MCRMA Technical Paper No 15
SCI Publication No P 327

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NEW APPLICATIONS: COMPOSITE CONSTRUCTION

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THE METAL CLADDING & ROOFING MANUFACTURERS ASSOCIATION

IN PARTNERSHIP WITH

THE STEEL CONSTRUCTION INSTITUTE

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Foreword

Over the past two decades, composite construction using steel decking has become increasingly popular in the commercial sector, where it is widely accepted as an economical alternative to more traditional forms of construction. The use of steel decking in other applications such as car parks and residential buildings is likely to yield considerable benefits in terms of cost and time savings, but perceived concerns such as durability have restricted its use in these areas in the past.

The aim of this publication and the accompanying case studies is to promote the use of composite construction using steel decking in a range of applications throughout the construction industry. The case studies cover commercial and other applications. The publication also addresses the barriers to the use of steel decking in car parks and residential buildings and presents practical solutions to the perceived problems.

This publication was written by Dr Graham Couchman and Dr Martin Heywood of The Steel Construction Institute with funding from the Metal Cladding and Roofing Manufacturers Association (MCRMA). The accompanying case studies were provided by members of the MCRMA Floor Deck Group.

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Introduction

In certain sectors, and primarily in the commercial building sector, composite construction has been popular for many years owing to the varied savings it can offer over other forms of construction. These include speed of construction, and reduction in floor depth, weight and cost. The success of composite construction is inextricably linked to the use of profiled steel decking as a constituent of composite slabs. Whilst recent years have seen continual use of composite construction in the commercial buildings market, they have also seen new and exciting developments in the use of this construction technique in other types of building. This publication considers several recent applications of composite construction including multi-storey car parks and residential buildings.

Composite slabs consist of profiled steel decking plus in-situ reinforced concrete. During the construction stage, the decking acts as permanent formwork to the concrete and also provides a working and storage area. Once the concrete has gained its strength, the shear bond between the decking and the concrete becomes sufficient for both materials to act together compositely.

Composite beams comprise hot rolled or fabricated steel sections that act compositely with the slab. Composite interaction is normally achieved by the attachment of shear connectors to the top of the beam. Typically these connectors are headed studs, which are normally (in the UK) attached to the beam flange by welding through the decking ('thru-deck' welding) prior to placing the concrete. The shear connectors transfer longitudinal shear force between the beam and the concrete, thereby allowing them to act together compositely. Some solutions achieve interaction between the steel beam and concrete without using mechanical connectors, for example, the Slimdek® system.

Benefits of composite construction

The principal benefits offered by composite construction are:

- The use of decking results in speedy construction. Bundles of decking are craned into position, then individual sheets are laid out by hand. This minimises crane time.
- The decking provides a safe working area for the concrete gang and other trades.
- The decked out area can provide temporary storage space, but care must be taken to avoid overload and/or damage.
- It is usually possible to eliminate the need for props.
- If it is properly fixed and orientated, the deck can provide lateral restraint to the beams during the construction stage.
- The use of decking reduces the amount of concrete required compared to traditional forms of construction. This results in a lightweight flooring system, especially when lightweight concrete is used.
- For most applications, it is possible to obtain the necessary fire rating by using lightweight mesh reinforcement within the slab, without the need for any applied fire protection to the decking itself.
- Decking is lightweight and is easily transportable. It is usually delivered to site in tightly packed bundles of a pre-cut length.
- Special hangers attached to the decking allow pipes, cable trays and ducting to be suspended beneath the slab. This facilitates the easy installation of services in a location that is convenient for future maintenance or replacement. Suspended ceilings may also be fitted in this way.
- Galvanizing provides a level of corrosion protection that is suitable for most applications. Additional measures may be necessary in aggressive environments (e.g. car parks).

Car parks

The above benefits combine to give an economical solution with significant cost savings compared to traditional forms of construction. They are the reasons why composite construction has made such an impact on the commercial buildings market, but the benefits are also applicable to other sectors. In particular, the benefits can be realised in the use of composite steel decking in multi-storey car parks and in residential buildings as described in this publication. The publication examines the reasons why this form of construction has rarely been used in the past for these structures and describes specific benefits that composite construction can provide to the client and/or contractor. The accompanying case studies, published by MCRMA, consider several recent uses of composite construction in commercial and residential buildings and car parks.

Traditionally, composite construction has not been used for car parks in the UK, primarily because of concerns over durability and the fire resistance of steel decking and beams. However, by careful design it is possible to address these concerns and take full advantage of the benefits of composite steel decking.

3.1 Design criteria

All well-designed car parks share the following characteristics:

- Ease of access to and egress from the parking bays.
- Few obstructions to the free movement of vehicles around the car park.
- Safe and secure environment for the car park users and their vehicles.
- Light and airy spaces to make them attractive to the public.

It has long been recognised that steel framed structures are well suited to these needs due to their ability to provide the necessary structural support with the minimum visible structure.

The first two characteristics are achieved by providing long span floors with few internal columns to impede the movement of vehicles. Where possible internal columns should be avoided altogether, but where this is not possible, the publication by The Institution of Structural Engineers, Design recommendations for multi-storey and underground car parks[1] and the Corus brochure Steel framed car parks[2] provide guidance on where best to locate these columns, so as to maintain parking efficiency, bay access and sight lines.

Steel beams are ideal for use in car parks due to their long span capability, but composite decking slabs are sometimes seen to be at a disadvantage compared to precast concrete units. It is true that precast units can span further than unpropped ‘shallow’ steel decking (6 m for precast units compared to 3.5 m to 4.5 m for unpropped decking), but this can easily be overcome by the use of secondary beams. Alternatively, deep decking can span 6 m unpropped or up to 9 m with

two lines of temporary props. The use of lightweight concrete and continuous decking should be considered to maximise the achievable span.

Figure 3.1 shows a typical arrangement of columns, and beams, for a multi-storey car park. The column spacing in this example follows the guidance in Design recommendations for multi-storey and underground car parks[1] by providing a clear column-free area of sufficient size to allow safe and unhindered access/egress to the parking bays and the free movement of vehicles around the car park.

The use of long clear spans also helps to fulfil the third and fourth basic characteristics of good design (noted above) in terms of providing a light and airy environment in which the car park's users feel safe and secure. This is very important in attracting members of the public to the car park. Decking helps in this respect by providing a lightweight solution, which minimises the size of columns required. Where secondary beams are required, these can usually be accommodated within the depth of the primary beams, keeping the depth of the floor structure to a minimum, thereby improving the appearance of the car park both internally and externally.

3.2 Overcoming the barriers

3.2.1 Durability

Multi-storey car parks present an aggressive environment for any material, due to the lack of protection from the weather and the use of chloride-based de-icing salts. Doubts about the durability of profiled decking and steel frames have for a long time dissuaded many designers and clients from considering composite solutions for this application. However, with careful design and detailing, durability need not be a problem. This has been proven by a number of examples that have performed well.

All steel decking is generally supplied as a galvanized product. However, galvanizing alone will not offer 100% protection to the steel. It is recommended that galvanised decking should be used in combination with suitable waterproofing to the top of the slab (this prevents the ingress of water, which could lead to corrosion of the top surface of the decking) and additional protection to the underside of the decking (to protect against moisture in the atmosphere). Provided that adequate provision has been made, a G275 galvanizing (275g of zinc coating per square metre) applied to the decking will be sufficient[2]. This is the standard thickness of galvanizing for decking in the UK and, although thicker coatings can be applied to steel (up to G600), decking with this thickness of galvanizing is not readily available and may be difficult to form. Additional protection to the underside of the decking should be in the form of a coat of epoxy paint or similar protection. This should be inspected regularly as part of the car park's routine maintenance programme and maintained or replaced as necessary.

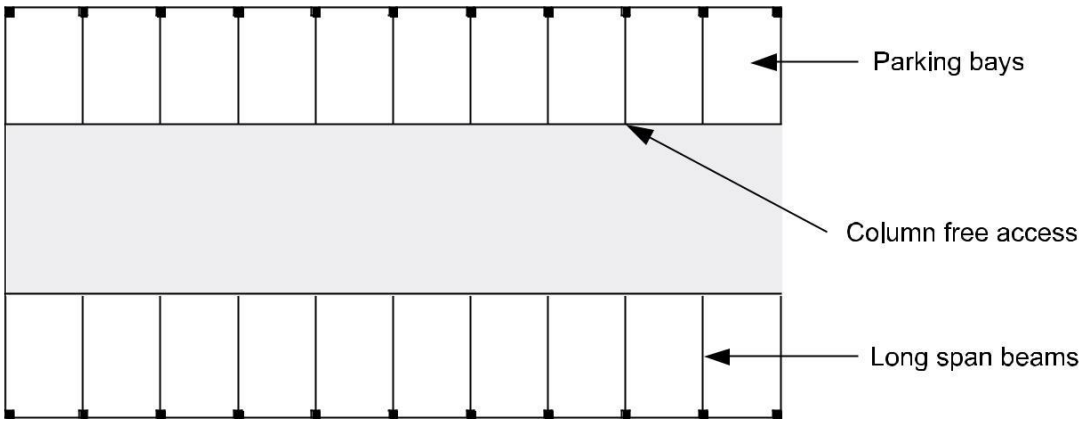

Figure 3.1 Column positions in a car park using composite construction

There is little that can be done to prevent large quantities of water from being deposited on the upper surfaces of a car park by vehicles. However, a well-designed and properly maintained drainage system will allow most of this water to be channelled away. As part of the drainage system design, it is essential that sufficient thought is given to the magnitude and direction of the fall on the slab to prevent ponding of water. It is recommended that all floor slabs are laid with a fall of between 1 in 60 and 1 in 20[1] with drainage channels or gullies suitably placed to catch the water. In designing the slab, care must be taken to avoid excessive deflections that might lead to local adverse gradients (preventing the water from draining properly). If necessary, precambering of the slab should be considered.

As well as providing good drainage, it is essential that suitable waterproofing is applied to the top surface of the slab. In some car parks, the waterproofing is only applied to the top deck. This is often justified by saying that the top deck is the only one fully exposed to the elements. However, the greatest threat to the durability of the car park comes from saline water deposited by vehicles. It is therefore recommended that all decks are waterproofed. Car park owners should note that waterproof membranes do not have an infinite life and will need to be repaired or replaced during the lifetime of the structure. Further guidance on the waterproofing of car parks is given in Design recommendations for multi-storey and underground car parks[1].

Many durability problems in car park decks stem from badly designed or poorly maintained joints and from cracks in the concrete. These allow the ingress of water into the slab, where it may corrode the reinforcement and steel members underneath. It is essential that sufficient anti-crack reinforcement be provided in the concrete topping, together with regularly spaced contraction and expansion joints (to relieve the thermal stresses in the concrete and prevent thermal cracks from occurring). All joints should be suitably and properly sealed.

When steel deck based composite slabs are used in conjunction with composite beams, ‘thru-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. The upper surface of the beams must be free of paint to avoid contamination of the stud welds. In the potentially corrosive environment of a car park this is, however, 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. (Note: The presence of paint on the shear studs should not compromise their performance, which does not rely on surface bond.) 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.

3.2.2 Fire Resistance

A perceived need to provide fire protection, as a means of achieving the required resistance, is sometimes quoted as a reason for not using steel in car parks. However, unprotected decks are widely accepted in commercial buildings and also provide sufficient fire resistance in car parks. The fire resistance requirements for open-sided car parks in the UK and Ireland are summarised in Table 3.1.

Regulations	Height of top floor	
	Up to 30 m	Over 30 m
England and Wales	15 minutes [1,2]	60 minutes
Scotland	15 minutes [3]	30 minutes [4]
Northern Ireland	15 minutes [1,2]	Not applicable (120 minutes default)

Table 3.1 Fire resistance requirements for open-sided car parks

1 Increased to 60 minutes for compartment walls separating buildings.

2 Increased to 30 minutes for elements protecting a means of escape.

3 Resistance of 15 minutes is 'deemed to satisfy' for up to 18 m.

4 Lower resistance may be possible (in agreement with checking authority).

For open-sided car parks (apart from escape routes), only 15 minutes of fire resistance is required compared to 60 minutes for a commercial building. Most (other than the smallest and lightest) universal beams and universal columns are able to achieve 15 minutes of fire resistance without applied fire protection[3].

Other types of car park, and escape routes in open-sided car parks, have higher fire resistance requirements, as given in Table A2 of Approved Document B [4]. In these cases, advice on the required applied fire protection and the filling of voids above the beams is given in The fire resistance of composite floors with steel decking (2nd edition) [3] and Composite slabs and beams using steel decking: Best practice for design and construction [5].

Tests have shown that composite floors using steel decking perform very well in fire, despite the decking losing strength due to the high temperatures. This performance is possible because, in the room temperature design of these slabs, it is (normally) assumed that there is no moment continuity over the supports. In reality, reinforcement over the supports provides moment resistance and therefore helps to carry the reduced load during a fire, even though the decking has lost strength and, therefore, the mid-span moment resistance has reduced.

3.2.3 Benefits of composite construction for car parks

Speed of construction: Using decking, it is possible to concrete all of the floors of a multi-storey car park in quick succession, thereby greatly reducing the construction period compared to traditional forms of construction.

Working space: The use of decking removes the need for expensive access arrangements and provides a safe working area for the concrete gang and other trades.

Storage space: Many multi-storey car parks are built in the centre of busy towns with little or no space for storing materials. The decking provides additional space for properly planned storage.

Crane savings: The use of lightweight decking reduces the craneage requirements in terms of time and number of cranes required. This can lead to cost savings and is also important in terms of the available space on a crowded town centre site.

Lightweight construction: Reduced usage of materials results in good value for the client and is good for the environment. It also reduces foundation loads, which could be important on brown field sites with poor ground conditions. A lightweight structure is also good from an aesthetic point of view.

Large spans: If secondary beams are used, a steel framed solution with composite decking can provide long clear spans in all directions, assisting the flow of traffic around the car park and providing the opportunity for the car parking layout to be changed during the life of the structure. The absence of internal columns also helps to create a light and airy environment, making the car park popular with the public, thereby increasing revenue to the owner.

Cost: Decking offers an economic solution in terms of initial cost and whole life cost. By speeding up the construction process, the use of decking reduces the time between the initial letting of the contract and the first revenue reaching the client.

Rethinking Construction: The use of steel frames together with composite steel decking satisfies the objectives of "Rethinking Construction" by innovation, prefabrication, improved quality and client benefits.

Residential Building

4.1 Introduction

Traditionally, composite construction has found little application in residential buildings in the UK because of the dominance of masonry houses. However, steel framed solutions are starting to find their way into the housing market and with the demand for houses at an all-time high, there is a need to introduce innovative solutions into this sector of the construction industry. Recent examples have shown that the traditional barriers to using composite construction in this sector (acoustic, thermal and fire performance) can be overcome.

4.1.1 Current situation

The majority of houses in the UK are single dwellings, built over the past 150 years as terraced rows, semi-detached or detached properties. Although there was a move away from single occupancy dwellings to multi-occupancy high-rise blocks in the 1950s and '60s, this type of building soon became unfashionable, and indeed problematical, and developers returned to more traditional low-rise houses. This trend has continued to this day.

Not only have house styles remained unchanged for decades, so have the methods of construction. The demand for single occupancy dwellings has been satisfied by traditional builders using traditional craftsmen such as bricklayers and carpenters. Despite the introduction of prefabricated houses and the growing use of light steel and timber framing, the residential sector of the construction industry is still dominated by traditional masonry houses.

The boom in high-rise multi-occupancy apartment blocks in the 1950s was fuelled by a desperate shortage of good quality affordable housing in post-war Britain. Once again, the UK faces a similar shortage, with the Government seeking the construction of 4 million new homes in 15 years, and it is likely that this will lead to a renaissance in medium- and high-rise residential buildings. Since these buildings are outside the scope of the traditional building trades, this situation presents an ideal opportunity for the rapid growth of alternative solutions such as the use of composite steel-concrete framing.

4.1.2 Future housing requirements

Unlike previous house-building booms, the UK in the early 21st century is faced with a shortage of land for residential development, particularly in the South East of England. This is forcing the Government, local authorities and developers to consider building on "brown field" sites and redeveloping inner cities. The scarcity of land in urban areas is likely to mean a return to multi-occupancy housing in the form of medium-rise apartment blocks. Composite construction using decking is ideal for such buildings, due to the speed with which the floors and can be constructed. Shortage of land is also likely to make the construction sites of tomorrow very congested places with little room for storage or cranes. Once again, the use of decking is ideal.

More than ever before, developers want a fast return on their investments and this requires fast, efficient construction. Traditional forms of construction fail in this respect, especially for medium rise buildings, where it is common to use in-situ concrete floors. By comparison, the use of composite construction together with steel framing allows much faster construction and the earlier entry into the building of the other trades.

While many developers might prefer to build individual luxury homes, the reality of the situation is that there is a particular need for affordable housing for key workers. Composite steel framed buildings meet this requirement by providing an economic and efficient solution. At the same time, the use of quality assured decking products means that quality does not have to be sacrificed for the sake of affordability. This is in line with the objectives of "Rethinking Construction".

Finally, there has been a steady decline in the numbers of tradesmen in the construction industry over recent years to the point where there are now serious skills shortages and house builders are looking to de-skill much of the construction process, or at least move the skill requirements off site. The solution to this problem is to move away from traditional house building towards modern forms of construction, including steel framing, prefabricated cladding and composite construction.

4.2 Overcoming barriers

4.2.1 Thermal performance

It is sometimes felt that lightweight residential construction lacks the thermal performance capabilities of more traditional masonry buildings. This is not true. The requirements for thermal insulation described in Part L (2002) of the Building Regulations[6] are stricter than ever and can be met in steel construction using the many modern insulation products currently available and appropriate detailing. Composite construction also offers sufficient thermal mass to provide adequate regulation of internal temperatures.

4.2.2 Acoustic performance

Approved Document E (2003 Edition)[7] sets out minimum standards of acoustic performance for walls and floors between dwellings that satisfy the requirements of Part E of the Building Regulations. These standards include single figure ratings for sound insulation and the requirement for site testing.

Single figure ratings

The performance standards include airborne sound insulation of walls between dwellings (separating walls), and both airborne sound insulation and impact sound transmission for floors between dwellings (separating floors). These are set out in Table 4.2 The performance standard for walls and floors within dwellings should have a minimum laboratory value (not site tested) for airborne sound insulation R_w) of at least 40 dB[7].

Building type	$D_{nT,w}+C_{tr}$	$L'_{nT,w}$
Purpose built dwellings	ε 45 dB	δ 62 dB
Dwellings formed by material change of use	ε 43 dB	δ 64 dB
Purpose built rooms for residential purposes	ε 45 dB	δ 62 dB
Rooms for residential purposes formed by material change of use	ε 43 dB	δ 64 dB

Table 4.2 Minimum performance standards of Approved Document E (2003)

Until 2003, the Standardised Weighted Level Difference, $D_{nT,w}$, was used as the single figure index for airborne sound insulation in the Building Regulations. The 2003 Approved Document E introduced a new measurement index, $D_{nT,w} + C_{tr}$ to replace the existing $D_{nT,w}$ for airborne sound. The C_{tr} term is a spectrum adaptation term, which is generally negative and adjusts the index taking additional account of the low frequency sounds that often cause problems in residential buildings. Thus, a $D_{nT,w} + C_{tr}$ rating is generally lower than the $D_{nT,w}$ rating for the same construction. The $D_{nT,w} + C_{tr}$ index is likely to be more demanding for lightweight construction, as it places more weighting on low frequency sound, which is the end of the sound spectrum where lightweight constructions perform less well.

Impact sound transmission is measured by, $L'_{nT,w}$, the Standardised Weighted Impact Sound Pressure Level.

Site testing

The Approved Document E (2003 Edition)[7] introduced a requirement for pre-completion site testing of acoustic performance. At least 1 in 10 of every type of separating wall and floor at every residential construction site are to be tested to show that the minimum performance standards in Table 4.2 have been met. The requirement for testing applies to residential buildings of all kinds, both purpose built and formed by a material change of use.

The acoustic performance of composite construction

Using composite construction, it should be possible to achieve adequate airborne sound reduction with the addition of a plasterboard ceiling. The use of a battened floor will generally satisfy the requirements of the Building Regulations for impact sound insulation. Two examples of possible forms of construction are shown in Figure 4.2 (based on Slimdek®) and Figure 4.3 (based on shallow deck).

Tests have been conducted on apartments using both deep and shallow decking to demonstrate the acoustic performance of these forms of construction. An airborne sound reduction of over 60 dB was observed. Details to prevent additional flanking sound transmission are well established.

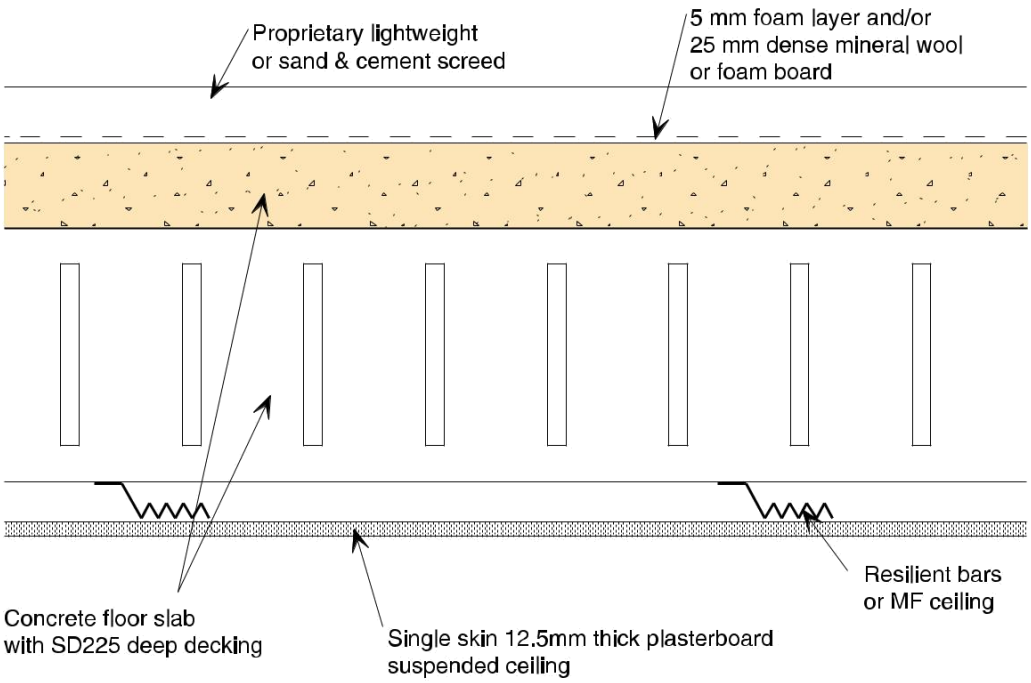

Figure 4.2 Screed floor

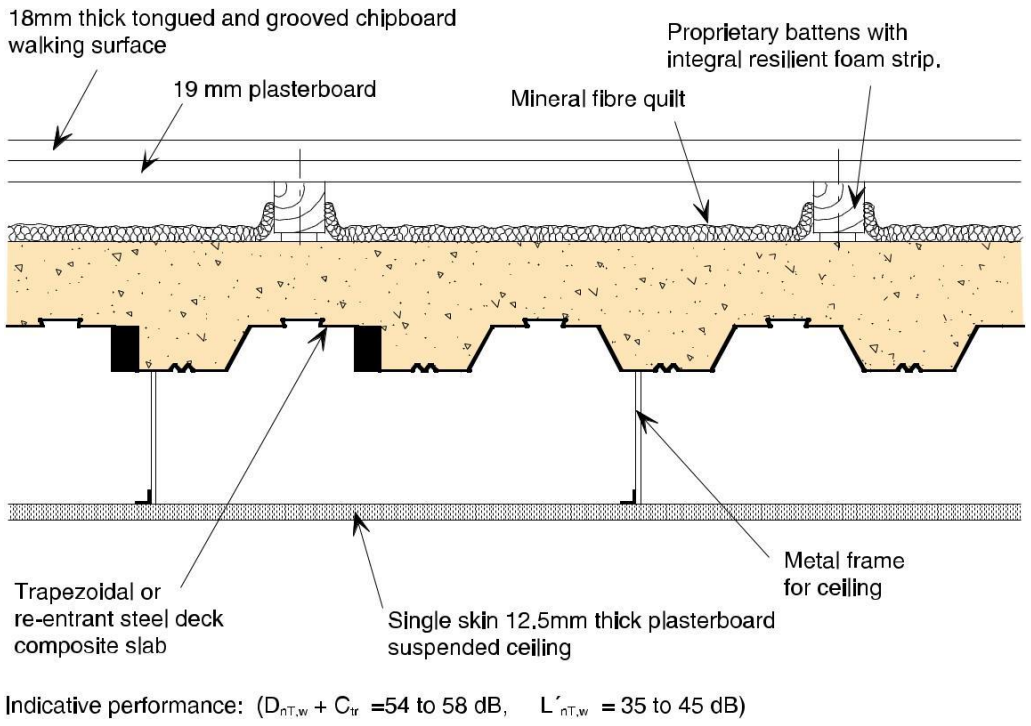

Figure 4.3 Raft floor

4.2.3 Fire Resistance

Performance requirements for the fire resistance of residential buildings are no more onerous than for commercial buildings, where composite construction has been used successfully for many years. The typical fire resistance requirement for a residential building is 60 minutes, as given in Approved Document B[4]. Advice on the required applied fire protection and the filling of voids between the beams and decking is given in The fire resistance of composite floors with steel decking (2nd edition)[3] and SCI-P-300 Composite slabs and beams using steel decking: Best practice for design and construction[5].

4.2.4 Benefits of composite construction for residential buildings

Speed of construction – All steel construction uses prefabricated components that can be rapidly installed on site. In multi-storey buildings, construction periods can be reduced by at least 20% in comparison with concrete construction, leading to:

- Savings in site preliminaries
- Rapid creation of a dry envelope
- Earlier return on investment
- Reduced interest charges.

These time-related savings in financial terms can easily amount to 2 to 3% of the overall project value. Importantly, in major residential building projects, the pre-sale of show apartments reduces the developer's working capital and cash flow.

Working space: The use of decking removes the need for expensive access arrangements and provides a safe working area for all trades as soon as the decking is fastened in place.

Storage space: Many new residential buildings are being built on congested urban sites with little or no space for storing materials. The decking provides additional space for storage.

Flexibility and future adaptability: The long spanning capability of composite construction means that different internal layouts can be achieved using non-load bearing internal partitions. In future, these layouts can be changed according to the wishes of the property owner without the need for any major alterations to the structure. This enhances the sustainability credentials of composite construction.

Reduced disruption to the locality: In inner city locations, it is important to minimise the disruption to the neighbouring buildings and nearby roads and the use of steel construction plays a major part in this by:

- Reducing materials use and waste creation
- Minimising on-site activity, thereby reducing noise and dust levels
- Reducing the overall construction period.

Improved quality: Off-site prefabrication improves quality by factory-controlled production, allowing the implementation of rigorous quality procedures. It also removes the reliance on site-based trades and eliminates much of the damage that can be caused to an unprotected building structure by the weather.

Environmental benefits: All steel construction is produced efficiently. All steel is potentially re-usable and up to 40% of steel production is from scrap. The shorter construction period also reduces the environmental impact.

Rethinking Construction: The use of steel frames together with composite steel decking satisfies the objectives of "Rethinking Construction" by innovation, prefabrication, improved quality and client benefits.

Conclusions

Although composite construction using steel decking has been used for many years for commercial buildings, several perceived barriers have restricted the use of this form of construction in car parks and residential buildings. The main barrier against the use of steel decking in car parks has been the durability of the steel in such an aggressive environment. However, with careful design and detailing, durability need not be a problem. In the residential sector, concerns regarding thermal and acoustic performance have sometimes dissuaded architects from considering composite solutions, but tests have shown that buildings with composite floors can be built to meet the Building Regulations.

Once these perceived barriers have been overcome, the use of composite construction with steel decking can yield considerable benefits to the client and contractor in terms of time and money. Composite buildings are fast to erect, because the concrete gangs and other trades can move quickly from one floor to the next. The decking also provides a safe working environment and may be used as a storage space for materials. This latter point is especially important in crowded town centre locations. In car parks, the long spans possible with composite beams allow the traffic to flow freely, unimpeded by columns. Long spanning beams might also prove useful in residential applications, where flexibility and adaptability are key words in building design.

Weighing up the benefits against the perceived barriers, it is clear that composite construction is a realistic alternative to traditional forms of construction for car parks, residential buildings and many other applications.

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