SCI Assessed of Kingspan *Floor-Dek* Design Guide

Report To Kingspan

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EXECUTIVE SUMMARY

Floor-Dek is a unique deep ribbed composite panel, used initially for roofing, but now increasingly used for suspended floors in housing or residential buildings. A *Floor-Dek* panel has 0.7 (or 0.9) mm thick top steel sheet and a 0.9 mm thick steel bottom sheet. The bottom sheet is has deep profiles to form vertical ribs. The core between the steel sheets is polyisocyanurate (PIR).

Kingspan have produced a design guide for their *Floor-Dek* product. SCI has reviewed the Kingspan design guide and have given it “SCI Assessed” status.

This report briefly describes the assessment process and also presents the Kingspan *Floor-Dek* design guide in Appendix A.

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1 Introduction

1.1 Background

Floor-Dek is a unique deep ribbed composite panel, used initially for roofing, but now increasingly used for suspended floors in housing or residential buildings. A *Floor-Dek* panel has 0.7 (or 0.9) mm thick top steel sheet and a 0.9 mm thick steel bottom sheet. The bottom sheet is has deep profiles to form vertical ribs. The core between the steel sheets is polyisocyanurate (PIR).

Kingspan have produced a design guide for their *Floor-Dek* product (presented in Appendix A). The design guide covers the structural application of *Floor-Dek* panels in housing and residential buildings for the following cases:

- Suspended separating floors requiring acoustic insulation and fire resistance
- Suspended ground floors, generally with intermediate supports, requiring a high level of thermal insulation
- Roof panels spanning between gables or from eaves to ridge, which create habitable space cost-effectively
- Loft floors with load-bearing and insulating functions
- Floors with a gypsum or concrete screed
- Supported on masonry walls, light steel framing or timber framing.

A typical cross-section of a Floor-Dek floor is shown in Figure 1.1.

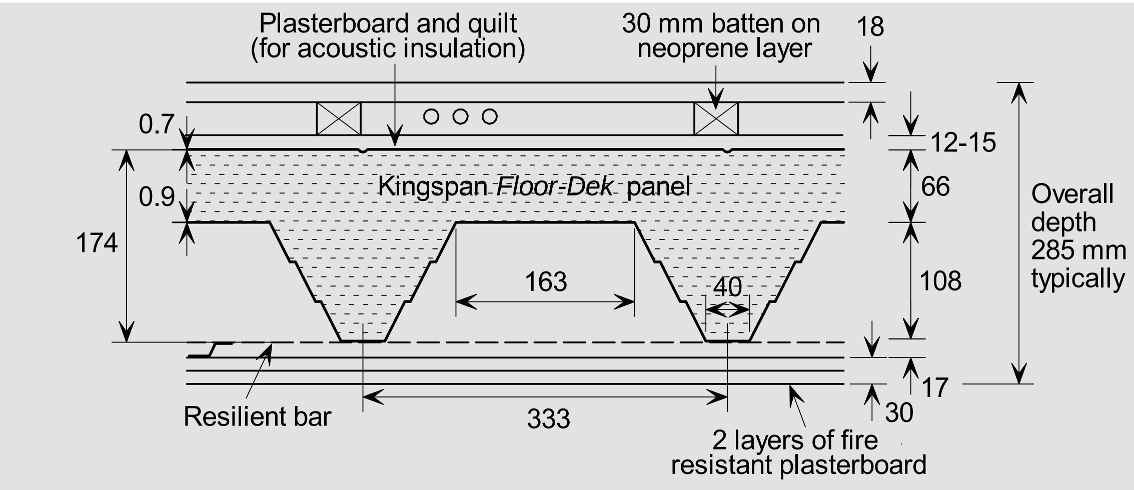


Figure 1.1 ***Floor- Dek* as a separating floor in residential buildings**

Kingspan submitted the design guide and the relevant background information to the SCI for independent verification and assessment under the “SCI Assessed” scheme.

2 Independent assessment

2.1 Outline procedure

The SCI assessment of the *Floor-Dek* design guide followed the procedure presented below:

1. Initial review of *Floor-Dek* design guide
2. Review of the background information used to derive values and procedures used in the *Floor-Dek* design guide
3. Review of test results and statistical interpretation of test results relating to *Floor-Dek* panels
4. Detailed review of *Floor-Dek* design guide to ensure that
   a) Procedures and design values are supported by the background information and test data
   b) Relevant codes of practice and national standards are followed correctly where appropriate e.g. BS 5950-6.
5. Feedback conclusions of the assessment to Kingspan
6. Repeat steps 2 to 5 as required to reach satisfactory conclusions
7. Produce final report.

2.2 Structural performance

A *Floor-Dek* panel is an innovative product that is not covered by any single National Standard or Code of Practice. Hence, the structural performance of *Floor-Dek* panels has been derived using a combination of design rules from Codes of Practice and the use of values derived from test results.

Structural tests to determine the following have been conducted by Kingspan:

- Bending resistance
- Bending stiffness
- Shear capacity

2.3 Examples

The *Floor-Dek* design guide includes worked examples showing how *Floor-Dek* panels should be designed in different situations. These examples have been independently checked by SCI for numerical accuracy and correctness of procedures.

3 Conclusions

SCI has reviewed the Kingspan design guide for their *Floor-Dek* product and the relevant background information. As a result of the review, the Kingspan *Floor-Dek* Design Guide has been given “SCI Assessed” status.

The “SCI Assessed” version of the Kingspan *Floor-Dek* Design Guide is presented in Appendix A.

APPENDIX A Kingspan *Floor-Dek* Design Guide

DESIGN GUIDE FOR KINGSPAN *FLOOR-DEK*

1. Introduction

Floor-Dek is a unique deep ribbed composite panel, used initially for roofing, but now increasingly used for suspended floors in housing or residential buildings. A *Floor-Dek* panel is 174mm deep and 1m wide, consisting of 3 ribs at equal spacing of 333 mm. It has a 0.7mm thick top steel sheet and a 0.9 mm thick bottom profiled sheet with vertical ribs. Both sheets are paint coated and the profiled lower sheet is coated to suit an external environment. The core is polyisocyanurate (PIR), which is fire resistant and possesses excellent insulating properties. The edges of the panels over-lap to form an air-tight seal.

Composite action occurs between the steel skins and the core, which is sufficiently strong that relatively high loads may be supported. This makes *Floor-Dek* suitable for flooring applications in housing and residential buildings with a span range of 3 to 4.6m. The top sheet may be flat or ribbed and its steel thickness may be increased to improve its structural properties further. This Design Guide presents the information necessary to design floors and roofs using *Floor-Dek.* The information in the Guide is supported by a wide range of test data, which is summarised in the Guide and is reported separately- see Kingspan Report on *Floor-Dek* in Flooring Applications.

The main dimensions of *Floor-Dek* and its use as flooring in housing are shown in Figure 1.1. The floor build-up in practice also includes a plasterboard ceiling and walking surface, such as a battened floor or gypsum screed, which also improves the acoustic insulation and rigidity of the floor. Services can be located above or below the floor.

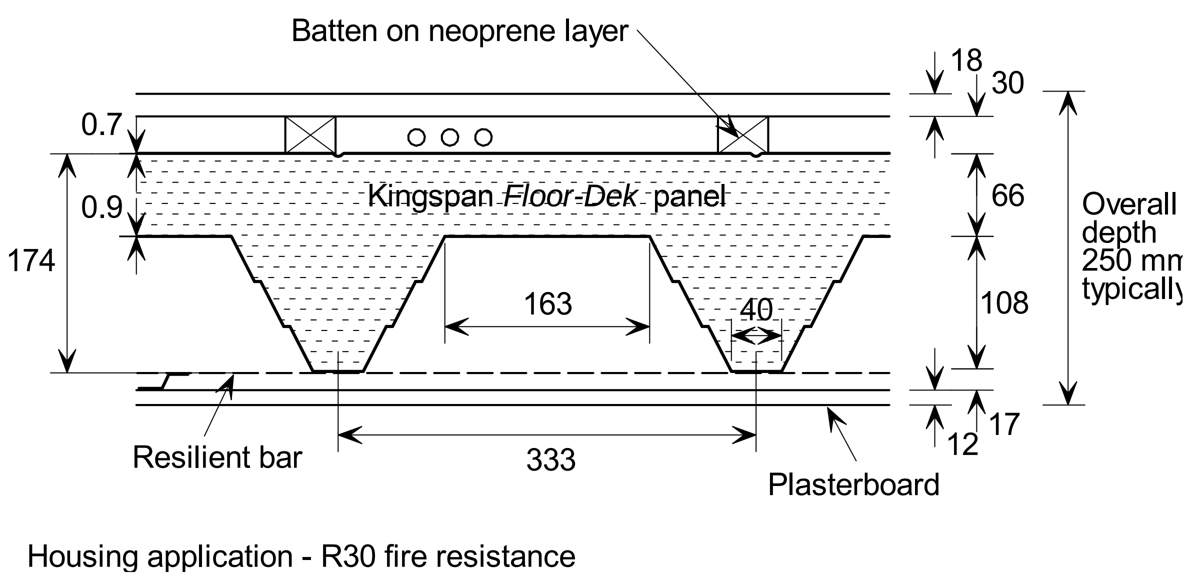


Figure 1.1 Use of *Floor- Dek* in housing

The advantages of *Floor-Dek* in flooring and roofing applications are:

- It is light in weight and is easily handled on site
- Long spans can be achieved with a high strength to weight ratio
- It is highly insulating for thermal and acoustic performance
- It is versatile in application for a range of building types
- It minimises the number of components to be installed
- It can be used in masonry construction, or light steel or timber framing, or can span between beams in structural steel frames
- Attachments may be made easily to the *Floor-Dek* panels
- Floors with a gypsum or concrete screed can incorporate embedded water pipes for heating
- *Floor-Dek* may also be combined with *Multibeam* C sections, which act as lintels by spanning over openings and also increase the span capabilities of the system.

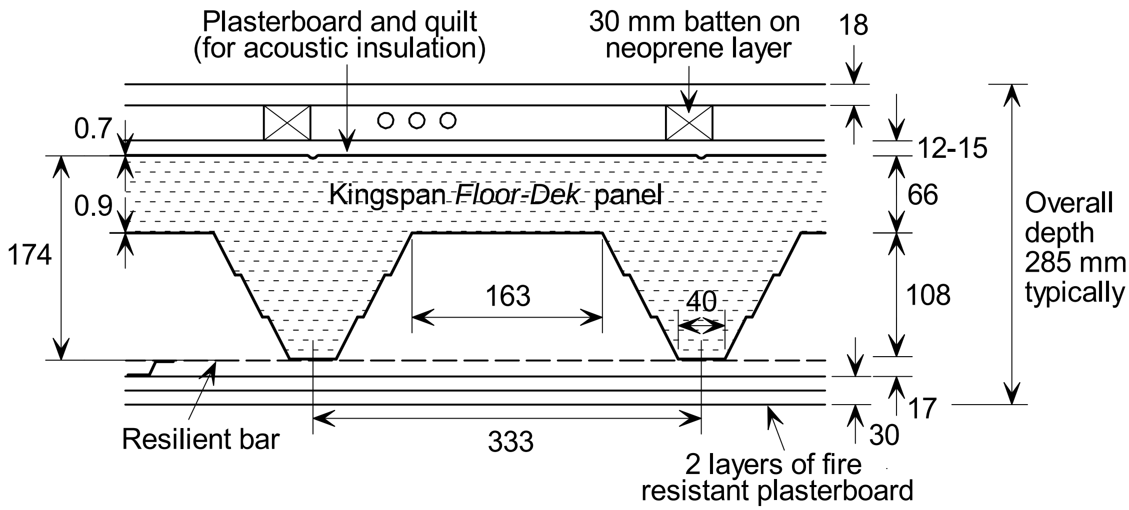
The Design Guide covers the structural application of *Floor-Dek* panels in housing and residential buildings for the following cases:

- Suspended separating floors requiring acoustic insulation and fire resistance
- Suspended ground floors, generally with intermediate supports, requiring a high level of thermal insulation
- Roof panels spanning between gables or from eaves to ridge, which create habitable space cost-effectively
- Loft floors with load-bearing and insulating functions
- Floors with a gypsum or concrete screed
- Support by masonry walls, or light steel or timber framing

1.1 Application in Housing and Residential Buildings

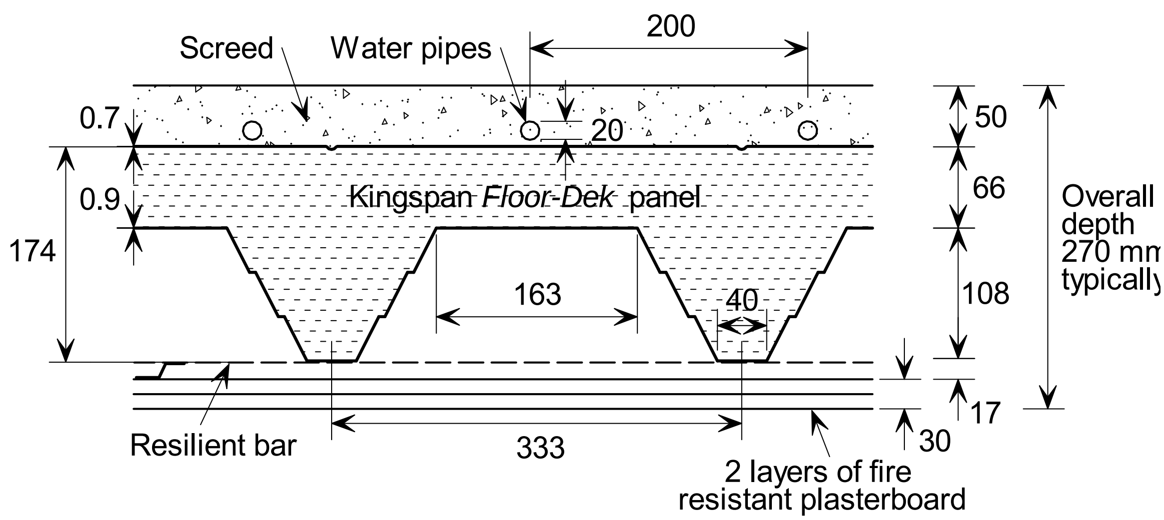
In housing, the primary feature of *Floor-Dek* is its long spanning capabilities, its shallow depth and light weight. The same system may also be used in ground floors and loft floors. In residential buildings, the primary requirements for separating floors are acoustic insulation and fire resistance, which are satisfied by double layers of fire resistant plasterboards fixed to resilient bars that are themselves fixed to the deck ribs, as shown in Figure 1.2. The overall floor depth can be as shallow as 250 mm in housing, or 285 mm in residential buildings.

Under-floor heating in gypsum or concrete screeds may also be used, as shown in Figure 1.3. In this case, the minimum screed depth is 30mm, increasing to around 50mm with embedded water pipes. The additional self weight of the screed is taken into account in the span capabilities of this application.



Residential application - R60 fire resistance

Figure 1.2 Use of *Floor- Dek* as a separating floor in residential buildings



Residential application - screeded floor

Figure 1.3 Use of *Floor- Dek* with a screeded floor and embedded water pipes for heating and cooling

Generally, *Floor-Dek* is used to replace timber floors in masonry construction, and therefore the *Floor-Dek* panels span as simply supported elements. The floor panels are supported on an extended Z section brackets placed over the masonry walls, or timber or light steel load-bearing walls, as illustrated in Figure 1.4(a). In housing, *Floor-Dek* may also be combined with composite panels acting as load-bearing walls, as shown in Figure 1.4(b) (but this is outside the scope of this Design Guide).

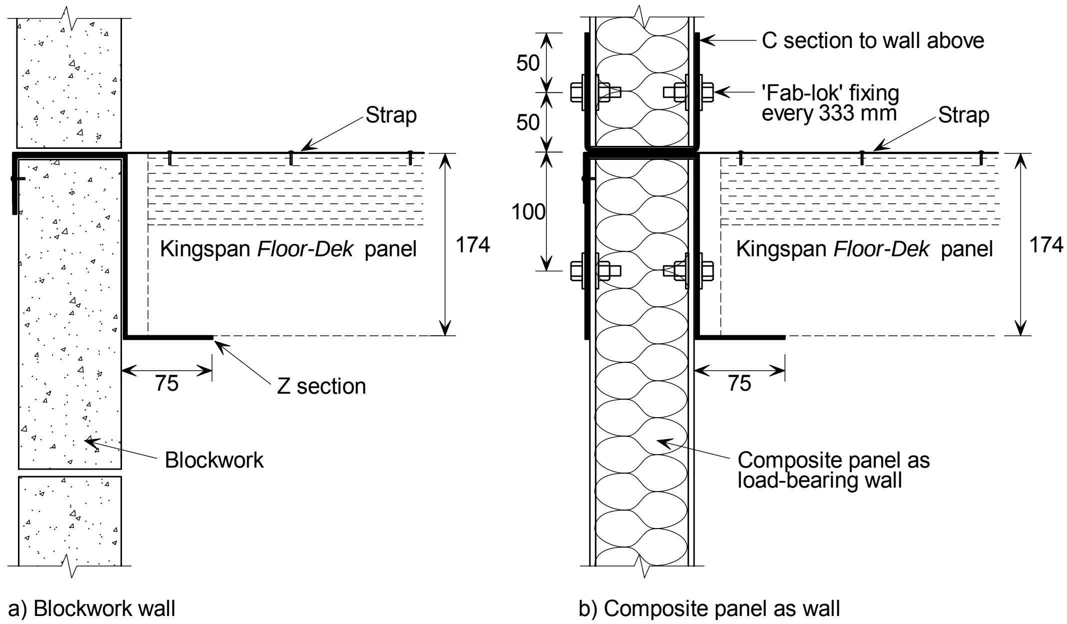


Figure 1.4 *Floor-Dek* floor supported by either by blockwork or load-bearing composite panels

In suspended ground floor applications, *Floor-Dek* achieves the required thermal insulation and is air-tight. Between floors, its high level of insulation will also help to improve the internal energy balance of the building. For ground floors, intermediate foundation supports may be provided, and in this case, the *Floor-Dek* panels span continuously over these supports.

The use of *Floor-Dek* composite panels in housing and residential buildings is limited to the following range of applications (loading given as unfactored loads):

- Suspended ground and intermediate floors in housing up to 4.6m span.
- Suspended ground and intermediate floors in residential buildings up to 4.2m span.
- Continuous floors over intermediate supports with spans up to 4.2m (subject to adequate width of the internal support).
- *Multibeam* or plain C sections of up to 6m span used in combination with *Floor-Dek* panels .
- Imposed floor loading of 1.5 to 3 kN/m^2.
- Support by 2.7mm thick Z sections placed over load-bearing walls (in timber, light steel or masonry).
- Minimum bearing of 65mm at the ends of the panels, or a minimum of 150mm at intermediate supports.
- Roofing up to 8m span with lightweight cladding or 6m with tiles
- Roof loading not exceeding 1.5 kN/m^2.
- Maximum line load of 10 kN/m applied over a minimum of 150mm width, based on the bearing pressure on the flat or micro- ribbed top sheet, or;
- Maximum point load of 5 kN applied over 300mm square area.

- Maximum bearing load on the ribs (as a line load) of 15 kN/m for a 150mm wide support.
- Fire resistance of 30 to 90 minutes (based on test performance).

Longer spans can be achieved by using plain C or *Multibeam C* sections placed parallel to the long edges of the *Floor-Dek* panels. Tests have shown that spans of up to 6m are achievable in flooring applications -see Section 3.6.

1.4 Fire resistance

For housing, 30 minutes fire resistance can be achieved by a single layer of 12mm thick plasterboard attached either directly to the *Floor-Dek* ribs, or preferably fixed to resilient bars that are used for improved acoustic performance.

For separating floors in residential buildings, 60 minutes fire resistance is generally required, which is achieved by the details specified for acoustic performance. This comprises two layers of 15mm thick fire resisting plasterboards, which are fixed to resilient bars placed at 400mm spacing and attached transversely to each rib. The additional floor covering is not important to the fire resistance.

A loaded fire test to BS 476 -20 was carried out on the *Floor-Dek* flooring system at the Building Research Establishment. The floor span was 4.15m. Two layers of 15 mm fire resistant plasterboard were screw-fixed to RB1 ‘resilient bars’ that were fixed to each deck rib. An imposed load of 2 kN/m^2 was applied in the test.

The test reached a fire resistance of 95 minutes and the failure point was defined by the rate of deflection, and not by insulation or integrity. This test result shows that the floor system is fire resistant and may be used also for multi-storey applications exceeding 20m high. A review of this fire test is given in the Appendix.

1.5 Acoustic performance

In all separating floors, it is recommended that two layers of 15mm thick fire resistant plasterboards are attached to resilient bars fixed across the ribs on the underside of the *Floor–Dek* panels. A variety of floor build-ups may be used to satisfy the required airborne and impact sound requirements of Part E of the Building Regulations 2002.

For housing not requiring this level of acoustic performance, a single layer of 12mm plasterboard may be used below the floor. Battens supporting floor boarding may be used on the upper surface of the *Floor–Dek* panels.

A series of laboratory tests was carried out at Taywood Engineering on *Floor–Dek* with various acoustic build-ups, and the results are presented in Table 1.1 in comparison to the Building Regulations Part E limits. On the basis of these tests, it is recommended that a 12 or 15mm layer of plasterboard and glass-wool quilt is placed on the top surface of the panel, which reduces the sound transfer by 3dB and satisfies the Building Regulations Part E. A battened floor or mineral wool floor is placed on it. For higher imposed loads, it is recommended that 15mm thick fire resistant or sound check plasterboard is used on the top surface, which would reduce the airborne sound transfer by an estimated further 2 dB.

If a gypsum screed is placed on the top of the panel, the minimum thickness is 30mm when using two layers of 15mm thick fire resistant plasterboard below. For a sand-cement screed, the minimum practical thickness is 50mm.

Table 1.1 Acoustic test results on various floor configurations

Floor details	Acoustic test performance	
	Airborne ≥ 45dB	Impact ≤ 62dB
Floor-Dek with two layers of 15mm thick fire resistant plasterboard below and 18mm OSB board on 30mm battens and mineral wool quilt above the *Floor –Dek* panel.	51-7 = 44 dB x	60 dB ✓
As above, but with a single layer of 12mm plasterboard and mineral wool quilt above the *Floor –Dek* panel.	53 -8 = 45 dB ✓	57 dB ✓
Quatro Deck above 2 layers of plasterboard below	54 -8 = 46 dB ✓ C_{tr} is estimated	44 dB ✓
75mm sand-cement screed 1 layer of plasterboard below	58-8 = 50 dB ✓ C_{tr} is estimated	59 dB ✓

The low frequency correction factor Ctr is given as a negative figure which modifies the Rw value

1.6 Thermal performance

The thermal transmittance or U value of the *Floor-Dek* panel is 0.25 W/m^2 ^{o}C, based on the average depth of 100mm of the PIR core, and also taking account of the effect of the joints between the panels. This makes *Floor-Dek* an excellent product for suspended ground floors, roofs and loft floors.

For roofs, a U value of 0.15 W/m^2 ^{o}C can be achieved by an additional 60mm layer of closed cell insulation board or 100mm of mineral wool placed on top of the *Floor-Dek* panel.

For ground floors, a U value of 0.25 W/m^2 ^{o}C can be achieved by the *Floor-Dek* panel itself, but in practice, a minimum depth of 30mm screed on a water resistant membrane would also be used. Additional insulation, if required, could be Kingspan Thermafloor TF70 insulation placed on *Floor-Dek* panel.

2. Practical Applications of *Floor-Dek* in Floors and Roofs

The following practical applications *of Floor-Dek* panels as floors are considered:

2.1 Housing

Floor-Dek panels replace timber floor joists in housing for both suspended internal and ground floors. Maximum spans are typically 4.6m in housing. The panels are supported on a continuous Z section placed over masonry or other walls. The minimum bearing length is 65 mm allowing for a nominal 10 mm gap at the ends of the panel. A single masonry strap with 3 screws to the top sheet is used to tie each panel to the wall. Working details for *Floor-Dek* floors in housing requiring 30 minutes fire resistance are shown in Figure 2.1.

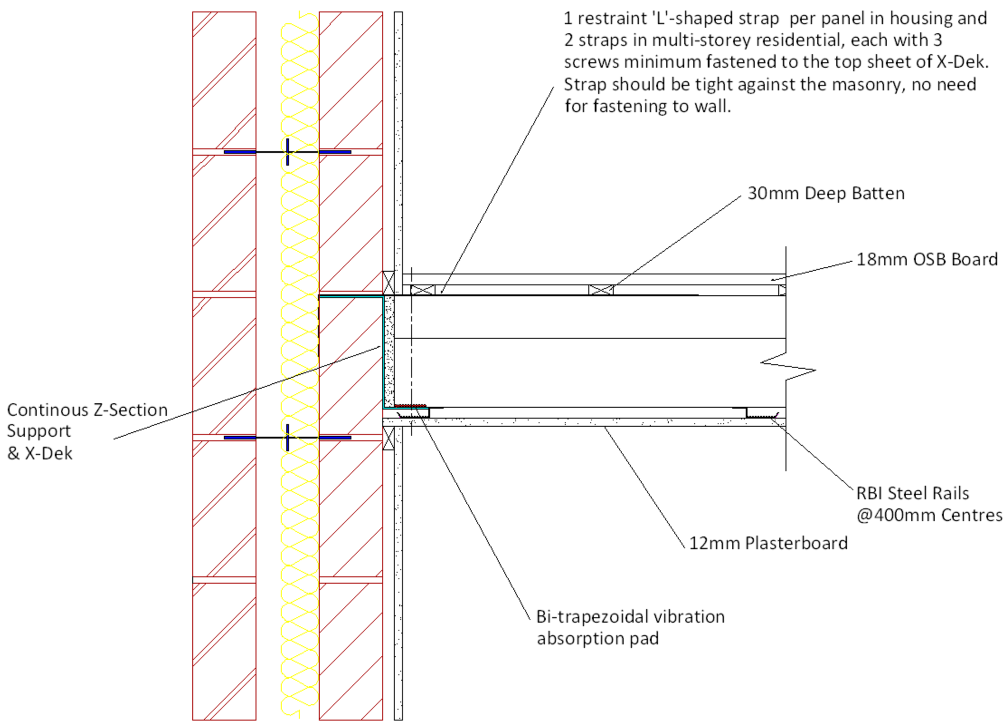


Figure 2.1 Detail of *Floor-Dek* as floor in housing attached to blockwork

A single layer of 12mm plasterboard may be attached to the ribs of the decking or alternatively fixed to RB1 resilient bars that are screw-fixed to the ribs of the *Floor–Dek* panel*.* On the top surface, 18mm OSB board may be attached to 30mm battens placed at 400mm centres that are screw fixed to the top sheet of the panel.

In suspended ground floor applications, the *Floor-Dek* panels may span over intermediate supports and foundations. However, in this case, the line load from any walls above is limited to a maximum of 10 kN/m (at working loads) in order to avoid local crushing of the top sheet or deck ribs. A membrane and an optional insulation layer, such as Expanded Polystyrene (EPS), is placed on the top of the panel so that it is effectively air- and water-tight and achieves high levels of thermal insulation.

Floor-Dek panels may also be used in the roof, either spanning along the slope between a ridge beam and the eaves, or alternatively spanning up to 7m between cross-walls- see design table in Section 3. Additional insulation may be placed on the top-side of the panel and battens fixed through the insulation to the *Floor-Dek* panel. Alternatively, the *Floor-Dek* panel may be inverted so that the ribs are upwards and a flat underside is on the room-side.

2.2 Residential buildings

Floor -Dek panels may be used in multi-storey residential buildings in the same way as for housing. However, because of the higher imposed loads in communal areas and the additional self weight of the floor due to the acoustic build-up layers, maximum spans are up to 4.2 m. These spans reduce to 3.6m in corridors and other more highly loaded public areas.

Again, the panels are supported on a continuous Z section placed over masonry or other walls. The minimum bearing length is 65 mm allowing for a nominal 10mm gap at the end of the panel. Two masonry straps with 3 screws to the top sheet are used to tie each panel to the wall. Construction details for separating floors in residential buildings are shown in Figure 2.2.

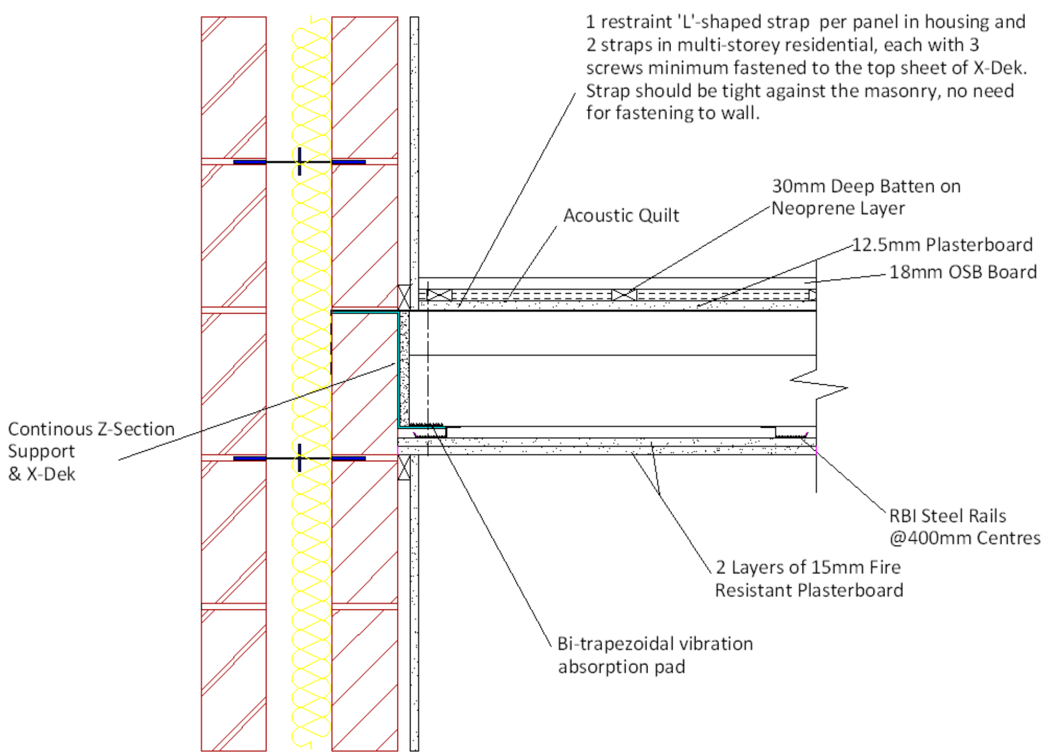


Figure 2.2 Construction details of *Floor-Dek* separating floor attached to blockwork

Two layers of 15mm fire resistant plasterboard are attached to the ribs of the decking through resilient bars placed at 400mm centres along the panel. 18mm OSB board may be attached to 30mm battens placed at 400mm centres. For additional acoustic insulation, a 12mm layer of plasterboard and 3mm thick glass wool quilt should be placed on the top surface of the *Floor-Dek* panel. For floors supporting higher imposed loads than 1.5 kN/m^2, it is recommended that this plasterboard layer is replaced by fire resistant or acoustic plasterboards which are more resistant to local crushing. The battens are screw-fixed through the plasterboard to the top sheet of the panel.

At large openings or above patio doors, *Floor-Dek* panels may be supported between the flanges of pairs of 180mm deep *C* sections. These sections placed back to back act as a slim floor-type beam, as shown in Figure 2.3. This allows the flooring system to be much more flexible in application for residential buildings. The target span of a pair of *Floor-Dek* panels with two 2mm thick *C* sections is 6m. Single C sections may act as lintels over openings with spans of up to 4.5m. *Floor-Dek* may also be used in structural steel frames in larger residential buildings -see Section 2.4.

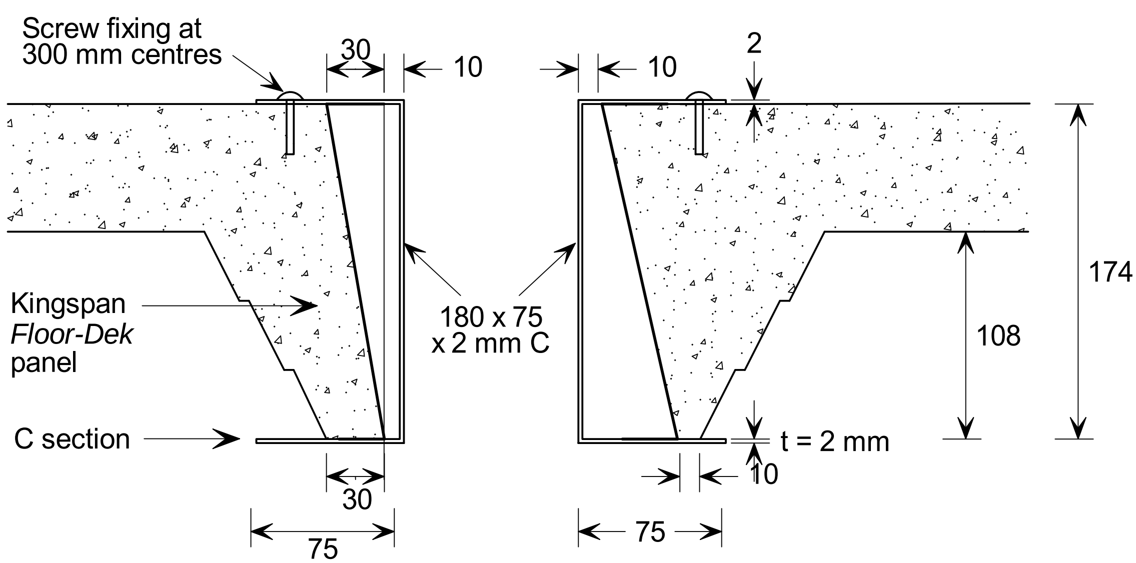


Figure 2.3 C sections acting as a slim floor beam to support edge of *Floor-Dek* over openings

2.3 Roofs and Loft Floors in Housing

Floor-Dek panels may also be used in roofing and loft floors in housing. In this way, longer spans can be achieved than using conventional timber trusses and the loft space can easily be adapted to habitable use. Construction details for *Floor-Dek* as a loft floor are shown in Figure 2.4. Other types of Kingspan composite panels may also be used in the roof.

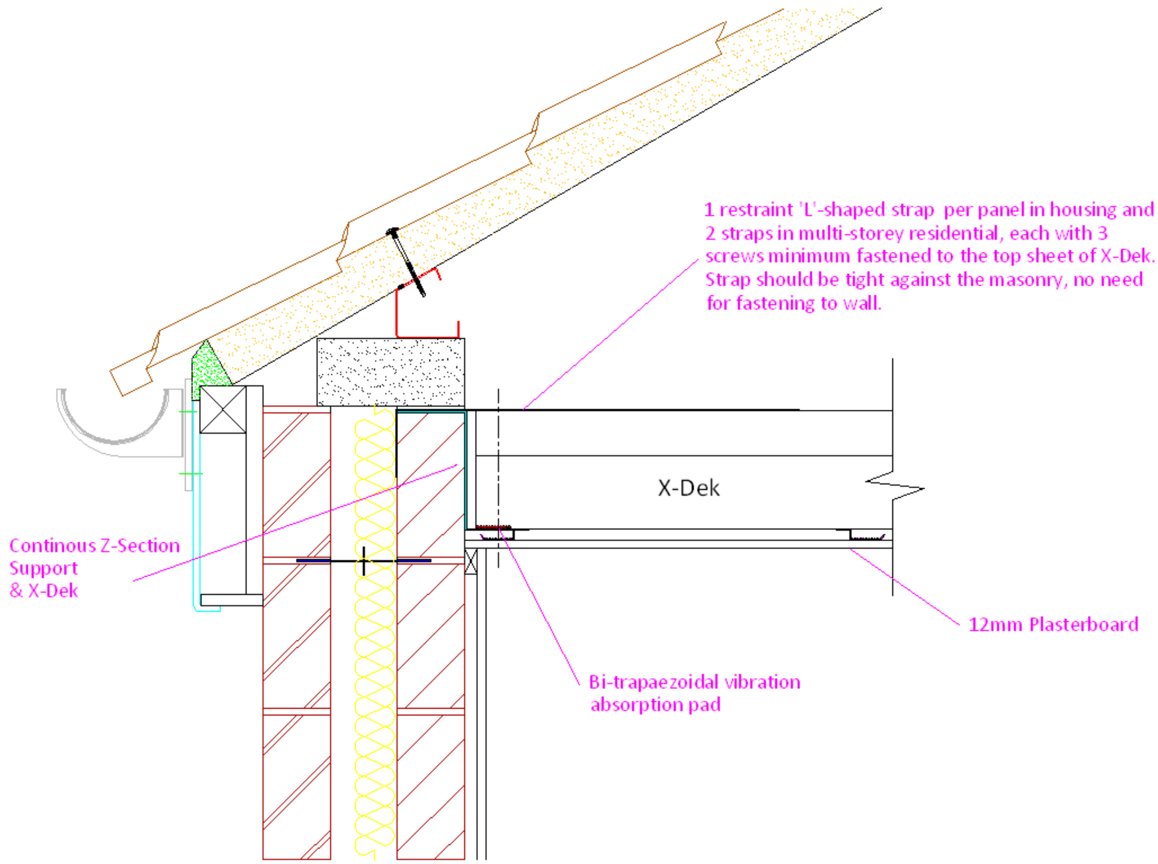


Figure 2.4 Detail of *Floor-Dek* in a loft floor to create habitable space

2.4 Floors in Structural Steel Frames

Floor-Dek panels are ideally suited as mezzanine floors in industrial buildings, or as intermediate floors in steel framed buildings of all types. The panels may be supported directly by the steel frame, as shown in Figure 2.5. Spans are generally limited to a maximum of 3.6m because of the higher imposed loads in these applications. Point loads or line loads applied to the floor should not exceed the limits given earlier.

Floor-Dek floors may be used in commercial buildings and can span continuously over the beams or are supported on slim floor type beams at approximately 3 to 3.5m spacing. Because of the need to pass services in the floor zone, a separate fire resistant layer may be required below the floor, which is supplemented by a suspended ceiling. It is suggested that the application is limited to buildings of up to 60 minutes fire resistance.

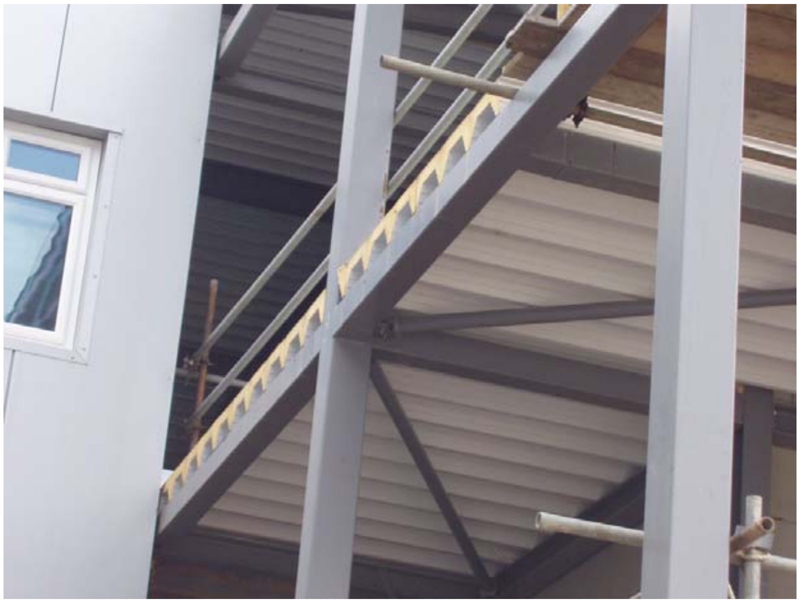


Figure 2.5 Application of *Floor-Dek* flooring in a steel framed building

2.5 Roofs in Structural Steel Frames

Floor-Dek panels are widely used to span up to 8 m as insulated roofing between rafters in industrial buildings to eliminate purlins and complex built-up roofing. In this application, the *Floor-Dek* panels are generally inverted so that the flat sheet forms the under-side and the ribs act as the external envelope, as shown in Figure 2.6. In some cases, additional roof sheeting is placed across the ribs and along the roof slope and creates the external envelope. This same technique may be used in other building types. It achieves a water-tight envelope and also provides a high level of air-tightness and thermal insulation.

Figure 2.6 *Floor-Dek* used in long span roofing applications

3. Structural Properties of *Floor-Dek*

3.1 Pure flexural stiffness

The elastic section properties of a *Floor-Dek* panel may be calculated from the second moment of area (inertia) of the steel skins separated by the PIR core and added to the inertia of the deck profile itself. The properties are reduced due to the influence of shear in the core – see following section.

The effective second moment of area of *a Floor-Dek* panel per unit width is theoretically:

$$I_{eff} = \frac{t_1\, t_2\, (\ell/s)}{(t_1 + t_2\, (\ell/s))} \times d_{eff}^{\,2} + I_s$$

where $d_{eff} = d_t + y_e$

and $y_e = \dfrac{(b_2 + b_3)d_p}{(b_1 + b_2 + 2b_3)}$

$$I_s = t_2\,[y_e^2\, b_1 + (d_p - y_e)^2\, b_2 + 2b_3\,(0.5d_p - y_e)^2 + b_3\, d_p^2/6]/\, s$$

where t_1 = steel thickness of top sheet
t_2 = steel thickness of deck profile
d_{eff} = effective depth of the ribbed panel
s = spacing of ribs = 333mm
ℓ = developed length of profile = $b_1 + b_2 + 2b_3$
b_1 = width of top of deck profile between the ribs =163 mm
b_2 = width of bottom rib of deck profile = 40 mm
b_3 = length of web of rib =126 mm
I_s = inertia of deck profile per unit width
d_t = depth of solid core = 66 mm
d_p = depth of deck profile =108mm
y_e = depth of elastic neutral axis of the deck profile from top of the profile

The depth of the elastic neutral axis of the composite panel from the top of the panel is given by:

$$y_c = \frac{t_2\, (\ell/s)}{(t_1 + t_2\, (\ell/s))} \times d_{eff}$$

The compression stress in the flat (or micro-ribbed) upper sheet due to an applied moment, M per unit panel width is:

$$\sigma_c = \frac{M\, y_c}{I_{eff}}$$

For a *Floor-Dek* profile with steel thicknesses, t_1 = 0.7mm and t_2 = 0.9mm (minus 0.04mm for zinc coating):

$$\ell = 40 + 163 + 2 \times 126 = 455\text{mm}$$

$$\ell / s = 455 / 333 = 1.37$$

Elastic neutral axis depth of deck profile

$$y_e = \frac{(40 + 126)}{(40 + 163 + 2 \times 126)} \times 108 = 39\,\text{mm}$$

Effective depth of composite panel,

$$d_{eff} = 66 + 39 = 105\text{ mm}$$

Second moment of area of deck profile,

$$I_s = 0.86 \times [39^2 \times 163 + (108 - 39)^2 \times 40 + 2 \times 126 \times (0.5 \times 108 - 39)^2 + 126 \times 108^2/6] / 0.333$$

$$= 1.91 \times 10^6\text{ mm}^4/\text{m}$$

Second moment of area of composite panel,

$$I_{eff} = \frac{0.66 \times 0.86 \times 1.37}{(0.66 + 0.86 \times 1.37)} \times 105^2 \times 10^3 + 1.91 \times 10^6$$

$$= 6.6 \times 10^6\text{ mm}^4/\text{m}$$

Elastic neutral axis depth of composite panel,

$$y_c = \frac{0.86 \times 1.37}{(0.66 + 0.86 \times 1.37)} \times 105 = 69\,\text{mm}$$

For an applied moment of 14.7 kNm at failure in a typical test, the compressive stress acting on the top sheet is:

$$\sigma_c = \frac{14.7 \times 10^6 \times 69}{6.6 \times 10^6} = 154\text{ N/mm}^2$$

In comparison, for the *Floor -Dek* panel with t_1 = t_2 = 0.9mm (net 0.86 mm);
I_{eff} = 7.5 x 10^6 mm^4 (a 12% increase on t_1= 0.7 mm).

3.2 Effect of shear on displacements

The shear displacement of a composite panel with uniform load, ω, is:

$$\delta_v = \frac{\omega L^2}{8 G_c A_v}$$

The corresponding bending deflection is:

$$\delta_b = \frac{5\omega L^4}{384\,EI_{eff}}$$

It follows that the total deflection is modified according to:

$$\delta_{tot} = \delta_b \left(1 + 9.6\left(\frac{E}{G_c}\right)\left(\frac{I_{eff}}{A_v L^2}\right)\right)$$

where E is the elastic modulus of steel = 205 x 10^3 N/mm^2

G_c is the shear modulus of the core (back-analysed from tests as being approximately 20 N/mm^2)

I_{eff} is the pure flexural second moment of area of the 0.7/0.9 panel = 6.6x 10^6 mm^4/m

A_v is the shear area of the panel per unit width
= (174 x 333 – 228 x 108)/0.33 = 100 x 10^3 mm^2/m

L is the panel span (in the range of 3.3 to 4.6m)

Using this data, it follows that the pure flexural displacement is increased by 30 to 50% due to the effects of shear in the core. However, the shear displacement does not add significantly to the stresses in the steel skins.

Example: For 0.7/0.9 *Floor-Dek* panel with the following data:
w= 3 kN/m^2, L= 4.35m and G_c = 20 N/mm^2:

$$\delta_b = \frac{5 \times 3 \times 4350^4}{384 \times 205000 \times 6.6 \times 10^6} = 10.3 \text{ mm}$$

$$\delta_{tot} = \delta_b \left(1 + 9.6\left(\frac{205000}{20}\right)\left(\frac{6.6 \times 10^6}{100 \times 10^3 \times 4350^2}\right)\right)$$

= 1.34 δ_b or 34% increase in bending deflection

= 13.8 mm for 0.7/0.9 *Floor -Dek* panel

For long term loading, the shear modulus G_c of the core is taken conservatively as one quarter of the initial value, or 5 N/mm^2. This means that the long term shear displacement is 4 times the initial value.

3.3 Design properties of *Floor-Dek*

A wide range of tests been carried out on *Floor–Dek* panels used as floors, and the design properties are established as in the following tables. The results are presented for the standard steel thicknesses ie a 0.7/0.9 panel, but are also extended to the use of a 0.9 mm thick top sheet (ie a 0.9/0.9 panel).

The bending resistances are determined as characteristic values and are presented in Table 3.1. The negative bending resistance is taken as the same for both top sheet thicknesses, as failure is dependent on the decking in compression.

The effective stiffness takes into account the influence of shear in the core, increased due to creep caused by sustained loading. For residential applications, it is assumed that the imposed loading is variable and short term, whereas the self weight and partition loads are permanent and therefore contribute to the creep effect. The calculated effective second moments of area of the *Floor–Dek* panels including the effect of shear are presented in Table 3.2. For simplicity, the design stiffness for deflection calculations may be calculated assuming that one third of the total load is considered to be long term and two thirds short term.

The influence of the stiffening effect of various types of boards is presented in Tables 3.3 and 3.4, which may be taken into account in deflection calculations. In residential buildings, using multiple layers of boards for acoustic insulation, the stiffening effect of the floor and ceiling boards can increase the second moments of area in Table 3.2 by up to 10%.

Table 3.1 Bending resistances (characteristic values) of *Floor-Dek* panels

Floor-Dek	Characteristic Bending Resistance (kN/m/m)	
	Positive bending $M_{e\ell}^{+}$	Negative bending $M_{e\ell}^{-}$
0.7/0.9 panel	13.6 kNm/m	18.1 kNm/m
0.9/0.9 panel	16.1 kNm/m	18.1 kNm/m

Table 3.2 Effective second moments of area (x 10^6 mm^4/m) of 0.7/0.9 *Floor-Dek* panels for various spans (including shear in the core)

Second moment of area (x 10^6 mm^4/m)	Span of floor or roof (m)						
	3.5	4.0	4.5	5.0	6.0	7.0	∞
Short term imposed loads	4.3	4.7	5.0	5.2	5.6	5.8	6.6
Loads – permanent	2.1	2.5	2.9	3.2	3.8	4.3	6.6
Design stiffness	3.5	3.9	4.3	4.5	5.0	5.3	6.6

Design stiffness is based on two thirds of the loading being variable and one third permanent

Table 3.3 Summary of measured bending resistances (kNm/m) of *Floor-Dek* panels

Floor build-up	*Floor-Dek* steel thicknesses:	
	0.7/0.9	0.9/0.9
Bare panel (average from 3 tests):	14.6	17.2
As above, plus 18mm OSB boards	18.2 (+24%)	20.0 (+16%)
As above, plus OSB boards on battens	15.8(+8%)	18.4 (+7%)
As above, OSB board plus 12mm plasterboard	Not tested	21.2 (+23%)

Table 3.4 Summary of measured second moments of area (mm^4/m width) of *Floor-Dek* panels for 4.35m span tests

Floor build-up	*Floor-Dek* steel thicknesses:	
	0.7/0.9	0.9/0.9
Bare panel:	5.0×10^6	5.4×10^6
As above, plus 18mm OSB boards	5.6×10^6 (+12%)	5.6×10^6 (+ 4%)
As above, plus OSB boards on battens	5.1×10^6 (+ 2%)	5.5×10^6 (+ 2%)
As above, OSB	Not tested	6.0×10^6 (+11%)

board plus 12mm plasterboard		

3.4. Design tables for single span applications

Design tables may be presented for *Floor-Dek* panels used in the following applications and with the design imposed loads as indicated:

- Housing (w_i = 1.5 kN/m^2)
- Residential buildings (w_i = 1.5 kN/m^2 plus an allowance of 0.5 kN/m^2 for partitions)
- Communal areas of residential buildings e.g. corridors or public space (w_i = 3 kN/m^2)
- Light commercial buildings (w_i = 2.5 kN/m^2)
- Commercial buildings (w_i = 3.5 kN/m^2) plus an allowance of 0.8 kN/m^2 for services, suspended ceiling and raised floor

The self weight and permanent loads acting on the floor take account of floor finishes, acoustic insulation, fire resistance and services. The self-weight of a *Floor-Dek* panel is approximately 20 kg/m^2. It is recommended that the minimum dead load for housing is taken as 0.5 kN/m^2. This load should be increased to a minimum of 0.7 kN/m^2 for residential buildings with various acoustic build-ups - See Table 3.5.

Table 3.5: Recommended self-weights used in design of *Floor-Dek* panels

Self weights of:	Recommended value (kN/m^2)
Floor-Dek panel	0.2
1 x 12mm plasterboard	0.1
2 x 15mm plasterboards	0.25
1 x 18mm OSB board and battens	0.15
30mm gypsum screed	0.6
50mm gypsum screed and embedded water pipes	1.0

The maximum limiting deflections are taken as:

- Span/450 under imposed load (taken from SCI P-301)

- Span/300 under total loads in order to limit visual deformations (this is a slight relaxation from the deflection limit for light steel floors in SCI P-301, but is reasonable if the following natural frequency limits are adopted)
- 15mm under total loads, as an alternative to the natural frequency check for floors in residential buildings

The critical design case for lightweight floors is generally that of control of perceptible vibrations. This is satisfied by ensuring that the natural frequency of the floor exceeds at least 3 times the maximum walking frequency. The minimum natural frequencies for light weight floors are taken as recommended in SCI publication 301:

- Rooms in single occupancy dwellings 8 Hz
- Corridors and public rooms 10 Hz
- Offices 10 Hz

The natural frequency of a floor can be established from the simple formula in which the static deflection under self weight loads and a nominal 0.3 kN/m^2 imposed load should not exceed 5mm (for the 8Hz limit) or 3.5mm (for the 10Hz limit). Partitions are not included in this calculation as they are considered to stiffen the floor as well as add to its loading.

Indicative design tables for various applications in housing, residential and commercial buildings are presented in Table 3.6. Load-span tables for housing, residential and commercial building applications are presented in Tables 3.7 and 3.8, as a function of imposed loading.

Table 3.6: Indicative maximum spans of 0.7/0.9 *Floor- Dek* for various applications

Application	Tiled roof in housing	Floors in:				
		Housing	Residential Buildings	Communal areas – Residential	Light Commercial	Commercial Buildings
Imposed load (kN/m^2)	0.6	1.5	1.5 + 0.5	3.0	2.5 + 0.5	3.5 + 0.5
Dead loads (kN/m^2)	0.9	0.5	0.7	0.7	1.5	1.5
Maximum Span (m)	6.2	4.7	4.1	3.7	3.1	2.9
Imposed load deflection (mm)	10	9	5	8	4	4
Total Deflection (mm)	31	14	13	11	10	10

Natural Frequency (H_z)	NA	8	9	11	11	12

Note: Dead loads include ceiling, floor-build-up and coverings, services etc
An allowance of 0.5kN/m^2 is made for lightweight partitions in residential and commercial buildings

Table 3.7: Maximum spans (m) with imposed load for 0.7/0.9 *Floor-Dek* floors

Floor Build-up	Imposed Loading (kN/m^2)					
	1.5	2.0	2.5	3.0	3.5	4.0
Lightweight floor (Self wt. $\leq$ 0.5 kN/m^2)	4.7	4.4	4.0	3.7	3.5	3.3
Lightweight separating floor (Self wt. $\leq$ 0.7 kN/m^2)	4.5	4.3	4.0	3.7	3.5	3.3
Screeded floor (30mm) (Self wt. $\leq$ 1.1 kN/m^2)	4.0	3.9	3.7	3.5	3.3	3.2
Screeded floor (50mm) or raised floor & services (Self wt. $\leq$ 1.5 kN/m^2)	3.8	3.6	3.4	3.3	3.1	3.0

Note: All loads are unfactored

Table 3.8 : Maximum spans (m) with imposed load for 0.9/0.9 *Floor-Dek* floors

Floor Build-up	Imposed Loading (kN/m^2)					
	1.5	2.0	2.5	3.0	3.5	4.0
Lightweight floor (Self wt. $\leq$ 0.5 kN/m^2)	4.9	4.6	4.2	3.8	3.6	3.4
Lightweight separating floor (Self wt. $\leq$ 0.7 kN/m^2)	4.6	4.4	4.1	3.8	3.6	3.4
Screeded floor (30mm) (Self wt. $\leq$ 1.1 kN/m^2)	4.1	4.0	3.8	3.6	3.4	3.2
Screeded floor (50mm) or raised floor & services (Self wt. $\leq$ 1.5 kN/m^2)	3.8	3.7	3.5	3.3	3.2	3.0

Note: All loads are unfactored

3.4. Continuous flooring applications

Continuous floors may be used in suspended ground floors over dwarf walls or in internal applications over load-bearing walls. Continuous floors benefit from their increased stiffness but suffer from the high local reactions and bending moments at the internal supports.

A series of tests was carried out on continuous *Floor-Dek* panels and it was concluded that the minimum support width should be 150mm. The characteristic maximum support reaction may be taken as 22.5 kN/m, based on crushing of the ribs of the panel under high negative moments. Combined bending and crushing at the internal supports should be calculated according to BS 5950-6. The maximum span of continuous floors is 4.5m in housing and 4m in residential buildings.

3,5. Effect of Local loads

Local line or patch loads may be applied to the *Floor-Dek* panels in various forms:

- Support by continuous Z sections
- Intermediate supports (particularly ground floors)
- Load-bearing walls and partitions above
- Equipment or storage racking

In such cases, failure may occur by crushing of the core below the flat sheet, or by crushing of the ribs. The acceptable magnitude of the line or patch load depends on the width of the load application, the duration of the load (as crushing is influenced by creep), and the local deformation that is permitted.

The results for the failure at the ends of a *Floor-Dek* panel when supported by a continuous 2.7mm thick steel Z section or angle are presented in Table 3.9. The characteristic end bearing resistance is 12.9 kN/m, based on a nominal 10mm end gap and 65mm bearing. Local deformation at the support is limited to 5mm.

Table 3.10: Test results for 2.7mm thick Z section supporting 2 ribs

Test (see above)	Maximum load applied per 0.66m width	Load at local deformation of panel	Max. vertical displacement
1. No gap	21.9 kN	16.3 kN	3.5mm
2. 10mm gap	21.7 kN	16.2 kN	5.5mm
3. 20mm gap	13.8 kN	9.3 kN	5.0mm
4. 20mm gap plus strap	16.6 kN	10.2 kN	6.5mm

For other cases of line loads, It is recommended that the top sheet of the *Floor-Dek* panel is ribbed rather than flat .The minimum width of line load is 150mm, and it is proposed that the bearing stress on the flat top sheet is limited to a maximum of 0.1 N/mm^2 under factored loads The maximum line load is therefore 15 kN/m (at factored loads) or 10 kN/m at unfactored loads. At a factored load of 15 kN/m, the maximum bearing stress on the 40mm wide deck ribs is 0.8 $N/mm^{2.}$ This bearing strength is consistent with the tests on continuous panels –see earlier.

For patch loads, the recommended bearing stress on the top sheet is also 0.1 N/mm^2, which corresponds to a maximum patch load of 9 kN (at factored loads) or 5kN at unfactored loads on a 300mm square area.

3,5. Long span applications

The application of *Floor-Dek* floors for spans longer than 4.5m requires the use of additional members in the form of plain C-sections or *Multichannel* sections that add to the bending resistance and stiffness of the floor. The C-sections are placed over the longitudinal edges of the *Floor-Dek* panel, so that they do not deepen the floor. Two C-sections per metre width were used to strengthen the panel, as illustrated in Figure 2.3. The steel thickness of the C-sections may be chosen with respect to the span. The C-sections are supported at the ends of the panel and the adjacent C-sections are joined together along their length.

This application was investigated by tests on 6m long panels incorporating standard 0.7/0.9 panels and 180 mm deep x 2mm thick plain C-sections. The tests were carried out in the vacuum test rig at Kingspan R & D -see Figure 3.1.

Figure 3.1: *Floor-Dek* panel with perimeter C sections lifted into vacuum rig

Two cases were tested:

- Plain panels with C-sections
- Panels with 19 mm OSB board fixed to 30 mm deep battens

The test results are presented in Table 3.12. It proved impossible to fail the panels in the vacuum rig and a maximum test load of 5.3 kN/m^2 was reached. The expected failure load would be of the order of 6 kN/m^2.

Table 3.12: Summary of test results on 6m span *Floor-Dek* panels

Test	Net Deflection at 3 kN/m^2	Deflection at max. load	Max. load in test	Effective inertia of panel
Plain panel with C-sections	27.0 mm	50 mm	5.3 kN/m^2	8.1 x10^6 mm^4/m
Panel with OSB board on battens	24.8 mm	45 mm	5.3 kN/m^2	8.8 x10^6 mm^4/m (8% increase0

For long span designs using plain C sections or *Multichannel* sections, the stiffness of the *Floor-Dek* panels and the light steel sections may be combined.

4. Design Calculations for *Floor-Dek* in Various Applications

Design calculations are presented for the following applications:

- Housing with spans up to 4.6m
- Residential buildings with spans up to 4.2 m
- Communal areas and corridors in residential buildings
- Continuous ground floors with gypsum screed

These calculations illustrate the design principles presented earlier and may be extended to cover other design cases. They are presented in accordance with BS 5950 Part 6 and with loading defined in BS 6399-1. Requirements for control of perceptible vibrations in lightweight floors are presented in The Steel Construction Institute Publication 301: Building Design using Cold Formed Steel Sections: Residential Buildings.

DESIGN OF *FLOOR-DEK* IN HOUSING

Consider the design of *Floor-Dek* in housing for spans of 4.6 m for the following load case:

	Housing
Imposed load (plus partitions)	1.5 kN/m^2
Self wt. (inc. ceiling & flooring)	0.5 kN/m^2
Total	2.0 kN/m^2

The critical design condition is likely to be control of vibrations. SCI P-301 recommends a maximum imposed load deflection of span/450 so that deflections are not visible, and a minimum natural frequency of $8H_z$ to avoid resonant effects due to walking .

Section properties of *Floor-Dek*:

The properties of *Floor-Dek* in bending for span of 4.6m are:

$M_{e\ell}$ = 13.6 kNm (characteristic resistance)
I_{xx} = 5.0×10^6 mm^4/m (short term value including shear effects)
I_{xx} = 3.0×10^6 mm^4/m (long term value including shear and creep effects)

Applied bending moments

For housing, the applied moment for a span of 4.6m clear span is:

M = $(1.6 \times 1.5 + 1.4 \times 0.5) \times 4.6^2/8$
= 8.2 kNm/m < 13.6 kNm/m OK

The end reaction is:

V = $(1.6 \times 1.5 + 1.4 \times 0.5) \times 4.6/2$
= 7.1 kN/m < 12.9 kN/m OK

For good serviceability performance in housing or residential buildings:

Deflections under total load < L/300 to limit visual deformations
or 15mm max.(as an alternative to the frequency limit)
Deflections under imposed load < L/450
Natural frequency > 8Hz

Kingspan Insulated Panels	Job No.	Sheet 2	Rev B
	Job Title KINGSPAN *FLOOR-DEK* PANELS		
	Subject DESIGN OF *FLOOR -DEK* FLOOR IN HOUSING		
	Client	Made by Kingspan	Date 3/2010
		Checked by	Date

Deflections

Deflection under Imposed load deflections using short term I_{XX}= 5.0 x 10^6 mm^4/m

$$\delta_{tot} = \frac{5w_i L^4}{384 EI_{xx}}$$

$$= \frac{5 \times 1.5 \times 4.6^4 \times 10^9}{384 \times 205 \times 5.0 \times 10^6}$$

= 8.5mm < 4600/450 = 10.2mm OK

Deflection under self weight load using long term I_{XX}= 3.0x 10^6 mm^4/m :

$$\delta_d = \frac{5w_d L^4}{384 EI_{xx}}$$

$$= \frac{5 \times 0.5 \times 4.6^4 \times 10^9}{384 \times 205 \times 3.0 \times 10^6}$$

= 4.7mm

Total deflection = 8.5 + 4.7 = 13.2 mm =< 4600/300 = 15.3 mm OK

Vibration sensitivity:

Natural frequency of floor, f, is given by the approximate formula:

$$f = 18/\sqrt{\delta_{sw}} > 8H_z$$

where δ_{sw} is the self wt. deflection (in mm) due to self wt. plus 30 kg/m^2 using the short-term stiffness or:

w_{xw} = 0.5+0.3 = 0.8 kN/m^2 (for housing)

$$\delta_{sw} = \frac{5 \times 0.8 \times 4.6^4 \times 10^9}{384 \times 205 \times 5.0 \times 10^6} = 4.6 \text{ mm}$$

$$f = 18/\sqrt{4.6} = 8.4H_z > 8H_z \quad \text{OK}$$

Conclusions:

Floor-Dek may be used in housing for clear spans up to 4.6m.

The total load deflection is the controlling design case.

Kingspan Insulated Panels	Job No.	Sheet 3	Rev B
	Job Title KINGSPAN *FLOOR-DEK* PANELS		
	Subject DESIGN OF *FLOOR-DEK* IN RESIDENTIAL BUILDINGS		
	Client	Made by Kingspan	Date 3/2010
		Checked by	Date

DESIGN OF *FLOOR-DEK* IN RESIDENTIAL BUILDINGS

Consider the design of *Floor-Dek* in residential buildings for a span of 4 m if partition loads are included, or 4.2m if there are no internal partitions, using the following loads:

	Residential buildings
Imposed load (plus partitions)	1.5 (+ 0.5 kN/m^2 for partitions)
Self wt. (inc. ceiling & flooring)	0.7 kN/m^2
Total	2.7 kN/m^2

The critical design condition is likely to be control of vibrations. SCI P-301 recommends a minimum natural frequency of $8H_z$ to avoid resonant effects due to walking .

Section properties of *Floor-Dek*:

The properties of *Floor-Dek* in bending for span of 4m are:

$M_{e\ell}$ = 13.6 kNm/m (characteristic resistance)
I_{xx} = 4.7×10^6 mm^4/m (short term value including shear effects)
I_{xx} = 2.5×10^6 mm^4/m (long term value including shear and creep effects)

These stiffnesses may be increased by 10% to allow for the stiffening effects of the multiple layers of boards in residential buildings designed for acoustic separation.

<u>Applied bending moments</u>

For residential buildings, the applied moment for a 4m clear span is:

$M = (1.6 \times 2.0 + 1.4 \times 0.7) \times 4.0^2/8$
$= 8.4$ kNm/m < 13.6 kNm/m OK

The end reaction is:

$V = (1.6 \times 2.0 + 1.4 \times 0.7) \times 4.0/2$
$= 8.4$ kN/m < 12.9 kN/m OK

For good serviceability performance in residential buildings:

Deflections under total load < L/300 to limit visual deformations
or 15mm max.(as an alternative to the frequency limit)
Deflections under imposed load < L/450
Natural frequency > 8Hz

Kingspan Insulated Panels	Job No.	Sheet 4	Rev B
	Job Title KINGSPAN *FLOOR-DEK* PANELS		
	Subject DESIGN OF *FLOOR-DEK* IN RESIDENTIAL BUILDINGS		
	Client	Made by Kingspan / Checked by	Date 3/2010 / Date

Deflections

Deflection under imposed loads using short term I_{XX}= 4.7 x 10^6 mm^4/m:

$$\delta_t = \frac{5 \times 1.5 \times 4.0^4 \times 10^9}{384 \times 205 \times 4.7 \times 10^6}$$

$= 5.2 < 4000/450 = 8.9$ mm OK

Deflection under self weight plus partition loads (considered as a long term load) using I_{XX}= 2.5 x 10^6 mm^4/m:

$$\delta_t = \frac{5 \times 1.2 \times 4.0^4 \times 10^9}{384 \times 205 \times 2.5 \times 10^6}$$

= 7.8mm

Total deflection = 5.2 + 7.8 = 13.0 mm < 4000/300 = 13.3 mm just OK

The total deflection is less than L/300 and 15mm, which shows that the floor is visually acceptable, and so the acceptability of the floor depends on the vibration sensitivity.

Vibration Sensitivity

Natural frequency of floor, f, is given by the approximate formula:

$$f = 18/\sqrt{\delta_{sw}} > 8H_z$$

where δ_{sw} is the self wt. deflection (in mm) due to self wt. plus 30 kg/m^2 using the short-term floor stiffness or:

w_{xw} = 0.7+ 0.3 =1.0 kN/m^2 (for residential buildings)

$$\delta_{sw} = \frac{5 \times 1.0 \times 4.0^4 \times 10^9}{384 \times 205 \times 4.7 \times 10^6} = 3.4 \text{ mm}$$

$$f = 18/\sqrt{3.4} = 9.7H_z > 8H_z \quad \text{OK}$$

Conclusions:

Floor-Dek may be used in residential buildings with partitions for clear spans up to 4m, taking account of the floor and ceiling build-up. The total load deflection is the controlling design case.

Deflections for 4.2m span without partitions

Deflection under imposed loads using short term $I_{XX} = 4.7 \times 10^6$ mm^4/m:

$$\delta_t = \frac{5 \times 1.5 \times 4.2^4 \times 10^9}{384 \times 205 \times 4.7 \times 10^6}$$

$$= 6.3 \text{ mm} < 4200/450 = 9.3 \text{ mm} \qquad \text{OK}$$

Deflection under self weight (considered as a long term load) using $I_{XX} = 2.5 \times 10^6$ mm^4/m:

$$\delta_t = \frac{5 \times 0.7 \times 4.2^4 \times 10^9}{384 \times 205 \times 2.5 \times 10^6}$$

$$= 5.5 \text{ mm}$$

Total deflection = 6.3 + 5.5 = 11.8 mm < 4200/300 = 14mm OK

The total deflection is less than L/300 and 15mm, which shows that the floor is visually acceptable, and so the acceptability of the floor depends on the vibration sensitivity.

Vibration Sensitivity

Natural frequency of floor, f, is given by the approximate formula:

$$f = 18/\sqrt{\delta_{sw}} > 8H_z$$

where δ_{sw} is the self wt. deflection (in mm) due to self wt. plus 30 kg/m^2 using the short-term floor stiffness or:

$$w_{xw} = 0.7 + 0.3 = 1.0 \text{ kN/m}^2 \text{ (for residential buildings)}$$

$$\delta_{sw} = \frac{5 \times 1.0 \times 4.2^4 \times 10^9}{384 \times 205 \times 4.7 \times 10^6} = 4.2 \text{ mm}$$

$$f = 18/\sqrt{4.2} = 8.7H_z > 8H_z \qquad \text{OK}$$

Conclusions:

Floor-Dek may be used in residential buildings without partitions for clear spans up to 4.2m, taking account of the floor and ceiling build-up. The total load deflection is the controlling design case.

DESIGN OF *FLOOR - DEK* IN COMMUNAL RESIDENTIAL AREAS

Consider the design of *Floor-Dek* in corridors or communal areas of residential buildings for a clear spans of 3.6m for the following load case:

	Communal
Imposed load	3.0 kN/m^2
Self wt. (inc. ceiling)	<u>0.7</u> kN/m^2
Total	3.7 kN/m^2

The critical design condition is likely to be control of vibrations. SCI P-301 recommends a minimum natural frequency of $10H_z$ for communal areas to avoid resonant effects.

Section properties of *Floor-Dek*:

The properties of *Floor-Dek* in bending for spans of 3.6 m are:

$M_{e\ell}$ = 13.6 kNm (characteristic resistance)
I_{xx} = 4.4×10^6 mm^4/m (short term value including shear effects)
I_{xx} = 2.2×10^6 mm^4/m (long term value including creep and shear effects)

<u>Applied bending moments</u>

For communal areas, the applied moment for a span of 3.6m clear span is:

$M = (1.6 \times 3.0 + 1.4 \times 0.7) \times 3.6^2/8$
$= 9.4$ kNm/m $<$ 13.6 kNm/m OK

The end reaction is:

$V = (1.6 \times 3.0 + 1.4 \times 0.7) \times 3.6/2$
$= 10.4$ kN/m $<$ 12.9 kN/m

For good serviceability performance:

Deflections under total load < L/300 to limit visual deformations or 15mm max. as an alternative to the frequency limit
Deflections under imposed load < L/450
Natural frequency > 10Hz

Deflections

Deflections under imposed loads using short term I_{XX}= 4.4x 10^6 mm^4/m:

$$\delta_i = \frac{5w_i L^4}{384\, EI_{xx}}$$

$$= \frac{5 \times 3.0 \times 3.6^4 \times 10^9}{384 \times 205 \times 4.4 \times 10^6}$$

= 7.3 mm < 3600/450 = 8 mm OK

Deflections under self weight loads using long term I_{XX}= 2.2x 10^6 mm^4/m:

$$\delta_d = \frac{5w_d L^4}{384\, EI_{xx}}$$

$$= \frac{5 \times 0.7 \times 3.6^4 \times 10^9}{384 \times 205 \times 2.2 \times 10^6}$$

= 3.4 mm

Total deflection = 7.3 + 3.4 = 10.7 mm < 3600/300 = 12 mm OK

The total deflection is less than L/300 and 15mm , which shows that the floor is visually acceptable, and so the acceptability of the floor depends on the vibration sensitivity.

Vibration sensitivity

Natural frequency of floor, f, is given by the approximate formula:

$$f = 18/\sqrt{\delta_{sw}} > 10H_z$$

where δ_{sw} is the self wt. deflection (in mm) due to self wt. plus 30 kg/m^2 or:

w_{xw} = 0.7+ 0.3 = 1.0 kN/m^2

$$\delta_{sw} = \frac{5 \times 1.0 \times 3.6^4 \times 10^9}{384 \times 205 \times 4.4 \times 10^6} = 2.4 \text{ mm}$$

$$f = 18/\sqrt{2.4} = 11.6\ H_z > 10H_z \quad \text{OK}$$

Conclusions:
Floor-Dek may be used in the communal areas of residential buildings for clear spans up to 3.6m. The controlling design cases are imposed load deflection and natural frequency.

DESIGN OF *FLOOR-DEK* AS CONTINUOUS GROUND FLOOR WITH SCREED

Consider the design of *Floor-Dek* in housing with a 30mm gypsum screed and insulation for a continuous ground floor span of 4m over a 150mm wide intermediate support:

Imposed load	1.5 kN/m^2
Self wt. of Floor-Dek	0.2 kN/m^2
Self weight of screed	0.6 kN/m^2
Total	2.3 kN/m^2

The critical design condition is likely to be crushing at the intermediate support. Based on test results, the bearing resistance of the ribs of the decking is 22.5 kN/m for a 150mm wide support.

Section properties of *Floor-Dek*:

The properties of *Floor-Dek* in bending for a 4m span are:

$M_{e\ell}$ = 18.1 kNm (characteristic resistance in negative bending)
(combined bending and web crushing is considered)

I_{xx} = 4.7×10^6 mm^4/m (short term value including shear effects)

I_{xx} = 2.5×10^6 mm^4/m (long term value including creep and shear effects)

Applied bending moments and reaction at internal support

For a continuous floor panel, the negative bending moment at the internal support is :

$M = (1.6 \times 1.5 + 1.4 \times 0.8) \times 4^2/8$

$= 7.0$ kNm/m -see below for interaction with crushing at support

Reaction at internal support = $1.25 \times (1.6 \times 1.5 + 1.4 \times 0.8) \times 4$

$R = 17.6$ kN/m < 22.5 kN/m

Combined bending and crushing: $\frac{F_w}{P_{w,Rd}} + \frac{M}{M_{Rd}} < 1.25$ to BS 5950-6

$$\frac{17.6}{22.5} + \frac{7.0}{18.1} < 1.25 \quad \text{or} \quad 0.78 + 0.39 = 1.17 < 1.25 \text{ OK}$$

Deflections under imposed loads as a continuous floor using I_{XX}= 4.7x 10^6 mm^4/m:

$$\delta_i = \frac{3w_i L^4}{384\,EI_{xx}}$$

$$= \frac{3 \times 1.5 \times 4^4 \times 10^9}{384 \times 205 \times 4.7 \times 10^6}$$

$$= 3.1 \text{ mm} < 4000/450 = 8.9 \text{ mm} \quad \text{OK}$$

Deflection under self weight loads:

$$\delta_d = \frac{3w_d L^4}{384\,EI_{xx}}$$

$$= \frac{3 \times 0.8 \times 4^4 \times 10^9}{384 \times 205 \times 2.5 \times 10^6}$$

$$= 3.1 \text{ mm}$$

Total deflection = 3.1 + 3.1 = 6.2 mm < 4000/300 = 13.3 mm OK

Vibration sensitivity:

Natural frequency of floor, f, is given by the approximate formula:

$$f = 18/\sqrt{\delta_{sw}} > 8H_z$$

where δ_{sw} is the self wt. deflection (in mm) due to self wt. plus 30 kg/m^2 or:

$$w_{xw} = 0.8 + 0.3 = 1.1 \text{ kN/m}^2$$

For vibrations, the floor is considered as single span:

$$\delta_{sw} = \frac{5 \times 1.1 \times 4^4 \times 10^9}{384 \times 205 \times 4.7 \times 10^6} = 3.8 \text{ mm}$$

$$f = 18/\sqrt{3.8} = 9.2H_z > 8H_z \quad \text{OK}$$

Conclusion:
Floor-Dek may be used with 30mm thick screed as a continuous ground floor in housing for spans up to 4m. The controlling design case is bearing on the ribs of the decking at the 150mm wide internal supports. For a 50mm thick screed, the maximum span would be 3.8m. The floor is very stiff due to its continuity over the internal supports.

Appendix: Fire Test on *Floor-Dek* Floor

Test details

On 28th January 2009, a loaded fire test to BS 476 -20 was carried out on the *Floor-Dek* floor system at the Building Research Establishment. The key data for the test specimen were:

- Four *Floor-Dek* panels using 0.7/0.9 mm steel thicknesses with edge fixings at 300mm centres,
- Floor dimensions of 4.15m clear span and 3.5m width with nominally 100mm end bearing.
- Two layers of 15 mm fire resistant plasterboards fixed to RB1 'resilient bars' placed transversely at 400 mm centres and fixed to each deck rib (i.e. at 330 mm centres).
- Imposed load of 2 kN/m^2 in addition to the floor weight of approximately 0.6 kN/m^2.
- Floor boarding (18 mm OSB) on 30mm deep battens fixed to the top of the *X-Dek* panels.

The test reached a fire resistance of 95 minutes and the failure point was defined by the rate of deflection of 11mm per minute and a deflection exceeded span/20. At 90 minutes, the temperature of the upper surface was less than 30 ^oC. The temperature of the deck ribs was estimated to be less than 150^oC, despite the loss of the outer plasterboard layer at approximately 75 minutes. The temperature of the top surface of the floor was less than 50^oC, which is well within the BS 476 test limits.

The deflection of the floor under its initial load was not measured but this was estimated to be approximately 10mm.The floor deflection remained at less than 15 mm for the first 60 minutes of the test, showing that the floor would be repairable even after a severe fire. At 90 minutes, the deflection was 110mm, and at failure, the deflection had reached over 180 mm, but the integrity of the floor was still maintained.

The load was maintained after this point and the integrity and insulation criteria were exceeded at 106 minutes. Importantly, no noxious fumes from the PIR core per emitted during the 90 minutes of the fire resistance period, because its temperature remained relatively low during the test.

Analysis of fire test

The applied bending moment of 5.7 kNm corresponds to a load ratio of approximately 0.45 relative to the characteristic bending resistance obtained from the tests earlier presented in this report. The critical temperature method is not appropriate for the composite panels because the controlling factors are shear in the core and shear-bond with the deck rib rather than pure bending.

The effective shear modulus of the core in normal conditions is G_C = 20 N/mm^2, and the shear modulus may be expected to reduce as the core temperature increases. Based on known information about the PIR core, its shear modulus elevated temperature may be expected to decrease linearly to zero at a temperature of 150^{o}C and therefore:

$$G_{C,\theta} = (1-(\theta-20)/130)\ G_C$$

At a core temperature of 100^{o}C at 60 minutes, $G_{C,\theta}$ is approximately 6.5 N/mm^2. The contribution of shear to the total deflection at this span is 30% at room temperature, and at 100^{o}C, the shear deflection will rise to close to 60% of the total. Therefore the deflection will increase by around 60% relative to room temperature i.e. from 10 mm to 16 mm. This agrees well with 15 mm deflection measured in the test at 60 minutes.

The elastic modulus of steel does not reduce significantly with temperatures up to 150^{o}C, and so the effect of these temperatures on bending deflection is variable.

The test results show the excellent fire resistance of *Floor-Dek* floors when protected by plasterboard. This test result may be extended to other design cases by equating to the applied moment in the test. For example, for commercial or communal or corridor applications with an imposed load of up to 3 kN/m^2, the maximum span is 3.4m for 90 mins fire resistance. For housing with an imposed load of 1.5 kN/m^2, the maximum span increases to 4.4m, but clearly housing does not require such long fire resistance periods