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REINFORCED STRUCTURAL STEEL DECKINGFIELD OF THE INVENTION

5 The present invention relates to structural steel decking panels and in particular to structural steel decking panels constructed from profiled steel on which concrete is poured to form composite slabs.

10 BACKGROUND

 Structural steel decking panels serve a dual function when used in the construction of composite steel/concrete floor slabs. The panels act as structural
15 formwork by supporting building materials and personnel before the concrete hardens. After the reinforcing steel (bars and/or mesh) has been laid, concrete is poured on top of the decking panels, and once the concrete reaches sufficient compressive strength, the decking panels act as
20 main reinforcement by interacting with the concrete, and continue to do so for the remainder of the life of a building.

 Structural steel decking panels are roll-formed
25 from flat steel strip into long panels of uniform cross-section. Decking panels are principally distinguished by differences in their cross-sectional shape or profile. The profiles used in the world today are very varied, for instance trapezoidal decks like Fielders Steel Roofing Pty
30 Ltd's (Fielders') KF70 and KF225 with "open ribs" (see Fig. 1) versus decks with "closed ribs" like Fielders' KF57 (see Fig. 2), but they all have one factor in common: the nominal thickness of the sheeting is constant around the profile perimeter. Also, roll-forming machines are
35 only designed to roll steel sheeting up a certain maximum thickness, typically 1.2 mm and always not exceeding 1.6 mm. This significantly restricts the maximum flexural

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stiffness and ultimate strength of a deck with a set geometry.

5 Some decking panel manufacturers modify the decking panels they produce once the panels have been roll-formed. This is done to improve their functionality or structural performance.

10 Important aspects of structural performance are flexural stiffness and ultimate strength. Flexural stiffness affects the magnitude of vertical deflections, in particular under the weight of wet concrete. The moment capacity and shear capacity of critical regions affects ultimate strength.

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It is known to modify a roll formed decking panel by attaching a flat sheet of steel across the entire base of the panel to form a "cellular deck". This is done to create closed cells for the passage of sensitive building services, in particular electrical cabling for computers, thus giving rise to so-called "electrified floors". However, whilst the flat steel sheets improve flexural stiffness and ultimate strength, the "cellular decks" do not provide optimum structural efficiency. Furthermore, 20 in applications where they are not required for cabling etc, they are not a cost effective decking.

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It is an object of the invention to provide a decking panel that has improved structural performance in terms of flexural stiffness and ultimate strength and avoids at least some of the problems described above.

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SUMMARY OF THE INVENTION

35 Broadly, according to the invention there is provided a structural steel decking panel for supporting wet concrete and subsequently reinforcing the concrete

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after it has hardened, the decking panel including:

(a) an elongate profiled steel sheet having a top side and an underside; and

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(b) a plurality of elongate reinforcing members connected to the sheet, and

(c) wherein the strength of the longitudinal shear connection, as described herein, between the sheet and the reinforcing members is sufficiently high to resist longitudinal shear failure between the reinforcing members and the sheet when the decking panel is subjected to top loading with construction loads and wet concrete.

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The decking panel of the present invention is selectively reinforced in areas in which there is a need for higher structural performance in terms of flexural stiffness and ultimate strength, particularly when the decking panel is subjected to top loading with construction loads and wet concrete. One of the key features of the decking panel of the present invention, as described above, is that the strength of the longitudinal shear connection between the sheet and the reinforcing members is sufficiently high to resist longitudinal shear failure between the reinforcing members and the sheet when the decking panel is top loaded. This is an important feature because it facilitates higher structural performance, particularly when the decking panel is subjected to top loading with construction loads and wet concrete.

The term "strength of the longitudinal shear connection" is understood herein to mean the strength of the connection between connected elements, such as the sheet and the reinforcing members, to resist longitudinal shear in response to longitudinal shear force generated by

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an applied top load and, therefore, is a measure of the ability of the connection to resist longitudinal shear.

5 In some situations it is preferable that there be complete shear connection, as described herein, between the sheet and the reinforcing members.

10 The term "complete shear connection" is understood herein to mean a condition in which the moment capacity of a vertical cross-section of the decking panel is not governed by the strength of the longitudinal shear connection between the connected elements.

15 In other situations it is sufficient that there be partial shear connection, as described herein, between the sheet and the reinforcing members.

20 The term "partial shear connection" is understood herein to mean a condition in which the moment capacity of a transverse cross-section of the decking panel is governed by the strength of the longitudinal shear connection between the connected.

25 Preferably the shear connection between the sheet and the reinforcing members is at least 30% of the complete shear connection.

30 More preferably the shear connection between the sheet and the reinforcing members is at least 40% of the complete shear connection.

35 Preferably there is complete interaction, as described herein, between the sheet and the reinforcing members.

The term "complete interaction" is understood herein to mean a condition in which there is no

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significant longitudinal slip along the interface between connected elements, i.e. the sheet and the reinforcing members, so the connected elements can be considered to act as a single, reinforced composite element when
5 determining flexural stiffness and calculating vertical deflections.

10 Preferably the reinforcing members are connected to the underside of the sheet.

Preferably the reinforcing members are welded or glued to the sheet.

15 Preferably the reinforcing members are elongate members.

Preferably the elongate members extend in a longitudinal direction of the sheet.

20 Preferably the reinforcing members are in the form of a bar or rod or plate.

25 Preferably the profiled sheet includes top and bottom flat flanges interconnected by web elements.

Specific embodiments of the invention will now be described in some further detail with reference to and as illustrated in the accompanying figures. These
embodiments are illustrative, and are not meant to be
30 restrictive of the scope of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

35 Preferred embodiments of the invention are illustrated in the accompanying representations in which:

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Figs. 1 and 2 show cross-sectional views of prior art structural steel decking panels;

5 Fig. 3 shows a cross-sectional view of a structural steel decking panel according to a first embodiment of the invention;

10 Fig. 4 shows a cross-sectional view of a structural steel decking panel according to a second embodiment of the invention;

15 Fig. 5 shows a cross-sectional view of a structural steel decking panel according to a third embodiment of the invention;

Fig. 6 shows a cross-sectional view of a structural steel decking panel according to a fourth embodiment of the invention;

20 Fig. 7 is a diagrammatic side view of the steel decking panel of Fig. 6 with a support directly under the reinforced area and the reinforcing members shown diagrammatically to illustrate the general location (and length) of the members;

25 Fig. 8 is a diagrammatic side view of the steel decking panel of Fig. 5 with the reinforced area between supports and the reinforcing members shown diagrammatically to illustrate the general location (and length) of the members;

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Figs. 9, 10 and 11 show cross-sectional views of further embodiments of structural steel decking panels according to the invention;

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Fig. 12 is a plot of applied load versus deflection for test samples generated during an

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experimental program to evaluate the invention; and

Fig. 13 is a series of spanning curves generated during the experimental program.

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A first embodiment of the invention is shown in Fig. 3.

With this embodiment, the structural decking panel 10 comprises a roll formed elongate steel sheet 12 having a top side 14 and an underside 16. The decking panel 10 is profiled and comprises top flanges 40, bottom flanges 42, interconnecting web elements 44, and side edge formations 46 that enable adjacent panels to be positioned side-by-side in an overlapping relationship.

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The decking panel 10 comprises two discrete elongate reinforcing members 20, each of which is connected to the underside 16 of the sheet 10 and extend in the longitudinal direction of the sheet 12. The reinforcing members 20 are connected to the sheet 12 so that there is substantially complete interaction between these components under normal operating conditions.

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With this embodiment of the invention, the reinforcing members 20 are cylindrical rods having a circular cross-section. However, reinforcing members with a wide variety of cross-sectional shapes may be employed to suit specific manufacturing and design requirements.

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With this embodiment of the invention, the reinforcing members 20 are attached to the underside 16 of the sheeting 12 and are positioned in cavities defined by ribs 48 in the top flanges 40 of the panel 10. The arrangement is such that there is substantial contact between the sheet 12 and the reinforcing members 20. The substantial contact contributes to strength of the shear

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connection between the reinforcing members 20 and the sheet 12. In addition, the arrangement is such that the reinforcing members 20 cannot come into contact with concrete that is poured on top of the panel 10. This means that there are no potential problems of reduction of the longitudinal slip resistance of the decking panel after the concrete hardens. Furthermore, the reinforcing members 20 do not interfere with any of the normal construction operations undertaken on the top side 14 of the decking panel such as the placement of reinforcement and pouring and compaction of concrete.

In other embodiments of the invention (not shown), reinforcing members 20 can be attached to selected areas of the top side 14 of the sheet 12.

The reinforcing members can be continuous over the whole length of the panel 12 or alternatively can be localised over short lengths in selected locations in order to improve economy or to avoid interference with the passage of vertical building services.

Two examples of panels having localised positions and lengths of reinforcing members 20 are shown diagrammatically in Figs. 6, 7 and 8. Figure 6 is a transverse cross-section that illustrates the positions of reinforcing members 20 against the web elements of the panel 12. The reinforcing members 20 extend part way along the length of the sheet 12. Figure 7 illustrates an arrangement in which the positions of the reinforcing members 20 in the Figure 6 panel are selected to be over supports 30 for the panel. Figure 8 illustrates an arrangement in which the positions (and length) of the reinforcing members 20 in the Figure 6 panel are selected to be between supports 30 for the panel.

The reinforcing members 20 can be made from a

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variety of materials including steel or advanced composite materials.

5 The reinforcing members 20 can be attached to the sheet 12 by various means including gluing, welding, screwing, clinching, and crimping.

10 It is preferred that the reinforcing members 20 be welded or glued to the sheet 12 in order to produce the required connection.

15 Attachment of the reinforcing members 20 to the sheet 12 can occur after a roll-forming process for forming the profiled sheet 12. Alternatively, the sheet 12 can be reinforced (by attachment of reinforcing members 20) prior to roll-forming the sheet.

20 As is indicated above, the strength of the connection between the reinforcing members 20 and the sheet 12 is important when the decking panel is subjected to top loading with wet concrete. With the embodiments described above and other embodiments of the invention, complete shear connection or partial shear connection may exist at a critical cross-section.

25 The term "critical cross-section" is understood herein to mean a transverse cross-section at which the ratio of design bending moment to design moment capacity (or when designing for shear, the ratio of design shear force to design shear capacity) is a maximum. (This is the cross-section from which failure would emanate.)

35 Longitudinal shear failure can be avoided during the formwork stage, ie before concrete hardens, by adjusting the design loads if the critical cross-section is likely to exhibit relatively low partial shear connection. Assuming that the moment capacity of the

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reinforcing members 20 acting alone is small compared with that of the composite element of the reinforcing members 20 and the sheet 12 (as is the case for the preferred embodiments of the invention, but not necessarily for all
5 embodiments of the invention) then the degree of shear connection required is reasonably high (about 30% or higher). Otherwise, the reinforcing members 20 will not make a significant contribution to the moment capacity of the decking panel 10 during the formwork stage.

10 Depending on the situation, the strength of the connection between the reinforcing members 20 and the sheet 12 may not be as important during the composite stage, i.e. after the concrete hardens and a composite
15 slab is formed. In this stage, the mechanical interlock developed by the decking panel 10 and the hardened concrete (per unit length of panel) usually becomes a significant factor in providing flexural stiffness and ultimate strength of the composite slab. Thus, break-down
20 of glue connecting together the reinforcing members 20 and the sheet 12 or loss of effectiveness of other forms of connection between these components may not be a concern.

The reinforcing members 20 may be attached in any
25 combination to selected areas of the top side 14 and the underside 16 of the decking panel. The reinforcing members 20 would normally be kept away from areas on the top side 14 that develop known, higher levels of mechanical resistance once the concrete has hardened (for
30 instance, webs with embossments impressed in them). Importantly, the strength of the longitudinal shear connection between the reinforcing members 20 and the sheet 12 should be such that longitudinal shear failure is avoided during the formwork stage, as described above.

35 Reinforcing members 20 can be placed at various discrete locations around the steel sheet 12. Examples of

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different locations are shown in Figs. 4, 5 and 6.

Referring particularly to Fig. 5, the reinforcing members 20 are connected to the flanges 40, 42 of the steel deck to increase the second moment of area about the major horizontal axis and therefore the flexural stiffness of the decking panel to vertical loading.

The moment capacity of critical regions can also be increased by changing the distribution of longitudinal compressive bending stresses that cause premature local buckling of the decking flanges and/or webs - for instance see Fig. 4, which is a case when this section is in positive bending.

Profiles that are asymmetric about the major horizontal axis can be reinforced to improve the balance between the compressive and tensile capacities of the flanges. An example of this is shown in Fig. 3, where it can be seen that reinforcing the narrower top flange 40 increases the balance between the cross-sectional areas of the top and wider bottom flanges 40, 42.

Reinforcing the web elements 44 can also improve shear (and bending) capacity - refer Fig. 6, which can be particularly useful in internal support regions.

A wide variety of profile shapes and reinforcing members 20 can be used so as to meet specific design requirements. Examples are shown in Figs. 9, 10 and 11.

Structural steel decking panels constructed according to the invention provide some or all of the following advantages.

- More efficient structural design by placement of reinforcement where it has the most effect. This

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overcomes a fundamental problem with roll formed steel decks - that the normal thickness of the sheets is constant around the profile perimeter.

- 5 • Longer deck spans or thicker slabs or beams or greater construction loads. This increases the range of applications in which a particular deck of maximum sheet thickness can be used in practice.
- 10 • Improvement in economy of roll form decks by combining them with cheaper reinforcing materials such as hot-rolled reinforcing bars or plates.

 To prevent the concrete from contacting the
15 reinforcing members 20, the members may be housed in small additional ribs or longitudinal stiffeners rolled into the steel decking (refer for example to Figs. 3 and 9). The additional longitudinal ribs and reinforcing members may have the same shape to help with their attachment (for
20 example refer Fig. 9).

 A feature of the invention is that a suitable structural steel decking panel can be used with or without additional reinforcement. This improves economy by
25 allowing the use of additional reinforcement only when it is required. The embodiments of reinforced closed rib decking panels shown in Figs. 10 and 11 illustrate this point.

30 The applicant carried out an experimental program to evaluate the performance of the invention. The results of the program are reported in Figures 12 and 13.

 The experimental program was carried out on the
35 embodiment of the decking panel shown in Fig. 3 (and Fig. 12). The panel tested comprised a 1.2 mm thick steel sheet 12 and solid 20 mm square steel bars as the

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reinforcing members 20. The performance of the panel was evaluated in relation to non-reinforced panels.

Specifically, the experimental program tested panels having the same profile but without the reinforcing members. One panel tested comprised a 1.2 mm thick steel sheet and the other panel tested comprised a 1.0 mm thick steel sheet. The profiles of these panels is shown in Fig. 12.

The panels were simply supported to form a span of 4.2 m between the supports. The panels were subjected to a loading that simulated uniform loading of the panels and the mid-span deflection of the panels and other properties were monitored.

Fig. 12 is a plot of applied load versus mid-span deflection for the 3 panels. Fig. 12 also plots the theoretical load/deflection for each panel - in the case of the decking panel of the invention, assuming complete interaction between the sheet 12 and the reinforcing members 20. It is evident from Fig. 12 that the reinforcing members 20 had a significant impact on the flexural stiffness and moment capacity of the panel and that the connection between the steel sheet 12 and the reinforcing members 20 resisted longitudinal shear very effectively as the deflection increased.

Fig. 13 is a series of spanning curves for the decking panel in accordance with the invention. The spanning curves were generated by imputing measured and calculated data of moment capacity, vertical shear capacity, and flexural stiffness from the deflection and similar tests described above into a spanning curve model. The spanning curves show that the same deck in accordance with the invention can be used to support wet concrete and construction loads during the formwork stage of the construction of a composite slab as a result of the

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improvements in flexural stiffness and moment capacity achieved by the reinforcing members 20 and the form of the connection of the members to the steel sheet. The line marked "X" is for the 1.2 mm decking panel alone, based on its strength only, which is the absolute maximum performance the unreinforced sheet can achieve if deflection of the panel under the weight of wet concrete is ignored. The numbers 130, etc indicate that the maximum ponding deflection of the concrete is the span length of the panel divided by 130, etc. It is clear from Fig. 13 that the performance of the decking panel in accordance with the invention has been vastly improved by adding the reinforcing members 20 and that much longer spans are possible during construction.

While the present invention has been described in terms of preferred embodiments in order to facilitate better understanding of the invention, it should be appreciated that various modifications can be made without departing from the principles of the invention. Therefore, the invention should be understood to include all such modifications within its scope.

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CLAIMS:

1. A structural steel decking panel for supporting wet concrete and subsequently reinforcing the concrete
5 after it has hardened, the decking panel including:

 (a) an elongate profiled steel sheet having a top side and an underside that is roll-formed from flat steel strip and has a maximum thickness of no more than
10 1.6mm; and

 (b) a plurality of elongate reinforcing members connected to the sheet and selectively reinforcing the sheet, the reinforcing members extending along the whole
15 length of the sheet or over short lengths of the sheet; and

 (c) wherein the strength of the longitudinal shear connection, as defined herein, between the sheet and
20 the reinforcing members is sufficiently high to resist longitudinal shear failure between the reinforcing members and the sheet when the decking panel is subjected to top loading with construction loads and wet concrete.

25 2. The decking panel defined in claim 1 wherein there is complete shear connection, as defined herein, between the sheet and the reinforcing members.

30 3. The decking panel defined in claim 1 wherein there is partial shear connection, as defined herein, between the sheet and the reinforcing members.

35 4. The decking panel defined in claim 2 wherein the shear connection between the sheet and the reinforcing members is at least 30% of the complete shear connection, as defined herein.

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5. The decking panel defined in claim 4 wherein the shear connection between the sheet and the reinforcing members is at least 40% of the complete shear connection.

5 6. The decking panel defined in any one of the preceding claims wherein there is complete interaction, as defined herein, between the sheet and the reinforcing members.

10 7. The decking panel defined in any one of the preceding claims wherein the reinforcing members are connected to the underside of the sheet.

15 8. The decking panel defined in any one of the preceding claims wherein the reinforcing members are welded or glued to the sheet.

20 9. The decking panel defined in any one of the preceding claims wherein the reinforcing members are elongate members.

25 10. The decking panel defined in claim 9 wherein the elongate members extend in a longitudinal direction of the sheet.

11. The decking panel defined in any one of the preceding claims wherein the reinforcing members are in the form of a bar or rod or plate.

30 12. The decking panel defined in any one of the preceding claims wherein the profiled sheet includes top and bottom flat flanges interconnected by web elements.

35 13. A structural steel decking panel for supporting wet concrete and subsequently reinforcing the concrete after it has hardened substantially as hereinbefore described with reference to the accompany drawings.