long,
- at split level internal edges of the deck, and
- along edges of ramps.

Assessment criteria may differ at each of these locations; see Section 3 of Reference 3. The provision, and its consistency, should therefore be established for the existing installation and assessed against the general requirements set out in Reference 3.

The presence of appropriate pedestrian protection must be confirmed at all but the last of the above locations. The requirements for pedestrian protection are also given in Reference 3.

4.4. The Strength Of Existing Edge Protection Systems

4.4.1. Strength Of Vehicle Restraint Systems

Table 1 (a-f) shows proved, safe performances for a range of vehicle edge protection restraints. These performances are established from dynamic System Compliance Tests on vehicle restraints that have been impact tested using the test specified in Reference 3, but with the centroid of the vehicle mass at a height of 375 mm.

The type of vehicle restraint being assessed should be checked against those listed in Table 1. If the system description is present in this Table, then the system has already been demonstrated by dynamic impact System Compliance Tests to be capable of providing restraint to the specified vehicle impact. Space should be available for the maximum deflections quoted in Table 1 without the restraint making contact with any cladding of a brittle material. Thereafter, only fixings of the system to the car park structure need to be checked for strength.

If the edge restraint is similar in form to one given in Table 1, and only differs by the section geometries or material strength being greater than those given in Table 1, then the restraint system itself may also be considered adequate. In this case, consideration should be given to whether the supporting structure is adequate to withstand the potentially higher loads transmitted to it from a stiffer restraint system.

If the type of vehicle edge restraint does not correspond with one given in Table 1, then its strength may need to be checked using the System Compliance Test specified in the Design Specification and Compliance Testing [3]. This dynamic test may be difficult to perform on site for safety reasons. If the edge protection system cannot be replicated practically and economically in an off-site test, then replacement may become the most economic option. This is especially so if there is evidence of corrosion and other deterioration of the existing installation.

The strength of fixings to the car park structure should be checked if they differ in nature from the frame fixture conditions given in Table 1, if there has been significant deterioration of the edge protection system or its fixings, or if there are reasons to doubt the strength of the frame locally near the fixings. In this case the pseudo-static Installation Compliance Test specified in the report on Design Specification and Compliance Testing [3] should be used. This test method can be carried out safely with less difficulty and is relatively cheap to perform on site. It should be applied to locations that are agreed on visual inspection to represent the most likely weak locations in the car park.

An alternative method of checking the satisfactory performance of the fixings, that may be suitable for some types of fixings, is described in Section 4.5, and involves testing the fixings directly for their tensile capacity (or shear capacity if that is how the fixing transmits load into the structure, e.g. into the columns).

Test Number	Edge Protection System			Impact Position	Results		Notes
	Restraint system Type	Supports	Frame Fixture		Maximum residual deflection at 375 mm height	Maximum dynamic deflection (mm)	
B1	1.5 sine wave 310x85x3 cold-formed section	203x203x52 UC columns @ 2.4 m centres	Direct with 2 sliding P-clips*	Middle of span 2 of 3	358	461	
B2	1.5 sine wave 310x85x3 cold-formed section	203x203x52 UC columns @ 2.4 m centres	Direct with 2 sliding P-clips* & braced ends	Middle of span 2 of 3	243	289	
B3	1.5 sine wave 310x85x3 cold-formed section	203x203x52 UC columns @ 2.7 m centres	Direct with 2 bolted P-clips*	Middle of span 1 of 2	408	507	
B4	2 x 1.5 sine wave 310x85x3 cold-formed section	203x203x52 UC columns @ 2.4 m centres	Direct with 2 sliding P-clips*	Middle of span 2 of 3	99	106	
B5	2 x 1.5 sine wave 310x85x3 cold-formed section	203x203x52 UC columns @ 2.7 m centres	Direct with 2 bolted P-clips*	Middle of span 1 of 2	164	182	
B6	Sigma 300x90x4 cold-formed section	203x203x52 UC columns @ 2.4 m centres	Direct with 2 sliding P-clips*	Middle of span 1 of 2	198	225	
B7	Sigma 300x90x4 cold-formed section	203x203x52 UC columns @ 2.7 m centres	Direct with 2 sliding P-clips*	Middle of single span	297	364	
B8	Sigma 300x90x4 cold-formed section	203x203x52 UC columns @ 2.4 m centres	Directly bolted	Middle of single span	174	197	

* 60 mm x 6 mm section fixed by one M20 x 8.8 bolt

Table 1a. Test Programme Results For 375 mm High Impact On Cold Rolled Sections Spanning Horizontally

Test Number	Edge Protection System			Impact Position	Results		Notes
	Restraint system Type	Supports	Frame Fixture		Maximum residual deflection at 375 mm height	Maximum dynamic deflection (mm)	
B9	CHS 193.7x8	356x 368x129 UC Columns @7.5 m centres	Directly bolted	Middle of single span	190	253	
B10	SHS 150x150x8	356x 368x129 UC Columns @7.5 m centres	Directly bolted	Middle of single span	183	265	
B11	CHS 168.3x8	356x 368x129 UC Columns @7.5 m centres	Directly bolted	Middle of single span	320	415	
B12	CHS 168.3x8	356x 368x129 UC Columns @7.5 m centres	Directly bolted	End of single span	116	158	
B13	CHS 193.7x10	356x 368x129 UC Columns @10.0 m centres	Directly bolted	Middle of single span	176	294	
B14	SHS 150x150x10	356x 368x129 UC Columns @10.0 m centres	Directly bolted	Middle of single span	227	399	
B15	CHS 168.3x10	356x 368x129 UC Columns @10.0 m centres	Directly bolted	Middle of single span	328	526	

Table 1b. Test Programme Results For 375 mm High Impact On Hot Rolled Sections Spanning Horizontally

Test Number	Edge Protection System			Impact Position	Results		Notes
	Restraint system Type	Supports	Frame Fixture		Maximum residual deflection at 375 mm height	Maximum dynamic deflection (mm)	
B16	1.5 sine wave 310x85x3 cold-formed section top level 560 mm	Cantilevered post* in socket 5 @ 1.6 m centres	Through bolt to solid slab 110 mm thick	Middle of span 2 of 4	26	90	Cantilever type B
B17	1.5 sine wave 310x85x3 cold-formed section top level 560 mm	Cantilevered I ⁺ on baseplate. 5 @ 1.6 m centres	Through bolt to solid slab 110 mm thick	Middle of span 2 of 4	2.0	17	Cantilever type A

* 130 x 75 UB in 100 x 190 x tapering 200 to 100 high socket on 330 x 280 x 8 base with four M12 x 8.8 bolts at 230 lever arm

+ 130 x 75 UB welded to 330 x 280 x 10 base with 100 x 8 stiffening brace, with four M20 x 8.8 bolts at 270 lever arm

Table 1d. Test Programme Results For 375 mm High Impact Against Rails Mounted On Cantilevered Posts (internal spans)

Test Number	Edge Protection System			Impact Position	Results		Notes
	Restraint system Type	Supports	Frame Fixture		Maximum residual deflection at 375 mm height	Maximum dynamic deflection (mm)	
B18	1.5 sine wave 310x85x3 cold-formed section top level 560 mm	Cantilevered post* in socket 5 @ 1.6 m centres	Through bolt to solid slab 110 mm thick	End of span 1 of 4	29	88	Cantilever type B
B19	1.5 sine wave 310x85x3 cold-formed section top level 560 mm	Cantilevered I ⁺ on baseplate. 5 @ 1.6 m centres	Through bolt to solid slab 110 mm thick	End of span 1 of 4	2	30	Cantilever type A

* 130 x 75 UB in 100 x 190 x tapering 200 to 100 high socket on 330 x 280 x 8 base with four M12 x 8.8 bolts at 230 lever arm

+ 130 x 75 UB welded to 330 x 280 x 10 base with 100 x 8 stiffening brace, with four M20 x 8.8 bolts at 270 lever arm

Table 1e. Test Programme Results For 375 mm High Impact Against Rails Mounted On Cantilevered Posts (end posts)

Test Number	Edge Protection System			Impact Position	Maximum residual deflection at 375 mm height	Maximum dynamic deflection (mm)	Notes
	Restraint system Type	Supports	Frame Fixture				
B20	175 mm thick concrete with 600 mm upstand	Cantilever with T12 @200 mm reinforcement	Monolithic	Centre of 7.36 m long wall	1.0	1.5	Rebars cast into 75 mm C35 topping on 150 mm hollowcore slabs
B21	175 mm thick concrete with 600 mm upstand	Cantilever with T12 @200 mm reinforcement	Monolithic	End of 6.12 m long wall	5.5	11.5	Rebars cast into 75 mm C35 topping on 150 mm hollowcore slabs

Table 1f. Test Programme Results For 375 mm High Impact Monolithic Concrete Upstand Wall.

4.4.2. Strength Of Pedestrian Protection

Pedestrian protection should be checked for its ability to provide:

- adequate height to restrain children, even if they are climbing on the vehicle restraint system, i.e. 1.1 m above the highest foothold,
- resistance to the through passage of a 100 mm diameter ball, and
- adequacy of strength. This may be done by calculation, or by tests similar to (but using reduced loads from) the pseudo-static vehicle restraint Installation Compliance Test. Appropriate loading arrangements should apply the specified 1.5 kN/m on the balustrade rail, 1.5 kN/m² on the balustrade area, or 1.5 kN at any point location, with each of these increased by a partial load factor of 1.25.

4.5. Strength Of Vehicle Restraint Fixings

The pseudo-static Installation Compliance Test can be used to demonstrate the suitability of a fixing arrangement into a particular structure. Alternatively, the individual anchor bolt strength required can be estimated from the following data, and the fixing adequacy checked against on-site pull-out tests.

4.5.1. Adequacy Of Bolted Connection Bolts

Bolted connections at metal-to-metal contact points should be designed in accordance with BS5950 or other appropriate standard.

Holes for fixings should be positioned to avoid reinforcement. Diamond drilling causes less soffit breakout on through-slab holes. Sealing the bolt into its hole will help to prevent water ingress and corrosion.

Stainless components have a strength typically 87.5% of the same size fixing of grade 8.8 steel.

4.5.2. Adequacy Of Anchor Bolts Fixing Cantilevered Vehicle Restraints To Decks

If the fixings are of a type that can be reinstated after removal of the edge protection system, then their suitability can be confirmed by individual pull-out tests. These tests should repeat the predicted combination of loads four times. This is to prevent minor impacts reducing the fixing capacity without that reduction being apparent prior to a significant impact.

Table 2 gives tensile bolt forces measured during the test programme when the dynamic impact load in the System Compliance Test was applied at 375 mm height, and symmetrically about the centreline of the middle post of a three-post installation. The vehicle restraint posts were through-bolted to the deck in these tests. Both measured total loads on the post and maximum loads per bolt are quoted.

Results given in Table 2 permit the proof test load for an individual bolt to be estimated. The proposed methodology is to proof test at the maximum load per bolt from Table 2 corresponding to the system in use. However, where the bolt to be tested is in close

proximity to other bolts or deck edges, the load value from Table 2 must be modified by the adjoining bolt proximity and edge proximity factors described in Section 4.5.3.

Some basic information necessary to complete the calculations is reproduced for convenience in Section 4.5.4.

Vehicle restraint Rail Type	Post Support Type	Deflection at 375 mm height (mm)	Total Number of Bolts per Post	Maximum Total Load* per Post (kN)	Maximum Load per Bolt (kN)
Standard motorway	Cantilever A	2	4 (2 tensile)	164.5	112.6
Standard motorway	Cantilever B	57	4 (2 tensile)	106.7	69.3
Standard motorway	Cantilever C	115	1	50.8	50.8

Table 2. Measured vehicle restraint deflections & bolt loads after 375 mm high impact { * Total Load equals Sum of loads on tensile bolts(s).}

4.5.3. Bolt Proximity Reduction Factors

Where more detailed design information for particular fixings is not available, the following reduction factors may be used where bolts are in close proximity with each other, or with the edge of the deck.

The edge proximity reduction in strength factor, k_e , may be taken[5] as

$$k_e = 0.20 (l_e / l_{min}) + 0.5 \leq 1.0$$

where l_e is the bolt centre to slab edge distance,
 l_{min} is the manufacturer's specified minimum fixing embedment length, and
 $l_{min} < l_e < 2.5 l_{min}$

Also, the adjoining bolt proximity reduction in strength factor, k_o , may be taken[5] as

$$k_o = 0.15 (l_o / l_{min}) + 0.5 \leq 1.0$$

where l_o is the bolt centre spacing,
 l_{min} is the manufacturer's specified minimum fixing embedment length, and
 $l_{min} < l_e < 3.0 l_{min}$

4.5.4. Other Fixing Design Data

The following data is reproduced from other British Standards for convenience. These specific extracts are needed to complete the fixing design procedure.

BS5950 specifies a design tensile stress in a grade 8.8 bolt as 450 N/mm^2 in direct tension, reducing to 375 N/mm^2 in pure shear.

BS8110 specifies a concrete friction coefficient against a steel surface of 0.4

Bolt Size	Area (mm)
M10	58.0
M12	84.3
M16	157
M20	245
M24	353

Table 3. Bolt Tensile Stress Areas (from BS4190)

5. DETERIORATION OF INSTALLED EDGE RESTRAINTS

Whilst the type of edge protection system installed may have adequate capacity for vehicle restraint, signs of deterioration of the components may indicate that capacity is impaired. An engineering judgement is necessary to decide whether the deterioration has reached the stage at which acceleration of the deterioration processes will result in an unacceptably rapid loss of strength.

The deterioration mechanisms to which edge protection systems are vulnerable are many. They are described in the TRL Limited report Guidance On The Inspection Of MSCP Barrier Systems [2]. For general information on deterioration of material properties there are many texts devoted to particular materials [e.g. 6,7]. The main factors that should be identified if present are summarised below for the common materials used in construction of edge protection systems.

5.1. Reinforced Concrete

Deterioration of reinforced concrete structures becomes most serious when the ferrous reinforcement loses its chemical protection from the alkalinity of the concrete, after which corrosion and deterioration of structural elements accelerates. The most common reasons for the reduction in alkalinity of the concrete are:

Carbonation by the natural diffusion of carbon dioxide into the concrete surface,

Chloride ingress from de-icing salt, from sea spray, from sea-dredged aggregates, or from pre-1977 addition as a concrete strength development accelerator,

Leaching of the alkaline components from the concrete by passage of water.

Pathways into the concrete that speed the processes of alkalinity reduction are created at cracks in the concrete, which may be due to:

Plastic settlement cracks caused by bleed water migrating to the surface as the aggregate settles in the freshly placed concrete,

Plastic shrinkage cracks caused by too rapid drying of the concrete without adequate curing,

Formwork movement due to inadequate support,

Early thermal contraction as the green concrete shrinks differentially as heat of cement hydration is dissipated,

Structural cracking due to stress or differential settlement,
Temperature and moisture variation in parts exposed to extreme, rapid microclimatic changes,
Frost damage of the surface caused by expansion of trapped pore water as it freezes,
Alkali-silica reaction of the cement alkalis with silicates present in the aggregates, and less commonly above ground level,
Sulphate attack of the complex chemicals forming the strength-giving components of hardened concrete.

5.2. Steel

The components of edge protection systems made of steel are vulnerable to corrosion by oxidation of the iron in the presence of water. This process is better prevented by specifying protection of the original design, as it is difficult to arrest or cure once it has started during use. Methods for prevention are:

Hot-dip galvanising, a very effective method provided the coating is applied to fully fabricated components that are not subsequently cut or otherwise damaged,
Sherardising by surface deposition of heated zinc powder on relatively small components,
Electroplating by imposition of an electric current to deposit a thin layer of zinc on small items such as fastenings,
Paint coatings to isolate and protect components from the environment,
Plastic coating over galvanised sheet to provide greater protection and improved appearance.

The protection provided by these methods is generally lost gradually over time, eventually allowing the underlying steel to corrode, and weakening the edge protection system.

5.3. Masonry

Masonry has often been used for pedestrian protection. Reinforced masonry suffers deterioration of the reinforcement by the same mechanisms as in reinforced concrete. Ties between leaves of masonry, or between the masonry and structural frame, are particularly vulnerable where they enter the mortar. Masonry, whether reinforced or not, is also subject to the same deterioration mechanisms in the mortar as concrete. Additionally, deterioration may be caused by:

Differential long-term expansion of clay bricks compared to the long-term shrinkage of concrete induces cracking.

5.4. Timber

Timber should be used only for pedestrian protection. It usually deteriorates by natural processes associated with:

Weathering,
Fungal attack,
Insect attack.

6. CONCLUSIONS

The proposed methodology for assessment of installed barriers is envisaged to be operated within the framework for the inspection and maintenance of multi-storey car parks given in the Interim Guidance of the Institution of Civil Engineers [4].

A condition survey of the restraint installations on each floor should be made [4]. Their type of installation should be determined, the material of construction described, and installation details identified in each location in the car park for which there are different specification requirements. These details then enable an assessment to be made of the restraint system, whether or not it is already System Compliance Tested, and whether it satisfies the specification in BS6399, etc. and modified as described in Reference 3 and summarised below. The maximum deflection clearances should be checked as part of the process.

The proposed specification given in Reference 3 is summarised below, with differences from the requirements in the current Standards underlined:

- **There is no proposed change of the 2500 kg design vehicle for vertical loading, or the corresponding 1500 kg mass for horizontal impact loading.**
- **No change to the 16 km/h impact velocity is proposed.**
- **No change is proposed to the 1.5 m impact width.**
- **Adoption of an impact height of 445 mm, raised from 375 mm, is proposed.**
- **It is proposed that a horizontal impact at 445 mm height be used to define the design impact.**
- **The present assumption of 100 mm vehicle deformation appears to be realistic for pseudo-static loading. No change is proposed to this value.**
- **Adoption of a full-scale dynamic compliance test is proposed for each edge protection system to prove it is able to resist the high dynamic flow stresses.**
- **A pseudo-static test is retained for use on installations within car parks.**
- **Deflection limitations are proposed for both test methods.**
- **The ramp edge protection requirement accords with the highway safety fence requirement, and is adequate.**
- **The same requirements should apply to stair well edge protection as at the edge of the deck.**
- **In the absence of traffic calming measures, all edge protection with greater than 20 m approach length should be designed for twice the static design force applied at 445 mm height.**
- **There is scope for relaxation of deflection criteria at split level deck boundaries.**
- **Pedestrian edge restraints should be provided to a height of 1.1 m measured above the highest foothold reached by a rise of less than 550 mm.**
- **Provided pedestrians are directed not to use the vehicle ramps, the pedestrian guard may be omitted on ramps.**

Reference 3 defines two full-scale load tests, one dynamic and the other pseudo-static, that have been developed to determine the compliance of a vehicle restraint system with the requirements of the proposed design specification. On the basis of the dynamic test programme and practical requirements relating to system performance, principles for acceptance of restraint systems are proposed in reference 3. A range of proprietary

vehicle restraint systems have been tested using the proposed dynamic test procedure and have been found to comply with the proposed acceptance criteria for both the proposed impact height of 445 mm and the former standard height of 375 mm. Results for tests on edge protection systems using the current standard impact height of 375 mm are presented in Section 4.4.1. Thus the performance of an existing installation can be judged against the original installation specification, and against the proposed new specification.

Fixings, and their anchorages, can be tested directly by pullout tests, or by the pseudo-static Installation Compliance Test described in reference 3.

An assessment should be made of the state of deterioration, and its likely effect on the restraints at the present time and until the specified date of the next recommended inspection [4].

Finally, the conclusions of the edge protection assessment should be clearly stated in a written report [4]. For each location of restraint, there should be a clear statement of whether the installation should be:

Strengthened or replaced because it does not provide adequate safety relative to the current recommendations. Urgent action may be required where the protection is seriously inadequate.

Strengthened or treated in a specified way to overcome or delay demonstrable deterioration, that should be implemented within the following year.

Treated in a specified way to minimise identified susceptibility to particular deterioration mechanisms, which may be implemented, or may not, but with recognisable long-term cost implications.

Accepted as in serviceable condition until the next inspection, for which a date should be recommended bearing in mind the regime of inspection frequencies given by the Institution of Civil Engineers.

The foregoing proposals have support from the car park vehicle restraint supply industry, and have been publicised at seminars and conferences organised by

- The Institution of Civil Engineers
- The Institution of Structural Engineers
- The British Parking association
- The British Cement Association

Additionally, the conclusions from this Project are being introduced to the forthcoming revisions to the ICE Car Park Inspection Guide and the IstructE Design Guide for Car Parks. Papers for publication in the technical press are being written also.

7. ACKNOWLEDGEMENTS.

The research reported in this document is funded by the Department for the Environment, Transport and the Regions (DETR), Bourne Steel Ltd., Composite Structures Ltd., Transport Research Laboratory, Health & Safety Executive, British Cement Association, British Parking Association (C Whapples), Metropolitan

Authorities' Technical Advisory Group - Transportation Committee, Berry Systems, Brifen Ltd., Hill & Smith Ltd., John B Menzies, Optimum Barriers, Varley & Gulliver Ltd., University of Southampton and Cranfield University.

8. REFERENCES.

- 1 Fenn, M A. *Literature review of multi-storey car park edge protection barriers*, Project Report PR/SE/616/99, TRL Limited, Crowthorne, Berkshire, September 1999.
- 2 Walker, R J. *Guidance on the inspection of MSCP barrier systems*, Project Report PR/IS/54/00. TRL Limited, Crowthorne, Berkshire, June 2000.
- 3 Jolly, C K. *Edge Protection In Multi-Storey Car Parks –Design Specification and Compliance Testing*, Third report produced under the Department for the Environment Transport and the Regions' Partners in Innovation Scheme, Contract Reference 39/3/570 CC1806.
- 4 National Steering Committee on the Inspection of Multi-storey Car Parks. *The inspection and maintenance of multi-storey car parks: Interim guidance*, The Institution of Civil Engineers, London, July 2000.
- 5 *Hilti Fastening Manual - Anchoring*, Hilti Corporation, Fastening Systems, FL-9494 Schaan, Principality of Lichtenstein.
- 6 *Appraisal of Existing Structures*, Institution of Structural Engineers, London, October 1996.
- 7 *Structural Effects of Alkali-Silica Reaction*. Institution of Structural Engineers, London, July 1992.