Design recommendations for multi-storey and underground car parks (Fourth edition)

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Constitution of Task Group

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Glossary

Term/abbreviation	Definition
Accessway	Carriageway not adjoining bays and used solely for the movement of vehicles.
Aisle	An accessway serving adjoining bays.
Bay	The parking area, exclusive of aisle or other adjoining area, allocated to one car.
Benchmark inspection	A post-construction assessment of the durability of the car park, to compare the as-built structural records and survey results with the original designs and specifications in the handover information pack, enabling future inspection and maintenance programmes to be defined.
Bin	Two rows of bays with the access aisle running between them. A *half-bin* is one row of bays and the aisle serving them.
CE Mark	The CE mark is a key indicator of a product's compliance with EU legislation, intended to allow the free movement of products within the European Economic Area. By CE marking, the manufacturer declares a product or system conforms with all relevant essential requirements, including technical performance and health, safety and environmental protection requirements.
Clearway ramp	A ramp system that does not include an aisle in its circulation and which provides unencumbered access between the parking floors and an entrance or exit.
Concrete wearing screed	A structural concrete applied *in situ* to concrete or precast units to act compositely with them and to form the finished flooring, as defined in BS 8204 – this term was formerly known as a structural concrete topping.
Condition survey	The visual examination of all accessible areas of a car park structure and associated fabric/elements, and measurement of evidence of deterioration, including any structural investigation.
Daily surveillance	Visual observation and reporting of equipment breakdown, obvious deterioration and damage to the car park structure, cladding and edge protection, and of untoward incidents in the use of the car park.
Deck	A slab or floor at any level of the car park.
Design service life	The intended working life for the structure, as set out in the design brief, on which recommended values for parameters such as concrete class and minimum cover for durability have been chosen to give a low risk of the reinforcement becoming excessively corroded and requiring significant repairs.
Dynamic capacity	This term may be applied either to the individual parts of a car park or to a car park as a whole. It is the maximum flow per hour of cars, or where appropriate, people which the part of the car park or the car park as a whole, as the case may be, can accommodate.
Inspector	A person competent by virtue of a combination of qualification, experience and training to undertake condition surveys of car park structures. Depending on organisational arrangements, the inspector may be employed by the same or a different organisation from the engineer. The inspector will usually be an experienced Chartered Civil or Structural Engineer.
Life-Care Plan	A long-term plan for the implementation of an inspection maintenance strategy for a car park structure.
Parking angle	The angle between the length of a bay and the aisle from which it is served.
Ramp	An accessway or aisle connecting parking areas at different levels. More usually, the term is applied to accessways only.
Reservoir	An accessway where cars may queue without obstructing movements in other parts of a car park or the external road system. A reservoir may also be described as a vehicle reservoir.
Routine inspection	Regularly scheduled visual inspection of a car park structure, cladding, edge protection and any other defined aspects of the car park.
Routine maintenance	A periodic activity intended to prevent or correct the effects of minor deterioration, degradation or mechanical wear of the structure or its components.
Static capacity	The total number of bays in a car park.
Structural appraisal	Evaluation of the structural adequacy of a car park structure, cladding and/or edge protection taking into account its environment, likely usage, extent of deterioration and anticipated design service life.

Foreword

Since the first edition of the car park design guidance document being published in the late 1970s, the perception and design features of multi-storey car parks have changed significantly. The growth of car usage and increased familiarity with different multi-storey car park facilities has led to increased public expectations on issues such as security and ease of access. Increasingly, car parks are recognised as an integral and vital part of a development, often forming the first impression a visitor has of a town or specific building. Many car parks designed in the 1960s and 1970s continue to give satisfactory levels of service and structural performance. However, some failures were reported in the mid-1990s, which mainly involved the older stock of car park structures. In recognition of the advances in car park technology and to allow the lessons learnt from such failures to be incorporated into design recommendations, a review of Institution guidance was begun in July 1999 which led to the publication of the third edition in June 2002.

A routine five year review in 2007 highlighted that the third edition was being widely used by owners, designers, operators and builders of car parks and therefore that it was important that it was kept up to date. The review particularly mentioned issues such as:

- the incorporation of the requirements of the Eurocodes
- an extension of the recommendations to include temporary and demountable car parks
- a review of the durability and exposure recommendations
- a review of the structural security and safety aspects of edge protection and protective barriers
- the inclusion of the requirements of the Safer Parking Scheme
- the inclusion of recommendations for setting up a Life-Care Plan
- a review of the operational requirements to include developments in electronic monitoring, variable message signing and payment systems.

This has led to a substantial overhaul of the third edition. However, the revisions follow the same familiar format of the previous documents. Chapter 7 – Fire Considerations has had a major revision and Chapter 8 – Durability of the Structure and Chapter 11 – Asset Management have been completely rewritten. Car park owners and designers should now find that these design recommendations reflect current thinking in all aspects of car park design.

Special thanks are due to all of the members of the task group and to their organisations, who have given their time voluntarily. They are all professionals from a wide range of backgrounds representing local authorities, operators, researchers and designers. Their input has been invaluable during the preparation of these updated design recommendations. During the review process, many members of the Institution have also provided comments on the document drafts which have contributed to its improvement. I would also like to thank the Task Group Secretary, Berenice Chan for her diligence in accurately interpreting the various detailed discussions that took place and for her help in assembling them into a coherent document.

The members of the task group and I are confident that this revised document provides a timely update to the previous design recommendations which will again achieve unqualified acceptance throughout the industry.

Derek Pike
Task Group Chairman

1 Introduction

1.1 General

Since the 1960s, car parking has become a major user of developable land. Multi-storey car parks, underground or basement car parks, and car parks in a multi-function building are common. Often, visitors gain their first impressions of a town from its car park, as this may be the first building with which they come into contact. The inferences are obvious. Although multi-storey car parks are mainly found in city and town centres, they also feature in airports, retail centres, conference centres, hotels, housing developments, places of employment (both offices and factories), places of entertainment, railway stations and sports facilities.

Certain features are common to all of these and essential if the car park is to fulfil its function. Potential users should readily be able to identify a car parking facility and its entrance. In urban areas, it helps if a public multi-storey car park can be easily recognised for what it is. Such car parks are usually open structures to permit natural ventilation and no higher than about 15m. Their main structural lines are typically near horizontal and, to meet circulation requirements, they may have external ramps.

A free-standing multi-storey car park (see Figures 1.1 and 1.2) is essentially a functional building generally composed of a series of floors supported on columns to provide large areas of uninterrupted floor space. Therefore engineering considerations tend to be the primary driver for the solutions, rather than appearance. Little weather protection is required, and there is generally no need to roof over the top floor. Coupled with the wear from traffic and attack from de-icing salts, this lack of weather protection can lead to severe exposure conditions inside the car park, which must be borne in mind when detailing. Often the emphasis is on achieving a low cost per car space, which leads to demands for a very economic building. If exterior ramps are called for, to meet circulation requirements, these considerably restrict design and appearance. The combination of these factors means that designing and constructing attractive multi-storey car parks is almost always a challenging task.

Where a car park is required as part of a development (see Figures 1.3, 1.4 and 1.5), its design should be integrated into the overall development. There may then be the option of designing the car park as a component part of a multi-function building or as a separate structure integrated into the development. For large developments, and when all costs are taken into account, there is no evidence that incorporating car parks in buildings with other functions significantly affects the cost of accommodating cars.

It may sometimes be desirable to site car parks underground (see Figures 1.6 and 1.7). However, these have specific environmental and design constraints and will normally require forced ventilation. The main plant intakes and exhaust ducts for fire protection and ventilation systems need to be carefully sited to avoid the impact of pollution from car fumes, smoke and noise. Siting car parks above ground usually reduces the cost of the structure and permits natural ventilation.

Complex issues arise when integrating a multi-storey car park among buildings of historic interest (see Figure 1.8). Such car parks are usually built to an entirely different scale and may have little in common with the unit – the motorcar – for which the multi-storey car park is designed. In such circumstances, a strong case can often be made for using underground car parks instead of an above ground solution. If multi-storey car parks must be provided, they can, with advantage, be small, even though this may result in a greater

Figure 1.1 The Genesis multi-storey car park, World Cargo Centre, Heathrow

Figure 1.2 Kuala Lumpur airport car park

Figure 1.3 Bluewater shopping centre car park, Kent

Figure 1.4 Liffey Valley shopping centre, Dublin

Figure 1.5 Oracle shopping centre, Reading

number of individual car parks than would be considered economical or desirable. It is tempting to say that multi-storey car parks should be harmonised with their surrounding buildings, but this can rarely be done intimately, if only because much of the elevation is often required to remain open to satisfy fire and ventilation requirements.

1.2 Scope of the report

This report is intended for use by structural engineers who have an appreciation of the design process for buildings. Although these guidelines are intended for structural engineers, some sections include notes that are appropriate to other construction professionals and car park owners/operators.

The scope primarily relates to multi-storey car parks above and below ground, for access and use by the public. Ground-level car parks, car parks using mechanical stacking systems and small private access car parks – where different operational requirements and standards may be considered acceptable – are not specifically covered. Nevertheless, some of the design guidance here may be considered relevant to such car parks but may need modifying to suit the specialist requirements of their operation and constraints of space e.g. the fire requirements for car parks incorporating mechanical stacking systems may be more onerous than for normal car parks. The form and order of the report has been established to provide chapters relating to key areas of design considerations in increasing detail, reflecting the typical considerations at various stages of design development. The three main stages and grouping of chapters are:
– agreement of the design scope and considerations necessary for general car park layout design and planning (see Chapters 1–3)
– structural considerations and issues related to the development of the structural form, framing and use of space (see Chapters 4–7)
– design details and specific measures that can be used to enhance durability (see Chapters 8–11).

This report complements existing standards and codes of practice by offering design guidance that is specific to car park design and construction. It is not intended as a stand-alone report and deliberately refers to current codes in both the United Kingdom and Europe without repeating the details they contain. Designs may require consideration of specialist areas such as seismic design; where this is needed, the designer should take specialist advice and make appropriate provisions. The guidance seeks to identify good practice and clarify interpretation of commonly used UK and European reference standards (see Section 5.1 for further details). It also illustrates areas of special concern in car park design where these differ significantly from the normal practice set out in building and construction codes. The guidance principles are intended to be applicable worldwide. However it must be recognised that local, regional and national variations to design requirements exist and these should be confirmed in developing the design basis.

The report has sought to retain those parts of the previous guidance that were found to be of significant value and are still current, while updating other areas in the light of recent developments, design feedback and advice from operators. The suggestions and guidance contained in numerous good practice guides prepared by operators and recognised motoring organisations have also been considered to allow the report to reflect current and likely future expectations of facilities in public car parks. In particular, the facilities for security, payment and access control change rapidly with technological advances and will continue to develop. In such cases, the guidance is limited to discussion of generic types of systems in frequent use and the consideration of particular issues that need to be taken into account in developing an appropriate structural design and specification for a car park.

1.3 Status of the report

The Institution of Structural Engineers has produced this report as a guide and as such, it is only intended for use as a guide. It is not intended to provide the definitive approach in any situation, as in all circumstances the party best placed to decide on the appropriate course of action will be the engineer undertaking the particular project.

Figure 1.6 Colon underground car park, Madrid, showing variety of landscaping above car park

Figure 1.7 A hillside car park in Seattle

Figure 1.8 Underground car park in London close to buildings of historic interest

2 Developing the brief and performance specification

2.1 Introduction

2.1.1 Scope

This section is designed to assist in discussions with the client who wishes to commission a design for a car parking facility. It is advisable first to carry out both technical and financial feasibility studies before proceeding with a detailed design so that the viability of the project can be tested and all the key requirements established.

2.1.2 Design brief

The client and the design team should establish the design brief jointly. Its purpose is to establish the technical aspects and constraints affecting the design. It is not intended to define the commercial and contractual obligations within the design team. It is essential that the whole design team reviews the client's initial list of requirements. In this respect, it is important to carry out a feasibility study based on a number of sketch designs that satisfy all of the relevant national codes of practice and design standards and, as closely as possible, the operational requirements of the client. It is only after such reviews that any benefits arising from variations to the original brief (such as the position of entrances and exits, or the maintenance strategy) can be properly assessed to justify their reconsideration. The brief to, and responsibilities of, the individual members of the team at each stage of the design and development should be agreed with the client.

After the feasibility design, the entire brief should be reviewed and any necessary changes agreed. However, since several alternative designs may have to be evaluated, it is important at the outset to agree with the client what criteria are to be adopted for the choice of the preferred solution. Clearly, this will often be on the basis of initial cost but should also consider such issues as whole life costs, building service life, asset management, safety, security and charging strategy, together with the further requirements of initiatives such as the Park Mark Safer Parking Scheme[2.1] managed by the British Parking Association. These issues having been taken into account, the client should formally sign off the accepted design brief before progressing to the detailed design stage.

2.1.3 The design team

The roles of the various members of the design team will depend on the client's expectations, the composition of the project team, and the procurement method adopted. A successful design will typically require input from the client's team, structural engineers, architects, landscape architects, planners, highway engineers, building services engineers, quantity surveyors, project managers, CDM co-ordinators and the contractor. Specialists such as fire engineers, acousticians and lighting experts may also be required.

However, there are other areas such as façade treatment, waterproofing, drainage, lighting and ventilation for which the design responsibility must be clearly established. The type of movement joints, membranes and drainage provision specified are critical to the durability of the structure. For this reason, the person taking responsibility for specifying such details must be aware of the design philosophy regarding durability and must fully appreciate the consequences of the chosen solutions for such details on the durability of the structure and its Life-Care Plan (see Chapter 11).

2.1.4 Limitations imposed by statutory requirements and public policy

Car parking provision is constrained by the requirements that usually affect the design, construction and fit-out of buildings but may also be affected by national and local policies aimed at traffic regulation. This may take the form of limited provision of parking spaces through application of the price-tariff mechanism or other devices. Many of these policies are being developed and are subject to change. It is therefore important that, before embarking on any project, the client confirms any requirements for accommodating future trends, before entering into development of design options.

2.1.5 Mixed-use structures

There are situations where a multi-storey car park has to be incorporated into a structure that will have other uses, such as car parking above or below a retail centre or offices.

In such circumstances, it is essential to consider these matters in the design of the car park and its relationship to the design of the rest of the building, particularly with respect to the structural grid. Where a future change of use or phased development is suggested, special details and arrangements may be required to provide durability, protection and flexibility for change. Leasing arrangements may also dictate aspects of an appropriate design solution. In structures integral to other developments, there may be whole life benefits in separating car park elements vulnerable to chlorides from the main structural elements of the building above the car park.

Ancillary services may also be envisaged and it may be necessary to seek specialist safety advice particularly if there is a requirement for fuel storage and/or sale.

2.1.6 Temporary and demountable car parks

Temporary and demountable car parks are often single-storey structures which are designed to provide additional parking over an existing car park. They are generally modular structures consisting of a series of components which can be dismantled and re-erected a number of times[2.2].

The design service life of temporary car parks is, by definition, less than for permanent car parks to make them economically viable, but the design service life of a demountable car park can be equivalent to a permanent car park. Whatever the proposed design service life is, both types of structures should be designed to the same visual, loading and in-service conditions as permanent car parks. Particular consideration should be given to the design of the edge protection measures and the prevention of progressive collapse from accidental impact.

2.2 Information to be considered for inclusion in the brief

2.2.1 Objective

The objectives of the client, particularly the purpose to which the car park will be put must be stated explicitly. A car park can be used for a number of separate purposes, or a combination of them, for example:

- A public car park operated as a public service for profit or through a subsidy.
- A facility for a specific development where the pattern of use may be expected to remain reasonably constant throughout the day.
- A facility for a given activity that will generate high peak demands at given times or lead to the assumption that there may otherwise be special design considerations. This could include provision for tidal flow.

It is also important to define the type and mix of vehicles for which the car park is required and whether there are likely to be any special requirements because of unusual vehicle dimensions.

It may also be necessary to consider whether there are any plans for future developments.

2.2.2 The site

The brief should contain a full description of the site, its previous use and its environs, with particular note of the adjacent highway network. The status of land at the time of writing the brief must be disclosed, particularly any restraints imposed by covenant or otherwise on construction or access. The brief must clearly state the situation regarding statutory consents and with whom the client expects the responsibility for the progressing of these consents to lie.

Any specific requirements with respect to environmental and pollution policy should be clearly stated.

2.2.3 Site conditions

Data on site conditions should be determined and stated, particularly subsoil conditions including water table and drainage levels and geo-environmental conditions including ground contamination and flood risks, as these are particularly important to the design and construction process. The arrangements for site clearance and collection of design data on ground conditions should be explained. Requirements for, and the value of, further detailed site investigations should be considered and agreed with the client. The need to carry out a topographical survey early on should also be emphasised.

2.2.4 Highway access

The purpose, layout, and present and future use of the adjacent highway network should be considered in the process of developing proposals for the detailed design and management of the entrance and exit arrangements for both pedestrians and vehicles. The impact of these issues can affect the viability of the project. Attention should be drawn to any proposed street improvements, the possibility of improvements being required as a consequence of the car park's construction, or any other matter that will affect the net site area available. The possibility of conveniently incorporating street lighting into the fascia of the structure where it abuts a public highway should be considered.

2.2.5 Statutory undertakers (Utility providers)

Existing records of services within or adjoining the site and likely to be affected by the works should be identified and requirements for further investigations considered.

Available capacities within the existing services network should be established, particularly with respect to drainage, water supply and electricity supply.

2.2.6 Design service life

The client's expectations for the life of the building should be clearly stated. The design service life would normally be 50 years but may have to be substantially reduced for structural systems that are particularly sensitive to corrosion, such as decks consisting of metal permanent formwork acting compositely with a concrete slab.

The life of a car park is conditional on the design specification and on the quality of construction and maintenance. The fundamentals of the Life-Care Plan (see Chapter 11) should be established and the influence of these issues on the design service life should be made clear to the client at the outset. It should be emphasised that research[2.3] into car park performance has shown that, if there is an absence of regular inspection and maintenance, the rate of deterioration of certain elements can be rapid. To achieve the desired performance, an enhancement to the normal building specification will frequently be required.

2.2.7 Asset management strategy

The client should agree the strategy to be adopted for the operation and maintenance of the car park. This should include short-term maintenance such as sweeping, drain inspection and façade cleaning and also longer-term issues, such as periodic washing down of trafficked surfaces, painting, and the policy for removing ice and snow. A regular structural inspection of the car park should include advice on the maintenance required to ensure the integrity of waterproofing membranes, sealants and joints (see Chapter 9). All of these issues should be set out in a specific Life-Care Plan (see Chapter 11).

2.2.8 Change of use

The client should indicate whether consideration is to be given at the design stage to a change of use of the whole or part of the car park at some time in the future. If this is to be considered, the client should agree full details of the changes to be considered. For example, the cost of including columns capable of supporting additional floors is nominal when compared to the cost and difficulty of finding a new site for the extension of a low-level car park.

2.2.9 Design and cost plan submission

The client should agree the manner and phases in which the completed scheme is to be submitted, together with a programme for the submissions. The method of procurement and associated programme implications should also be agreed.

It will be for the client to prescribe the manner in which the details of the cost plan are to be presented. The client should also include in the brief any cost information he has that is likely to affect the cost plan or economics.

2.3 Design considerations

2.3.1 Structural

The basic brief should:
- state the preferred code system (Eurocodes, BS or other) to be used throughout the design process
- state any preferred structural materials or make it clear that the choice is left to the design team
- state the client's views on the use of specialist or bespoke materials (e.g. deck waterproofing, fire protection)
- specify required environmental and exposure conditions in relation to appropriate codes of practice or make clear that the choice will be left to the design team to eliminate any differences in interpretation. If an enhanced level of provision is required, reference documentation should be specified
- state whether the structure is expected to be wholly above ground, wholly underground or a mixture of the two. The final recommendations may rest with the designer in the light of investigations undertaken, but any over-riding factors affecting the choice should be stated
- state whether the design and construction should achieve a sustainability rating through for example the use, sourcing and delivery of construction materials
- state the basis on which the client will allow the design team to make decisions, without prior reference, and the frequency and mode of reporting required, including any particular hold points for approvals that will require a specific report or stage of completion.

2.3.2 Environmental

Environmentally sustainable solutions for the building should be seriously considered. CIRIA report C638[2.4] outlines the implications of climate change and provides guidance on managing the associated risks. The client should state their policy on environmental issues such as energy use, embodied energy, rainwater harvesting and building re-use. It should be noted that local authorities are increasingly requiring that alternative sources of power be used to some extent. Also Part L of the UK Building Regulations[2.5] may be deemed to be applicable to a car park if it is within an office complex.

The client's attention should be drawn to any requirement to protect adjacent buildings from noise, dirt or fumes – not only from vehicles but also from heating, ventilating plant, or cleaning equipment.

2.3.3 Appearance

The client will need to state clearly how the finished building should look, drawing attention to any special circumstances that will affect the final choice. As a part of this process, the inter-relationship between the vehicle containment system options and the appearance should be explained.

The external appearance of a multi-storey car park is important (see Figures 2.1, 2.2, 2.3 and 2.4). The normal principles of architectural design apply. It is worth noting that, as car parks seldom have fully clad elevations, the structural form can have a dominant influence (see Figure 2.5).

It is unfortunate that the finish and detailing of any building are often the first elements to suffer when costs have to be reduced. As there is generally so little margin available in multi-storey car parks, this short-term view has, in the past, had a disastrous effect on the quality of the appearance and long-term performance. The great difference in quality between the best and the worst designs suggests that cost alone is not always the most important factor in

Figure 2.1 Elevational treatment of Q-Park Charles St.

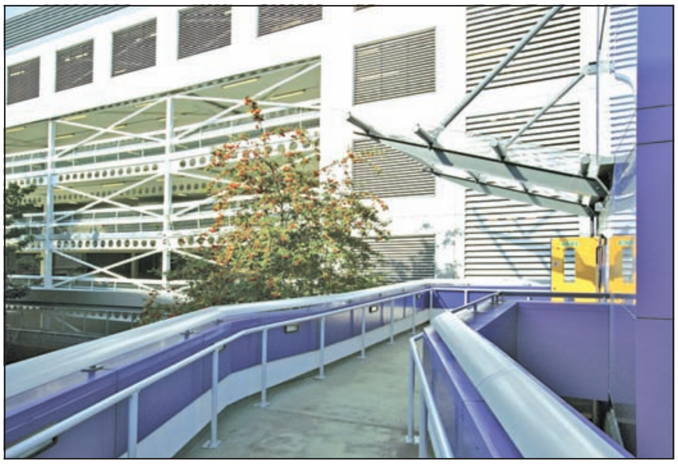

Figure 2.2 Mixed façade treatments

ensuring a satisfactory quality of appearance. For good architecture and engineering, there are no substitutes for skill, experience and sympathetic handling at the design stage.

The treatment of the site surrounding a multi-storey car park can have a considerable impact on the building itself; even in urban situations there is often an opportunity for hard and soft landscaping (see Figures 2.6 and 2.7). Intelligent use of landscaping and planting can be an important way of relating and connecting the car park with other buildings, and is also of great value in softening the visual impact of the car park. However, regular maintenance must be an important part of any landscape strategy. Vehicle and pedestrian access points provide an opportunity for treatment to avoid monotony. Shrubs, trees and flowers can help, particularly at these points, and will be much appreciated by users. In designs for urban areas, buildings are not necessarily marshalled in terraces and parades. This feature of urban planning gives scope to set back structures from the highway and facilitates the use of external ramp systems and the siting of entrance and exit controls outside car parks (see Figure 2.8).

However, external ramps may go against many of these positive siting issues and can sterilise large areas of the site. Straight ramps are usually more difficult to treat than curved ones but the sides of the ramps do offer obvious opportunities for careful thought and interesting treatment. However well ramps are dealt with, they are seldom considered things of beauty and often need to be hidden.

Although the scope for internal decoration of multi-storey and underground car parks is often constrained by budgets, to gain full public acceptance, people must be attracted to them. A light, airy and welcoming interior appearance helps. Carefully designed lighting and well-chosen colour schemes can do much to improve the internal environment and are fundamental for ensuring safety and security (see Figure 2.9(a) and (b)). These should not be applied all over but are particularly valuable to denote access routes and key positions for drivers and their passengers when they become pedestrians. Vandalism is a perpetual hazard but the cost of vandal-resistant surfaces for large areas of the interior can be prohibitive. Again, key danger areas should receive special attention.

Full consideration of services required in the car park must be taken at the design and planning stage to permit full integration. This will usually include signs and signposting methods, as well as power, lighting, security and fire control systems.

2.3.4 Town planning

Consideration should be given to the requirements of the local planning authority, and any documents already in the client's possession should be supplied with the brief. Special planning requirements, particularly in respect of preservation, conservation and redevelopment, should be taken into account.

Planning policy guidance relating to development is regularly issued. For example, the UK Government has for many years issued Planning Policy Guidance Notes (PPGs) covering a wide range of land uses and designed to provide a consistency of approach across different regions of the country.

Figure 2.3 An example of a façade with strong horizontal features

Figure 2.4 External elevation of Ocean Village Car Park

Figure 2.5 Stockley Park Car Park, Heathrow. The structural form dominates the appearance of the car park

Figure 2.6 New World Square Underground Car Park, Cannons Marsh, Bristol showing effective use of hard and soft landscaping

The provision of parking is a significant element of transport policy since its presence or absence has a major influence on the choice of transport mode. It can be argued that all parking is related to development; indeed, local authorities use parking policy to influence the demand for travel by private car within their areas. Such policies cover both parking provided by local government or the private sector and parking provided specifically in association with new development or redevelopment proposals.

Development projects vary considerably in scale, content and location. Mixed land uses are increasingly being provided on the same sites or nearby. Operational economies of scale lead to larger developments and the resulting demands for parking can lead to parking provision that can be complex and environmentally intrusive. Addressing the balance between operational requirements and environmental impact presents a challenge for designers.

A planning authority will consider a planning application within the context of its approved development plan. That plan itself has to be consistent with the hierarchy of adopted policies and plans. These are typically:
– Planning Policy Guidance.
– Regional Planning Guidance.
– Structure Plans.
– Local Plans.
– Spatial Development Strategy and
– Site Development Briefs.

For metropolitan and unitary authorities in the UK, a single Unitary Development Plan (UDP) may replace the Structure and Local Plans.

These documented policies significantly affect both the location and the nature of new developments, typically including parking guidelines that should apply. Many local authorities publish parking

Figure 2.7 Example of urban planning showing effective use of landscaping and siting

Figure 2.8 Example of external ramp, Q-Park Waterloo St.

(a)

(b)

Figure 2.9 Example of decoration showing good use of quality finishes, lighting and security (a) before refurbishment and (b) after refurbishment

guidance, applying various requirements according to the location of the site and its proximity to public transport. These local guidelines, which translate national policy into local situations, must always be considered when designing a new development.

Where Regional Planning Guidance (RPG) is issued – for example by the UK Government – it is normally formulated in the light of advice from local authorities addressing strategic issues such as the provision of housing, employment and transport.

Structure Plans, such as those provided by County Councils, and Unitary Development Plans are normally compatible with RPG to provide strategic planning guidance over a wide area. Local Plans, such as those developed by District Councils, cover a smaller area and normally conform to the Structure Plan. Local plans typically provide the detailed planning framework and constraints applicable to specific sites. The combination of all of these plans and policies provides the framework within which decisions are made about new development proposals. Planning-led systems of development control are frequently used. For example, since 1991 in the UK, planning decisions must be in accordance with development plans unless material considerations indicate otherwise. Development proposals themselves are typically dealt with through applications to the local planning authority for consent. This can either be a consent in principle, with reserved matters to be determined later (outline application), or a consent in detail, which will define the exact scale and nature of the development, including parking provision and means of access. In preparing a planning application, the developer and design team need to consider all guidance and policies that may affect a scheme and specifically transport issues. Documents supporting such an application should deal explicitly with these issues.

Transport implications will significantly influence decisions on identifying development sites for different purposes, and supporting documents should seek to quantify the impact of the proposal. 'Before and after' scenarios may have to be considered or comparison made with alternative proposals.

Although forecasts will continue to depend heavily on predictions of growth in the use of private cars, new developments are increasingly required to consider, and often encourage, other modes of transport and to provide for them within the planning of infrastructure. It is therefore essential that, in designing car park facilities, proper consideration be given to providing facilities that can safely be used by mobility-restricted users, pedestrians, cyclists and public transport users as well as by private cars and service vehicles.

2.3.5 Building Regulations and other legislation

The brief should include any exchange of correspondence with the building control authority concerning application of relevant regulations and legislation, which may have implications for the final design. The brief should either list the relevant local regulations and legislation or cite an alternative regulatory regime agreed with the client.

The client has responsibilities to comply with national and local health and safety legislation. For example, in Europe this will include Health and Safety Directives, and specifically in the UK, the CDM Regulations[2.6, 2.7]. Any local variations in regulations must be considered and accommodated. For example, in Northern Ireland, The Building Regulations (Northern Ireland)[2.8] apply and are supported by technical booklets. In addition, separate Construction Design and Management Regulations[2.9] apply.

In assessing risk, designers should consider the dangers that can occur in multi-storey car parks from failure of barrier connections, poor maintenance regimes and deterioration of key structural elements leading to failure by corrosion of connections. To mitigate the consequences and reduce the probability of recurrence, potential weaknesses should be identified and a means of safe access for their maintenance should be considered.

In completing the structural design, the designer should consider the construction sequence, stability and access requirements needed to complete the construction process and in-service maintenance safely. Design choices must be made in the light of the CDM regulations, which require designers to eliminate or reduce risk during construction, maintenance, de-commissioning and demolition.

2.3.6 Security

In addressing general security issues, the brief should consider the assessment guidelines[2.10] of the Park Mark Safer Parking Scheme run by the British Parking Association to deter criminal activity and create a safer environment for the general public and their vehicles within the car park.

For the location and design of car parks which are considered to be vulnerable to terrorist attack such as those constructed under or adjacent to sensitive buildings (e.g. government offices or embassies) specialist advice should be obtained.

2.4 Operational criteria

2.4.1 General

It is recommended that a schedule of operational criteria should be prepared after feasibility studies of:
– traffic requirements
– site requirements
– accommodation and operational requirements.

For smaller car parks (i.e. with fewer than 200 spaces), a common study may serve these three requirements. Larger parking developments may generate high traffic flows, and the need to analyse traffic and site requirements is of primary importance. In such cases, it is recommended that both traffic and site feasibility studies be carried out. In every case, adjacent concurrent or proposed developments should also be taken into account in the studies.

Unless the studies require any special dimensions to suit operational criteria, it is recommended that the designer uses the dimensions in Chapter 4.

2.4.2 Traffic feasibility and impact

If a separate traffic feasibility study is required, it should include the external road system. The traffic study provides the flows required for the site study and identifies key requirements. For example, in urban areas with high car-park flows, the siting and design of entrances and exits may be critical. The traffic feasibility study may also influence the calculation of the dynamic capacity (see Section 2.4.5(a)).

Many new developments are of a size or type that generate additional journeys on the adjoining transport infrastructure. This additional demand may necessitate changes to the highway layout or to public transport services. Wherever possible, opportunities should be taken to provide direct access to public transport and to pedestrian/cycle infrastructure, thus helping to modify the total transport impact.

The developer or promoter will normally be required to provide a full and detailed assessment of how trips to and from the development might affect the highway network and/or public transport facilities. The transport impact assessment should be an impartial description of impacts and should include both positive and negative aspects of the proposed development.

The transport impact assessment addresses two related issues:
– the effects of additional traffic on the safety and efficiency of the existing network (volume/capacity)
– the effects of additional traffic in terms of noise, pollution and visual intrusion (environment).

Traffic impact assessments are now usually required from developers in support of a planning application, the primary responsibility resting with the developer. Standard formats for assessment are available and may be required. For example, The Institution of Highways and Transportation, with the endorsement of the Department of Transport, has published *Guidelines on traffic impact assessment*[2.11].

Before undertaking a full Traffic Impact Assessment (TIA), a scope analysis should be carried out by the developer, in conjunction with the Planning and Highway Authority, to agree the key aspects to be addressed by the TIA. This analysis study should set out details of data to be collected, the area of analysis, key junctions to be considered, the methodology to be adopted and the years for assessment. Such a study will provide a basis for assessing the level of resources that will be required to undertake the TIA. It will also be invaluable to all involved and should ensure that work is not undertaken unnecessarily and that resources are directed to those aspects requiring most attention.

Before further time and resources are devoted to an application for detailed consent, approval in principle for a particular type of development is often sought by way of outline planning consent. The access arrangements for a site is one area of technical analysis where outline conceptual designs may not be sufficient to determine the practicality or safety of a scheme. An outline design often contains insufficient information to enable a highway authority to enter into an agreement with a developer, relating to the costs and layout of the access, and therefore needs to be treated with caution. If appropriate agreements are not determined at the outline stage, it may not be possible to reach a satisfactory outcome at the detailed application stage. Consequently, even with an outline application, access details may need to be provided.

The hierarchy of decision-making and responsibility for obtaining consents and planning permissions must be agreed within the project team and the client. It should be noted that planning decisions might not be determined solely by the local planning authority. For example, the Secretary of State, as the highway authority for trunk roads and motorways in the UK, has powers to direct the local planning authority to refuse an application on highway grounds, whereas the local highway authority can only advise the local planning authority.

2.4.3 Site feasibility requirements

2.4.3.1 Introduction

At this stage, the functional design appropriate to the site and parking requirements is prepared. This process may involve preparing trial designs in accordance with the client's brief and traffic requirements. The performance requirements determined at this stage are given in Sections 2.4.5(b) and (c).

Proposals for new developments will include layouts of access roads and car parking. Pedestrian access, facilities for cyclists and the design of public transport infrastructure, such as bus stops and shelters, should also be considered in detail.

Where highway authorities require independent safety audits in support of proposals for new highway works associated with development proposals, they should be undertaken in accordance with relevant guidelines (e.g. Institution of Highways and Transportation guidelines[2.12]).

Where parking space is to be provided, the following points should be considered when preparing a development plan:
– accessibility and convenience
– disabled persons
– vehicle access and safety
– operation and maintenance
– impact on surrounding road network.

These are discussed in the following sections.

2.4.3.2 Accessibility and convenience
The location of parking and loading areas should be close enough to the building or land they serve to reduce the likelihood of drivers parking indiscriminately to avoid walking. Acceptable proximity may be affected by the nature of the walk involved. A longer walk may be acceptable in a safe and pleasant environment with easy gradients and good lighting. As a guide, 400m is a generally accepted maximum walking distance.

2.4.3.3 Disabled persons
When considering the allocation of parking spaces to disabled persons, the designer should consider the definitions provided in the UK by both the Blue Badge Scheme and by the Equality Act[2.13] or other local requirements. However, the planning process will often set the minimum requirements for the number of spaces to be provided.

The location of spaces allocated to disabled persons is particularly important and should be as close as possible to the destination, wide enough for wheelchair access and connected to the destination without steps. However, when this is not possible, a combination of steps, ramps and lifts may be necessary.

2.4.3.4 Vehicle access and safety
Geometric standards that allow reasonably comfortable clearance for the types of vehicles for which the spaces are provided should be applied. Special attention will be necessary at turning points and to give adequate headroom and ground clearance on ramps. Good standards of visibility must be maintained at all times, particularly when car park access joins a main road. It is generally necessary to ensure that queues of vehicles waiting for access do not extend back to the main road.

2.4.3.5 Operation and maintenance
Some form of access control is generally needed so that parking spaces are used in the way that is planned. Sometimes, this might extend to fully automatic doors, grills or even cages for individual vehicles to prevent vandalism. The running surface should be free-draining and resistant to attack by oil or petrol. It may also be necessary to employ attendants to ensure that operational and visitors' spaces are used correctly. Good design can minimise the need for supervision and maintenance. Robust and vandal-proof light fittings and safety barriers may have to be provided.

2.4.3.6 Impact on surrounding road network
The number of spaces provided should relate to the capacity and functions of the surrounding road network and the characteristics of the use of the particular development.

2.4.4 Accommodation and operational requirements

To complete the schedule of operational criteria, accommodation and operational requirements should be listed and agreed with the client early in the development of the project concept (see Sections 2.4.5(d) to (h)).

2.4.5 Schedule/checklist of operational criteria

The following schedule is not exhaustive and only indicates the principal points that may need to be considered.

Points to be considered, discussed and agreed with the client, before starting each of the agreed design stages are:

(a) Capacity
- The number of car spaces required, usually stated as a minimum capacity. This should include those spaces reserved for the disabled and those assigned to parents with young children.
- If part of the car park is to be used for a special category of user, or vehicle, or part of it is to be partitioned as individual lock-ups, a breakdown into types of accommodation is required.
- The capacity is usually derived from the results of a parking study for the development that the car park serves; alternatively, the requirement may be to make appropriate use of a particular site.
- Phasing to suit demand and the use of temporary structures for event parking.

(b) Layout
- Floor and ramp arrangement.
- Arrangements of entrance/exit lanes and provision of reversible or tidal access lanes.
- Arrangement of control gates, including the preferred method of checking entry and exit.
- Reservoir space at entry.
- Reservoir space at exit.
- The arrangements required for normal and emergency pedestrian entrance, egress and circulation.
- Provision for the disabled.
- Escalators and lifts. Requirements should be specified; any special requirement, e.g. provision for shopping trolleys, should be stated.
- Required vehicular and pedestrian access and exit points, usually minimised, including those to be kept under CCTV surveillance.
- Areas where fuel storage is to be allowed.
- Areas where car washing is to be allowed.

(c) Dimensions and headroom
- Bay size (width and length). Where there are special requirements, the appropriate bay sizes should be stated for each requirement.
- Aisle width.
- Clearway widths.
- Layout and minimum outer kerb radius for helical ramps.

– Required headroom.
– In mixed-use buildings, the headroom required for floors not used wholly for parking.

(d) Internal accommodation requirements
– Payment kiosk requirements, including fittings.
– Managers' office floor area and fittings.
– Staff-room floor area and fittings.
– Staff toilet provisions.
– Toilet accommodation required for car-park users, including provisions for the disabled.
– Electricity substation requirements.
– Storage accommodation.
– Management control room to be provided.

(e) Mechanical and electrical equipment
– Requirements for ramp heating.
– Requirements for plug-in battery charging or engine-heating systems for alternative fuel vehicles including arrangements for payment.
– Entrance and exit control and payment systems together with audit requirements and flexibility required for replacement/refurbishment.
– Vehicle movement detection, counting systems and monitoring requirements.
– Performance requirements and capacities for lifts including the lift waiting time.
– Expected rate of air change and maximum permissible carbon monoxide content at any point in the car park.
– Whether forced or natural ventilation is to be used.
– Temperature range to be maintained in the car park, in particular the necessity for heating staircases.
– The general arrangements expected with regard to sprinklers, fire points, cut-off doors and alarm systems.
– Requirements for access to emergency vehicles.
– Means of protection from mechanical damage and interference by unauthorised persons.
– The standard of lighting expected and the method of control required.
– Surveillance and security arrangements affecting the geometry of the structure.
– Requirements for provision of CCTV, to cover all areas inside and out.
– Secure access provisions, e.g. swipe card and automated facilities to prevent unauthorised access.
– Requirements for provision of car wash facilities.

(f) Finishes, road markings and signs
– Preference for finishes or facing materials, including the use of walls for advertising.
– Restrictions on floor finishes, e.g. areas required to facilitate use of shopping trolleys, and any compatibility requirements when using membrane waterproofing systems.
– Illuminated direction signs and floor markings to facilitate circulation may be required, together with floor level numbering and reference markers to enable users easily to retrieve their vehicles.
– Requirements for external signing should be stated.

(g) Operational and maintenance considerations
– Preferred method of providing drainage to the parking areas and ramps, e.g. pumped or gravity systems.
– Data relating to the local drainage infrastructure.
– Method of operation and control of pumps.
– Levels of standby power required for ventilation, lighting and pumping equipment.
– Maintenance and services requirements.
– Requirements for bird roosting control, e.g. netting.
– Frequency of major maintenance and any requirements for abnormal loading.
– Level of standby and automatic monitoring systems.
– Means of access required for replacing fittings and cleaning.
– For basement car parks, the acceptance criteria and required environment must be discussed and agreed with the client.

(h) Security
– Address compliance with the Park Mark Safer Parking Scheme[2.1, 2.10].
– Blind spots.
– External lighting.

(i) Barriers
– Requirements for protection barriers for vehicles and pedestrians. The efficient design of the vehicle restraint system is essential as the cost of barriers represents a significant proportion of the cost of the structural frame.
– Preferences for forms of barriers and the level of maintenance.

(j) Liaison and reporting
– The arrangements to be made to keep the client informed of project developments.
– Confirmation of key decision points and levels of authority to implement changes.
– Confirmation of programme milestones and dates when specific approvals and reporting are envisaged.

2.4.6 Cost benefits

The whole life cost benefits of various solutions should be discussed with the client at this initial stage. In addition to the usual cost-benefit analysis that should be carried out for the various structural options in terms of spans, materials, user benefits, etc., an analysis of the various recommendations contained in this document concerning durability will require client decisions about the design service life of the structure, the maintenance regime and their effect on costs. A more costly robust initial solution is likely to have a longer-term benefit in terms of reduced maintenance and life-cycle costs. It is important to involve the client in this process in order to agree the strategy for determining the most suitable solution.

2.4.7 Choice of solution

Finally, it is essential to remember that any given problem or set of criteria often has more than one satisfactory answer. It is clearly important that reasonable solutions be considered, and so the client's brief should not be unnecessarily restrictive but should be broadly based to give the designers the opportunity to exercise their skill, experience and judgment in formulating proposals for the most effective and economic parking facilities.

2.5 References

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2.10 Associations of Chief Police Officers. *Park Mark Safer Parking Scheme – Assessment guidelines for parking facility owners/operators*. Available at: http://www.britishparking.co.uk/files/saferparkingscheme/Guidelines%20Manual%20Web%20ready.pdf [Accessed: 29 November 2010]

2.11 Institution of Highways and Transportation. *Guidelines on traffic impact assessment*. London: IHT, 1994

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3 Internal planning and management of traffic and pedestrians

3.1 Operational design requirements

3.1.1 Introduction

The design, capacity and operation of a multi-storey car park will be determined by such factors as:
– amount of land available
– number of spaces required, bearing in mind the need to justify the capital costs in terms of the expected net revenues
– impact on the external road network of the traffic generated by the car park.

Short-stay parking, usually higher-priced, in the more central locations will have a greater turnover for a given level of occupancy and will therefore attract more traffic throughout the day. Long-stay parking – especially when directly associated with a large office or factory building, or a transport interchange or park and ride site – will produce high traffic flows only in the morning and evening peak periods.

This could create radically different entry and exit requirements. For example a typical workers' car park will have perhaps 70% of the capacity fill and empty in the peak hour; with few of these vehicles moving during the day. However in a shoppers' car park each space could be used four or more times but the demand would be much more evenly spread across the day. In a 500 space car park, peak flow in a long-stay car park could be 350 vehicles per hour whereas in an equivalent short-stay car park it may only be about 200, assuming a ten hour day.

Car parks must be carefully managed if they are to provide a high standard of service. Long-term maintenance plans, covering the fabric of the building, running surfaces and equipment, must be drawn up in the form of a Life-Care Plan so that appropriate budgetary provision can be made. Day-to-day attention to sweeping and cleaning, localised damage, removal of graffiti, repair of defective lights, signs, lifts and ticket machines is essential. Staff training is also important to ensure service levels are maintained.

Figure 3.1 Q-Park Museumplein, Amsterdam – thoughtful design to create a safe and secure environment

The Safer Parking Scheme (Park Mark®)[3.1] is an initiative of ACPO (Association of Chief Police Officers) and ACPOS (Association of Chief Police Officers Scotland). It is managed by the British Parking Association (BPA). The scheme is supported by the Home Office, the Scottish Executive and all police forces in England, Scotland, Wales and Northern Ireland. See Reference 3.2 for the assessment guidelines of this scheme.

The objective of the scheme is to certify car parks that have introduced effective measures to create a safe and secure environment both structurally and for the user (see Figure 3.1). It provides a design framework for architects and developers of new parking facilities. The objectives of the framework can be achieved by thoughtful design and apply to car parks in any location.

It is important that surveillance, either by human presence or by CCTV, covers all areas of the site. The layout should seek to minimise or avoid out-of-sight areas or obstructions that provide hiding places. Landscaping and boundary features should not obstruct surveillance or provide opportunities for concealment. High levels of illumination are required throughout (see Figures 3.2, 3.3 and 3.4) and light fixtures and fittings should incorporate vandal-resistant features, with cables and wiring securely enclosed. Parking areas should avoid blind spots and vehicle and pedestrian access routes should be monitored with an effective CCTV system. Payment meters should be positioned in busy areas that are well overlooked. Adequate sight lines should be provided to enhance safety at points where traffic movements and flows conflict such as at the exit points from ramps between floors. Similarly, clearly defined priority and good visibility is vital where pedestrian access routes need to cross principal circulatory traffic routes.

Where statutory requirements allow, lifts should open directly onto wide, well-illuminated and unobstructed landing areas and not directly onto the parking decks without the provision of pedestrian guarding. The designer should also consider the risks that could arise from circulating cars, or cars that are being parked, impacting and possibly penetrating the stairwells and lift shafts. The design of the structure should include appropriate barriers to protect against such an event. Vandal-resistant and accessible operating panels should be provided along with vision panels in lift doors. Stairways should be wide, with open but not easily climbable balustrades to allow good visibility (see Figure 3.5). All access and exit points should be fitted with gates or grilles.

To manage the car park, there is usually an operator's office/kiosk but, where there are several car parks within the same locality the control room is often linked to area traffic control and CCTV, allowing the car park to be monitored remotely. There can be

Figure 3.2 New World Square Car Park, Cannons Marsh, Bristol, showing effective methods of illuminating the interior

benefits in discussing security arrangements with the client and the police architectural liaison officer. As well as normal security measures and CCTV systems, there may be requirements for external telephone lines, personal attack alarms, operation of barriers, door locks to relevant standards, and protective screening for cash-handling facilities. The level of security and principles for the provisions required should be discussed and agreed at an early stage of the concept development.

3.1.2 Capacity

The number of spaces available in a car park is termed its storage, or static capacity, as distinct from the dynamic capacity, which is the maximum inflow or outflow of vehicles. The largest single determining influence on dynamic capacity is usually the type of control employed at entry and exit, including the way any charges are collected. With minimal formalities on

Figure 3.4 Champs Elysées Pierre Charron Underground Car Park, Paris, showing effective methods of illuminating the interior

Figure 3.3 Example of an illuminated interior, Q-Park Sauchiehall St.

entry or exit, the dynamic capacity is determined by the capacity of the circulatory aisles but on larger car parks the capacity of the ramping system may be the governing factor. As a general rule, the dynamic capacity should be sufficient to permit up to 25% of the static capacity to enter or leave the car park within 15 minutes (i.e. up to 100% turnover in an hour) with sufficient provision for queuing at peak periods (see Section 3.2.5).

In addition, as cars are arriving and departing simultaneously, those already in the car park searching for a space may miss newly vacated spaces. Where entry is controlled, deliberate under capacity margins of about 5%, depending on size and turnover, are sometimes introduced to overcome this problem.

The maximum practical occupancy is likely to be lower than the theoretical static capacity, particularly

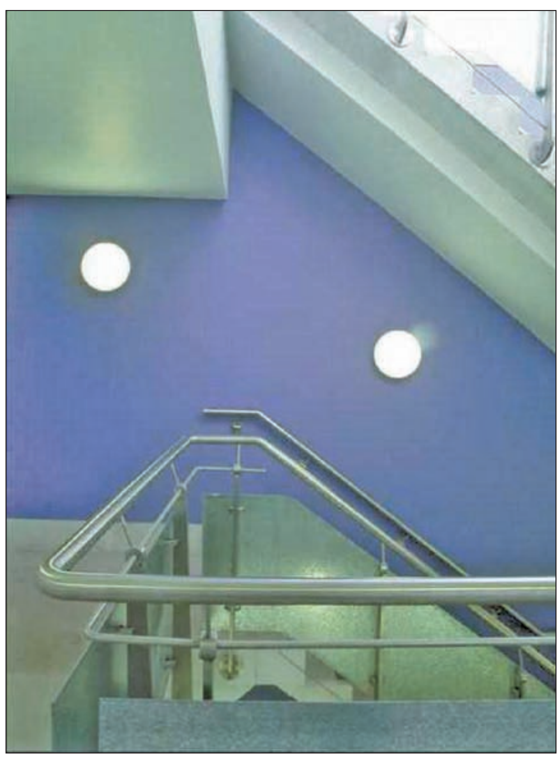

Figure 3.5 New World Square Car Park, Cannons Marsh, Bristol, showing details of landings and stairways

where there are no marked bays or car park staff to ensure disciplined parking. Where parking discipline is particularly poor and spaces between columns are badly designed, actual occupancy can be as much as 50% below the theoretical capacity.

3.2 Dynamic capacity requirements

3.2.1 Introduction

In regard to design geometry the requirements covered in the following sections are considered critical to the dynamic operation of the car park.

3.2.2 Aisle capacities

The dynamic capacity of an aisle is based upon its width, bay dimensions, proportion of cars reversing into bays and lighting levels. RRL Report LR221[3.3] examines simple bays/aisle systems and identifies ways of calculating the inflow and outflow capacities for tidal flow. This report was however published in 1969 and vehicle design and performance and driver behaviour has changed significantly since its publication but it is the only guidance currently available.

TRRL Report 1126[3.4] gives the turnover capacity, which is more appropriate to short-stay car parks. However, as the inflow and outflow capacities apply to long-stay car parks or periods of peak entry and peak exit, caution has to be applied for short-stay facilities. Retail centres can experience constant arrivals and departures, which effectively reduce aisle capacities. To overcome this and to increase car-park efficiency, the introduction of clearway ramps can be considered to bypass parking aisles. Typical aisle capacities for given design bay dimensions are shown in Table 3.1. However, for the reasons described above, the designer should use this data with caution.

These dynamic capacities should be compared with the expected inflows and outflows for the car park to determine circulation and ramp-location details. Usually, traffic flow demands are considered as dependent on the trip purpose; where this data is not available, common practice is to assume a demand equal to one-quarter of the car park static capacity arriving or departing over 15 minutes. This simple method enables design concepts to be developed before the results of detailed assessments (normally undertaken by a highway engineer) are available.

3.2.3 Vehicle speeds

Free-flowing conditions are essential to the economic fulfilment of dynamic capacity and can override the benefits gained from increasing vehicle speed.

Table 3.1 Calculated capacities for 6m aisles with 90° parking

Bay	Width (m)	Length (m)	Aisle capacity (cars/hr)		
			Inflow	Outflow	Turnover
Long-stay	2.3	4.80	865	740	400
Standard	2.4	4.80	905	765	415
Short-stay	2.5	4.80	955	790	435

Although operators generally display speed limits of 8km/h (5mph) within car parks to minimise risks to pedestrian safety, design criteria for the geometry and barriers are normally based on 16km/h (10mph) (see Section 3.3.5).

3.2.4 Ramp capacity

The same TRRL study (RRL Report LR221[3.3]) that investigated aisle capacities also estimated ramp capacity. However the research looked at a single ramp with a gradient of 7.7%. The research does not seem to consider the effects of different gradients or the impact of changes in priority at the start/end of the ramps. Therefore the results should be treated with caution. The research suggested that the average capacity of straight up-and-down ramps is about 1,850 cars per hour but this figure can be reduced significantly by the change in direction to enter/exit the ramp. RRL Report LR221[3.3] gives a method of calculating capacity of bends on accessways and ramps. Circular ramp radii of 7.5m, 9.0m and 12.0m measured to the outer kerb with lane widths of 3.65m have operational capacities of 1200, 1460, and 1700 cars per hour respectively but these figures can be reduced significantly by the change in direction to enter/exit the ramp. Narrow ramps with poor visibility have reduced flow capacity as drivers exercise greater caution for safety. The designer needs to trade off between the desirability of wide easy ramps with good sight lines, which allow drivers to travel more quickly, and the safety risk from vehicles circulating at too high a speed.

3.2.5 Vehicle reservoir at entrance, and entrance layout

The peak hour arrival rate of cars may exceed the capacity of the entrance barriers and/or the dynamic capacity of other parts of a car park. To prevent a queue extending on to a public road, a vehicle reservoir should be provided.

Where drivers may have to wait to enter a car park because it is full, the layout of the entrance reservoir should preferably allow a return to the highway without entering the car park.

3.2.6 Vehicle reservoir at exit

If the exit barriers are to function at their maximum operational capacity, drivers must be able to pull away as soon as the barrier opens. If cars have to wait to enter the highway, a queue may form and obstruct the barrier to an extent that unacceptably reduces capacity. In these circumstances, a vehicle reservoir will be required between the exit barriers and the highway.

The calculation of the vehicle storage area should be undertaken using junction-analysis software, such as the UK Transport Research Laboratory programs, which calculate the vehicle queues for various traffic-flow conditions and type of junction.

3.2.7 Bay turnover

Turnover, or the number of times a bay is used during the day, is a measure of the car-park use. It is calculated by dividing the number of cars entering the car park during the day by the number of bays in the car park. For instance, a fully occupied car park used solely by drivers parking all day would have a bay turnover of 1.0 and if not fully occupied the bay turnover would be less than 1.0. Turnovers vary significantly and typical bay turnovers in excess of five cars per day have been reported for short-stay multi-storey car parks.

A high turnover is associated with short stays and considerable internal movement. Attention is drawn to the recommended bay width of 2.50m for short-stay parking as opposed to 2.3m for long-stay. The additional width facilitates loading/unloading and helps drivers manoeuvring in and out of the bays. In addition, for a high-turnover car park, short multiple-search paths are desirable. These should be laid out systematically to help drivers searching for a vacancy, while minimising the number of vehicles circulating (see Section 4.4.7).

Ideally motorists entering the car park should pass as many parking spaces as possible but when leaving pass as few spaces as possible. The search pattern should minimise conflict between opposing flows and have provision for recirculation should a vacant space be missed on the in-route.

The split-level layout is likely to prove unsatisfactory for a high turnover owing to the complicated search paths associated with certain bays. For a high turnover, the flat deck layout is likely to be better, with clear-span construction to give drivers good visibility and to help them manoeuvre in and out of bays. Free-flow ramps both up and down may be required, together with directional and informational signing for drivers and pedestrians.

3.2.8 Design variations

Car park design must consider the customer carefully and provide a system that is simple and safe. It must also be compatible with the locality and follow the guidelines established by the Local Planning Authority in terms of appearance and scale. These principles of use and planning tend to control the size of the car park, circulation facilities, and geometric design requirements.

The design details presented provide general guidance only and local variations will occur. It is also acknowledged that, although primarily for UK application, the design parameters are functions of European car design and driver behaviour, and thus can be applied to car parks throughout Europe. Where the approach is used outside the UK for concept development, local standards and Building Regulations will have to be examined along with insurance requirements.

3.3 Traffic management

3.3.1 Introduction

For the full dynamic capacity of a car park to be attained, traffic must flow smoothly into, out of and within the building, enabling drivers to enter, park and later locate their car and leave as easily and quickly as possible.

To prevent queuing at the entrance and any associated impact on the external road system, entry capacity should be equal to, or greater than, the maximum expected arrival rate. An access road should provide a queuing reservoir for those times when the entry to the car park is operating at or near its dynamic capacity. It should be designed to assist transition from the higher speed travel on the external road network to the reduced speed within the parking area. Access roads should be used exclusively for entry into the car park so that traffic on the adjacent roads is unaffected.

The rate of outflow at the exit from the car park should not exceed the reserve capacity of the road into which it discharges and priority must be retained on the external road system, so that any queuing takes place within the curtilage of the car park. Queuing within the car park is permissible but wherever possible the layout should be configured in such a manner that it does not adversely affect car park circulation.

Wider bays permit easier and quicker manoeuvring and increase the effective aisle capacity. They also make getting into and out of vehicles more convenient particularly for two-door cars. Any columns between bays should be positioned so as not to impede manoeuvrability or obstruct the opening of car doors. The additional width for disabled parkers may be shared between two adjacent bays.

Smooth and rapid traffic flow can be achieved only by careful design of the car park and by intelligent selection of the parking-control system. It is apparent that the layout, location and function of each car park will influence the selection of the parking-control system to be adopted.

Traffic control is enforced in car parks at various stages:
– at entry
– within the car park
– in the collection of parking fees
– at the exit.

The type of any control[3.5, 3.6] to be used on entry and/or exit is most important and is usually determined by the way charges are collected. In general, entry to a car park should not be permitted unless an appropriate space is available. Entry may be controlled by a lifting-arm (see Figure 3.6) or a rising-step barrier (see Figure 3.7).

3.3.2 Entry controls

3.3.2.1 Introduction

Whenever entry has to be controlled, either for charging purposes or to prevent congestion, the choice has to be made between lifting-arm and rising-step barriers. Traffic signals, CAR PARK FULL signs, ticket-issuing machines and SEASON TICKET ACCEPTABLE machines may accompany these. Where provision for cycles or powered two-wheelers (i.e. motorcycles, scooters, mopeds and electric cycles) is required, special entry and exit facilities are recommended.

3.3.2.2 Lifting-arm barriers

Lifting-arm barriers (see Figure 3.6) are generally preferred since they are easily visible to the motorist and straightforward in operation. While the mechanism is robust, the arms are easily damaged and may require frequent maintenance and repair through accidental damage or vandalism. Incorporating shear

Figure 3.6 Lifting-arm entry barrier

bolts or breakable plates to prevent damage to the mechanism simplifies repair. Where barriers have to be sited where headroom is restricted, articulated arms may be needed. Some barrier and vehicle detection systems can be inconsistent when required to detect powered two-wheelers. Accordingly, great care is required when selecting barriers for use in car parks accessible to powered two-wheelers. A separate control lane for the sole use of cycles and powered two-wheelers is generally preferable.

3.3.2.3 Rising-step barriers

Rising-step barriers (see Figure 3.7) consist of a steel plate that can be mechanically raised from its ‘down’ position, level with the roadway, to its ‘up’ position in which it protrudes above the road surface to form a barrier to traffic. Such barriers, which are more expensive than lifting arms, have been found to be more vandal-resistant and to provide a more positive vehicle barrier. Cases have been reported of vehicles being damaged, either by barrier malfunction or because they were not immediately visible to motorists. It is recommended that they should always be accompanied by a lifting-arm barrier or a traffic signal that shows red until the barrier is fully lowered, thus avoiding possible damage by equipment malfunction or driver error.

Figure 3.7 Rising-step entry barrier

Due to their greater vandal resistance, rising-step barriers have been used with some success for controlling unattended car parks, often in conjunction with collapsible traffic plates at the exit.

3.3.3 Capacity of entry lanes

The vehicle capacity of entrance lanes will depend on how fees are collected. The capacities (in general terms) for each system are shown in Table 3.2.

For the purposes of the initial design of the entrance and exit of a car park, it can be assumed that a lifting-arm barrier will be capable of passing 360–400 vehicles per hour (vph) and a rising step about 180–200vph. The higher end of these ranges would be achieved where there is some kind of automated vehicle identification, such as a tag which allows the barrier to remain open for successive vehicles. If a lifting-arm barrier is combined with payment at the barrier, the capacity will drop to about 180vph.

In designing car parks with some form of access control it must be recognised that equipment will develop faults from time to time. Therefore it is good practice, when possible, to build some reserve capacity into the system so that the expected peak flow can be accommodated even when one lane is non-operational. This can be achieved by providing an extra lane, or a reversible lane where space is short. If this is not possible, consideration should be given to doubling-up parking equipment so that if a unit fails a reserve can quickly be switched on.

It has to be recognised that regardless of the theoretical capacity of the entry/exit, achievable flow may be limited by other constraints such as the internal ramp capacity or highway conditions outside the car park. Where queuing may occur on entry to the car park, the designer should ensure that there is a sufficient reservoir inside the entrance to ensure that traffic does not queue on to the highway.

In designing car park entry lanes, it is important to recognise that maximum efficiency will be achieved when motorists can drive into the car park in a straight line and that capacity will be reduced if bends are introduced or if there are poor sight lines. When tickets have to be obtained ahead of the barrier arm, it is particularly important to ensure that drivers can remove tickets from the issuing machine with ease while seated in their cars (see also Section 3.4.6). For countries such as the UK that drive on the left, this can be particularly difficult to arrange with a left-hand bend immediately before the entrance.

Where access (in or out) is by way of a ramp, the control should always be located at the start of the

Table 3.2 Maximum capacities for entry lanes

Fee collection system	Capacity of a single lane[a] (cars/hr)	
	Lifting-arm barrier	Rising-step barrier
No ticket issue	550	500
Automatic ticket issue	360[b]	360[b]

Notes

a It is recommended that manufacturers should be consulted for the performance of their current models of equipment to determine the actual requirement.

b Figures quoted by manufacturers may be up to 25% higher.

ramp and never on or at the end of a ramp. Wherever possible, controls should be sited to avoid queuing on the ramp or finding that it is not possible to enter or leave the car park because the equipment is faulty.

3.3.4 Control within the car park

3.3.4.1 General

Once motorists have passed through the entrance control, their aim will be to find a convenient vacant bay as quickly as possible. To ensure convenient and efficient operation, a clear system of signs and floor markings is essential. With car parks housing up to 400 to 500 cars, only the main routes need be signed, drivers being left to locate vacant bays. However, in larger car parks, this approach is too haphazard and usually results in delay and inefficiency. It is therefore usual to divide large car parks into units of 100 to 300 bays and to guide incoming cars to units with vacant bays. This guidance can be achieved by means of electronic detectors that activate vehicle counters that constantly monitor occupancy. These counters automatically switch internally illuminated signs (see Figure 3.8) to guide incoming motorists to units with vacant bays. While it is unusual to install such a guidance system in very small car parks, there may be circumstances where it will be helpful to motorists to do so.

While electronic control systems may be necessary in large car parks, for smaller car parks with fewer than 500 bays the internal design and layout should optimise the circulation with minimum signage. This can be achieved by providing a logical search path that the incoming motorist will follow through the car park and which will enable them to find a parking space with ease. It is recognised that there will be instances where, in order to take advantage of small or awkward shaped sites, it will be necessary to construct car parks that rely entirely for their successful operation on electronic control equipment, and this may be justifiable in congested city sites.

Modern access control systems consist of multiple components that are networked together within the structure and may well have external communication links to a remote control room.

3.3.4.2 Guidance Systems

It is becoming increasingly common to use automated guidance systems to help bring a driver to a vacant parking bay. These can operate on a hierarchy of signing. The driver will first see a street side Variable Message Sign (VMS) which gives information about the availability of parking in the town, perhaps at a zonal or neighbourhood level, or to specific car parks if the system is small. At the entry to the car park the driver will be told how many spaces are available. Within the car park signs will indicate the availability of spaces by floor, and on the parking deck further signs will direct drivers to an aisle or area of the car park where there are spaces. Finally, they will be guided to an individual space by bay location systems where each individual parking space has a guidance device installed which uses coloured lights to show whether or not the bay is vacant (see Figures 3.9 and 3.10). This type of system allows a driver to be quickly guided to the nearest vacant space and studies have shown that the systems can be cost-effective in reducing search times and ventilation needs, particularly in large underground car parks.

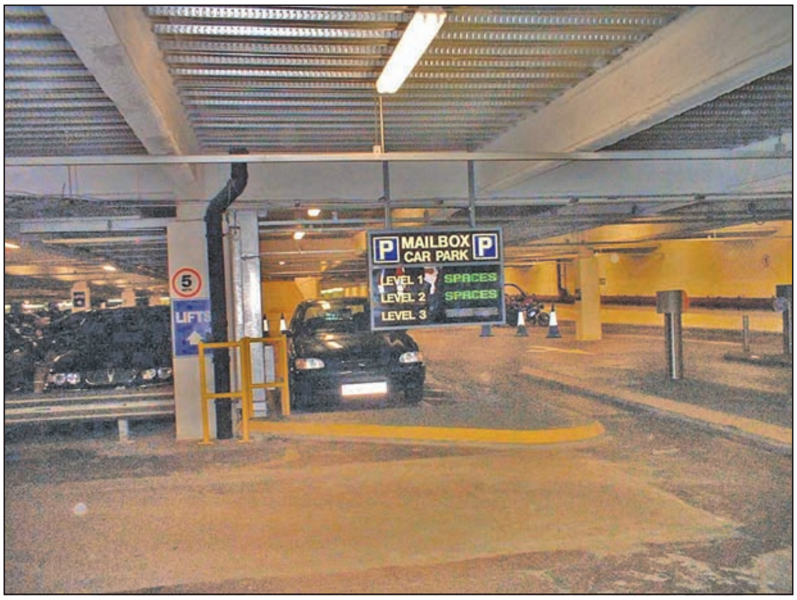

Figure 3.8 Illuminated variable message sign

If bay guidance systems form part of the conceptual design of the car park they can influence the configuration of the layout and circulation.

3.3.4.3 Surface-mounted bay detectors

Wireless or cabled surface-mounted bay detectors can also detect the occupancy status of a parking bay on surface level car parks. Installed into each bay, the information can be linked into external VMS systems (although a standard loop based counter system on entry and exit would be a more economical alternative). Most do not display the status of each bay to motorists and as such are primarily used to assist enforcement in large limited-stay period car parks such as supermarkets. Developments are being made in this field to integrate these surface-mounted bay detection systems with internet based on-line parking payment systems.

A recently developed system that detects the period of bay occupancy and that visually displays the occupancy status is to be introduced in the near future.

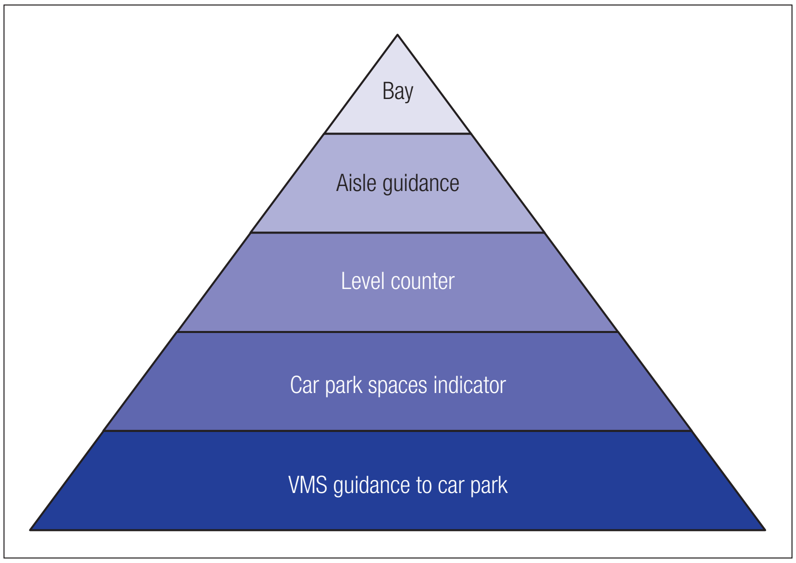

Figure 3.9 The hierarchy of car park guidance systems

Figure 3.10 Bay guidance showing both aisle guidance and individual bay indicators

3.3.4.4 System infrastructure

All these devices combine to create a considerable need for cabling for communications systems. The designer needs to plan for this at the outset and to ensure that they have allowed for the cable runs that would be required. In addition, most entry and exit barriers are operated in association with inductive loops and the designer needs to work closely with the equipment supplier to ensure that the required loops can be installed and operate without problems being caused by, or to, the reinforcement.

3.3.5 Speed control

Because car parks are a mixed environment of pedestrians and vehicles, a speed limit of 8km/h (5mph) is recommended; a limit generally recognised as minimising the risk of serious injury to pedestrians. Nevertheless, the geometry and vehicle restraint barriers are normally designed for 16km/h (10mph).

Although not desirable, speed controls are often necessary on long straights. The common forms are speed humps (ideally sinusoidal humps) or road-narrowing using post and barriers or bollards. It is important to note that speed humps can cause localised impact loadings and can restrict headroom. They are unsuitable for use in areas accessible to disabled persons, and should not extend over the full width of the drive aisle in order to allow pedestrians to pass by.

3.3.6 Vehicle restraint barriers

A key aspect of vehicle control within a car park is the restraint of vehicles that get out of control. In such cases, the car might be driven at high speed into other parked cars or the perimeter balustrade. As a result, high standards of design and maintenance (see Chapter 11) are necessary for perimeter barriers (see Figure 3.11), with care being taken to ensure that external cladding is adequately protected. For further details of vehicle restraint, see Section 5.8. Vulnerable columns must be designed to resist impact and/or accommodate loading from the vehicle impact barriers where there is insufficient space for independent support systems.

3.3.7 Signing

Car parks must be adequately signed to help and direct drivers unfamiliar with the area. This helps to avoid congestion and reduces the amount of time and fuel wasted while searching (see Figure 3.12). Where there is a choice of car parks, signs should direct drivers to the one most appropriate for their purpose, such as long-stay or short-stay or parking provided in conjunction with a particular event. Consideration could be given to introducing networked, computer-controlled variable message signing (VMS) (see Figure 3.13), linked to entry and exit, to direct drivers to car parks where spaces are still available. It is essential that the information given by variable message signs is reliable if drivers' confidence and compliance are to be maintained. Direction signs to car parks should not be used to advertise for the benefit of the operator, whether public or private.

A comprehensive system of signing and road marking should be provided within the car park to assist circulation, to achieve the most appropriate search path and to find the quickest exit. Where several search paths are available, it may be helpful to indicate which levels have vacant spaces.

Highway signs and markings should be used inside car parks but standard size signs are generally not suitable. In consequence, several systems of internally illuminated signs have been developed, clearly conveying their message in words and symbols. Because of the limited headroom common in car parks, signs should be carefully sited to ensure they do not reduce headroom and are not obstructed either by structural elements, services, or by vehicle or pedestrian movements.

Figure 3.11 Mixed steel and concrete vehicle edge restraints, respectively fronting lightweight pedestrian restraints and masonry cladding

Figure 3.12 Example of good signage, Q-Park Sauchiehall St.

Figure 3.13 Guidance sign showing available occupancy of car park

Road markings may be similar to those of standard highway design, but will be of little value if not maintained, kept clean and well lit. Internal floors should therefore be cleaned regularly to avoid the accumulation of rubber worn from car tyres and other dust and debris.

The layout of the internal lighting can also be used to guide the motorist. For example, if fluorescent fittings are generally arranged parallel to the parking aisles, a fitting at right-angles to the aisle will help draw attention to a ramp position.

3.3.8 Security Systems

3.3.8.1 Introduction

A car park should be designed so that, as far as is practical, it provides a safe environment for users and their vehicles. This can be achieved by a combination of the design of the structure and by the use of technology to inhibit wrongdoers.

3.3.8.2 Help Points

Vandal-resistant Help Points should be installed in pedestrian areas, particularly stairwells. They should be linked to the main car park security office and should be connected to the CCTV system. Figure 3.14 shows a Help Point connected to CCTV. Also in the picture is a vandal-resistant wide-angle mirror.

3.3.8.3 CCTV

CCTV can be used to monitor the car park so that any activity within the car park is being overseen and can be recorded. In designing the car park the designer should be aware of the benefits of CCTV and the need for clear sight lines so that all areas of the car park can be observed with the minimum number of cameras. Where practical, cameras should be located so that each camera is observed by another camera. This helps to ensure that vandals cannot damage a camera without being recorded. CCTV not only helps to deter crime, it can also be used to help manage the facility. Figure 3.15 shows an example of CCTV in a vandal-resistant dome.

3.3.8.4 Full height access control gates

These gates are high speed bi-folding access/exit control gates that can open and close at very high speeds. They are used in car parks to improve security as they prevent both unauthorised vehicle and pedestrian access. Traffic signals are often installed with these gates.

Gates are more costly to install and maintain than barriers. In many city-centre public car parks in

Figure 3.14 Help Point

Europe, gates are used with barriers to make the car park very secure. The gates will only open with a car present and they open only when the ticket mechanism is used (see Figure 3.16).

3.3.9 Payment systems

3.3.9.1 General

The selection of the appropriate payment system will be influenced by the location, function and layout of the car park. It must be considered as an integral part of the design concept.

The requirements for payment systems are clearly not the same in all car parks and will be greatly influenced, for example, by the nature of the parking demand in the area. In a shoppers' car park, a variable tariff will usually be needed to favour short-stay parking and encourage rapid turn-around. A commuters' car park, on the other hand, may well be operated more effectively on a fixed-charge basis. Other considerations such as the state of congestion

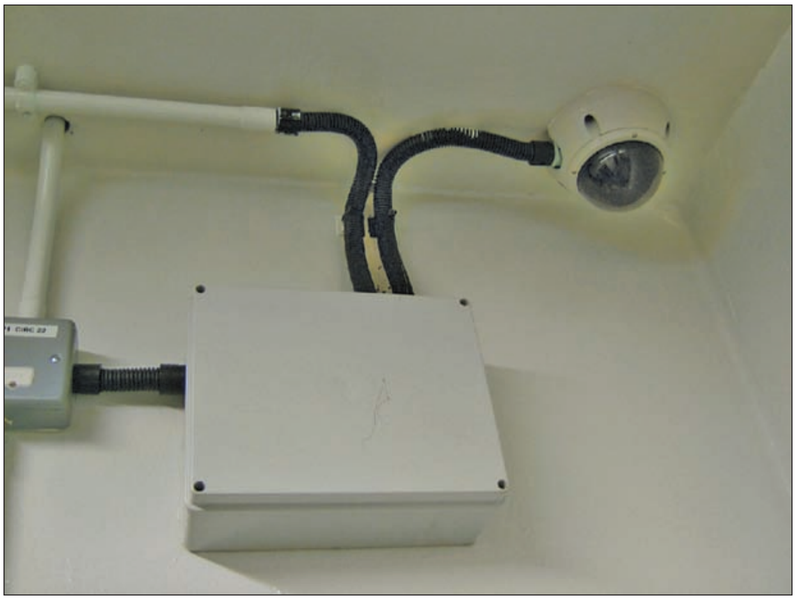

Figure 3.15 CCTV showing a vandal-resistant dome

Figure 3.16 Security gates

of the surrounding highways and queuing space restrictions within and outside the car park may also be important.

There are a wide range of potential payment systems that can be used in a car park ranging from the traditional 'man in a box', through 'pay and display' to highly automated 'pay on foot' systems. Realistically the 'man in a box' type of system is seldom used anymore and so will not be considered. Other common systems and their implications for the car park building are discussed in the following sub-sections.

3.3.9.2 Open access 'Pay and Display'

'Pay and display' parking meters, where a driver pays at a machine and takes a ticket to display in a car, are still widely used in car parks and under certain conditions remain the appropriate technology to use. Advantages include the lack of barriers at the entrance and exit, which means that vehicles would not queue onto the street because of an equipment malfunction. This can have a significant impact on the design of the entrance and exit of the car park. Further, because there are multiple payment points, an equipment failure does not reduce revenue take.

The machines can be mains, battery or solar powered (using a remote solar panel in enclosed spaces) and can include intercom systems. Payment is usually by coins or cards, including EMV (Europay, Mastercard and Visa) compliant cards, although some machines are now available with note readers.

Drivers pay in advance for their parking and this can be a disadvantage where the driver may be unsure of their length of stay.

Modern machines have continuous remote monitoring and control via comms links, using technologies such as the mobile phone system. This can have implications for the location of machines where structural elements can obstruct the signal but this may be overcome by the use of remote antennae. If 'pay and display' is to be used the provider should become involved as early as possible to address such issues.

The number of machines provided depends upon the sort of parking behaviour expected and the patterns of use. For example, at a commuters' car park where most parkers arrive and depart in a relatively short time, more machines might be needed than say a shoppers' car park where the arrivals are more evenly spread over the day. As a rule of thumb about one machine per 100–150 spaces is a good starting point, with at least two machines per floor.

Increasingly 'pay and display' systems are being complemented by mobile phone-based services where the user can pay via a mobile phone service rather than using the 'pay and display' machine. Checking these payments requires that the car park staff use a real-time, on-line handheld computer, so if this facility is offered in the car park, the structure must not have any dead spots for the computer system's signals. This may require additional cabling.

3.3.9.3 'Pay on foot'/'Pay at exit'

The most common payment system now used in car parks is known as 'pay on foot'. The name derives from the way the system operates whereby the payment process is completed as a pedestrian, separate from the exit process. Figures 3.17 to 3.19 show typical 'pay on foot' systems. A simpler system where the driver pays a cashier at the exit barrier has largely gone out of favour. Apart from issues of cash security, the maximum throughput of an automated exit lane with 'pay on foot' is about 360 vehicles per hour which is double that achieved with a staffed lane operated by a cashier.

With 'pay on foot' systems the customer takes an encoded ticket at the entrance and when ready to

Figure 3.17 Example of payment facility at Dublin Airport

Figure 3.18 Example of payment facility at New World Square Car Park, Cannons Marsh, Bristol

leave goes to a pay station where the ticket is automatically read and the fee calculated. On receipt of the payment the ticket is re-coded and the driver can then drive to the exit where the ticket is used to open the barrier. A range of technologies are used for this purpose including: bar code, magnetic strip, chip cards and chip coins, however the fundamentals of the operation are the same. To cater for drivers who forget to validate their ticket, emergency 'late pay' bays should be provided close to the exit control.

All ticket-issuing terminals should be fitted with an intercom linked to the car park office and/or security office. For UK installations, the intercom should be positioned directly below the ticket-issuing/receiving slot for ease of use. All intercoms and Help Points should be integrated with CCTV systems and, if applicable, with any barrier control system. Call forwarding allows barriers, CCTV and alarms to be operated remotely.

3.3.9.4 Automatic Number Plate Recognition

Automatic Number Plate Recognition (ANPR) when integrated with a barrier control system can be used for access control and for additional security. When linked to a 'pay on foot' system, it can additionally reduce the risk of vehicle theft by printing the registration number of a vehicle on the motorist's ticket at entry. The corresponding ticket must be used with the same vehicle at the exit to allow egress from the car park. ANPR systems can also be linked to the police and therefore can detect any stolen vehicles etc.

In large car parks ANPR can be used for vehicle location; motorists can type in their registration number on the touch screen which displays the approximate location of their vehicle (see Figure 3.20).

It is worth bearing in mind that ANPR systems do not have a 100% read accuracy rate. Causes of failure include dirty and damaged number plates. ANPR systems can be integrated with CCTV systems for additional security (see Figure 3.21). At car park entrances/exits vehicle and driver details can be obtained in addition to the registration plate by using extra cameras.

3.3.9.5 Pay Stations

In many car parks, although the majority of the pay stations are fully automated, operators will provide a cashier station where customers can interact with an attendant. This allows customers to query charges, deal with lost or damaged tickets and so on.

In determining the number and position of pay stations it is important to understand the expected pattern of pedestrian movement in and out of the car park. Although the machines are expensive it is not generally good practice to site single machines as machine breakdown involves the customer in a search for another machine. Where practical, machines should be paired or placed successively on a natural pedestrian route. A good example would be a large car park where two machines are placed at the pedestrian entrance with back-up machines in the lift lobby on higher floors.

Pay stations can usually take a range of payments using coins, bank notes, credit and charge cards and even foreign currency. A typical modern coin acceptor will recognise over 15 different coins and could, for example, accept both sterling and euro coins and notes. The use of any bank card will require EMV compliant equipment. EMV stands for Europay, Mastercard and Visa; these three card issuers collaborated to develop a standard for credit card payments using a Chip and Pin credit card which has become a *de facto* international standard.

Figure 3.19 Example of payment facility at Berthelot Car Park, Lyons

Figure 3.20 Vehicle location system

Figure 3.21 Automatic Number Plate Recognition system

The most modern systems also allow the use of credit cards and mobile phone payment. A credit card can be read at the entrance and read again at the exit and the fee calculated and collected without the need to go to a pay station. This does require a system which issues a receipt on exit. Credit cards can also be used with a pre-booking system where a driver reserves a space in advance, using the credit card as a means of identification. The driver uses the credit card at the entrance barrier and the pre-booked space is activated. With a mobile phone, having taken a ticket at the entrance the user makes a payment via a phone and the revenue system is updated to recognise the ticket as a 'paid' transaction and allow the vehicle to leave without the driver going to a pay station.

These systems rely on local networking of the equipment for their operation and so when designing the car park structure the engineer must ensure that sufficient ducting is provided to allow this. Further, since typically this type of equipment has about a ten-year effective life, the designer should allow for ease of replacement. With a mobile phone payment option, ease of use is greatly facilitated if the car park is designed so that there are no network dead spots within the structure. This may require additional equipment, particularly in underground car parks.

Of course, many car parks have regular parkers who will use a season ticket or pass-card. These can use many different technologies but again the philosophy is consistent, that a user will be allowed to enter and leave the car park for a fixed period or for a fixed number of times. Pass and season ticket systems can also use electronic or infra-red tags which are read remotely to pass the vehicles.

Increasingly, car parks also use CCTV to link the parking act to a specific vehicle. This adds to the security of the car park since the car and ticket have to be matched to exit the car park and if a driver loses a ticket the exact time of arrival can be tracked. Indeed, some car parks rely on CCTV and an automated number plate recognition system to identify and pass permitted vehicles with no other identification required. Clearly, if this type of technology is envisaged, the designer needs to ensure that the design of the structure will allow for the location of suitable cameras and/or antennae.

As toll systems and road charging becomes more common, an increasing number of vehicles will carry a remotely readable tag which deals with motoring charges. In some countries, such as Portugal, the motorway toll system (called Via Verde) has already been extended to cover payment for parking and car park designers need to consider the possibility of installing this type of equipment in the future.

The problems of fee collection are far fewer when parking charges do not vary with the length of time that the vehicles are parked. However, a variable tariff enables control to be exercised on the type of parking. Unfortunately, variable-charge tariffs are the most difficult to operate and require extensive and detailed control for their effective operation.

Parking charges should be clearly displayed at the entrances to car parks along with other information about the terms and conditions of use, such as maximum length of stay, excess charges, and whether disabled badge-holders may park free. An 'escape route' should also be provided for drivers who choose, at the last moment, not to enter and pay.

Figure 3.22 High Street Car Park, Manchester, showing entry and exit arrangements

3.3.10 Control of exit

With unrestricted free parking or pay-and-display, there is generally no need for exit control equipment. Lockable gates or other barriers may be required to close the car park when it is out of use but, apart from this, only normal highway traffic control measures would be required. If control is necessary, exit lanes are often controlled by barrier arms (see Figure 3.22). The capacity of such an exit lane depends on the system of payment, the car-park layout and configuration, and the capacity of the surrounding highway system. Consideration and choice of exit barriers are similar to those for entry (see Sections 3.3.2 and 3.3.3).

A completely free-flowing exit can be provided if collapsible traffic plates are installed in the roadway. These plates, which are hinged at ground level on their leading edge, are arranged so that they permit free traffic flow in one direction while providing a positive barrier to vehicles travelling in the other. They operate effectively but require frequent maintenance since, although robust, they can be damaged and so fail to provide an effective barrier.

3.3.11 Exit capacities

Estimates of the maximum exit capacities of a single lane are governed by the different payment systems, exit and barrier geometry, staff efficiency, and capacities of the local road network. Typical limits are given in Table 3.3.

Table 3.3 Capacities for exit lanes

Fee-collection system	Capacity (cars/hr)
Ticket on entry and payment at a manned exit	190
Ticket on entry and variable payment to a machine linked to the exit barrier	215
Ticket on entry and operation of the exit barrier by a prepaid ticket or token	320

Note
If specific information is available or detailed modelling of the specific location is undertaken, the above limits may be increased by 25%.

3.4 Pedestrian control

3.4.1 Introduction

The construction of a new car park may affect existing pedestrian routes and there may be a need to divert them and provide new pedestrian crossings and signing.

It is now becoming more common to have pedestrian access that is controlled by using the car park ticket to open the doors and operate the lifts.

Within the car park, ticket machines and entrances to lifts and stairways should be demarcated from parking areas. Signs should direct pedestrians to the appropriate exit and each level should be given a unique identity to help drivers to find their cars on their return. Letters or numbers are often used but colour schemes or graphics based on animals or flowers may be easier to remember.

Disabled badge-holders should have the most convenient spaces in a car park reserved for their use in areas where the decks are reasonably level; ticket machines must be easily accessible to them unless charges are waived. Care must be taken to ensure that disabled people can leave the car park easily, preferably without having to rely on lifts, as these may occasionally be out of order.

The safety of pedestrians should always be considered and every car park should be designed with this in mind. There are many points of potential conflict between pedestrian and motorists that with careful design can be made safer at little cost.

3.4.2 Pedestrian/vehicle conflict

Ideally parking decks should have designated pedestrian walkways, so removing the conflict between pedestrians and vehicles (see Figure 3.23). Although this may give safety benefits there are cost implications. In general, areas requiring special attention are stairs, lifts and running aisles.

Stair and lift enclosures should be positioned outside vehicle turning and running areas, but where this is not possible, entrances must be positioned so that pedestrians approaching and leaving the car park and parking decks are subject to the minimum of risk of conflict with vehicles. Particular care should be taken in the provision of guardrails to prevent pedestrians from walking directly into the path of moving vehicles.

3.4.3 Ramps

The split-level arrangement of multi-storey car parks has floors arranged at mezzanine or intermediate levels to reduce the gradient and length of the inter-floor ramps. With split-level car parks, there is less scope to position the main lift and stair shafts so that there is level access from all floor levels. However, to minimise the risk of accidents in a busy car park, use of vehicle ramps by pedestrians should be avoided at all times. It is strongly recommended that the layout includes separate stair access or ramps for pedestrians (see Figure 3.24). Routes must also be planned to make provision for disabled users (see Section 3.4.6). For example, BS 8300[3.7] and part 'M' of the Building Regulations[3.8, 3.9] give useful guidance for access and facilities for the disabled. Sight lines at the ends of access ramps need particular attention to reduce the risk of accidents at points where conflict between vehicle circulation movements and pedestrian movements can occur (see Figure 3.25).

Figure 3.23 Protected pedestrian walkway at Ocean Village Car Park

Figure 3.24 Separate access for pedestrians at ramps

Figure 3.25 Parc Croix Rousse showing clear sight lines at ramps

3.4.4 Aisles

In aisles, pedestrians and motorists have to use the same space. Motorists circulating through the car park and manoeuvring in and out of bays impose a risk to pedestrian safety but accidents in main parking aisles are uncommon. Ideally, pedestrian routes should be delineated and clearly defined along the edge of the running aisles. Research has shown that bay markings with short sidelines may encourage motorists to drive further into the bays, in effect increasing aisle width.

3.4.5 Lifting-arm and rising-step barriers

Pedestrian routes should be kept well clear of lifting-arm and rising-step barriers. Experience has shown that pedestrians attempting to pass through them are likely to be hit by a descending barrier or may trip over the step barrier.

3.4.6 Disabled persons

It is essential that the needs of both disabled drivers and disabled passengers are properly met. Failure to do so could result in the operator facing substantial personal compensation claims under the terms of the Equality Act 2010[3.10]. It is also likely that some aspects will also be a requirement of planning consent. Guidance is set out in *Approved Document M*[3.8] of the Building Regulations and proper compliance with these standards is likely to be sufficient to avoid legal and planning problems. *Approved Document M* refers to the Disability Discrimination Act 1995 which has now been repealed and replaced by the Equality Act 2010.

Car park operators now face the difficulty that there are two statutory definitions of 'disabled'. There is a specific concession granted to drivers and passengers with a defined mobility impairment who receive a blue badge[3.11]. However there is also a more general duty imposed under the Equality Act 2010 not to discriminate against any person on the grounds of a disability. The most common disability is a hearing impairment and any system of voice communication needs to take account of this.

Generally it is possible to go beyond the required minimum standards without material extra cost (see Figure 3.26). Among best practice are:

Figure 3.26 Example of disabled bays

- Clear signage at the entrance as to the location of 'disabled' spaces and whether normal charges are incurred. There is no statutory obligation to provide off-street free parking for blue badge-holders or indeed any other type of disability. However many car park operators do.
- Positioning spaces on level rather than sloped areas and avoiding gullies, drains, kerbs, pillars and other obstructions.
- Locating spaces on multiple floors near to lifts or destination entrances rather than all on a single level with increased distances for pedestrians.
- Using 'Disabled badge-holders only' signs similar to those used on highways, avoiding local designs and the term 'disabled driver'.
- Providing safe pedestrian routes between the parking space and vehicle-free area, together with resting points with suitable seating if distances exceed 50 to 100m.

Common problems that need to be avoided include:
- Barrier operating systems that cannot be operated by some disabled drivers due to lack of reach, loss of manual dexterity or loss of right arm.
- Payment machines that cannot be reached by wheelchair users or people of restricted growth.
- Heavy manual fire doors.
- Steep pedestrian ramps.
- Forgetting that the majority of disabled people with mobility problems do not use a wheelchair, but are ambulant or visually impaired.
- Taking advice on disability issues from disabled people and their organisations that lack relevant specialist expertise.

A small proportion of vehicles used by disabled people exceed 2.2m in height to accommodate occupied wheelchairs or a motorised wheelchair roof box. It is estimated that this is less than 1% of the fleet and on this basis 2.1m headroom should generally be acceptable. Where it is not possible to position taller vehicles outside the car park, consideration should be given to increasing the headroom at ground floor level. Height restrictions should be imposed to prevent taller vehicles from entering the upper decks owing to their increased weight.

There is guidance with regard to the number of spaces that should be provided for disabled badge-holders. Typically this is around 6% of the total. This should not be taken as an inflexible standard as the real demand will vary enormously depending on the destinations served by the car park and other parking in the locality. For example a car park serving a hospital might require 20% of spaces to be reserved for disabled people whereas a car park serving rail commuters might require almost no spaces if there is adequate provision for disabled people nearer the station entrance.

3.5 Lifts

Quality of service is the prime consideration to the car-park user. The designer has to consider how to achieve satisfactory quality, in terms of user satisfaction, taking into account all of those factors that are not considered or perceived by the user.

The technical design of the lift installation is complex and should be carried out by a specialist (see Section 6.6).

Lift positioning should be suitable for the function of the car park and its structural form, and should take into account the overall size of the car park, how far the users have to walk and how obvious the alternatives are. Proximity to stair cores and good signage are also important factors. Construction of the lift shaft and lift well should take account of all aspects of safety including ventilation and fire safety (e.g. the recommendations of BS 5655-6[3.12] as regards safety provisions for lift wells). Various regulations apply for operating and maintaining lifts and these are often reviewed, generally to make them more stringent. Handover documents must cite the relevant criteria appropriate for the car park and its maintenance, and these should be included in the Life-Care Plan (see Chapter 11).

In selecting lifts, it is common to assume that they carry 80% of the nominal personnel capacity. For a shopping centre car park, it is unlikely that lifts will be capable of carrying more than 50% of capacity. If trolleys are available and able to be used in the car park, even 50% could be optimistic, particularly in small lifts. Door widths must be adequate for such traffic and also be able to accommodate a double buggy. At least one lift in each group must be suitable for the disabled. As a guide, one lift is appropriate for every 225 car spaces above or below street level, or one-person lift capacity is required per 100m^2 of lettable area for a food supermarket. This means having two 20-person lifts for a 4000m^2 store. Of course, the empty trolleys must be returned to the stores which provided them, and trolley collection points should be clearly indicated on each parking level. In addition, staff will be needed to collect these empty trolleys and take them back to the supermarkets. This would normally be done outside peak periods, and the passenger lifts would be used. This may not always be possible, and so other means of returning these empty trolleys, possibly by providing an additional lift, may be necessary.

In more general planning terms, the following points should be taken into account:

- Two lifts operating as a group provide a much better service than two single lifts sited in different parts of the car park; the improvement is even more pronounced for four lifts together rather than two groups of two.
- If lift lobbies are provided at every other parking level, suitable ramps should be provided for wheelchairs, prams and trolleys.
- Vandalism can markedly affect quality of service. Adequate provision for servicing, maintenance and emergency callout is a partial answer, but reducing vandalism itself is desirable. For guidance see BS EN 81-71[3.13]. Planning that provides better architectural finishes, CCTV, and lighting in lift lobbies and staircases will discourage potential vandals.
- In the event of fire, either in the car park or in the building(s) with which it is connected, the alarm system should automatically home the lifts to a predetermined floor, leaving them there with the doors open. They should then be controllable only by security staff or the fire authorities. The homing floor should have escape routes to the outside, and it may be a different level from the ground floor depending on whether the fire is in the car park or connected building(s).
- In large or multi-use buildings, fire-fighting lifts should be considered as a part of the fire strategy.
- Some alarm facilities should be provided in each lift, so that signals may be relayed to a continuously manned centre in the event of emergencies.
- The need for standby power supplies for emergency lighting in the lift cars and lobbies and for homing the lifts in the event of a power failure should be considered.

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4 Design geometry and layout

4.1 Introduction

Although a car park is designed to suit the local environment with appropriate linked facilities for pedestrian movement, its use should be seen as a pleasurable experience for the user. This means that the designer should consider the full range of operational elements to achieve a comprehensive design solution that results in a safe, easy-to use, high-quality car park.

This design process is influenced by the parking purpose, how often users visit, payment and control systems, and relationship to the external highway network. Hence, for short-stay parking such as for shoppers – where higher dynamic and turnover capacities are required – wider bays are recommended. However, for office environments and long-stay parking where users are familiar with the parking procedures and turnover is a lot lower, narrower bays could be considered. Similarly, in a small car park, a low dynamic capacity may be acceptable, since at worst few drivers will be inconvenienced and then only for a short period. In a large car park, such a restraint is likely to be unacceptable because of the larger number of drivers affected and the greater delay that would be caused.

For small private car parks, it is sometimes suggested that narrower bays may be used and headroom restricted, lack of circulation capacity being overcome by controlling the circulation and the parking of cars. However, for public car parks, this would give rise to a poor car parking environment, which could impact on security fears and lead to low usage or crime. It is to be noted that the size of the car is a variable and the current market provides a full range of vehicles including sports, saloons, estates, four-wheel drive (4 × 4s) and multi-person vehicles (MPVs). The car market is not restrictive and so the flexibility of car dimensions has to be considered within the design with particular attention to widths and headroom requirements. The latter are most applicable to 4 × 4s and MPVs, which when fitted with roof bars or boxes can lead to a marked increase in clearance requirements.

Any requirements for access for emergency vehicles will fundamentally affect all aspects of car park design and therefore associated issues require early consideration, especially with respect to access routes.

It is recommended that provisions be made for entrance and exit controls from the inception of planning of a car park. In many instances, for both public and private car parks, entrance and exit controls are required to: restrict use to those authorised; exclude cars when the car park is full; prevent cars entering by an exit; and ensure that payment for use is made. The design should also allow for flexibility in the type of controls to be installed since in time it may be necessary to install controls where none are required initially, or to alter those installed as a consequence of changing circumstances. If initial provision is not made for entrance and exit controls, it may later be difficult or impossible to make adequate provision within the site area.

The car park has to provide good pedestrian links to external facilities. The links through the car park will require careful application of the design details with consideration given to footways, crossings, and standing areas adjacent to lifts and doorways. Good visibility with suitable clearances will enable people to move safely through the car park.

Many factors influence whether a user will find the car park easy to use and be comfortable in the car park. The most important elements are outlined below:
– size of car park and ease of circulation
– layout in terms of column spacing, ability to find available spaces easily, aisle and ramp widths, headroom and ramp gradients
– safety and security
– level of visibility
– lighting
– quality and style of internal surface finishes
– clear and concise user information and signage.

This Chapter examines the key elements that control design standards under three headings:
– the car (see Section 4.2)
– geometric requirements (see Section 4.3)
– layout (see Section 4.4).

The recommendations apply to all classes of multi-storey and underground car park available for public and private use. Special consideration and different standards will apply if the car park is required to provide access routes for large emergency vehicles, e.g. fire engines.

Recommended dimensions in this Chapter are net and allowances should be added for finishes and fittings and the sizes of columns where these protrude into the parking bays. For bays demarcated by lines on floors, dimensions are to the centres of lines.

4.2 The car

A UK review of manufacturers' details[4.1] for new cars available in 1999/2000 identified a change in vehicle characteristics since the second edition of this document. Such vehicle characteristics may vary with time and will depend on the country being considered. In particular, the introduction of MPVs and 4 × 4s has increased headroom requirements. A range of European vehicle dimensions (excluding limousines and extended vehicles) is given in Table 4.1.

The turning circle of a car is not prescribed in the Road Vehicle (Construction and Use) Regulations[4.2]. The design standards within this document are presented to accommodate the swept paths of the design cars. However, where the designer requires the geometry to be confirmed, computer-generated swept paths should be employed. Current programs include Autotrack and Autoturn.

Turning circles can range from 10.2m for a typical small car to 12.62m for a large car; for larger limousines it could be up to 15.0m. These are minimum kerb-to-kerb turning circles and do not include body overhangs and driver ability. Hence, practical turning circle diameters for large cars could range from 13.4m to 15.0m. A simple template of a large car is shown in Figure 4.1.

The examination of new cars available in the UK[4.1] shows that the height of 95% of standard cars fall below 1.85m, exclusive of roof racks/boxes. However, for MPVs and 4 × 4s, the 95 percentile increases to 2.05m. Adding a roof box increases the 95 percentile vehicle height to some 2.35m and 2.55m respectively.

Table 4.1 Comparison of typical vehicle dimensions

Vehicle group	Proportion of vehicle group	Length (m)	Width[a] (m)	Height[b] (m)
Small car	95%	3.95	1.75	1.75
Standard car	95%	4.75	2.06	1.85
Large car	95%	5.40	2.24	2.05
MPVs	95%	5.10	2.20	1.90
4 × 4s	95%	5.05	2.25	2.05

Notes
a Width including wing mirrors.
b Height excluding roof boxes, racks and roof bars.

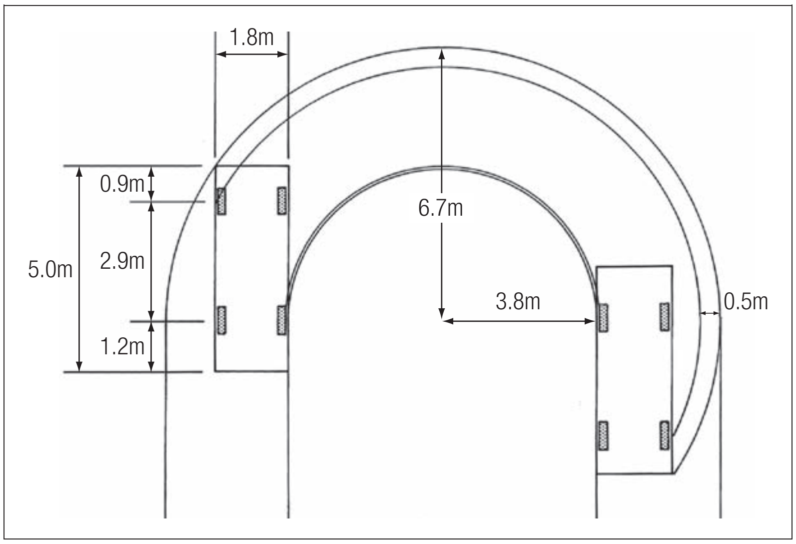


Figure 4.1 Swept path of notional large saloon car

4.3 Geometric requirements

4.3.1 Introduction

Parking arrangements should be designed to allow drivers to manoeuvre easily and safely and, where appropriate, to segregate vehicles from pedestrian areas and routes. The manoeuvring ease is a function of aisle and bay widths, which also influence the dynamic capacity of the car park. This is of particular importance for short-stay car parks, such as at retail centres, where aisle capacities are critical to the operation of the car park. For longer-stay car parks, this is not so critical; therefore the bay dimensions could be reduced where customers are more familiar with the parking arrangements, such as at office or station car parks. Geometric requirements for other countries may differ from those in the UK.

4.3.2 Bay width and length

Recommended practice is to design for normal use by the standard car and for occasional use by the large car. However, consideration needs to be given to the requirements of specialist car parks, and to increased vehicle dimensions. Typical bay dimensions for standard cars are shown in Table 4.2.

4.3.3 Aisle width and bin width

Guidance for aisle and bin widths for various parking angles with bays on each side is shown in Table 4.3. These preferred dimensions are clear of any structure or edge details (but see Sections 4.3.4. and 4.3.5). Aisle widths are designed to accommodate any overhang of vehicles beyond 4.8m. To suit constraints imposed by limited space or particular user operations, variations to these dimensions can be considered. Where this results in reduced dimensions, the client should be made aware of the variations and the resulting limitations, such as restricted space between parked vehicles and more difficult manoeuvring. Where comfort parking conditions are required, as in retail parks, operators often specify greater dimensions.

Although they increase the dynamic capacity of an aisle, parking angles of less than 90° are little used in underground and multi-storey car parks, as the space requirement per bay increases and cost efficiency is reduced. As a general guide, 45° car parking reduces the total parking space by some 20% compared with 90° parking. Hence, the parking angles and associated aisle widths are provided for guidance, and circumstances may justify using different widths.

Table 4.2 Car bay dimensions

Type of parking	Length[b] (m)	Width (m)	Comment
Mixed use	4.80	2.40	Mixed occupancy
Short-stay	4.80	2.50	Typically less than two hours
Long-stay	4.80	2.30	One movement per day, e.g. business car park
Disabled user	4.80	3.60[c]	–
Parent/child	4.80	3.20[d]	–

Notes
a All the dimensions are to be clear of any projections, but see Section 4.3.4.
b The preferred dimension is 4.80m for all bay lengths. However, with restricted space and appropriate signage, this can sometimes be reduced for small/city vehicles (see Section 4.4.1).
c The bay width for use by disabled persons allows for the door to be fully opened to improve movement in and out of the car and to provide greater room for assistance to be given to those less mobile. Additional details are given in Traffic Advisory Leaflet 5/95 *Parking for Disabled*[4.3] and the Building Regulations[4.4,4.5].
d The bay width for use by parent and child allows for the door to be opened more fully for access to child seats.

Table 4.3 Recommended aisle and bin widths

Parking angle	Preferred aisle width (m)	Bay width (m)	Preferred bin width for 4.80m bay length (m)
90°	Two-way aisle: 6.95	All	16.55
90°	One-way aisle: 6.00	All	15.60
60°	4.20	2.30 2.40 2.50	14.85 14.95 15.05
45°	3.60	2.30 2.40 2.50	13.65 13.80 13.95

4.3.4 Side clearance on structure

Increasing the width of parking bays where they are adjacent to walls or vehicle barriers should be considered. This increase will be subject to the edge detail form, but an additional side clearance of some 300mm is suggested from the bay marking to the edge detail.

4.3.5 Column location

Clear-span construction is preferred, as it provides a safer environment for both drivers and pedestrians, but other design considerations often dictate the use of internal columns. The sizing of these columns and the spacing has to be carefully considered to maintain parking efficiency, bay access and sight lines. Columns at the front of the bays can reduce accessibility. Therefore, to improve parking manoeuvres, the recommended distances of columns from the aisle are shown in Figure 4.2.

It is recommended that no fewer than three standard bays are provided between interbin columns adjacent to aisles and that bay widths be clear of finished column faces. However, a projection of 150mm to 200mm into the bay is acceptable if columns are within the recommended setback zone from the aisle (see Figure 4.2). Where larger columns are provided, as in mixed-use developments, special attention is required to maintain satisfactory clearances and operations. In such cases, the co-ordination of building and car park grids will need to be an iterative process.

It is also to be noted that columns within the mid-third of the bay will obstruct doors and should be considered carefully, especially where shear walls are being proposed. Additional side clearances will be required with shear walls.

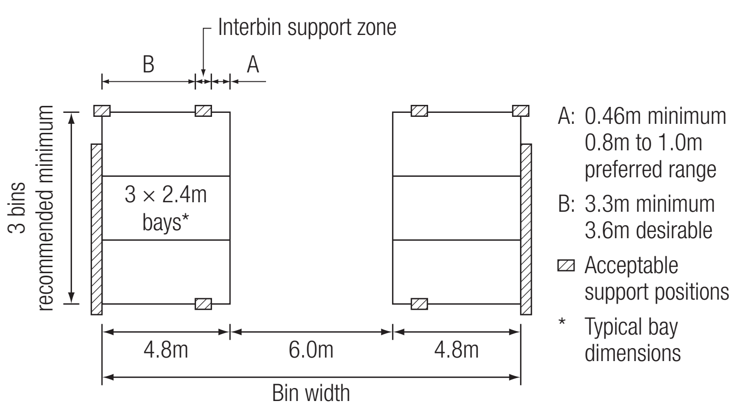


Figure 4.2 Support positions related to parking geometry

4.3.6 Headroom and ground clearance

The recommended minimum clear height or headroom, measured normal to surfaces, for vehicles is 2.10m. This minimum is applied to entrances, exits, bays, aisles and ramps and so careful attention needs to be given to the various requirements applicable to each area. Additional clearances will be needed at changes in gradient such as at ramps and where traffic-calming measures are used (see Figure 4.3). All design and geometry assumes 100mm ground clearance beneath vehicles, which covers all standard cars.

To determine structural height, it is recommended that outline designs be prepared for signage, lighting, ventilation, barrier controls, sprinkler system and any other possible projections below structure such as conduits and drainage pipes. The downward projections of these various services should be estimated and added to the headroom to determine the clear structural height required. In addition, allowance should be made for finishes, dimensional tolerances and structural deflections. It is recommended that the headroom be checked at the bottom of ramps since cars will span from ramp to floor.

Traffic-calming measures, such as speed humps and tables, must be carefully located. These measures are typically 75mm to 100mm high and so will restrict headroom locally. Where rising-step traffic control is proposed, pits 300mm to 600mm deep may be required. This local increase in depth must be taken into account when considering the available headroom on the floors below.

For safety, the headroom indicator board at the entrance to the car park is normally set some 50mm to 100mm below the actual headroom within the car park. Hence, the operational headroom could be set below the minimum clear floor height in the client's brief. This needs to be taken into account, discussed and clarified with the eventual operator.

The minimum headroom of 2.10m will generally cater for all MPVs and 4 × 4s (without roof boxes) as long as allowance is made for transitions on ramps, particularly in split-level car parks where a maximum gradient of 1:6 is frequently applied. Examples of these headroom design elements are given in Figures 4.3, 4.4 and 4.5. Increased headrooms may be applicable to car parks located in tourist areas where a greater proportion of vehicles with roof boxes is likely.

Where provision is required for designated spaces for high-top conversion vehicles, e.g. those for disabled people, a minimum clearance of 2.60m is recommended[4.6] for the full access route in lieu of the normal minimum headroom of 2.10m. If sufficient vertical clearance for high-top conversion vehicles can not be maintained along all routes in the car park, drivers should be warned about the height restrictions before they begin to queue for, or enter, such areas. At that point, there should be directions to a suitable alternative parking space.

4.3.7 Floor gradient

Floors should be laid to a minimum fall of 1:60 for drainage. Special consideration must be given to areas where the structure is pre-cambered.

Deflections of long-span beams can also affect the gradient required to maintain drainage falls (see Section 5.7.2 and Chapter 9). Where continuous parking deck ramps are considered, the recommended maximum gradient is 1:20. Where parking ramps are steeper than 1:20, difficulties may be experienced in opening, and in keeping open, a car door on the up-gradient side and in closing a door on the down-gradient side. In addition, shopping trolleys may roll away, and those with impaired mobility could experience problems. Flatter gradients are therefore preferable. In motorcycle parking bays, gradients should be arranged to avoid crossfalls.

4.3.8 Ramp and accessway gradients

The recommended maximum gradients for vehicle ramps are given in Table 4.4.

Site constraints may dictate that ramps steeper than those specified in Table 4.4 be considered. In this event caution should be exercised and a Design Risk Assessment prepared to ensure that the steeper ramps are properly considered and there are no unresolved design risks.

If ramps are steeper than 1:10 or the floor is laid to a fall of 1:60 or greater away from the top of the ramp, a transition length is required. These transition gradients should be sited at the top and bottom to reduce the risk of vehicle grounding. The transition length should be at least 3.00m and its gradient half the gradient of the ramp. This transition can extend into the circulation aisle with appropriate blending of grades.

Pedestrians (particularly with push chairs) will often use vehicle ramps within a car park but this is of some concern, as pedestrian safety is compromised. The vehicle ramps are usually of a gradient between 1:6 and 1:10, which are unsuitable for disabled people, for whom guidelines require the steepest permissible to be 1:12. It is recommended

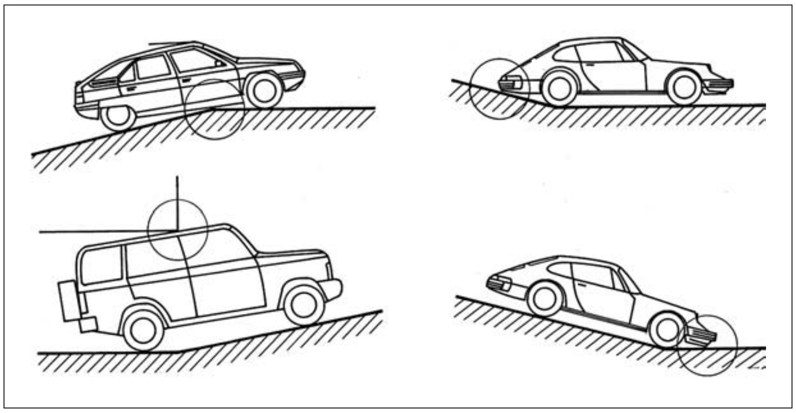


Figure 4.3 Possible points of damage to vehicles

that separate pedestrian routes be provided, ideally with gradients between 1:15 and 1:20 with level landings every 10m. Full details are presented in supporting documents to The Building Regulations[4.4, 4.5].

4.3.9 Ramp and accessway curvature, widths and clearance on structure

The recommended outer kerb radii for one way curved ramps are shown in Table 4.5.

The turning circle of the large design car can be between 13.40 and 15.00m diameter between kerbs. In consequence, if the proportion of large cars using a car park is expected to be above average, it is recommended that curved ramps and accessways have an outer kerb radius of not less than 9.00m. A typical two-way spiral ramp is shown on Figure 4.6. The recommended minimum widths for curved ramps are shown in Table 4.6.

On long straight ramps, the recommended width between kerbs is 3.00m. However, where cars turn on entering or leaving a straight ramp, a widening or flare is usually required at the ramp ends. The amount of flare required depends on the ramp width and the approach and exit manoeuvre at the top and bottom of the ramp. Clear sight lines are valuable in these locations. For a split-level car park with a short ramp, a constant ramp width of 3.50m is more appropriate (see Figure 4.7). Table 4.7 gives the recommended

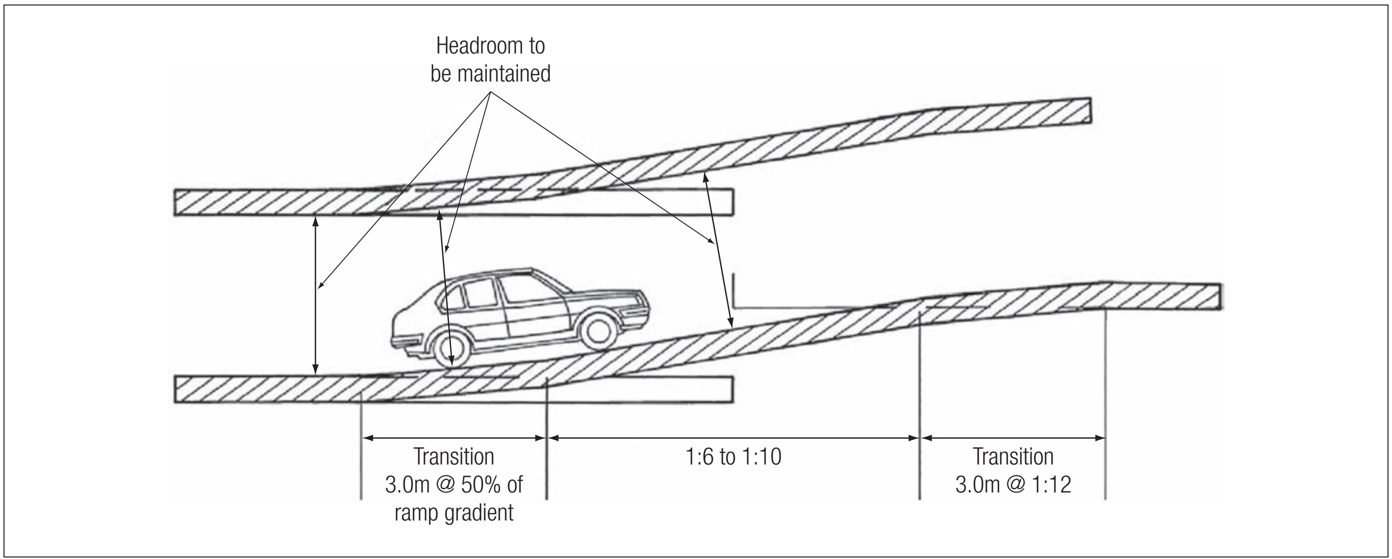


Figure 4.4 Typical ramp elevation

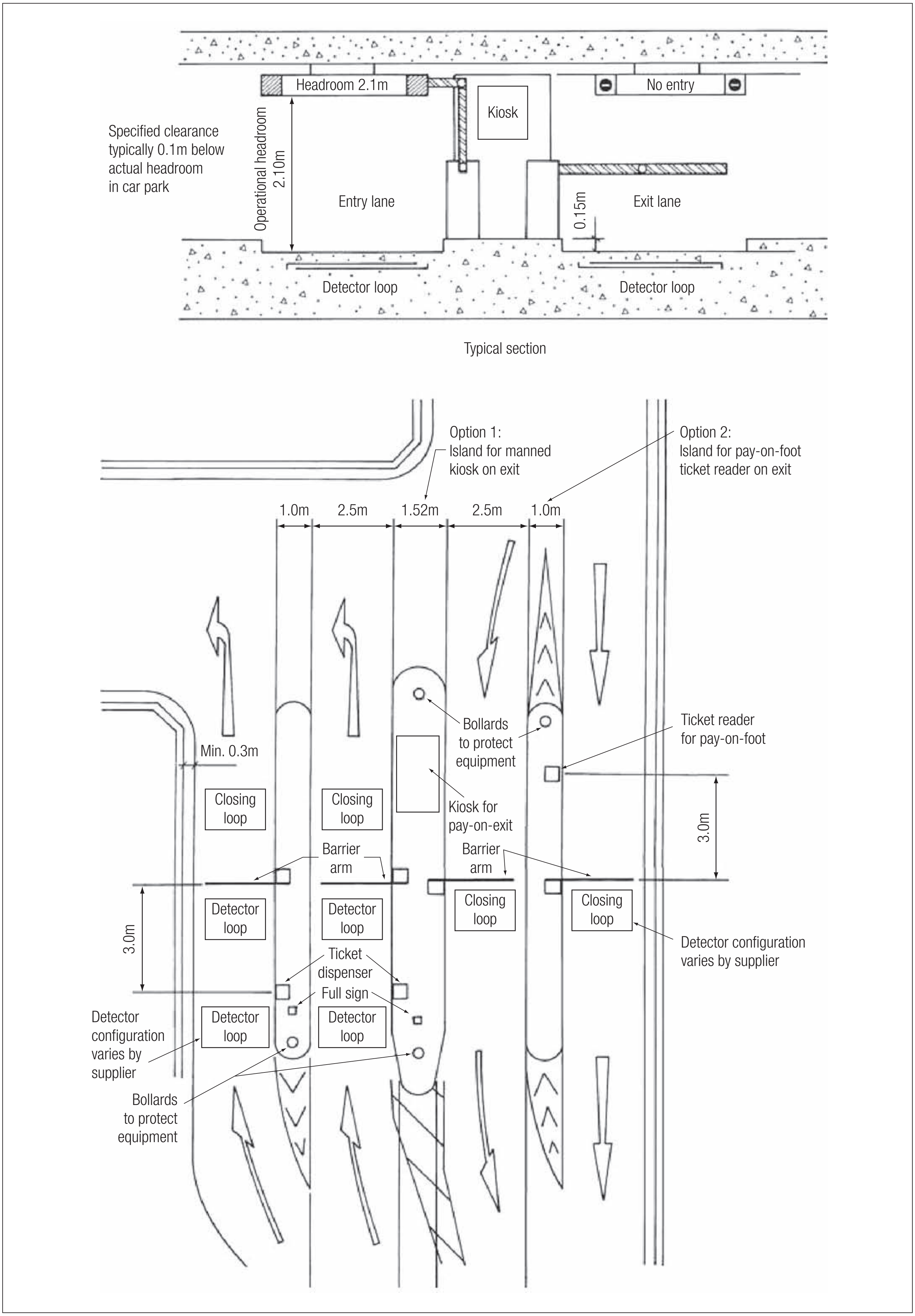


Figure 4.5 Layout of entry/exit controls

Table 4.4 Maximum gradients for vehicle ramps

Ramp type	Rise	Maximum gradient
Straight ramp	Not greater than 1.50m	1:6[a]
	Greater than 1.50m and less than 3.0m	[b, a]
	Greater than 3.0m	1:10
Curved ramp	Not greater than 3.00m	1:10[c]
	Greater than 3.00m	1:12[c]

Notes
a With transition slopes top and bottom.
b Maximum gradient reduces linearly for ramp rises between 1.5m and 3.0m.
c Gradient measured on centre line.

minimum widths for one-way straight ramps and accessways.

4.3.10 Superelevation

Curved ramps should have superelevation: the recommended maximum provision is 1:20.

4.3.11 Kerb height

Any raised kerbs within the car park need careful consideration, especially as regards the fixing detail and its interface with deck waterproofing. As kerb details often lead to maintenance concerns, kerbs should be omitted from parking levels wherever possible.

The use of concrete kerbs within ramps also needs careful consideration, as whilst they will provide additional protection to the structure, edge details and equipment, they will increase the risk of damage to the vehicles. The use of concrete kerbs to separate opposite flows of traffic on two-way ramps is not generally recommended as drivers on the falling ramp find the kerb difficult to see and the kerb could unnecessarily restrict the movement of vehicles. The use of painted kerbs or rumble strips rather than concrete kerbs can be considered, provided the structure has been designed accordingly.

The recommended kerb height is 100mm. When it is important that cars do not mount kerbs, such as near control equipment, the recommended kerb height is 150mm above channel level. The disabled and parents with pushchairs should be accommodated by providing drop kerbs on designated routes.

4.3.12 Entry and exit arrangements

To prevent queuing at the point of entry, the entry capacity should be equal to, or greater than, the maximum expected arrival rate. Vehicle reservoirs are required between the public road system and the entrance barriers to store vehicles during peak operations and provide a transition from the higher speed external highway network to the slower access road configuration. The rate of flow from the car park should respect the highway and junction capacity, so that any queuing takes place off the highway. However, as it is likely that queuing will occur at peak exit times, facilities should be allowed for queuing within the car park on each side of the barriers.

Table 4.5 Recommended outer kerb radii for one-way curved ramps

Option	Radius (m)	Structure clearance to outside kerb (m)	Structure clearance to inside kerb (m)
Recommended	12.00	0.60	0.30
Preferred minimum	9.00		
Absolute minimum	7.50		

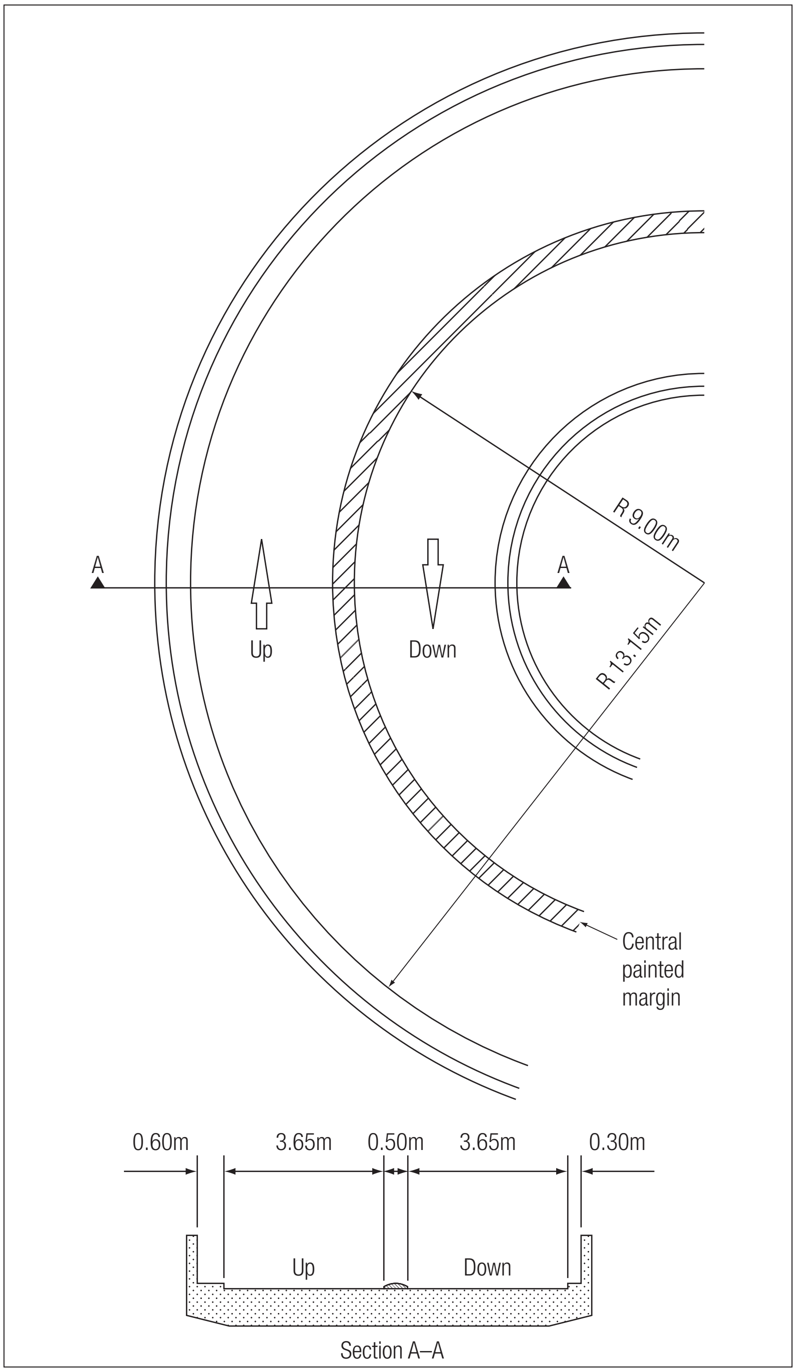


Figure 4.6 Two way spiral ramp

Table 4.6 Recommended minimum widths for curved ramps and accessways

Ramp type	Ramp width (m)	Width of additional central margin (m)	Structure clearance outside kerb/margin (m)	Structure clearance inside kerb/margin (m)
One-way	3.65	n/a	0.60	0.30
Two-way	7.00	0.50		

Note
See Figure 4.6.

It may sometimes be appropriate to provide a facility for vehicles to escape the car park system before passing the barrier line on entry. Where required, suitable turning arrangements will need to be accommodated.

It may also be advantageous to site the entrance and exit side by side, with one or more lanes made reversible. Then, if peak inbound and outbound demands occur at different times, a lane or lanes may be reversed as appropriate.

The entry and exit lanes within these reservoirs are typically 2.75 to 3.0m wide. However, if this width is maintained adjacent to ticket issue and reader machines, or at payment stations, drivers will experience difficulties as they may not be able to reach the machinery or kiosk. This will reduce the dynamic capacity of the system as drivers lean out of the windows, open doors, or even get out of their vehicle to use the machine. Hence, drivers should be encouraged to approach ticket machines and payment stations as closely as possible by restricting the width of the lanes adjacent to control equipment to 2.50m. A typical gate layout is shown in Figure 4.5. Selection of rising-step barriers has implications to the structural form and headroom (see Section 4.3.6).

Where approach and exit routes of control systems are on bends, the swept paths of the vehicles should be checked and lanes widened if need be. Positioning entry or exit controls on bends is not recommended. Access lanes to control equipment should provide generous space for drivers to manoeuvre cars into position for easy operation of the equipment from within the car. Where space allows, it is recommended that a straight of at least 6.00m be provided on the approach to control equipment. In addition, the area alongside the equipment should have shallow gradients to reduce braking and starting difficulties. Gradients between 1 : 20 and 1 : 40 are desirable.

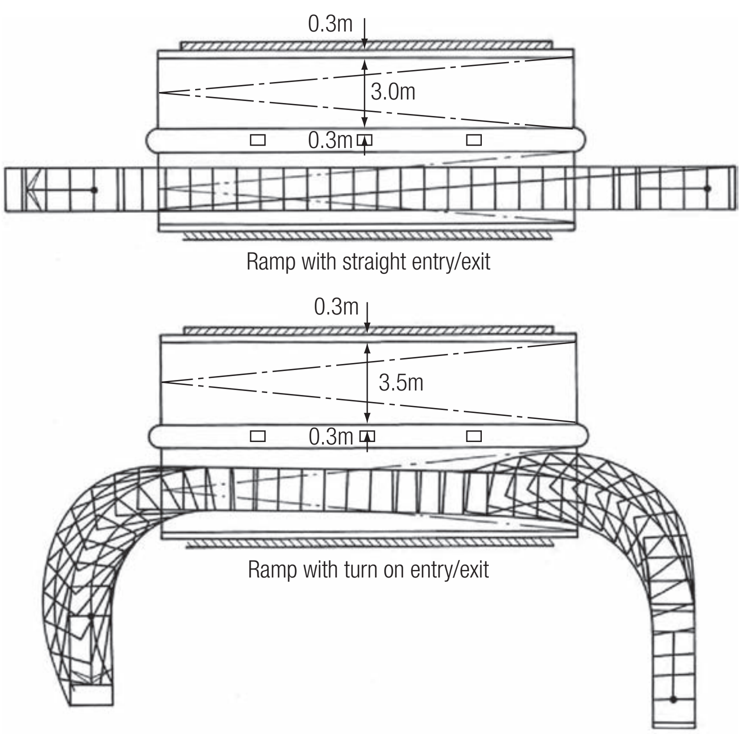


Figure 4.7 Ramp widths and clearances

Table 4.7 Recommended minimum widths for one-way straight ramps and accessways

Ramp type	Position	Width (m)	Additional side clearance to structure (m)
One-way[a]	Width for straight approach	3.00	0.30
	Entry/exit section for turning approach	3.50	

Note
a For two-way ramps a central margin of 0.5m is recommended.

The design of the lane layout near the entry and exit controls should consider the consequences of equipment or vehicle failure. This could include providing duplicate machines, additional lanes, the ability to bypass failed cars or machines, or vehicle waiting areas before the control systems. Actual requirements will depend on individual circumstances, including the provision made by manufacturers in equipment to reduce malfunctioning. However, these facilities will help minimise the potential disruption to the throughput of vehicles.

4.4 Car park layout

4.4.1 Principles

The car park design has to carefully consider the customer and provide a system that is easy and safe to use. It must also be compatible with the locality and follow the guidelines established by the Local Planning Authority in terms of appearance and scale. These principles of use and planning tend to control the size of the car-park system, the circulation facilities, and application of the geometric design requirements (see Figure 4.8).

Short-stay operations, such as facilities associated with retail centres, will have a greater turnover for a given level of static capacity and so will attract more two-way traffic throughout the day. Long-stay facilities associated with large office or business complexes and railway stations will produce high single-direction traffic flows in the mornings and evenings. Car parks expected to carry considerable traffic flows throughout the day or under tidal conditions should preferably have one-way-only systems, which give increased dynamic capacities.

Drivers free to use any bay will want to park as close as possible to their destination. At car parks where this nearest level is also close to the control gates, this desire can quickly create entry system congestion, especially during busy periods while arriving drivers wait for others to move out. Examples of this are the car park floor closest to the shopping mall level, the cinema, or other leisure operations. This can therefore give a false impression of the static efficiency, with excessive congestion being noted on the first levels of the car park, at the control gates and on the external network, while the parking levels further away can be nearly empty. Careful planning of ramps and exit locations can overcome this by allowing rapid search routes, taking customers to other levels without the need to circulate at each level.

In large tidal flow car parks and short-stay facilities, provision should be made to short-circuit the car park with a rapid 'up' route and, if necessary, a rapid 'down' route. Search paths for incoming drivers should not generally involve more than 500 bays (see Section 4.4.7).

The maximum practical occupancy will probably be lower than the theoretical static capacity owing to a number of factors. Not all drivers will park in the first vacant bay, parking discipline may be poor, and those already in the car park may miss vacated spaces. Therefore, where entry is controlled, deliberate under-capacity margins of about 5% are sometimes introduced. In addition, to enhance static and dynamic efficiencies, re-circulation to the various car park levels should be possible without drivers having to leave the car park.

The size of the car park is guided by:
– the adequacy of the dynamic and static capacity
– the length of the search paths
– the ability to short-circuit levels by rapid-ramp systems
– planning guidelines.

In European standards, a proportion of parking spaces can often be smaller to reflect local predominance of the small-car market. If this is a general trend, small car bays of 4.00m by 2.30m could become more acceptable as a standard within UK car parks. Another area of variation relates to the aisle width. For 90° parking this can be reduced to 5.50m providing that the bay width is at least 2.50m.

These variations in design geometry clearly identify the challenge for the designer, who has to balance users' requirements and planning authority standards against the client's brief.

In the USA, larger vehicles and other standards apply[4.7]. Accordingly, design parameters will have to be reviewed and further research undertaken.

If cycle and motorcycle bays are required, they should have an up-hill entry gradient and minimum cross-fall. They are preferably located on the car park entry level.

Where parking facilities have to accommodate high vehicles, e.g. those for disabled persons, the first floor could be designed with greater headroom (see Section 4.3.6). In such cases, additional height restriction warnings and measures will be required to prevent movements into areas with lower headroom.

4.4.2 Cul-de-sac parking

As bays within cul-de-sacs (see Figure 4.9) are generally off a driver's search path, it is preferable to avoid multiple cul-de-sac aisles. If they are used, the maximum cul-de-sac capacity should be six parking bins in length. If cul-de-sac parking of greater than the recommended maximum is dictated by the constraints of the site then vehicle turning space must be considered in the layout of the parking bins. Manoeuvring into and out of the end bays can be especially difficult and so larger bays are usually necessary which leads to less efficient use of space.

Figure 4.8 Example of typical car park layout

Special note should also be taken of s.7.5.2.2 with respect to escape distances in the event of fire.

4.4.3 One-way and two-way aisles

Drivers want to be able to find their way around the car park easily so that they can concentrate on looking for a vacant space. Cross movements should be avoided and aisle widths should be suitably sized. One-way circulatory systems and aisles, which normally have a higher dynamic capacity than two-way systems, can do much to reduce confusion and congestion.

Drivers sometimes disregard one-way operations, leading to flow disruption and perhaps a safety hazard. This can be managed by good signing and lane markings. However, if two-way movements are considered likely, two-way aisles should be introduced. This will require wider aisles and better visibility along with the correct markings and signing. Although this problem is more applicable to surface-level facilities, it should be borne in mind.

4.4.4 Parking angle

Placing bays at an angle of less than 90° is a convenience for drivers since it facilitates entry and exit. This in turn improves the dynamic and turnover capacity of the aisle. However, a disadvantage is that a greater floor area per car is required. This reduction in static efficiency – namely the ratio of area provided in bays to the total floor area – can significantly increase the cost per space. For standard bay dimensions and one-way aisle operations, reductions in the order of 3% can be expected for angles from 90° to 70°. For 45° parking, this reduction can be about 20%.

4.4.5 Parking-area layout

4.4.5.1 Introduction

Parking-area layouts may be classed as:
– flat deck
– split-level
– ramped floor.

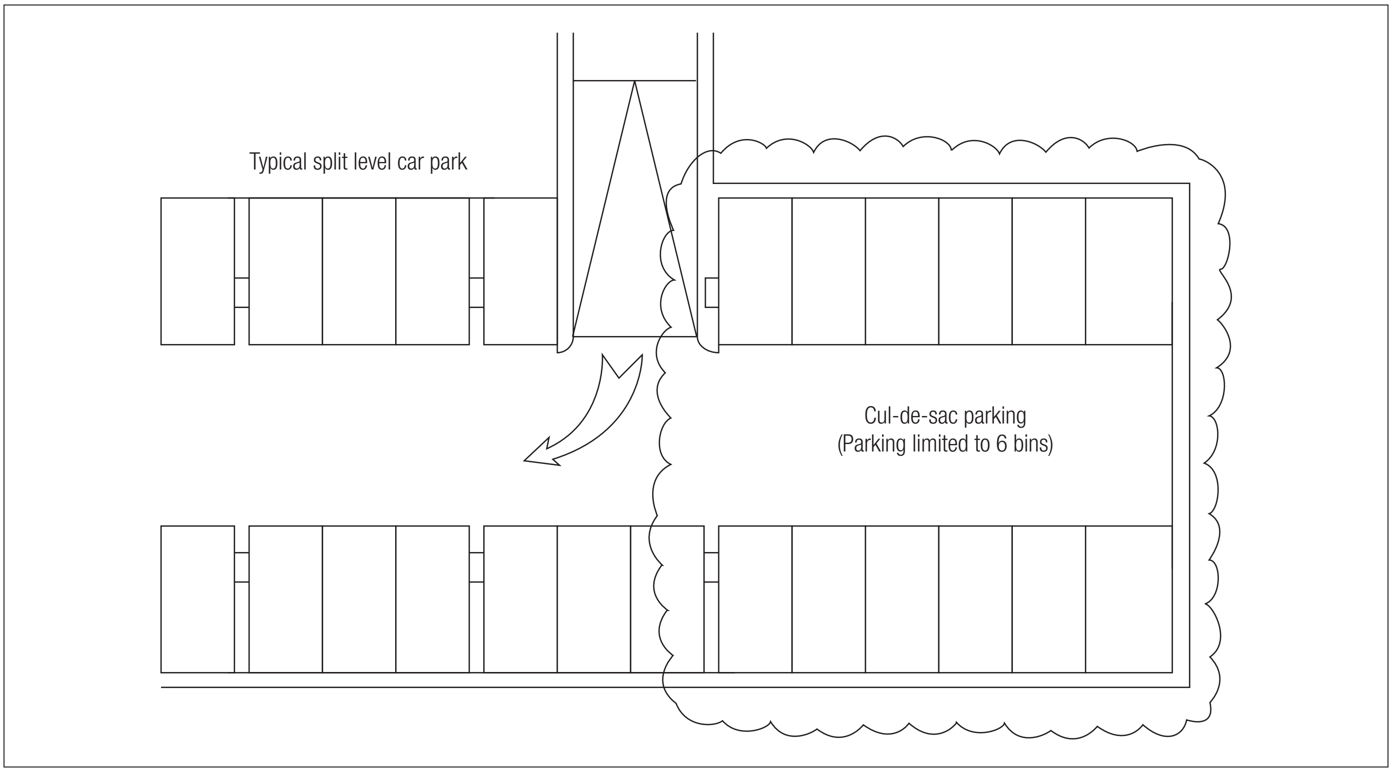


Figure 4.9 Cul-de-sac arrangement with larger end bays

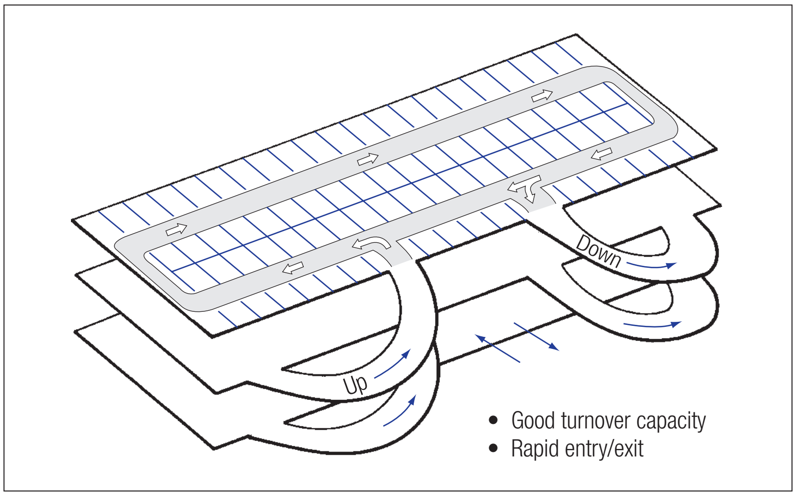


Figure 4.10 Flat deck car park with external ramps

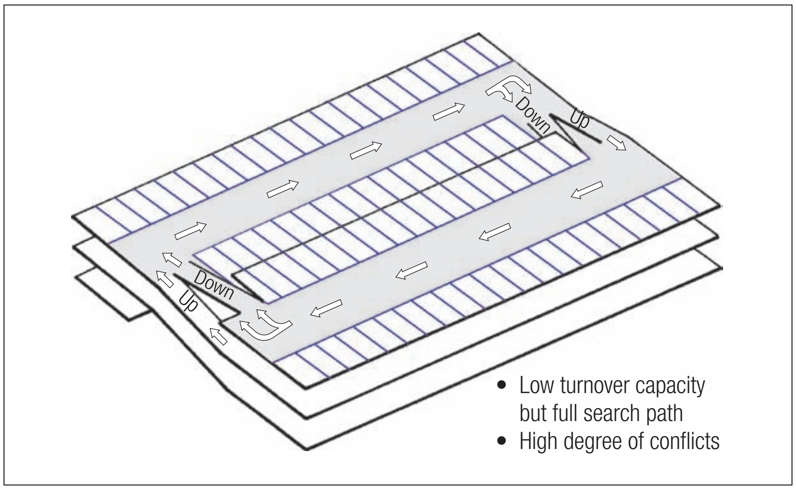


Figure 4.11 Split-level car park with combined entry and exit circulation and with end ramps

The principles of each of these layouts are reviewed in the sub-sections below.

4.4.5.2 Flat deck layout

A flat deck layout is shown in Figure 4.10. Each deck is flat. The decks are linked by ramps, the illustration showing external curved ramps. Straight ramps may be used, in which case they are usually internal. Flat deck car parks are normally built in multiples of a bin width, but the layout is adaptable. In Figure 4.6, the ramp circulation is anticlockwise to suit the entrance and exit arrangements. In the UK, a clockwise circulation is preferred, that is with the driver on the inside of the turn. This is not regarded as essential.

4.4.5.3 Split-level layout

Split-level layouts are shown in Figures 4.11, 4.12 and 4.13. The illustrations operate with drivers entering by the up ramp system and leaving by the down ramp. In an underground car park, the same principles apply but the ramps reverse. The parking levels are flat decks or levels. The rise between levels is half the floor-to-floor height. Since the rise between levels is usually 1.50m or less, the ramps may be at 1:6. This class of car park is commonly built with up to 12 levels, inclusive of the ground levels. It is usual for aisles to be one-way since they are part of the ramp circulation, which is one-way. The usual widths of the levels are a bin or multiples of a bin but may be adapted to a site.

In Figure 4.11, the up-and-down ramps are at the ends of the structure. The scissor arrangement of the up-and-down ramps has a low dynamic capacity because sight distances are short where traffic streams merge. As shown in Figure 4.11, the departure route is long.

In Figure 4.12, the up-and-down ramp systems have been separated. The down-ramp system is short, and the up- (or entry-) ramp system, in principle, includes the remaining bays.

Figure 4.13 illustrates the use of a short up-entry-ramp system as well as a short down-ramp-exit system.

Attractions of the split-level layout are its compactness, that the ramp system is internal and that the space taken up by the ramps is a minimum. It may be difficult to search systematically for a vacant bay. In car parks laid out on the lines of Figures 4.12 and 4.13, a driver may see a vacant bay that cannot be reached, if the one-way aisle system is observed, without first going up a level and then down a level. Similarly, when leaving from some bays, it is necessary first to go up a level. Lifts and stairs should access all levels to avoid pedestrians needing to use vehicle ramps. Particular care is required in the design of details to provide adequate visibility and clearance at overhangs (see Figure 4.14).

4.4.5.4 Ramped floor layouts

Ramped floor layouts are shown in Figures 4.15, 4.16 and 4.17. Cars are parked off an aisle, which also acts as a ramp. The ramp may be two-way.

Figure 4.15 shows a one-way aisle system with a clearway down (departure) ramp. Since there is a single search path, this layout is not recommended for a capacity of more than 500 bays: even then, the search path may be found inconveniently long. Instead of a clearway departure ramp, a departure parking ramp may be used.

In Figure 4.16, the down parking ramp is end-to-end with the up parking ramp.

In Figure 4.17, the up-and-down parking ramps are interlaced. The view has been exploded to show all ramps.

Ramped floor car parks are usually built two bins wide, and the layout is not adaptable to a site. The ramp need not be laid out as in the illustrations: it may, for instance, be laid out as an oval or a square. Ramped floor car parks with steep gradients should be avoided as it may be found difficult to open, or hold open, a car door on the up-gradient side and to close a door on the down-gradient side.

4.4.6 Ramps

Ramps are required to give access to parking levels. In a car park with three or more parking levels, access to those levels may involve the use of aisles (as with split-level car parks), or the layout may not require drivers to route through aisles. A clearway ramp is a ramp system that does not include aisles. Ramps may be straight or helical (circular in plan).

Clearway ramps are used when it is desired to speed access time, to avoid through-traffic in parking areas, or where a ramp aisle system has insufficient dynamic capacity. If only one clearway ramp is provided, it is usually the departure ramp.

Failure to design to an adequate standard will reduce capacity and can increase the accident risk.

In some layouts, traffic contra flow occurs on straight ramps or crossovers between ramps. In these unusual cases, it is recommended that traffic streams be separated by a barrier, as drivers could be required to drive on the opposite side of the carriageway to that normal on public roads. A barrier

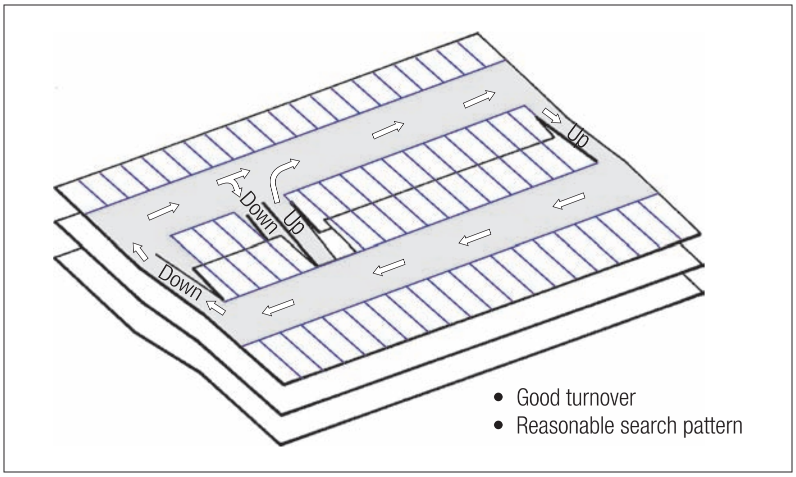


Figure 4.12 Split-level car park with separate entry and exit circulation and with short down (exit) ramp system

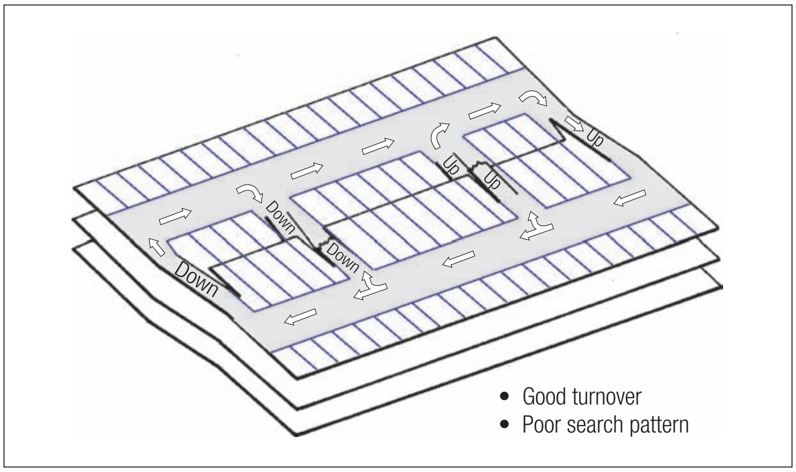


Figure 4.13 Split-level car park with separate entry and exit circulation and with short up (entry) and down (exit) ramp systems

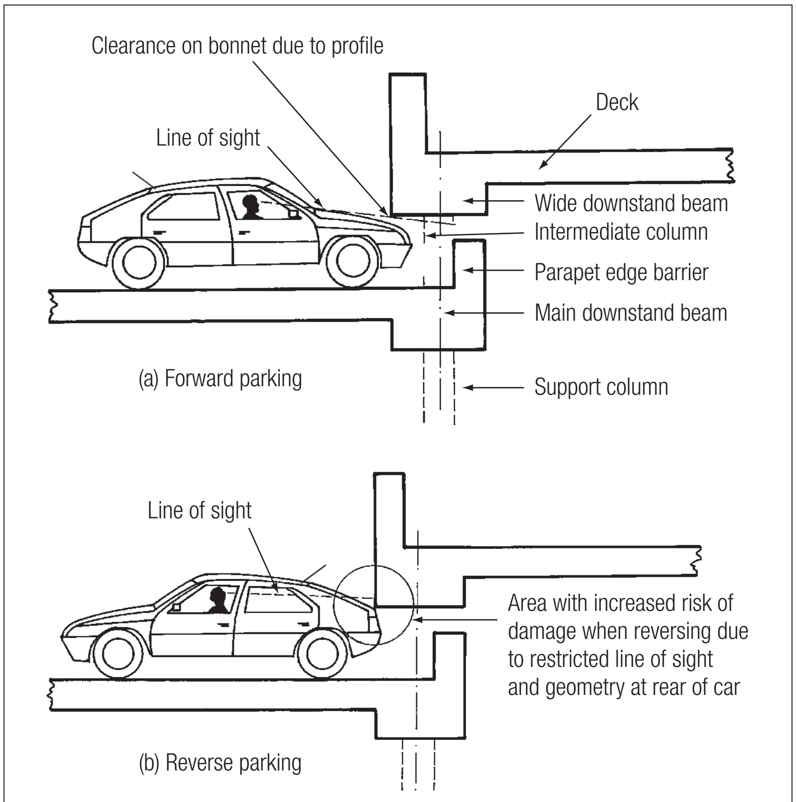


Figure 4.14 Clearance and visibility issues around downstand beams

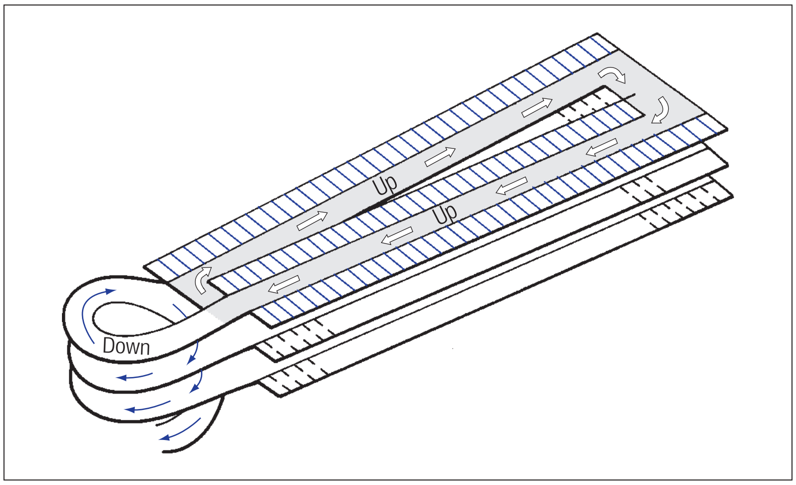


Figure 4.15 Ramped floor car park with a clearway down (departure) ramp

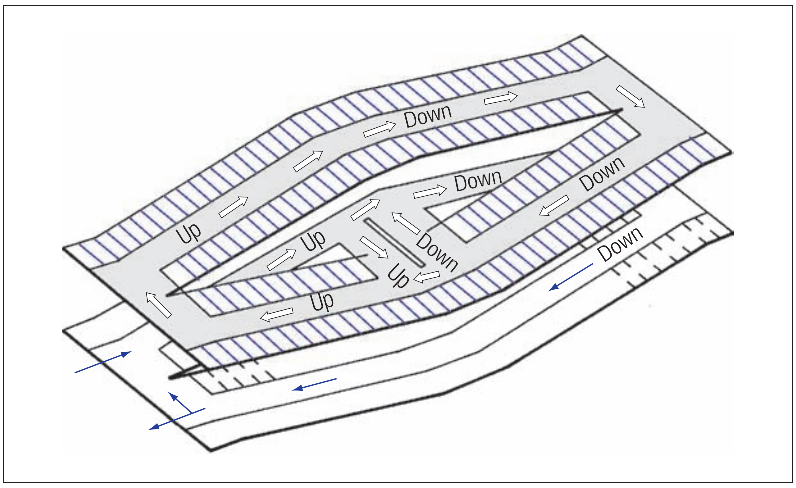


Figure 4.16 Ramped floor car park with separate entry and departure parking ramps

may extend beyond the ends of a ramp or crossover to discourage drivers from attempting to drive in the wrong lane.

Figure 4.15 illustrates the use of a helical ramp. Usually, helical ramps are external but they may be internal. The recommended direction of flow in the UK is clockwise, that is, with the driver on the inside of the turn. This is recommended for ramps of minimum radius (see Table 4.5 and refer to Figure 4.6 for recommended radii). With a larger radius, an anticlockwise flow is acceptable; ramps are in use with an anticlockwise flow.

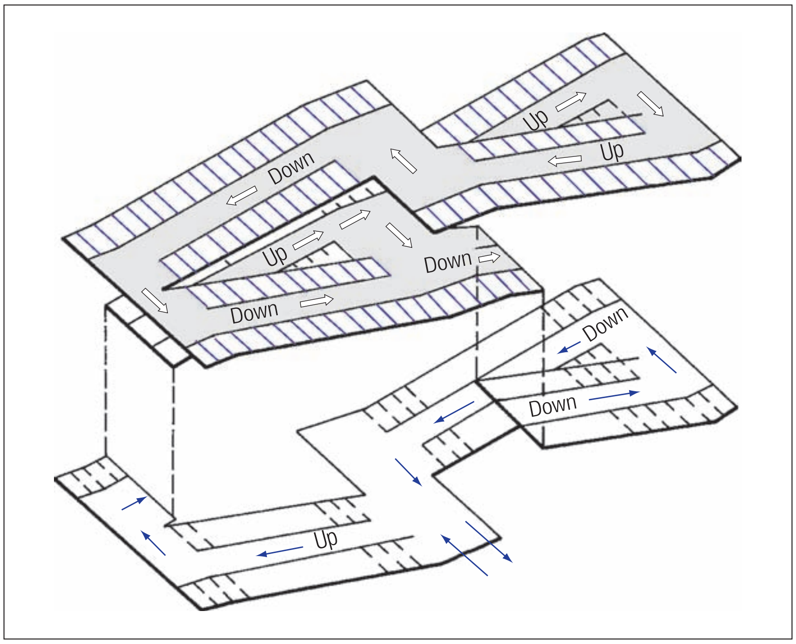


Figure 4.17 Ramped floor car park with interlaced entry and departure parking ramps

Concentric helical up-and-down ramps, serving alternate floors, may be used in larger car parks. In such instances, the outer ramp should be the up-ramp as it will have the lesser gradient.

4.4.7 Choice of layout

The factors affecting car park layout are so many and variable that it is impractical to propose ideal layouts. The *Car Park Designers Handbook* [4.8] considers many alternative configurations with advice on appropriate layouts. The predominant use to which the car park will be put should be borne in mind. A primary consideration is the duration of stay, which varies with the trip purpose. Parking may be less than one hour for shopping, but for business trips the duration is usually longer; it is even longer for work trips. For park-and-ride (e.g. at a railway station or airport for short-haul travel), the facility to park without delay is important.

The search path of 500 bays is the ideal maximum. Therefore, car parks of more than 500 bays should ideally have more than one search path. Car parks with internal ramp systems have been built with substantially greater capacity than 500 bays but, as previously mentioned, public car parks are commonly used at well below their design capacities. If an attempt is made to use such a car park near its capacity, delays can be expected. A short search path will provide incentive to short-duration parking or to park-and-ride travellers.

In larger car parks, long circulation aisles are inevitable. This can lead to excessive vehicle speeds if no controls are provided. Typically, speed humps are suggested as a form of speed control. However, these must be considered in the context of fixings and waterproofing maintenance, slab impact loadings, and headroom restrictions.

For larger car parks, the preferred layout is usually flat deck with straight or helical clearway ramps (see Figure 4.10).

Internal variable message signs can be used to manage circulation and to divert drivers past full floors or areas. These must be carefully designed with good visibility of signs located before the decision point. The system also requires good levels of management and maintenance.

4.5 References

4.1 'Buyers guide new car tables'. *What Car*, October 1999, pp. 196–269

4.2 *Road vehicles (Construction and Use) Regulations 1986*. London: HMSO, 1986 (SI 1986/1078) [as amended]

4.3 Department of Transport et al. *Parking for disabled people. Traffic Advisory Leaflet 5/95*. London: DTLR, 1995

4.4 *The Building Regulations 2000. Approved Document M: Access to and use of buildings*. 2004 ed. London: NBS, 2006

4.5 *The Building Regulations (Northern Ireland) 2000. Technical Booklet R: Access and facilities for disabled people*. London: TSO, 2000

4.6 *BS 8300: 2009+A1: 2010: Design of buildings and their approaches to meet the needs of disabled people*. London: BSI, 2009

4.7 Chrest, A.P. et al. *Parking Structures: planning, design, construction, maintenance and repair*. 3rd ed. Norwell, Ma: Kluwer, 2001

4.8 Hill, J. et al. *Car park designers' handbook*. Thomas Telford, 2005

5 Car park design and construction

5.1 General

Designers should be aware that, on 31 March 2010, the British Standards for structural design were withdrawn and replaced with new British Standards for structural design that harmonise with Eurocodes. These are supported by National Annexes containing information on nationally determined parameters for the design of building and civil engineering works constructed in the UK.

The Building Regulations 2000 for England and Wales[5.1] and those for Northern Ireland[5.2] together with their approved documents are unlikely to be updated to refer to these new British Standards until 2013. However the 2010 revision to the Building Regulations for Scotland[5.3] does refer to these new British Standards.

On all publicly funded projects within the EU (above a financial threshold) the Public Procurement Directive[5.4] must be adhered to. This directive indicates the conditions when the new British Standards must be adopted, although it may be permissible to depart from these in some circumstances provided the departure is shown to be technically equivalent to the relevant standard which is a question of substance and cannot be taken for granted.

The British Standards Institution (BSI) has published a table of withdrawn and replaced standards and further information about the use of the Eurocodes[5.5]. The withdrawn British Standards will no longer be revised or updated.

Once the appropriate system of standards has been chosen; it should be used exclusively throughout the design and construction process.

5.2 Loading

5.2.1 Design loads

The imposed loading applicable to decks and ramps in car parks is given in standard codes e.g. BS EN 1991[5.6–5.12] with the appropriate National Annex, or BS 6399: Parts 1[5.13] and 2[5.14] in the UK. Vehicular weight has tended to diminish with time, but the payload has increased. Consequently, the design load has remained constant in successive loading standards.

5.2.2 Uniformly distributed imposed loads

For a normal mix of vehicles, subject to the maximum weight of any vehicle being 2500kg, the imposed uniformly distributed load given in BS EN 1991[5.6] and BS 6399-1[5.13] is 2.5kN/m^2. Consideration should be given to increasing this figure if the weight of vehicles entering the car park exceeds 3000kg, or if vehicles are to be packed more densely than normal by automated systems. There are local loading variations, which should be verified even when designs are referenced to UK codes. For example, the load may vary in National Annexes for other European countries, and in Hong Kong a uniform distributed imposed load of 4kN/m^2 is adopted. For multiple floor loads it is recommended that the approach in BS EN 1991[5.6] be adopted with design Eurocodes, or that in BS 6399-1[5.13] be adopted with British Standards. For car parks, this does not allow any reduction in column load from loaded areas and requires that all storeys be assumed to be simultaneously loaded.

Local authorities often require fire engine access to designated areas, particularly at roof level. This requirement should be established at an early stage since it has a significant effect on the roof structure, the ramps, any intermediate floor access zones, and columns.

Snow loading on roofs need not normally be considered in combination with vehicle loading, unless the car park is being designed for long-term parking, or is in an area with high snowfall. Cladding loads may be influenced by icing, particularly on exposed grillages.

5.2.3 Wind loads

The wind speeds and loading applicable to car parks are determined from standard codes *BS EN 1991-1-4 Actions on Structures. Wind actions*[5.9] and *BS 6399: Part 2: Loading for buildings: code of practice for wind loads*[5.9, 5.14] and advice notes such as *BR173 Design guide for wind loads on unclad framed building structures during construction*[5.15]. Sufficient voids must be provided in cladding to ensure adequate ventilation. Percolation through the building will result in drag on the bodies of the parked vehicles and will be transferred to the floors by shear in the tyres. It is therefore recommended that the minimum wind loading be taken as acting over the entire elevation area of the structure with no reduction for openings. Enhanced wind drag must be considered in cases that are susceptible, particularly those structures with lightweight steel floors and for demountable structures.

Local wind pressures on cladding components must be designed on the basis that maximum pressure and suction is applied to both faces of each cladding component simultaneously.

5.2.4 Other loads

In addition to wind load, car park structures should be designed to withstand vehicle impact loads. Lateral loads also arise from vehicles changing direction vertically at ramps and from friction when they turn or brake. Horizontal loading is more important in car parks than in other building types where additional stiffening is derived from partitions and finishes.

Lateral loads should be safely transferred to the foundation through the structural system, e.g. slabs, beams, bracing and columns.

Lift systems and travelators apply significant additional loads to localised areas of the structure, so provision for their inclusion should be established at an early stage.

Allowance must be made for access of any abnormal loads for maintenance.

5.2.5 Ground pressures

Flotation may dominate the design and construction of basement and semi-basement parking levels. The most critical flotation case is often during the early stages of construction. Provisions for drainage of the basement and ground in the immediate vicinity must be considered. Lateral soil pressures on the walls, uplift and ground heave pressures under the ground-bearing slab will dominate section geometry and design of basement and semi-basement parking levels. The scale of such pressures is likely to be several orders of magnitude higher than the normal imposed dead or live loads on the floor slab. Further advice is available in *Design and construction of deep basements*[5.16].

5.2.6 Load combinations for normal design situations

Loading on car parks is generally similar to that on other buildings. However, the ease with which imposed load can be moved makes the analysis of pattern loading cases important. Thermal strains may also induce forces that can be significant if restrained, particularly for exposed roof slabs.

Structural design and detailing should be carried out with critical combinations of dead load, imposed live load, snow, wind load, thermal load, the notional live loads from relevant parts of BS EN 1991[5.6–5.12] or all relevant parts of BS 6399-1[5.13], BS 6399-2[5.14] and the other lateral loads as listed in Sections 5.2.4 and 5.2.5. Design against flexure, shear and torsion should be carried out, using design methods and partial safety factors according to the appropriate codes of practice for the structural material and construction type.

5.2.7 Load combinations for abnormal design situations

5.2.7.1 Introduction

The loads given in Sections 5.2.7.2 and 5.2.7.3 should be considered using the appropriate combination partial factors for loading. Note that where access to the car park for emergency vehicles such as fire engines is required, the design loading may have to be increased.

5.2.7.2 Punching shear of jack or wheel loads on slabs less than 150mm thick

Floor slabs should be designed to carry the more onerous of the following:

- Wheel loads as shown in Table 5.1. The figures are based on the maximum tyre pressures recommended for given tyre sizes. However, BS EN 1991-1-1[5.6] recommends an axle load of 20kN spread on two 100mm squares for vehicles up to 30kN gross weight, and 90kN spread on two 200mm squares for heavier vehicles up to 160kN gross weight. In both cases the loaded areas are at 1.8m centres.
- A jack load of 12.5kN acting over 50mm × 50mm. This contact area need not be considered closer than 0.75m to a floor edge.

Table 5.1 Wheel loads

Contact area (mm)	Imposed load on flat slab (kN)
150 × 150	6.5
175 × 175	9.9
⩾200 × 200	12.5

If traffic-calming measures such as speed humps are used, it must be demonstrated that the equivalent static wheel loading remains below these values. It is generally preferable to use post or barrier control features to avoid impact loads on slabs and maintain headroom.

5.2.7.3 Vehicle impact into a column

Vehicle impact may be from within, either directly or by transmission from the edge protection barriers, as explained in Section 5.6. Impact may also be from outside the car park at ground level. Section 4.3 of BS EN 1991-1-7[5.12] provides equivalent static design loads for a wide range of vehicular impacts against structures.

5.2.8 Robustness of structural frame

Car park structures should have provisions for robustness as given in the relevant codes of practice.

In the UK, *Building Regulations Approved Document A*[5.1, 5.2, 5.3] and the codes of practice for construction materials should be referred to for measures against collapse disproportionate to the cause, e.g. a local accident, effects of fire, etc.

Section 3 of BS EN 1991-1-7[5.12] provides recommendations on how to identify potential accidental actions, and how to limit the extent of consequent local failure.

5.2.9 Landscape loading

A wide variety of loading may result from different landscaping schemes for roofing areas and must be carefully considered. In deriving the appropriate loading, account must be taken of the particular planting scheme required, mature size of plants, and flexibility for future changes. The imposed loading from landscaped areas, water features and concentrated tree loads can be an order of magnitude higher than the normal vehicular imposed loading for car parks. Even where thin, drained grassed areas are proposed, it is recommended that a minimum imposed load of 7.5kN/m^2 be adopted. Similarly, loads from water features and rock features must be carefully considered as they can add significant loading, limit flexibility for future changes, increase structural costs, and require a continuing operation and maintenance commitment.

In deriving the loading to be applied, the long-term growth and access requirements for maintenance plant, which can impose concentrated loads, must be considered. The provision of tree planters (see Figure 5.1) in particular must be carefully planned, as the increased depth of soil required (typically at least 1.5m), the weight of the mature tree, and overturning effects of wind loads all lead to concentrated and local loading. In the absence of more specific details, it is recommended that a percolation factor of 50% be used in conjunction with the projected elevation of the fully mature tree to derive wind forces. Use of

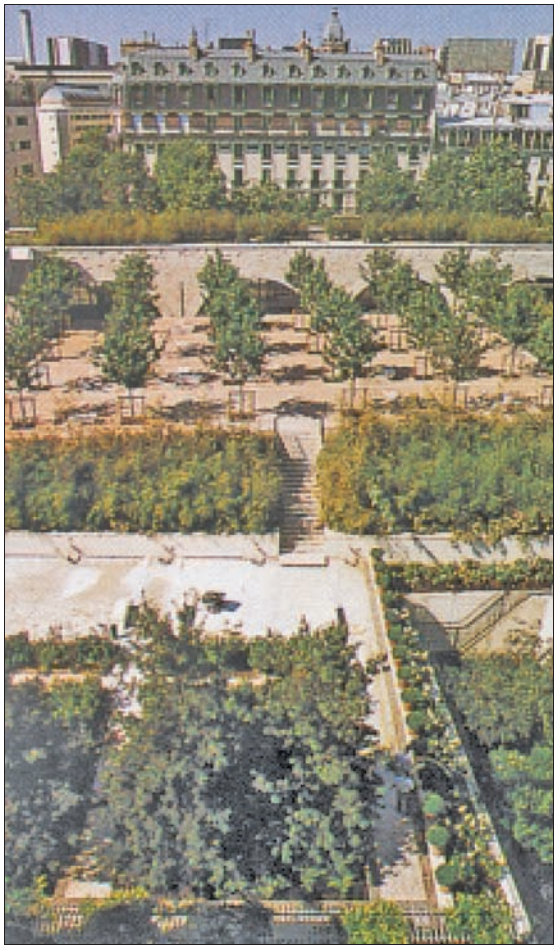


Figure 5.1 Parc Hector Malot underground car park, Paris, showing a selection of landscaping features

overturning loops below or at the soil surface should be considered to anchor trees adequately. In general, the cost of supporting trees is high and, for economy, they are normally placed over column and/or principal support positions.

The features of landscaped areas will normally include provision for drainage, irrigation and access for maintenance. Owing to the difficulties of access to inspect membranes and the need to both irrigate and drain landscaped areas, such areas will normally require an enhanced waterproofing membrane and a root barrier or positive measures to prevent structural damage by root penetration. The membrane must be adequately protected to prevent damage from horticultural maintenance. The soil must be properly drained, without being too steep, and falls of 1:100 to 1:40 would normally be used in conjunction with a positive drainage system to ensure the soil does not become saturated (see Figure 5.2). Loading must consider the effects of blockages to the drainage system and the increased loads resulting from storm inundation.

The roof loading must allow for the maximum weight of vehicles that will be used for maintenance, such as tractors and grass cutters, which can impose concentrated wheel and patch loading. Provision of edge barriers, means of access, and means of avoiding steep slopes requiring frequent maintenance must be properly dealt with so that landscaped areas can be safely maintained.

Water features are often considered to be a desirable component of a landscaping scheme. They also impose loading significantly higher than normal car park loading and, as with landscaping in general, must be carefully considered for each project.

The restrictions on loading, the requirements to control growth, and the maintenance regime to ensure loading does not exceed the design level must be clearly defined and agreed with the project client as part of the brief. This information is an essential part of the operational manual and health and safety file.

5.2.10 Response of structure to vibration

Human perception of vibration in buildings varies between individuals. It also varies depending on the activity being undertaken by those individuals. Stationary people are more aware of vibrations than those who are moving. Those people engaged in detailed operations, e.g. in hospital theatres or on printed circuit boards, are particularly sensitive to movement.

Empty car park structures lack the damping normally provided in buildings by partitions and finishings. However, the dynamics of most car park structures are generally found to be satisfactory when the design gives natural frequencies above 5Hz, even when compartments within the structure adjoining the car parking zones are in use as offices or for sensitive activities. Where car parks form part of a mixed use development, measures to reduce vibration of the interface or shared floors should be

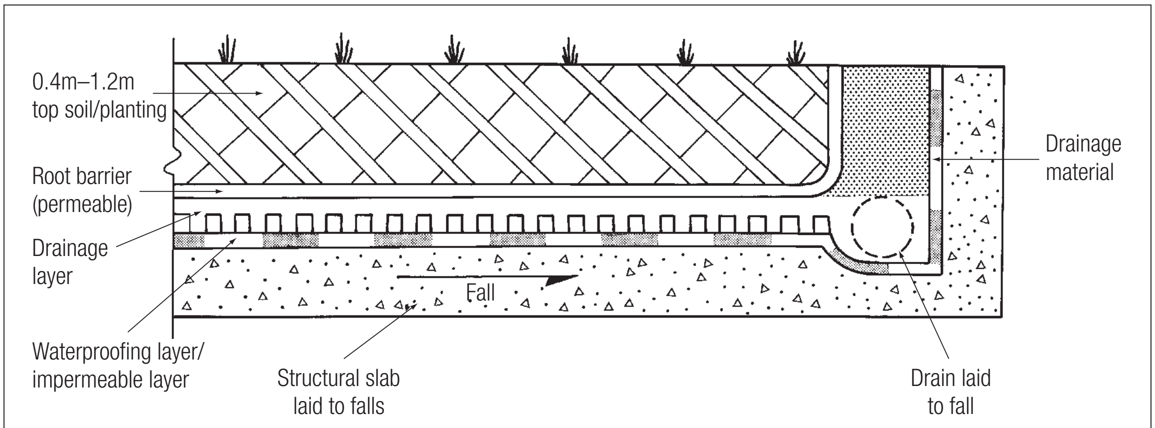


Figure 5.2 Minimal roof planting details

enhanced to suit the more onerous condition as defined in BS 6472-1[5.17].

User perception of vibration is lessened by the user's motion either when walking or when travelling in a car. In stand-alone car parks with lightweight construction and spans up to 16.0m it has been found that a minimum natural frequency of 3Hz is satisfactory. This vibration frequency is that calculated for simply-supported primary beams and floor slabs, together with secondary beams where appropriate within the effective width. Cars parked on the decks provide additional damping to the structure by their mass supported on damped suspension. Additional guidance for such situations with cars present and absent within the structure is provided on page 14 of *Steel-framed car parks* published by Corus[5.18]. Any end restraint will assist in damping the vibrations and its contribution should be considered if justification of the vibration characteristics is by *in situ* testing of the completed structure.

Unusual or long span structures may be more sensitive to dynamic loading and their response to vibration should be checked. Irregular surfacing, badly aligned movement joints, and speed-retard humps can have an adverse effect on dynamic movement.

5.3 Structural materials

5.3.1 Introduction

Conventional materials commonly used in car park construction are concrete and steel, combined in a variety of ways. Concrete may be both reinforced and prestressed. Steel is used either alone as the principal structural material, or compositely with concrete.

5.3.2 Concrete construction

Concrete car parks may be assembled from precast units or cast *in situ*. *In situ* concrete structures may be cast on a wide variety of proprietary formwork and falsework systems; proprietary lift-slab methods avoid the need for formwork for some types of car park.

The use of lightweight-aggregate concrete can also be considered. In car parks, the weight of the concrete slab usually exceeds the live load, and a 25% reduction of this weight is significant, both in the slab and in its effect on column and foundation loads. Lightweight concrete also offers better fire performance. This must be set against the disadvantages: a smaller permitted span/depth ratio, additional shear reinforcement in the slab, and in composite beams a slightly reduced effective breadth of flange and an increased number of shear connectors. Lightweight concrete generally provides less durability than normal weight concrete, and implications of its use on long-term performance should be considered.

5.3.3 Steel construction

Uncased structural steelwork is often used in car park structures. Its use in above-ground car parks can often be justified using fire engineering analysis techniques. However, in some cases it may be necessary to apply for a relaxation of the regulations from the appropriate authority. If in doubt as to whether an application is required, the position should be checked with the appropriate authority. Maintenance costs are likely to be higher for uncased steelwork than for concrete, but the difference is not considered to be great.

When fire protection is provided to steelwork, systems must have adequate strength to resist bumps and scrapes. Systems whose performance in fire is degraded by scrapes should be avoided.

5.3.4 Composite construction

Car parks in composite construction generally comprise a framework of steel beams and columns supporting concrete floor slabs (see Figure 5.3). The latter usually combine in composite structural action with the steel beams in one or both directions and can be wholly cast *in situ* or precast with *in situ* joints and topping. Some of the advantage in speed of erection afforded by prefabrication may be lost if wholly *in situ* construction is adopted for floor slabs.

5.4 Methods of construction and structural design for car parks above ground

5.4.1 Introduction

The structural form of a multi-storey car park will be heavily influenced by the design geometry adopted (see Chapter 4). Designs commonly use *in situ* concrete, precast concrete, structural steel, or a combination of some or all of these materials. Guidance on the location of columns is given in Section 4.3.5.

5.4.2 Floors

5.4.2.1 General

With the exception of some temporary structures, car parks use concrete for the deck structure. It is recommended that all be laid to a minimum 1:60 fall. This requirement can complicate deck joint details, and must be borne in mind from the outset.

Figure 5.3 Buttercrane car park, Newry, Co Down – cellular beams with PCC units

The car park decks must also be designed to resist the horizontal and vertical loads applied by cantilevered edge-protection systems and fixing arrangements.

Roof decks usually have a waterproofing layer. However, to limit cracking, some deck construction methods can conform to water-retaining design standards. Waterproofing can then be omitted if there is adequate resistance to frost. Water-retaining specifications do not guarantee that there will be no opportunity for water penetration, but will generally reduce crack widths. As with any system, care still has to be taken at joints.

High chloride concentrations can occur on car park decks, owing to deposition of vehicle-borne salt combined with poor drainage and detailing. This could cause reinforcement corrosion, particularly in top steel for slabs continuous over supports and especially for roof slabs. Areas close to vehicle entry points also have increased vulnerability. Refer to Chapter 8 for more information on durability issues.

The main types of floor construction are:
- precast concrete hollowcore slabs
- precast concrete permanent shuttering
- precast solid slab
- precast concrete double tees
- *in situ* flat slab
- *in situ* concrete ribbed slab
- metal decking permanent shuttering
- concrete wearing screeds
- steel decking.

These are discussed in the sub-sections below.

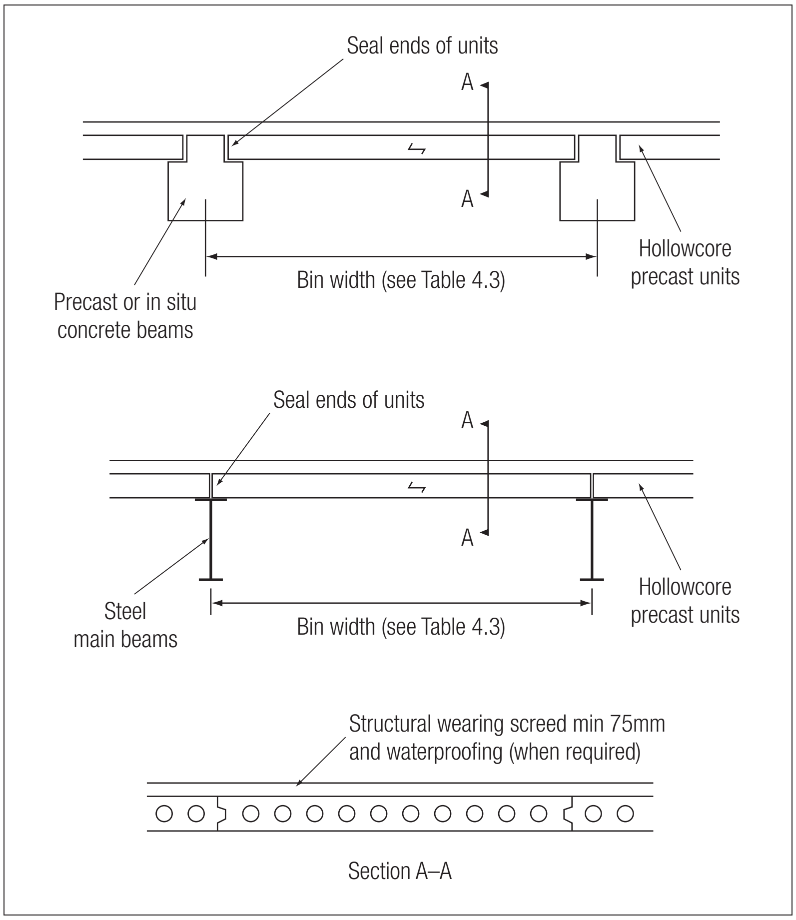


Figure 5.4 Diagrammatic hollowcore slab details

5.4.2.2 Precast concrete hollowcore slabs

These are mass-produced pre-tensioned voided units (see Figure 5.4), produced by long line methods and sawn to length. They use high strength concrete and usually have high standards of quality control. Units with span capability up to 15.6m are available. During the design process the following issues should be given careful consideration if hollowcore units are used in car park construction:
- They have no lateral distribution reinforcement; lateral strength and diaphragm action usually require use of a bonded reinforced *in situ* concrete wearing screed. This is also often required to provide a suitable running surface for vehicles.
- Slab bearings require careful consideration. Hollowcore units on uneven bearings have been known to split longitudinally to relieve transverse tension across the units induced by poorly aligned seatings. Concrete ledge seatings with large cover to reinforcement should be configured so that they do not spall when the hollowcore units deflect cyclically under live or thermal loading.
- There is no concrete cover to the ends of the prestressing strands in hollowcore units. Suitable protection must be applied after casting.
- Hollowcore units have hidden voids. These can fill with water, either during erection or from failure of waterproofing membranes (see Section 8.6.1). It is unlikely that prestressing strands will have adequate cover for durability onto the hollow cores, leading to possible deterioration. Manufacturers may be able to provide weep holes to try and drain trapped water away, but inspection of the cores remains impossible. Bridge practice has moved away from permitting hidden voids because of the problems of salt water ingress[5.19].

5.4.2.3 Precast concrete permanent shuttering

Units, as shown in Figure 5.5, are typically solid and 50mm or 75mm thick, and may be reinforced or pre-tensioned. They are usually cast individually. Units are designed to span between primary beams and to act with an *in situ* concrete wearing screed. Precast units may require propping during construction and a practical span of up to 4.8m is achievable, limiting applications of this method.

5.4.2.4 Precast solid slab

This form of construction has limited span capacity, but forms an economic solution when used compositely with steel beams. The method is used in proprietary systems to provide some of the thinnest decks.

5.4.2.5 Precast concrete double tees

Units, as shown in Figure 5.6, are cast using a long line pre-tensioned method, but individually shuttered with stop ends to form the unit ends. They are typically 600mm deep for 15.6m clear span. They may be used with an *in situ* concrete wearing screed, in which case a top flange depth of 75mm is common, or without *in situ* topping, in which case the top flange thickness is likely to be at least 100mm. The long-line process means that it is necessary to provide *in situ* protection to the exposed reinforcing strands at the unit ends. If constructed with no *in situ* structural topping, great care has to be taken to accommodate pre-cambering and waterproofing.

5.4.2.6 *In situ* flat slab

Flat slab construction is often proposed for car parks, since it can reduce clear floor heights. The slabs can be reinforced or post-tensioned and with uniform thickness or waffle construction. Two-way spanning *in situ* flat slab construction can economically fit column spacings up to 8m. There are proprietary systems in which slabs are stack cast at ground level and jacked into position. Careful detailing and construction are required at the slab-to-column interface to prevent cracking and/or moisture paths that can promote corrosion of critical joints (see Chapter 8).

5.4.2.7 *In situ* concrete ribbed slab

Ribbed concrete slabs spanning one way (as shown in Figure 5.7) can easily be configured to deal with both long-span and short-span solutions. Usually they are of reinforced construction, but post-tensioned solutions are also possible. It is important that continuous designs pay proper attention to the possibility of chloride ingress, as the main slab reinforcement will be at the top of the slab at the supports.

5.4.2.8 Metal decking permanent shuttering

Galvanised steel metal decking, as shown in Figure 5.8, can be used as permanent shuttering and can be designed to act compositely with an *in situ* concrete slab. Measures must be taken to prevent water ingress through the concrete, both during and after construction. Trapped moisture and condensation can cause hidden corrosion of the metal decking and will require specialised perforated units. Exposed roof slabs are particularly susceptible to such effects. Sealing the top surface may aggravate this condition and an enhanced maintenance regime will be necessary. For these reasons, this system should be used with caution (see Section 8.3.3).

5.4.2.9 Concrete wearing screeds

Thin *in situ* concrete slabs or wearing screeds are commonly used in conjunction with steel (see Figure 5.8) and precast concrete (see Figure 5.9) structural floor components. Steel reinforcement in the form of welded mesh mats and/or loose bars should always be incorporated. It is important that details are developed that take into account such issues as:

– reinforcement details at sheet overlaps to maintain specified cover
– pour sizes and shrinkage
– concrete grade and mix design (see Chapter 8)
– influence of camber and/or deflection on concrete wearing screed thickness
– asymmetric deflection as slab or screed construction progresses
– post-construction fatigue of the screed under load cycling where adjoining structural floor components have different flexural stiffness
– workmanship during construction, in particular concrete compaction and support of reinforcement to prevent displacement during pouring and finishing operations. Concrete wearing screeds thinner than 75mm are difficult to construct.

5.4.2.10 Steel decking

Steel decking may be suitable for car park floors, and has certainly been used for temporary car parks. Care should be taken to provide adequate skid resistance, and there are issues concerning durability. Steel decks tend to be thin and can be sensitive to vibration. They also tend to transmit noise.

5.4.3 Frames

5.4.3.1 Introduction

The design solution for the floor slab and the constraints on the column positions (see Chapter 4)

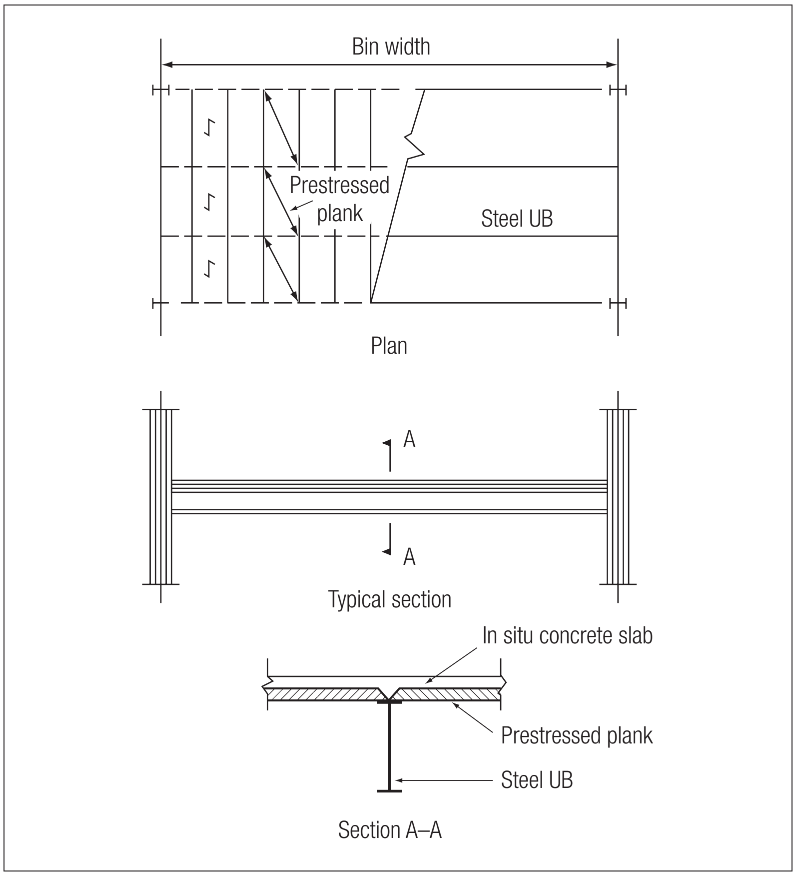


Figure 5.5 Precast concrete permanent shuttering

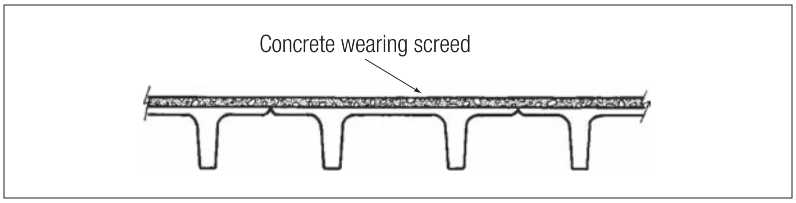


Figure 5.6 Precast concrete double tees slab section

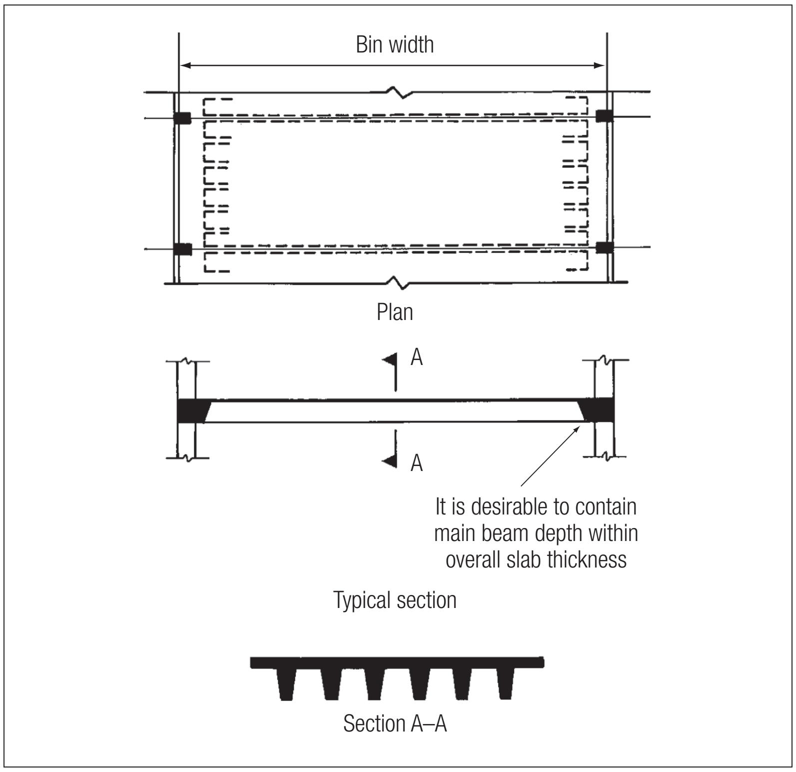


Figure 5.7 *In situ* concrete ribbed slab

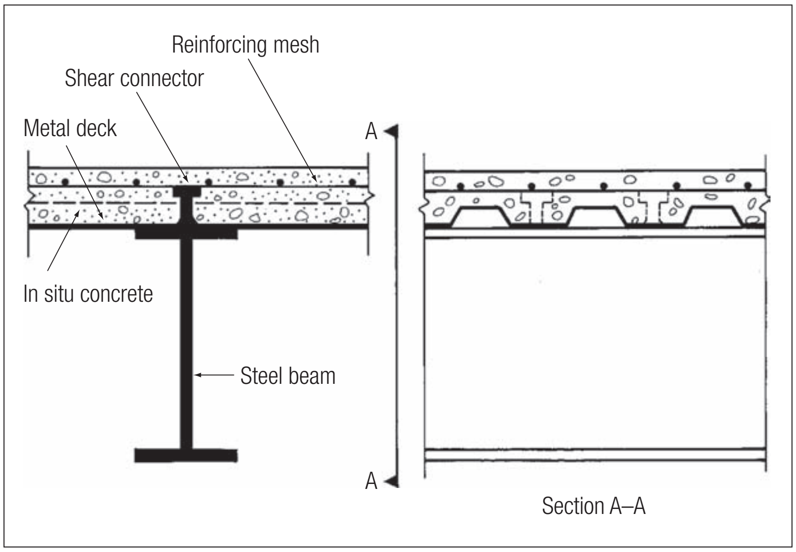


Figure 5.8 Metal decking permanent shuttering

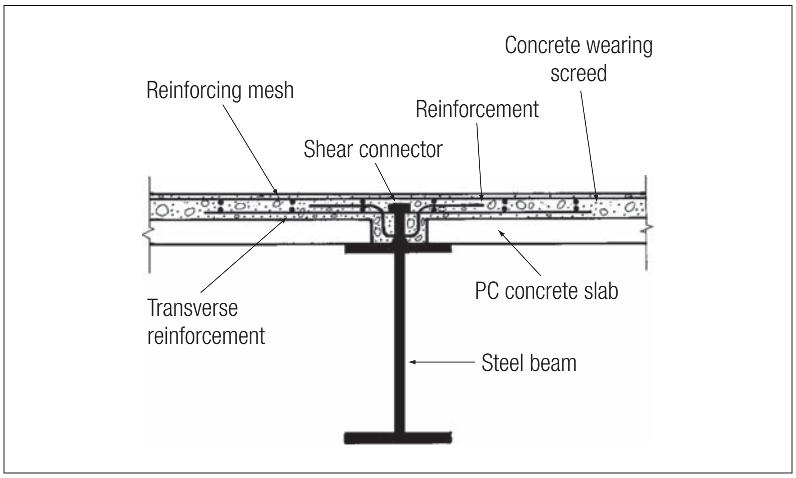


Figure 5.9 Composite beam, slab and structural topping

will largely dictate the form and type of principal framing adopted (see Figures 5.10, 5.11 and 5.12). Each of the main types of floor construction usually has a compatible framing system, being either:

– precast concrete[5.20]
– *in situ* concrete[5.21, 5.22]
– structural steel[5.18].

Figure 5.10 Clear span frame arrangement

5.4.3.2 Integral framing solutions

The framing system for the *in situ* concrete flooring options is designed as an integral part of the floor slab. This is also true for steel frames incorporating steel beams and composite concrete slabs.

5.4.3.3 Separate framing solutions

Separate frames are typically used in conjunction with precast floor construction. The precast floor slabs are characterised by long-span decks with the steel or concrete support frame span minimised to accommodate the large end reactions. A deck span of three parking bays is typical. A primary concrete beam can either be part of the precast system or *in situ* concrete. Cranked precast floor units can be effective in reducing secondary framing at ramps. With arrangements using long spans or split-level floors in combination with short columns, particular care is required to prevent local cracking on the column.

Care should be taken in design and detailing of ends of slabs and secondary beams bearing directly onto primary beams without bearing materials. A sagging secondary member may bear on the edge of the primary beam, risking spalling. Particular attention should be paid to the requirements of BS 8110-1 Clause 5.2[5.23].

5.4.4 Foundations

The design of foundations should follow normal practice[5.24, 5.25]. Guidance on this may be obtained from *Allowable settlements of buildings*[5.26] and *Soil-structure interaction: the real behaviour of structures*[5.27]. Care must be taken when considering articulation of any potentially stiff continuous members to avoid cracking of concrete or unacceptable structural distortion in steel. It should be borne in mind that loadbearing ground-floor columns and walls may not be restrained by the ground-floor structure and may be subject to vehicle impact from without and within. Foundations must be designed to have sufficient lateral resistance to these loads.

The lighter weight of a steel-framed structure compared with a concrete frame can have a significant effect on foundation costs in certain soil conditions[5.28, 5.29]. The reduced weight coupled with the structural flexibility provided by this form of construction can permit column loads to be carried by pad foundations. A heavier rigid building on the same site may require some form of ground improvement at pad locations or a different foundation solution such as piles or a rigid raft.

5.4.5 Ground floors

5.4.5.1 Introduction

Several options are available for ground-floor construction. The choice of a particular type will depend on ground-bearing capacity, relative levels and client preference. The different types are summarised in the sub-sections below.

5.4.5.2 Asphalt

A flexible asphalt construction will usually be economic where low ground-water level and reasonable ground-bearing capacity exist and where the client has no objection to a dark coloured finish. In general, asphalt finishes must be laid after completion of the superstructure; limited headroom may preclude mechanised laying techniques.

5.4.5.3 Brick or concrete paving

Brick or concrete paving offer an alternative to asphalt. Hand-laying methods suit the restricted headroom well, and a light coloured surface is easy to achieve. Line painting and its maintenance may be reduced by incorporating contrasting paviors.

5.4.5.4 Concrete

An *in situ* concrete slab either ground-bearing or suspended is suitable for slabs where ground conditions are poor or where water levels are high. *In situ* concrete also offers good durability and the light coloured finish is often favoured by clients. *In situ* concrete is also suitable for basements and semi-basements and where high ground water levels are possible. In these circumstances, issues such as flotation, waterproofing, joints and service penetrations should be carefully considered (see Section 5.5).

5.4.6 Lateral stability

All the common ways of providing lateral stability by use of lift or service shafts, shear walls, cross bracing or moment frames can be employed in car park structures. Positioning of the lateral stability systems must take into account maintaining circulation, sight lines and a light aspect as well as discontinuities at movement joints. The location of the lateral load-resisting system within the structure is particularly important to control stresses when high thermal loads are predicted.

5.5 Methods of construction and structural design of underground car parks

5.5.1 Introduction

The available site area, proximity of adjacent structures, flotation issues and methods of construction are the principal design constraints in generating the geometry and structure of underground car parks. See References 5.9, 5.13 and 5.20.

5.5.2 Categories of underground car park

There are two main categories of underground car park:

- Car parks below buildings where the shape of the car park is usually controlled in varying degrees by the shape of the building above; column positions are dictated by integrating the design of the car park with the building above and column sizes are likely to be large. The use of transfer structures, where the geometry of the grid is changed, is usually expensive and not adopted without good reason.
- Car parks below open spaces such as roads, squares, sports areas, public parks or similar public access areas. Their geometry is controlled by the method of construction access or by the geometry of circulation. The use of the area above the car park for landscaping, highway or public access infrastructure, will affect the loading, structural form and the waterproofing of the car park.

Figure 5.11 Alternative steel clear span frame arrangement

5.5.3 Methods of construction

The methods of construction are identical to those for constructing deep basements; selection of the method depends critically on soil and groundwater conditions. Where a basement is to be constructed up to the boundary of the site, the space required for the temporary and permanent works may be a prime consideration in the method selected. Sometimes, these methods are directed at avoiding temporary works by using the permanent structure of the finished building to provide temporary support as excavation proceeds. Such methods are generally only used when traditional temporary support methods are precluded by cost or space considerations.

The following methods minimise temporary works and are often used for top-down construction:

- diaphragm walls
- contiguous pile walls
- sheet pile walls.

Figure 5.12 Cantilever frame arrangement

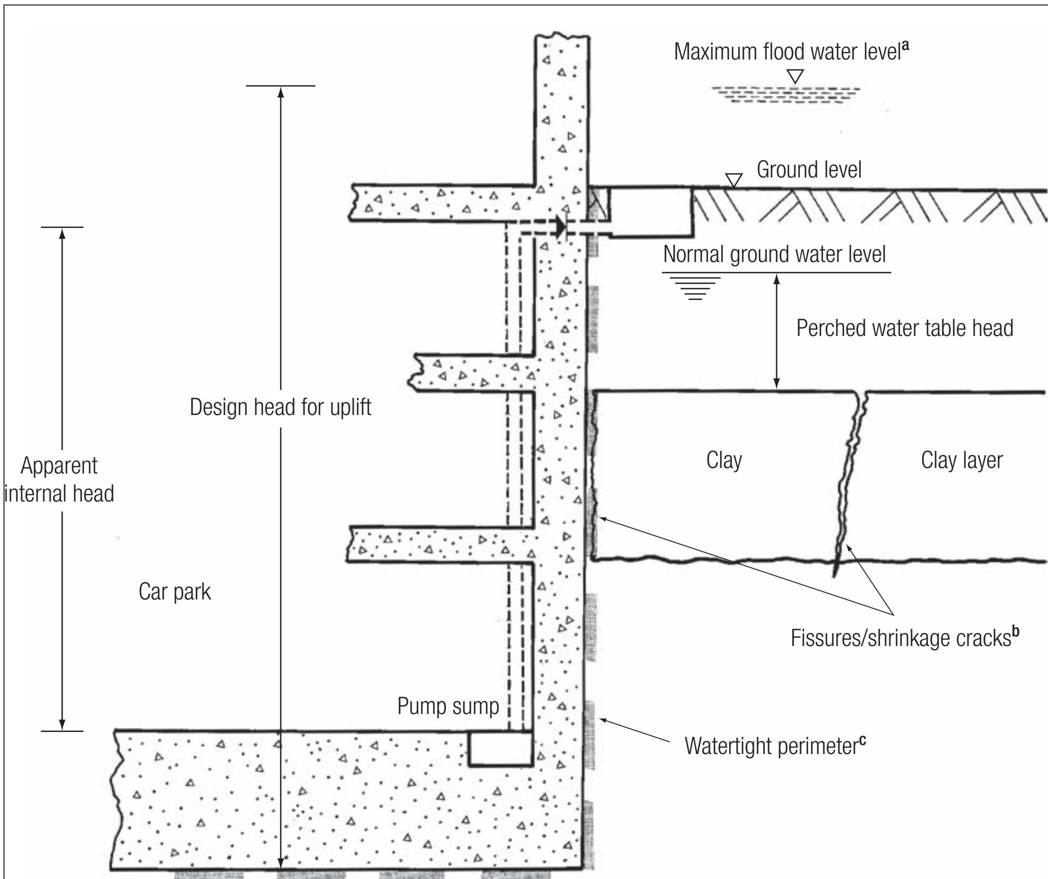
Where space permits and the geotechnical conditions are appropriate, open cut excavations can provide an economical solution.

5.5.4 Control of ground water

As car parks are lighter than other building structures, specific consideration must be given to the method of controlling and managing water ingress and the potential development of uplift pressures. Loads arising from even modest depths of water will give rise to significant effects, particularly in the temporary construction state before full minimum dead loads are in place and may give rise to instability if not properly addressed. An uplift pressure of $10kN/m^2$ per metre of unbalanced water depth that can arise above the base level must be considered in both the permanent and temporary load cases. In clay soils, the potential for a link through drainage to remote flood conditions, through fissures to artesian pressures and the possibility of perched water tables must all be considered since they can lead to enhanced uplift pressures.

Using pumped systems or pressure-relief valves to limit uplift pressures often appears to provide initial economy, but will require a constant operational and maintenance commitment throughout the life of the structure to ensure significant uplift pressures cannot be generated. The operational cost, risk and consequences of failure of such systems must be balanced against the initial costs of passive measures through the use of thicker base slabs or tension piles in conjunction with watertight boundaries to overcome potential buoyancy. Acceptance of the consequences of the risks of pumping and other alternatives, such as provision of pressure-relief valves to allow controlled flooding of lower levels and balancing of water levels in extreme circumstances, may be considered acceptable for some car parks but must be agreed in advance with the client and relevant authorities.

Even with watertight boundaries, it is recommended that underground car park levels be equipped with positive drainage systems linked to sumps and pumps to allow surface run-off and wash-down water to be removed. Great care must be taken in detailing service provisions to ensure the watertight perimeter is not compromised by service connections and ducts that could lead to water ingress (see Figure 5.13).
It is particularly important to agree the acceptance criteria and required environment for basement and underground car parks with the client, e.g. the level of humidity or condensation that will be acceptable. This agreement is essential before the design of structural and ventilation works takes place and can be an area of significant misunderstandings if issues are not clearly addressed and agreed.



Notes

a The alignment for approach ramps and flood protection measures may mean flood water levels can exceed adjacent ground levels without flooding the car park entrance ramps.

b The presence of even small fissures in the clay or less pervious soil will allow the full pressure head to develop, even if flow rates are low.

c Care is required to ensure service routes do not compromise integrity of perimeter.

Figure 5.13 Hydraulic linkage and design head considerations

5.6 Temporary and demountable car parks

5.6.1 General

Temporary and demountable car parks are generally modular structures and comprise a series of components which can be dismantled and re-erected on more than one occasion[5.30]. Car stackers, rising platforms and mechanical systems are excluded from this document.

Temporary car parks often comprise single-storey structures which are designed to provide additional parking over an existing surface car park. Generally these are founded on spreader plates with no connection to the existing surfacing and levelling jacks are built into the columns to correct any movement at foundation level.

However, temporary and demountable car parks are not limited to a single-storey and foundations may or may not be provided, depending on the ability of the existing surface to support the structure without excessive settlement.

5.6.2 Performance criteria

Although the design life of temporary car parks is often less than permanent car parks to make them economically viable, the design life of some demountable structures can be equivalent to permanent car parks. Whatever the design life, both types of structure should be designed to the same loadings and conditions as permanent car parks, including edge protection and measures to prevent progressive collapse from accidental impact.

Skeletal cladding is a popular choice for this type of structure and consideration should be given to the additional loading from icing during the winter, especially in areas subject to driving rain and snow.

The structural design and choice of materials and finishes should be suitable for the purpose intended. Sharp edges, trip hazards and poorly located bracings which impose a risk to personal injury must be avoided.

Permanent drainage systems are not necessary for temporary structures provided that the decks are laid to falls to prevent ponding and the surface water is properly managed. All decks and joints between the components should be properly sealed to prevent uncontrolled leakage to the floor below.

Fire protection and means of escape provisions should be identical to those for permanent structures.

5.6.3 Inspection and maintenance

Temporary and demountable structures must be inspected and checked at regular intervals by a competent person to ensure that all bolts are in place and tightened to the correct torque. Levels and vertical measurements should be taken at column positions to check that the structure is performing within the designer's settlement criteria, and any necessary adjustments should be made to prevent over-stressing the structural members and connections.

5.7 Designing for movement

5.7.1 General

Structural elements of car parks are susceptible to movement both during and after construction. Some of the principal reasons are:
- elastic structural deflections
- temperature changes during construction and in service
- shrinkage
- creep
- differential settlements.

With careful design, appropriate joints can be provided to accommodate such movement and to suit the structural design. Car parks can suffer from premature deterioration if the sealants break down, e.g. under traffic loading, allowing water and salts to get into the joints (see Chapter 8).

Allowance should be made for the fact that the exposed nature of car park structures produces a greater design temperature range than in other building structures. Joints must also take account of the potential for differential movements between the relatively flexible car park deck and the stiff zones created by ramps and access shafts. Typical mastic joint fillers can accommodate around 20% strain, so a mastic-filled joint would typically need to be five times as wide as the predicted movement. Elastomeric joint fillers are generally regarded as more effective for joints with large predicted movements. Their additional cost must be balanced against potentially expensive remedial work in the event of joint sealant failure.

Concrete Society Reports TR 22[5.31], TR 44[5.32], and TR67[5.33] provide valuable guidance on various causes of cracking, which can lead to premature deterioration of structural elements. Structural design should also be aimed at controlling such cracking, including those resulting from differential strains due, for example, to restrained movements at the interface between pours or between precast and *in situ* concrete.

5.7.2 Deflection

The prediction of long-term service deflections is of great value to confirm that falls are and will remain sufficient to prevent the ponding of water on surfaces or in concrete drainage channels.

In normal circumstances, falls of 1:60 are considered adequate to accommodate construction tolerances, pre-camber and the effects of deflection under short and long-term load. For less usual conditions, such as long-span beams or transfer structures, detailed calculations of deflection should be undertaken to ascertain that the slab drainage strategy is not compromised.

5.7.3 Temperature

Multi-storey car parks are different from other buildings, in that they have a structural frame that is usually fully exposed to the external air. This means that the effects of temperature-induced movement[5.34] must be specifically considered and catered for. These structures can be considered as intermediate between bridges (where temperature loads are well codified and established) and normal building frames where the structural frame is normally within a controlled environment.

Temperature movements are restrained by the lateral stability systems. Careful consideration should be given to the location and interaction of such systems to avoid large forces being generated by restrained thermal movement. In concrete structures, these can lead to load reversal, causing cracking of elements not designed to resist the stresses induced. Constrained expansion often occurs inadvertently between the deck and ramps or stair structures. If the adverse interaction between lateral restraint systems cannot be avoided, then either the system should be isolated from the slab, or a movement joint should be introduced to separate the systems. Care must be taken to provide for any lateral load transfer function to be maintained.

Temperature differential through top decks will cause thermal bowing in summer. This requires consideration when deck joints are being configured. See Appendix A *Designing for temperature effects.*

5.7.4 Shrinkage

Shrinkage in concrete must be accounted for in the design of the deck, for example as given in BS EN 1992-1-1[5.35] or BS 8110-2[5.36]. The characteristics of shrink and creep vary in different countries and climates. For example, tropical or equatorial zones with high temperature and humidity, such as Hong Kong, will differ significantly from the basis stated in the Eurocode or BS 8110.

In general, precast concrete deck and frame elements will have largely completed their shrinkage cycles by the time they are incorporated into the structure. However, shrinkage must be considered in the configuration and sequencing of *in situ* concrete frames and decks, or any system with a continuous *in situ* concrete topping. Post-tensioning, if used, will cause elastic shortening, the effect of which must be taken into account.

Frame shrinkage must be considered and accommodated by joints in brittle facing materials such as brickwork. Joints in façades are normally required at much closer centres than those in the principal structure. For example, brickwork may require joints at 9m–12m centres and horizontal supports may also be required to restrain brickwork panels.

5.7.5 Creep

Creep can have a significant effect on the deflection of reinforced or prestressed concrete units over time. Methods for calculating its effects are well documented in BS EN 1992-1-1[5.35] and in BS 8110[5.36]. Creep can be more significant for concrete car park construction than other structures for the following reasons:

– There is usually pressure to minimise column frequency to improve vehicle circulation. This often leads to long span prestressed floor designs[5.37].
– The ratio of dead load to total load tends to be higher in car parks than in other structures. A typical concrete car park when completed (but empty) can be 75% of its gross characteristic design weight. This compares with approximately 50% for typical office structures. A high proportion of the design imposed load is also achieved in service.

Creep significantly modifies the effective elastic modulus of concrete beam members over time. This can mean that members whose deflection performance is adequate shortly after construction can be inadequate after perhaps 10–20 years. Deflection of concrete beams can increase by approximately 25–50% which can adversely affect drainage provisions.

It is essential that adequate consideration be given to the creep effects and their effect on the drainage strategy at the design stage. It is usual to locate gully outlets and downpipes at column positions. Creep and consequential long-term deflection of concrete beam members can lead to ponding at beam mid-span or cantilever tip locations.

5.7.6 Movement joints

Adequate allowance must be made for car park structures to respond to temperature-induced volumetric change and for shrinkage of reinforced or prestressed concrete structures (see Figure 5.14). See also Sections 5.7.3 and 5.7.4. *TR67 Movement, restraint and cracking in concrete structures*[5.33] gives relevant guidance on this issue.

Installation of movement joints must also take account of the season of construction. Ideally, joint widths should be adjusted during construction to suit the temperature conditions prevailing at the time of installation and seek to minimise the range of post-construction movement. As with all joints, provision should be made for easy replacement of components with a design service life less than that of the main structure (see also Chapter 8). BS 6093[5.38] gives guidance on the design of joints in building structures.

5.8 Edge protection

5.8.1 General

The edge protection for car parks must fulfil two primary safety functions:
– vehicle crash/restraint barrier
– pedestrian/child safety barrier.

The dimensions of barriers must comply with national standards such as BS EN 1991-1-7[5.12] or BS 6180-1[5.39], including the relevant National Annex to Eurocodes, governmental, or other relevant requirements. In its capacity as a vehicle crash barrier, the edge protection must keep an errant vehicle within the structure. Car parks are usually constructed in city centres with extensive pedestrian access around the outside of the structure. The requirements for containing the errant vehicle include the constraint that any impact does not dislodge the cladding onto pedestrians.

For structural design, it is essential to limit the energy imparted by an errant vehicle to a barrier or column and accept such an incident as a local accident. The design should be aimed at avoiding any large-scale damage and disproportionate collapse of the structure. (See the loading and appropriate material Eurocodes, e.g. BS EN 1991[5.6] and BS EN 1992[5.35] or BS EN 1993[5.40] and *Approved Document A*[5.1–5.3].)

The cost of edge protection represents a significant component in the cost of a car park and warrants careful consideration. Proprietary car park systems may rely for their economy on the interaction of barriers with the frame.

5.8.2 Designing edge protection

There are three principal types of crash barrier: those that span between primary structural members (commonly horizontally between the columns, see Figure 5.15); those that cantilever up from the car park deck (see Figure 5.16); and those that are monolithic with the deck (see Figure 5.17).

The first type consists mostly of hot-rolled steel sections that absorb the vehicle energy by yield mechanisms. Recently, wire systems have also been proposed. Fibre composite systems that absorb energy by fracture mechanisms are also potentially suitable.

The second type consists of cold-formed section rails supported on either cold-formed posts or hot-rolled steel posts. The most common rail is the standard section motorway barrier; trapezoidal-section and sigma-section open-box beams are also used. The posts can be subdivided into two further categories: stiff, fully welded construction of the post with its base; and flexible posts incorporating sprung steel construction or an energy-absorbing buffer between the post and its base.

The third type is of monolithic concrete construction with continuity reinforcement between the wall and floor deck. Most of the load is carried by cantilever action, though in some cases the barrier acts as a three-sided supported slab. The relative rigidity and greater mass of such a barrier means that it benefits from the momentum at impact being distributed throughout much of the structure and on energy being absorbed by elastic strain.

5.8.3 Expected performance

Vehicle crash barriers are required to withstand a notional load representing vehicle impact. They should not deflect excessively, fail catastrophically or permit the vehicles to ride over the top. In the UK, barriers are designed to BS EN 1991-1-7[5.12] or BS 6399-1[5.13]. The basic impact load is derived by equating the kinetic energy of the characteristic mass (normally 15kN) at the limiting velocity (4.5m/s) to the potential energy absorbed by the mean resisting force generated by the deflecting barrier and 100mm of crumpling vehicle. The impact load must be spread over a 1.5m width and the standards specify this to be at 375mm height. There is a case for taking this load at the internationally agreed car manufacturer's common contact height of bumpers of 445mm[5.41].

It has been demonstrated that the high strain rate occurring in edge protection components makes pseudo-static testing non-conservative. Suitability of edge protection systems must therefore be demonstrated by characteristic vehicle dynamic tests at an internationally approved laboratory (e.g. TRL) or, conservatively, by the test specified in *Edge protection in multi-storey car parks: design specification and compliance testing*[5.41].

As a part of the inspection and maintenance, testing may be required to assess barrier effectiveness *in situ*; for example, if there is a reason to believe that a barrier may have inadequate strength owing to deterioration or after an incident involving excessive

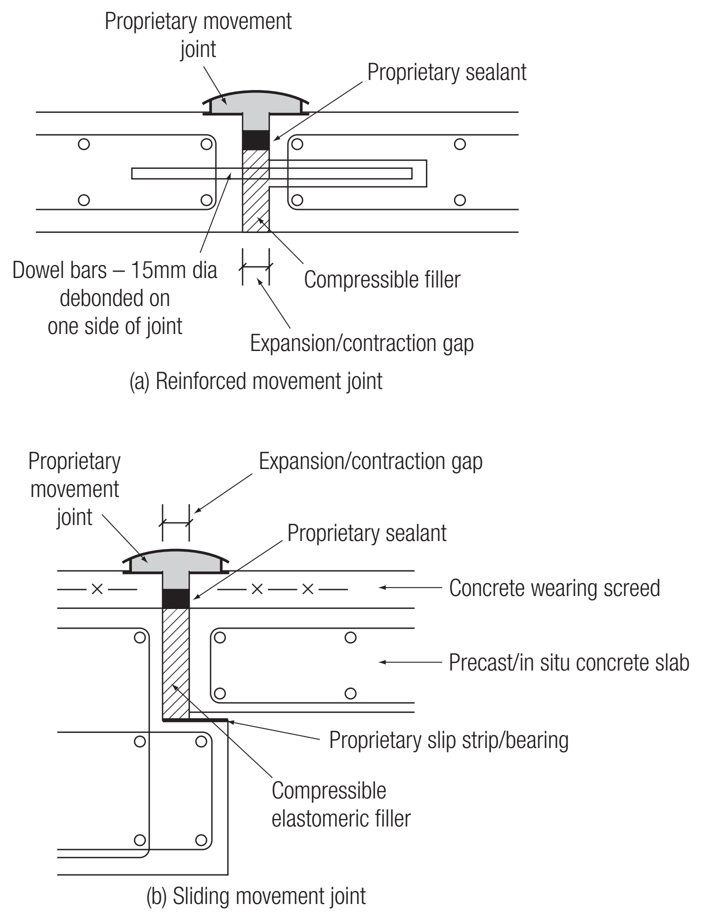


Figure 5.14 Typical examples of movement joints

Figure 5.15 Circular hollow section vehicle restraints spanning horizontally between columns

Figure 5.16 A restraint post cantilevered from the car deck (after impact on rail)

accidental impact. Testing may be particularly relevant to older car parks, which may not have been built to current design rules. Details of such tests are given in the document *Edge protection in multi-storey car park: assessment method for installed restraint systems*[5.42].

The barrier must not deflect by more than the clear distance between the original position and any cladding made from a brittle material. The total deflection of barriers spanning horizontally should not exceed 600mm. Where barriers provide pedestrian restraint, they must not deflect beyond the edge of the deck, except at split levels. Deformation of the barrier beyond repair (i.e. requiring replacement) is acceptable providing it does not lead to progressive collapse. It must be replaced if damaged.

Figure 5.17 A monolithic concrete upstand restraint (after impact)

5.8.4 Fixing protective barriers

Any fixing bolts on which the barrier support relies for attachment to the structure must not fail or pull out (see Figure 5.18). However, as long as the barrier beam is contained in a fail-safe configuration (such as between column flanges), locating bolts may beneficially be designed to fail to restrict damage to the primary structural members (e.g. columns).

Cantilevered barriers attached directly to the concrete deck should have fixings that are rigidly anchored into the concrete. Through-bolts with plate washers beneath, big enough to resist the predicted combination of tension and shear forces, are satisfactory.

Other types of proprietary anchor may be suitable, but their ability to remain anchored into the slab under successive load applications must be demonstrated. This is to prevent minor impacts reducing the fixing capacity without that reduction being apparent before a significant impact. Suitability of fixings is often confirmed by tests that repeat the predicted combination of loads four times before application of a failure load to determine the total safety factor.

Setting supporting posts on plinths will enhance durability. Holes drilled for fixings should be positioned to avoid reinforcement. For through-slab holes, diamond drilling causes less soffit breakout than percussion drilling. Sealing the bolt into its hole will help prevent water ingress and corrosion. Using stainless steel components is also advantageous.

5.8.5 Requirements of long access carriageways

When the vehicle approach length to a barrier exceeds 20m in a straight line (at the ends of the floors or at the ends of ramps), traffic-calming measures must be installed to restrict the vehicle to the specified velocity, or the barrier and its primary structure support should be designed to withstand an enhanced impact of at least double the force created by the standard requirement.

5.8.6 Barriers near ramps

Any barrier within 5m of an inclined ramp that could be impacted by a vehicle approaching on or leaving that ramp, must be designed to resist half the basic impact force at a height of 610mm.

5.8.7 Protective barriers

The basic barrier requirements together with the long access carriageway requirements and the ramp

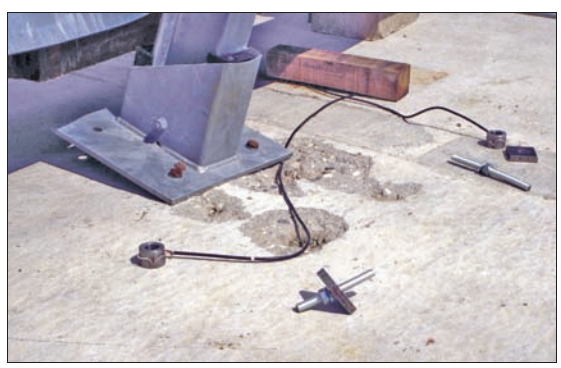


Figure 5.18 Failed restraint support – bolt failure (after impact)

requirements outlined above should also be applied to internal edges of the vehicle decks, such as at staircases, and at split-level deck edges.

Deflection criteria may be relaxed at the internal edges of split-level car parks, provided designated pedestrian routes do not pass immediately next to the lower deck edge beneath these barriers.

5.8.8 Pedestrian safety

The edge protection must restrain children from accidentally endangering themselves. The provision must therefore be similar to that of balustrades. However, the attraction of barriers and posts for climbing must be taken into account.

The edge protection must not permit the passing of a 100mm diameter ball and must exceed 1.1m above the top of a separate barrier beam or the top of the upstand of an integral barrier.

5.9 Resistance to explosions

Explosions within car parks may be caused by liquid or gaseous fuel, or from chemical explosives.

Because car parks have open plans and considerable venting to extract fumes, the effects of liquid fuel or gas explosions are unlikely to be critical to the overall structure, though they may make individual structural components ineffective. This is a condition that is covered in the normal building design codes[5.12, 5.13]. A designer's risk assessment should be considered if the car park is beneath occupied floors of the building or exceeds 6 storeys. Subsequent fire is more likely to be critical.

In the rare event that a car park must be designed to resist chemical explosions, appropriate loads are given in BS EN 1991-1-7[5.12].

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6 Building services

6.1 General

The design of building services is usually the remit of the mechanical and electrical design consultant. However, throughout the design process, efforts should be made to reduce the environmental impact of the building services systems within the car park.

The purpose of this section is to highlight those issues that interface with the structural design. Building services equipment will typically need to be renewed every 15–20 years, i.e. twice or three times during the life of a car park. It should therefore be designed and installed so that it can be removed and replaced without damaging or altering the structure, therefore a surface installation fixed directly to the structure should be considered. If it will not be possible to close the car park for an extended period to replace building services plant, the design should allow the car park to be closed section by section for replacing building services plant while the remainder remains operational.

6.2 Lighting

6.2.1 General

Although some car parks may benefit from being partially day lit, it will usually be necessary to provide lighting for continuous use, at least in some areas. It may be possible to make use of daylight for part of the year. The lighting controls and luminaires can be designed to allow advantage to be taken of available daylight, thus reducing operational costs.

Consideration should be given to control luminaires by the use of movement detectors with run on timers. This system would typically control half of the luminaires with others being constantly illuminated. Movement detectors would be typically ultrasonic. This system cannot be considered if discharge lighting is specified.

It is recommended that controlled luminaires are not fitted on ramps or in exit and entry areas.

Lighting should be sufficient to assist the safe movement of vehicles and pedestrians and enable staff to carry out their functions. It should also be of a standard that will help reduce vandalism and crime, i.e. luminaires with steel bodies, polycarbonate diffusers with non-standard screws should be considered. The quality of the lighting will have a strong effect on the attitudes of users and will affect both the degree of vandalism and the general care taken with the building (see Figure 6.1). Lighting has a central role in the Park Mark Safer Parking Scheme[6.1].

The nature of car park structures normally inhibits the scope of the lighting designer, but nevertheless an early association with the architect and structural engineer may produce, within a reasonable budget, a better-considered, visually attractive, easily maintained lighting scheme.

A particular challenge is created in car parks by the low headroom and structural form that make it difficult to provide the reasonably even lighting that would be expected in commercial buildings. Research in the UK on acceptable lighting quality for multi-storey car parks has led to a marked increase in recommended uniformity (minimum to average) to 0.40, against a previous recommendation of 0.04. In these situations discharge luminaires may be fixed directly to the underside of the ceiling slab, thus providing further efficiency savings. This should be balanced against the fact that lighting controls cannot be used with this lamp type.

Good lighting could have a major influence on the building's commercial success. Uniformity was considered the most important single factor in subjective assessments of lighting quality.

In addition, high-quality lighting can be a major factor in obtaining acceptance of a multi-storey car park near high-quality or historic buildings. At least one city (Lyon, France) has made high-quality lighting of car parks mandatory as part of a campaign to improve the night-time visual environment.

Colour can be of considerable use in identifying hazards. Unless light sources with poor colour rendering are used, drivers should be able to discriminate between primary colours. However it should be borne in mind that about 10% of males have some form of colour vision deficiency.

Colour rendering should also be considered in the selection of luminaires in relation to CCTV systems.

Colour recognition and the overall efficiency of lighting systems can be improved by painting walls, floors and ceilings of car parks.

Figure 6.1 New World Square car park, Cannons Marsh, Bristol – showing a well-lit interior

Many national lighting codes now require the designer to make assumptions during the design procedure on the maintenance regime to be followed. They are based on designing for a minimum maintained illuminance[6.2]. These assumptions are fed into the calculation procedure. To put it simply, if maintenance standards will be high, less allowance has to be made in the design for dirty luminaires and lamps beyond their design service life. It is therefore essential that the client agrees on the maintenance regime to be followed before design begins, since the decision has major commercial implications for the car park operator. This maintenance regime should be contained within the operation and maintenance manual.

A multi-storey car park can form a major part of the night-time scene in an area and care is needed both to make the structure aesthetically acceptable by means of appropriate lighting and to ensure that light pollution and obtrusive light are kept to a minimum. Avoiding lighting pollution is particularly difficult on open top decks. Environmental zones have been defined from city-centre locations to national parks and similar, with recommended maximum luminances for each[6.3].

6.2.2 Vehicular areas

6.2.2.1 Access ramps and routes and parking bays

The appropriate design criteria are usually laid down in road lighting standards such as BS EN 13201[6.4] and the standard BS EN 12461-1[6.5]. Typical design illuminances are given in Table 6.1.

A uniformity of 0.4 (minimum to average) should be achieved over most of the area at floor level. One cost-effective approach may be to position luminaires directly over the access routes, since this also helps provide directional guidance for motorists. However, this can cause problems if not supplemented by appropriate extra luminaires, since parked vehicles will cause heavy shadows around the perimeter of the building, providing areas where criminals and vandals can hide and making it difficult to see pedestrians leaving or arriving at their vehicles.

There is a need for particular care in lighting areas where pedestrian and vehicular routes intersect. Vehicle headlights may cause glare for pedestrians and it is therefore essential that the lighting is sufficient to enable them to move safely and be seen by drivers.

Table 6.1 Recommended luminance for multi-storey and underground car parks

Area	E_{ave} (lux)	E_{min} (lux)
Parking bays, access lanes	75	50
Ramps, corners, intersections	300	120
Entrance/exit zones (vehicular)	night: 75	See text
	day: 300	
Pedestrian area, stairs, lifts	100	50
Disabled parking	300	n/a
Roof level parking in Rural Zones E1 and E2	15	6
Roof level parking in Urban Zones E3 and E4	30	12

Note
Uniformity E (min) to E (ave) greater than 0.4 as in BS EN 13201[6.4].

In addition to providing light on the road surface, care should be taken to ensure that vertical surfaces such as columns are well lit, especially at corners, bends, junctions and the building perimeter. Additional lighting should be provided at pedestrian entrance and exit areas.

UK lighting recommendations are based on UK practice in car park design. In some countries, car park ramps are steeper and curves are tighter. In such cases, the illuminance requirements may need to be increased to allow for the more difficult driving task.

6.2.2.2 Entrances and exits

By day, exterior illuminances can reach 50,000lux and can vary widely. Illuminances in entrances and exits by day should therefore be sufficient to minimise the adaptation required of drivers. It may be appropriate to provide for illuminances of up to 1,000lux. However, at night the interior of the car park may be at a higher illuminance than the street outside. Appropriate controls will therefore be required to adjust the lighting to suit the external conditions. If space is available, daylight louvres over the entrances/exits of the car park can be used to reduce the illuminance contrast. Consideration should be given to providing luminaires by entrances and exits of the same colour group as external lighting, thus reducing colour contrast.

Appropriate positioning of payment barriers/desks can control vehicle speed at the car park entrance or exit and minimise problems of adaptation for drivers. However, it should be borne in mind that a driver entering a car park on a sunny day will need time to adapt to interior lighting before carrying out transactions with staff or operating ticket-issuing equipment.

6.2.2.3 Toll booths, barriers and obstructions

Care is needed to ensure that obstructions in the vehicle route are adequately lit for safe driving.

At toll kiosks and ticket-issuing machines, suitable lighting will be required to enable drivers to read instructions, handle cash and tickets, etc. Modern equipment may incorporate internally lit displays and/or Visual Display Terminal (VDT) screens and care will be needed to provide sufficient light for drivers to handle money while avoiding reflections in displays. It may also be necessary to comply with the requirements of the Health and Safety (Display Screen Equipment) Regulations 1992[6.6] or equivalent legislation in other European countries implementing the Display Screen Equipment Directive.

Barriers such as those for traffic calming, e.g. speed humps and rising barriers, should be adequately lit for safe driving. Formal standards[6.7] for road lighting of such areas are being developed in some countries.

Any other obstructions in the roadway should be specifically lit to ensure that they are not a hazard to drivers. The direction of lighting should ensure a distinct difference in luminance between the obstacle and its background.

6.2.2.4 Open top floors

When providing lighting for open top floors of multi-storey car parks, care should be taken not to provide excessive spill light and light pollution. Although it may appear attractive to mount luminaires at low level, it is difficult to meet uniformity requirements and much light will inevitably be projected upwards, while vehicles will cause problems with shadowing. If column-mounted luminaires are used, types should be chosen with no upward light output. Generally, hinged columns should be considered for ease of maintenance.

Care should also be taken that light from this area does not cause nuisance to occupiers of adjacent buildings, particularly in residential areas. Luminaires with good cut off angles should be specified.

6.2.3 Pedestrian areas

Design should follow the recommendations of the relevant national standards. In Europe, the road lighting code of practice includes relevant information[6.8]. Recommendations may also be included in national interior lighting codes[6.2]. Any pedestrian areas that will be regularly used by staff should be considered as part of the workplace and lit appropriately (see Section 6.2.4).

Particular requirements will apply to staircases, especially where they form part of designated emergency exit routes.

6.2.4 Staff areas

All areas continuously occupied by staff should be lit to a minimum of 200lux[6.9]. Staff may make use of VDT equipment as part of ticket-issuing or closed-circuit television monitoring. Such spaces should be provided with lighting that complies with the EC Display Screen Equipment Directive or national legislation[6.6]. Guidance[6.10, 6.11] is available on complying with the requirements of such legislation. Interior lighting should be carried out in line with CIBSE *Code for lighting*[6.2].

6.2.5 Emergency lighting

In many countries, it will be mandatory to provide emergency lighting on public pedestrian routes and exit routes used by staff. In Europe, the requirements of EN 1838[6.12] should be followed. However, this has numerous national deviations and is therefore being implemented in most countries as a new edition of the national standard[6.13, 6.14].

Emergency lighting should be in the form of illuminated emergency legend panels and various emergency luminaires. System types vary from central battery to self-contained systems. Consideration on system selection should be given to ongoing system servicing and maintenance balanced against the effect of carrying out this maintenance within the car park.

6.2.6 Lighting controls

Even if a car park is designed for continuous operation and requires permanent artificial lighting, it will still be necessary to provide lighting controls to enable maintenance to be carried out on specific areas. Also, many countries have legislative requirements[6.15, 6.16] for low energy luminaires and lighting controls to minimise energy use.

To minimise the cost of running lighting it may, if a significant amount of daylight enters the building, be worth considering daylight-linked control by means of photocells. Publications[6.17] are available to assist in assessing the amount of available daylight and suitable control regimes.

If the car park is to be used only during specific hours, time-switch control should be considered.

Consideration should be given to the use of movement sensors. These sensors would be confined to bay areas switching typically half the luminaires off during unoccupied periods. The use of movement sensors would be complemented by the use of high frequency fluorescent luminaires benefiting from an instant strike and no run up time.

The selection of control devices should be carefully considered to prevent false actuation by external weather conditions.

6.2.7 Equipment considerations

Car parks are aggressive environments and all electrical equipment should be chosen carefully to ensure it is suitable. Matters that may need consideration are: vandalism, weather resistance, resistance to de-icing salt used on roads, resistance to petroleum compounds (in addition to any electrical safety aspect, see Section 6.5.1) and minimal maintenance.

Recent developments in light sources make it possible to combine high efficiency with good colour rendering. Sources such as metal halide (a high-pressure discharge lamp) now have acceptable lives and good colour rendering combined with colour stability, while being compact and efficient.

Luminaires providing better space/height ratios are more suited to car parks designed without downstand beams. Where downstand beams are employed more luminaires will be required to meet lighting uniformity requirements.

6.2.8 Multi-purpose spaces

Increasingly, suggestions are being made that ground floors of car parks can be used for activities such as occasional markets. However, normal car park lighting will not normally be suitable for such situations. If it is known at the design stage that there will be such a requirement, a supplementary lighting installation complying with the relevant provisions of the national code of practice, e.g. the CIBSE *Code for lighting*[6.2], should be installed. This should have a separate control system.

6.2.9 Signs

6.2.9.1 General

Positions of signage should be considered at the early design stage so that cable routes for lighting can be incorporated (see Section 6.7). Internal signs should be positioned for maximum visibility; often the sides of structural beams will provide suitable positions. Sign colours need to be chosen after the light sources have been chosen to ensure that colours can be distinguished. Note particularly that high-pressure sodium lamps give little colour discrimination.

Signs can be internally or externally illuminated. Internally illuminated signs need to be positioned where they will not be accessible to vandals.

Polycarbonate signs will only provide limited vandal resistance and most signs are made from brittle plastics.

External signs should comply with the recommendations[6.18] published by the Institution of Lighting Engineers on maximum surface brightness.

6.2.9.2 Non-illuminated signs
The internal lighting system should be designed to take into account the locations of all non-illuminated signs. The locations of these signs should be agreed at the lighting design stage. The lighting system should be designed to allow the artificial lighting system to illuminate these signs. Consideration should be given to mounting height and associated issues with glare.

6.2.9.3 Illuminated signage
This generally comprises of illuminated box emergency signage luminaires. In the UK, these luminaires are to be designed and installed to the British Standard for emergency lighting[6.12].

Other illuminated signs will comprise of general information and are more commonplace where the car park forms part of a general building or multi-site facility. In these situations signs are to be sited in such locations that they inform but do not distract drivers. Further details relating to signage are outlined in Chapter 3.

6.3 Heating

6.3.1 General

The principal heating issue in car parks is associated with the melting of ice and snow particularly for exposed car park ramps and decks during prolonged cold spells. This can be achieved either by using heat to keep the surface temperature above freezing point or by reducing the freezing point by the use of chemicals. However, designing the car park so that there are no places where water can accumulate on roadway surfaces can eliminate a great deal of the problem.

6.3.2 Ramp heating

Exposed car park ramps and decks can suffer from ice and snow during extremely cold conditions or prolonged periods of bad weather. In the past, ramp heating has been recommended as a means of dealing with ice and snow. However, experience has shown that it is not particularly effective and should be considered only when other measures such as de-icing chemicals are not suitable. Installation and running costs can be high and, since the heating elements have to be buried in the ramp, any failure will require closure of the car park for maintenance access. If regular icing is expected, it is better to design ramps so that they are not open to the elements.

6.3.3 Open top floors

It is not feasible to provide heating to prevent snow accumulating on open top floors. However, suitably designed falls should permit melted snow to escape and prevent ice forming.

6.3.4 Special provisions for cold climates

In cold countries, it may be necessary to provide heating to protect parked vehicles from damage. A common solution is to use unit heaters, in which case the motors and starting equipment should meet the requirements laid down in Section 6.5.1.

6.3.5 Staff areas

Staff areas that are continuously occupied should be treated as normal interior spaces and the appropriate guidelines on suitable environmental conditions should be followed. It should be remembered that staff may occupy spaces such as ticket booths for extended periods carrying out largely sedentary tasks and the environmental criteria should be chosen accordingly[6.19].

6.4 Ventilation

6.4.1 General

Ventilation has to be provided in car parks to avoid the risk of fire and explosion from petrol fumes and to prevent injury to health from the gases in vehicle exhausts. The most important of these is carbon monoxide. Since it is almost impossible to extract it locally, the usual approach is to use dilution ventilation.

The physical design of the car park can have a significant influence on ventilation requirements. Entrance and exit tunnels should be as short as possible so that vehicle movement will create adequate ventilation. Their relationship to ticket machines and pay booths should be such that vehicles do not queue in confined spaces. Where possible, pay booths should be in the open, as this will avoid the need for specific ventilation.

Air intakes should be positioned where they will draw in fresh air. The only suitable position may be at roof level. Guidance[6.20] on minimising air pollution at air intakes for office and similar buildings is equally applicable to car parks. If it is not possible to ensure fresh air, this must be taken into account when calculating air change rates.

Internal working spaces should be fitted with suitable carbon monoxide sensor/alarm units.

The ventilation systems should also be designed to take into account any gases released in the charging of electric vehicles. The charging of electric vehicles should be confined to specific areas.

6.4.2 Carbon monoxide levels

The rate of emission of carbon monoxide by car engines is changing as energy efficiencies increase and 'clean' engines become more common. However, the figures in Table 6.2 have been used

Table 6.2 Carbon monoxide emissions

Type of vehicle	Carbon monoxide emitted	
5-passenger	1.47m^3/h	0.41 litres/s
7-passenger	2.52m^3/h	0.70 litres/s

Table 6.3 **Maximum carbon monoxide levels**

Position	Traffic flow	Maximum carbon monoxide level
General car park area	Normal	30 parts in 1 million over 8 hours
	Peak	90 parts in 1 million over 15 minutes
Entrance and exit tunnels	Transient occupation only	90 parts in 1 million over 15 minutes

successfully for some years for designing ventilation schemes for car parks and may be used unless more accurate statistics are available from vehicle manufacturers or other sources.

The ventilation rate should be arranged so that the carbon monoxide level in the car park does not rise above the levels in Table 6.3.

It is recommended that the rate of air supply be calculated twice, once using the expected average traffic flow rate and a concentration of 30 parts in 1 million of carbon monoxide over an eight hour period and the second using peak traffic flow rate and a concentration of 90 parts in 1 million of carbon monoxide over a 15 minute period; the higher of the two results should then be used for design.

6.4.3 Natural ventilation

Where car parks are above ground, every effort should be made to take advantage of natural ventilation. However, this will very much depend on the wind speed and direction. Permanent ventilation openings to the external air in the two opposing longer sides can, in favourable conditions, provide sufficient cross-flow ventilation. Where cross flow ventilation requires assistance, impulse fans can be used.

At each level, openings should have an aggregate area of at least 2.5% of the area of the parking space at that level and be so distributed as to provide effective cross ventilation. This approach may be accepted by building control bodies as meeting the legislative requirements.

6.4.4 Mechanical ventilation

For all underground car parks and for those above ground where adequate natural ventilation cannot be provided, mechanical ventilation should be designed so that there is redundancy to allow for maintenance, e.g. three air-handling units where two can cope with the peak demand. Controls must be such that each air-handling plant can be controlled separately and isolated electrically and mechanically during maintenance or repair. A secondary source of electrical supply should be provided fed from a separate supply point. If continuous operation of the car park in adverse conditions is a requirement, standby generation should be provided adequate to provide power to the ventilation equipment at normal loading.

Air handling plant and ductwork is a traditional means of ventilating basement car parks and areas where there is insufficient natural ventilation. However, the installation and running costs can be high as it is necessary to extract air at both high and low level, due to the varying densities of gases that can build up within the car park. The system therefore requires large quantities of ductwork to ensure that the whole car park is covered and it tends to run continuously even though the need for ventilation at any one time may be within a localised area.

The more modern alternative is to use impulse (or jet) fans which rely on moving air to points of extract. These systems require no ductwork and are controlled by sensors to operate based upon the air conditions local to them. They can also control smoke, especially if programmed to work in conjunction with detectors. Make-up air is generally brought in through openings for ramps and extraction is via fans which are strategically placed in relation to fire escapes, allowing persons to escape in a safe, smoke free environment. When impulse fans are used for smoke control purposes, designers should consult the appropriate British Standard[6.21]. This details the calculation method for smoke and heat control systems for covered car parks.

If there are toilets in the car park without direct access for fresh air, they will require a supply-and-extract system on the same lines as for any other internal lavatories. Auto-changeover of fans should be considered.

6.4.5 Noise control

Air-handling plant can be noisy even when well designed. Care should be taken that it does not cause a nuisance to neighbours. A noise survey may be necessary, from which an acceptable maximum noise level can be estimated. Specific planning conditions should be considered at design stage.

Noise of motor vehicles, especially starting, stopping and on ramps, should also be estimated and any necessary abatement measures taken to prevent it escaping through entrances, exits and other significant openings.

Care should also be taken that noise within the car park is not excessive; hard, reflective surfaces and low ceilings mean that noise generated by vehicle engines may result in levels that can distract drivers.

6.5 Electrical services

6.5.1 Environment

The electrical installation for any areas accessible to the public should be designed to resist weather, fumes and vandals[6.22, 6.23, 6.24]. This will dictate the choice of corrosion-resistant materials designed to thwart the efforts of vandals. Normal national codes of practice (e.g. the IEE Wiring Regulations in the UK[6.25]) normally provide suitable guidance.

Consideration should be given to providing a galvanised trunking and conduit containment system. This system should be installed surface fixed directly to the building structure, using vandal-proof fixings. Careful planning of containment routes should be considered at the design stage allowing penetrations of beams and floor slabs to be co-ordinated. Twin compartment trunking systems should be specified to provide containment for band one and band two circuitry.

For areas used only by staff, it may be preferable on aesthetic grounds to use equipment designed for use in normal buildings. However, care should still be taken that suitable equipment is used in any areas where flammable gases may be present[6.22, 6.23].

6.5.2 Design

If continuous operation of the car park is required, the electrical distribution system should be designed with multi-phase distribution at all stages from the H.V. transformer through switchgear, so that operation can continue if any phase fails. If standby generation is incorporated, the switchgear should be designed so that generators can be operated individually and in parallel with any part of the main installation. It may be appropriate to size supplies to ventilation plant with spare capacity in case the capacity of the plant needs to be increased during the life of the car park.

Distribution boards should ideally be located outside vehicle/public areas. If a distribution board is located in exposed areas it should be enclosed within a suitable vandal-resistant enclosure. Distribution boards should be comprised of MCB protective devices.

Residual current devices (RCDs) should protect all socket outlets except those in 'office' type areas. Tripping current should not exceed 30mA.

6.5.3 Electrical charging points

It may be considered appropriate to provide charging points for electric vehicles, particularly if the local authority is actively encouraging their use. However, there are at present no general standards for connections between vehicles and shore socket outlets. Vehicle manufacturers should be consulted as to the appropriate facilities to be provided, their positioning relative to parking bays and any special requirements for venting gases.

Charger units should generally be comprised of free standing bollard units complete with integral meters and industrial plug and socket[6.26] connections (see Figure 6.2). Charger units should be RCD protected and separately metered.

6.6 Lifts and escalators

Designing lift and escalator installations is a specialised skill, since engineering, traffic flow and aesthetics need to be taken into account[6.27].

Technically, the quality of service is normally defined by the waiting interval (the average time before a lift is available to a potential user) and the 5-minute ratio (the proportion of the total population that the lift system can carry in a 5-minute interval). The first of these criteria is directly valid for car park lifts, but the second is normally the worst case, based on the requirements for personnel arriving at, say, an office block at the start of work, and is not therefore directly applicable. However, there can be an anomaly, which is dealt with below.

Often, the population using the lifts in 5 minutes is calculated from the maximum rate at which cars can enter the car park and the average occupancy of each car, both factors being determined as part of the traffic study associated with car park design. However, when the car park is associated with a single building or a building complex such as a

Figure 6.2 Free standing charging point for electric vehicles

shopping precinct, the exodus to the car park at the end of work will constitute the worst case and be akin to the conventional 5-minute ratio. This needs to be taken into account in selecting the appropriate type and size of lift. These lift traffic flow calculations should be carried out at an early stage of the design in order to finalise the lift strategy and its effect on the car park layout.

Lift groups should be based on a waiting time of 40–60 seconds and a population movement relevant to the particular car park requirements defined above. Because the total car park height is kept to a minimum, there is normally little opportunity for lifts to make long flights between stops and so they tend to be selected on the basis of fairly low speeds.

Most lifts require motor rooms. Often, these are above the lift, but some hydraulic lifts have the motor room underneath the lift shaft or to one side. However, hydraulic lifts can be temperature sensitive and therefore they are not always suitable for the external environment of a car park. There are specific requirements[6.28] on dimensions of motor rooms and clearance inside the room to allow for maintenance access.

If a fire-fighting lift is required then a secondary power supply will be required. This can take the form of a second low voltage supply emanating from another sub-station transformer or a stand-by generator. If the car park forms part of a large complex, for example an airport, then a secondary transformer supply will no doubt prove more economical. However, for most stand-alone car parks a stand-by generator will be the only option.

Multi-storey car parks will normally be required to satisfy legislation for disabled access and to meet the reasonable requirements of users, e.g. those carrying shopping, children, etc. However, such lifts will normally be unmanned. If possible, the car park should be designed so that lifts can be observed from manned points such as control rooms or toll booths. If not, then closed circuit television may be required. In any case, lifts will need to be as vandal-resistant as is compatible with an acceptable appearance. The balance between aesthetics and vandal resistance does vary considerably between car parks.

Escalators should not be installed where staff are not available to deal quickly with emergencies. They are not a substitute for lifts in complying with legislation on disabled access.

6.7 Provision for information technology and security

6.7.1 Provision for current equipment

Early consideration should be given to the requirements for cable routes for data cables since the form of construction and the limited headroom will otherwise make it difficult to provide suitable routes. Except in staff areas that are, essentially, normal building interiors, all such cable routes should be in galvanised steel trunking and galvanised steel conduit to allow access for later changes. Care is needed to ensure that trunking can accommodate the minimum bending radii of the various cables likely to be used, particularly fibre optic cables. There will usually be a requirement for cable routes:
- from staff areas to ticket machines and/or toll booths
- from control equipment to signs at entrances and exits
- from control rooms to street ducts leading to nearby road signs (car park full)
- for telecommunication operators' lines.

There may also be a requirement for power supplies and control signals for illuminated rooftop advertising signs.

The provision of trunking to serve CCTV and help point positions can be a particularly difficult aspect, since they will usually be at mid or high level and will require careful route planning. It is therefore essential to settle the positions of help points early in the design.

In view of the speed of development of CCTV technology and the likelihood that the initial installation will be replaced early in the life of the building, long-term best value may well be provided by a comprehensive high-level 'ring main' trunking route with regularly spaced junction boxes from which short links can be made to future camera positions. Particular care is needed to make such high-level trunking vandal-resistant.

Power and data lines should be separated electrically, preferably by separate trunking routes. Guidance[6.30] is available on design criteria for such installations. Alternatively, they can run parallel in multi-compartment steel trunking, provided that suitable cable types are used. Where possible, power and data cables should cross at right-angles.

There may be a requirement for uninterruptible power supplies for computer-based payment systems. This will normally best be provided by discrete units for each item of computer equipment. Such equipment normally requires little maintenance other than occasional servicing of batteries.

6.7.2 Provision for future developments

It is impossible to predict the future except that it will be different. The wise designer will advise the client to install spare cable routes during construction for future use by applications not yet considered. In addition, IT equipment has a very short life. Where possible, it is better to provide duplicate cable routes between control rooms, barrier equipment, payment equipment, toll booths, etc., so that a new IT system can be installed while the old remains operational. Once the changeover has taken place, the original cabling can be stripped out without affecting the new system, and the cable routes made available for future changes.

Although the types of cable for IT installations are constantly changing, fibre-optic cabling is increasingly being used. The basic requirement for cable routes giving physical protection and electrical shielding are unlikely to change. Fortunately, it appears that in general the physical volume of data cables is not increasing significantly even though the amount of data being transmitted escalates with each new technology.

6.7.3 Induction loops

The positions of induction loops should be decided early so that they can be laid during construction. Slots in decks for induction loops should not be cut after construction, as they can weaken the concrete, reduce cover and even damage reinforcement.

Where possible, induction loops should be laid in conduit with accessible junction boxes, so that they can be replaced in the event of faults without having to cut into the deck.

6.7.4 CCTV systems

These systems will generally comprise fully functional colour cameras in car park areas and static colour cameras in lobbies, lift cars and by ticket machines.

All cabling is to be contained within galvanised steel conduit and trunking. The system design should be agreed to allow a co-ordinated containment detail to be produced, so that the position of structural holes can be determined.

Cameras can have pre-set alarm functions linked to help points and ticket machines. The CCTV system specification should be designed in conjunction with the lighting systems and to the requirements of the Park Mark Safer parking Scheme assessment guidelines[6.29].

6.8 Fire alarm systems

In the UK the installation of fire alarm systems is subject to the requirements of BS 5839[6.31]. The system design will vary dependent upon building design, usage and occupancy and the associated risks.

Cabling can be contained within a common galvanised steel trunking system, clipped direct (not recommended) or tied to a galvanised steel cable tray or basket. The installation of a cable tray or basket could be prone to vandalism and again is not recommended.

The planning of cable and containment routes should be carried out at an early stage during the building design to minimise the effect on structure.

6.9 Lightning protection/earth bonding

Although not usually the highest buildings in an area, multi-storey car parks should be equipped with appropriate lightning protection. Guidance on design is contained in a European code of practice[6.32], which also contains information on protecting IT equipment against lightning strikes.

Lightning protection can take various forms but will usually consist of a network of copper tapes linking air terminations to buried copper earthing rods. It may be possible to make use of steelwork within the concrete structure as an alternative to copper tapes, but great care is needed to ensure that all relevant joints between reinforcing rods are bonded and of low impedance. It will in any case probably be necessary to bond the lightning protection system to the reinforcement. Bond is also required to other metalwork within the 'separation distance' of the lightning protection network. This will always include the utility services.

All earth bonding should be undertaken in line with the current edition of the IEE Wiring Regulations[6.25] or local/national wiring regulations. Earth bonding should also be applied to a steel frame structure and ductwork systems.

6.10 Part 'L'

As car parks are classed as unoccupied buildings with no heating and cooling they do not fall into the scope of the Part L Regulations[6.15] and a Simplified Building Energy Model (SBem) calculation is not required. However, designers should ensure that in these areas, lighting efficacies (LM/W) and specific fan power (w/(ltr/sec)) are within the requirements of Part L.

If the car park has office areas greater than 50m^2 then an SBem calculation will be required. If the area is below 50m^2 designers should ensure that in these areas, lighting efficacies (LM/W) and specific fan power (w/(ltr/sec)) are within the requirements of Part L.

6.11 BRE Environmental Assessment Method

Car park areas are excluded from the BRE Environmental Assessment Method (BREEAM) assessments. This is because they are classed as un-occupied buildings.

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7 Fire considerations

7.1 General principles

The structure of a modern multi-storey and/or underground car park is likely to use non-combustible materials and is considered a low fire risk. However, the cars parked in it pose a fire risk, as do other items such as refuse bins. For this reason and the need to provide a safe means of escape, the recommendations in this chapter need to be considered to limit the impact of a fire and provide means to control it. High fire risk areas and other ancillary accommodation should always be separated from the enclosed car park area to limit the spread of fire. The risks in a car park are generally well defined and predictable. This makes it possible to treat fire considerations in a different way to those adopted for general buildings whose use might change.

Fire spread from vehicle to vehicle is the major concern when considering fire loading in an enclosed car park. The loading will depend on:
– number and mix of vehicles in the car park at the time of a fire
– the proximity of one car to another
– the height of the ceiling
– degree of ventilation in the affected area
– the presence of sprinklers.

Recent research[7.1] into the growth and spread of fires in car parks revealed that there is a risk of fire spreading from car to car, particularly where early intervention by the fire brigade is not possible.

Many new cars are constructed of a mix of components that often include synthetic materials, including all-plastic bodywork. Experiments indicate that the danger of spread of flame from a burning vehicle to adjacent vehicles is quite low with steel-bodied motor cars, although tests have not been carried out with plastic-bodied vehicles (see Figures 7.1 and 7.2). However, where cars are parked nose to nose, or above each other on car stackers, the risk of spread is increased. When there is ample cross-ventilation, the fire exposure from a burning car may not be intense. In such cases, sprinkler protection may be of assistance in containing a fire. However, the value of sprinklers to steel-bodied vehicles is greatly reduced, as the source of the fire may be shielded from the water jet. While the sprinklers may be ineffective in controlling a fire inside a car, they do reduce the risk of fire developing in rubbish, and where the sprinkler heads are placed between parking bays they will usually assist in controlling the spread to adjacent vehicles.

The design of sprinkler systems for split-level car parks should take into account the fact that there is evidence to show that smoke and flames will travel underneath vehicles (see Figure 7.3) parked at a higher level.

Whereas the fire load density in smaller private car parks can be fairly well defined, in commercial car parks a much larger fire load will need to be considered to take account of unknown factors. Where there may be a risk of free-flowing petrol from a ruptured petrol tank, there may well be an accelerated knock-on effect on adjacent parked cars. Fire hazard should be assessed with input from a specialist in this field.

The provision of ventilation is vital to dissipate smoke and hot gases. In considering escape from car parks, the most critical aspect is often the control of smoke[7.2] and toxic fumes to give time to escape. This requires allowance for specialist ventilation systems and compartments to provide safe, smoke-free refuges.

Fire safety provisions for a new car park will need to comply with the requirements of the building control body. The principles that must be addressed are:
– means of escape
– structural integrity
– prevention of fire spread (both internal and external)
– facilities for fire-fighting
– ventilation and smoke control.

Figure 7.1 Beam damage from a car fire

Figure 7.2 Slab damage from a car fire

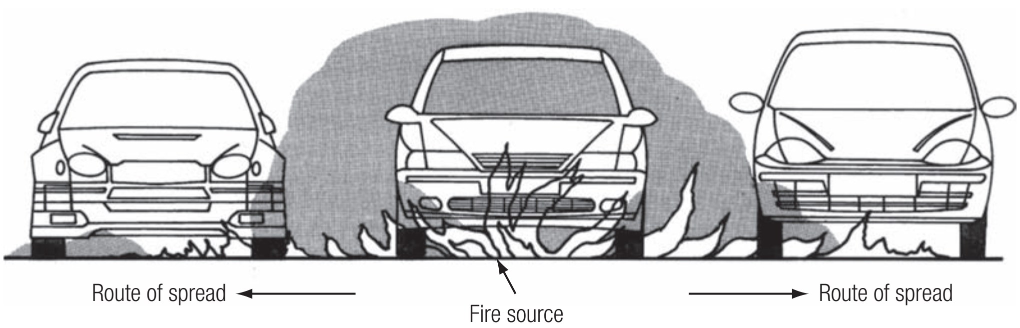

Figure 7.3 Routes of fire spread under cars

In multi-storey car parks, the fire safety measures required will be governed by the following factors:
- volume of the building and/or fire compartment
- height of the building
- use of basement construction
- provision for ventilation
- provisions for adequate smoke control
- distance from the boundary or the distance to other buildings
- use category of other parts of the same building or adjacent buildings, and the separation provided
- accessibility around the car park to fire-fighting appliances and provision of fire-fighting equipment within the car park, including dry/wet rising mains for the use of the fire brigade
- spacing and adequacy of fire-protected pedestrian escape routes
- special zoning requirements.

Whilst open sided car parks with adequate ventilation require little structural fire resistance, enclosed or basement car parks may require structural fire resistances of up to 2 hours. Adequate natural ventilation is normally defined as a total of 2.5% of the net floor area, adequately spread around the perimeter so as to allow cross-venting. Where the car park is adequately ventilated, it may be possible to omit applied fire resistance altogether. For example, the *Scottish building standards technical handbook: domestic; non-domestic*[7.3] allows a steel framed car park to have no additional fire resistance where the structural elements comply with limits on the Hp/A factor (Heated perimeter/cross sectional area). Where structural fire resistance is required, this may take several forms such as concrete cover or encasement, sprayed, intumescent paint or board protection. Whatever system is chosen, it must be robust enough to endure bumps and scratches that could be reasonably foreseen in this environment. The structure itself should be robust enough that local damage from a fire would not cause disproportionate collapse. Particular attention may need to be given to the structures of car stackers which are likely to collapse even in a well ventilated fire unless provided with sprinkler systems.

Enclosed or underground car parks must be adequately ventilated to ensure no build up of fumes. A mechanical system may also double up to form a smoke extract system, provided it is capable of withstanding the additional high temperatures of the smoke. This would normally require the use of fans which would withstand 300°C for 1 hour and some of the distribution ductwork to be fire rated for stability and integrity. The system would step-up to the required 10 air changes/hr on detection of a fire. An impulse fan system can also be employed, provided it has adequate controls to ensure the smoke is channelled towards the extract points, wherever the fire may start. The provision of smoke ventilation, which starts automatically on detection of fire, is essential to maintain adequate conditions for means of escape and to allow fire fighters vision through the car park to the seat of the fire.

The area of fire engineering and provision of equipment generally requires specialist input and advice.

7.2 Specific risks

The risk of cars catching fire is greatest immediately after their arrival in the car park. Another significant risk of fire comes from petrol spillage, which is most likely when a car owner is thoughtless enough to be pouring petrol into their tank. Notices warning against such practices are therefore desirable.

Unfortunately arson cannot be entirely ruled out and measures to improve the general security of car parks help to reduce the possibility of fire through this cause. Supervision and routine maintenance to ensure that no rubbish or other materials are stored in car parks is essential. The advice of the fire authority should always be obtained on fire-prevention measures.

In multi-storey and underground car parks, a number of aspects must be taken into account to control the effects of fire. These include:
- early detection of a fire to safeguard people in the building as well as property
- educating staff who work in the building
- fire warning notices
- reducing fire hazards
- frequent risk assessments
- compartmentalising areas of high fire risk
- providing CCTV
- general security
- measures to limit spread of fire and smoke
- fire suppression systems.

The means for preventing spread of fire by using compartments and provision of fire-resistant boundary walls needs to be considered. Examples of the typical requirements that have to be addressed are contained in the guidance documents to the Building Regulations[7.4, 7.5, 7.6, 7.7].

7.3 Fire safety standards

The standard of structural fire resistance required is normally measured in relation to values determined by the fire test described in standards such as the European harmonised fire tests BS EN 1363-1[7.8], BS EN 1365[7.9] Parts 1–4 and BS EN 1364-1[7.10], or the UK fire tests BS 476: Parts 20[7.11], 21[7.12] and 22[7.13]. The *Scottish building standards technical handbook: domestic; non-domestic*[7.3] for compliance with the *Building (Scotland) Regulations 2004*[7.6] sets out the mandatory requirements and calls up both the relevant British Standards and the European harmonised fire tests. For England and Wales, *Approved Document B*[7.5] draws on the same references.

The standard of structural fire resistance for multi-storey car parks as a whole or for different parts of the structure must conform to national regulatory requirements and should be agreed with the relevant building control body and/or fire authority. Due account must also be taken of local legislation that may impose additional requirements. For example, Section 20 of the *London Building Acts (Amendment) Act 1939*[7.14], which is principally concerned with the danger of fire in tall buildings, imposes additional requirements to those given in the Building Regulations[7.4]. Reference may also need to be made to the London District Surveyors Association's *Fire Safety in Section 20 Buildings Fire Safety Guide No.1*[7.15]. There is also further guidance for all enclosed car parks in the *Code of practice for ground floor, multi-storey and underground car parks*[7.16] published by the Association for Petroleum and Explosives Administration.

The structural form of a car park and general absence of non-structural, fire-resistant finishes, suggest that a fire engineering approach such as that in BS 9999[7.17] and BS 7974[7.18] could be adopted for design of structural elements and means of escape. It should be appreciated that a fire engineering approach will not always result in less onerous measures than those arising from prescriptive rules, particularly where there is a lack of adequate ventilation.

The requirement for hydrants, dry risers, hose reels and fire extinguishers should be agreed with the local fire authority. All fixtures and fittings that contribute to the essential safety of people using car parks and which are part of the basic fire resistance of the structure should be designed to be as vandal-resistant as possible.

7.4 Fire detection and extinguishing equipment

7.4.1 General

These recommendations assume that the prompt attendance of the public fire service is assured and that adequate hydrants and an ample water supply are available. Early in the design, it is advisable to discuss all work of this type with the building control body; particularly the local authority building control where local legislation is applicable.

The fire authority must also be consulted where persons are to be employed to work in the enclosed car park; these may include kiosk attendants, supermarket trolley attendants, maintenance personnel and security personnel. In these circumstances, the car park will be controlled under the *Regulatory Reform (Fire Safety) Order 2005*[7.19], and a formal risk assessment should be made.

It is recommended that hand appliances for use by trained staff should also be provided as automatic detection and extinguishing equipment can be rendered inoperative by explosions or vandalism. Suitable fixed and portable fire-extinguishing equipment to deal with the hazards involved is an essential additional safeguard even when all necessary precautions have been taken in the design of the building structure. In selecting extinguishing equipment, care should be taken to ensure that, while effective for use against petrol and oil fires, the items do not give rise to toxic gases when their contents come into contact with hot surfaces. Some equipment that is suited for use outdoors presents a toxic risk in confined spaces.

Automatic smoke detectors would not normally be installed in car parks because of the risk of false alarms from smoky car exhausts. Programmed beam detectors could provide an answer but may suffer from delays in detection.

Guidance on approved fire-extinguishing appliances should be sought from professional bodies such as the Loss Prevention Council Certification Board.

7.4.2 Sprinklers

As the fuel source is often oil-based, the use and type of sprinklers for car parks have to be carefully considered. In addition, the unoccupied nature of car parks makes the sprinkler heads prone to vandal damage. Any sprinkler system installed must comply with standards such as BS 5306-2[7.20] and BS EN 12845[7.21].

In cold climates, some sprinkler systems can be rendered ineffective by freezing, unless pipework is insulated and trace-heated. A pre-action system can alleviate some of these problems as in normal operating conditions the pipework is not full of water. There is also less chance of accidental discharge in the event of damage to the heads.

7.4.3 Automatic fire alarms

A fire-alarm system should be installed within an enclosed car park to provide early warning. Provision in enclosed car parks is not always mandatory but is advisable, especially to warn persons in remote parts of the car park.

The fire-alarm system should be installed and maintained in accordance with standards such as BS 5839-1[7.22]. Where an automatic fire-alarm system is to be installed, consideration should be given to the type of detection, as smoky car exhaust fumes may activate the system.

Owing to the possibility of vandalism, a linear aspirating automatic fire alarm system should also be considered. Because this system is less noticeable, vandals will not be tempted to interfere with it. This type of system is less prone to false activations.

7.4.4 Hand-held portable fire-fighting equipment

Hand-held portable fire-fighting equipment should be installed throughout the car park in accordance with the requirements of the fire authority. Typically this might require fire points not more than 15m from any point in the car park as follows:
– **Hose reels**: Hydraulic hose reels should be provided and so located that at least one nozzle can be taken to any part of the car park. The hose should have an internal diameter of at least 19mm and the nozzle should have an internal diameter not less than 4.75mm. The water supply should be such as to ensure that the operating nozzle pressure cannot be less than 1 bar.
– **Foam extinguishers**: 9-litre capacity foam extinguishers or 9kg dry powder extinguishers for each 230m^2 of floor area.
– **Buckets of absorbent material**: To deal with small fires from spilt petrol, three 5-litre buckets of readily available absorbent material e.g. sand, should be provided on the same basis as the foam extinguishers. Buckets should have lids to keep the absorbent material dry.

European standard EN 3[7.23] makes recommendations for the siting and distribution of extinguishers and on the suitability of the various types for use on different fires. The intervals between routine inspections are set out, along with details of the maintenance regime for each type of extinguisher. Periodical testing by discharge is also covered, including recommended intervals between discharges for the various types of extinguisher:
– water
– foam
– carbon dioxide
– dry powder
– chemical
– sand.

It is safest for portable extinguishing points to be located adjacent to exits, so that a user can turn their back on the fire and maintain a safe route to an exit.

7.5 Means of escape

7.5.1 Statutory controls

Consideration must be given to the requirements of local and statutory bodies and their powers of enforcement. For example, the enforcing authorities throughout the British Isles are the local authorities and the fire authority. Their powers rest in the Building Regulations[7.4, 7.5, 7.6, 7.7] and the *Regulatory Reform (Fire Safety) Order 2005*[7.19] respectively. Local authorities also often have additional powers under local legislation.

7.5.2 Rules for guidance

7.5.2.1 General

It is always best to enquire of the relevant local and statutory authorities what standards they impose. However, there are some basic commonsense rules that should enable the designer to produce an initial proposal for discussion with the relevant authority.

The principal factors governing escape provision are:
– the number of occupants that may have to escape from the compartment
– the time to travel from any point in the building to a place of safety.

The first of these factors governs the width of exits and the second, because of the effect it has on travel distance, the number and spacing of exits. When referring to an exit in terms of escape, it must be an exit from the fire compartment to a place of relative safety, not just a means of leaving the car park.

The appropriate means of escape should take into account:
– protected routes of escape
– travel distances
– smoke venting
– places of safety
– exits to the street
– fire safety management and warning systems
– segregation of areas of high fire risk
– ability of persons to move or negotiate doors etc., for example children, the disabled or the elderly. Refer to BS 9999[7.17].

Clearly defined routes must be provided with adequate consideration of:
– exit signage
– fire safety signage
– illumination of escape routes.

It is within these considerations that a proper and sufficient means of escape in case of fire can be designed so that, if fire breaks out, anyone within the car park will be able to vacate the area without outside assistance and reach a place of safety.

7.5.2.2 Escape routes

Maximum allowable escape distances can be found in such guidance as *Approved Document B*[7.5] of the England and Wales Building Regulations[7.4]. Table 2 of the Approved Document[7.5] treats car parks as 'Storage and other non-residential' for the purpose of horizontal escape. Following such guidance leads to a maximum allowable escape distance of 25m where there is escape in one direction only, or 45m where there is escape in more than one direction. Open air top decks are often taken as 'Plant room or rooftop plant – escape route in open air'. This leads to a maximum allowable escape distance of 60m where there is escape in one direction only, or 100m where there is escape in more than one direction. These distances are to a place of relative safety, which could be out of the building, to a protected stair or to a different horizontal fire compartment.

At least two exits should generally be provided. With split-level car parks, it is normally acceptable if each is provided with alternative exits, one of which should be to a final exit while the others may be by way of an adjoining level to another exit. Travel distances to these exits should be within the limits previously specified. Such exits should be remote from each other and, as far as possible, sited at the extremities of the building to obviate dead ends.

Where site restrictions or practical planning constraints mean a dead end cannot be avoided, it is recommended that the maximum direct distance from a dead end to the nearest exit serving the floor area should not normally exceed 12m. It may also be acceptable to allow for an escape distance of 12m to a point from which escape is available in two separate directions, provided that the direct distance to the nearest exit does not exceed 30m.

Parking bays and/or service-vehicle loading bays should be laid out to ensure unobstructed access to the exits, which should be clearly visible and well signed.

7.5.2.3 Width of escape routes

The number of persons likely to use the premises should be assessed, with surge loading taken into account where applicable. In the absence of specific information or guidance from the local fire authority, total occupancy is often assumed to be 2 persons per car parking space in public car parks and 1.5 persons per car parking space in private car parks.

The minimum width of any escape route within a floor area and of any exit can then be calculated using formulae in the relevant standards, e.g. Table 4 of *Approved Document B*[7.5]. Generally, the designer should assume that one exit is unavailable at the fire floor, and design the remainder of the exits for the total number of occupants.

The capacity of stairs not less than 1100mm in width can be calculated by using the following formulae[7.5]:

$$P = 200w + 50(w - 0.3)(n - 1)$$

where:
P is the number of people that can be served
w is the width in metres
n is the number of floors served by the stair.

Where a ground-floor exit also discharges through a staircase final exit, the latter may have to be increased to accommodate the extra people. Similarly, where a basement staircase connects to a staircase from above (if permitted), the final exit may need to be widened.

In selecting the width of staircases (see Table 7.1), it may be unnecessary to assume the stair is out of action throughout its entire height provided adequate smoke control or protected lobbies are provided. Protected lobbies are necessary where refuge points for disabled persons are provided. Unprotected staircases may be satisfactory where the travel distance and the numbers using it are low. In this situation one staircase will need to be assumed out of action and the other escape routes designed accordingly. Protection to staircases is normally comprised of fire doors and fire resistant construction. If the stair is external, protection may only be needed to shield the stair from the effects of fire in the building, the rest remaining unenclosed.

Where the number of persons on any floor area, or to any adjoining split levels, is unlikely to exceed 50, the minimum staircase width could be reduced to 800mm, provided it does not serve more than four storeys. This width is unlikely to be suitable if the stair is also likely to be used as an accommodation stair.

Where access is provided from a basement storey to a protected staircase serving upper storeys of the building or more than one basement storey of car parking, a protected lobby should be provided between the protected staircase and the basement storey, at each level. The lobby should be ventilated with an opening or shaft direct to the external air not less than $0.4m^2$ in area; any such shaft should be enclosed with fire-resisting construction. Guidance is given in Section 4.35 of *Approved Document B*[7.5].

Table 7.1 Width of escape route staircase

Number of floors	Number of persons one staircase can accommodate		
	1.2m width	1.5m width	1.8m width
1	240	300	360
2	285	360	435
3	330	420	510
4	375	480	585
5	420	540	660
6	465	600	735
7	510	660	810
8	555	720	885
9	600	780	960
10	645	840	1035

Where parking is provided only on the level immediately above or below the vehicle entrance level, one of the required routes of escape may be by way of a vehicle ramp. In that case, however, it is normal to reduce the maximum direct distance permissible to 12m to the foot of the ramp. This is because an occupant is not considered to have escaped from the fire zone until they have reached the other end of the ramp.

A ramp that affords a means of escape should not be steeper than 1:12. If the ramp is also intended as a means of access by disabled persons, it will require further provisions such as landings at prescribed distances along its length. Emergency egress for disabled persons should be carefully considered. Generally, an arrangement where self evacuation can be achieved is preferred. In situations where a disabled person is able to make it to a relatively safe refuge point, a means of attracting attention and a procedure for assisted evacuation should be adopted. Intervention and assistance from the fire brigade should not be assumed. Lifts should not be used for evacuation purposes unless they have been specifically designed with the necessary provisions.

7.6 References

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7.2 *BS 7346-7: 2006: Components for smoke and heat control systems – Part 7: Code of practice on functional recommendations and calculation methods* *for smoke and heat control systems for covered car parks*. London: BSI, 2006

7.3 Scottish Building Standards Agency. *The Scottish building standards technical handbook: domestic; non-domestic*. Edinburgh: The Stationery Office, 2010

7.4 *The Building Regulations 2010*. [s.l.]: The Stationery Office, 2010 (SI 2010/2214)

7.5 *The Building Regulations 2000. Approved Document B: Fire Safety. Vol 1: Dwellinghouses; Vol 2: Buildings other than dwellinghouses*. 2006 ed. London: NBS, 2007

7.6 *The Building (Scotland) Regulations 2004*. Edinburgh: The Stationery Office, 2004 (SSI 2004/406)

7.7 *The Building Regulations (Northern Ireland) 2000. Technical Booklet E: Fire Safety*. London: TSO, 2005

7.8 *BS EN 1363-1: 1999: Fire resistance tests – Part 1: General requirements*. London: BSI, 1999

7.9 *BS EN 1365: Fire resistance tests for loadbearing elements* [6 parts]

7.10 *BS EN 1364-1: 1999: Fire resistance tests for non-loadbearing elements – Part 1: Walls*. London: BSI, 1999

7.11 *BS 476-20: 1987: Fire tests on building materials and structures – Part 20: Method for determination of the fire resistance of elements of construction (general principles)*. London: BSI, 1987

7.12 *BS 476-21: 1987: Fire tests on building materials and structures – Part 21: Methods for determination of the fire resistance of loadbearing elements of construction*. London: BSI, 1987

7.13 *BS 476-22: 1987: Fire tests on building materials and structures – Part 22: Methods for determination of the fire resistance of non-loadbearing elements of construction*. London: BSI, 1987

7.14 *London Building Acts (Amendment) Act 1939*. London: HMSO, 1939

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7.16 Association for Petroleum and Explosives Administration. *Code of practice for ground floor, multi storey and underground car parks*. Barton-le-Clay: APEA, 1995

7.17 *BS 9999: 2008: Code of practice for fire safety in the design, management and use of buildings*. London: BSI, 2008

7.18 *BS 7974: 2001: Application of fire safety engineering principles to the design of buildings*. London: BSI, 2001

7.19 *The Regulatory Reform (Fire Safety) Order 2005*. London: TSO, 2005 (SI 2005/1541)

7.20 *BS 5306-2: 1990: Fire extinguishing installations and equipment on premises – Part 2: Specification for sprinkler systems*. London: BSI, 1990

7.21 *BS EN 12845: 2004+A2: 2009: Fixed firefighting systems – Automatic sprinkler systems – Design, installation and maintenance*. London: BSI, 2004

7.22 *BS 5839-1: 2002+A2: 2008: Fire detection and alarm systems for buildings – Part 1: Code of practice for system design, commissioning and maintenance*. London: BSI, 2002

7.23 *BS EN 3: Portable fire extinguishers* [several parts]

8 Durability of the structure

8.1 General

Car parks normally operate in exposure environments that are more severe than for a typical building structure, being the public's interface between normal buildings and the highway. In addition to conventional design approaches for durability, car park structures should be assessed against the following specific exposure parameters:

- the natural environmental exposure conditions, in particular the proximity to the coast (typically within 8km), as salt deposition will increase the aggressiveness towards the structure
- the local operational conditions at the proposed location, in particular the use of chloride-based de-icing salts (hereafter 'de-icing salts') on the roads around the car park or the use of salts on the car park deck surfaces themselves
- the design service life, normally taken to be 50 years.

The exposure conditions for car parks in countries where de-icing salts are frequently used are much more severe than those for conventional buildings. The form of the construction also will have a significant influence on the severity of conditions that lead to deterioration of vulnerable details.

Codified guidance is available on the durability requirements for the three common forms of car park construction considered in these recommendations:

- Concrete framed structures and concrete decks and ramps: the durability requirements in Europe for *in situ* and precast concrete are determined from BS EN 206[8.1], interpreted specifically in the UK in BS 8500[8.2], as required by design to structural codes such as BS EN 1992-1-1[8.3] or BS 8110[8.4] (see Section 8.2).
- Steel framed structures, sometimes including steel decks and ramps: the durability requirements are determined from EN ISO 12944-4[8.5], which gives guidance on the life expectancy of the different paint protection systems (see Section 8.3).
- Basements and buried structures: determined from BS EN 206[8.1] or BS 8500[8.2] (see Section 8.4).

Durability of car park structures is not addressed specifically in either the steel protection standard (EN ISO 12944-4[8.5]) or the concrete standards (BS EN 206-1[8.1] or BS 8500[8.2]). Explanation of the durability requirements and interpretation of the guidance documents is given in the following Sections.

Where de-icing salts are frequently used, durability considerations for concrete, steelwork and waterproofing systems will need to be considered in the design. Additional measures can be used to enhance the durability of a car park. The extent and value of these measures should be considered against the cost and disruption implications of maintenance and remedial work during the design service life of the structure.

8.2 Concrete durability

8.2.1 Introduction

The main exposure classes of BS 8500[8.2] are reproduced below:

- XO: No risk of corrosion or attack
- XC: Corrosion induced by carbonation
- XD: Corrosion induced by chlorides other than from sea water
- XS: Corrosion induced by chlorides from sea water
- XF: Freeze–thaw attack.

The standard does not specifically draw attention to the exposures found in and around car parks and so additional recommendations have been provided in the following sections.

8.2.2 General

8.2.2.1 Introduction

Some elements of a car park such as columns, parapets and foundations are in conditions of exposure similar to those in normal buildings. The main mechanism for deterioration of concrete above ground is carbonation (XC) of the exposed surface, leading to loss of alkalinity and hence reduced protection against corrosion of embedded reinforcement. The more serious mechanism is chloride-induced reinforcement corrosion arising from chloride ions in de-icing salts (see Section 8.2.2.2), which are brought into the car park on the wheels of vehicles and sometimes spread onto the deck surface in icy weather (XD). Car parks in locations where de-icing salts are used or where sea spray deposition is likely, need to be designed to resist chloride attack otherwise the reinforcement will become corrosively active (XS).

Given that car parks are normally external structures exposed to rain, where rain is regularly brought onto the decks on the bodies and wheels of cars or may be otherwise wetted by cleaning operations, the presence of water and oxygen will drive the corrosion process, leading to loss of section of the steel reinforcement and spalling of the concrete cover.

Care is required with elements that are exposed to direct wetting, which may need special attention to address the risk of water penetration through the element or the freezing of the element while wet (XF).

Special consideration is also required where the structure has a design service life outside the scope of these recommendations, which is 50 years.

Less commonly, concrete can be at risk from alkali–silica reaction[8.6, 8.7] and the foundations of a car park can be attacked by chemicals in the soils, such as sulfate attack, acidic soils, thaumasite[8.8] etc. These deterioration mechanisms are dealt with in specialist guidance[8.9], the recommendations of which have been incorporated in BS 8500[8.2].

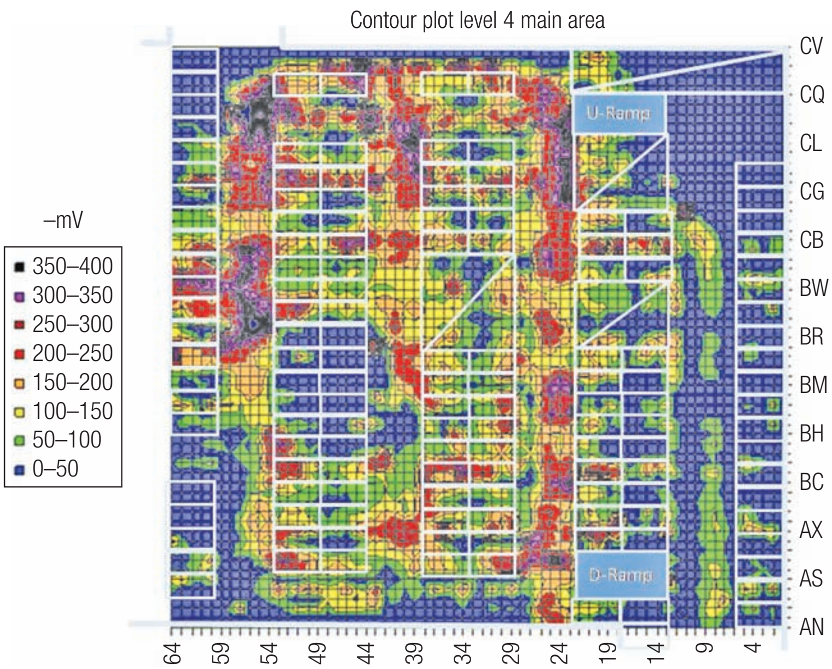


Figure 8.1 Half-cell potential survey of a car park deck showing localised high corrosion risk in vehicle tracks and wheel positions in parking bays

8.2.2.2 Chloride ion attack

The biggest threat to the durability of concrete car parks is exposure to chloride ion. Structures near the coast, typically within 8km of the shore, are known to be at increased risk of sea salt deposition, which affects the external envelope and roof slab. Salt also collects on the road surface outside the car park and, as is also the case with chloride-based de-icing salts used to treat roads in winter, the salt is carried onto slabs and ramps in all parts of the car park by the wheels of cars. Water run-off from cars, due to rain and melting ice and snow can also carry the salt-contaminated water into all parts of the car park, collecting in areas with poor drainage. In some cases, car park operators will use de-icing salts on the slab surfaces to reduce the slipping risk to users, despite advice to the contrary. Prevention of chloride ion penetration into the concrete from these sources has therefore to be a primary consideration in car park durability design.

Evaluation of concrete elements in car parks where premature deterioration has occurred[8.10, 8.11] has shown that surfaces or details exposed to de-icing salt need greater protection and/or higher standards than for concrete elsewhere. Corrosion of unprotected embedded metal, including reinforcing and prestressing steel, (both for pretensioning and post-tensioning) is caused by concentration and ingress of chloride ions from de-icing salts or from sea spray in coastal environments. As sufficient water and oxygen is normally present in the car park environment, rapid 'galvanic' corrosion and loss of section of the reinforcement will occur if the chloride ion concentration in the concrete at the depth of the embedded metal gets too high[8.12].

Research by BRE[8.12] and others has indicated that corrosion of reinforcing steel is initiated when the concrete surrounding it has reached a threshold of approximately 0.4% chloride ion, expressed by weight of cement in the concrete (bwc). The threshold is reduced to 0.1% bwc for concrete containing prestressing steel. Special care is therefore needed to protect the concrete surface against penetration of chloride ions.

At the threshold values, large anodes and cathodes develop on the reinforcement, which can be measured on the surface of the concrete using the half-cell potential technique[8.13], as illustrated in Figure 8.1. To avoid high chloride ion concentrations, particular attention to detail is required at joints, interfaces between dissimilar materials or where cracking can occur. This is particularly important at column heads where hidden corrosion of structural connections might lead to sudden collapse. The Concrete Society provides guidance on non-structural cracks in concrete[8.14] and the relevance of cracks to corrosion of reinforcement[8.15].

A frequent factor in premature deterioration is retention of water, either on rough, textured surfaces or in areas of ponding. Unless there is an effective waterproofing membrane on the concrete surface (see Section 8.6), ponding water will slowly penetrate into the concrete surface. As well as increasing the risk of damage due to freeze–thaw action, the surface water is likely to contain chloride salts from sea spray or from de-icing salts.

The combination of poor drainage and the lack of beneficial cleaning or rain-wash on the sheltered lower floors, leads to a concentration of chloride salts on the surface as the water evaporates. This has obvious implications for the durability of reinforcement embedded in the concrete. Cycles of wetting and drying, which are features of car park environments, also act to accelerate the ingress of chlorides into the concrete surface and into any cracks.

The time to onset of corrosion cannot be reliably predicted and will depend on: the quality of the as-constructed concrete; the amount of salt carried into the car park; and the effectiveness of drainage and wash-down procedures. If the concrete is allowed to dry rapidly, with adequate falls to shed water from the surface quickly, then this will not only reduce the time when chloride penetration can occur, but also keep the concrete resistivity high and so minimise rates of corrosion if the reinforcing bar does become corrosively active.

Problems associated with chloride salt attack and corrosion are much less severe where the design and construction incorporates the following:
– specified minimum cover to the reinforcement
– thorough compaction of the concrete
– well-designed and cohesive concrete mix
– properly designed and sealed movement and construction joints
– adequate drainage through proper falls
– good ventilation, allowing slabs and ramps to dry quickly
– waterproof membrane systems (see Section 8.6).

Water and salts will find accelerated passages through poorly designed and leaking joints, and through honeycombed concrete surfaces. High quality concrete construction is therefore the first line of defence against chloride ingress. If water can penetrate through the concrete slab to the soffit, the water will evaporate and leave behind any chloride ions that were in the water, concentrating the salts in the concrete and leading to corrosion of soffit reinforcement.

Water passing through concrete in this way will also be highly alkaline and can contain a saturated concentration of calcium hydroxide. In reaction with carbon dioxide in the air, the water will evaporate and leave behind characteristic white staining or hollow stalactites, along with drips onto the floor below. While in itself this does not significantly reduce the durability of the concrete, it will pose a risk to users of the car park and cause damage to paintwork of cars, which creates operational problems.

Good detailing will prevent problems of water penetration. It is good practice to provide a drip detail to prevent water running back along the soffit from joints in the slab or at the edge parapets. Attempts to stop leakage by sealing the underside of joints or cracks will tend to exacerbate deterioration by trapping moisture and chloride ions in the slab.

8.2.2.3 Variation in severity

The rate at which de-icing salts build up in the car park surface varies considerably and depends on the highway salting regime outside the car park. In mild localities salting is infrequent. In northern urban areas there will be a particularly frequent salting regime. De-icing salt build-up will also vary with the number of vehicles a day using the car park and even the frequency of use of individual spaces. Analysis shows that over many years the salt concentration in the concrete will be higher in the wheel tracks at entrance areas and in-ramps and at wheel positions in the most frequently used parking bays (see Figure 8.1). The exit ramps are less contaminated, as the cars will have left behind much of the harmful salt on the concrete slab surface.

Table 8.1 summarises the above mentioned factors that can create risks of premature deterioration in car parks. These durability factors and their mitigation are discussed further in the following sub-sections.

8.2.3 Durability design

Durability recommendations vary between countries and as noted above, car parks are not specifically covered by EN 206[8.1] or BS 8500[8.2]. The recommendations in Table 8.2 are for a car park in the UK and use the terminology of BS 8500 regarding exposure classes, which control among other things the concrete compressive strength and the cover to the reinforcement[8.16]. The recommendations assume the following:
– The concrete strength class should be C32/40 or greater (i.e. a characteristic cylinder strength of 32MPa, equivalent to a cube strength of 40MPa).
– De-icing salts are not applied directly to the elements by the car park operator as part of a maintenance regime.
– The car park will be well-drained.
– The car park will have good ventilation.
– The car park has a 50 year design service life.
– Freezing of internal elements is unlikely to occur.
– Soffits, columns and walls are rarely exposed to spray from de-icing salts.
– Elements are not immediately adjacent to a highway (and are therefore not subject to external splash or spray).
– ASR risk and sulfate or other forms of attack have been assessed separately and are outside the scope of Table 8.2.

The exposure class will need to be re-assessed if any of the above assumptions are not valid.

The exposure class for the concrete will be reduced if the surface is protected with a waterproofing membrane (see Section 8.6). Consideration should be given to the maintenance regime for the membrane; the concrete surface may become locally vulnerable to chloride ion ingress if the membrane fails and is left unrepaired, such as over cracks and splits or areas where the surface has worn away[8.16].

The above exposure classes take into account the following characteristics of car parks:
– Concrete for exposed top decks and ramps will be subject to rainfall and other forms of wetting and is at risk of freezing while wet. In the UK, BS 8500[8.2] permits omitting entrained air in all concrete of class C40/50 and above. For concrete of less than class C40/50, entrained air should be used where the concrete is at risk of freezing while wet, unless it is protected from wetting by a liquid-applied waterproof membrane.
– The same durability requirements should be applied to structural concrete wearing screeds to precast units. Where reliable supplies of air-entrained concrete are not available, class C40/50 concrete is an appropriate choice.
– Intermediate levels of a car park are often wetted by rainwater, brought in on tyres of vehicles or penetrating through part-clad sides. In cold regions, snow is brought into the car park either on the vehicles or blown in through open sides, which can then melt. However, experience suggests the inside surfaces of car parks are rarely subjected to freezing while wet.
– Local conditions will dictate whether higher requirements for freeze–thaw resistance are required on intermediate decks. If frost problems have arisen, they are normally associated with ponding and/or poor-quality concrete. In colder climates, more rigorous measures may be necessary.

Table 8.1 Factors affecting the durability of car parks

Potential durability problem	Actions that may be taken individually or together to minimise the problem[a]
Uncontrolled cracking[b]	– Choice of structural system e.g. *in situ*, precast, post-tensioned, composite decking (s5.4) – Design to control crack sizes (s5.4) – Use of synthetic fibres for plastic and drying shrinkage control (s8.2.4) – Thorough curing regime (s10.2.5) – Design for movements and volume changes (s5.7) – Select low shrinkage concrete mixes (s8.2.4) – Correct finishing practices (s10.2.4) – Correctly detailed reinforcement e.g. staggered laps (s10.2.2) – Consider additional diagonal anti-crack reinforcement at corners of voids and other stress risers (s5.4) – Use protective coatings and membranes (s8.6)
Leaking through slabs	– Crack control (see also 'Uncontrolled cracking' in this Table and s8.2 and s5.7) – Good drainage provision (s9.2) – Properly installed and maintained joint systems and liquid-applied sealants (s9.3) – Use protective coatings and membranes (s8.6)
Freeze–thaw damage	– Provide adequate falls and drainage (s9.2.2) – Specify air entrained concrete (s8.2.4) – Check air entrainment level of concrete at discharge (s8.2.4) – Use protective coatings and membranes (s8.6)
Corrosion of reinforcement	– Assess all relevant exposure conditions (s8.2.3) – Concrete mix enhancement (s8.2.4) – Corrosion protection measures (s8.2.5) – Adequate design of cover to reinforcement (s8.2.5) – Enforcing cover to reinforcement at construction (s10.2) – Provide adequate drainage (s9.2) – Use protective coatings and membranes (s8.6) – Ensure the quality of concrete is good (s8.2)
Poor concrete mix quality	– Use the correct cement type (s8.2.4) – Use a low shrinkage concrete (s8.2.4) – Use admixtures to improve placing and minimise water demand (s8.2.4) – Use effective curing (s10.2.5) – Use correct finishing practices (s10.2.4) – Enhance the concrete with coatings and membranes (s8.6)

Notes
a Refer to quoted section number for further information.
b Cracking can be controlled, but not completely eliminated.

8.2.4 Concrete specification

The exposure classes set out in BS 8500[8.2], as supplemented by Table 8.2, should provide protection against deterioration in the UK, subject to the limitations listed in the assumptions. Where the limitations cannot be satisfied, the specification requirements for the concrete will need to go beyond the recommendations in Table 8.2. Extreme exposure situations that are known to increase the risk of

Table 8.2 Recommended exposure classes for use with BS 8500

Element type and location	Recommended exposure class	Recommended exposure class in coastal areas
Top surface of decks and ramps at the entry level of car park	XD3 (XC3/4)[a] and XM1[b]	XD3(XC3/4)[a], XS1[c] and XM1[b]
Top surface of decks and ramps exposed to freezing e.g. roof level	XF2 and XD1(XC3/4)[a] Optional – XM1[b]	XF2, XS1(XC3/4)[a] and XD1[d] Optional – XM1[b]
Top surface of decks and ramps in other locations	XD1 (XC3/4)[a, b]	XS1 (XC3/4)[a] and XD1[b, d]
Soffits of decks and ramps	XC3/4	XS1 (XC3/4)[a]
Vertical elements	XC3/4	XS1 (XC3/4)[a]
Vertical elements exposed to freezing	XC3/4 and XF1	XS1 (XC3/4)[a] and XF1
Elements protected from rainfall e.g. internal areas such as stair enclosures	XC1	XC1

Notes
a Exposure classes given in brackets denote classes which are less critical and assumed in BS 8500[8.2] to occur simultaneously with the main exposure class.
b While BS EN 1992-1-1 Cl 4.4.1.2[8.3] advises that for abrasion class XM1 (moderate) a sacrificial layer of 5mm of concrete may be used, for car parks, BS 8204[8.17] abrasion class AR4 (light duty industrial and commercial) is recommended as equivalent – see Section 8.4.
c XD3 condition is more critical.
d XS1 condition is more critical.

premature corrosion of reinforced or prestressed concrete include:
– Design service life of more than 50 years: carbonation and chloride ingress are time dependent and extra cover or higher strength class may be needed.
– Structures exposed to tropical or arid climates: higher temperatures will accelerate carbonation and chloride ion penetration.
– Buried car parks or foundations exposed to saline groundwater: unless effectively tanked, evaporation of groundwater passing through the walls may concentrate chloride salts at the inner reinforcement layer.
– Very severe freeze–thaw cycles: may require air entrainment in high strength concrete (see BS EN 206[8.1]).

Concrete specifications can be enhanced by a combination of measures that either protect the concrete or enhance its penetration resistance to chloride ions and other aggressive agents. Recent developments in concrete technology have shown that there are a number of ways of enhancing the resistance of concrete to chloride-induced corrosion. Some of these are simple and can be adopted in normal car parks, others are commonly used on major bridge and infrastructure projects, but may also be considered for car parks.

Changes in mix composition can significantly improve the durability of the concrete and reduce the chances of premature deterioration. Option selection needs to consider the local availability of materials and the ability of the contractor to place, compact and cure the concrete to achieve the intended benefits.

The common options for improving the durability of reinforced concrete are summarised below[8.18]:
– Cement additions including ground granulated blastfurnace slag (ggbs), fly ash (fa) and silica fume (sf): these can reduce the rate of penetration of chloride ion for a given strength class.
– Plasticising or superplasticising admixtures: these enable the water/cementitious (w/c) ratio to be reduced and thereby substantially improve the durability of the concrete and the resistance to chloride ingress.
– Low water demand mixes, that are based on minimum voidage tightly packed aggregate of good grading and shape: these mixes help lower the w/c ratio and reduce shrinkage of the concrete.
– Waterproofing admixtures: these reduce the absorption of water and water-borne salts into concrete and have been used successfully for waterproof basement construction.
– Macro synthetic polymer fibres: these have the potential to improve the post-cracking properties of hardened concrete and can be used as a corrosion-free alternative to nominal bar or fabric reinforcement[8.19].

Care must be taken to ensure consistency of properties when using admixtures or combinations. Changes in elements of a mix can have a disproportionate effect and a high degree of quality control is necessary.

8.2.5 Corrosion prevention

8.2.5.1 Introduction

Corrosion of steel reinforcement or other embedded metal is a severe problem that may weaken the car park before it has reached its design service life. While modifying or protecting the concrete (see Section 8.2.4) will achieve some improvement in durability, alternative design considerations can also be considered for the reinforcement. Alternatively, non-ferrous reinforcement can be used (see Section 8.2.6).

8.2.5.2 Cover to reinforcement

When specifying concrete cover, several points must be considered:
– Maintaining the correct cover to the top reinforcement in slabs and ramps is essential, as this is the most critical zone for chloride ion penetration.
– Care is required in detailing, as tolerances for placing reinforcement, formwork construction, concrete thickness and finish are sometimes not compatible with the cover tolerance.
– The mass of *in situ* concrete will cause deflections in conventional formwork, which can reduce concrete levels and affect cover depths; this can also be a problem with concrete wearing screeds applied over prestressed precast concrete planks or where steel decking is used (see Sections 8.5.2 and 8.3.3).
– Cover over column and wall reinforcement should be similar to top cover in adjacent slabs, particularly if these are at or near gutter lines or in areas exposed to salt-laden slush and splash.
– Precast members exposed to salts should either include cover requirements at their ends or have equivalent protection (e.g. an impervious coating system), particularly as joints formed above these ends may leak chloride-laden water.
– Anchorages and vent tubes for grouted post-tensioned elements are potential locations for ingress of water containing de-icing salt, which could lead to corrosion of the tendons. These vulnerable details must be sealed to protect them effectively and must be regularly inspected.
– Cutting or forming of chases or holes in structural members must not be undertaken without due consideration of the structural and durability implications.

8.2.5.3 Corrosion-resisting reinforcement

In addition to high-quality concrete cover, additional protection of the reinforcement can be provided by the choice of steel or by using coatings.

Austenitic 316 stainless steel minimises the risk of corrosion in concrete[8.20]. Because of its cost, it is only normally appropriate in local areas where conditions are particularly severe, e.g. barrier fixings and bearing shelves. It should be detailed to ensure that it is electrically isolated from other reinforcement. Electrical contact between stainless and conventional reinforcing steel can lead to induced galvanic corrosion in situations where chloride ions reach the depth of the conventional reinforcement.

Galvanised reinforcing steel can extend the time to corrosion of reinforcement in carbonated concrete, but is not recommended for exposure to heavy chloride-contamination found in car parks[8.21].

Epoxy-coated reinforcement to BS ISO 14654[8.22] offers improved protection against reinforcement corrosion due to carbonation and chloride ingress. Particular care is needed during delivery, bending, cutting and site placement to repair any exposed areas of steel, which would otherwise lead to localised corrosion.

8.2.5.4 Protecting prestressing strand

The more stringent control of materials and fabrication normally associated with precast prestressed concrete construction, including higher strength, less permeable concrete and higher precision on cover, has resulted in fewer early problems with prestressed units compared with *in situ* concrete.

Prestressed precast planks are normally finished with a high strength concrete wearing screed, to BS 8204-2[8.17]. A range of problems associated with cracking and movement of the wearing screed above the prestressed units can lead to leakage. Problems can also occur at the ends of the units, particularly at bearing shelves, where leakage through joints can penetrate into the prestressing curtailment area or cling to the soffits, leading to corrosion of the strand.

The highly stressed strand is more sensitive to loss of section than conventional reinforcement, which can lead to sudden, undetected failure of wires of the strand. It is particularly important to detail and protect these units, particularly at the cut end faces, and inspect the vulnerable units regularly. The potential problems from the penetration of chloride-bearing water into hollow precast units also need to be considered when detailing drainage.

Post-tensioned tendons can be provided in various shapes and forms and comprise two main types:
– fully-bonded (grouted) tendons in ducts or in pre-formed holes (ductless)
– unbonded tendons, normally in polypropylene sleeves encased in corrosion-inhibiting grease.

Compared with pre-tensioned tendons, post-tensioned design allows the tendon depth to be varied along the element. Problems have been found with corrosion of grouted post-tensioned tendons inside ducts, particularly in bridges[8.23]. The research findings highlight the importance of using pressure-tested ducts, appropriate grout, a high standard of grouting practice and checks on the quality of the final grout and effective protection of anchorages by waterproof mortar and/or protective coatings.

8.2.5.5 Other embedded metals

Electrical contact between dissimilar metals, particularly between uncoated reinforcement and stainless steel, lead (sometimes used around drains), brass, copper (also used as flashing materials) and bronze must be avoided. These metals can promote galvanic corrosion of reinforcing steel if they are in electrical contact with it and the surrounding concrete becomes contaminated with chloride ions. Particular care is needed with the detailing of the many fixings into the concrete that are often required in car parks. It is also important to isolate galvanised or aluminium elements from non-galvanised reinforcement, as the galvanised coating or aluminium element will corrode sacrificially.

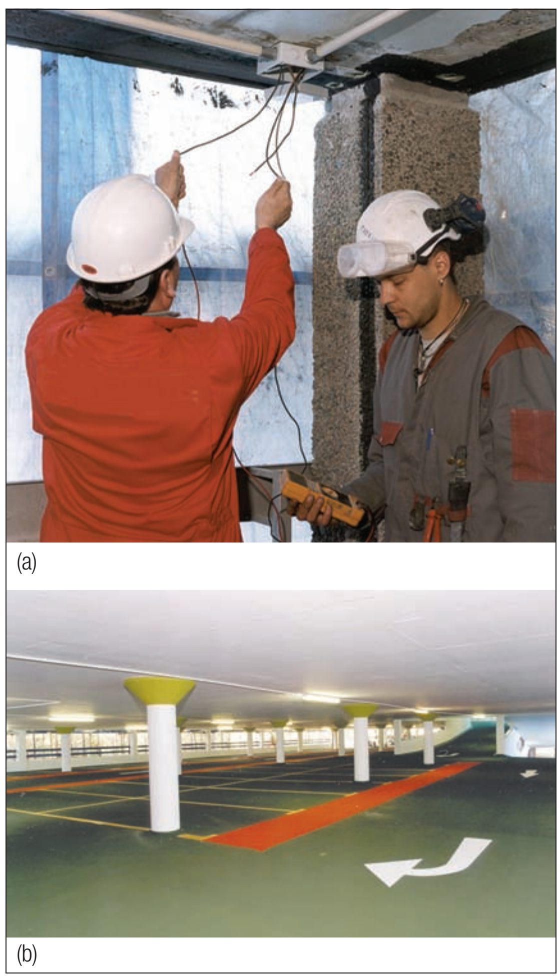
Embedded metal electrical conduit can adversely affect the structural performance of concrete, as ducts may become a route for chloride ion ingress. Steel conduit with insufficient cover can rust and unprotected aluminium conduit can be susceptible to severe corrosion in moist concrete. It is recommended to fix metal conduit to the concrete surface, rather than embed it, or to use embedded plastic conduit.

8.2.5.6 Controlling electrochemical corrosion

Cathodic protection (CP) of reinforced concrete is being used increasingly for new build structures in extreme exposure conditions to prevent corrosion, including bridges, tunnels and other structures with long service lives exposed to seawater conditions and for car park structures in saline ground. It is also used frequently for the repair of existing structures, including car parks.

The performance requirements of CP systems are set out in BS EN 12696[8.24], with further guidance and interpretation given in The Concrete Society *Technical Report 36*[8.25]. For cathodic protection to be effective, all the steel reinforcement in each area must be electrically continuous and not surrounded with any electrically-isolating material. This is not normally a problem, as electrical continuity is achieved in conventional cage construction through tie wire and physical bar contact. Special consideration is needed if the structure comprises discrete precast elements, which would have to be electrically connected together, or where the structure contains high tensile (prestressing) steel[8.24].

With these checks complete, a circuit is completed between the reinforcement and an anode system using the cover concrete as the electrolyte, which renders the reinforcement cathodic relative to the anode and therefore unable to corrode. The power supply for the CP system is usually either an impressed current from a low power 12V supply or from the sacrificial corrosion of a metal anode such as zinc. With a final coating, the CP system is virtually undetectable in both new build or repair situations (see Figure 8.2).



(a) (b)

Figure 8.2 (a) Installation of discrete anode systems followed by (b) application of cosmetic and protective coatings

8.2.6 Non-ferrous reinforcement

Quality-controlled, pultruded fibre-reinforced plastic (FRP) bars are now available as a non-ferrous alternative to steel bars. Early experience indicates that these materials offer high durability in aggressive chemical environments, including salt and fuel contamination. Design guidance for the use of FRP reinforcement is contained in the Institution report *Interim guidance on the design of reinforced concrete structures using fibre composite reinforcement*[8.26].

Unlike steel reinforcement, FRP bars do not require a cement-rich, highly-alkaline environment for their long-term corrosion protection. Some fibres (e.g. glass) are sensitive to the alkali in concrete and fibres incorporated in polymers can become damaged in the damp highly-alkaline conditions of concrete. If such fibres and polymers are to be an effective replacement for steel, care needs to be taken to match thermal effects, stiffness, moisture movement and strain to failure parameters.

8.3 Structural steel

8.3.1 Introduction

Steel may be used as an alternative to reinforced concrete for framing, in composite design or for concrete-filled steel columns. All-steel framing and decks are also used, particularly for demountable car park construction.

8.3.2 Corrosion protection

Corrosion protection recommendations for structural steel above ground are contained in EN ISO 12944-4[8.5]. No specific guidance is given for protection of structural steel for use in car parks.

Where exposure to chloride ions is expected, either due to run-off or direct exposure from sea spray, then the car park durability design needs to address this enhanced corrosion risk. In particular, consideration is needed of the selection of steel components and detailing to provide appropriate corrosion protection and to avoid mixing different types of steel or metals leading to bi-metallic corrosion.

Primary requirements of the design are to prevent exposure of the steel frame and steel fixings to direct/indirect salt exposure and impact damage and to meet fire requirements. Where these have been achieved, normal steelwork painting systems for outdoor exposure can be used, subject to consideration of fire protection.

Where there is a risk of direct salt exposure, such as at the base of steel columns adjacent to driveway areas, the higher standard of paint specification used for bridge steelwork may be more appropriate, as set out in EN ISO 12944-4[8.5].

In extreme exposure conditions, the life expectancy of the paint protection system may not be as long as the design service life of the car park and programmes of planned maintenance painting may be required at deteriorating areas identified from inspections (see Chapter 11).

Particular problems can arise where steel elements enter concrete, creating an interface that cannot normally be inspected. Steel corrosion can be particularly severe where cracking develops in the concrete at the junction, creating a downward crevice into which organic matter and/or salts can concentrate. This maintains the damp conditions that accelerate corrosion of bare steel. Corrosion can also arise with fixings into holes having cavities or with poor-quality mortar infill that rapidly carbonates. Also, as the surface layers of concrete become carbonated with time, they lose the alkalinity that protects the steel from corrosion.

Corrosion protection on embedded steel must be continued into the concrete for at least the specified depth of cover for reinforcement. Slots (typically 10mm wide) should also be provided in the concrete at the junction with the steelwork to receive mastic sealant to BS 6213[8.27], which should be regularly inspected and maintained.

Bolts into the slab or columns for barriers and cladding fixings, etc., are similarly at risk. The choice of details for barrier and cladding fixings should take into account the ease with which such elements can be removed for inspection and replacement if there is a risk of deterioration.

8.3.3 Composite concrete and steel decking

8.3.3.1 General

Profiled galvanised steel sheeting is often used as permanent soffit formwork for reinforced concrete slabs which act compositely to provide external tensile reinforcement for the slab. It is also used for car park decks and ramps where the risk from corrosion is low, with particular care being taken to provide good falls for drainage and/or waterproofing to the slabs. In such cases, the Steel Construction Institute's *Advisory Desk Note AD201*[8.28] states it is desirable to use the metal decking as permanent formwork only, i.e. not as external tensile reinforcement. Even if it is non-structural, corrosion of the steel decking will still be unacceptable as a service criteria and therefore it should only be used if it can be appropriately protected and maintained.

The live traffic loading and low concrete thickness both give rise to a greater risk of cracking in the lightweight construction than would be the case for the more conventional applications of composite decking in offices and other building applications, where cracking would be of little consequence.

With car parks built in areas where de-icing salts are used, or where there are other chloride sources, the chloride ions will percolate through cracks in the concrete slab and the salts will become trapped between the concrete and the steel sheeting. This can lead to severe corrosion of the permanent soffit formwork. Corrosion damage on the upper, hidden surface of the decking is very difficult to monitor and rectify and may reduce the life expectancy of the slab before major maintenance is required.

For these reasons, additional attention to detail is needed when metal decking is used for car parks and good drainage measures must be used to shed water from the surface, along with using elastomeric waterproof membranes reinforced over cracks (see Section 8.6) to prevent chloride ion penetration. For continued satisfactory performance, the membrane will need to be inspected and repaired or replaced promptly if defects form in it.

8.3.3.2 Fire protection

Extra considerations are required for steel elements that are likely to become wet in service from rainfall or splash, which will compromise certain fire protection systems and/or lead to a build-up of moisture and chloride salts in the fire protection, presenting a possible corrosion risk to the steel.

8.4 Basements and buried structures

The deterioration processes for car park ramps and decks built below ground are similar to those for above-ground structures described in Section 8.1, subject to the following specific considerations:
– Soil and groundwater conditions may pose a risk of sulfate attack on the concrete.
– Brackish or saline groundwater can be concentrated at the inside face of reinforced concrete walls and base slabs, leading to chloride ion attack of the reinforcement.
– Bacterially active clay soils can form sulfate and acid by bacterial interaction with harmless sulfides and enhanced protection may be required.

Reference to standard durability provisions in BS 8500[8.2] provides the necessary guidance on how to design for these specific forms of exposure to be found with car parks below ground.

The Institution report[8.29] on basement structures provides comprehensive guidance on other aspects of below-ground construction.

8.5 Concrete finishes

8.5.1 General

The concrete floor of a car park should be serviceable and resistant to wear from wheeled traffic. Puddles, crude irregularities, cracks and stains will attract the attention of the driver and passengers. Puddles of water that contain chloride ions from de-icing salts will also pose a threat to the durability of the structure.

The designer would hope that car park users never notice the floor surface profile, the appearance of which can have an important influence on the customer's reaction to a car park. Uneven, heavily tamped surface finishes will be uncomfortable to walk on in soft-soled shoes and make manoeuvring trolleys more difficult. A smooth trowelled surface has less skid resistance than a textured finish. Power trowelled surfaces are exceptionally smooth and of low skid resistance and increase the levels of tyre noise in turning areas. The surface should be suitable for the application of traffic direction and bay markings.

It should be noted that vehicle speeds in car parks should be low and, even in the wet, skid resistance may not be as critical as in normal highway design.

Concrete surfaces of consistently good appearance can only be achieved with consistent materials, timing and surface finishing processes. Even minor changes in day-to-day methods cause irregular textures and patterning that detract badly from the appearance of a floor (see also Chapter 10).

A concrete deck should be designed and detailed, specified and constructed to drain effectively, thereby preventing ponding of water on the surface. The positions of construction joints need to be well planned, as they are the points of weakness where leaks may occur. It is prudent to locate vulnerable details such as construction joints away from areas likely to be subject to water collection and run-off. This approach assumes that decks between planned joints are uncracked and that any construction joints that open up because of shrinkage or temperature change will be sealed later as part of routine maintenance. Experience indicates that unplanned non-structural cracking of car park decks is a common problem and conservative design is needed to allow for shrinkage, creep and thermal movements and to prevent unplanned restraint: a common problem is caused by fixity of the deck to rigid stair cores which restrain movement and induce cracking. Proper design for movement is essential – see TR67[8.30].

If a concrete deck is not protected by a membrane (see Section 8.6), salt ingress will in time penetrate into opened construction joints and cracks, leading to reinforcement corrosion that will cause structural weakening and spalling damage that is expensive to control and remedy.

Where significant cracks (greater than 0.3mm) occur in the concrete deck or ramp, these should be sealed to prevent water penetration. If the crack is measured and shown to be passive, such that no future movement is expected, repair can be made using a structural resin certified to BS EN 1504-5[8.31] that will transmit force (Category F). However, where movement is reversible or seasonal, care must be taken to ensure the crack will not simply re-form alongside the re-bonded crack and a ductile resin (Category D) or swelling and foaming resin (Category S) should be used. Alternatively, where the crack is relatively linear, a mastic-sealed formed joint may be cut into the slab, by saw-cutting a parallel-sided chase over the crack.

BS EN 1504[8.31] is a performance standard for products and systems used in construction, including new build as well as repair works. Products and systems complying with the standard receive a CE mark certifying among other things that it meets the performance requirements, it has an approved quality assurance scheme in place and it meets regulations for health and safety and the environment.

Workmanship on site for the preparation and use of injection resins is set out in BS EN 1504-10[8.31].

8.5.2 Types of floor finish

8.5.2.1 General

Even when water ponds only occasionally on intermediate floors, blotchy, dusty patches can result after drying out. In the direction of fall, a standard of regularity at least equal to that of concrete floor screeds to SR2 given in BS 8204[8.17] is recommended; similar regularity tolerances are given in BS EN 13670[8.32]. BS 8204 requires a maximum

Table 8.3 Concrete finishes for concrete and common applications

Type	Normal application	Examples
Formed surfaces		
Basic finish	Where no particular requirement is needed	Foundations
Ordinary finish	Where not of visual importance or to receive applied finishes	Areas with applied render finish or unseen surfaces such as inside ducts or lift shafts
Plain finish	Where visual effect is of some importance	Areas seen occasionally and areas with prepared, direct painted areas where there are some particular requirements
Special finish	Where special requirements have to be given	Areas where surface regularity and/or colour are important
Unformed surfaces		
Basic finish	A closed uniform surface produced by levelling. No further work is required	Area to receive a screeded finish or other applied finishes
Ordinary finish	A level uniform surface produced by floating or similar process	Area for false floor and other applied floorings
Plain finish	A dense smooth surface produced by trowelling or similar	Normal warehouses and factories, areas of plant rooms and work areas without other finish than paint
Special finish	A surface where special requirements have to be given for further working of another finish	Areas of warehouse floors for special trafficking

Note
This table is taken from BS EN 13670[8.32].

permissible departure from a 2m straight-edge resting in contact with the floor to be less than 5mm. Abrupt depressions of any depth over 3mm should be avoided (e.g. a boot imprint), particularly where a waterproof membrane is to be applied (see Section 8.6). Regularity is largely determined at the striking-off stage, since the finishing techniques change merely the character of the upper surface and remove minor imperfections in the surface.

Special care is needed with the levelling and finishing of certain types of construction if ponding is to be avoided and mid-span propping may be necessary:
– Composite concrete and steel decking can be prone to mid-point defection as concrete is added and guidance on this is given in the *Good Concrete Guide 5*[8.33].
– Prestressed precast concrete planks can also deflect as the concrete wearing screed is added and the pre-camber at mid-span reduces.
– Longer term creep and shrinkage can also increase mid-span deflections over time.

Attaining an acceptably smooth surface is not a separate stage in the floor casting process. Success comes from setting out carefully the intended finished levels, placing concrete evenly, compacting it uniformly and controlling the amount of surcharge ahead of the straightedge when striking off. Regardless of the texture specified, finishing should be a separate process that follows striking off.

Table F4 in the new European Standard BS EN 13670[8.32] gives guidance on executing concrete works and discusses types of finishes, as summarised in Table 8.3. No specific guidance is given in BS EN 13670 for the unformed surface finish of car park decks and ramps and these need to be considered carefully by the designer, with trial areas specified as required. The traditional standard for car park surfaces that do not require membranes or other finishes is either a 'Basic' or an 'Ordinary' finish, as defined in Table 8.3, without power trowelling.

8.5.2.2 Finishes for car park deck and ramp surfaces

The following recommendations are for unformed surfaces (UF) using the type definitions in Table 8.3.

UF1 – Textured finishes
This provides a fine texture onto a smoothed concrete surface that has been floated to the correct regularity and falls using either a skip float for a 'basic finish', or a power float for uniform 'ordinary finish', as defined in Table 8.3. Texturing improves the appearance and enhances skid resistance.

Texturing is applied by roller or by stiff brush once the concrete has begun to stiffen. The roller can be a cylinder with projecting studs to produce a pattern of indentations or an open cylinder made with expanded metal to produce a weave pattern. Brush-worked finishes are produced with a stiff wire or bristle brush.

These finishes can suffer from variations in uniformity from pour to pour and unless specified carefully can adversely affect free drainage.

UF2 – Smooth but unpolished surface
This is a 'plain finish', as defined in Table 8.3, and is a smooth but unpolished surface, sometimes called a matt trowelled finish. This is normally required only in areas where a car deck membrane is to be applied or for forming water-collecting channels. The floor smoothness should be appropriate to the proposed type of waterproof membrane. For a uniformly smooth surface, a power trowel technique is normally used but with minimal passes so that polishing does not occur. The exact requirement should be checked with the manufacturer of the waterproof membrane.

As a minimum, this surface would normally be prepared by vacuum shot blasting before applying the membrane, so achieving perfection in the finished surface is not as important as with a plain power-trowelled surface.

UF3 – Power-trowelled surface
Power trowelling after floating is a 'special finish' (Table 8.3) and quickly produces a dense, smooth and hardwearing surface with negligible 'ripple' or 'chatter' marks from the power trowel. Such a surface not only has advantages in terms of ease of drainage and reduced water retention, but also improves the wear and durability of the surface, minimising dusting of the surface. Care should be taken to avoid excessive power trowelling as this can create a weak surface layer.

The surface has a much lower skid resistance than a textured finish, especially when the surface is wet. The surface also causes more squeals from rubber tyres than either UF1 or UF2 finishes. However, it is being used increasingly in car parks, primarily because of its speed and efficiency of finish.

UF4 – Grinding
Grinding can be used as an alternative to wet trowelling or to rectify an unsuitable surface. The machine skims the concrete surface to expose a sound, dust-free and extremely hard surface. Grinding cannot easily correct bad surface regularity but can eliminate the early dusting arising from first use of good concrete or improve a heavily dusting surface that was badly cured.

Before grinding, the effect on the cover should be checked and alternative measures, such as applying waterproof membranes, should be considered (see Section 8.6). Unless combined with vacuum collection, grinding is a dusty process. The cost is reduced when grinding is carried out between 24 and 48 hours after casting. The smooth finish that results will have similar disadvantages to the UF3 finish in terms of skid resistance and tyre squeal.

UF5 – Tamped surfaces
While popular several years ago, the tamped finish is used less often today on parking areas particularly when they can be used by pedestrians. The use of large area pour methods for slabs also make it difficult to provide a uniform tamped finish because of the difficulty of positioning tamping rails. These finishes are normally used for vehicle ramps and circulation areas (see below).

The tamped surface is produced by raising and lowering a compacting beam in its final pass to produce a surface with ridges at a fairly regular spacing of 20mm to 30mm and up to 5mm high. Heavier tamping may produce deeper ridge depths but this may impede drainage and lead to contaminants being trapped at the bottom of the grooves. There is also a tendency for residual bleed on the ridges resulting in dusting during use.

It is often difficult to maintain an even distribution of ridges and uniformity from pour to pour, due to slight changes in the concrete mix. Also the terms light, medium or heavy tamp are hard to quantify in a specification. A trial panel is recommended as a control for the actual works.

8.5.2.3 Abrasion resistance
Resistance of the floor to wear and abrasion will affect the appearance and functionality of the ramps and circulation areas. Power steering has become common even in lighter small cars, increasing the wear of the surface in key manoeuvring areas. Unless abrasion of the surface is considered, uneven wear will occur, with weak, laitance-rich areas becoming quickly eroded, leading to depressions that will themselves lead to other problems including ponding of water on the surface.

Little specific guidance exists on how to deal with surface abrasion and wear in car parks. General guidance on abrasion and wear is given in BS 8204-2[8.17] for direct finished (DF) concrete and concrete wearing screeds (WS). The standard refers to BS EN 13892-4[8.34] which describes a test to measure the abrasion resistance of a floor surface based on wear caused by steel wheels. For direct finished surfaces that receive moderate abrasion from rubber tyred traffic, which would be typical of a car park, the surface class in Tables 3 and 4 is given as AR4/DF (Light duty industrial and commercial), with a maximum test wear depth of 0.4mm.

BS 8204-2[8.17] also covers the abrasion resistance of wearing screeds applied, for example, over precast concrete planks, and recommends the same abrasion resistance as for direct finished concrete (AR4/WS). The standard also identifies the benefits that can be achieved from upgrading the surface by dry shake/sprinkle finishes. The recommendations in BS 8204-2[8.17] assume the concrete surface is a smooth trowelled finish, so the assessment method is not appropriate for ramps or slabs of substantial slope and is normally unsuitable to assess tamped, uneven finishes.

Floor hardeners can be used to reduce surface dusting and improve abrasion resistance. A suitably constructed car park slab or ramp should not require a floor-hardening treatment. The occurrence of dusting depends on the effectiveness of the initial curing of the slab and the severity of the abrasion. In general, more dusting can be tolerated in a multi-storey car park than in most factory buildings, although this will depend on the maintenance programme as well as the standard for dust prevention set by the car park owners.

As an alternative to higher strength concrete or floor hardeners, BS EN 1992-1-1[8.3] advises that for abrasion class XM1 (moderate) a sacrificial layer of 5mm of concrete may be used. This approach could lead to problems of ponding on surfaces with only gentle falls, as mentioned above, and is not normally used for car park structures.

8.5.3 Parking and pedestrian areas

With the exception of vehicular ramps, all parts of the car park should be suitable for both vehicles and pedestrian use. All designated pedestrian areas should be clearly defined and any finishes should minimise the risk of slipping; for example, some waterproof membranes and surface coatings can be slippery when wet. The most common specification for these areas is Type UF1 (non-tamped textured finish), although UF4 (Power-trowelled) finishes are being used increasingly despite the lower skid resistance.

8.5.4 Vehicle ramps and circulation areas

Where vehicle ramps are steeper than 1:10, a Type UF5 tamped surface is recommended, with the grooves in a chevron pattern to facilitate drainage. Brushed (Type UF1) or smooth surface finishes (Types

UF2 to UF4) may not have sufficient traction in wet or icy conditions.

If the tamped finish is too heavy, it will impede drainage and lead to contaminants being trapped in the bottom of the grooves. Because of the lack of compaction in the ridges and the tendency for some residual bleed, this finish can be dusty and will wear unevenly.

Where vehicular ramp and deck slopes are less than 1:10, a Type UF1 finish may be used, unless a car deck waterproofing/wearing membrane is to be used.

A trial panel is recommended as a control for the actual works.

8.5.5 Walls, columns and soffits

Smooth, high-quality plain-finished concrete is most suitable for walls, columns and soffits and can be specified using Table 8.3. In modern car parks, the surface is often given a decorative, anti-carbonation or anti-graffiti treatment to improve appearance (see Section 8.6.4).

Exposed edges of concrete sections should be chamfered to enhance their appearance and to improve safety. Although cast-in galvanised or steel corner guards can do much to protect concrete columns in vulnerable locations, careful detailing is required and unless radiused angles are used, the steel corners can be sharp and pose a risk to persons falling. For this reason, their use should be limited.

Special feature finishes can be used to good effect and can be varied throughout the car park. They should not be abrasive or endanger users of the car park. Where deep profiles are used, the design and installation must be carefully checked to ensure the minimum cover to the reinforcement is maintained.

8.5.6 Basements and buried structures

In general, the finish is similar to that described for walls, columns and soffits (Section 8.5.5) but a special feature finish is often used for effect or for directional assistance, e.g. chevrons can be cast into the surface. Special care is required when selecting paint systems for external walls (see Section 8.6.4).

8.6 Membranes and coatings for concrete

8.6.1 General

Section 8.1 describes various measures for reducing the natural absorptive qualities of concrete, which result in chloride ions being rapidly drawn into the surface. The car park is an interface between the highway and buildings, with cars bringing harmful salts onto the ramps and slabs.

A properly applied and maintained membrane for decks and ramps can be a highly effective means of reducing the risk of chloride-induced reinforcement corrosion providing it is maintained over the life of the car park. For this reason membranes for car park decks and ramps and protective and cosmetic coating systems for walls and soffits are being increasingly used for entrance ramps and slabs, for roof levels and also for intermediate levels.

Coatings may also be applied to beams, soffits, walls and columns to provide both protection and improved appearance. Coatings can be particularly beneficial when applied to the bottom 1m of walls and columns to prevent the penetration of salt-containing water splashed up by vehicles.

Membranes fall into two main types:

- liquid-applied polymer systems that are applied by spray roller, squeegee or trowel and bond onto the concrete surface
- conventional asphalt systems that have a separation layer between itself and the concrete.

Traditionally, asphalt systems have only been used on the roof deck ramps and internal areas over occupied premises, where full waterproofing characteristics are required. Asphalt is suitable for external application and will tolerate damp concrete, high humidity and offer early rain damage resistance during application, as well as having in-service performance that tolerates freezing conditions in winter and high solar gain in summer. Many liquid-applied membranes are now available that also meet these performance requirements.

Increasingly the liquid-applied polymer systems are being used on lower levels, particularly in entrance areas, where salts are brought in from the road outside. Intermediate level membranes have a lower performance requirement and are often thinner, less flexible and more vulnerable to traffic wear and damage than those used on the exposed roof decks. If lower performance intermediate level membranes are used, it is prudent not to reduce the concrete durability requirements significantly (see Section 8.2.3).

Decisions on the use of membranes and coatings will usually be based on a cost benefit comparison, but less obvious factors include:

- Typically, membranes and coatings will have to be re-applied in whole or in part every 10–20 years leading to a loss of revenue due to closure of sections of the car park. Solar radiation, de-icing salts, fuel and oils, shrinkage hardening and embrittlement can all reduce the life of membranes. However, experience has shown that thin membrane systems may require to be re-applied within 5 years of installation.
- Membranes and coatings can significantly enhance the appearance of the car park, brightening it considerably.
- Concrete durability improvements, such as mix changes and enhancements, include both capital costs and on-costs for contractors using difficult or unfamiliar materials and methods.
- Sealants generally have a shorter life than the structure. The relative maintenance cost of the sealants should therefore be taken into account when deciding which method of waterproofing to adopt (see also Chapter 9).
- The membrane or coating may be sensitive to excess moisture in the surface (from recent rainfall) and to the concrete internal relative humidity (which should typically be no greater than 75%); allowing adequate drying times can affect the construction programme.
- Local defects or cracks in joint seals, membranes and coatings can allow chloride ion ingress and in time corrosion in the reinforcement below. It is therefore essential to maintain their integrity at all times if their full value is to be obtained.

– Ease of application and maintenance, with liquid-applied membranes requiring more preparation, a drier concrete surface and more coats than a mastic asphalt, but are likely to be more attractive and can be longer lasting and are of lighter weight.
– The relatively short life and high maintenance cost of top deck waterproofing systems should be compared with installing a traditional roof structure to achieve effective weather protection[8.35].
– The system should hold an independent test certificate covering the intended use and relevant characteristics when applied to concrete (e.g. EOTA certification or equivalent).
– The manufacturer should be able to demonstrate the successful application of the system on similar sites that have been in place for at least five years. This should be backed by independent performance-related documentation.

These points should be discussed with the client and a strategy agreed as these are long term considerations.

8.6.2 Deck waterproofing – general

Car park owners, operators and users all have an interest in preventing water penetrating through roofs and floors of car parks. Water leaking through cracks and failed joints can result in damage to car paintwork, particularly when aggravated by local ponding above. Water passing through cracks in the structure or around features such as holding-down bolts for vehicular restraint barriers, drainage outlets, etc., will lead to rapid deterioration of the structure. Ponding of water may also result in a health and safety issue if it freezes, causing cars to skid or pedestrians to slip, leading operators to add their own de-icing salt to the decks and ramps.

For any waterproof membrane to be fully effective, a carefully developed and effective drainage scheme, particularly for exposed decks, is required (see Section 4.3.8).

Special consideration must be given to waterproofing a car park deck that forms the roof to shops or commercial premises. The cost of eradicating water leaks when the car park is in use normally greatly exceeds the additional preventive expenditure required at construction stage.

Where car wash facilities are to be operated inside car parks, decks and joints should be waterproofed and extra provision made for drainage (see Section 9.2.3).

Before a membrane can be applied, the concrete surface must first be checked and approved as suitable to receive the system. Correct falls must be provided and areas of potential ponding rectified by compatible surfacing treatments or grinding down of high points. Car park deck membranes are not normally suitable for permanent immersion conditions and long exposure to immersion can result in premature failure.

Good preparation of the concrete is an essential prerequisite to providing lasting protection by a membrane. At non-structural cracks or at construction joints, substantial movement can occur, as the car park responds to temperature changes, typically moving by 0.5–1mm. Long term shrinkage of the concrete can also cause cracks to open further and structural flexure of the slab may cause rapid opening and closing.

With liquid polymer systems, it is unlikely a bonded waterproof membrane will be able to bridge over or withstand substantial movement of non-structural cracks unless it is specifically reinforced at these locations. Unbonded mastic asphalt construction may also fail over wide cracks, particularly if there is reversible movement.

With cracked concrete, it is normal to seal or re-bond the crack or joint with a resin system complying with BS EN 1504-5[8.31] before the membrane is applied (see also Section 8.5). Care must be taken to choose the correct flexibility of resin, to ensure a new crack will not simply form alongside the re-bonded crack.

Alternatively, a mastic-sealed formed joint may be created over the joint (see also Section 8.5).

If the cracks are fine (<0.3mm), the manufacturer may advise that they be filled and the membrane be locally thickened (a stripe coat) over the line of the crack, sometimes reinforced with fabric. Providing a debonded strip over the line of the crack may also help to accommodate movement, although with power steering in most cars this layer can sometimes be ripped off the surface.

Alternatively, where cracking is expected, proprietary movement joint systems should be provided, terminating the membrane either side of the joint (see Section 9.3).

Concrete detailing should take account of any waterproof membrane system to be used, avoiding sharp corner edges and specifying the use of 45° fillets to upstands etc., as necessary. Upstands should not normally be coated to any appreciable height, as these may be subject to damage from vehicles and trolleys.

8.6.3 Concrete deck waterproofing by use of a membrane

8.6.3.1 General

A car park waterproof membrane should have the following properties:
– Capacity to bridge live structural cracks (up to 0.3mm wide) which open up after waterproofing and may be subject to rapid cyclic movement.
– Chemical durability and compatibility with joint materials with which it comes into contact.
– Capacity to be bonded to concrete and/or capable of performing unbonded.
– A surface that is skid and slip-resistant and capable of resisting the abrasion and loadings from vehicles and trolleys.
– Tolerance to being laid during local weather and/or to a damp concrete surface.
– Resistance to direct solar exposure and maintaining its flexibility under freezing conditions (top decks of car parks only).

8.6.3.2 Liquid-applied polymer membranes (bonded)

The membrane element of a system for vertical upstands and horizontal surfaces normally has a minimum dry film thickness of 1mm and is formulated to bridge both live cracks up to 0.3mm wide and narrow passive cracks (<0.5mm). The membrane must be capable of accommodating rapid cyclical movement at low temperatures without splitting, which is verified by the crack bridging test of BS EN1504-2[8.31].

A good ductile and resilient liquid-applied membrane system usually comprises at least three layers: primer, waterproof layer and wearing surface incorporating non-slip aggregate.

The final surface finish should be skid and slip-resistant and ideally available in different light-stable colours to differentiate between parking bays and traffic aisles. It should be checked that the material used for line markings is compatible with the membrane system as many systems use line-marking materials of the same generic type as the membrane.

The surface finish must be designed to withstand abrasion and loadings from pedestrian and vehicular traffic normally expected in a car park. The system should also be capable of dealing with the variable abrasion conditions at turning areas, ramps, aisles, parking bays and kerb upstands. Suitable protection to edges of kerbs, etc., may be required if the membrane is not capable of resisting scuffing from vehicles.

It should be noted that BS EN 1504-2[8.31] was not specifically intended for car park deck membranes and is commonly used for coatings applied to non-trafficked surfaces such as walls and soffits of slabs. For the severe exposure conditions normally in car parks, the minimum performance requirements of BS EN 1504-2 may not be relevant. Further guidance on the selection of appropriate generic types of coatings and their application is contained in the Liquid Roofing and Waterproofing Association's Code of Practice[8.36].

Workmanship for liquid-applied membrane application on site is set out in BS EN 1504-10[8.31]. The concrete surface will need to be finished to a smoothness suitable for the type of membrane to be applied, as set out by the manufacturer. As this type of membrane is fully bonded, it is vital that the surface is properly prepared by vacuum shot blasting or other similar means to remove all oil, grease, dust and laitance before laying a membrane; this operation is normally the responsibility of the waterproofing contractor. During construction, the type of curing membrane to be used on the concrete should be carefully considered for compatibility with the membrane system.

Water vapour trapped in the concrete substrate below a roof deck membrane can lead to blistering and debonding in the heat from the sun and it is imperative that there is a path for water vapour to escape. For thin concrete slabs with uncoated soffits, moisture and vapour can escape from below. However, if the slab is thick, has a vapour-proof polyethylene membrane beneath, or a steel permanent shutter, the surface membrane should be capable of breathing and allowing trapped water to escape without causing blistering. In this specific case, the water vapour Class should be reduced from Class III to Class II or Class I.

While waterproof membranes applied to the top deck and top ramps receive the worst exposure conditions, including thermal movements that induce crack opening and solar radiation that accelerates embrittlement, intermediate deck and ramp membranes receive less extreme exposure. The appearance of the car park can be greatly enhanced with intermediate deck coatings. Some of these are not full elastomeric membranes and often do not have the same crack-bridging capabilities as the spray-applied or thin, poured car deck membranes. Such deck coatings would not be expected to be fully waterproof, unless so specified. Such materials offer limited protection against chloride ion ingress but enhance the environment and dynamics inside the car park. Other key properties, including adhesion to concrete and resistance to shearing under car tyre action, should not be compromised.

Deck coatings and decorative paints (see Section 8.6.4) can be highly effective in maximising illumination and reflectance in basement areas. Appropriate ventilation is needed when these are to be applied in confined spaces (see Section 8.6.3.4 on health and safety).

8.6.3.3 Mastic asphalt

Traditional mastic asphalt waterproofing can provide a cost-effective solution, provided care is taken during preparation and application. The material is particularly sensitive to reflective cracking and so care is needed to seal passive cracks and fill depressions that could form points of failure. Guidance on mastic asphalt wearing courses is given in BS 8204-5[8.37].

Mastic asphalt should not be bonded directly to the concrete deck. An underlay of sheathing felt should be used or, for partial separation, a felt or mat of woven glass fibre. This is important to prevent reflective cracking over moving cracks in the concrete.

On ramps where the gradient is less than 1:10, mastic asphalt can be used provided it is bonded to the concrete. The concrete surface should be prepared by tamping or stippling to provide a key for the asphalt. Special care and detailing is needed at the intersection of ramps and floors.

The life of the mastic asphalt depends on the formulation, with thin systems having an expected life of up to 15 years, whereas 20 years is available for some polymer asphalt systems[8.35].

Asphalt materials can yield under the combined effects of loading and increase in temperature. They are not suitable as a founding layer for impact-resistant barriers and consideration should be given to the use of plinths to raise any baseplates and fixings above the level of the waterproofing. When laid over insulating roof screeds subject to solar gain, asphalts may overheat and soften in service, leading to splitting and rutting.

Bituminous materials should not be used with polysulphides, since uncured polysulphide and bitumen are mutually soluble, leaving the cured material weak at the interface; also, tar-based surface treatments are unsuitable over membranes of synthetic rubber. All materials should be checked for compatibility and evidence of successful previous use.

8.6.3.4 Health and safety

Where membranes are to be applied in confined spaces, fumes can build up and respiratory equipment or forced ventilation may be required. Reference should be made to the manufacturer's Material Data Safety Sheet and safe usage guidelines to specify the works safely. When considering membranes, fire resistance should be taken into account. CE marking of liquid-applied membranes to EN 1504-2[8.31] includes testing to establish the Euroclass for fire resistance to EN 13501-1[8.38].

8.6.3.5 Maintenance

Regular inspection is important to ensure that the waterproofing is fulfilling its requirements. Where required, maintenance/repair should be carried out strictly in accordance with the manufacturer's/installer's recommendations. It is essential to clean and inspect the waterproofing/wearing membrane annually and record any proposed maintenance.

8.6.4 Decorative and protective coatings

8.6.4.1 General

Good-quality concrete with adequate cover to reinforcement, complying with BS 8500[8.2] does not require any special paint finish for protection against the normal conditions of exposure. However, car parks are often painted to enhance their appearance and improve the lighting levels. The use of bright colours, painted walls, decks and soffits can do much to obviate dark areas and reduce opportunities for crime. Guidance on painting concrete is given in The Concrete Society's *Technical Report 50*[8.39].

Special consideration is required when painting external basement walls, depending on the level of the water table. If the concrete is likely to be saturated, the paint system must have a low water vapour diffusion resistance if blistering and failure are to be prevented. This is a performance requirement for decorative and protective paint systems within the scope of BS EN 1504-2[8.31].

Performance requirements for concrete coating systems are included in BS EN 1504-2[8.31], (Principle 1, Method 1.3) and should be specified to be CE marked in accordance with this standard.

8.6.4.2 Decorative coatings

Most decorative paint can be applied by brush, roller or spray. Good surface preparation is vital if the finish is to be a success. All surfaces should be clean, dry and free from cracks or defective areas, as set out in BS EN 1504-10[8.31]. All cracks and defects should be repaired before treating the surface with a fungicidal wash, if this is required. When the concrete surface is porous, special primers may be needed before the final coat is applied.

Special anti-graffiti paint systems are available to protect vulnerable areas of the car park; these either form an impervious seal that can be cleaned with solvents or are sacrificial and can be easily removed and replaced.

8.6.4.3 Protective coatings

These coatings have been specially formulated to resist acidic gases, chemical attack and water ingress and are within the scope of BS EN 1504-2[8.31]. Surface preparation is similar to that for decorative painting, although where anti-carbonation coatings are required it may be necessary to fill blow holes and imperfections before painting to provide a continuous film of paint.

8.6.4.4 Intumescent coatings

Intumescent coatings provide fire resistance to steel-framed structures. Consideration needs to be given to the moisture content and preparation of the steel for successful application. Advice should be sought on the suitability of coatings and, in particular, their resistance to abrasion. Accidental damage or vandalism could remove the coating and thus compromise its performance in a fire.

8.7 References

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9 Drainage and joints

9.1 General

The investigations carried out on car parks that have begun to deteriorate before reaching their expected life to first major maintenance have often found that poor drainage and joint leakage are implicated. If the decks and ramps are not laid to proper falls that encourage water containing de-icing salt to drain away quickly, chloride ions quickly penetrate the surface. Therefore it is recommended that all decks are provided with provision for surface water drainage to cater for wind blown rain, water carried in by cars and for periodic washdowns as part of the maintenance regime. If the falls are correct but the gully designs are such that they block easily or are not maintained, the result will be the same.

Similarly, joints in the ramps and decks must be properly detailed and maintained, otherwise chloride ion penetration will occur at the slab edges or the cut edges of precast beams. In severe cases, water will run along the underside of the slab, which may have been detailed for a less severe exposure (i.e. it was anticipated that the joint would be maintained and so the beam was not expected to come into contact with de-icing salts) and therefore have less cover to the reinforcement.

Correct specification and maintenance of drainage and jointing systems is therefore extremely important for the long-term durability of the car park.

9.2 Drainage

9.2.1 General

Well designed and properly maintained drainage is essential to ensure that all water deposited on the exposed surfaces is rapidly discharged through an effective drainage system. To achieve this, all drainage outlets should be recessed below the finished top surface of the concrete to ensure that no ponding occurs. Standing water is detrimental to both the structure and the operation of the car park. In the UK, drainage is designed to BS EN 752[9.1] and BS EN 12056[9.2]; local standards will apply in other countries. Key issues for consideration, beyond those in the standards, are discussed in the following Sections.

9.2.2 Required falls

The specified minimum falls to the finished surface of the roofs and floors are normally based on the following:

– the quantity of water likely to fall on the area under consideration
– the texture and accuracy of the floor finish
– the sensitivity of the structure to deflection and creep
– the anticipated efficiency of any waterproofing.

It is recommended that falls in the finished surface should be a minimum of 1:60 at all levels of parking except where particularly smooth, plane surfaces with short drainage lengths can be guaranteed. This minimum requirement applies to all trafficked surfaces, irrespective of whether the area is covered or exposed – the more generous the fall the greater the ability to shed water and to prevent harmful chloride salts saturating the concrete. User comfort also has to be considered and falls greater than 1:20 or sudden changes in fall should generally be avoided. The decks in basement and underground car parks should also have a minimum fall of 1:60 to allow for washing down.

9.2.3 Parking areas

The roof is the most exposed area and the drainage should be designed in accordance with local rainfall statistics. In storm conditions, some build-up of water is inevitable and the edges of decks should be designed to contain water and prevent wetting of the decks below. Intermediate floors are wetted by rain blowing through partly open sides and by snow and ice melting on parked cars. The quantity of water deposited on intermediate decks from this source is likely to be about 2 litres per parking space per parked vehicle in the UK; this also depends on the average stay, with shopper car parks having short stays and more water, while commuter/business car parks will often have a full day stay per bay. Proprietary drainage network analysis programs and methods are used to design drainage systems.

Although the direction of fall depends on the geometry of the car park, falls and drainage channels should be designed to suit the type of structure and to take account of any sensitive structural details. Provided the drainage is well designed, it is not essential to lay the fall of the decks outwards towards the exterior of the car park.

Where car-wash facilities are to be operated or allowed inside car parks, allowance should be made for higher than normal discharges of water and salt through drainage channels and associated pipework.

9.2.4 Ramps and circulation areas

Falls towards ramps should be avoided but, if the geometry of the car park does not allow this, drainage paths should be intercepted to avoid water discharging onto the ramps. Adequate drainage should be provided at the bottom of ramps, particularly at roof and entry levels, to remove water swiftly and prevent ponding and possible freezing over.

It is often the case that ramps are finished with an exaggerated tamped finish to increase traction and skid resistance. This can cause water and melting ice to pond in the small depressions. If a heavily tamped finish is a requirement, then it is recommended that chevron or diagonal tamping is used to facilitate the rapid drainage of any water.

Operators will periodically wash down all levels of the car park and may operate car-valeting services inside the car park. Therefore drainage should be provided at the bottom of all ramps.

9.2.5 Pedestrian areas

Where decks are laid to falls, pedestrian areas should ideally be situated at the higher end of the gradient. Staircases, lifts, etc., should be above general deck level or discreet drainage should be provided to intercept water flowing towards staircases and lifts.

Drainage channels, slots and gratings, etc., should be dimensioned to minimise risk to pedestrians tripping and stumbling.

9.2.6 Piped systems

Piped systems should be arranged to be as unobtrusive as possible, both externally and from within the car park. Wherever possible, downpipes should be located on the shielding side of the column to avoid traffic impact and fixed so that they do not encroach into the adjacent parking space. Protective hoops or shielding may need to be provided where it is not possible to use the structure to shield the pipes. Consideration should also be given to the possibility of additional loading on horizontal pipe runs, arising from vandalism.

It is essential to make adequate provision for access to and rodding of the drainage system. Traps for protection against salt, grit, oil and petrol entering the surface-water disposal system should be provided in accordance with the requirements of the local authority.

9.2.7 Interceptors

Interceptors are required to prevent spillages of oil and petrol from entering the main surface water drainage. Petrol interceptors should be located outside the car park but if this is not possible they should be in positions that are easily serviceable without disrupting the operation of the car park. Where deep interceptors are located inside the car park, consideration must be given to access and loading requirements for maintenance vehicles.

9.3 Joints

9.3.1 General

The structural requirements for joints are described in Section 5.7.

In locating and selecting the type of movement joints, account should be taken of the need to maintain drainage falls and to minimise ponding. Ideally, movement joints should run parallel to the drainage falls and preferably be located at the higher end of sloping surfaces.

9.3.2 Proprietary movement joints

Proprietary movement joints should be suitable for trafficked areas but should not impede traffic flow or impose excessive dynamic loading on the structure. Joints in a waterproofed area should be compatible with the system of waterproofing and should be watertight over their entire length, including the ends.

9.3.3 Sealants

9.3.3.1 General

Joint fillers and sealants should be compatible with the size of joint, the magnitude of movement, the dynamic effects of traffic and any spillages during normal use of the car park. Local codes will give suitable joint designs for the range of movement expected; in the UK, design is to BS 6093[9.3] and the sealant should comply with BS 6213[9.4].

The material used to seal joints in structures can be conveniently divided into two categories: pre-formed materials and *in situ* compounds. To be satisfactory, both groups should possess the following characteristics:

- For external use and where a waterproof joint is required, the sealant must be, and remain, impermeable over the full range of anticipated movement (see Section 5.7).
- The joint must be durable, as periodic removal may be difficult and expensive.
- Ideally, the joint should have a similar design service life to that of the building, but this is rarely achievable. Consideration must be given to the consequences of joint failure and means of its replacement.
- It must be bonded to the sides of the groove in which it is inserted. In practical terms, this means that the sealant should bond well to damp concrete.
- As the joint opens and closes, the sealant must deform in response to the movement without loss of integrity.
- It should be comparatively easy to install in all weather and site conditions relevant to the location of the structure.
- Joints used with waterproof membranes should be designed in conjunction with the waterproofing membrane manufacturer. The contractor laying the membrane should also be responsible for providing any joints, to avoid contractual difficulties.

The sealant, whether pre-formed or *in situ*, is normally accommodated in a rebate in the concrete. The shape and dimension of the groove are important in ensuring a satisfactory and durable seal. A rule-of-thumb method for sizing a joint is that the depth of the groove to be filled by sealant should be about half the width, but this depends on the specific materials used. For grooves that are too deep, pre-formed foam beading or similar materials are used to pack out the joint. For butt joints in slabs, provision must be made to prevent the filler material from falling through when the joint is open.

9.3.3.2 Pre-formed materials

Pre-formed materials are often based on neoprene, which is considerably cheaper than *in situ* systems such as polysulphide and silicone rubber. However, when the cost of accurately forming the joint to receive the pre-formed neoprene strip is taken into account there is usually only a small cost difference.

9.3.3.3 *In situ* compounds

In situ compounds are divided into a number of types, the thermosetting materials being the most common.

9.3.3.4 Thermosetting compounds, chemically curing

Materials in this category are one-or two-component compounds that cure by chemical reaction to a solid state from the liquid or semi-liquid state in which they are applied.

High-grade materials in this class are flexible and resilient and possess good weathering properties; they are also inert to a wide range of chemicals. These compounds include polysulphides, polyurethanes, silicone rubber and epoxide-based materials. They can be formulated to have an extension-compression range in excess of ±25% over a temperature range from −40°C to +80°C.

While thermosetting compounds are considerably more expensive than mastics and thermoplastics (see Sections 9.3.3.6–9.3.3.8), they accommodate far greater movement and are more durable. Some formulations require a primer on the concrete and it is particularly important to ascertain whether the particular product will bond to damp concrete or whether a dry surface is required. Complete adhesion between the sealant and the sides (but not the base) of the sealing groove is essential for a liquid-tight joint. In the UK climate, it is virtually impossible to ensure dry concrete on most sites.

9.3.3.5 Thermosetting compounds, solvent release

Sealants of this type cure by the release of solvents present in the compound itself. The principal materials in use are based on such compounds as butyl, neoprene and polyethylene. Their general characteristics are similar to those of solvent-release thermoplastics, but their extension-compression range is lower, at about ±7%.

9.3.3.6 Mastics

Mastics are generally composed of a viscous liquid binder with added fillers or fibres. They maintain their shape and stiffness by the formation of a skin on the surface and do not harden throughout the material nor set in the generally accepted use of the term. The binders are usually low melting-point asphalts, polybutylene, or a combination of these. They are used where the overriding factor is low initial cost and maintenance and replacement costs are not considered important. The extension-compression range is small and so these materials should only be used where a small range of movement is anticipated.

9.3.3.7 Hot-applied thermoplastics

These materials become fluid on heating and on cooling they become an elastic solid, but the changes are physical only and no chemical reaction occurs. Typical are the rubber-bitumen compounds that are used extensively in many countries. As the sealant has to be applied in a semi-liquid state, it is only suitable for horizontal joints; it is used largely for roads and airfield pavements. The movement range that this type of material can accommodate is greater than that obtained with mastics, but is still small compared with thermosetting chemical-curing elastomers.

9.3.3.8 Cold-applied thermoplastics

These materials set and harden by either the evaporation of solvents (solvent release) or the break-up of emulsions on exposure to air. Sometimes a certain amount of heat is applied to assist workability, but generally they are used at ambient temperature. This type of sealant can accommodate only a small amount of movement; in addition, it hardens with age and suffers a corresponding reduction in elasticity.

9.3.4 Construction joints and non-structural cracking

Unless construction joints are adequately reinforced to prevent opening up due to contraction, it may be necessary to seal the joint, particularly if there is a risk of water ingress and reinforcement corrosion. Similarly, non-structural cracks can open, particularly in response to temperature changes. Although non-structural cracking is an intrinsic feature of reinforced concrete, it nevertheless needs to be controlled to ensure the design service life of the car park is maintained. The subject of non-structural cracking is complex and a good summary of the processes is given in The Concrete Society's *Technical Report No. 22, Non-structural cracks in concrete*[9.5].

The appropriate treatment for the construction joint or crack depends primarily on its width, the range of expected movement in response to temperature and loading, future widening of the crack due to long-term drying shrinkage and its restraint (e.g. by connection to solid stair or lift shafts). Where there is doubt about the extent of movement, a period of monitoring using crack gauges could be considered. Typical methods for sealing cracks are:
– where minimal future movement is expected, the crack can be sealed by a rigid, structural resin such as an epoxy injection system
– where slight movement is expected, non-structural foaming resins based on polyurethane resins can be used
– where large movements are expected, cracks may need to be cut out to form a groove and then filled with sealant (see Section 9.3.3).

Using a rigid material (e.g. epoxy resin) in situations where large movements are possible may be self-defeating and can even make matters worse. It is to be expected that the concrete will crack elsewhere owing to the movement strains and reinforcement in the slab may redistribute the crack, forming many fine cracks in the place of one large one. The resulting fine moving cracks can be particularly difficult to seal.

9.4 References

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10 Quality control during construction

10.1 General

The durability of a structure is often more sensitive to site practice than to the choice of materials used. While general statements in specification clauses normally cover these matters, the lack of quality control checks and adequate supervision can compromise durability of both steel and concrete elements, although the latter is far more open to abuse.

Good practice for concreting works is covered in a number of guidance documents[10.1, 10.2] and a new European Standard on execution of concreting works[10.3]. However, in the severe conditions to which car parks can be exposed, a higher quality of construction is needed to achieve a durable structure and the design should contain details that can easily and reliably be constructed to achieve good concrete quality and reinforcement cover. Similarly, the quality of handling and protection of steel members and their factory-applied protective coatings[10.4] will have a significant effect on long term durability.

10.2 Quality issues

10.2.1 Introduction

As stressed throughout this document, car parks are not ‘normal’ buildings. Commonly, car parks are in whole or in part external exposed structures. In the UK, this exposure leads to conditions that are in some ways worse than for civil engineering structures such as bridge decks. The quality of the concrete in particular must be to an appropriately high standard to resist the exposure.

Despite all the care taken in designing the structure, specifying the cover and concrete mix composition[10.5], the final actions of placing the concrete are essential to durability. A lack of attention to detail when either designing temporary works, or placing and compacting concrete, or prematurely stripping formwork, can negate the design efforts and produce a structure with poor durability.

For car park construction and for the slab and ramp decks in particular, the whole workforce should understand the objectives of these recommendations and use high standards of construction practice. Adequate supervision should also be built into the contract to ensure the design intent is realised, particularly in situations where the exposure of the structure is severe.

10.2.2 Construction tolerances

The severity of exposure in car parks makes it essential to achieve the specified minimum reinforcement covers within tolerances. The reinforcement position must mirror the intended falls in the slab or ramp and thereby prevent either too low or too high depths of cover. The cover to reinforcement can only be consistently achieved if there is adequate tolerance on the reinforcement bending, the formwork and steel fixing and if the reinforcement can be fixed as detailed.

Before pouring concrete, checks are recommended to review the following:

- the drawings to assess the buildability before starting construction
- the formwork proposals
- the proposals for steel fixing and in particular the frequency of spacers
- ensuring multiple overlaps do not reduce the cover, particularly where fabric reinforcement is used
- the proposals for placing and compacting the concrete
- the mix design, aggregate selection and curing methods
- precautions for protection in inclement weather.

During placing, it is most important that the finished level of the top surface of the slab or ramp is placed accurately in accordance with the construction drawings. Failure to achieve the correct levels and falls will reduce the cover depth at the top, which is the most critical area with respect to durability (see Chapter 8). Deflection is a particularly important consideration with composite construction, such as precast planks with a concrete topping or steel-concrete composite decking, both of which may develop mid-span deflections.

For the top surface, the specified cover must be checked and the required datum level recorded by the contractor before concreting. Immediately after concreting, the top surface datum level must be re-checked and adjusted as necessary before the concrete stiffens. For formed surfaces, the cover must be checked immediately before placing the concrete and spot checks made after the formwork has been removed.

10.2.3 Placing and compaction

Best practice needs to be followed to ensure the concrete is placed carefully, without encouraging honeycombing or segregation and then vibro-compacted to full consolidation to achieve the correct falls. The contractor must ensure the concrete is carefully inspected at the point of delivery for consistency and elapsed time since batching, before approving for placing. If the consistency is not correct, the load should be rejected and specifically extra water should not be added to the concrete by the contractor. However, in exceptional circumstances and if specifically instructed by the contractor, the supplier may add water to a slightly stiff concrete to bring it in tolerance, recording the quantity of water added from the truck’s tank, and then the concrete should be thoroughly remixed. Samples should be taken for strength testing if water is added by either party. Concrete should be rejected if the consistency remains out of tolerance.

When placing concrete onto ramps and decks laid to falls, greater long term durability is achieved by starting the concrete placing at the lowest point and working up the slope, which reduces the risk of slumping, segregation and plastic cracking.

Self-compacting concrete (SCC) is currently outside the provision of BS 8500[10.5] although it is included in Part 9 to EN 206[10.6]. It is being used increasingly for a variety of structures including car parks. SCC can offer significant benefits in terms of the speed, quality and cost of construction, particularly with congested reinforcement, but requires special consideration in terms of formwork design and the requirement not to vibrate[10.7]. Due to the self-levelling properties of the concrete it will not be possible to achieve the designed falls without a further operation (e.g. non-structural screeds).

For compliance purposes, the air content of air-entrained concrete[10.8] is normally measured at the point of delivery. When conveyed over long distances, particularly by pump, air loss can occur between the point of delivery and the point of discharge. It is the air content at the point of discharge into the formwork that is critical for resistance to freeze–thaw action and this should be checked both at delivery and discharge, making an adjustment as necessary to the air content needed at delivery. The actual air loss should be established at the beginning of each concrete placement as well as each time the placing conditions change.

Concretes with low water/cement ratio and those containing entrained air or silica fume need extra care, as the cohesion of the concrete is often significantly greater than for more conventional concrete. To achieve full compaction with these types of concrete, longer vibro-compaction times may be required. In addition, because these concretes have little bleed, there is less natural protection against plastic cracking and so consideration should be given to providing extra protection against wind and high temperatures before finishing can begin (see Section 10.2.4).

Particular attention should be paid to achieve full compaction adjacent to construction and expansion joints, because any subsequent water penetration at joints will affect the durability of the structure.

10.2.4 Protection and finishing

A compromise is often required between the needs to cure, protect and texture the surface. If done properly, protection and finishing of the concrete surface will be a labour-intensive operation. General guidance is given in publications[10.1, 10.3], but no specific guidance is available for car parks at this time.

The timing of the protection and finishing is of fundamental importance if a dense and durable slab top surface is to be produced. The finishing operation requires a concrete surface that has begun to stiffen, yet is generally free from bleed water. The surface must be protected from severe drying conditions if plastic shrinkage cracking is to be avoided. Slab and ramp construction is particularly prone to plastic shrinkage cracking caused by these conditions.

Rainfall will have a damaging effect on the concrete surface if the works are not adequately protected, not only forming pock-marks on the surface but also weakening it if the water is mixed into the concrete as part of the finishing (see below).

During the finishing operations, surface evaporation from the slab surface should be minimised. This can best be achieved by avoiding extremely hot, dry or windy weather conditions. Where practical, the slab should be sheltered from direct exposure to the sun and rain and protected against the passage of wind over the surface.

Excessive bleed of the concrete can cause plastic settlement cracking in the surface. Both plastic shrinkage and plastic settlement occur while the concrete is still in the plastic state. With vigilance by the supervisor (where there is one), the incidence of cracks can be identified and action taken immediately to remove them by re-vibrating the concrete, provided the timing is carefully considered. It is not acceptable simply to finish the surface with a tool to drag laitance into the plastic cracks, as these cracks will soon be exposed again by the wearing action of vehicle tyres and will form a direct path to the reinforcement. Guidance on non structural cracks and their prevention is given in TR22[10.9] and information on their repair by resin injection is given in Chapter 8.

Most finishing problems arise from too much bleed water escaping from the concrete. In attempting to provide the required finish, the bleed water is often mixed into the top surface during tamping or floating operations potentially forming a weak, friable top layer that has poor resistance to abrasion and excessive dusting. Excessive bleed can be prevented through correct mix design, using well-graded fine aggregate and including water-reducing admixtures that provide a concrete with a higher slump without using additional water. Air entraining admixtures also help in reducing the bleed and increasing the stability of the concrete, but will lower strength which must be compensated for by increasing the cement content and lowering the water/cement ratio.

Finishing requires particular care to accommodate the sometimes conflicting needs of providing good skid resistance, the application of a waterproofing membrane and providing unimpeded runoff of surface water and dissolved salts (see Figure 10.1).

The final finishing process for 'as-finished' concrete surfaces can be a subject of potential disagreement. Brushed and tamped finishes in particular are subjective and little guidance is in place to standardise the finish. The latest guidance on execution of concrete works[10.3] does not refer to textured concrete surfaces and so the surface should

Figure 10.1 Example of surface finishes

be defined as a 'special' category and accurately described in the contract documents in terms of the initial regularity of the surface and the tooling to be used to create the finished appearance. Brushed or tamped finishes should be drawn across the concrete surface in the direction of the fall, allowing water to drain from the formed grooves in the surface. Provision should be made for the contractor to prepare a trial panel to set an agreed standard for the finish.

For concrete finishes to receive liquid-applied membranes, the manufacturers will normally require a smooth, closed texture, but not one that has been power trowelled to a polished surface. This can be described as a matt trowelled surface, requiring only a light power trowelling (minimal passes, blades at low angle) to remove slight undulations and steps in the surface.

10.2.5 Curing

The resistance of concrete to both chloride ingress and carbonation is substantially enhanced if the surface cover layer of concrete has fully hydrated in the period following casting. To achieve this, full curing measures must be taken immediately the finishing is complete.

Concretes containing CEM 1 cement (formerly OPC) hydrate rapidly and good surface qualities can be achieved in 3–6 days if water loss from the surface is prevented. Cements containing fly ash or blastfurnace slag (broad designation II or III) need extended curing for full surface hydration and resistance to carbonation to be achieved. More information on cement types is given in BS 8500[10.5] and associated references.

Curing should begin immediately following completion of finishing operations for each area[10.1]. Field experience has shown that traditional methods of curing, such as laying wet hessian on the slab covered with plastic sheets for a minimum of 7 days, produces good results for concrete cast *in situ*, particularly where a rough, tamped or textured surface is used. Care is required to ensure the hessian is kept wet with potable water during this time. High performance spray-on curing membranes are also available that have a similar performance to traditional wet curing and are particularly suitable for smooth power-finished surfaces (see Section 8.5).

If curing membranes are used, particular care is needed to ensure the product is compatible with any waterproof membrane to be applied subsequently (see Section 8.6).

10.3 References

10.1 The Concrete Society. *Concrete practice: guidance on the practical aspects of concreting. Good Concrete Guide 8*. 4th ed. Camberley: The Concrete Society, 2008

10.2 *BS 8000-2.1: 1990: Workmanship on building sites – Code of practice for concrete work – Part 2.1: Mixing and transporting concrete*; *BS 8000-2.2: 1990: Workmanship on building sites – Code of practice for concrete work – Part 2.2: Sitework with in situ and precast concrete*. London: BSI, 1990; *BS 8000-9: 2003: Workmanship on building sites – Code of practice for concrete work – Part 9: Cementitious levelling screeds and wearing screeds – Code of Practice*. London: BSI, 2003

10.3 *BS EN 13670: 2009: Execution of concrete structures*. London: BSI, 2010

10.4 *BS EN ISO 12944-4: 1998: Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 4: Types of surface and surface preparation*. London: BSI, 1998

10.5 *BS 8500-1: 2006: Concrete – Complementary British Standard to BS EN 206-1 – Part 1: Method of specifying and guidance for the specifier; BS 8500-2: 2006: Concrete – Complementary British Standard to BS EN 206-1 – Part 2: Specification for constituent materials and concrete*. London: BSI, 2006

10.6 *BS EN 206-9: 2010: Concrete. Additional rules for self-compacting concrete (SCC)*. London: BSI, 2010

10.7 The Concrete Society. *Self-compacting concrete: a review. Technical Report 63*. Camberley: The Concrete Society, 2008

10.8 Cement Admixtures Association. *Concrete air-entraining admixtures. Admixture Sheet ATS 5*. Knowle: Cement Admixtures Association, 2006. Available at: http://www.admixtures.org.uk/downloads/ATS%205%20Air%20Entraining.pdf [Accessed: 24 August 2010]

10.9 The Concrete Society. *Non-structural cracks in concrete. Technical Report 22*. Camberley: The Concrete Society, 2010

11 Asset Management

11.1 Introduction

Car park asset management is the process of safely and predictably maintaining the structure and its component parts in service, over a known design service life, to deliver reliable financial returns. Good asset management, in engineering terms, is a whole life cost balancing exercise of operational maintenance costs, capital replacement costs of items at the end of their planned life and revenue interruption when maintenance works are required (see box below)[11.1].

Asset management is about a public entity or private business knowing:
– what assets it owns
– how it expects its assets to perform
– what condition its assets are in
– how its assets should best be looked after
– when assets need to be repaired or replaced
– what assets will cost over their planned life
– what may need to be done differently in the future to manage its assets better
– how all of this will impact on the most cost effective provision of service to its customers.

Planned inspection, maintenance and replacement of routine M&E items in car parks is not new and is expected by the operator with much of it embedded in legislation, such as the electrical regulations and the *Health and Safety at Work etc Act*[11.2]. The need to inspect, maintain and repair a car park structural frame over its design service life is a relatively new concept, with the need arising out of the sudden failure and collapse of several car park structures in the UK and elsewhere[11.3].

In the UK it has been generally assumed that buildings constructed to current design and durability codes would not require significant inspection or maintenance over their design service life, typically 50 years. By contrast, structures such as highway bridges with an indefinite life, severely exposed to de-icing salts, are recognised as needing regular inspection, maintenance and where necessary, structural repair and strengthening works to maintain them in a safe and serviceable condition.

Like highway bridges, car parks are also exposed to the elements; they take vehicle loading and can receive de-icing salt run-off from contaminated water and ice on vehicle wheels and wheel arches. As a result, the exposed decks and ramps can begin to deteriorate structurally very early in their service life. Alternative de-icers such as urea should not be considered a panacea but be used with caution and with reference to manufacturers' instructions. In addition to chloride ion contamination, structural deterioration can be caused by other mechanisms during service, including:

– impact damage from vehicles, reducing the cover
– carbonation of the concrete over time, resulting in reinforcement corrosion
– alkali–silica reaction, producing expansion and cracking
– freeze–thaw action on unprotected or under-specified concrete
– thermal and shrinkage cracking, providing pathways directly to the reinforcement
– surface abrasion and wear
– failure of protective coatings and waterproof membranes
– poor quality or inadequate cover to steel reinforcement.

A car park does not show signs of deterioration everywhere at the same time. The more information is available when the first signs of deterioration begin, the easier it will be for inspection observations to be understood as to the cause and how to remedy defects, with resultant cost savings (see also Section 11.2.2).

Every owner/operator has a legal obligation to maintain their car parks in a safe condition. This obligation is intended to protect all persons entering the building, including the operator's employees, users and including persons entering lawfully or otherwise[11.4]. There are no exceptions. This requirement also extends to the immediate perimeter of the building to protect persons from falling concrete, or from vehicles which may accidentally cause the failure of the edge protection barriers or dislodge the cladding. Saving on maintenance does not always save money. Neglecting basic preventative care increases the likelihood of premature failure, the consequences of which can be severe.

With the collapse of some older car parks, the Institution of Civil Engineers issued *Recommendations for the inspection, maintenance and management of car park structures*[11.3]. The purpose of the recommendations was to help inform both owners and designers of the causes of deterioration in car parks and give guidance on programming the future inspection and maintenance of the structures, termed the car park Life-Care Plan (LCP).

A useful definition of the difference between asset management and life-care is that the former is the process for managing the facility to achieve the required financial returns[11.5], whereas life-care is the engineering process for inspecting, testing and maintaining the car park to ensure that the required level of structural safety is maintained. Effective car park asset management is therefore the combination of life-care and conventional fiscal management of the non-structural items of the asset, optimised to give best value.

11.2 Life-Care Plan

11.2.1 General

However well designed or constructed, car parks deteriorate as soon as they go into service which, if ignored, can ultimately impact on their asset value and ability to generate income. The deterioration process is complex and largely dependent upon two inter-related variables, time and expenditure[11.4]. Deck membranes and surface protection systems can slow down the rate of deterioration, but they may not arrest it completely and the protection afforded will reduce with time. Inappropriate patch repairs can accelerate the rate of deterioration by promoting the development of additional corrosion cells[11.3]. Wrongly specified repair materials and inappropriate temporary propping during repairs can also lead to premature failure.

Once started, deterioration cannot be permanently halted or reversed, but it can be managed through a programme of structured and planned maintenance as set out in the Life-Care Plan (LCP). The LCP should help owners identify the actual and potential problems, enabling sufficient funds and resources, financial or otherwise, to be allocated to maintain adequate levels of safety and to avoid diminishing property values.

The LCP should contain all that is known about a car park structure. The structure is defined as the structural frame, but also includes the edge protection and the perimeter cladding, which may be subject to accidental vehicle loads over the service life. The ICE[11.3] recommends that the owner/operator of the car park should appoint an experienced Chartered Structural Engineer ('the engineer') to be responsible for preparing the LCP, advising on all aspects of material durability, structural safety and maintenance/repair strategy for the car park. Where possible, the original design team should prepare the LCP, as they will be best placed to advise on the particular features of the car park.

As set out above, the Initial LCP is best prepared on or around the time of handover, when the condition of the car park should be known reliably. Situations may arise where the Initial LCP is not completed within three years of handover or an existing older car park is to be brought back into service thus requiring an initial LCP.

The LCP is a living document, which must be updated as and when information changes. For new buildings it may comprise a single summary document, cross-referencing to other documents in the handover information pack; for an older car park, it may comprise multiple files and reports depending on the age, complexity and condition of the car park.

By its nature, the LCP is ideally suited to being incorporated into an asset management database, allowing the information to be stored, retrieved and updated easily. It can also be set up to produce the required planned inspection and maintenance schedules, works orders and monitor expenditure, automatically (see Section 11.2.6).

11.2.2 Handover information pack

The handover documentation for all new structures should include a health and safety file. In the UK, this is mandatory. In addition to the requirements of the CDM Regulations[11.6], the handover information pack should identify the materials used in the car park and include reference to any unusual structural, mechanical and electrical facilities and maintenance requirements, in particular:

- description and general history
- comprehensive description of the envisaged behaviour of the structure in the design, including envisaged movement and change of shape
- identify critical areas of the car park in terms of possible attack (see Table 8.2) and how this has been addressed in the design
- specifications
- as-built drawings
- O&M manuals for the M&E installations
- detailed and comprehensive records of the construction and installation history
- the presence and dangers of confined spaces (e.g. in lift machinery wells); notwithstanding the apparently open and ventilated nature of car parks, accumulation of fuel fumes and exhaust gases is a significant risk to operations staff and users.

11.2.3 Initial Life-Care Plan

The handover information pack for a new car park forms the baseline information for the Life-Care Plan (LCP), but is unlikely to contain all relevant information needed by 'the engineer' to decide whether the car park has been built to meet the design intent. Additional work may be required to fill gaps in the information, which may include a review of records, visual inspection or limited testing if the quality of the construction is particularly poor. Examples of the types of information that need to be incorporated in the LCP include:

- design and construction features that may require special attention or inspection, such as bearings or cladding fixity
- any location where the construction deviates from the design or specification, which may become a point of weakness in the future, such as low cover to reinforcement or poorly compacted/weaker concrete
- construction-stage repair or strengthening to any damaged or otherwise defective areas, which may fail in the future
- enhanced protection applied to the structural members, including deck membranes and anti-carbonation paints to beams, columns and cladding.

Some of this information should be collected in any case during the construction liability period, as the owner will need to identify actual and potential defects that could lead to future maintenance burdens.

For an older car park, more information will be needed to establish the baseline condition and a benchmark inspection may be needed (see Section 11.2.4).

Once collated, the data is used to produce the Initial LCP. The document will set in place a programme for inspection and routine maintenance of the car park, comprising three inspection levels[11.3]:

- **Level 1: daily surveillance inspections** by car park operations staff, to identify obvious signs of damage (accidental or otherwise).
- **Level 2: six monthly routine inspections** by trained inspectors working under the supervision of a chartered engineer, recording any changes from the as-built information in the LCP.
- **Level 3: condition inspection** normally carried out every eight years by a Chartered Engineer, depending on the age and condition, to identify through limited testing and inspection any

premature deterioration of the car park, with the first such inspection being termed a benchmark inspection (see Section 11.2.4). Sometimes this is followed by a Special Inspection to investigate particular defects in greater depth.

Note: Surveillance or routine inspections can only identify surface defects and cannot determine a car park's structural adequacy or the potential rate of deterioration of the component parts.

Structures designed to the recommendations in this document should be less likely to suffer premature deterioration than previous car park designs. However, when a routine or condition inspection indicates developing deterioration, the frequency and types of inspection will need to be reviewed. Special Inspections are intended to investigate the cause and extent of the early signs of developing deterioration (e.g. ponding, cracking, seepage, deterioration in waterproofing membranes, etc.), cost-effective pre-emptive action can often be taken before a major problem develops.

The output from all inspections should be drawings, logs, photographic records and test results where appropriate, identifying to 'the engineer' any items which require immediate attention or further investigation. Normally, the identification of defects from a Level 1 or 2 inspection may trigger a Level 3 inspection or a Special Inspection.

Once complete, the condition inspection should identify any deficiencies in the construction and recommended actions, including:
– immediate actions
– scheduled future actions, such as further surveillance, inspection or repair.

'The engineer', in conjunction with the owner/operator can develop a range of different options for each action, taking into account issues such as capital cost, life expectancy and client cash-flow preferences.

Figure 11.1 illustrates graphically how premature asset deterioration can occur which, if left unchecked, could result in critical deterioration that poses a threat to the stability of the car park[11.7]. It shows two repair cycles which restore the functionality of the car park, based on[11.1]:
– Two programmes of substantial expenditure (Repair 1 and Repair 2), intended to restore the car park to near its expected condition to achieve its design service life.
– Targeted annual maintenance actions to keep the car park above a critical deterioration level.

Feedback from the inspections and any actions taken must be immediately captured and updated in the Initial LCP. Development of the LCP is discussed in Section 11.2.5.

11.2.4 Benchmark inspection and appraisal

For new car parks the benchmark inspection can easily be carried out and documented at the time of handover and included in the Initial Life-Care Plan (LCP).

For older structures without any LCP, the ICE recommendations[11.3] provide the following advice:
– For structures of between 3 and 8 years old, a benchmark condition inspection is required to establish the level of deterioration in the car park structure. This will be followed by regular condition inspections nominally every eight years.
– For structures more than 8 years old, with no record of a structural appraisal having being carried out, a full structural appraisal should be undertaken without delay.
– For all car parks, a full structural appraisal should be repeated at a maximum of 16 year intervals, to evaluate the integrity and adequacy of the structure, edge protection and cladding. The appraisal should be supplemented by Special Inspections as necessary and examine in particular the impact of any structural deterioration, changes in code provisions, vehicle loadings and use of the various levels of the car park.

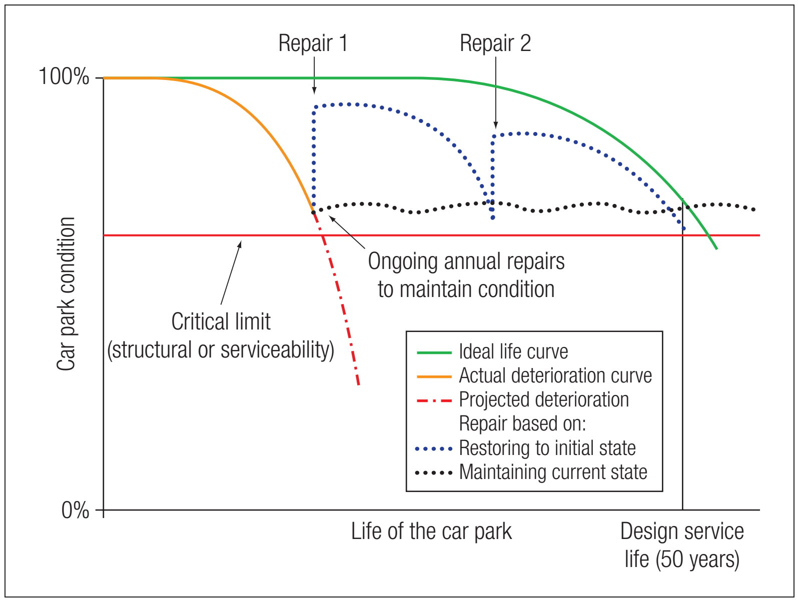

Figure 11.1 Possible asset deterioration profiles for a car park

Some of the above recommendations are directly relevant to the refurbishment of existing car parks or extending car parks (see Section 11.3).

11.2.5 Development of the Life-Care Plan

Because the Life-Care Plan (LCP) is a living document, it is never in a 'final' state but is always subject to update and revision, feeding back results from inspections and assessments to modify future inspection intervals, routine maintenance works and any capital expenditure needed to strengthen or replace any deteriorated elements. The LCP will develop over the first 16 years of the life of the car park, taking input from the results of the benchmark survey (at 8 years) and the condition survey and structural appraisal (at 16 years), which may identify suspect areas that need closer monitoring or more frequent inspection; as Figure 11.1 illustrates, specific elements or parts of the car park may be following a path of premature deterioration, for example because of failure of waterproofing or jointing systems.

A summary schedule should be produced in chronological order with future actions indicated at key stages. Warranties, completion certificates, product data sheets, health and safety requirements, etc., should also be filed in the LCP. Above all, the Life-Care Plan should be simple and easily understandable by the intended users of the document, including the owner/operator, staff carrying out inspections and ‘the engineer’. Ideally the documentation should be kept by a registered keeper who has an understanding and appreciation of its purpose and importance[11.4].

After 16 years, ‘the engineer’s’ recommendations for inspection intervals may be modified significantly to account for the specific findings for the car park, in agreement with the owner/operator. The content of the LCP is therefore bespoke and specific to each car park and client.

As well as inspection intervals, the LCP must provide a programme for all routine maintenance and capital replacement works to be carried out at manufacturers’ scheduled intervals to maintain the structural performance of the car park, including:
– mastic joint sealants, typically with a life of 10 years, which fail by splitting and debonding
– deck waterproofing, typically with a life of 10 to 20 years, which fail by splitting, debonding or wearing away
– anti-carbonation paint systems, typically with a life of 10 to 20 years, which may become ineffective over time
– special ancillary materials, such as bearings, movement joints, cladding fixings, edge protection systems, which will have a finite life
– any concrete repair and strengthening works, including corrosion control systems such as impressed current cathodic protection
– maintenance painting of steelwork, taking into account the severity of the local macro environment, the original paint specification and the likely life to first maintenance at the applied film thicknesses.

A typical schedule of car park maintenance actions is given in Table 11.1[11.7].

The LCP maintenance and capital replacement programme should also include the operation and maintenance requirements for the mechanical and electrical plant. Earlier sections in this *Report* list the types of equipment used for building services, traffic management (including vehicle access controls and signing), on-site staff accommodation and fire detection and prevention systems.

Including M&E maintenance and replacement schedules in the LCP is not specifically mentioned or addressed in the ICE recommendations[11.3]. However, it is recommended that the LCP should be extended to ensure all inspection, maintenance and replacement information is held in one place, with the LCP cross-referencing as appropriate, specifications and maintenance schedules held in the O&M manuals of the handover information pack.

Table 11.1 Summary of best practice maintenance actions for a typical car park, including valuation considerations

Item	Interval
Initial Life-Care Plan survey	At construction
Benchmark condition survey	Between 3 and 8 years
Level 1 – surveillance	Daily
Level 2 – routine inspection	Every 6 months
Level 3 – condition inspection	Every 8 years
Special inspection	As required
Structural appraisal	Every 16 years
Drain cleaning	Every 6 months
Routine maintenance	Monthly
Wash-down and deck cleaning	Every 6 months
Cosmetic repairs	As necessary
Surface protection	Every 10–15 years
Preventive repairs	As necessary
Structural repairs	As necessary
Refurbishment	Target date
Demolition and replacement	Design service life (unless extended)
Design service life	Set by stakeholder
Works value	Annual base cost
Whole life value	As necessary
Current value (if defect free)	As necessary
Residual value after works	As necessary

Note
This Table is reproduced from Reference 11.7.

11.2.6 Automation

Because the Life-Care Plan (LCP) is a living document, the LCP data is commonly captured in an asset management database, allowing the information to be stored and updated easily. Historically, there have been problems with finding the construction drawings for car parks, which may be required for maintenance and refurbishment contracts. Often the drawings are unobtainable, illegible when reproduced from microfilm or showing only general arrangement without the reinforcement detailing essential for structural checks. A database keeps all relevant information secure and constantly available. Many suppliers provide stand-alone client-friendly systems for one or multiple car parks, or can host the data externally.

If computer-based records are used (see Figure 11.2), they will need to be reviewed occasionally to ensure compatibility with software changes. For this reason, the preservation of a hard copy version of the LCP data is also prudent, the information being kept by the client with the health and safety files.

11.3 Upgrading existing structures

11.3.1 General

The ICE recommendations[11.3] primarily apply to existing car parks and require that a retrospective Life-Care Plan (LCP) is produced that considers among other things:
– the structural adequacy of the car park in the as-built condition
– any changes in design codes since the time of construction
– the effect of deterioration in concrete and steel that could reduce its structural performance.

This approach will be relevant to new-build designers in situations where an existing car park is being

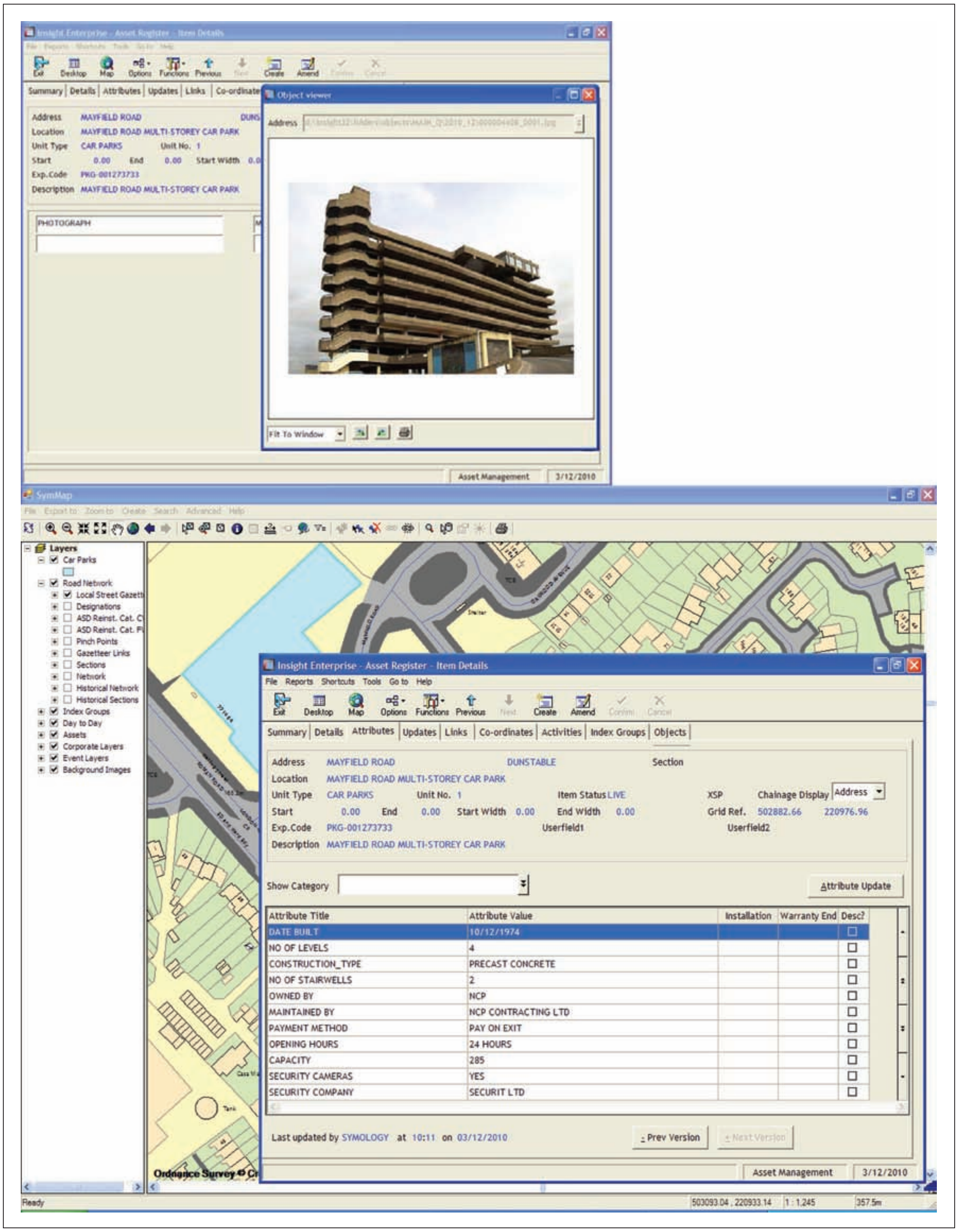

Figure 11.2 Screen shots from a typical GIS-based asset management system

extended. The LCP and associated documents is therefore the starting point to understand how an existing structure may be upgraded.

Without an LCP, the first point of reference should be the health and safety file, which will make the task of identifying materials used in the car park much easier and will normally include reference to any unusual structural, mechanical and electrical facilities and maintenance requirements.

11.3.2 Structural limitations on modifications and change of use

The structure will have been designed for a specific loading and maintenance regime, which may include some provision for changes in use or modifications. The Life-Care Plan (LCP) should make clear any particular limitations that apply to:

- extensions and increased height
- loading for alternative uses and during works in the structure
- surfacing thickness
- planting and landscaping loads
- drilling through elements and opening up (e.g. sensitivity of structure near columns in flat slabs)
- identification of any areas not designed for chloride resistance where salt should not be applied for de-icing
- washing of vehicles, which should only be carried out in areas where a waterproof membrane has been applied

– requirement for cleaning of the decks and ramps and drains, including a regular washing-down at least annually at the end of the winter to reduce the build-up of de-icing salts, ideally by wet vacuum to remove surplus water
– performance of fixings and edge barriers
– zoned areas designated for fuel storage
– areas designated for car washing.

Changes in use of particular levels of the car park may significantly affect the durability of the structure. In particular, actions that lead to increases in humidity, or physical wetting of the concrete slab surface, may accelerate deterioration of the reinforced concrete, providing moisture to fuel the corrosion process. As noted in Chapter 8, with good drainage and air flow, reinforced concrete car parks are tolerant to relatively high levels of chloride ion build-up in the concrete surface, but changes that upset these conditions may accelerate corrosion.

11.4 References

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Appendix A Designing for temperature effects

The serviceability implications of temperature-induced movement and restrained cracking in structures need consideration, as excess joint movement causing leakage and cracking can lead to durability problems. The design temperature range that may need to be considered can be determined from BS EN 1991-1-5[A.1] and the Institution's manual for Eurocode 1[A.2].

The moments induced in columns by heating and cooling of the top slab relative to slabs below, as well as changes in reactions from the differential within the top slab, can be significant in flat slab punching shear.

Thermal bow for simply supported units should be considered. For a first estimate it can be taken conservatively as:

$$\frac{(\text{coeff. expansion} \times \text{temperature difference} \times \text{length}^2)}{(8 \times \text{thickness})}$$

More detailed guidance can be obtained from the Eurocodes e.g. BS EN 1992 for concrete structures[A.3].

In general, steel and concrete frames have a similar coefficient of expansion. This may be taken as $12 \times 10^{-6}/^{\circ}C$. Certain types of aggregate, e.g. limestone and granite, have lower coefficients of expansion[A.4] and could be considered for use as part of the design.

Temperature effects may be introduced into the design as shown in BS EN 1991[A.1] and the Institution's manual for Eurocode 1[A.2].

Movement joints must make suitable allowance for the effect on the joint width of the temperature during construction. Some mastic joint fillers may not be suitable for multi-storey car park construction, since their movement accommodation factor is limited.

In order that all these issues are considered in a rational way, the following procedure is appropriate for the design process:

(1) Establish proposed basic car park form and elevational treatment, lateral stability system, ramp and stair locations.
(2) Calculate design temperature of top deck frame.
(3) Establish likely mean temperature during construction, and hence the temperature range.
(4) Taking account of both the lateral stability system and any other secondary lateral restraint present, calculate frame movements at elevations and other critical features.
(5) Check that any constrained expansion forces are acceptable.
(6) Check that frame movements are compatible with elevational treatment.
(7) If (5) or (6) are unsatisfactory, either revise layout or introduce movement joints.
(8) If movement joints are adopted, recalculate frame movements.
(9) Re-check that frame movements are compatible with elevational treatment and proposed movement joint details.
(10) Check top deck thermal bowing effects.

References

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Appendix B Acknowledgement of illustrations

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