

Corus Construction & Industrial

Steel-framed car parks



Avebury Boulevard multi-storey car park
Milton Keynes



Contents

5 Introduction

Attributes of good car park design
Advantages of steel construction

6 Outline design

Dynamic efficiency
Flow patterns

7 Circulation design

Ramp width and slope
Car park layout

9 Structural form

Foundations
Column positions
Floor and frame solutions
Underground car parks
Vehicle safety barriers
Deflection
Dynamic performance
Stability

16 Fire resistance

18 Durability

The steel frame
Concrete floors
Metal decking
Waterproofing
Refurbishment

21 Aesthetic design

22 Commercial viability

23 Latest developments

Demountable car parks
Wholly automatic multi-storey car parks

24 Sizing data sheets

28 Case studies

34 Bibliography

35 Support for the construction industry from Corus Construction & Industrial

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Introduction

The multi-storey car park is a unique style of building; one in which all elements of the structure are normally exposed to the public.

This publication gives examples of good practical design that enable the structure to blend with all environments whilst utilising the inherent versatility, elegance and economy of a steel frame.

Fundamental design information is given to illustrate how steel, with its ability to accommodate long clear spans and minimise column sizes, can create aesthetically pleasing, economic, secure, user-friendly car parks.

This guide is intended to assist the designer with the preparation of budget schemes, without the need for complex calculations at the outset. It does not however, relieve the designer of his responsibility for providing full design data for the built structure. Further guidance is available in the Institution of Structural Engineers publication 'Design recommendations for multi-storey and underground car parks' (THIRD EDITION).

Attributes of good car park design

- Easy entry and egress to car park and stalls
- Uncomplicated and logical traffic flow
- Unimpeded movement
- Light and airy
- Low maintenance
- Safe and secure

Advantages of steel construction

This guide will demonstrate that steel construction is ideally placed to satisfy all the requirements of good car park design. Steel is:

- Ideal for long spans
- Lightweight
- Robust
- Fire resistant
- Easily maintained
- Vandal resistant
- Minimalist
- Economic

Steel is also an ideal material for satisfying the requirements of 'Rethinking Construction':

- Reduced costs
- Reduced time on-site
- Off site fabrication of primary structure
- Increased productivity
- Certainty of budget and time
- Improved efficiency in the use of materials
- Reduced wastage
- Safer construction
- Improved quality

Steel solutions also have excellent sustainability credentials:

- Composite construction uses materials more efficiently
- Minimised waste
- Recycled and recyclable material
- Adaptable construction
- Lightweight construction leads to more efficient foundations than for other forms of construction
- Long life product

Outline design

The dimensions of large, standard and small size cars are well established and are presented in Table 4.1 of the Institution of Structural Engineers publication ‘Design recommendations for multi-storey and underground car parks’ (THIRD EDITION). These dimensions form the basis of the geometry required for stalls, aisles and ramps. The minimum dimensions are based on the standard car and the bin size on the parking angle and stall width. This is shown in Table 1.

Table 1. Effect of varying parking angle on parking bin requirements

Parking angle	Stall width (m)	Stall width (m) parallel to aisle	Aisle width (m)	Bin width (m) (stall length 4.80m)
45°	2.3	3.25	3.60	13.65
	2.4	3.39		13.80
	2.5	3.54		13.95
60°	2.3	2.66	4.20	14.85
	2.4	2.77		14.95
	2.5	2.89		15.05
75°	2.3	2.38	4.98	15.45
	2.4	2.49		15.50
	2.5	2.59		15.55
90°	All	All	One way aisle 6.00	15.60
90°	All	All	Two way aisle 6.95	16.55

Dynamic efficiency

The dynamic efficiency of a car park depends on the ease with which entry, egress and parking can be achieved. The general principle should be that cars cover as many stalls as possible on entry and as few as possible on exit. The layout of the exits and the size of the reservoir capacity are other major factors when considering dynamic efficiency.

Flow patterns

There are two flow patterns used in modern car park construction: one way and two-way flow. These can be combined with either 90° or angled parking.

- *One-way flow systems*, if used with angled parking, provide a very good solution to the parking problem. They ensure easier entry and exit to stalls and allow significant flow capacities to be achieved with the self-enforcing flow pattern. Difficulties can arise when the intended flow is ignored and therefore good signage is required.

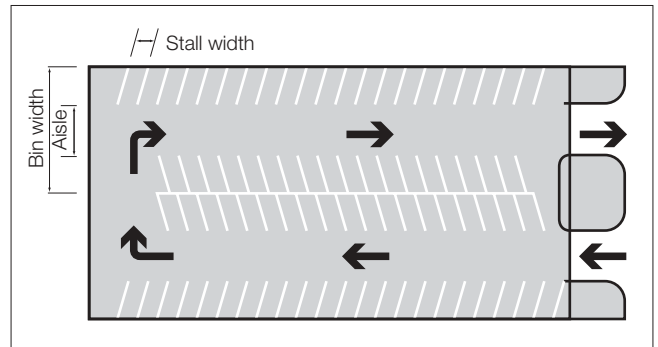


Figure 1. One way flow, angled parking

- *Two-way flow systems* are more familiar to the user and if properly designed can achieve a higher flow rate than one-way systems. They require marginally more space and are therefore less structurally efficient than one-way systems. Two-way systems are best used with 90° parking as their use with angled parking can cause confusion to the driver.

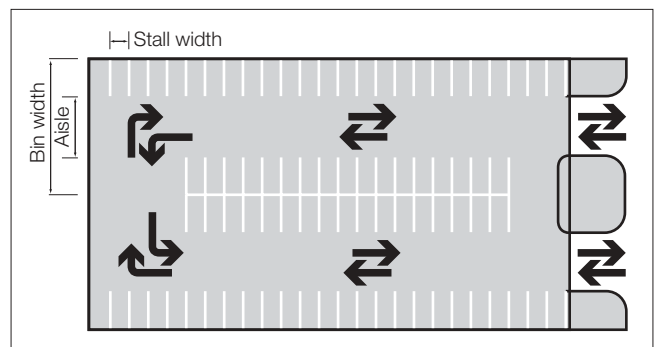


Figure 2. Two way flow, 90° parking

Circulation design

Ramp width and slope

The widths of the ramps should usually be no less than 3.5m for a single ramp and 7.0m for a double ramp. It is recommended that ramp widths are kept in line with stall widths, for example with single flow traffic, the ramp would be two stall widths wide and for two way traffic flow, three stall widths wide.

The slope of the ramp is dependent on the clear headroom (2.1m minimum) and the structural zone. The growth in popularity of the larger multi-purpose vehicles (MPV's) has had an effect on the minimum clear height and ramp length requirements. The shallower and wider the ramp, the better it will meet the needs of users. However less steep ramps are longer. Typical slopes range from 1:6 to 1:10. Steeper gradients may be used if transitions are provided at the top and bottom of the slope.

Refer to the Institution of Structural Engineers publication 'Design recommendations for multi-storey and underground car parks' (THIRD EDITION) for detailed guidance on rampwidths and slopes.

The split-level system, shown in Figure 3, offers a method of reducing ramp length, whilst keeping the gradient within reasonable limits by staggering the parking levels by half a storey height.

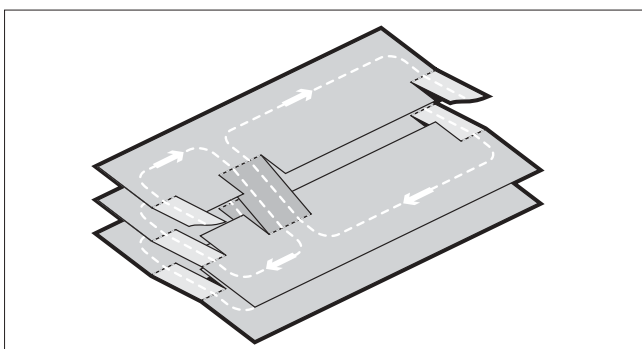


Figure 3. Split-level layout

Car park layout

There are many layouts used for multi-storey car parks, each offering specific advantages to the user and operator. The layouts indicated are those most commonly used in the UK. All are eminently suited to a steel-framed solution, which will be competitive on price and provide excellent performance.

Split-level layouts (Figure 3) have good dynamic flow rates and excellent structural efficiency. They can be used with one-way and two-way circulation patterns and a variety of ramp arrangements to achieve the desired performance.

This is probably the most popular layout in the UK for car parks with row capacities greater than 24 cars. Entry and exit traffic are separated and the flow pattern is simple and uncomplicated. When built in steel, with column free spans, this layout will give the best combination of economy and operating efficiency.

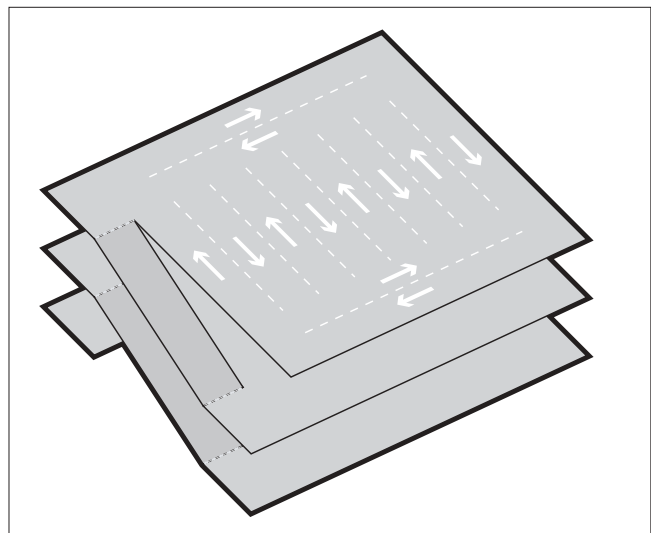


Figure 4. Flat deck layout

Flat deck layouts (Figure 4) are becoming increasingly popular for their simplicity of construction, clean lines and ease of use. They are particularly suitable in situations where the floor levels have to be matched to another building. This layout is less efficient than the split-level arrangement but can have comparable dynamic capacity for infrequent users. However the larger search paths can be frustrating for frequent users where a 'parking ramp' solution may be more acceptable.

The layout illustrated (Figure 4) would be used for smaller car parks where the dynamic capacity is not critical. Two-way flow is used with external rapid entry and exit ramps.

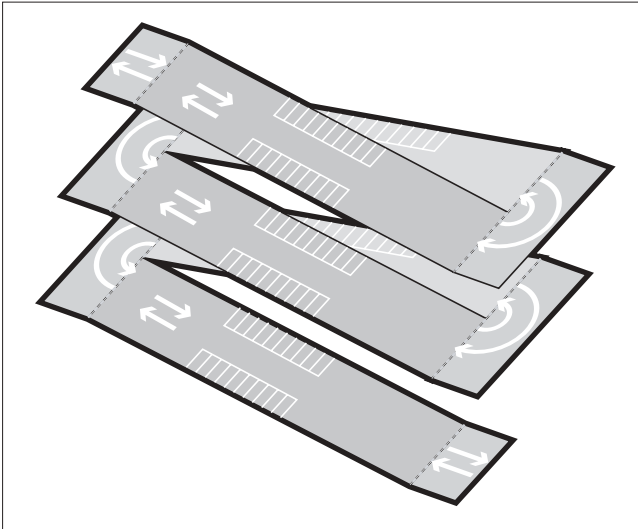


Figure 5. Parking ramps

Parking ramps (Figure 5) may be used with great success where frequent users are the prevalent customers, for example, a large office. Their main advantage is that the user must pass all stalls on entry to the car park, resulting in a rapid search path and less frustration. Users can be disadvantaged when exiting the car park unless an express exit is provided.

The parking ramp shown is a single ramp with two-way flow. It offers ease of use combined with efficient usage of space. External ramps may be added if rapid exit from the park is required. In this case a one-way system would be preferred.

Whichever type of layout is chosen, a number of key principles should be followed:

- Keep it simple. What looks like a clever solution could be difficult for the user
- Minimise the workload on the driver and avoid confusion as to where to go and what to do. This is solved partly by signs but mainly by good design.
- Cover as many stalls as possible on the entry route
- Pass as few stalls as possible on the way out
- Separate inward traffic from outward traffic if possible, without causing additional complications
- Circulate to the right if possible so that the driver is on the inside of the turn



Structural form

The structural design of a car park will usually determine its quality as a user-friendly structure. The structural form should provide:

- Ease of entry and egress to and from stalls so that users can gain rapid entry and exit without the risk of damage to vehicle or injury to person.
- Few obstructions to movement. The driver should be guided through the park without encountering severe obstructions such as columns in the drive path and badly parked cars caused by inefficient design or layout.
- A light and airy environment. The environment the car park provides will often determine how profitable it is. A light and airy environment should be one of the major goals of the car park designer. Steel is ideally placed to provide this type of environment because of its lightweight nature and long span capabilities. This can be further enhanced if open web sections are chosen. See case study 2.
- A safe and secure environment. Today, personal security is high on the list of priorities for any building; car parks are no exception and due to their public nature they must be safe for users and their vehicles. A building with minimal internal structure will help to enhance the feeling of security by making the area as open as possible with few barriers to sight lines. The light and airy environment made possible with steel will help to enhance the feeling of security required of these buildings.

Foundations

The design loading for car parks is given in BS 6399, which specifies an imposed loading of 2.5kN/m² for the parking areas and ramps. The loading on foundations is greatly influenced by the material chosen for the frame. Steel is the lightest practical construction material and will often allow the use of simple foundations where other, heavier materials will not. The type of foundation required is often the deciding factor on whether a project is viable. Steel is often the only viable construction material for multi-storey car parks.

Column positions

The desirable attributes indicated above will only be completely fulfilled if there are no internal columns (Figure 6). If steel is chosen as the frame material a clear span solution can be used for the majority of car parks.

However there may be occasions, for example, where the car park is beneath another form of structure with a different span arrangement, where internal columns must be used (Figure 7). This arrangement has an impact on the column cross centres and a comparison of possible geometry for clear span and propped alternatives is presented in Table 2.

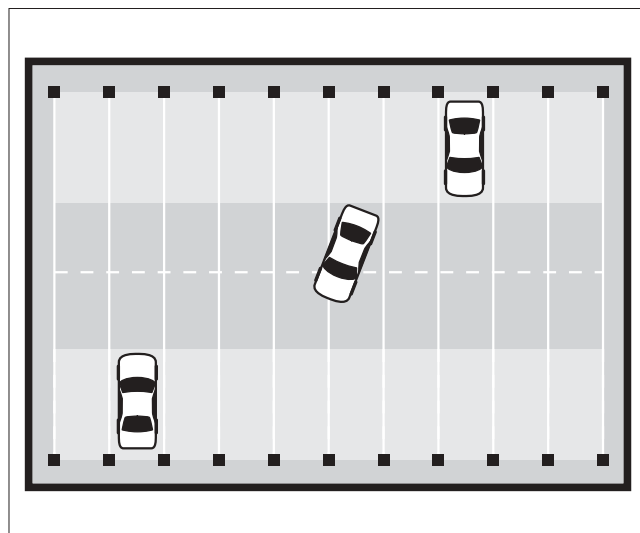


Figure 6. No internal columns to impede traffic flow

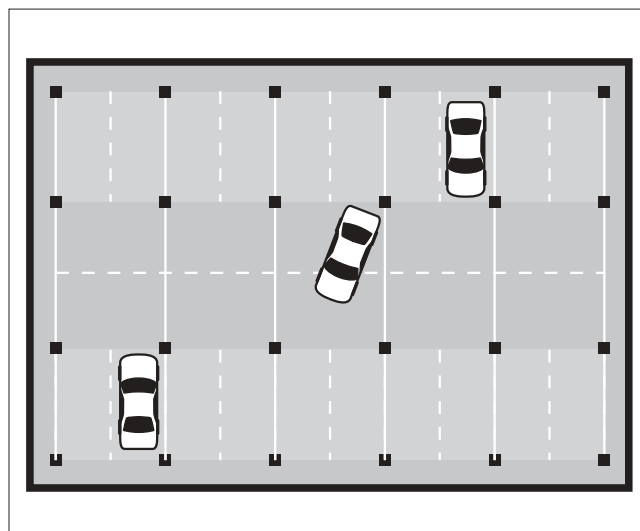


Figure 7. Alternative positions of columns impede traffic

Table 2. Effect of internal columns on overall width

No. of cars between columns	Column cross centres option (2.4m stall width)	Reduced column cross centres for clear span
2	(a) 2.400 x 2 } (b) +0.300 x 2 } = 5.7m (c) +0.150 x 2 }	4.8m
3	(a) 2.400 x 3 } (b) +0.300 x 2 } = 8.1m (c) +0.150 x 2 }	7.2m
4	(a) 2.400 x 4 } (b) +0.300 x 2 } = 10.5m (c) +0.150 x 2 }	9.6m

(a) Stall width (b) Clearance to column (c) Half column width

It is generally preferable to arrange longitudinal column and beam spacings to coincide with parking stall widths; the equivalent of one, two or three stall widths are the most commonly used. Using a single width has the advantage of visually separating the stalls for the driver, but it is not suitable when using internal columns. With column spacing of two stall widths it is generally only necessary to use secondary beams when shallow profile steel decking is used to form the slab. Other slab solutions may require secondary beams when the column spacing is in excess of two bay widths. Secondary beams are used to avoid propping of the floor during construction, to limit depth of construction and ensure economy of design.

Floor & frame solutions

A variety of floor systems can be used in multi-storey car park construction. The ultimate choice will depend upon many factors, such as height restrictions and structural layout. Five of the most common types of floor construction used in steel-framed car parks are shown (Figures 8-12). With all the illustrated systems the steel beams may generally be designed either compositely or non-compositely. The exception is where precast units run parallel to the primary beam, in which case the primary beam will be a non-composite design.

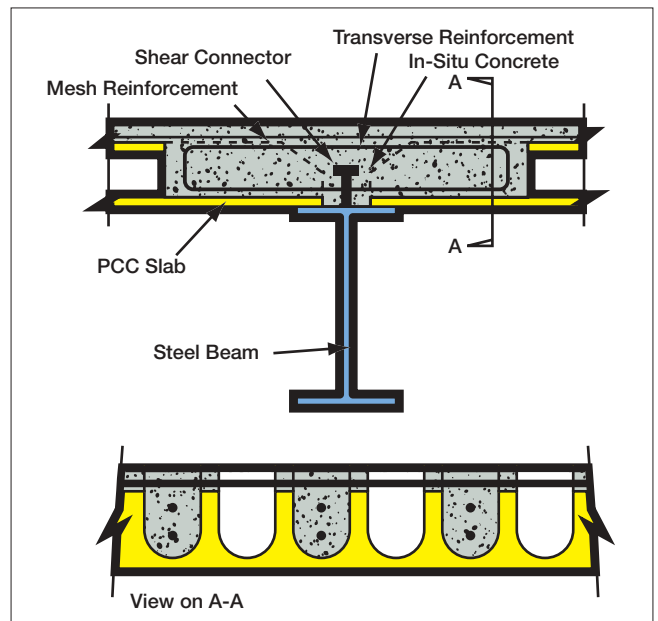


Figure 8. Composite beam with PCC hollow core slab

Figure 8 shows hollow core pre-cast units used compositely with the steel beams. To achieve composite action, alternate cores of the precast units must be broken out and filled with in-situ concrete for the effective width of the slab. Additional transverse reinforcement is also required. A concrete topping would normally be used to give adequate resistance to moisture penetration and to tie the pre-cast units together to form a monolithic floor slab. Detailed guidance is available in SCI publication P287, 'Design of Composite Beams Using Precast Slabs'.

The system has the advantage that wider spacing of main beams can be achieved because of the pre-cast unit's spanning capabilities, and low self weight. Speed of construction will be improved over a solid slab, leading to greater cost savings on the scheme. In the non-composite version of this system the cores of the

pre-cast units do not require to be broken out, this leads to faster construction times at the expense of greater steel weight.

The metal deck solution, shown in Figure 9, has been used for a small number of car parks in the UK. As well as performing a role as part of a composite slab, the metal deck also acts as permanent formwork to improve speed of erection and reduce crange requirements compared with the other systems described. The maximum unpropped span of these types of decks is around 4.5m (consult manufacturer's literature for exact details), therefore the spacing of the main beams cannot be greater than one stall width unless secondary beams are used.

When metal deck is used in conjunction with composite beams, through deck welding of the shear studs is beneficial because it enables continuous sheets of decking to be laid on the steel beams prior to fixing the studs. It may also enhance the way in which the decking behaves as transverse reinforcement adjacent to the studs. However, in the potentially corrosive environment of a car park, the need, when using through deck welding, to keep the upper surface of the beams free of paint (to avoid contamination of the stud welds) may be unacceptable. This leaves the designer with four options:

- Use shear connectors that are attached to the beams without the need for welding. A number of connectors that use shot-fired pins are available.
- Weld the studs to the beams in the fabrication shop, prior to applying the corrosion protection. With this solution the decking is best laid in single span lengths and butted up to the studs. This makes the decking less structurally efficient and requires stop ends to prevent the in-situ concrete escaping through voids. Alternatively, holes may be punched in the deck so that it can slot over the studs, but this may be more difficult to achieve in practice.
- Use non-composite beams.
- Use a combination of non-composite secondary beams and composite primary beams. The decking can then be laid in continuous lengths across the secondary beams, which are normal to the span of the primary beams.

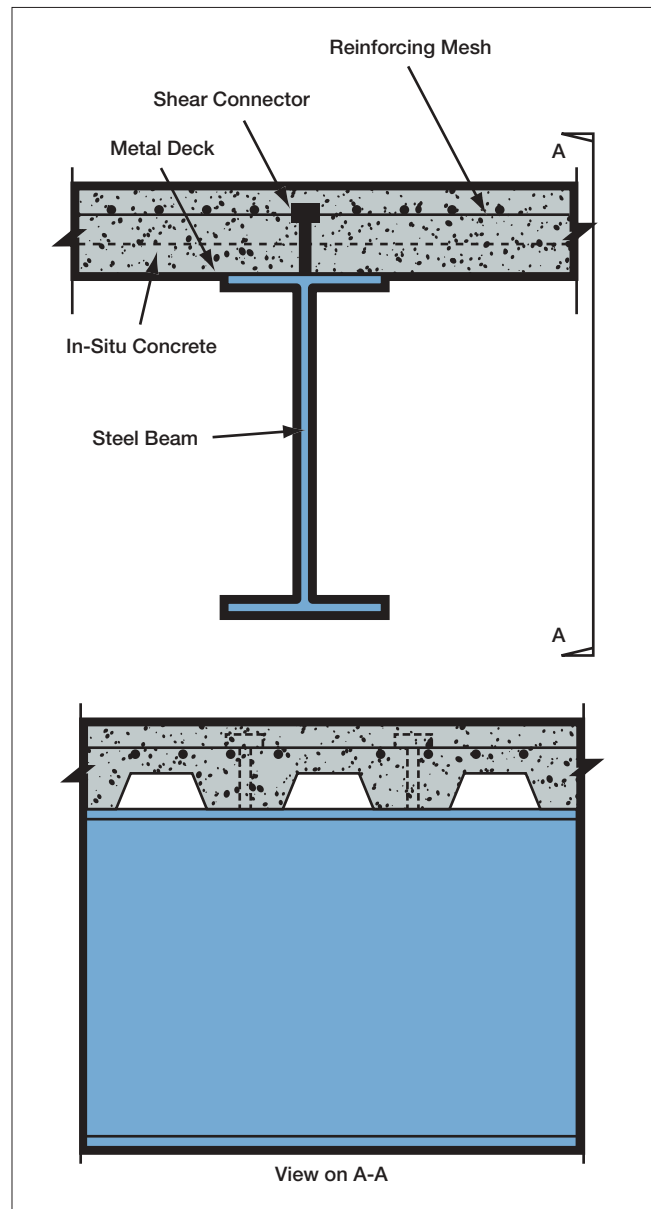


Figure 9. Composite beam and metal deck

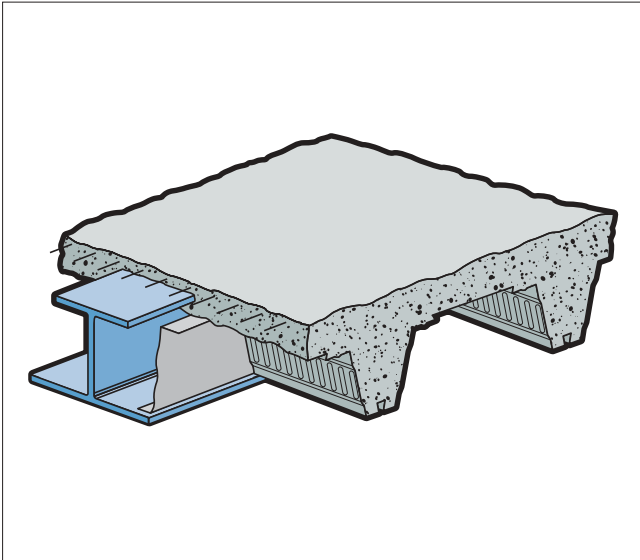


Figure 10. Slimdek® and deep decking

Deep decking enables the elimination of secondary beams because it can span up to 9.0m. Deep decking will provide the maximum benefit when used with Slimdek®, as shown in Figure 10, typically spanning around 9.0m.

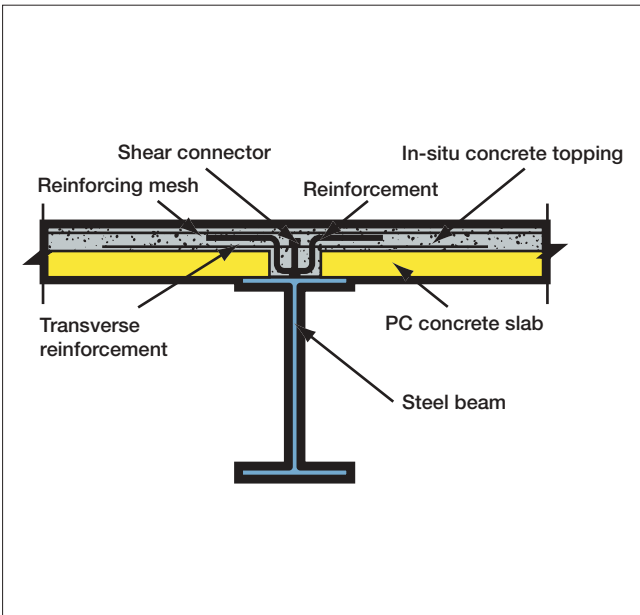


Figure 11. Composite beam with composite PCC slab and topping

Figure 11 shows a composite beam with composite pre-cast concrete slab and topping. The pre-cast slab in this case is solid and usually only 75mm to 100mm thick.

This spans between beams, the maximum span being around 5m, allowing main beams to be spaced at two stall widths, without propping of the slab during construction. Composite construction is achieved with

shear connectors welded to the top flange of the steel beam. These should be welded ‘in the shop’ so that corrosion protection can be applied. Transverse reinforcement will be required and additional bars may also be required at the stud location to act as bottom reinforcement.

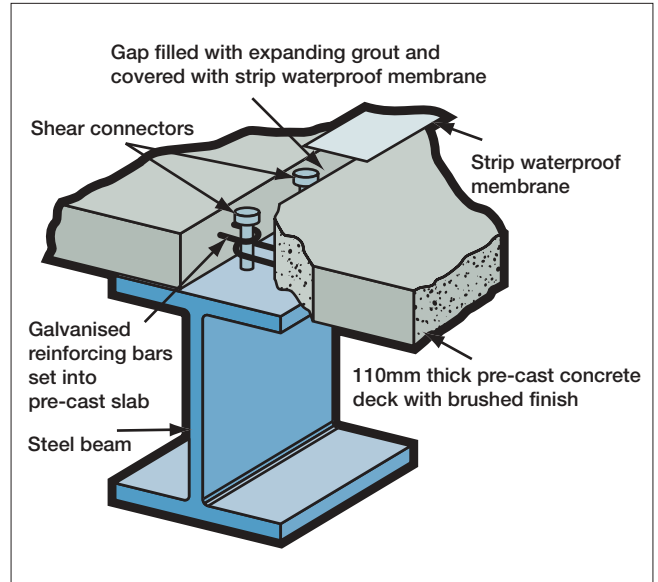


Figure 12. 'Montex', pre-cast slab system

A variation on the pre-cast slab design is the 'Montex' system illustrated in Figure 12 which is a proprietary design using special slabs with hooped bars emerging from the ends of the units. These are used to tie the system together as illustrated in Figure 12. The void is filled with in-situ concrete and then covered with a strip waterproof membrane.

Underground car parks

Steel sheet piles are ideal for producing an efficient, cost effective and quick retaining structure for underground car parks and deep basement car parks. Floors can be designed to act as struts for the finished structure, which can be utilised in the ‘Top Down’ construction method.

This combined with the ability of a steel sheet pile retaining wall to accept vertical bearing loads make this form of construction particularly effective for car parks beneath new buildings. Further information on underground car parks is contained in the Steel Construction Institute publication SCI-P275: Steel Intensive Basements.



Figure 13. @Bristol underground car park.

Vehicle safety barriers

All car parks should be fitted with adequate vehicle safety barriers to prevent accidental damage to the structure and restrain out of control vehicles. Edge barriers in particular should be adequate to restrain vehicles and be of a height and design, which will safeguard small children. BS 6180: 1999 'A code of practice for barriers in and about buildings' may be of assistance.

Deflection

Where clear span construction and high strength steels are used for the main beams, deflection may govern the design. These beams may therefore be pre-cambered to compensate for dead load deflection and to minimise the risk of ponding, when in-situ concrete solutions are used. An additional pre-camber may be introduced to compensate for a proportion of the live load deflection (usually up to 1/3). This has the advantage that the beams have a slight upward bow, which avoids the optical illusion of a heavily deflected beam when it is, in reality, level. The theoretical deflections, allowed for in pre-cambers, do not always occur and care must be taken to ensure that any permanent set does not impede the efficient drainage of the slab.

Dynamic performance

The dynamic performance of floors in buildings has become an important issue in recent times, which has led to a review of design practice in this area. In buildings such as hospitals, the dynamic performance can be critical, but in buildings such as car parks, where there is an expectation of disturbance from traffic movement, it is much less important. The human perception of movement in a car park will be less than in



Figure 14. Pre-cambered cellular beams as used at the Buttercrane Centre car park, N. Ireland.

other situations because users are either in motion themselves, by walking, or sat in a car and isolated from external vibration by the suspension.

Traditionally, steel-framed car parks have been designed using a minimum frequency as a sole measure of dynamic performance. SCI publication P076 suggests the minimum frequency of the floor (including the concrete slab, primary and secondary beams, where appropriate) should not be below 3Hz. More recent guidance from the Institution of Structural Engineers suggests an increase, but it appears that this is not based on any adverse comment from users or owners.

For vibration, consideration of natural frequency alone can be misleading, as it is the amplitude of vibration that most people feel. The amplitude can be expressed in terms of displacements, but, in practice, this can be difficult to measure. As a consequence, most modern Standards describe the sensitivity of human exposure to vibrations in terms of acceleration amplitudes. In BS 6472, accelerations are expressed relative to a 'base value', which is adjusted with frequency according to human perception, so forming a 'base curve', as shown in Figure 15. The ratio of the predicted (or measured) acceleration to the base curve value is then defined as a 'response factor'. A variety of response factor values are recommended for different floor types, but there are no recommended values for car parks in BS 6472.

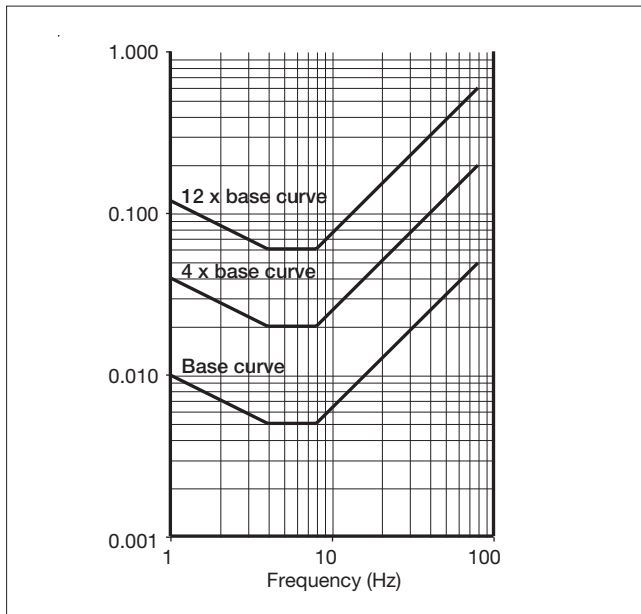


Figure 15. Vertical vibration curves taken from BS 6472

To compensate for this 'omission' in the British Standard, a study was made of 9 steel-framed car parks incorporating long spans. All were constructed in the last 15 years, with no adverse comment about the dynamic behaviour being known. The examples included 7 car parks with composite beams and pre-cast units (with a concrete topping or asphalt finish), and 2 with composite beams and a concrete slab using metal decking as permanent shuttering. Secondary beam spans ranged from 15.6m to 28m, and floor slabs spanned between 3.6 and 7.2m. The most onerous floor area in each example was chosen to calculate the natural frequency and the corresponding response factor. An 'empty' case (assuming 1.1% damping) and a 'full' case (assuming 2.5kN/m² imposed loading and 4.5% damping) were considered.

The results of the study are shown in Figure 16. Floor natural frequencies ranged from 2.8 to 5.18Hz 'empty' and 2.2 to 4.2Hz 'full'. The natural frequencies tend to be lower under full loading because of the higher mass mobilised. Response factors ranged from 3.6 to 64.5 for the 'empty' cases and 0.9 to 26.6 for the 'full' cases. The ratio of the natural frequency 'full' to 'empty' was nearly always about 0.8, which merely reflects a consistent ratio of dead loading only to full loading of 0.64 for car park construction. Response factors are generally higher for the 'empty' case, where the mass and damping is less.

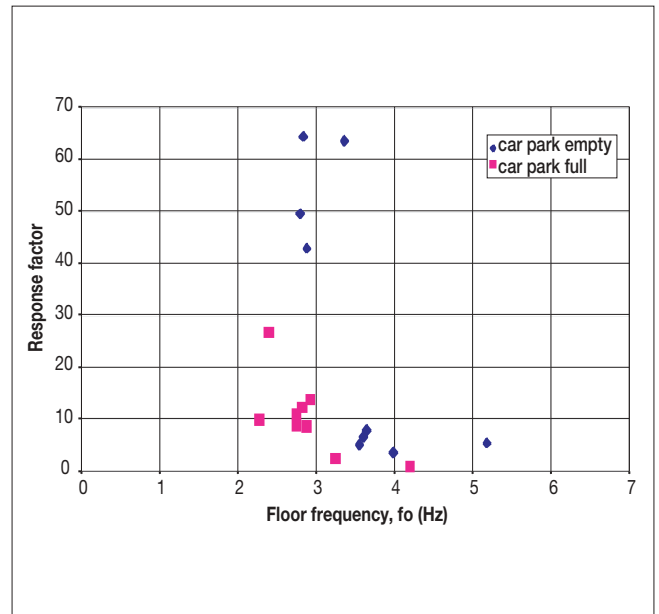


Figure 16. Car park dynamic performance

To demonstrate the level of accuracy in the analysis presented here, a car park framed with long span cellular beams, which has been subjected to vibration tests in Atlanta, Georgia, USA, has been analysed using the same method. The difference between the measured and calculated values of frequency and response factor was less than 10%.

The above results clearly show that there has been a recent history of car park construction with low natural frequencies and high response factors, which have received no adverse comment. The study shows that the traditional natural frequency value of 3.0Hz can be maintained for design, and used with confidence. For normal steel-framed solutions, the adoption of this value leads to bare floors (damping 1.1% with no imposed load) possessing a maximum response factor of approximately 65. This response factor value can be used as guidance where more detailed calculations are deemed to be appropriate. No guidance is given for a full car park because the characteristics are different and it is considered that design based on the criterion for the empty case is sufficient.

This section has been concerned with human-induced vibration, but excitation may be caused by impact from cars running over uneven surfaces or discontinuities, such as expansion joints. Careful detailing and workmanship should ensure that any joints are level and can be traversed smoothly, and that the gaps are no larger than necessary. Regular maintenance should prevent the wearing surface from deteriorating.



Figure 17. Cross bracing as used at the Genesis car park, World Cargo Centre, Heathrow

Stability

The stability and robustness of a structure is a vital structural design consideration. Multi-storey car parks pose a particular problem because they contain few internal walls. This is especially true of demountable structures. There are various methods to ensure structural stability against horizontal forces; two of the most common options are outlined below.

- a) Braced structure. Suitable bays or cores are placed around the building to provide stability in two orthogonal directions. Bracing may take the form of cross members or eccentric type bracing. In car parks the eccentric bracing can be used across the structure because it allows relatively unimpeded circulation throughout the floor area. An example of a braced car park structure is shown in case study 1.
- b) Unbraced structure. In this case the frame is designed as 'rigid'. Moments are transferred from beams into columns via moment connections and stability is gained from the stiffness and continuity of the connections. This may result in the need for haunches in clear span construction.

A combination of these methods may be used. For example, use a rigid frame across the structure and brace longitudinally at the outside edge of the building.

Whichever method of achieving stability is chosen, it is important to consider the construction stage of the building as well as the completed structure. The floor slab in most cases is designed to carry the horizontal forces to the braced parts of the structure. Until this plate has gained sufficient strength it may be necessary to provide temporary plan bracing.

Fire resistance

Steel-framed car parks have been rigorously fire tested in a number of countries (Table 3). These tests demonstrate that most unprotected steel in open sided steel-framed car parks has sufficient inherent resistance to withstand the effects of any fires that are likely to occur. Table 3 lists the maximum temperatures reached in open sided car park tests in four countries. These can be compared with the limiting temperatures of 620°C for beams carrying floor slabs and 550°C for columns, at which failure is expected to occur.

Open sided car parks are defined in Approved Document B to the Building Regulations 2000 for England & Wales as having open ventilation of at least 5% of the floor area at each level, at least half of which should be in opposing walls.

The fire resistance requirements for open sided car parks in the United Kingdom and Ireland are outlined in Table 4. The dominant period is 15 minutes. Most universal beams and columns will achieve 15 minutes fire resistance without added protection although a small number of sections at the lower end of the range, for example the 152 x 152 x 23UC and 127 x 76 x 13UB, will do so only when less than fully loaded.

In general, where a section does not have 15 minutes inherent fire resistance, it is usually more efficient to increase the section size than to fire protect.

Table 3. Fire tests in various countries

Full scale fire tests	Maximum measured steel temperature	
	Beam	Column
UK	275°C	360°C
Japan	245°C	242°C
USA	226°C	–
Australia	340°C	320°C

Table 4. Open sided car parks

Requirements from regulations	Height of top floor	
	Up to 30m	Over 30m
England and Wales	15 minutes * + ◇	60 minutes
Scotland	30 minutes #	30 minutes
Northern Ireland	15 minutes * +	Not permitted
Republic of Ireland	15 minutes *	Not permitted

- * Increased to 60 minutes for compartment walls separating buildings
- + Increased to 30 minutes for elements protecting a means of escape
- ◇ The European Supplement to Approved Document B outlines details of beams and columns, in terms of section factors, which are deemed to satisfy the requirement to achieve 15 minutes fire resistance without protection.
 - I. Beams supporting concrete floors, maximum section factor = $230m^{-1}$ or open section beams with a minimum lower flange thickness $\geq 9mm$.
 - II. Free standing columns, maximum section factor = $180m^{-1}$ or open section columns with a minimum lower flange thickness $\geq 12.5mm$.
 - III. Wind bracing and struts, maximum section factor = $210m^{-1}$ or flats, angles and channels with a thickness $\geq 10mm$ or hollow sections with a wall thickness $\geq 6mm$.
- # A note similar to that in the European Supplement to Approved Document B exists in Technical Standards Part D, page 33D. This says that, where the topmost storey of the building is at a height not more than 18m above ground, the requirement for the structural frame will be met by:
 - I. Beams supporting concrete floors, each beam having a maximum section factor = $230m^{-1}$.
 - II. Free standing columns, each having a maximum section factor = $180m^{-1}$.
 - III. Wind bracing and struts, each having a maximum section factor = $210m^{-1}$.

Section factor (H_p/A) = Heated perimeter/Cross Sectional Area. These are calculated for most common situations in the Corus sections brochure.

The data on limiting section factors can also be expressed as a function of load ratio as defined in BS 5950 Part 8, Code of Practice for Fire Resistant Design. A fully loaded beam or column is normally assumed to have a load ratio of 0.6 for the fire limit state. Provided the load ratio is less than 0.6, most universal beams & columns will achieve 15 minutes fire resistance without fire protection. The exceptions, and the maximum load ratios to achieve 15 minutes fire resistance for non-composite construction, are provided in tables 5 and 6 on the right:

Table 5. Maximum load ratios for 15 minutes fire resistance – UB exceptions*

UB section size	Section factor (Hp/A)	Maximum load ratio to achieve 15 minutes fire resistance
127x76x13UB	285m ⁻¹	0.54
152x89x16UB	275m ⁻¹	0.54
178x102x19UB	270m ⁻¹	0.54
203x133x25UB	250m ⁻¹	0.57
254x102x22UB	285m ⁻¹	0.49
254x102x25UB	259m ⁻¹	0.56
305x102x25UB	285m ⁻¹	0.48
305x102x28UB	255m ⁻¹	0.58
356x127x33UB	250m ⁻¹	0.58
406x140x39UB	245m ⁻¹	0.59

* Where design is governed by serviceability, the majority of these sections will achieve 15 minutes fire resistance. This should be assessed on a case by case basis.

Table 6. Maximum load ratios for 15 minutes fire resistance – UC exceptions

UC section size	Section factor (Hp/A)	Slenderness ratio*	Maximum load ratio to achieve 15 minutes fire resistance
152x152x23UC	310m ⁻¹	81	N/A, Choose next in the section range
152x152x30UC	240m ⁻¹	78	0.36
152x152x37UC	190m ⁻¹	77	0.45
203x203x46UC	205m ⁻¹	58	0.51
203x203x52UC	185m ⁻¹	58	0.58

*Assumes an effective length of 3 metres. The actual failure temperature is a function of the slenderness ratio.

In practice, many sections will have load ratios lower than 0.6.

The latest version of BS 5950 Part 8 was published in 2003, after the European Supplement and the most recent version of Technical Standard D. This differentiates between composite and non-composite beams and between different degrees of shear connection. The effect of this will be that composite beams will be assumed to have lower failure temperatures than non-composite beams. This could be taken to mean that some additional beams will not achieve 15 minutes inherent fire resistance when designed compositely. However, composite beams have enhanced robustness because of the effects of continuity in the floors. This has been investigated and the results published in Report No. 75 – Fire Safety in Open Car Parks, published by the European Convention for Constructional Steelwork, which concludes that, in the event of a fire in an open car park, no failure will occur.

Durability

A car park should be designed to give the best possible return on investment and should therefore be maintenance free as far as possible. Maintenance requirements, and how they should be carried out, are described in the ICE publication “The inspection and maintenance of multi-storey car parks”. Maintenance is of particular importance to ensure that drainage gullies and downpipes are clear of debris to enable water to drain efficiently from the car park.

Car parks, by their very nature exist in environments that are far from ideal. The air is often contaminated with fumes from car engines. The surfaces of the structure may be sprayed with water, which in winter can be contaminated by de-icing salts and other highly corrosive elements that can percolate through cracks in the concrete slab. Although the effect of these can be minimised by good drainage design, crack control, and/or the application of protection to the top surface of the slab, it is still necessary to give complete protection to those components within the car park, which are likely to be in close contact with these contaminants. The major elements are the steel frame and the concrete, or composite floor slabs.

The steel frame

Steel is a durable framing material. It will, if protected correctly, give a long life with minimal maintenance.

In most cases all that is required is a repaint at the first maintenance period, which can be 20 to 30 years or more, depending on the initial protection specified. Three suggested treatments are given in Table 7. The durability of the protection system is primarily influenced by the corrosivity of the environment. The corrosivity categories are based upon those given in ISO 12944 Part 2 and ISO 9223.

Concrete floors

The concrete within a car park is particularly susceptible to deterioration, so grade 50 concrete should usually be specified. Pre-cast units are generally more durable than in-situ concrete due to factory controlled production conditions. It is recommended therefore, that one of the pre-cast systems outlined above should be used with a limited amount of structural topping. To minimise the percolation of corrosive fluids through cracks floors should be sloped at 1:60 falls to aid drainage, and the

top surface of the concrete slab should be protected with an appropriate proprietary waterproofing system. Manufacturers guidance should be followed for the correct choice of product and application.

Metal decking

G275 galvanizing (275g/m² of zinc) is the standard protective coating for composite steel decking. This level of corrosion protection to the upper surface of the decking will be sufficient, provided adequate provision has been made to prevent the ingress of water (using reinforcement to control cracking, and waterproofing the top surface of the concrete). The underside of the decking should be given additional protection in the form of a pre-applied coating or epoxy paint applied in-situ. Such an additional layer of protection has the advantage that it can be regularly inspected and remedial work undertaken if required. However, it is recommended that Corus be consulted on durability and future maintenance issues at an early stage if this solution is to be adopted.

Waterproofing

Car parks require treatment against the effects of an external climate. The car park environment can be very onerous, especially where aggressive snow and ice clearing methods are adopted. It is therefore recommended that at least the top deck of the car park is waterproofed with a traditional bituminous membrane or liquid applied seamless coating. It is also good practice to treat other floors to prevent ingress of water. It is important to specify the correct product and ensure that installation and maintenance are fully in accordance with the supplier's recommendations.

With all floors it's necessary to provide adequate falls and drainage to prevent the build up of water on the slabs.

There is a growing trend to use a lightweight roof over the top parking deck. This gives added protection to the top floor of the car park allowing users to park in all weathers. The aesthetic appeal of a car park can be significantly enhanced by this method enabling the park to blend in with the urban environment. The long-term benefits of reduced maintenance can far outweigh the initial cost of this approach. The car parks at Aylesbury and Guildford typify this method of construction.

Table 7. Suggested corrosion protection systems

		Car parks					
Environmental category (Note 8)		C3		C4		C5	
System number		B12		E6		E9	
Anticipated durability of the coating system in years and environment categories (Notes 1 & 2)		C3		20+		25	
		C4		15-20		15-20	
		C5		8-20		12	
Shop applied		Surface preparation (BS 7079: Part A1)		N/A		Blast clean to Sa 2½	
Coatings (Note 5)		Hot dip galvanize to BS EN ISO 1461 (Note 3)		85µm		Zinc rich epoxy primer 40µm	
		None (Note 4)		High build epoxy MIO 100µm		Zinc rich epoxy primer 40µm	
Site applied		Coatings		None (Note 4)		High solid aliphatic polyurethane finish 80µm	
Relative costs (Note 6)		1		1.18		1.55	

(Based on information extracted from 'A Corrosion Protection Guide: For steelwork exposed to atmospheric environments', see Bibliography)

Notes

1. Coating system durability given in the table is based on practical experience. It is the expected life, in years, before first major maintenance. This is taken as degradation level Ri3 from ISO 4628 Part 3 (1% of surface area rusted). It should be noted that this does not imply a guarantee of life expectancy. In coastal areas, the coating life expectancy may be reduced by up to 30%.
2. The durability of galvanized steelwork is derived from the figures in BS EN ISO 14713.
3. Galvanizing should be carried out to Standard BS EN ISO 1461.
4. Where painting of galvanized steelwork is required for aesthetic or other reasons, suitable systems from ISO 12944 may be used.
5. The thickness values given for primers are the total thickness used and may include a prefabrication primer.
6. The relative costs given here are for guidance. There will be considerable variation that may typically be +/- 50% for a variety of reasons. Quotations should be obtained before making the final selection of the protective treatment.
7. It should be noted that the colour of micaceous iron oxide (MIO) is limited.
8. Environmental categories are based on those given in ISO 12944 and ISO 9223.



Figure 18. Guildford 946 space Car Park adjacent to railway and local housing



Figure 19. Aylesbury 600 spaces on 5 levels developed by Safeway Stores plc for Aylesbury Vale District Council

Refurbishment

One of steel's major advantages is the ease with which it can be refurbished and adapted. Car parks in steel are no different in this respect. Where examples can be found they have been refurbished with minimal expense and great success as at the refurbished Waitrose car park at Weybridge.



Before refurbishment



After refurbishment



Refurbished interior

Figure 20. Waitrose car park at Weybridge.

Aesthetic design

Steel car park structures have been designed to accept all types of external cladding. Examples include Platisol sheets as at Poole, steel mesh panels as at Aldershot, steel mesh and fins at Milton Keynes and brick as at Aylesbury, Guildford and Tallaght.

There are various steel cladding systems ranging from the simple sheet to sophisticated composite panels. All are compatible with the steel frame.

Brick cladding of steel frames is well proven for offices, car parks and many other structures. Steel's inherent accuracy is a positive advantage when attaching brickwork support systems.

The cladding may be designed to be load bearing as well as aesthetic. In particular crash barriers have been designed as an integral part of the cladding system. These may be load resistant (stiff) or energy absorbing (flexible). The steel frame provides an excellent interface for connection of either type.



Figure 23. Avebury Boulevard multi-storey car park, Milton Keynes.



Figure 24. Tallaght multi-storey car park.



Figure 21. Poole car park.



Figure 22. Royal Pavillion car park, Aldershot.

Commercial viability

The cost per space for a basic average-sized (250 spaces) multi-storey car park is in the region of £3,000-£4,000 (2002 figures) inclusive of framework, floors, barriers, foundations and cladding.

The cost of a steel frame in real terms has decreased appreciably over the last few years through greater efficiency in both the steel manufacturing and fabrication industries. The shorter construction period made possible through the use of a steel frame and consequently the earlier return on investment increases the commercial viability. The elimination of fire protection costs has had a major influence in making a steel-framed car park one of the most competitive options available.

Midsommer Boulevard car park
Milton Keynes



Latest developments

Demountable car parks

The exponential upward trend in the use of cars in the UK is resulting in the need to provide a greater number of car parks. Large companies and institutions especially, have a growing need for parking facilities. This need may be met in many cases by the use of demountable structures, to give an eminently flexible solution to the parking problem. Steel is considered to be the only practical solution that can be constructed as demountable.

The car park at Luton is an example of a car park, which could be demountable with some minor modifications.



Figure 25. Simple car park in Luton

Wholly automatic multi-storey car parks

This form of car park takes half the volume of a conventional car park to store the same number of cars. This is because these steel-framed car parks do not require access ramps or roadways within the car storage area. The driver parks the cars on a robot trolley within an entrance module. From this point the trolley takes the car to an empty parking space. When the driver wants the car back, it is retrieved by a robot trolley and returned to an exit module.

Construction is simply a steel framework with cladding to match the local environment. Since this form of car park requires less energy to run, operating costs are lower than for a conventional car park. This form of car park can be built either above or below ground.



Figure 26. Fully automated car park building in Istanbul

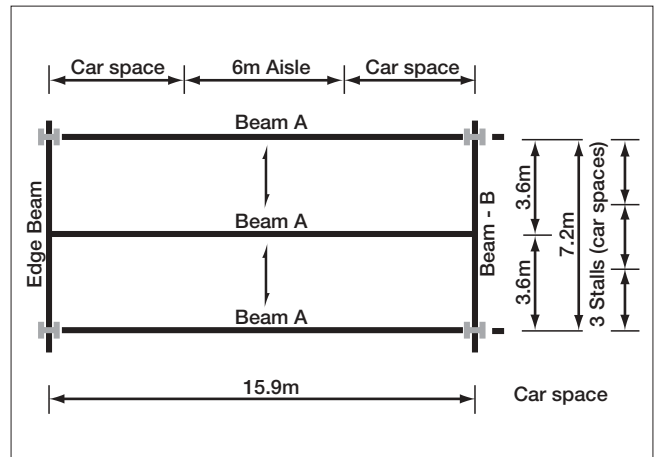
Sizing data sheets

Assumptions

The car park layouts shown are based upon the following assumptions

- Design is given for internal and edge beams where appropriate for one bay of a car park
- Imposed loading is taken as 2.5kN/m^2
- No account is taken of pattern loading
- Grade S355 to BSEN10025:1993 is used for all main and secondary beam steel
- Grade S275 to BSEN10025:1993 is used for all ties
- Approximate weights of steel given are based on a car park 72m long x 32m wide with car parking spaces at 2.4m wide. An allowance of 4% for connections and bracing has been assumed
- All in-situ concrete is normal weight, grade 50
- Beams and slabs are unpropped (vertically)
- Column sizes are based on the lower length of a 4-storey car park
- Beams have been chosen to give a minimum frequency of 3.0Hz
- Imposed load deflection limit: $\text{Span}/360$
- Total load deflection limit: $\text{Span}/150$
- Pre-camber approximately equivalent to deflection due to dead load + $1/3$ deflection due to imposed load

The structural sizes presented for layouts 1 to 4 have been derived on the assumption of balanced loading and effective temporary restraint of the compression flanges during construction. For further guidance on this issue refer to SCI publication SCI-P287.



Layout 1

Floor construction:

75mm deep precast planks.

Composite slab depth – 140mm overall

Beam 'A':

$610 \times 229 \times 101$ UB, grade S355

Composite with 104 – 19mm diameter shear studs x 95mm long

Camber approximately 80mm

Beam 'B':

$610 \times 229 \times 101$ UB, grade S355

Composite with 30 – 19mm diameter shear studs x 95mm long

Columns:

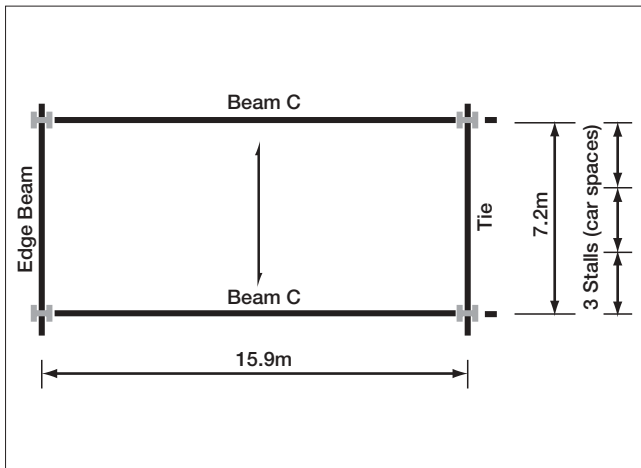
$305 \times 305 \times 97$ UC, grade S355

Approximate weight of steel:

45.2 kg/m^2 (0.86 tonne/parking space)

Overall depth of construction:

743mm



Layout 2

Floor construction:

150mm deep hollow core precast units.
Composite slab depth – 200mm overall

Beam 'C':

762 x 267 x 147 UB, grade S355
Composite with 148 – 19mm diameter shear studs x
120mm long
Camber approximately 95mm

Tie:

203 x 133 x 25 UB, grade S275

Columns:

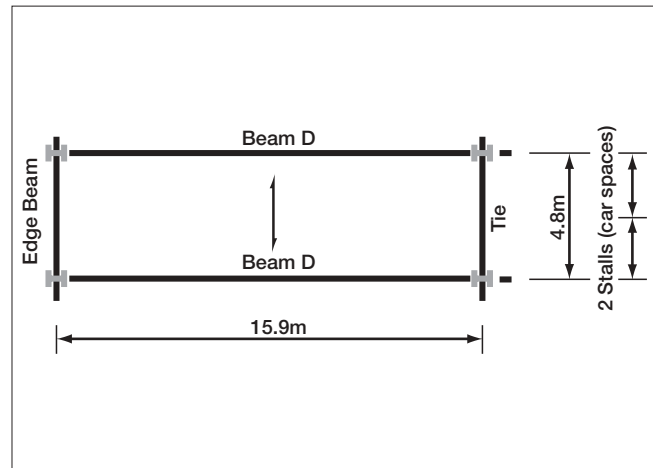
305 x 305 x 118 UC, grade S355

Approximate weight of steel:

45.2 kg/m² (0.86 tonne/parking space)

Overall depth of construction:

743mm



Layout 3

Floor construction:

100mm deep precast planks.
Composite slab depth – 150mm overall

Beam 'D':

610 x 229 x 125 UB, grade S355
Composite with 104 – 19mm diameter shear studs x
120mm long
Camber approximately 85mm

Tie:

152 x 152 x 23 UC, grade S275

Columns:

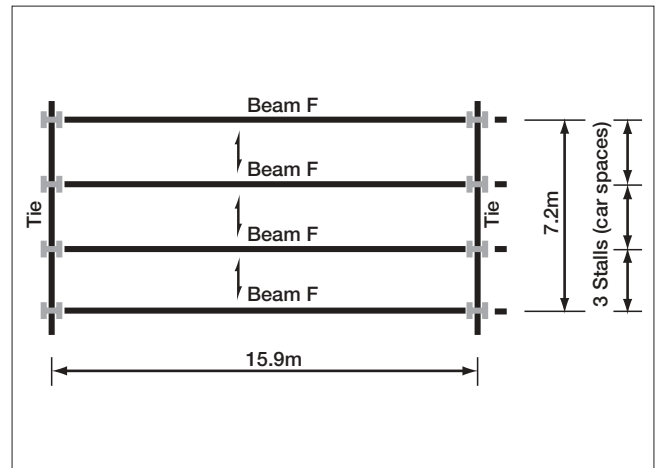
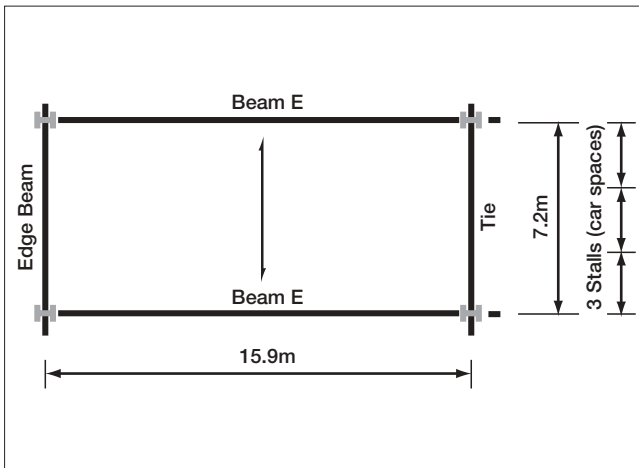
254 x 254 x 73 UC, grade S355

Approximate weight of steel:

36.2 kg/m² (0.69 tonne/parking space)

Overall depth of construction:

762mm



Layout 4

Floor construction:

210mm deep hollow core precast units.
Composite over 1m width

Beam 'E':

610 x 210 / 305 x 152 Asymmetric Cellular Beam, grade S355
400mm diameter cells @ 600mm centres
Top tee – 533 x 210 x 122 UB
Bottom tee – 305 x 305 x 158 UC
Composite with 99 – 19mm diameter shear studs x 120mm long

Tie:

203 x 133 x 25 UB, grade S275

Columns:

305 x 305 x 118 UC, grade S355

Approximate weight of steel:

30.2 kg/m² (0.58 tonne/parking space)

Overall depth of construction:

819mm

Layout 5

Floor construction:

110mm pre-cast “Montex” slabs.
Expanding grout infill with strip waterproof membrane

Beam 'F':

457 x 191 x 74 UB, grade S355
Composite with 74 – 19mm diameter shear studs x 95mm long
Camber approximately 105mm

Tie:

127 x 152 x 19 tee, grade S275

Columns:

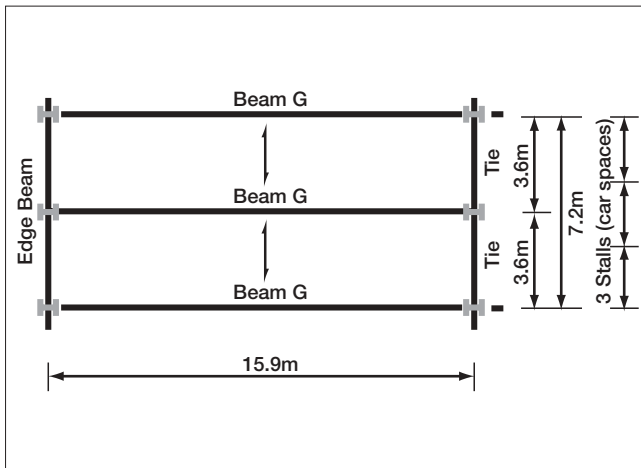
203 x 203 x 46 UC, grade S355

Approximate weight of steel:

40.8 kg/m² (0.78 tonne/parking space)

Overall depth of construction:

567mm



Layout 6

Floor construction:

Comflor 70, 1.2mm gauge
Slab 120mm thick

Beam 'G':

533 x 210 x 82 UB, grade S355
Composite with 86 – 19mm diameter shear studs x
95mm long
Camber approximately 100mm

Tie:

127 x 152 x 19 tee, grade S275

Columns:

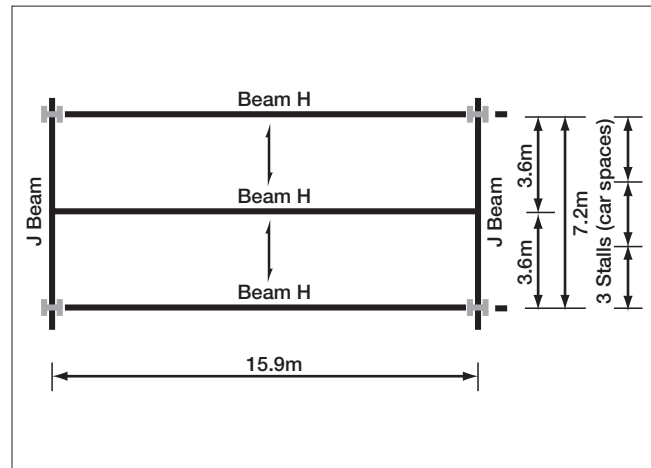
203 x 203 x 52 UC, grade S355

Approximate weight of steel:

31.4 kg/m² (0.60 tonne/parking space)

Overall depth of construction:

648mm



Layout 7

Floor construction:

Comflor 70, 1.2mm gauge
Slab 120mm thick

Beam 'H':

533 x 210 x 82 UB, grade S355
Composite with 86 – 19mm diameter shear studs x
95mm long
Camber approximately 100mm

Beam 'J':

533 x 210 x 82 UB, grade S355
Composite with 30 – 19mm diameter shear studs x
95mm long

Columns:

254 x 254 x 89 UC, grade S355

Approximate weight of steel:

37.0 kg/m² (0.71 tonne/parking space)

Overall depth of construction:

648mm

Case study 1

World Cargo Centre, Heathrow.



Brief

The brief was to design a 1000-space multi-storey car park for staff at Heathrow's World Cargo Centre to suit the site constraints. The car park was to incorporate a small retail area at ground floor and meet the requirements of a gold standard award. It was to be durable, fit for purpose and give value for money.

Attributes

- 5 levels of open single deck parking.
- Minimum clear headroom of 2400mm.
- Galvanized protection system.
- Waterproof membrane to top floor and first floor retail area.
- Steel vehicle impact barrier system

Special features

The construction process was radically re-engineered to reduce cost and time and to develop what was to become known as the "World Class Construction Process".

Efficiency and economy in the use of structural steelwork by standardisation, modularization and a simple design approach resulted from the innovative design and construction processes.

Technical information

Area (suspended): 19,100m²

No of floors: 5 including the ground floor

No of parking spaces (incl. ground floor): 1,000

Steel tonnage: 728T

Construction period: 39 weeks

Date completed: March 1997

Design: Steel frames at 7.2m centres, 150 deep hollow core units with 75mm structural topping.

Façade: Aluminium Cladding

Total construction costs: £3,900,000

Total cost per space: £3,900

Total cost per m² (including ground floor): £163

Type of contract: Design & Build

Client: BAA plc

Architect: HGP Architects

Engineer/fabricator: Bison Structures Ltd

Management contractor: MACE

Case study 2

Buttercrane Centre multi-storey car park, Co Down.



Brief

The client's brief for this project included an extension to the retail area of an existing shopping center plus the provision of approximately 600 car parking spaces. The car parking areas were to be bright and welcoming to the shoppers whilst keeping within tight budget costs.

Attributes

- Nine levels of parking on split deck construction
- Clear span construction using compositely designed, cambered cellular floor beams. High specification paintwork and good quality lighting provide a bright and comfortable environment
- Top decks are overcoated with an elastomeric waterproof membrane which is colour coded to indicate the parking areas
- The structure and foundations were designed and constructed to allow for an additional two levels of car parking in the future

Special features

A 225mm pre-camber in the cellular beams was used for natural water shedding. This was provided at no additional cost.

Technical information

Area (suspended): 12,300m²

No of floors: 5 including the ground floor

No of parking spaces (incl. ground floor): 606

Steel tonnage: 500T

Construction period: 30 weeks total

Date completed: November 1997

Design: Pre-cast concrete slab (75mm thick) with in-situ topping on clear span steel frame using composite cellular beams and universal columns.

Façade: Facing brickwork

Total construction costs: £2,445,000

Total cost per space: £4,035

Total cost per m² (including ground floor): £171

Type of contract: JCT 80 – negotiated contract

Client: Buttercrane Centre Ltd

Architect: WDR & RT Taggart

Engineer: WDR & RT Taggart

Contractor: O'Hare & McGovern

Fabricator: Ballykine (Structural Engineers) Ltd

Cellular beams supply: Westok Structural Services Ltd

Managing agents: Lambert Smith Hampton

Case study 3

Stockley Business Park, Heathrow.



Brief

Stockley Park is an intensively developed business park containing a mixture of buildings and surface parking located near Heathrow Airport. 170 additional car parking spaces were required. The design and construction programme was very short and the surrounding environment dictated a structure of high aesthetic and constructional quality.

Attributes

- High architectural quality
- Pre-fabrication allowed very rapid design and construction (26 weeks from concept to completion)
- Piled foundations were used because of the difficult ground conditions
- Open design improves the safety of the environment, enhanced by metal halide lighting and improved all-round observation
- Narrow columns save floor space and allow very tight stall widths to be used
- Slim pre-cast and glass floor reduced the height and access ramp length

Special features

- Clear span construction allowed the car park to be built without losing ground floor parking.
- Very tight spacing of bays at 2.2m
- Marine Styling.

Technical information

Area (suspended): 3,100m²

No of floors: 1 additional floor (suspended)

No of parking spaces (incl. ground floor): 178

Construction period: 16 weeks

Date completed: December 1995

Design: Steel portal frames of tapered I section plate girders with tubular legs and tie rods. The deck comprises pre-cast concrete and glass panels.

Façade: Open

Total construction costs: £1,200,000

Total cost per space: £6,742

Total cost per m² (including ground floor): £190

Type of contract: Traditional

Client: BP Properties Ltd

Architect: Broadway Malyan

Engineer: Ove Arup & Partners

Main contractor: Try Construction Ltd

Fabricator: Dyer (Structural Steelwork) Ltd

Case study 4

Bradford city centre multi-storey car park.



Brief

The Client's brief for this project was to produce a modern, safe car park on a restricted site, to service the needs of shoppers visiting Bradford city centre. The car park was to provide around 430 spaces next to the existing Co-op store, Sunwin House. After being in the planning stages for a number of years Clugston managed to bring in some innovative value engineering ideas to take the project through to reality.

Attributes

- 7 levels of parking utilising a Vehicle Circulation Model (VCM) construction technique.
- A combination of the steel frame and pre-cast decks has enabled a lightweight easily constructed car park on a very restricted city centre site.
- The use of clear span construction and open sides to the car park give a light and open environment in which to park. A high level of low energy lighting contributes to the enhancement of the environment.
- Cost effective design solution.
- Clear span construction using compositely designed, cambered cellular floor beams.
- The clear span construction has helped to provide a safe environment in which to park.
- Top decks are overcoated with an elastomeric waterproof membrane which is colour coded for user-friendly parking.

Special features

As an alternative to a split level layout the VCM circulation system was adopted. This system is the property of Hill Cannon (UK) LLP, Royal Chambers, Station Parade, Harrogate, is subject to a UK patent no GB2 269 610 B and is available for use under licence.

The use of VCM resulted in minimum cut and fill operations and idealized internal circulation without conflicting zones.

The deck construction comprises self-finished Trideck units, the designs of which are also the property of Hill Cannon (UK) LLP, subject to a UK patent, and are available for use under licence.

Technical information

Area (suspended): 9456m²

No of floors: 7 including the ground floor

No of parking spaces (incl. ground floor): 432

Steel tonnage: 410T

Construction period: 48 weeks

Date completed: October 2003

Design: Pre-cast units laid on the steel frame

Façade: Insulated cladding, mesh panels, low level facing blockwork

Total construction costs: £3,590,000

Total cost per space: £8,310

Total cost per m² (including ground floor): £325

Type of contract: Design and Build

Client: United Co-Operatives

Architect: Bowman Riley

Engineer: BSCP

Parking consultant: Hill Cannon (UK) LLP

D&B main contractor: Clugston Construction

Fabricator: Cauntton Engineering

Case study 5

The Parishes multi-storey car park, Scunthorpe.



Brief

Parking facilities are a strategic element of 'The Parishes', a £40 million redevelopment of Scunthorpe Town Centre. The ground plus four level 700 space car park provides safe, secure parking for shoppers, patrons of the 7 screen cinema complex and other town centre amenities and facilities.

Attributes

- 4 levels of parking utilising a Vehicle Circulation Model (VCM) construction technique
- A combination of the steel frame and pre-cast hollow core plus structural topping decks has resulted in a lightweight easily constructed car park on the site of an existing surface car park
- The use of clear span construction and open sides create a light and open environment. A high level of low energy lighting and CCTV surveillance contributes to the enhancement of the environment
- Circa 30 disabled spaces, motorcycle and cycle parking
- Office, Shopmobility and storage facilities are incorporated at ground level
- Curtain wall glazing creates light, airy feel to stairs
- Cost effective design solution
- Clear span construction using compositely designed, cambered cellular floor beams
- The clear span construction has helped to provide a safe environment in which to park
- Top decks are overcoated with an elastomeric waterproof membrane which is colour coded for user-friendly parking

Special features

As an alternative to a split level layout the VCM circulation system was adopted. This system is the

property of Hill Cannon (UK) LLP, Royal Chambers, Station Parade, Harrogate, is subject to a UK patent no GB2 269 610 B and is available for use under licence. The use of VCM resulted in minimum cut and fill operations and idealized internal circulation without conflicting zones.

Designed to comply with the requirements of the AA/Association of Chief Police Officers 'Secure Car Park Award' scheme.

An enclosed link bridge at second floor level provides sheltered access to a terrace area, the main retail elements and the cinema complex

Technical information

Area (suspended): 11,900m²

No of floors: 5 including the ground floor

No of parking spaces (incl. ground floor): 700

Steel tonnage: 510T

Construction period: 48 weeks

Date completed: October 2002

Design: Pre-Con pre-cast units on the steel frame

Facade: Steel cladding, curtain walling and low level facing blockwork

Total construction costs: £3,000,000

Total cost per space: £4,286

Total cost per m² (including ground floor): £202

Type of contract: Design and Build

Client: Quintain

Architect: CDA Architects, Brighton

Engineer: Ward Cole, Lincoln

Parking consultant: Hill Cannon (UK) LLP

Contractor: Clugston Construction

Fabricator: Conder Structures

Case study 6

Ipswich station multi-storey car park.



Brief

The brief was to design and build a 435 space multi-storey car park to service rail commuters. The car park was designed to blend in with the adjacent Victorian architecture of the listed station building and surrounding private residences. The car park was also designed for, and subsequently successfully achieved, the Secured Car Park Award. The project was won in a competitive tender scenario.

Attributes

- 7 split levels of parking.
- All steel components fully galvanised to 85 microns DFT.
- High performance polymer modified asphalt waterproof system to top floor.
- Untensioned corrugated profile safety barrier.
- High quality architectural appearance including in-situ brickwork and metal cladding.

Special features

The multi-storey car park was based upon Bourne Parking's unique prefabricated Montex modular technology, which provides the following key benefits for multi storey car parks:

- High quality factory produced building solutions.
- User friendly and safe clear span column free layouts that meet the recommendations of the Secured Car Park Award.
- Fast track construction techniques to ensure the shortest possible programme.
- Phased construction and planned logistical management for minimal disruption to existing facilities.
- Reduced whole life cost of the building as a result of low, long-term maintenance requirements.

- A wide range of elevational finishes to compliment any surrounding local environment.

Construction was undertaken adjacent to a live railway line. Furthermore, the station remained operational throughout construction, and Bourne Parking carefully managed the interface with general public, commuters and station traffic.

Technical information

Area (suspended): 7,000m²

No of floors: 7 including the ground floor

No of parking spaces (incl. ground floor): 435

Steel tonnage: 400T

Construction period: 36 weeks

Date completed: October 2001

Design: 16m clear span Montex structural steelwork frame and 110mm deep Montex precast concrete floor units.

Façade: Brickwork and architectural metalwork

Total construction costs: £2,600,000

Total cost per space: £5,977

Total cost per m² (including ground floor): £265

Type of contract: Design and Build

Client: Anglia Railways/Railtrack

Architect: Charter

Engineer: Whitby Bird & Partners

Contractor: Bourne Parking Ltd

Fabricator: Bourne Parking Ltd

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